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Evaluation of Stage-Wise Deficit Furrow Irrigation Application on Water Advance - Recession Time and Maize Yield Components at Koga Irrigation Scheme, Ethiopia

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Abstract

Well-organized irrigation management has an imperative role for integrated water resources management. 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 water advance - recession time and maize yield components. 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 mean advance time. The maximum advance rate across growth stages (0.144 m/s) was noted during the development stage. Effect of stage-wise application level had a significant ($P<0.05$) effect on agronomic parameters. The maximum (147.3 cm) and minimum (4.3 cm) plant height were recorded during late season and first growing stage at full irrigation level ($D_{all,}0$ (T6)) and application of 0.25ETc ($D_{all,}75$ (T4)) throughout the growth stages, respectively. Maximum (8.55cm) and minimum (3.17 cm) stalk diameter at knee height were obtained in treatment $D_{all,}0$ (T6) and $D_{all,}75$ (T4). Maximum (2) and minimum (1.07) number of ears per plant were obtained in full irrigation treatment ($D_{all,}0$ (T6)) and 0.25ETc irrigation treatment ($D_{all,}75$ (T4)) throughout the growing season, respectively. The highest yield (58.92 qt/ha) was obtained when full irrigation was applied in all growth stages. The maximum (164.28 qt/ha) and minimum (130.34 qt/ha) aboveground biomass were obtained when 100% of ETc and 0.25 of ETc were applied starting from the first to the end growth stages.

Keywords: Agronomic parameters, Deficit irrigation, Koga irrigation scheme, Stage-wise, Water advance - recession time.

INTRODUCTION

Water is increasingly recognized as a major component in economic development and poverty reduction. Both surface and ground water resource is valuable natural resource in the development of Ethiopian Agricultural sector (Seleshi, 2010). 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.

Most of time many irrigation schemes in Ethiopia are designed as surface irrigation methods so as to save money and energy. From the surface irrigation methods, furrow irrigation system is widely used particularly in modern irrigation schemes (Clemmens, 2007).

The specific reason for initiating the research was that Koga and many other developed schemes suffers from serious water shortage due to poor surface irrigation management and lack of physical and chemical soil property analysis, 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 stage-wise deficit furrow irrigation application on water advance and recession time, and to evaluate the effect of stage-wise deficit irrigation application on maize yield components.

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 9^0C and 32^0C, respectively. The dominant soil type of the area is mainly paleosol with clay texture.

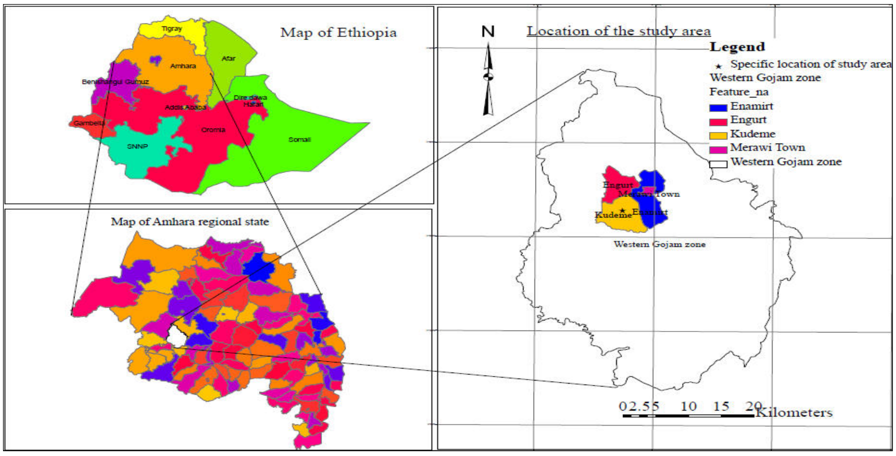


Figure 1. Location map of Koga irrigation scheme

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.

