Effect of Irrigation Scheduling on Yield and Water Productivity of Maize (*Zea mays)* in the North West Ethiopia

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Abstract

The importance of irrigation scheduling is that it enables the irrigator to apply the exact amount of water to achieve the goal, optimize production and minimize adverse environmental impact. Therefore, the objective of this study is to quantify the effects of irrigation regimes on yield and yield components of Maize in the two Lake Tana basin experimental sites (Koga and Rib) during 2016/17 and 2017/18. The treatments were factorial combinations of five irrigation depths (50, 75, 100, 125, and 150 % of ETc) and two irrigation intervals (14 and 21 days) and laid out in a randomized complete block design with three replications. The collected data were analyzed using SAS 9 software and significant treatment means separated using least significant difference at 5 %. Application of optimum irrigation regime increased the grain yield over the deficit and excess irrigation regime plot, and their interaction showed no significant effect on the average grain yield and water use efficiency of maize. In Koga, the highest grain yield (7.3 t ha^{-1}) and water use efficiency (0.9 kg m^{-3}) were obtained from 100 % ETc. In the case of Rib, the highest grain yield (10.97 t ha^{-1}) and water use efficiency (1.9 kg m^{-3}) was obtained from 21 days irrigation interval. Therefore, for Koga and similar agro-ecologies, maize can be irrigated with 562 mm net irrigation depth and 21-day irrigation interval while at Rib and similar agro-ecologies, maize can be irrigated with 447 mm net irrigation depth and 21-days irrigation interval.

Key words: *Irrigation interval, Irrigation scheduling, Koga and Rib*

Introduction

Water demand in all aspects is increasing globally more than the rate of population increase (UN, 2018). Besides, expansion of irrigated agriculture, change in consumption pattern and climate change aggravate the demand (Ercin et al., 2014). However, most farmers who live in developing countries cultivate most crops using flood, border and furrow irrigation techniques that result in losing up to 50% water through deep percolation and tail water loss (Tewabe et al., 2020).

To meet food demand by 2050, sub-Saharan Africa maize output must increase up to four-fold (Hein et al., 2019). Introducing appropriate water management is pertinent to provide sufficient food for the rapid population growth. Ethiopia has experienced severe drought, temporal and spatial variations of water resources for the last four decades even though an ample amount of water resources from precipitation, surface, and subsurface source (Muktar and Yigezu, 2016). The population is growing rapidly and is expected to continue growing, which inevitably leads to increased food demand. To maintain self-sufficiency in the food supply, one viable option is to raise the production and productivity per unit of land through irrigation (Awulachew et al., 2005). Implementing sound irrigation water management practices is essential. Since irrigation is widely expanded in the Amhara region particularly in the Lake Tana basin. Farmers can irrigate their crops based on traditional know-how causing nutrient leaching, waterlogging, and severe water shortage problems in the study area. Proper amount and timing of irrigation water applications is a crucial decision for a farm manager to meet the water needs of the crop, to prevent yield loss, and maximize the irrigation water use efficiency resulting in beneficial use and conserve water resources (Allen et al., 1998). Therefore, the objective of this study was to determine crop water requirements and irrigation scheduling using the CROPWAT model for better resource allocation and crop productivity.

Materials and Methods

Description of the Study Sites: The field experiment was conducted in two sites of the Amhara region during the dry seasons of 2016/17 and 2017/18, North West Ethiopia. Koga irrigation scheme is located in the Northwest of Ethiopia at Mecha district, 41 km to the

West of Bahir Dar city and 543 km to the North of the capital city, Addis Abeba at 37° 7' 29.72" Easting and 11° 20' 57.85" Northing and an altitude of 1953 m a.s.l. The average annual rainfall of the area is about 1118 mm. The mean maximum and minimum temperatures are 26.8 ^{0}C and 9.7 ^{0}C respectively. Rib irrigation site is located in Fogera district Northwest of Ethiopia, 60 kilometres to the East of Bahir Dar city and 644 km North of the capital city, Addis Abeba at 37° 25' to 37° 58' Easting and 11° 44' to 12° 03' Northing and an altitude of 1794 m a.s.l. It receives 1400 mm mean annual rainfall. The mean daily maximum and minimum temperature of the study area was 30°c and 11.5°c. The area is characterized by mild altitude agro-ecology. The available phosphorous (ppm) and pH (1:2.5H2O) of the study area is 36.7 & 6.7 at Rib and 6.1 and 4.6 at koga. The trial was conducted in 2013 and 2014 at the experiment field of Adet agricultural research centre

Ethiopia (Figure 1).

