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Water Requirement and Irrigation Scheduling of Selected Legume Crops Using CROPWAT 8.0 at Amibara, Middle Awash Valley Ethiopia

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Abstract: Determination of crop water requirements and appropriate irrigation scheduling is one of the key agricultural water management to apply the required water needed to the crop at a required time. A study was carried out to determine the crop water requirement and irrigation scheduling of the selected legume crops grown under irrigated conditions at Amibara Middle Awash Valley, Ethiopia. The crops include chickpea, common bean, and mung bean. By using the 33-years climatic data, crop evapotranspiration (ETc), reference crop evapotranspiration (ETo), and irrigation water requirement for each crop were determined using the CROPWAT model which is based on the United Nations' Food and Agriculture Organization (FAO) paper number 56 (FAO56). The study shows that the CWR for the October 15 planted chickpea, common bean and mung bean was 372.6mm, 412.1 mm, and 333.3mm respectively. The gross irrigation requirement was estimated to be 583.6 mm, 646.6 mm, and 531 mm for chickpea, common bean, and mungbean respectively. These results could be used as guidelines for the user for appropriate irrigation scheduling of the selected legume crops in the study area.

Keywords: Reference Evapotranspiration, Crop Water Requirement, Irrigation Requirement, Legume Crops, Cropwat

1. Introduction

Proper irrigation scheduling and efficient irrigation water management are crucial for the sustainability of irrigated agriculture. This is particularly important in the Middle Awash Valley, where continuous droughts, raising in salinity as a result of poor irrigation water management, and increasing competition among irrigation water users have limited the availability of water supplies [7]. Efficient use of water resources can be made possible through the assessment of crop water requirements and proper scheduling of irrigation.

Crop water requirements depend on climatic conditions, crop area and type, soil type, growing seasons, and crop production frequencies [3, 4]. The irrigation schedule recommendations for various crops should be location-specific, considering the soil types and agro-ecological conditions [10] CROPWAT 8.0 is a significant practice used by scientists for the assessment of crop evapotranspiration, CWR, and irrigation scheduling [8].

For the past five years, various adaptation research work was conducted by Werer Agricultural Research Center to introduce highland rain feed legume crops, especially chickpea, common bean, and mung bean to the lowland of Middle Awash Basin by using irrigation. The research findings of Werer Agricultural Research Center indicated that the performance of those legumes crops under the irrigated condition of Middle Awash is good and obtained maximum yield.

Currently, the farmers in the study area are interested in the production of those legume crops due to the high yield and salt tolerance potential of the crops. Considering the importance of the crops and farmers' interests, there is a lack of information concerning Middle Awash Valley on Crop water requirements and irrigation schedules of chickpea, common bean, and mung bean crops. Hence an attempt has been made with the general objectives to determine the Crop Water Requirement (CWR) and Irrigation Scheduling by using CROPWAT 8.0 software for the selected legumes crops (chickpea, common bean, and mung bean) at Amibara, Middle Awash Valley of Ethiopia.

2. Materials and Methods

2.1. Study Area

The study was conducted at Amibara, Middle Awash Valley of Ethiopia. It lies between 09°13′– 09°50' N and Longitude 40°05'– 40°25' E at an altitude of 750 m above sea level. The area is dry, with a semi-arid climate, receives a mean annual rainfall of 589 mm with an average minimum and maximum temperature of 15 and 38.4°C, respectively. The monthly evapotranspiration was greater than monthly rainfall throughout the year (Figure 1) implies that in the study area, irrigated agriculture is mandatory for crop production and agricultural sustainability because rainfall is in deficit throughout the years. The study area soils were clay in texture and moderately alkaline in reaction. The data collected on various soil physical properties are presented in Table 1.

Table 1. *Soil physical and chemical properties of the experimental field.*

Soil properties	Soil depth (cm)		
	0-30	30 -60	60- 90
Particle size distribution			
Sand (%)	10.8	12.8	12.8
Silt (%)	32	32	34
Clay (%)	57.2	55.2	53.2
Textural class	Clay	Clay	Clay
Bulk density (g/cm^3)	1.29	1.30	1.31
Field capacity (weight basis %)	40	39.5	39
Permanent wilting point (weight basis %)	24	23	22
Total available water (mm/m)	206.4	214.5	222.7

