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Research Article

Determination of Optimal Irrigation Scheduling for Durum Wheat in the Central Highland Vertosol of Ethiopia

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Abstract

The field trial was conducted for three years from 2014/15 to 2016/17 to determine optimal irrigation scheduling. There were five levels of irrigation water application; 60%, 80%, 100%, 120%, and 140% of the allowable soil moisture depletion levels (ASMDL) for each of the treatments laid out in a randomized complete block design with three replications. In the study, the combined year analysis result showed that there is a significant yield difference among the irrigation water applications at a $P < 0.05$ level of significance. The highest yield (5.269 tone ha^{-1}) was obtained by applying irrigation water of 80% ASMDL followed by 120% ASMDL (4.734 tone ha^{-1}) however the least yield (4.165 tone ha^{-1}) was observed at irrigation water application of 60% ASMDL of the recommended level which means the application of 40% less water than the FAO recommended level. There is no significant difference in water use efficiency between the treatments, but the highest water use efficiency has been observed at 80% ASMDL. The overall result of this experiment suggests that the application of irrigation water using 20% less than the FAO recommendation (100% ASMDL) can sufficiently be used for irrigation scheduling of irrigated durum wheat under central highland vertosol conditions. Therefore, to have a higher yield of irrigated durum wheat it was recommended to flush frequently before critical depletion occurred.

Keywords

Crop Water Requirement, Irrigation Scheduling, Water Use Efficiency, Irrigated Wheat, Soil Moisture

1. Introduction

Water could be a strategic resource for the social, economic, and environmental property of various countries, notably for water-scarce countries where over 40% of the world population lives. It's used for food production to satisfy the requirements of the increasing population [1]. Federal Democratic Republic of Ethiopia is blessed with ample water resources with twelve major stream basins with an annual runoff volume of 122 billion cubic meter of water and a calculable 2.6 to 2.65 billion cubic meter of groundwater potential [2]. Irrigation programing is vital for developing best management practices for irrigated agriculture [3]. Wheat is one of the foremost necessary staple food crops within the world. Federal Democratic Republic of Ethiopia produces 70% of total wheat production in eastern Africa [4]. Macaroni wheat is one of the two major species of wheat fully grown in of Ethiopia (tetraploid macaroni wheat & hexaploid bread wheat) [5]. Generally, in Federal Democratic Republic of Ethiopia irrigated wheat is cultivated on areas of 23.16 thousand hectares of land.

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2. Material and Methods

2.1. Description of the Study Area

The trial was conducted at Debre Zeit Agricultural Center irrigation farm. Its geographical location ranges from 08° 43' 48" to 08° 46' 45" Northern and from 38° 59' 45" to 39° 01' 48" eastern. The center is found on nearly level of an awfully gently sloping topography with a gradient of 0 to 2% slope. It's embossment variations with altitude starting from 1610 to 1908 meters above sea level. According to long term record of meteorologic data, the annual rain fall of the study area is 810.3 mm (Table 1) about 70% rain fall of the area occurs from June to September with its peak in July and August. The maximum and minimum temperatures are 28.3 ℃ and 8.9 ℃ respectively.