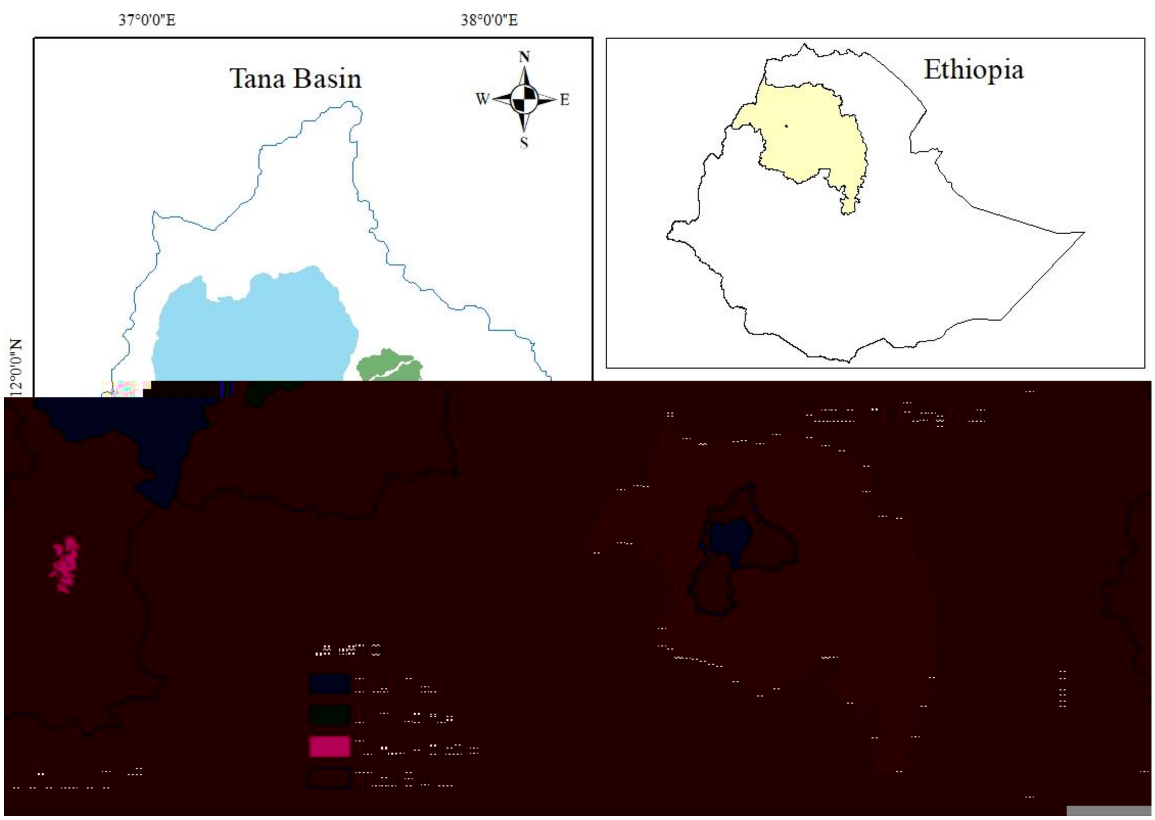

Figure 1. Location of the study area

Experimental Design and Setup

Experimental Setup: The on-farm trial was conducted with ten different treatments and arranged with a random complete block design with three replications (Figure 2). Two irrigation intervals i.e. 14 and 21 days and five irrigation depths (50, 75, 100, 125 and 150 % Evapotranspiration of the crop (ETc)) of variable depths at four growth stages were selected based on CROPWAT 8.0. Besides, we used 70 % field application for the trial. Thus, the treatments were set and evaluated for verification of the CROPWAT prediction with field experimentation (Table 1). The test crop maize a variety of BH-545 planted on 3 m by 6 m plot size, spacing between treatments and block was 1 and 2 m respectively. The test crop maize had 0.75 m and 0.3 m spacing between row and plants respectively. P_2O_5 fertilizer applied at a rate of 92 kg ha^{-1} at planting and 46 kg N ha^{-1} applied half at planting and the remaining half at 45 days after planting. The water application method was a surface irrigation technique that applies through furrow and a siphon hose was used for measuring the amount of water we applied using a constant head. The flow rate was estimated using the volumetric method. This has been done by collecting water in a tank of known volume. Q = V/t where, V = volume of the container (m^3), t = time taken (hr) and Q = discharge of irrigation water (m^3 hr^{1}) for both experimental sites (Gore and Banning, 2017).