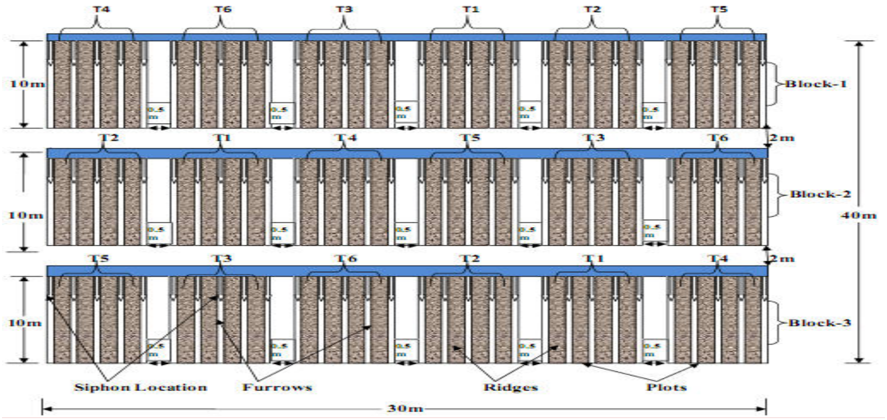


Figure 2. Layout of the experimental field

Soil physical and chemical properties

Four diagonal points in the experimental field were opened before plowing and four undisturbed and disturbed soil samples were taken each at 25 cm depth interval up to a depth of 1 m. Considering that effective root zone of maize goes up to 100 cm (FAO, 2002) using auger and a known volume core soil sampler cylinder to analyze moisture at field capacity (θ_{FC}) and permanent wilting point (θ_{PWP}). Depth of 0-25 cm, 25-50 cm, 50-75 cm and 75-100 cm interval were taken from the experimental plots before sowing the crop. The composite soil samples were analyzed for soil texture, soil pH, electrical conductivity (EC), bulk density and organic matter (OM) using standard procedures at Adet Agricultural Research Soil Laboratory.

Determination of infiltration rate

Double-ring infiltrometer metal rings with 30 cm and 60 cm of internal and external diameter, respectively, were used to measure the infiltration characteristics of the soil (Walker, 1989). The rings were driven into the ground by using a hammer having 2 kg and filled with water. The drop-in water level or volume in the inner ring was used to calculate an infiltration rate using a scaled rod and by recording a time taken to infiltrate.

Advance time

To measure the rate at which the advancing front moves across a surface-irrigated field, three stakes were placed along the length of the furrows (i.e. at 0 m, 5 m and 10 m) having a constant field slope of 0.28%. The clock time was recorded when the irrigation water supply was diverted onto the field and when the advancing front reached each stake and then advance time was calculated using equation 1 (Walker, 1989).

$$A_r = \frac{L_t}{T_a} \tag{1}$$

Where A_r is advance rate (m/s), L_t is length traveled by water front furrow length (m), and T_a is the time taken by water front to travel from head to end of the required length (s).

Crop data

Crop data were measured during different growth stages of the sample crop at each plot. The crop parameters included sowing date, fertilization application date, harvest date, crop yield and above ground biomass components per plot were recorded from the central ridge (row) of each treatment. To examine the effect of deficit irrigation at different growth stages of the crop plant height was recorded at every growth stages. Six plants at physiological maturity were randomly selected from the middle row (furrow ridge) for each treatment in order to evaluate plant height and diameter of plant stalk at knee height. Number of cobs per plant and 1000-grain weight were properly counted and measured at harvest. Furthermore, above ground biomass and grain yield per plant was also harvested by hand from the two center ridges of all plots to estimate the water productivity of stage-wise deficit irrigation practice.

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 2.

$$ET_c = ET_o \, x \, K_c \tag{2}$$

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 3.

$$NIR = ET_c - P_e \tag{3}$$

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 4. Furrow irrigation application efficiencies in general vary from 45-60% Allen et al. (1998).

$$GIR = \frac{NIR}{E_a} \tag{4}$$

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 5 in the root zone (Yonts and Eisenhauer, 2007).

$$Z_{req} = SMD = 10 \times (\theta_{FC} - \theta i) \times D_i \tag{5}$$

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).

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).

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

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 7 (i.e. 2.14 l/s) by using 0.28% average slope of the experimental plot along the irrigation furrow.

$$Q = CA\sqrt{2gh} \tag{7}$$

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).

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

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

Soil physical and chemical properties, infiltration rate, water advance and recession time, and yield related variables, were collected. From this, effects of irrigation level on the mean advance time related with crop growth stages, and some yield components such as plant height, diameter of plant stalk, number of ears per plant and 1000-grain weights were estimated. The effects of different treatments on advance time and yield components 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 and chemical property values at each soil layer are presented in Table 2 and 3, respectively.