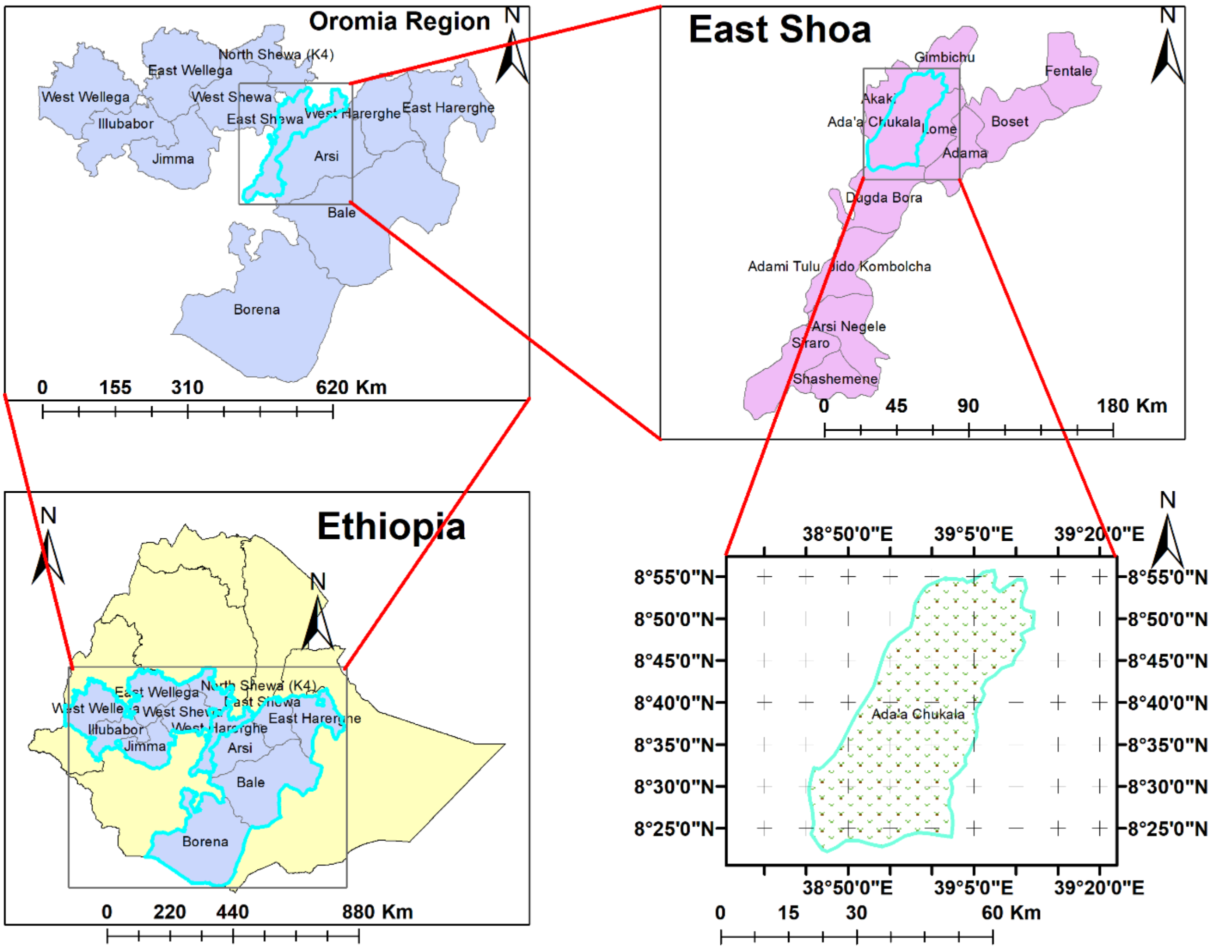

Figure 1. *Location of the study area.*

The mean maximum temperature varies from 23.7 to 27.7 ℃ while the mean minimum temperature varies from 7.4 to 12.1 ℃ (Table 1 & Figure 2). However, maximum, and minimum reference Evapotranspiration (ETo) was recorded as 4.7 and 3.3 mm/day in May and July respectively (Table 1 & Figure 2).

According to the study of Y. Seleshi et al. and Z. Tessema et al. [6, 7], the kiremt (June- August) is the main rainy seasons and Tseday (September-November) is that the spring season generally called the harvest season. Bega (December-February) is attributed to the dry season. Belg (March–May) is the time of year season with occasional showers however it's short-lasting rainfall. Belg within the study space receives quite little rain to support crop production whereas kiremt is understood by long time of rain for the year. Regarding 76% you look after the entire rainfall of the area falls in kiremt or wet season, regarding 15% in belg and therefore the rest is in bega or dry season that wants full irrigation within the space. The mean maximum temperature varies from 23.7 to 27.7 ℃ whereas the mean minimum temperature varies from 7.4 ℃ to 12.1 ℃ (table 1 and Figure 1). However, maximum, and minimum reference Evapotranspiration (ETo) was recorded as 4.7 and 3.3 mm/day in May and July respectively (Table 1 & Figure 2).

