Determination of Crop Water Requirements and Irrigation Scheduling of Wheat at Koga and Rib irrigation Schemes, Ethiopia

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Abstract

In counties where water resources are limiting factors; there is a need to improve water resource management, determine water requirement and scheduling which are key parameters for precise irrigation management. This study was conducted to determine the crop water requirements (CWR) and irrigation scheduling of wheat at two locations under different weather and soil condition, North West Ethiopia. CROPWAT 8.0 model was used to determine the crop water requirement. The Penman-Monteith method was applied to calculate the reference evapotranspiration (ET0) and the United States Department of Agriculture (USDA) soil conservation service method was used to estimate the effective rainfall. Crop coefficients (kc), rooting depth, depletion level, and other agronomic parameters were adopted from FAO guidelines. Field data including; field capacity (FC), permanent wilting point (PWP), initial soil moisture depletion (%), available water holding capacity (mm/meter), infiltration rates (mm/day), and local climate data were determined in the study area. Five levels of irrigation water depth (50%, 75%, 100%, 125%, and 150%) and two irrigation intervals (14 and 21 days) were arranged in a randomized completely block design with three replications. The result was analyzed using SAS version 9.0 statistical software. The results showed that the irrigation regime had an impact on yield and water productivity. At Koga, irrigating 75% CWR (12 mm, 22 mm, 51 mm, and 48 mm) at initial, development, middle and late-stage respectively within 14 days irrigation interval gave 3.36 t/ha wheat yield and 1.07 kg/m^3 water productivity. While at Rib, irrigating 75 % CWR (0 mm,21 mm, 76 mm, and 78 mm) at initial, development, middle, late-stage) respectively within 21-day irrigation interval gave 3.73 - 4.77 t/ha yield and 1.07-2.5 kg/m^3 water productivity. Therefore, to attain an optimum yield and water use efficiency at Koga and Rib, wheat could be irrigated with an average irrigation application depth of 33 mm and 44 mm every 14 and 21 days irrigation interval respectively.

Keywords: *Irrigation scheduling; Crop Water Requirement; wheat; Koga; Rib*

Introduction

Irrigation is the means to optimize plant water use and increase crop production. Implementing comprehensive irrigation water management practices is essential to improve excessive irrigation and eliminate the associated problems (Al-Kaisi et al., 1997). The relation between yield and crop water consumption has been investigated and the result water resources (Allen et al., 1998). Therefore, the objective of this study was to determining crop water requirements and irrigation scheduling using the CROPWAT model for better resource allocation and crop productivity.

Materials and Methods

Site Description

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 Ababa at 37°7'29.72" Easting and 11°20'57.85" Northing and at 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 0C and 9.7 0C 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 Ababa 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 as mild altitude agroecology. The trial was conducted in 2013 and 2014 at the

field at Rib irrigation scheme, Western Amhara, Ethiopia (Figure 1). The field capacity (FC) and permanent wilting point (PWP) of Koga and Rib are (32 % and 59 %) and (18 % and 21 %) respectively. In Figure 2, the Koga Effective rainfall, Average rainfall, dependable rainfall, and ET_0.