Table 2. Soil physical properties of the experimental site

Pit no	Depth (cm)	p(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

Note: BD–bulk density, θ_{FC}–moisture content at field capacity, θ_{PWP}–moisture content at permanent wilting point and TAW–total available water content with the respective soil layer.

Table 3. Soil chemical characteristics of the study area

Pit no.	Soil depth (cm)	pH	EC (dS/m)	OC (%)	OM (%)
1	0-25	5.05	0.44	2.03	3.50
	25-50	5.19	0.13	1.11	1.92
	50-75	5.10	0.35	0.92	1.58
	75-100	4.91	0.33	0.54	0.93
2	0-25	5.45	0.18	2.02	3.48
	25-50	5.14	0.11	1.30	2.24
	50-75	5.09	0.10	0.75	1.30
	75-100	5.13	0.21	0.53	0.91
3	0-25	5.72	0.15	2.06	3.55
	25-50	5.19	0.13	0.87	1.50
	50-75	5.04	0.13	0.78	1.34
	75-100	5.26	0.78	0.43	0.74
4	0-25	5.42	0.26	2.03	3.49
	25-50	5.17	0.12	1.10	1.89
	50-75	5.15	0.20	0.84	1.45
	75-100	5.23	0.205	0.45	0.78
Mean	0-25	5.41	0.26	2.03	3.51
	25-50	5.17	0.12	1.10	1.89
	50-75	5.10	0.19	0.82	1.42
	75-100	5.13	0.38	0.49	0.84
	0-100	5.20	0.24	1.11	1.91

Note: pH – power of hydrogen ion, EC – electrical conductivity, OC – organic carbon and OM – organic matter at different soil profiles.

Infiltration rate characteristics of the study area

The average basic infiltration rate of the soil was found to be 3.14 mm/hr. According to Allen *et al.* (1998) clay soil basic infiltration rate ranges from 1 to 5 mm/hr. The determination of basic infiltration rate of the soil is used to cross-check where the application level for each furrow was caused as runoff or not.

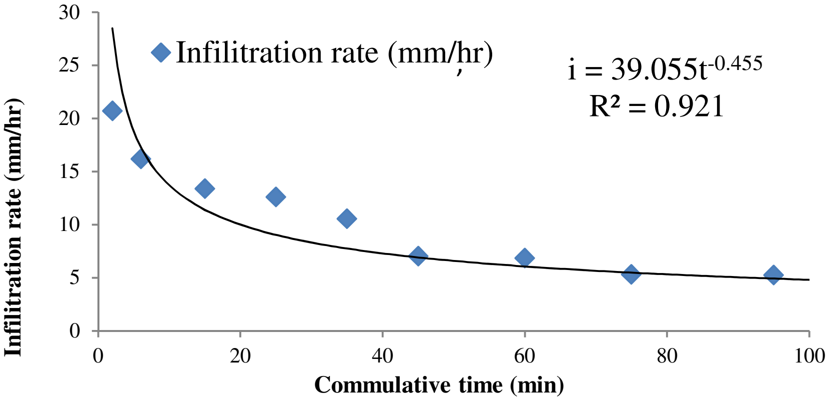


Figure 3. Infiltration rate curve

Crop Water Requirement and Irrigation Schedule

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 4) using Kc values of maize crop estimated by Allen *et al.* (1998). Total ETc of maize crop in this experiment was 410 mm, for a total growing period of 115 days.

Table 4. Crop water requirement (ETc) and irrigation schedule at the experimental site

Date	Irrigation 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

Note: * NIR simulation was done excluding of rainfall.
** GIR was calculated using 60% application efficiency.

Irrigation Water Depths and Amount of Water Saved in the Experimental Plots

Table 5 presents net and gross irrigation depths and the amount of saved water during the total growing season of the crop according to the percentage of deficit.

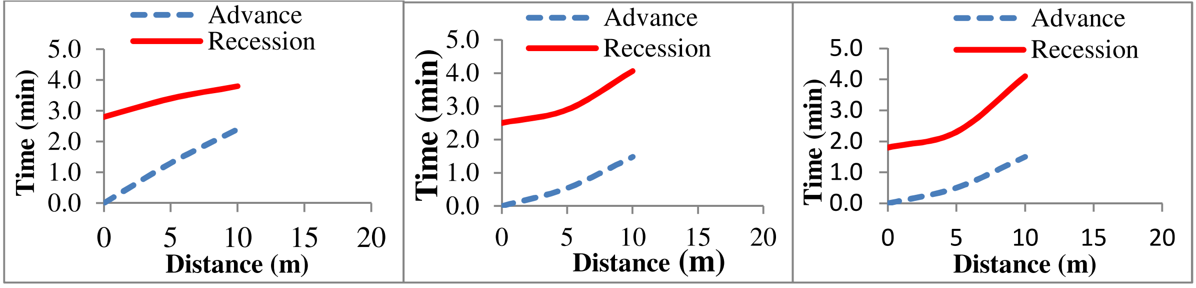
Table 5. Irrigation water depths and the amount of water saved during the total growing season of the crop