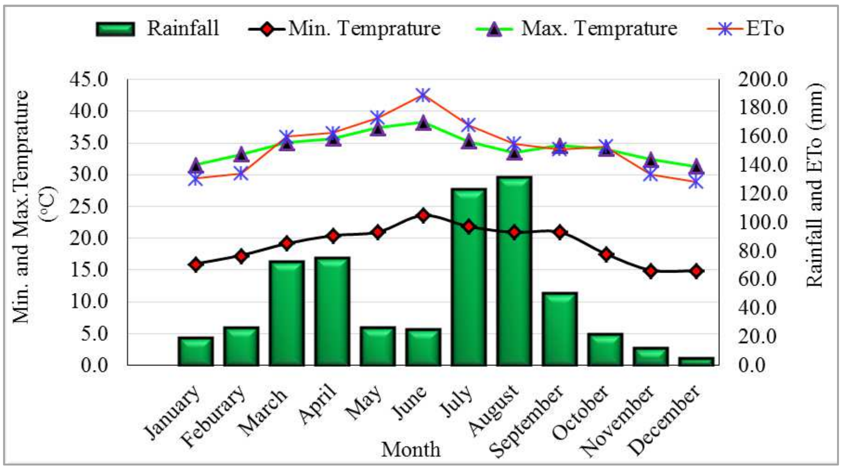

Figure 1. *Mean monthly rainfall, evapotranspiration, minimum and maximum temperature from 1987 to 2020 of the study area.*

The infiltration rate of the study area has been determined experimentally by the use of a double-ring infiltrometer. Figure 2 shows that the average basic infiltration rate of the study soil was 5 mm/hour. It means that a water layer of 5mm on the soil surface will take one hour to infiltrate.

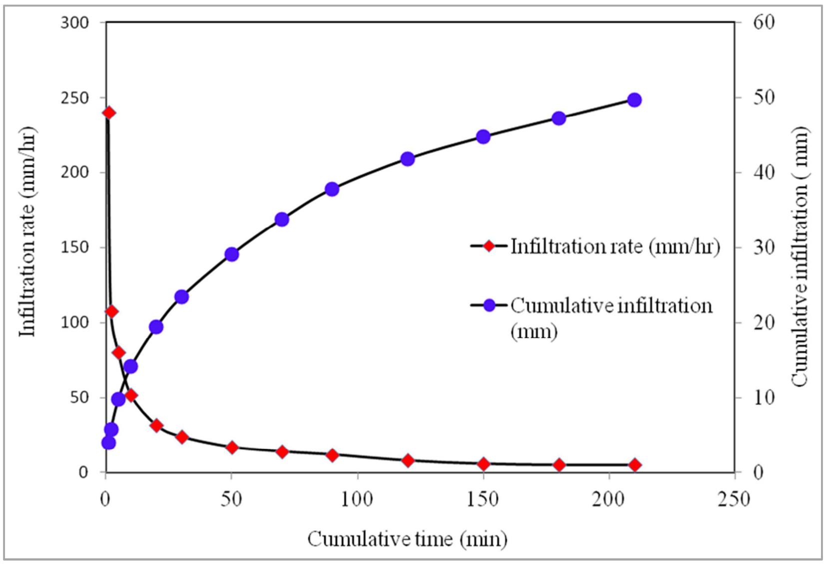

Figure 2. *Infiltration characteristics of the study area soil.*

2.2. Model Description

CROPWAT 8.0 has been developed by Joss Swennenhuis for the Water Resources, Development, and Management Service of FAO. The most common version now is CROPWAT 8.0 Edition, which was developed with assistance from the University of Southampton and the Institute of Irrigation and Development studies. CROPWAT is a computer program that uses the FAO Penman-Monteith procedure for the estimation of reference crop evapotranspiration (ETo), crop evapotranspiration (ETc), and irrigation scheduling.

2.3. Input Data for the Model

The initial data needed for the model to determine crop water requirement and irrigation scheduling are Meteorological data, crop growth data, & soil data [5].