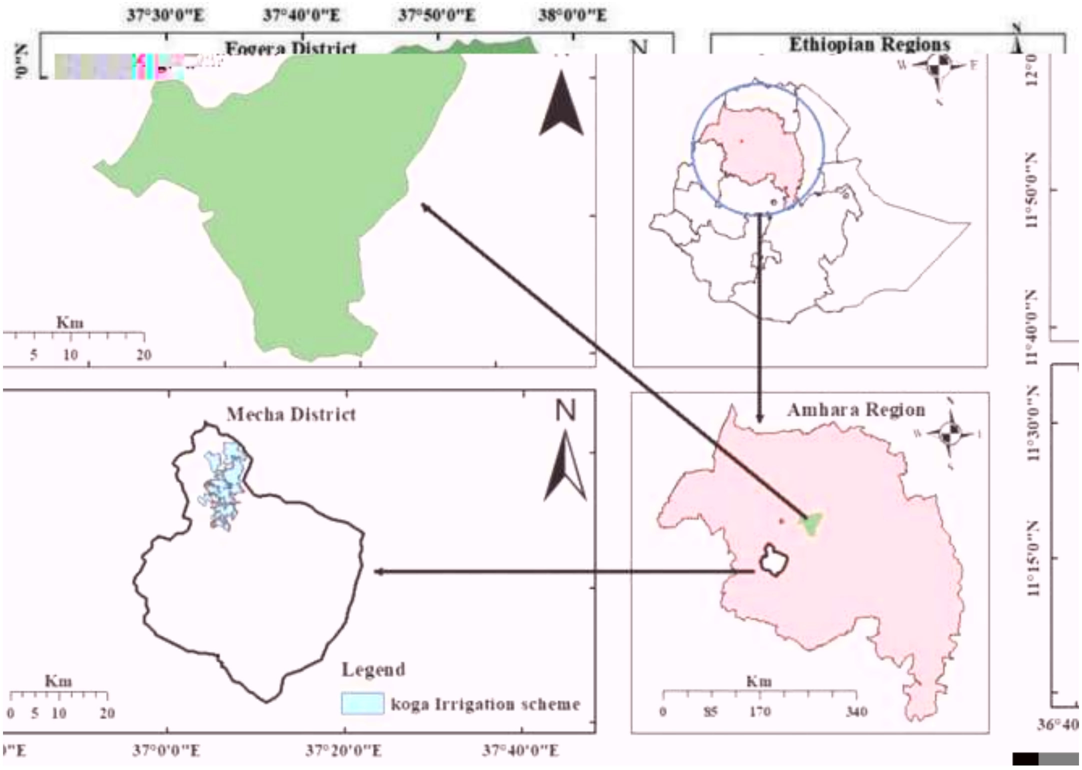

Figure 1. The location map of the study areas

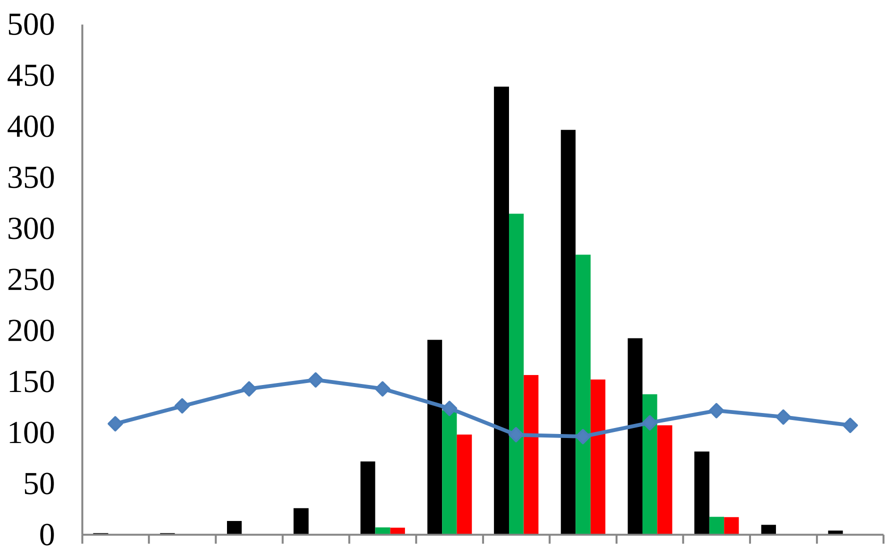

Figure 2. Koga Effective rainfall, Average rainfall, dependable rainfall, and ET_0

Methods

The field experiments were conducted in a randomized complete block design (RCBD) with three replications. The crop wheat; a variety of TAY was used and planted on 0.2 m spacing between row and by drilling 125 kg ha^{-1} seed. DAP was applied at a rate of 100 kg ha^{-1} at planting and 138 kg ha^{-1} Urea; half at planting and a half at 45 days after planting was applied. All the agronomic practices were equally treated for each treatment. Reference evapotranspiration (ETo) and the crop evapotranspiration (ETc) were estimated using Doorenbos and Pruitt (1977) FAO penman-Monteith method; Equations 1 and 2 respectively. Crop and irrigation water requirement was computed using the CROPWAT 8.0 software. Data of initial soil moisture, soil texture, and water holding capacity of the soil were collected before planting. Local rainfall data was used for estimation of effective rainfall and it was generated based on 80 percent dependable rainfall. USDA Soil Conservation Service method was used for the estimation of effective rainfall.