Treatment	NIR (mm)	NIR (m^3/ha)	GIR (mm)	GIR (m^3/ha)	Water saved		
					(mm)	(m^3/ha)	(%)
$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

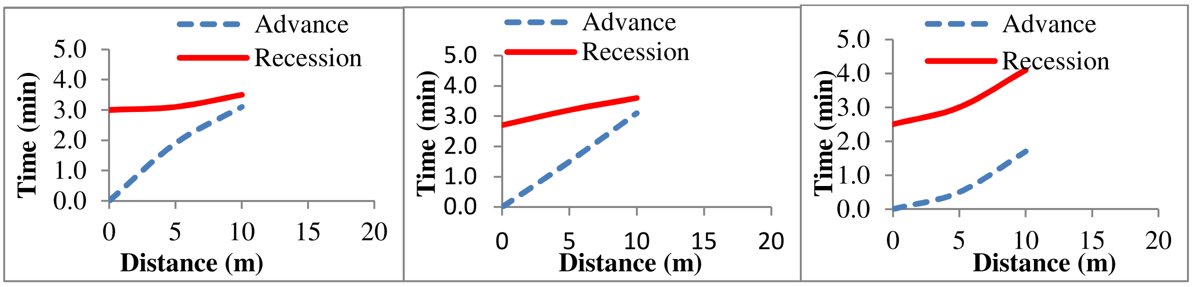
Water Advance and Recession Time

The mean result curves of each treatment in terms of advance and recession time are shown in Figures 4, 5, 6 and 7 at initial, development, mid and late growth stages, respectively. The result shows that the water deficit treatments received less water than those at the tail side of not water deficit treatments. The vertical difference between advance and recession curves at any particular point gives the infiltration opportunity time. Since the furrows were blocked-end with different application level with respect to plant growth stage, infiltration opportunity time was increased for no deficit treatments and decreased for stressed treatments from the head end to tail end of furrows.

As it is shown on the Figures below, those continuously deficit irrigation treatments had smaller opportunity time than treatments which were not irrigation water stressed throughout the total growing season. This result indicates that furrows which were irrigated by full application level may be received a fair share of water and it improves the distribution uniformity of water along the furrow.

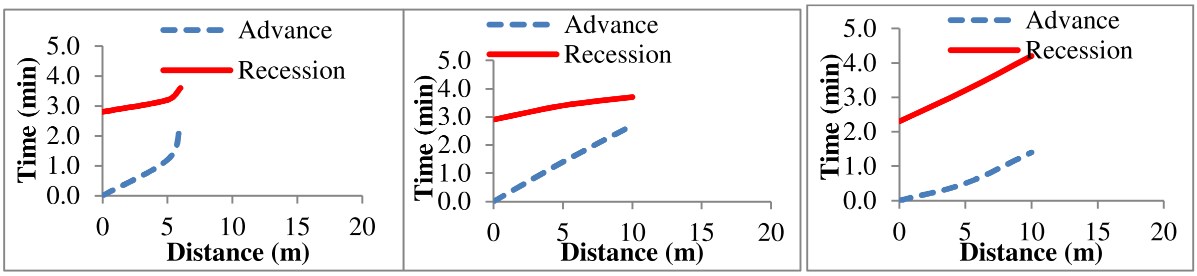


Treatment $D_{1,2}$25 (T1) Treatment $D_{2,3}$50 (T2) Treatment $D_{3,4}$50 (T3)

