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Water Requirement and Irrigation Scheduling of Potato (*Solanum tuberosum* L.) by Using CROPWAT 8.0 at Welmera District, Centeral Highland of Ethiopia

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Abstract

Determination of crop water requirement (CWR) is essential for better irrigation practices, irrigation practices and efficient use of water. A study was carried out to determine the crop water requirement and irrigation scheduling of potato crop grown under irrigated conditions at Holeta, Central Highland of Ethiopia. The 30-year climatic data (1993- 2023) collected from Holeta Agricultural Research Center were used for ETo determination. The results shows that, the maximum ETo was recorded in February and March which was 4.2 mm/day whereas the minimum value of 2.6 mm/day was recorded in July. Effective rainfall of 175 mm was maximum in August while the effective rainfall was zero in November and December. The CWR, NIR and GIR for potato crop was 444.9 mm, 371.7 mm and 741.5 mm respectively. For the 1st January planted potato irrigation should be given nine times (1-Jan, 12-Jan, 26-Jan, 9-Feb, 21-Feb, 5-Mar, 16-Mar, 26-Mar, and last irrigation on 6-Apr) with a gross irrigation water amount of 38.5 mm, 33.4 mm, 40.4 mm, 49.9 mm, 64.1 mm, 63.9 mm, 66.3 mm, 63.9 mm, and 67.6 mm depth respectively. The results of this study can be useful in preventing over or under-irrigation and for future planning of water resource, thereby helping to save water in meeting the CWRs, and can be used as a guide for farmers to select the amount and frequency of irrigation for the crops being studied.

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Keywords

Cropwat 8.0, ETo, Crop water requirement, Potato, Gross irrigation and Net irrigation.

Introduction

Population growth, high water competition, and the effect of climate change have caused water shortage problems in Ethiopia. Proper water management improves water efficiency; determining the water requirement of field crops is an option for improving water productivity (Tewabe *et al.,* 2022).

Not watering at the right time and correct amount can result in plant water stress and reduce the quality and yields of crops. On the other hand, over-watering can increase the risk of nutrients leaching below the root zone, waste resources (water, energy, and nutrients), and environmental impacts (Dong, 2023).

The irrigation scheduling is the process of determining when to irrigate and how much water to apply per irrigation. Proper irrigation scheduling is essential for the efficient use of water, energy and other production inputs (Khan *et al.,* 2007; Bhat *et al.,* 2017).

CROPWAT 8.0 is a widely used method by various scientists to estimate crop evapotranspiration, CWR, and irrigation scheduling (Moseki *et al.,* 2019; Roja *et al.,* 2020; Gebremariam *et al.,* 2021; Solangi *et al.,* 2022).

Potato (*Solanum tubersum* L.) is a root crop and ranks first in its volume of production and consumption followed by cassava, sweet potato and yam in Ethiopia (Wassihun *et al.,* 2019).

During the dry season, there was water conflict among the water users in the district due to the scarcity of irrigation water and large competition among the water user. Currently, irrigated potato is widely expanded in the welmera district. Farmers can irrigate crops based on traditional know-how causing nutrient leaching, water logging, and severe water shortage problems in the study area. By considering the lacking of adequate information and knowledge gap on crop water and irrigation requirements among the farmers practicing irrigation for most of the crops grown in the area, the current studies used agro climatic data and the CROPWAT 8.0 model to project irrigation water demands and create irrigation schedules for potato crop in the study area.

Materials and Methods

Study area

Welmera district is one of the special zones of Oromia National state surrounding Shaggar City, Ethiopia. The district is located at 34 km to the west of Addis Ababa and it lies between 08°50′ – 09°15' N and Longitude 38°25'– 38°45' E at an average altitude of 2400 m above sea level. Total geographical area of the district is 1046 km2 and the average annual rainfall is 1034 mm. The soil which is predominant in this area are Red clay soils. The district consist of highland and mid highland agro climatic zone that cover about 61% and 39% of the total area respectively.