Where: ETo = reference evapotranspiration [mm day-1], Rn = net radiation at the crop surface [MJ m^{-2} day^{-1}], G = soil heat flux density [MJ m^{-2} day^{-1}], T = mean daily air temperature [°C], U2 = wind speed at 2 m height [m s^{-1}], es = saturation vapour pressure [kPa], ea = actual vapour pressure [kPa], es-ea = saturation vapour pressure deficit [kPa], slope vapour pressure curve [kPa $°C^{-1}$], $^{-1}$]

Where:

ETc = Crop Evapotranspiration

ETo = Reference Crop Evapotranspiration

Kc = Crop coefficient

Treatment Setup

The on-farm trial was conducted in the dry season with ten (10) treatments. The two factors of irrigation depth and frequency were factorially arranged and laid out in RCBD. The Two irrigation intervals of 14 and 21 days and five irrigation depths (50, 75, 100, 125, and 150 % of CWR) at four growth stages were selected from the output of the CROPWAT 8.0 model (Figure 3). The gross irrigation water requirement was determined using 70 % application efficiency for both locations. To verify the CROPWAT generated depth, field experiments were carried out for two consecutive years at both locations.

Table 1. The on-farm trail treatment combination

Treatment	Depth and Interval	Treatment	Depth and Interval
T1	50% CWR at 14 days	T6	50% CWR at 21 days
T2	75% CWR at 14 days	T7	75% CWR at 21 days
T3	100% CWR at 14 days	T8	100% CWR at 21 days
T4	125% CWR at 14 days	T9	125% CWR at 21 days
T5	150% CWR at 14 days	T10	150% CWR at 21 days

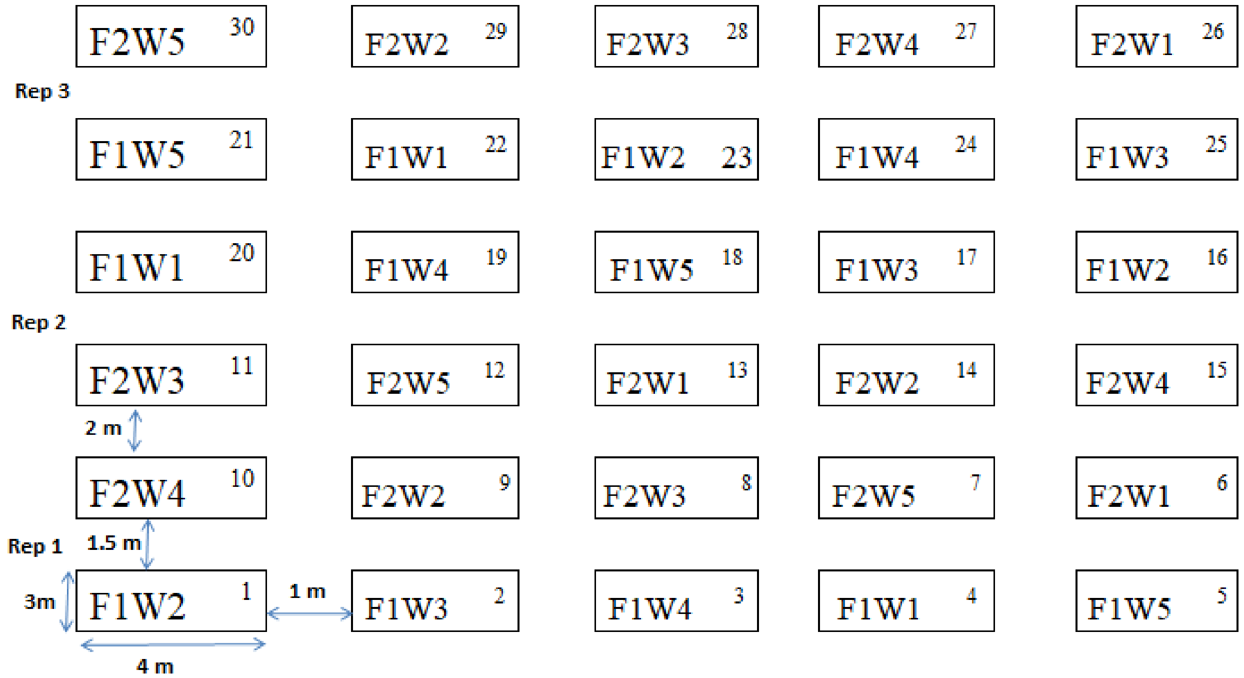

Figure 3. Field Layout of the experiment (where: W1 = 150 % CWR, W2 = 125% CWR, W3 = 100% CWR, W4 = 75% CWR, W5 = 50% CWR while F1 and F2 are 14 day and 21day irrigation frequency respectively).