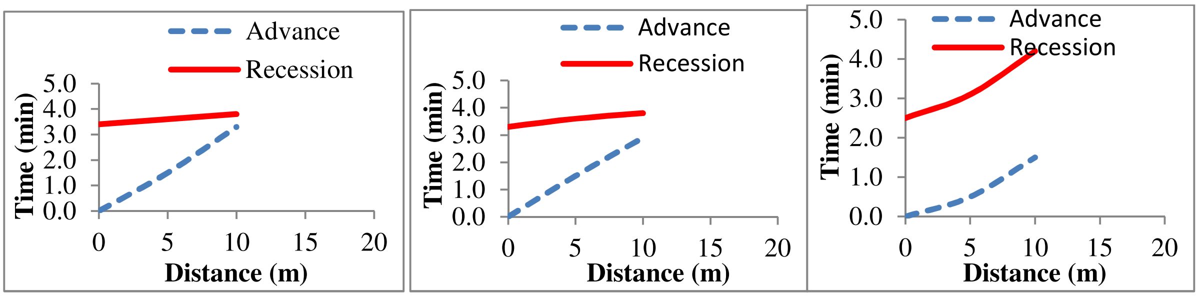


Treatment $D_{all,}$ 75 (T4) Treatment $D_{all,}$ 50 (T5) Treatment $D_{all,}$0 (T6)

Figure 4. Advance and recession graph during initial growth stage

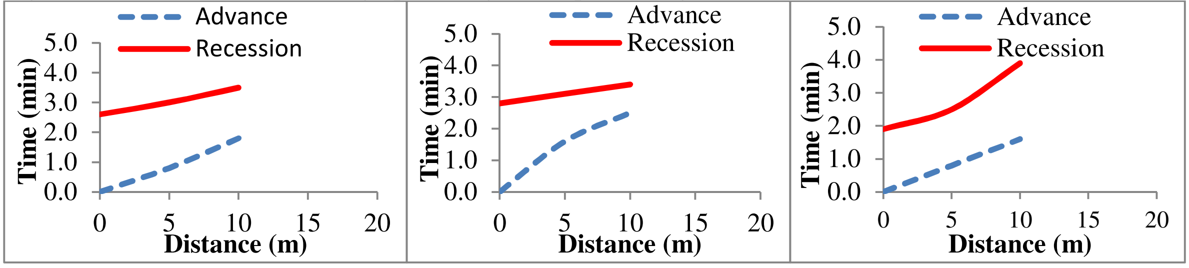


Treatment $D_{1,2}$ 25 (T1) Treatment $D_{2,3}$50 (T2) Treatment $D_{3,4}$50 (T3)

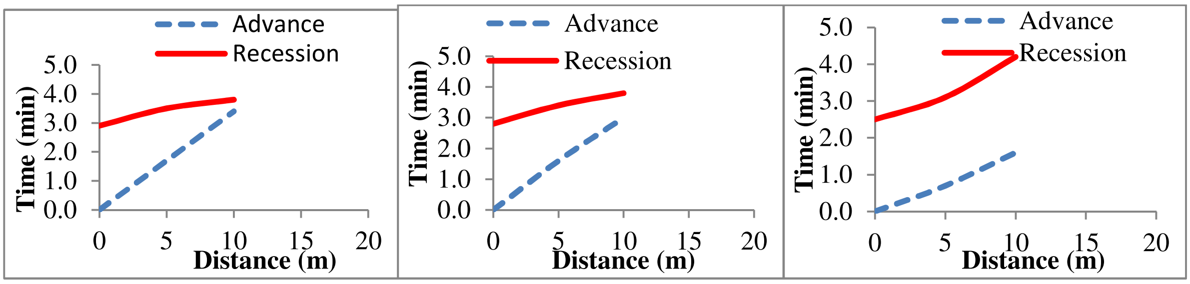


Treatment $D_{all,}$ 75 (T4) Treatment $D_{all,}$ 50 (T5) Treatment $D_{all,}$0 (T6)

Figure 5. Advance and recession graph during development stage

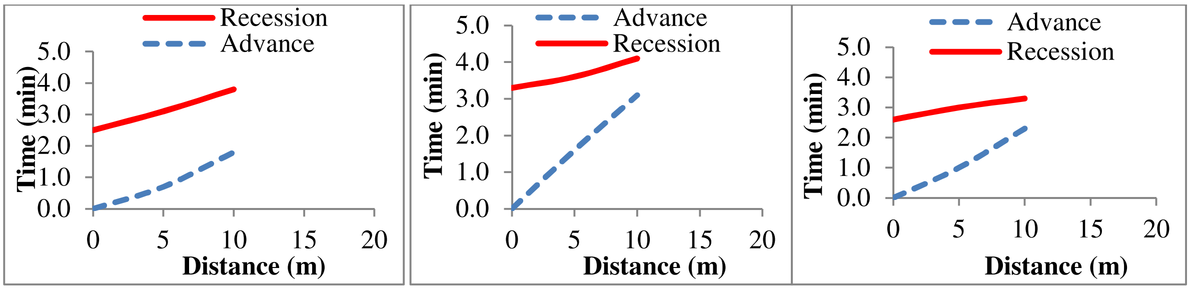


Treatment $D_{1,2}$25 (T1) Treatment $D_{2,3}$50 (T2) Treatment $D_{3,4}$50 (T3)