In the study area, June to September is the main rainy season, which accounts for 70% of the total rainfall. Based on 30 years (1993-2023). The average annual rainfall for the study area was 1034.3 mm. The mean annual minimum and maximum temperatures of the study area were 6.4^{o}C and 22.7^{o}C respectively (Table 1).

The monthly evapotranspiration was greater than monthly rainfall starting from the month of June to September (Figure 2). The remaining month of the year evapotranspiration exceeds rainfall this implies that for production of potato during the rainfall season (June to September), the season available effective rain fall is enough to compensate the Crop water requirement. So, there is no any extra irrigation requirement is needed and in the remaining season, available effective rain fall is less to compensate the Crop water requirement. So, in order to maintain the crop water requirement, it requires flow from the other water resources.

Model description

CROPWAT model (Smith, 1992) is a decision supporting tool developed by water development division of FAO in computer programing language for calculating crop water requirement, irrigation water management, and irrigation scheduling using soil, crop and climatic data.

Input data required for calculation of CWR, IWR, and irrigation scheduling

Three types of data are required to use the CROPWAT software, namely climate data, soil data, and crop data (Mehanuddin *et al.,* 2018). After all inputs have been correctly introduced, the software gives some important outputs, such as reference evapotranspiration, effective rainfall, net irrigation requirement, gross irrigation requirement and irrigation scheduling.

Data Collection

Climate data

For this study, 30 years (1993 to 2023) climate data were obtained from the Holeta Agricultural Research Center meteorological station to calculate reference crop evapotranspiration (ETo). Climate data include maximum temperature, minimum temperature, relative humidity, wind speed, and sunshine hours were used for estimation of reference evapotranspiration. ETo is one of the important parameters required for crop planning and irrigation strategies (Mehta and Pandey, 2015). Among various methods of ET estimation, Penman– Monteith method is most widely used around the globe (Kumar, 2017; Sravya *et al.,* 2019) and given in eq. 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 = Saturation vapor pressure at a given period (kPa), ea = Actual vapor pressure (kPa), and

γ = Psychrometric constant (kPa-1)

Crop data

The Cropwat software needs some information about potato crop i.e. crop name, planting date, harvesting date, yield response factor, Crop coefficient (KC) and the crop growth stages. The crop growing season has been divided into four based on Doorenbos and Pruitt (1977). The initial stage refers to crop germination/transplanting. It also refers when the soil surface is not covered by the crop (canopy cover < 10%). The crop development stage denotes the vegetative period of the crop that includes from the end of initial stage to full canopy cover (canopy cover 70 – 80%). The mid-season stage represents the period between full ground cover to the time of start of maturity (leaf yellowing). Late season stage stands for the crop period from end of mid-season stage to full maturity (Araya *et al.,* 2011). The information was obtained from FAO manual 56 and adapted to the local climate conditions. In Table 2, the details of crop information, including sowing date, crop coefficient, and duration of growth stages, were described.

Soil data

The Cropwat model requires data such as total available soil moisture, maximum infiltration rate, maximum root depth, initial soil moisture depletion, and initial available soil moisture. This information was obtained from FAO Manual 56 and Information on soil properties i.e., Field Capacity (FC), Permanent Wilting Point (PWP), infiltration rate, initial soil moisture depletion were done at Holeta Agricultural Research Center soil laboratory using the gravimetric method.

Rain data

The rainfall data recorded from the Agro meteorological station for the last 30 years (1993 to 2023) was used and applied in CROPWAT software to obtain effective rainfall. The effective rainfall is a portion of rainfall which is effectively used by the plants. This effective rainfall was used to determine the irrigation requirement. The effective rainfall was determined based on the Food and Agriculture Organization of the United Nations, Water Resources Development Management Service (FAO/AGLW), which is expressed as:

$$Pe = 0.6 * P - 10 \text{ for month } \leq 70 \text{ mm} \quad \ldots (2)$$

$$Pe = 0.8 * P - 24 \text{ for month } \geq 70 \text{ mm} \quad \ldots (3)$$

Where Pe is the effective rainfall (mm) and P is rainfall (mm/month).