Results and Discussion

The soil sample was taken before planting of wheat takes place and analysis using laboratory procedure. The field capacity (FC), permanent wilting point (PWP), and available water (AW) was done at Adet Agricultural Research Center soil laboratory using the gravimetric method. The result as shown in the table the soil texture was varied in the study site. The result of the soil sample analysis at the Koga site shown that (Table 1) the soil textural classification lay under the clay soil texture according to (Hazelton & Murphy, 2016), and the other physical characteristics were also similar with (Abiyu & Alamirew, 2015). The soil analysis at Rib has shown that the soil is a light clay classification and has high alluvial deposited soil that comes from the upstream mountainous area of the Rib River. Meanwhile, the net irrigation depth of the study area is depicted in Table 2.

Table 1. Soil characteristics of the study area

Site	FC (%)	PWP (%)	Sand (%)	Silt (%)	Clay (%)
Koga	30.8±1.7	18.9±1.2	20.2±4.8	22.4±2.7	57.3±4.5
Rib	59.0±1.3	21.0±1.4	24.0±2.4	36.0±3.5	40.0±5.2

Effect of crop water requirement and irrigation scheduling on wheat

Effect of different irrigation scheduling treatments on crop growth parameters, yield, and water productivity at Koga and Ribb irrigation scheme was presented in tables below. The ANOVA table showed that yield and water productivity were not significant differences over the year (Y), year by frequency (F), and year by depth (D) for both locations (Table 3).

Table 2. The net irrigation depth of the study area

Treatment	Location	
	Koga	Rib
	Net irrigation depth (mm)	Net irrigation depth (mm)
14D x 50% CWR	223	219
14D x 75% CWR	334	328
14D x 100% CWR	445	437
14D x 125% CWR	557	547
14D x 150% CWR	668	656
21D x 50% CWR	234	232
21D x 75% CWR	345	349
21D x 100% CWR	456	465
21D x 125% CWR	567	581
21D x 150% CWR	679	697

Note: 14D=14 days irrigation interval, 21D=21 days irrigation interval

Wheat Water productivity

The water productivity at Koga irrigation frequency, irrigation depth, and their interaction showed a highly significant difference in the water productivity of wheat (Table 3 and 4). The lowest (0.33 kg/m3) and the highest (1.07 kg/m3) water productivity were obtained for 150 and 75 % CWR at 21-day irrigation intervals respectively. The 14-day results are in close agreement with Kebede (2003) and (Bekele and Tilahun, 2007) who reported that when irrigation water becomes a limiting factor, yield losses due to reduced soil moisture could be compensated for by water use efficiency. The water productivity at Rib showed that irrigation frequency and depth were a highly significant difference (Table 5 and 6). The lowest (0.70 kg/m^3) and the highest (2.38 kg/m^3) water productivity were obtained for 150 % CWR and 50 % CWR irrigation depth within 14 and 21day intervals respectively. However, their 0.05). These results are also in close agreement with Kebede (2003) and (Bekele and Tilahun, 2007) who reported that when irrigation water becomes a limiting factor, yield losses due to reduced soil moisture could be compensated for by water use efficiency.

Wheat yield

The statistical analysis at Koga showed that irrigation frequency, irrigation depth, and their interaction have a highly significant difference in the grain yield of wheat (Table 3). The lowest (2.06 t ha^{-1}) and the highest (3.6 t ha^{-1}) grain yield of wheat were obtained for 50 and 125 % CWR at 14-day irrigation intervals respectively. The yield showed an increasing trend with the increase of water level up to 125 and 75 % CWR at 14 and 21day irrigation interval respectively. However, a further increase in irrigation level hurt the grain yield of wheat. The production was low compared to other productive areas of northwestern Amhara; this might be due to the soil condition (acidic soil) of the Koga command area since wheat is very sensitive to soil acidity. Besides, the soil at Koga has very low organic matter content and available phosphorus content according to the category by (Choudhury and Kumar, 1980). This result is in line with the finding of Ali and Yasin (1991), who reported that a high yielding wheat variety demands, adequate nutrient supply and optimum water to achieve maximum grain yield.