Table 1. Treatment combination

Treatment	Frequency (days)	Total net irrigation depth (mm)	
		Koga	Rib
1	14	307	277
2	14	435	373
3	14	562	469
4	14	690	566
5	14	818	662
6	21	267	276
7	21	368	361
8	21	469	447
9	21	570	532
10	21	670	618

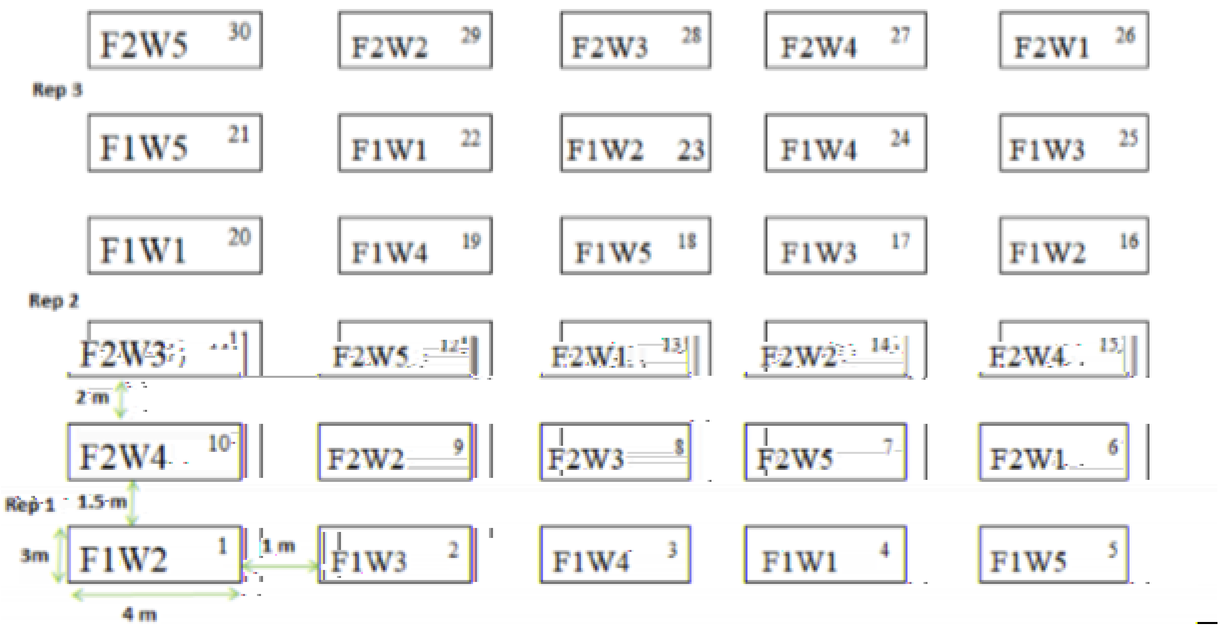

Figure 2. Field Layout of the experiment

Note: W1: 150 % CWR, W2: 125 % CWR, W3: 100 % CWR, W4: 75 % CWR, W5: 50 % CWR while F1 and F2 are 14 day and 21 day irrigation frequency respectively.

Data Analysis: Description of CROPWAT model: CROPWAT software model is a computer program used for irrigation planning and management developed by FAO and; is widely used to estimate reference evapotranspiration (ETO) and crop evapotranspiration (ETc) (Abdalla et al., 2010). It allows the development of recommendations for improved irrigation practices, the planning of irrigation schedules under varying water supply conditions, and the assessment of production under rain-fed conditions or deficit irrigation (Clarke *et al*., 2001). Although several methods exist to determine ETO; the Penman-Monteith method has been recommended as the appropriate combination method to determine ETO based on climatic data (Allen *et al*., 1998).

Crop Water Requirement and Irrigation Scheduling: Crop water requirement and irrigation scheduling were estimated using CROPWAT 8.0. Then the generated crop water and irrigation requirements values are shown in (Table 2). Besides dependable rainfall, (FAO/AGLW formula) method was used for the estimation of effective rainfall.