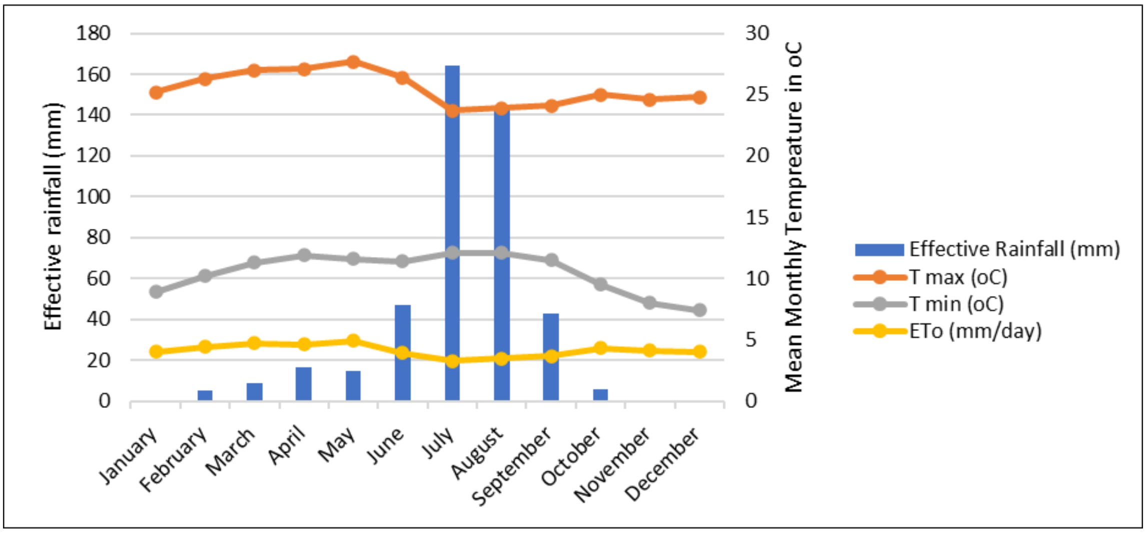

Figure 2*. Long-term climate data of study area.*

Table 1*. Long-term climate data of the study area.*

Month	T_{max} (°C)	T_{min} (°C)	ETo (mm/day)	RF (mm)	P_e (mm)
January	25.2	8.9	4.0	9.4	0.0
February	26.3	10.2	4.4	24.8	4.9
March	27.0	11.3	4.7	31.5	8.9
April	27.1	11.9	4.6	44.2	16.5
May	27.7	11.6	4.9	41.3	14.8
June	26.4	11.4	3.9	88.9	47.1
July	23.7	12.1	3.3	235.1	164.1
August	23.9	12.1	3.5	208.2	142.6
September	24.1	11.5	3.7	83.6	42.9
October	25.0	9.5	4.3	25.9	5.5
November	24.6	8.0	4.1	7.4	0.0
December	24.8	7.4	4.0	1.0	0.0
Average	25.5	10.5	4.1		

T_{max} = maximum temperature
T_{min} = minimum temperature
RF = Rainfall
P_e = Effective rainfall
ET_o = reference evapotranspiration

2.2. Experimental Design and Treatment Combinations

The experiment was designed as one factor experiment in a complete block design (RCBD) arrangement with three replications. The experiment enclosed five levels of soil water depletion levels (ASMDL) as a treatment and the five level of ASMDL are (60%, 80%, 100%, 120% and 140%) FAO focused ASMDL. For wheat crop suggested allowable soil wetness depletion level is 55% and also the different treatments allowable soil wetness depletion levels were calculated supported on this value [8].

Table 2. Treatment setup.

Treatment	Description
ASMDL1	60% ASMDL
ASMDL 2	80% ASMDL
ASMDL 3*	100%ASMDL (control)
ASMDL 4	120%ASMDL 4
ASMDL 5	140% ASMDL 5

*ASMDL = Available Soil Moisture Depletion Level

2.3. Reference Evapotranspiration

The reference evapotranspiration (ETo) of the site was calculated using FAO Penman-Monteith through CROP-WAT8.0 software, supported FAO Irrigation and drainage Paper 56 [9]. FAO56 adopted the Penman-Montieth technique as world standard to estimate ETo from meteoric knowledge. The Penman-Monteith equation integrated within the CROPWAT program is expressed by the subsequent equation (1).