Crop evapotranspiration, Net and Gross Irrigation Requirement

The term crop water requirement is defined as the "amount of water required to compensate the evapotranspiration loss from the cropped field". "Although the values for crop evapotranspiration and crop water requirement are identical, crop water requirement refers to the amount of water that needs to be supplied, while crop evapotranspiration refers to the amount of water that is lost through evapotranspiration" (Allen *et al.,* 1998). The Crop evapotranspiration (ETc) is obtained by multiplying reference crop evapotranspiration (ETo) values with the Crop coefficients (Kc). The Kc values for wheat, maize and barley 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 (Allen *et al.,* 1998) as:

$$ETc = ETo \times Kc \quad \ldots (4)$$

Where ETc is crop evapotranspiration in mm, Kc is crop factor in fraction and ETo is reference crop evapotranspiration in mm per day.

The net irrigation requirement was calculated using the following equation.

$$NIR = ETc - Pe \quad \ldots (5)$$

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:

$$GIR = (NIR / Ea) \times 100 \quad \ldots (6)$$

Where GIR is gross irrigation requirement (mm), NIR is net irrigation requirement (mm) and Ea is application efficiency (%).

Ea, represents application efficiency of irrigation operation which depends on the characteristics of the adopted irrigation methods. In this study Ea of 60% for surface irrigation was used to estimate the gross irrigation requirement using equation.

Irrigation scheduling

Irrigation scheduling is a simple tool to determine how much water to deliver to crops and when. Each crop has several stages, namely the initial stage, the developmental stage, the middle stage, and the late stage.

At each stage, the irrigation requirement is different, so irrigation must be properly planned for the optimal use of water (Solangi *et al.,* 2022). In the CROPWAT software, many irrigation scheduling options are available for selecting irrigation timing, irrigation application, and irrigation efficiency.

In this study case for potato crop, the irrigation scheduling can be done at 50% depletion level as irrigation application time as indicated in FAO 56, and the irrigation application option of refill soil to field capacity at 100% was selected. An irrigation efficiency of 60% was considered due to furrow irrigation being the main irrigation application method for the study area.

Data analysis

The long-term mean monthly climatic data were used in the CROPWAT 8.0 model to determine the ETo for the study area. The ETo data obtained was further used to calculate the ETc. The flowchart showing the methodology for estimating crop water requirements and irrigation scheduling using the CROPWAT model is shown in Figure 3.

Results and Discussion

Analysis of soil data

Crop performance and efficient use of the available water can be optimized by determining the water holding capacity of the soil, the water requirements, and the response of each crop grown, using an effective soil moisture monitoring system and irrigation scheduling. The particle size of the sample was determined using the hydrometer method (Tewabe *et al.,* 2020). The result revealed that the texture of the soil changed as it got deeper in the soil profile. The topsoil 0-30 cm is sandy clay in texture, while the 2nd layer (30-60 cm) and the 3rd layer (60-90 cm) were sandy clay loam and clay respectively.

The average moisture content on a volume basis at Field Capacity (FC) and Permanent Wilting Point (PWP) were 36.85% and 26.61%, respectively. Table 3 shows that the average volumetric Total Available Water (TAW) was 133.12 mm/m and had a bulk density of 1.3 cm-3.

Reference Evapotranspiration (ETo)

The reference evapotranspiration (ETo) for the district was calculated from the Penman- Montieth equation using agro-climatic data. The result indicated in Table 4, gives the Reference Evapotranspiration (ETo) for all the months in a year, the peak ETo was reported in the month of February and March (4.2 mm/ day) and the lowest reference evapotranspiration is found in the month July (2.6 mm/ day).

A significant variation in ETo between seasons can be caused by variations in climatic factors such as temperatures, solar radiation, and rainfall as well as wind, and relative humidity. The results obtained in this study are similar to Adeniran *et al.,* (2010); Nivesh *et al.,* (2019) which showed that ETo was lowest during the peak of the rainy season to highest during the peak of the dry season.