2.3.1. Meteorological Data

Meteorological data for the study area have been obtained from the Werer Agricultural Research Center meteorological Station, for the 1987 - 2020 period. These data include average monthly minimum and maximum air temperature in °C, average monthly relative humidity in %, average monthly sunshine hours in hr. /day, average monthly precipitation in mm, and average monthly wind speed in m/s. The 80% probability of all these data was calculated using the weibul, probability estimation method as described in equations (2) used in the model to determine reference evapotranspiration (ETo) by using equation (1).

$$\text{ETo} = \frac{0.408\Delta[\text{Rn}-\text{G}]+\left(\frac{900}{\text{T}+273}\right)\text{u2}(\text{es}-\text{ea})}{\Delta+\gamma[1+0.34U2]} \quad (1)$$

Where; ETo = Reference crop evapotranspiration (mm day^{-1}),

Δ =Slope of the saturation vapor pressure curve (kPa^{-1}),

Rn = Net radiation at the crop surface (MJm^{-2} day^{-1}),

G = Soil heat flux density (MJ m^{-2} day^{-1}),

T = Mean daily air temperature at 2 m height (°C),

U2 = Wind speed at 2 m height (m/s),

es-ea = Saturation vapor pressure deficit (kPa),

es = Saturation vapor pressure at a given period (kPa),

ea = Actual vapor pressure (kPa), and

γ = Psychrometric constant (kPa^{-1}).

$$\text{80\% Weibull probability} = \frac{(r)*100}{n+1} \quad (2)$$

Where, r represents the rank and total number of data used in the analysis.

2.3.2. Crop Data

The Cropwat software needs some information about chickpea, common bean, and mungbean crops i.e. crop name, planting date, harvesting date, Crop coefficient (Kc) values depending on the crop growth stages, duration of four main crop growth stages (initial, development, mid-season and late season), rooting depth, critical depletion and yield response factor which were taken from FAO Irrigation and drainage paper 56. The sowing date for chickpea, mungbean and common bean was October 15 and the harvest date was December 23 for mungbean, whereas, for chickpea and common bean, the harvest date was considered January 12.

2.3.3. Soil Data

The Cropwat model needs general data like total available soil moisture, maximum infiltration rate, rooting depth, initial soil moisture depletion, and initially available soil moisture. This information was obtained from the Laboratory results of Werer Agricultural Research Center and the infiltration rate was measured by using the double-ring infiltrometer as described by Smith and Mullins [6].

2.3.4. Rain Data

The daily rainfall data were collected from the meteorological station of Werer Agricultural Research Center for 33 years (1987-2020) and the 80% probable of 31 years data was used in CROPWAT software to obtain effective rainfall To account for the losses due to runoff or percolation which was calculated in the model using Food and Agriculture Organization of United Nations, Water Resources Development Management Service (FAO/AGLW) as:

$$Pe = 0.6*P - 10 \text{ for month} < 70 \text{ mm} \quad (3)$$

$$Pe = 0.8*P - 24 \text{ for month} > 70\text{mm} \quad (4)$$

Where Pe is the effective rainfall (mm) and P is rainfall data from 80% probability of exceedance (mm/month).

2.4. Crop Water Requirement, Net and Gross Irrigation Requirement

The Crop water requirement (ETc) is obtained by multiplying reference crop evapotranspiration (ETo) values with the Crop coefficients (Kc). The Kc values for chickpea, common bean, and mung bean at the different growth stages (initial, development, mid and late-stage) are obtained from the FAO-56 crop manual. The crop water requirement (CWR) was determined using the CROPWAT program based on the FAO Penman-Monteith method [5] as:

$$ETo = ETc*Kc \quad (5)$$

Where ETc is crop evapotranspiration in mm, Kc is crop factor infraction and ETo is reference crop evapotranspiration in mm per month.

The net irrigation requirement was calculated using the following equation.

$$NIR = ETc - Pe \quad (6)$$

Where NIR is net irrigation water requirement (mm), ETc is crop water requirement (mm) and Pe is effective rainfall (mm). The gross irrigation requirement was obtained using the following equation:

$$GIR = NIR/Ea * 100 \quad (7)$$

Where GIR is gross irrigation requirement (mm), NIR is net irrigation requirement (mm) and Ea is application efficiency (%). Application efficiency of 60% was used to estimate the gross irrigation requirement using the equation.

2.5. Irrigation Scheduling

Irrigation scheduling allows the users to decide when to irrigate and how much water to apply. In the CROPWAT software, many irrigation scheduling options are available in selecting Irrigation timing, Irrigation application, and Irrigation efficiency. In this study case for all the selected legume crops, the irrigation scheduling can be done at 50% depletion timing and the irrigation application option is to refill soil to field capacity at 100% and the irrigation efficiency of 60% was considered with irrigation application by furrow irrigation method.