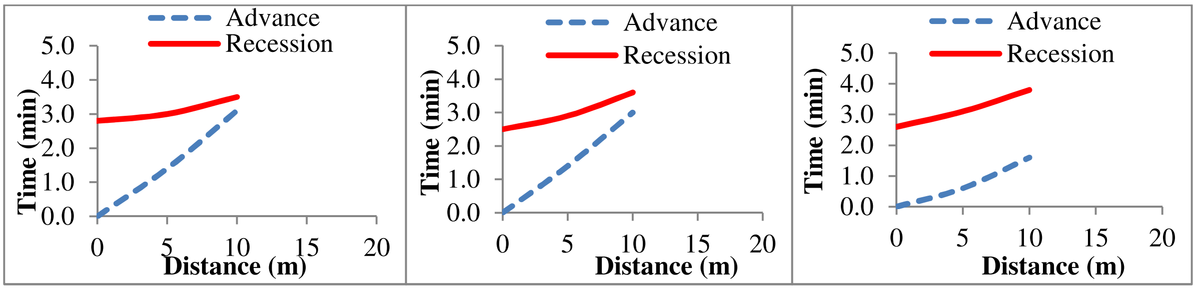


Treatment $D_{all,}$ 75 (T4) Treatment $D_{all,}$ 50 (T5) Treatment $D_{all,}$0 (T6)

Figure 6. Advance and recession graph during mid growth stage



Treatment $D_{1,2}$25 (T1) Treatment $D_{2,3}$50 (T2) Treatment $D_{3,4}$50 (T3)



Treatment $D_{all,}$ 75 (T4) Treatment $D_{all,}$ 50 (T5) Treatment $D_{all,}$0 (T6)

Figure 7. Advance and recession graph during late growth stage

The mean advance time (Table 6) during initial, development, mid and late season show that the effect of irrigation treatments were statistically significant ($P<0.05$). The advance rate across growth stages showed that the highest (0.144 m/s) value was obtained during the development stage. This may be attributed to the roughness of the furrow at the initial period.

Table 6. Effects of irrigation level on the mean advance time related with crop growth stages

	Mean advance time (m/s)*			
	Growth stages			
Treatment	Initial	Development	Mid	Late
$D_{1,2}25$ (T1)	0.0667^{b}	0.0721^{b}	0.1022^{b}	0.1046^{b}
$D_{2,3}50$ (T2)	0.1337^{a}	0.0622^{b}	0.0536^{c}	0.0528^{d}
$D_{3,4}50$ (T3)	0.1325^{a}	0.1395^{a}	0.1073^{ab}	0.0782^{c}
$D_{all,}75$ (T4)	0.0477^{d}	0.0524^{b}	0.0490^{c}	0.0514^{d}
$D_{all,}50$ (T5)	0.0515^{c}	0.0574^{b}	0.0537^{c}	0.0553^{d}
$D_{all,}0$ (T6)	0.1332^{a}	0.1444^{a}	0.1171^{ab}	0.1266^{a}
SEm±	0.00449	0.00448	0.00401	0.00348
LSD (0.05)	0.01424	0.01420	0.01272	0.01103
CV (%)	5.8	6.2	6.1	5.5

*mean of three observations.

Crop Yields and Yield Components

To evaluate the effect of stage-wise deficit irrigation on plant height, diameter of plant stalk per plant at knee height, maize yield per plot and aboveground biomass per plot were analyzed.

Plant height

The mean plant height (Table 7) during initial, development, mid and late season shows that the effect of irrigation treatments were statistically significant ($P<0.05$).