Rainfall and Effective rainfall

Effective rainfall is that fraction of the overall rainfall that substitutes or possibly reduces the respective net amount of irrigation water needed. The effective rainfall (Peff) for the district was calculated using the USDA-SCS method.

Figure 4 represents the month-wise total and effective rainfall of the study area. Maximum effective rainfall of 175 mm was observed in August, while effective rainfall was zero in November and December.

It shows that November and December are the driest months in the study area, during which crops need irrigation without considering rainfall. The study result found that the total average effective rainfall is 597.6 mm, which is 57.8% of the average annual rainfall of 1034.3 mm.

Table.1 Climate characteristics

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad
	°C	°C	%	km/day	Hours	MJ/m?/day
January	4.1	23.5	51	104	10.4	**22.7**
February	5.2	24.3	54	112	9.6	**22.9**
March	6.8	24.5	55	112	7.9	**21.5**
April	8.4	24.1	61	104	7.2	**20.6**
May	8.3	24.4	59	112	7.4	**20.4**
June	8.1	22.7	69	69	5.7	**17.5**
July	9.3	20.3	78	69	3	**13.6**
August	9.2	20	81	69	3.1	**14**
September	7.8	20.6	72	86	5	**16.9**
October	4.8	22.4	59	138	8.3	**21.2**
November	2.8	22.8	54	130	9.8	**22.1**
December	2.2	23.1	58	130	9.7	**21.2**
Average	**6.4**	**22.7**	**63**	**103**	**7.3**	**19.6**

Table.2 Details of the crop required as per the CROPWAT model

```
Crop Name:  Potato                  Planting date: 01/01    Harvest: 30/04

Stage                   initial     develop      mid        late       total

Length (days)             25          30          40         25         120
Kc Values                0.50        -->         1.15       0.75
Rooting depth (m)        0.30        -->         0.60       0.60
Critical depletion       0.25        -->         0.30       0.50
Yield response f.        0.45        0.80        0.80       0.30        1.10
Cropheight (m)                                   0.60
```

Table.3 Soil physical and chemical properties of experimental field

Soil properties	Soil depth (cm)			Average
	0-30	30 -60	60- 90	
Particle size distribution				
Sand (%)	47.49	48.46	12.8	**36.25**
Silt (%)	11.3	17.95	34	**21.06**
Clay (%)	41.19	33.69	53.2	**42.69**
Textural class	Sandy Clay	Sandy Clay loam	Clay	**Clay**
Bulk density (g/cm^3)	1.29	1.30	1.31	**1.3**
Field capacity (weight basis %)	35.64	37.54	37.38	**36.85**
Permanent wilting point (weight basis	25.15	27.52	27.17	**26.61**
Total available water (mm/m)	**135.32**	**130.26**	**133.75**	**133.12**

Table.4 Reference crop evaporation

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
ETo	**3.9**	**4.2**	**4.2**	**4.0**	**4.1**	**3.3**	**2.6**	**2.7**	**3.2**	**4.0**	**4.0**	**3.8**

Table.5 Crop water Requirement, net and gross irrigation requirement for potato

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	NIR Req.	GIR Req.
			Coeff	mm/day	mm/dec	mm/dec	mm/dec	**mm/dec**
Jan	1	Init	0.5	1.95	19.5	0.8	18.6	**32.5**
Jan	2	Init	0.5	1.97	19.7	1.2	18.5	**32.8**
Jan	3	Deve	0.54	2.19	24.1	2.2	21.9	**40.2**
Feb	1	Deve	0.75	3.11	31.1	3.1	28.1	**51.8**
Feb	2	Deve	0.98	4.12	41.2	3.9	37.3	**68.7**
Feb	3	Mid	1.15	4.83	38.7	5.1	33.5	**64.5**
Mar	1	Mid	1.16	4.89	48.9	6.4	42.6	**81.5**
Mar	2	Mid	1.16	4.89	48.9	7.6	41.3	**81.5**
Mar	3	Mid	1.16	4.82	53	8.9	44.2	**88.3**
Apr	1	Late	1.14	4.65	46.5	10.6	36	**77.5**
Apr	2	Late	0.99	3.99	39.9	12.1	27.8	**66.5**
Apr	3	Late	0.82	3.34	33.4	11.5	21.9	**55.7**
Total					**444.9**	**73.2**	**371.7**	**741.5**