Table 2. Crop and irrigation water requirements of maize in Koga and Rib

Month	Decade	Stage	Koga					Rib				
			Kc*	ETc1	ETc2	ER	IWR	Kc	ETc1	ETc2	ER	IWR
Dec	2	Init	0.30	0.99	1.0	0.0	1.0	0.30	0.90	0.9	0.0	0.9
Dec	3	Init	0.30	1.01	11.1	0.0	11.1	0.30	0.90	10.0	0.0	10.3
Jan	1	Dev	0.31	1.06	10.6	0.0	10.6	0.30	1.00	9.6	0.0	9.6
Jan	2	Dev	0.51	1.79	17.9	0.0	17.9	0.50	1.50	15.0	0.0	15.3
Jan	3	Dev	0.81	3.01	33.1	0.1	33.0	0.80	2.40	27.0	0.0	26.8
Feb	1	Dev	1.10	4.37	43.7	1.0	42.7	1.00	3.40	34.0	0.0	34.0
Feb	2	Mid	1.29	5.37	53.7	1.4	52.3	1.20	4.10	41.0	0.0	40.7
Feb	3	Mid	1.29	5.56	44.5	1.7	42.8	1.20	4.20	34.0	0.0	33.6
Mar	1	Mid	1.29	5.73	57.3	1.9	55.4	1.20	4.30	43.0	0.0	43.3
Mar	2	Mid	1.29	5.90	59.0	2.2	56.8	1.20	4.50	45.0	0.0	44.5
Mar	3	Late	1.21	5.66	62.3	2.8	59.5	1.10	4.30	47.0	0.0	46.7
Apr	1	Late	0.90	4.30	43.0	1.3	41.7	0.80	3.30	33.0	2.0	30.8
Apr	2	Late	0.58	2.86	28.6	0.8	27.8	0.60	2.20	22.0	3.0	19.5
Apr	3	Late	0.38	1.84	5.5	2.9	0.7	0.40	1.50	4.5	1.0	2.6
Total					471.3	16.1	453.3			365.0	6.0	359.0

***** Kc is crop coefficient, ETc1 is potential crop evapotranspiration in mm day^{-1}, ETc2 is potential crop evapotranspiration in mm dec^{-1}, ER is effective rainfall in mm dec^{-1}, IWR is irrigation water requirement in mm dec^{-1}, Init, Dev, Mid and Late stands for initial, development, middle and late-stage respectively.

Statistical Analysis: The collected data were subjected to analysis of variance (ANOVA) using SAS version 9. The mean comparison was done by using the least significant difference test at 5 % probability level.

Results and Discussion

Dynamics of Soil Volumetric Moisture Contents: Changes in the volumetric soil water content of the irrigation regime treatments during the first year experimental periods are shown in (Figure 3). Although the experiment was conducted during the dry season, there was a rainfall (31 mm at Rib and 42 mm at Koga) during the middle stage of the crop in both years, leading to an increase in the soil moisture content of the entire treatments. Even though both 14 and 21-day interval received the same rainfall, irrigation depths of a 21-day interval is below field capacity (FC) due to less irrigation volume as compared to 14-day interval irrigation depths.