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (1)$$

Where:
ET_o: reference evapotranspiration (mm day^{-1}),
R_n: 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 at 2 m height (℃),
u2: wind speed at 2 m height (m s^{-1}),
e_s: saturation vapor pressure (kPa),
e_a: actual vapor pressure (kPa),
e_s-e_a: saturation vapor pressure deficit (kPa),
Δ: slope of vapor pressure curve (kPa $℃^{-1}$),
γ: psychrometric constant (kPa $℃^{-1}$).

Table 3. Kc values, critical depletion, and yield response factors of durum wheat.

Kc & Yield factor	Description				
	Initial	Devel	Mid	Late	total
Growing period (days)	28	28	37	28	121
Kc values (fraction)	0.30	-	1.15	0.30	
Critical depletion (fraction)	0.55	-	0.55	0.80	
Yield response (fraction)	0.40	0.60	0.80	0.40	
Maximum crop height (m)		0.30	0.77	1.2	1.2

Kc = crop coefficient

2.4. Crop Water Requirements (CWR) and Irrigation Scheduling

2.4.1. Crop Water Requirements

Crop water demand is outlined as the depth of water under to fulfill water loss through evapotranspiration (ET) of a disease-free crop growing in massive fields beneath non-restricting soil conditions (standard conditions) as well as soil water and fertility to attain full potential production under a given growing area [10]. It's the overall amount of water needed by the crop from the time it's seeded to the time it's harvested. The quantity of water needed to compensate the evapotranspiration (ET) loss from the cropped field is outlined as crop water demand (CWR). Though the values for crop evapotranspiration (ETc) and crop water demand area identical, crop water demand refers to the quantity of water that must be supplied, whereas crop evapotranspiration refers to the amount of water that's lost through evapotranspiration.

$$ET_c = ET_o * K_c \quad (2)$$

Where:
ETc = Crop evapotranspiration (mm/day)
ETo = Reference evapotranspiration (mm/day)
Kc = Crop coefficient (fraction)

2.4.2. Irrigation Requirement and Irrigation Scheduling Determination

Irrigation water demand is that the quantity of water that has must be provided through the irrigation system to make sure the crop’s full water demand. If irrigation is the sole supply of water for the plant, then the irrigation water demand will be at least equal to or larger than crop water demand to permit for inefficiencies within the irrigation system or to compensate different loses. The net irrigation demand (IRn) doesn't consider losses that are occurring within the method of applying irrigation water. IRn and losses represent the gross irrigation demand (IRg). It's necessary to understand that the estimation of crop water necessities is that the initial stage within the estimation of irrigation demand of a given cropping program. Hence the calculation of crop water necessities and irrigation necessities should not be viewed as two unrelated procedures [11]. The irrigation water demand primarily represents the distinction between the crop water demand and effective precipitation [12].

$$IWR = ET_c - P_e \quad (3)$$

Where:
IWR is the net irrigation depth in mm,
ET_c is the crop water requirement in mm,

3. Results and Discussion

The cumulative crop evapotranspiration (ETc) for the time from planting (3rd week of November) to harvest for the irrigation experiment was 18.6mm, 74.4mm, 213.6mm and 123mm for initial, development, middle and late stages respectively of net crop water demand throughout the cropping season of durum wheat. As indicated the best crop water demand was discovered throughout the mid-stage as indicated in Table 4 as presented by [13].