Where, Dev = Development stage, Mid = Middle stage, Init = Initial stage, NIR= Net irrigation requirement, GIR= Gross irrigation requirement

Figure.1 Geographical location of the study area

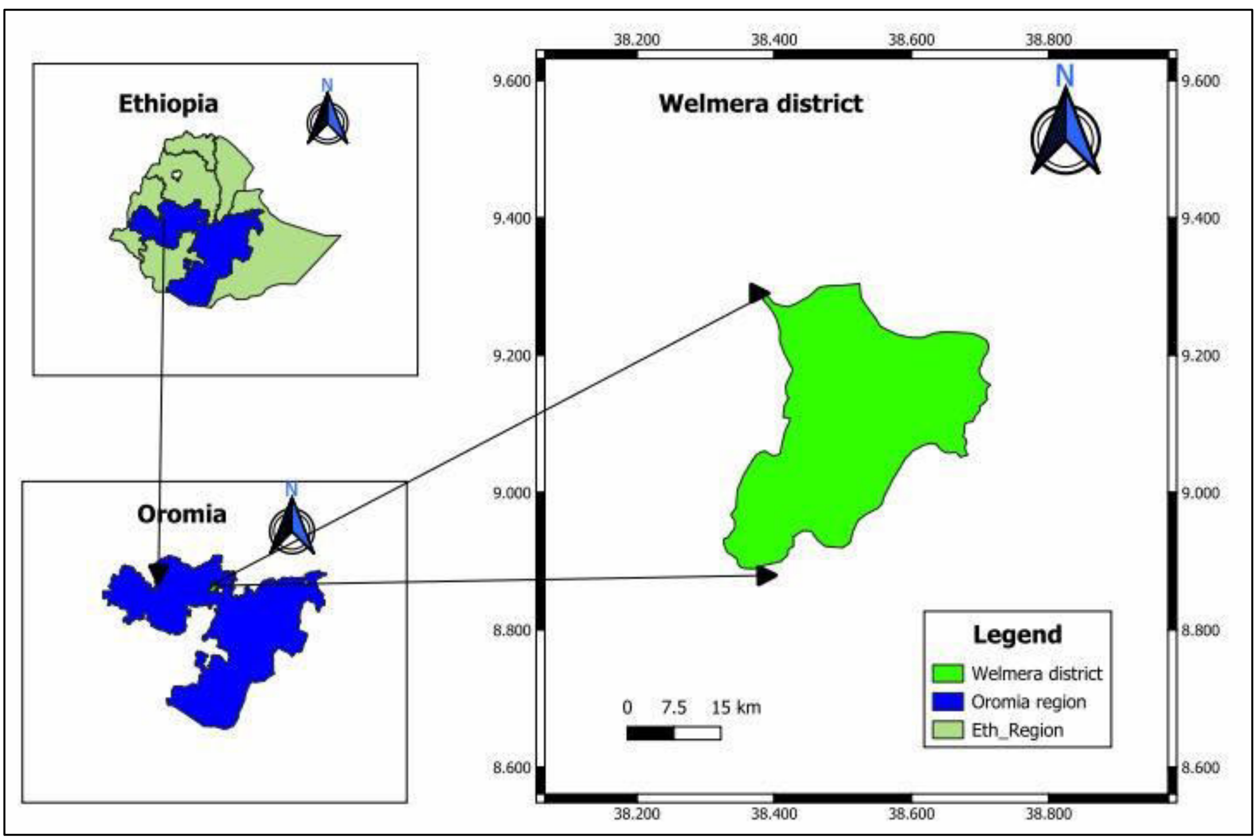
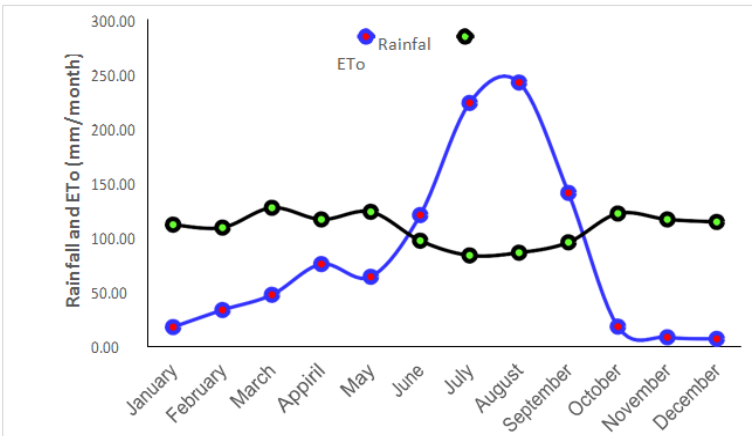