3. Results and Discussion

3.1. Reference Crop Evapotranspiration

The following table 1 gives the Reference Evapotranspiration (ETo) for all the months in a year, in which the highest reference evapotranspiration is found in June (290 mm/month) and the lowest Reference evapotranspiration is found in December (164.3 mm/ month) due to differential changes occurs in the weather conditions like temperature, sunshine hours, humidity and wind speed.

Table 1. *80% Probable long-term monthly climatic data from 1987-2019.*

Month	Min. Temp (°C)	Max.Temp (°C)	RH (%)	WS (m/sec)	Sunshine (hours)	ETo (mm/month)	Rainfall (mm)
Jan	16.0	31.6	55.0	2.8	8.8	168.6	19.3
Feb	17.3	33.3	51.0	2.7	8.8	167.9	26.2
Mar	19.2	35.0	51.0	3.1	8.5	208.3	72.6
Apr	20.4	35.7	51.0	3.2	8.4	209.8	75.3
May	21.0	37.4	44.0	3.6	9.2	247.0	26.6
Jun	23.6	38.4	40.0	5.2	8.7	290.0	25.3
Jul	21.9	35.2	54.0	5.0	7.2	235.3	123.1
Aug	20.9	33.5	60.0	3.6	7.3	192.8	131.1
Sep	21.0	34.7	56.0	4.3	8.1	214.9	50.5
Oct	17.6	34.1	51.0	3.3	9.1	210.8	21.7
Nov	15.0	32.4	50.0	2.9	9.4	178.9	12.1
Dec	14.9	31.4	53.0	2.6	9.1	164.3	5.3

Data were obtained from Werer Agricultural Research Center. WS = wind speed and RH = Relative humidity, ETo = Reference evapotranspiration.

Table 2. *Crop water Requirement and Irrigation Requirement for chickpea.*

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			Coeff	mm/day	mm/dec	mm/dec	mm/dec
Oct	2	Init	0.4	2.72	16.3	0	16.3
Oct	3	Init	0.4	2.61	28.7	0	28.7
Nov	1	Deve	0.47	2.94	29.4	0	29.4
Nov	2	Deve	0.72	4.27	42.7	0	42.7
Nov	3	Mid	0.96	5.51	55.1	0	55.1
Dec	1	Mid	1.03	5.69	56.9	0	56.9
Dec	2	Mid	1.03	5.46	54.6	0	54.6
Dec	3	Late	0.92	4.92	54.1	0	54.1
Jan	1	Late	0.57	3.08	30.8	0	30.8
Jan	2	Late	0.37	2.00	4.0	0	4.0
Total					372.6	0	372.6

Table 3. *Crop water Requirement and Irrigation Requirement for common bean.*

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			Coeff	mm/day	mm/dec	mm/dec	mm/dec
Oct	2	Init	0.4	2.72	16.3	0	16.3
Oct	3	Init	0.4	2.61	28.7	0	28.7
Nov	1	Deve	0.49	3.04	30.4	0	30.4
Nov	2	Deve	0.79	4.71	47.1	0	47.1
Nov	3	Mid	1.09	6.28	62.8	0	62.8
Dec	1	Mid	1.18	6.52	65.2	0	65.2
Dec	2	Mid	1.18	6.26	62.6	0	62.6
Dec	3	Late	1.05	5.59	61.4	0	61.4
Jan	1	Late	0.62	3.34	33.4	0	33.4
Jan	2	Late	0.37	2.02	4.0	0	4.0
Total					412.1	0	412.1

Table 4. Crop water Requirement and Irrigation Requirement for mungbean.

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			Coeff	mm/day	mm/dec	mm/dec	mm/dec
Oct	2	Init	0.4	2.72	16.3	0	16.3
Oct	3	Deve	0.41	2.68	29.5	0	29.5
Nov	1	Deve	0.69	4.34	43.4	0	43.4
Nov	2	Mid	1.08	6.42	64.2	0	64.2
Nov	3	Mid	1.19	6.81	68.1	0	68.1
Dec	1	Late	1.17	6.46	64.6	0	64.6
Dec	2	Late	0.77	4.07	40.7	0	40.7
Dec	3	Late	0.41	2.17	6.5	0	6.5
Total					333.3	0	333.3

3.2. Crop Water Requirement

The CWR was estimated by calling up the appropriate climate and rainfall data sets, together with soil and crop data files and the corresponding planting dates. Based on the data, fed to the CROPWAT model the crop water requirement has been determined for the selected legume crops. The crop water requirement is equal to the irrigation requirement for chickpea, common bean, and mung bean crops because the effective rainfall during the crop growing season is nil. The result in table 2 shows that chickpea requires a 372.6mm crop water requirement. The water requirement of common bean and mung bean was 412.1mm and 333.3mm respectively (Tables 3 and 4).