Table 4. *Crop water demand of durum wheat under.*

Month	Decade	Stage	Kc (frac)	ETc (mm/day)	ETc (mm/dec)	p_e (mm/dec)	Irr. Req. (mm/dec)	CWR (mm)
Nov	3	Init	0.3	1.29	11.6	7.7	3.9	18.6
Dec	1	Init	0.3	1.48	14.8	0.1	14.7	
Dec	2	Dev	0.3	1.43	14.3	0	14.3	
Dec	3	Dev	0.52	2.45	26.9	0.1	26.8	74.4
Jan	1	Dev	0.86	4.16	41.6	8.3	33.3	
Jan	2	Mid	1.14	5.12	51.2	12.4	38.8	
Jan	3	Mid	1.19	5.91	65.1	10	55.1	213.6
Feb	1	Mid	1.19	6.43	64.3	6.6	57.7	
Feb	2	Mid	1.19	6.69	66.9	4.9	62	
Feb	3	Late	1.11	6.36	50.8	3.9	46.9	
Mar	1	Late	0.82	4.44	44.4	0.8	43.6	123
Mar	2	Late	0.51	2.98	29.8	0	29.8	
Mar	3	Late	0.32	1.83	3.7	1	2.7	
Total					485.4	55.8	429.6	429.6

Frac = fraction
Dec = decade
Irr.Req = irrigation requirement
CWR = crop water requirement

Table 5. *Combined ANOVA for determination of optimal irrigation scheduling for durum wheat.*

Irrigation level	Over year combined analysis result		
	BM (ton/ha)	GY (ton/ha)	WUE (kg/m^3)
ASMDL1	8350.70[c]	4164.93[d]	15.99[a]

Irrigation level	Over year combined analysis result		
	BM (ton/ha)	**GY (ton/ha)**	**WUE (kg/m^3)**
ASMDL2	10746.50^a	5269.10^a	20.02^a
ASMDL3	8993.10^{cb}	4524.31^c	16.90^a
ASMDL4	9618.10^b	4734.38^b	16.82^a
ASMDL5	8715.30^{cb}	4475.69^c	18.68^a
R-square	0.95	0.99	0.31
CV (%)	8.02	1.21	22.46
LSD $_{(0.05)}$	1051.80	79.20	NS

BM = biomass
GY = grain yield
WUE = water use efficiency

4. Conclusions

The combined year analysis result of the study showed that there was yield variations among the irrigation water applications at a $P < 0.05$ level of significance. The very best yield (5.269 tone ha^{-1}) was obtained by applying irrigation water of 80% ASMDL followed by 120% ASMDL (4.734 tone ha^{-1}) but the least yield (4.165 tone ha^{-1}) was ascertained at irrigation water application of 60% ASMDL which suggests application of 40% less water than the management treatment (FAO suggested, available soil wetness depletion level, ASMDL). There's no vital distinction of water use efficiency between treatment; however, the very best water use efficiency has been ascertained at 80% ASMDL. The application of irrigation water 20% less than the Food and Agriculture Organization of the United Nations recommendation (100% ASMDL) can be used for irrigation programing of irrigated durum wheat under central highland vertosol condition. Therefore, to own higher yield of irrigated durum wheat it had been suggested to irrigate frequently before critical depletion occurred.

Abbreviations

T_{max}	Maximum Temperature
T_{min}	Minimum Temperature
RF	Rainfall
P_e	Effective Rainfall (mm)
ET_o	Reference Evapotranspiration (mm day^{-1})
ASMDL	Available Soil Moisture Depletion Level
R_n	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 at 2m Height (℃)
u2	Wind Speed at 2m Height (m s^{-1})
e_s	Saturation Vapor Pressure (kPa)
e_a	Actual Vapor Pressure (kPa)
e_s-e_a	Saturation Vapor Pressure Deficit (kPa)
Δ	Slope of Vapor Pressure Curve (kPa ℃$^{-1}$)
γ	Psychrometric Constant (kPa ℃$^{-1}$)
Kc	Crop Coefficient
ETc	Crop Evapotranspiration (mm/day)
IWR	Irrigation Depth Requirement (mm)
ET_c	Crop Water Requirement (mm)
Frac	Fraction
Dec	Decade
Irr.Req	Irrigation Requirement
CWR	Crop Water Requirement
BM	Biomass
GY	Grain Yield
WUE	Water Use Efficiency

Conflicts of Interest

The authors declare no conflicts of interest.

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