Table 3. ANOVA for yield and water productivity at Koga

Parameter	Degree of Freedom (DF)	Mean square Yield (t/ha)	Water Productivity (kg/m^3)	1000 Seed weight (g)
Year (Y)	1	0.15 ns	0.005 ns	ns
Replication (R)	2	0.02 ns	0.0008 ns	ns
Frequency (F)	1	1.71 **	0.02 *	ns
Depth (D)	4	1.76 **	0.62 **	ns
Y*F*D	4	0.55 **	0.48 **	ns
R*F	2	0.09 ns	0.006 ns	ns
F*D	4	1.95 **	0.14 **	ns
Error	28	0.07	0.004	0.089

*Note: ns is not significant, * significant and ** highly significant.*

Table 4. Mean yield and water productivity analysis result of Koga

Frequency (day)	Depth (%CWR)	Yield (t/ha)	water productivity (kg/m^3)
14	50%	2.06^{bc}	0.92
14	75%	3.36^{a}	1.07
14	100%	3.04^{ab}	0.66
14	125%	2.61^{b}	0.64
14	150%	2.33^{bc}	0.62
21	50%	1.94^{bc}	1.02
21	75%	1.36^{e}	1.07
21	100%	2.87^{b}	0.68
21	125%	2.95^{ab}	0.96
21	150%	2.09^{bc}	0.33
CV (%)		8.9	8.03

The statistical analysis of mean wheat yield at Rib showed that irrigation frequency, irrigation depth, and their interaction have a highly significant difference (Table 5 and 6). The lowest (3.96 t ha-1) and the highest (4.54 t ha-1) grain yield of wheat were obtained for 150 and 125 % CWR at 21 14 day irrigation intervals respectively. The result reveals that an increasing trend with the increase in water level up to 125 and 100 % CWR at 14 and 21day irrigation interval respectively. The total grain yield of wheat at Fogera plain (Rib) was much larger than the Koga irrigation scheme this is due to the condition of the soil at Fogera is fluvisols which are deposited from upper catchments and have good nutrient content. The combined effect of fertilizer and irrigation water can improve the wheat yield. This finding also similar to Ali and Yasin (1991), who reported high yielding wheat variety demands adequate nutrient supply to maximum grain yield.

Table 5. ANOVA for yield and water productivity at Ribb

		Mean Square		
Source	DF	1000 seed weight(g)	yield(t/ha)	Water productivity (kg/m^3)
Year (Y)	1	2224 **	12325861.8 **	10.4 **
Replication (R)	2	2.99 ns	348861.79 **	0.04 **
Frequency (F)	1	3.9 ns	25030.8 ns	1.17 **
Depth (D)	4	4.85 *	471892.6 **	3.56 **
Y*F*D	4	2.9 ns	471240.4 **	0.1 **
R*F	2	1.3 ns	10015.06 ns	0.006 ns
F*D	4	0.37 ns	501773.9 **	0.09 **
Error	28	1.73	50381	0.005
CV (%)		4.2	5.4	5.6

*Note: DF Degree of freedom, ns not significant * significant and ** highly significant*

Table 6. Mean yield and water productivity analysis result of Ribb

Frequency (Day)	Depth (%CWR)	Yield (t/ha)	WP (kg/m^3)
14	50	3.67^{c}	1.88^{b}
14	75	4.25^{ab}	1.48^{c}
14	100	3.99^{bc}	1.03^{d}
14	125	4.54^{a}	0.93^{de}
14	150	4.13^{ab}	0.70^{e}
21	50	3.98^{bc}	2.38^{a}
21	75	4.27^{ab}	1.81^{b}
21	100	4.14^{abc}	1.36^{c}
21	125	4.03^{bc}	0.96^{d}
21	150	3.96^{bc}	0.90^{de}
CV (%)		2.2	1.79

Note: WP Water Productivity, CWR- Crop Water Requirement

Conclusion and Recommendations

The effects of the irrigation regime were assessed by examining the effects on yield and water productivity of wheat at the Koga and Rib irrigation scheme. The study revealed that the irrigation regime (interaction effect of irrigation frequency and depth) affected the yield and water productivity of wheat at Koga and Rib irrigation schemes. At Koga, irrigating wheat within a 14-day interval using 75 % CWR irrigation depth gave 3.36 t/ha yield and 1.07 kg/m^3 water productivity. At Rib irrigation scheme, irrigating wheat within 21 days using 75% CWR irrigation depth has a high yield advantage gives 4.27 t/ha and 1.81 kg/m^3 optimal grain yield and water productivity respectively. Therefore, at the Koga irrigation scheme, irrigating 75% CWR (12 mm, 22 mm, 51 mm, and 48 mm) at initial, development, middle and late-stage respectively within 14 days irrigation interval could be applied to achieve optimal wheat yield and water productivity. While at Rib irrigation scheme, irrigating 75 % CWR (0 mm, 21 mm, 76 mm and 78 mm) at initial, development, middle, late-stage) respectively within 21-day irrigation interval could be applied to achieve optimal wheat yield and water productivity. However, to attain maximum wheat yield and water productivity further study is crucial in the area of fertilizer and irrigation water interaction.

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