3.3. Irrigation Scheduling

The irrigation scheduling can be done at critical depletion timing and the irrigation application option is to refill soil to above or below field capacity at FAO recommended allowable depletion level for each crop. The irrigation application date, net irrigation requirement, and gross irrigation requirement for the chickpea pea, common bean, and mungbean crops have been illustrated in Tables 5, 6 and 7 respectively.

Table 5. Irrigation requirement and irrigation scheduling of October 15 planted chickpea.

Date	Day	Stage	Net Irrigation Requirement (NIR) in mm	Gross Irrigation Requirement (GIR) in mm	Flow in l/s/ha
22-Oct	8	Init	21.5	35.9	0.52
31-Oct	17	Init	23.5	39.1	0.5
8-Nov	25	Dev	23.5	39.2	0.57
15-Nov	32	Dev	27.2	45.4	0.75
21-Nov	38	Dev	26.8	44.7	0.86
26-Nov	43	Dev	27.6	46	1.06
1-Dec	48	Mid	27.7	46.2	1.07
6-Dec	53	Mid	28.5	47.4	1.1
11-Dec	58	Mid	28.2	47.1	1.09
16-Dec	63	Mid	27.3	45.5	1.05
21-Dec	68	Mid	26.8	44.6	1.03
27-Dec	74	End	29.5	49.2	0.95
4-Jan	82	End	32	53.3	0.77
12-Jan	End	End			
Total			350.1	583.6	

Table 6. Irrigation requirement and irrigation scheduling of October 15 planted common bean.

Date	Day	Stage	Net Irrigation Requirement (NIR) in mm	Gross Irrigation Requirement (GIR) in mm	Flow in l/s/ha
22-Oct	8	Init	21.5	35.9	0.52
31-Oct	17	Init	23.5	39.1	0.5
8-Nov	25	Dev	24.3	40.6	0.59
15-Nov	32	Dev	29.7	49.4	0.82
21-Nov	38	Dev	29.9	49.8	0.96
26-Nov	43	Dev	31.4	52.3	1.21
1-Dec	48	Mid	31.6	52.7	1.22
6-Dec	53	Mid	32.6	54.3	1.26
11-Dec	58	Mid	32.3	53.9	1.25
16-Dec	63	Mid	31.3	52.2	1.21
21-Dec	68	Mid	30.6	51	1.18
27-Dec	74	End	33.5	55.9	1.08
4-Jan	82	End	35.7	59.5	0.86
12-Jan	End	End			
Total			387.9	646.6	

Table 7. *Irrigation requirement and irrigation scheduling of October 15 planted mungbean.*

Date	Day	Stage	Net Irrigation Requirement (NIR) in mm	Gross Irrigation Requirement (GIR) in mm	Flow in l/s/ha
23-Oct	9	Init	24.4	40.6	0.52
2-Nov	19	Dev	30.1	50.2	0.58
9-Nov	26	Dev	30.4	50.6	0.84
14-Nov	31	Dev	30	50	1.16
19-Nov	36	Mid	32.1	53.5	1.24
24-Nov	41	Mid	33.7	56.1	1.3
29-Nov	46	Mid	34.1	56.8	1.31
4-Dec	51	Mid	32.6	54.4	1.26
9-Dec	56	Late	32.3	53.8	1.25
18-Dec	65	Late	39	65	0.84
23-Dec	End	Late			
Total			318.7	531	

4. Conclusion

From the study, it is concluded that Reference Evapotranspiration, Effective Rainfall, Crop water requirement, and Irrigation water requirement can be estimated using CROPWAT 8.0 Software with the input of climatic data like rainfall, maximum and minimum temperature, relative humidity, wind speed, and sunshine hours. The results of this study reveal that the total seasonal water requirement for chickpea, common bean, and mung bean was 372.6mm, 412.1mm, and 333.3mm respectively. The gross irrigation requirement considering 60% irrigation application efficiency was estimated to be 583.6 mm, 646.6 mm, and 531mm for chickpea, common bean, and mungbean respectively. The outcomes obtained from this study can be used by water resource planners for future planning, thereby helping to save water in meeting the crop water requirement and it can be used as a guide for the farmers to make the decision on much water to apply to a field.

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