Table.6 Irrigation requirement and irrigation scheduling of early January planted potato

Date	Day	Stage	Net Irr	Gr. Irr	Flow
			Mm	mm	l/s/ha
1-Jan	1	Init	23.1	38.5	4.45
12-Jan	12	Init	20	33.4	0.35
26-Jan	26	Dev	24.2	40.4	0.33
9-Feb	40	Dev	29.9	49.9	0.41
21-Feb	52	Dev	38.5	64.1	0.62
5-Mar	64	Mid	38.3	63.9	0.62
16-Mar	75	Mid	39.8	66.3	0.7
26-Mar	85	Mid	38.4	63.9	0.74
6-Apr	96	End	40.5	67.6	0.71
30-Apr		End			

Figure.2 Monthly rainfall as compare with reference evapotranspiration.



Month

Crop Water Requirement and irrigation Water Requirement

Estimation of the CWR was carried out by calling up successively 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 potato crop. The crop water requirement and irrigation water requirement of potato, was 444.9 mm, and 741.5 mm respectively (Table 5). The determined above crop water requirement for each crops are within the range indicated in the FAO 66 (Steduto *et al.*, 2012) which are 350 to 650 mm for potato.

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 result indicated that in the study area, the total growing days (from sowing to harvesting) for potato sown on January 1st take 120 days. irrigation should be given nine times (1-Jan, 12-Jan, 26-Jan, 9-Feb, 21-Feb, 5-Mar, 16-Mar, 26-Mar, and last irrigation on 6-Apr) with a gross irrigation water amount of 38.5 mm, 33.4 mm, 40.4 mm, 49.9 mm, 64.1 mm, 63.9 mm, 66.3 mm, 63.9 mm, and 67.6 mm depth respectively (Table 6).

Figure.3 Flow chart for the estimation of irrigation demand and scheduling using CROPWAT model