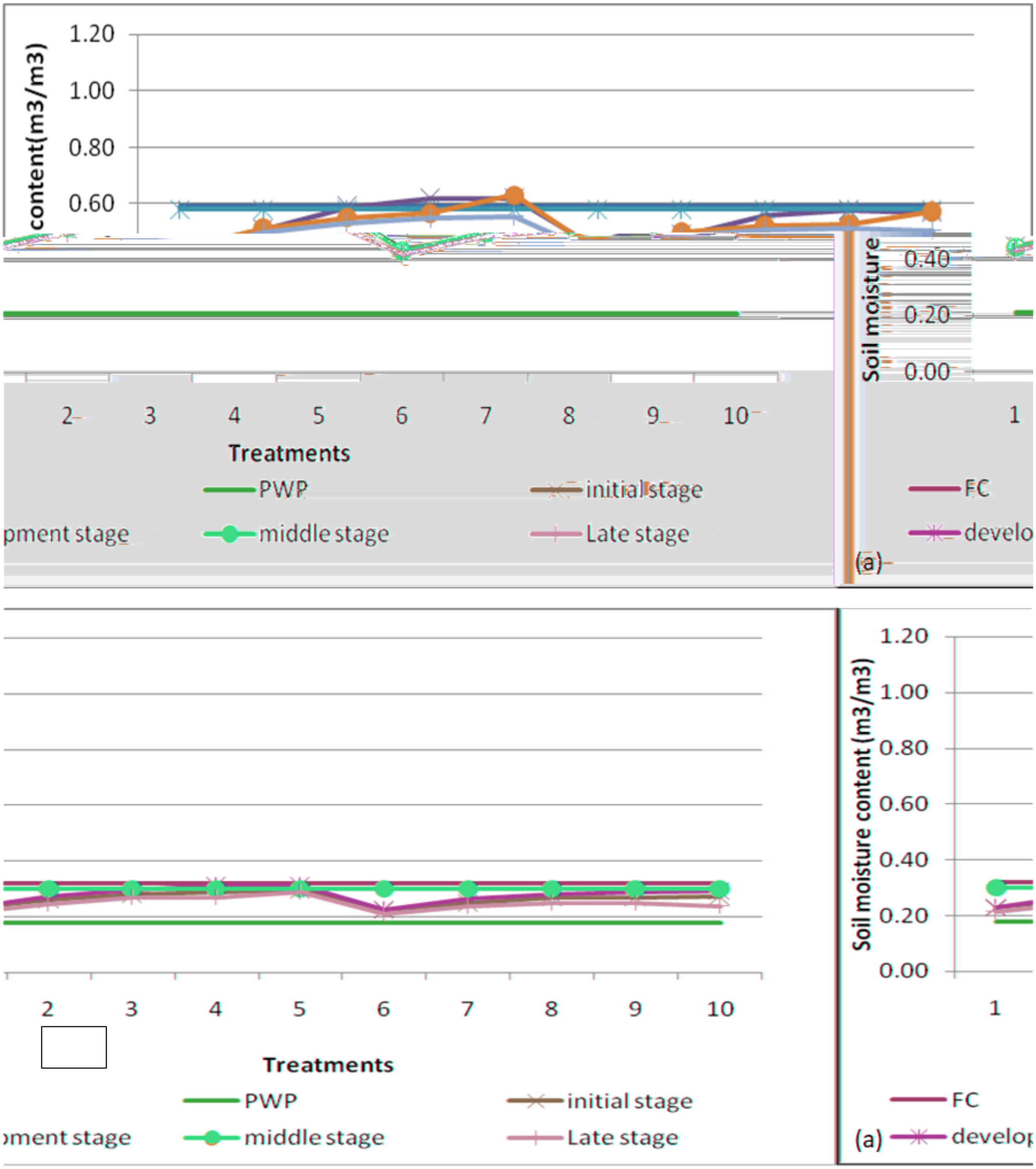

Figure 4. Average volumetric soil moisture content in four-crop growth stage vs irrigation regimes during 2016/17 experimental season (a) Koga (b) Rib irrigation scheme

Effect of Irrigation Regime on Grain Yield, Yield Component and Water Use Efficiency

As shown in Table 3, most parameters showed no significant difference for the interaction of irrigation interval and irrigation depth at ($P < 0.05$).

Grain Yield: Effect of variable irrigation regime on yield is presented in table 4a, irrigation depth alone significant ($P < 0.05$) in Koga (Table 3). The maximum (7.3 t ha^{-1}) grain yield was scored at 100 % ETc. This implies that the application of an optimum irrigation regime increased the grain yield over the deficit and excess irrigation regime. This is in line with the finding of Ekubay (2020) that showed the maximum grain yield (7.3 t ha^{-1}) achieved in 100 % ETc in northern Ethiopia. In the case of Rib, the irrigation interval showed a significant difference and the maximum (10.97 t ha^{-1}) grain yield was scored at 21-day irrigation interval and the minimum (9.97 t ha^{-1}) at 14-day irrigation interval as described in Table3. Maximum yield response to 21-day irrigation interval was due to high water holding capacity of the soil and manageable volumetric soil moisture content during the experimental season as shown in Figure 3a. Besides, 75 % ETc gives maximum yield (10.88 t ha^{-1}) as compared to full irrigation. This might be the occurrence of rainfall during the middle stage of the crop which leads to an increased soil moisture content of the deficit treatments. The finding is in line with Demelash and Ranamukhaarachchi (2004), Song et al (2019), and Ekubay (2020) irrigating sufficient water during the reproductive period of maize increase the grain yield. Generally, this study showed improvements in water amount and frequency of irrigation numbers as compared to conventional practice. The Previous finding of Ashiber (2017) indicated that 14-day irrigation interval with 140 % ETc is convenient to produce maize in North West Ethiopia.