Table 7. The effect of irrigation application level on the mean plant height

Treatment	Mean plant height (cm)*			
	Growth stages			
	Initial	Development	Mid	Late
$D_{1,2}25$ (T1)	7.81^{b}	55.65^{b}	110.78^{b}	141.84^{b}
$D_{2,3}50$ (T2)	12.20^{a}	57.88^{b}	104.50^{c}	132.33^{c}
$D_{3,4}50$ (T3)	12.12^{a}	66.73^{a}	104.51^{c}	121.45^{d}
$D_{all,}75$ (T4)	4.33^{d}	29.76^{d}	73.56^{e}	86.62^{f}
$D_{all,}50$ (T5)	6.69^{c}	47.78^{c}	85.06^{d}	98.79^{e}
$D_{all,}0$ (T6)	12.18^{a}	66.22^{a}	114.83^{a}	147.28^{a}
SEm±	0.146	1.870	1.678	1.607
LSD (0.05)	0.325	4.167	3.738	3.581
CV (%)	1.9	4.2	2.1	1.6

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

Many studies have been reported that deficit irrigation affects on plant height of maize (Payero et al., 2006, Ghooshchi et al., 2008, Yenesew and Ketema, 2009). These studies give clear evidence that the plant height is highly dependent on appropriate water supply.

Diameter of plant stalk

The mean diameter of plant stalk at knee height (Table 10), shows that the effect of irrigation treatments were statistically significant ($P<0.05$). Maximum stalk diameter was obtained in treatment $D_{all,}0$ (T6), and gradually decreased with increasing the percentage of water deficit. Minimum stalk diameter was obtained when one-fourth of ETc was applied throughout the growing season ($D_{all,}75$ (T4)). And it might be affect the number of nodes per plant and surface area of leaves to conserve the amount of water lost through transpiration. This result coincide with Porro and Cassel (1986) and Muhammad *et al.* (2001) that stem diameter and leaf area decreased when minimum irrigation water was applied.

Table 10. Effect of irrigation treatments on mean plant stalk diameter, number of ears per plant, 1000-grain weight, grain yield and aboveground biomass

Treatment	Mean plant stalk diameter (cm)*	Mean number of ears per plant (no.)*	Mean thousand grain weight (kg)*	Mean grain yield (qt/ha)*	Mean aboveground biomass (qt/ha)*
$D_{all,}0$ (T6)	8.55^{a}	2.00^{a}	0.49^{a}	58.92^{a}	164.28^{a}
$D_{1,2,}25$ (T1)	7.63^{b}	1.98^{a}	0.48^{a}	55.29^{b}	161.89^{a}
$D_{2,3,}50$ (T2)	7.11^{c}	1.79^{b}	0.38^{b}	42.62^{c}	152.29^{b}
$D_{3,4,}50$ (T3)	6.17^{d}	1.74^{c}	0.35^{c}	39.62^{d}	153.90^{b}
$D_{all,}50$ (T5)	5.24^{e}	1.44^{d}	0.30^{d}	27.62^{e}	144.20^{c}
$D_{all,}75$ (T4)	3.17^{f}	1.07^{e}	0.16^{e}	13.10^{f}	130.34^{d}
SEm±	0.0773	0.0195	0.0024	0.753	2.341
LSD (0.05)	0.1722	0.0434	0.0054	1.677	5.215
CV (%)	1.5	1.4	0.8	2.3	1.9

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

Number of ears per plant and 1000-grain weights

The mean number of ears per plant and 1000-grain weights (Table 10) shows that the effect of irrigation treatments were statistically significant ($P<0.05$). However, the two treatments ($D_{all,}75$ (T4) and $D_{all,}50$ (T5)) provided with 0.25ETc and 0.5ETc throughout the whole growth stages had a significantly low number of ears per plant. Maximum (2) and minimum (1.07) number of ears per plant were obtained in full irrigation treatment ($D_{all,}0$ (T6)) and 0.25ETc irrigation treatment ($D_{all,}75$ (T4)) throughout the growing season, respectively. Ghooshchi *et al.* (2008) had also reported reduction in number of ears per plant under severe water stress.

On the other hand, the mean thousand grain weights decreased as percentage of deficit increased (Table 10). The probability may be as a result of shrinking and reduction of individual grain.

CONCLUSIONS AND RECOMMENDATIONS

In terms of good advance time across growth stages, the overall maximum of 0.144 m/s was obtained during the development stage.

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. The maximum (164.28 qt/ha) and minimum (130.34 qt/ha) aboveground biomass were obtained when 100% of ETc and 0.25 of ETc were applied starting from the first to the end growth stages.

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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