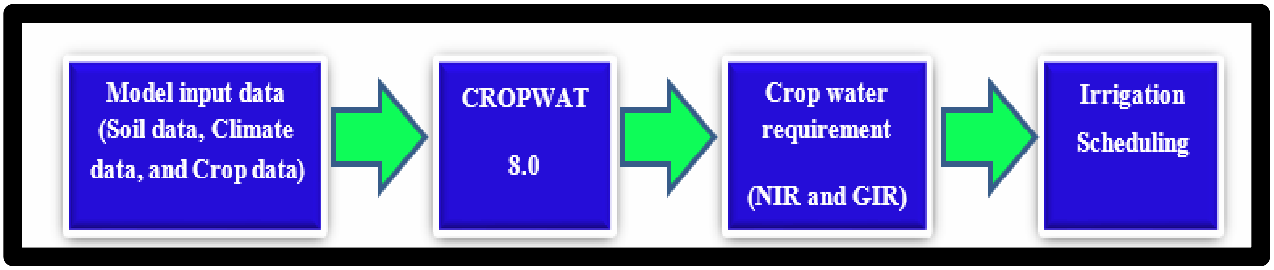
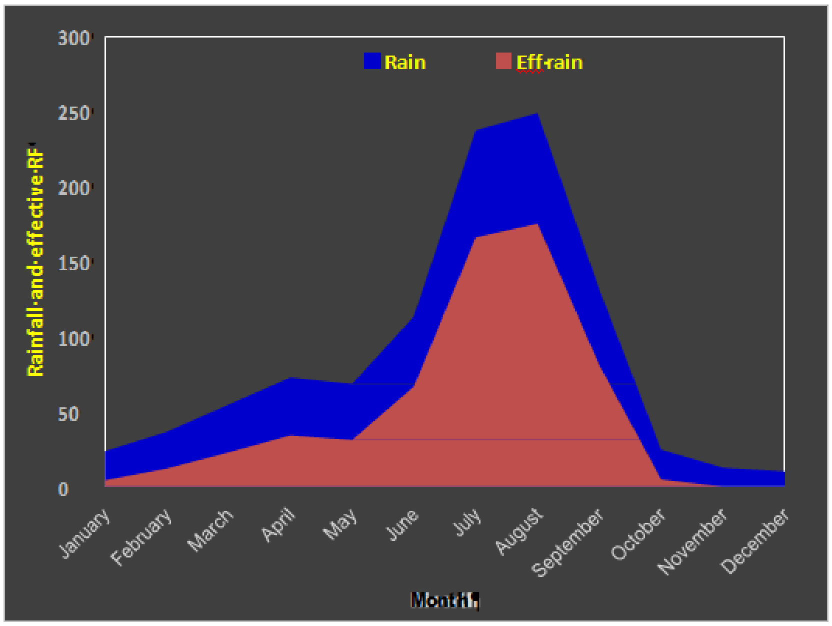


Figure.4 Rainfall and effective rainfall of the district



Conclusion

The Crop water requirement (CWR), Net irrigation requirement (NIR), growth irrigation requirement (GIR), and irrigation scheduling of potato were estimated using CROPWAT 8.0 for the Welmera district. From the study, it is concluded that the irrigation scheduling, the net and gross irrigation water requirement of potato 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 maximum ETo was recorded in February and March which was 4.2mm/day whereas the minimum value of ETo in July was 2.6 mm/day. Effective rainfall of 175 mm was maximum in August while the effective rainfall was zero in November and December. The total seasonal crop water requirement, net and gross irrigation requirement considering 60 % irrigation application efficiency was estimated to be 444.9 9 mm/ period, 371.79 mm/ period and 741.5 per season respectively.

For 1st January planted potato, irrigation should be given nine times irrigation should be given nine times (1-Jan, 12-Jan, 26-Jan, 9-Feb, 21-Feb, 5-Mar, 16-Mar, 26-Mar, and last irrigation on 6-Apr) with a gross irrigation water amount of 38.5 mm, 33.4 mm, 40.4 mm, 49.9 mm, 64.1 mm, 63.9 mm, 66.3 mm, 63.9mm, and 67.6 mm depth respectively. The findings obtained from this study can be used by water resource planners for future planning, thereby helping to save water in satisfying crop water requirement and it can be used as a guide for the farmers to adopt water-saving practices by applying the required amount of water at a required time for optimize production the crop being studied.

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Author Contributions

Nigusie Abebe: Investigation, formal analysis, writing—original draft. Mohammed Temam: Validation, methodology, writing—reviewing.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical Approval: Not applicable.

Consent to Participate: Not applicable.

Consent to Publish: Not applicable.

Conflict of Interest: The authors declare no competing

Abbreviations

ETo: Reference evapotranspiration, CWR: Crop Water Requirement, GIR: Growth Irrigation Requirement

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