The grain yield production at the Koga irrigation scheme is low as compared to Rib. This might be due to poor soil fertility and acidification at Koga and good nutrient content at Rib as mentioned in the site description section. Maize is sensitive to soil acidity and its suitable pH ranges from 5.8 to 7, while at Koga, it was about 4.6 that was below the critical level. Besides, the soil organic matter and available phosphorus was very low based on Clements and McGowen (1994) category.

Green cob number: Application of optimum irrigation regime increased the green cob number over the deficit and excess irrigation regime plot as shown in Table 3. Irrigation interval showed a significant difference in green cob number ($P < 0.05$) in Koga. The maximum 50,148 and the minimum 44,481 green cob number (approximately 1 cob per plant) was scored at 21 and 14-day irrigation interval respectively. The finding is in line with Amare et al. (2018) showed that the maize variety BH-545 gives one cob number per plant with 14-day irrigation interval in the Koga irrigation scheme. Despite the non-significance response of irrigation regime to cob number in Rib, the maximum 47527-cob number scored at 21 - day irrigation interval.

Cob Length and Cob Diameter: The maximum 14 cm cob length and 3.9 cm cob diameter scored at 21- day irrigation interval in Koga (Table 3). Similarly, the maximum 17.5 cm cob length and 4.96 cm cob diameter were scored at 21- day irrigation interval in Rib. Cob length and cob diameter do have not a strong correlation with the grain yield. This might be the occurrence of rainfall in the sensitive stage of the maize as described in Figure 3 above.

Water Use Efficiency: The interaction effect between irrigation interval and depth showed a non-significant ($P < 0.05$) in both locations (Table 3). Increasing the water depth from 50 to 150 % ETc resulted in a decrease of water productivity from 2.7 to 1.1 kg m^{-3} at Rib and 1.4 to 0.6 kg m^{-3} at Koga irrigation scheme. By reducing the frequency of irrigation from 14 to 21 days water productivity increased from 1.6 to 1.9 kg m^{-3} at Rib and 1.2 to 1.4 kg m^{-3} at Koga irrigation scheme. Compared with the optimum irrigation regime, the deficit irrigation treatments saved a significant depth of water with a minimum yield loss. Other authors like Song et al. (2019), Ekubay (2020) and Enyew et al. (2020) reported similar findings.

Table 3. Combined mean of yield and yield component

		Koga					Rib				
		Gy	Gcn	CL	CD	WUE	Gy	Gcn	CL	CD	WUE
D*	1	6.2	44630	13.6	3.9	1.4	10.49	44912	16.9	4.92	2.7
	2	5.6	47315	14	3.8	0.9	10.88	45328	17.58	4.8	2.1
	3	7.3	49537	13.7	3.9	0.9	10.34	47448	17.1	4.9	1.6
	4	6.9	48148	13.3	3.9	0.7	10.57	45787	16.6	4.95	1.3
	5	7.1	46944	14	3.9	0.6	10.1	47447	17.5	4.96	1.1
F	1	6.6	44481.5	13.5	3.9	1.2	9.97	44858	16.8	4.9	1.6
	2	6.6	50148	14	3.9	1.4	10.97	47527	17.5	4.92	1.9
LSD (5%)	D	0.01	0.44	0.14	0.12	0.001	0.87	0.8	0.09	0.018	0.001
	F	0.86	0.001	0.008	0.66	0.13	0.04	0.12	0.004	0.57	0.0001
	F*D	0.91	0.58	0.047	0.35	0.95	0.3	0.19	0.04	0.11	0.2
CV(%)		19.6	13.5	5.7	3.6	19.1	18.1	14.4	5.3	2.7	19.8

***** F- irrigation water frequency (day), D- Irrigation depth (mm), Gcn-Green cob number (no/ha), Gy-Grain yield (t ha^{-1}), CL- Cob length (cm) CD- Cob diameter (cm), and WUE- water use efficiency (kg m^{-3})

Conclusion

The result of the current study revealed that the effect of the irrigation regime was not significant on grain yield, cob number, cob length, and cob diameter and water use efficiency. In Koga, most parameters respond for irrigation depth than irrigation frequency, giving water below or above 100 % ETc affects most parameters. In the case of Rib, most parameters respond to irrigation frequency than irrigation depth. The net irrigation water requirement was found to be 447 mm to 562 mm throughout the growing season in the Lake Tana basin. Therefore, 100 % ETc and 21 days irrigation interval is recommended for Koga and similar agro-ecologies. For Rib and similar agro-ecologies, 75 % ETc and 21 days irrigation interval is recommended.

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