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# Determinations and Validations of Crop Water Requirements for Major Vegetable Crops Using CROPWAT Model at Oda Bultum District

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## ABSTRACT

*To avoid over or under-irrigation, it's critical to estimate the water consumption of the crop appropriately. In the Oda Bultum District of Eastern Oromia, the study's goal was to ascertain and validate the crop water requirements of tomatoes, onions, and hot peppers for appropriate management under surface irrigated conditions. The CROPWAT simulation, which utilizes the FAO-Penman Monteith approach, it served as a basis for determining the required water quantity for irrigation for each crop and the reference crop evapotranspiration using the 30-year climate data obtained from the Ethiopian National Meteorological Institute. The research showed that harvested water necessity and irrigation water requirement of onion, tomato, and hot pepper with a developing time of 135, 120 and 135 days require 409 and 398 mm, 412 and 358mm, and 589.8 and 422.3 mm, respectively, of water during the slow time of year and yield water requirement. Planning district-wide water management techniques for the chosen crops and avoiding excessive or insufficient irrigation may benefit from this study. These outcomes can be utilized for arranging and the most effective water need and improve cultivation of the onion, tomato, and hot pepper in the research area. This research could help avoid excessive or insufficient irrigation and support the development of effective water management plans for the chosen crops in the district.*

***Keywords:*** *Climate, Crop water requirement, CROPWAT, Vegetable crops.*

## Introduction

The FAO chose to help program CROPWAT 8.0 to process reference evapotranspiration (ET0), crop water requirements (CWR), water system booking, and water system water necessities (IR) utilizing precipitation, soil, yield, and environment information [13;14; 36]. Water is essential for both national growth in agricultural productivity and economic performance. However, it is transforming into increasingly scarce due to rising demand in agriculture and industry. Given that Crop and livestock production is crucial for sustaining the population, Effective utilization of existing water resources is crucial for fulfilling agricultural demands [40]. CropWat 8, a Windows program, calculates crop water requirements and irrigation needs using soil, climate, and crop data. It produces irrigation schedules tailored to diverse management strategies and assesses water availability across varying crop configurations. Furthermore, it analyzes farmers' irrigation methods and forecasts crop outcomes under both rain-fed and irrigated systems. CropWat functions as a comprehensive tool for irrigation planning and management, integrating field-level factors such as climate, crop type, and soil characteristics [10].

CropWat supports the calculation of reference and crop-specific evapotranspiration, helps design irrigation schedules, and determines water needs for different cropping systems during irrigation planning [30]. To optimize water use and boost efficiency, precise yield forecasting is essential. are necessary under real-world field conditions. Crop water requirements fluctuate both spatially and temporally [39].

The importance of simulation models in comprehending there has been substantial advancement in understanding soil-plant-atmosphere interactions in recent years[18]. Several models, including budget [34] and CropWat [16], have been developed and employed to simulate water balance in cropped fields. Onions thrive at elevations ranging from 500 to 2400 m.a.s.l., with Ethiopia's optimal growing zone identified between 700 and 1800 m.a.s.l. The ideal conditions for bulb formation include daytime temperatures between 18.3°C and 23.9°C, and nighttime lows of 10–12°C [20]. For best growth, onions require deep, well-aerated, alluvial or sandy loam soils with a pH range of 6 to 8 [5]. They are sensitive to poor drainage and moderately affected by soil salinity. In Ethiopia's eastern regions, onions hold significant agricultural value, ranking as the second most cultivated vegetable after potatoes [5].

Onion (*Allium cepa L.*) is highly sensitive to soil moisture fluctuations and requires adequate irrigation throughout its growth cycle. Generally, the crop demands between 350 and 550 mm of water, though the actual requirement varies with climate, soil type, and crop duration. In areas experiencing higher evapotranspiration (ET) rates, supplemental irrigation beyond this range becomes essential to maintain optimal yield and bulb quality. Insufficient irrigation can lead to reduced bulb size, splitting, and early bolting, while over-irrigation may promote diseases and negatively affect storability.

It is important to note that onion is not suited for dryland farming due to its shallow root system and high sensitivity to water stress. Hence, precise irrigation scheduling is crucial for ensuring uniform growth and productivity. In irrigation science, crop evapotranspiration (ETc) and crop water requirement (CWR) are closely related: ETc quantifies the amount of water lost through combined processes of transpiration and evaporation (a negative water balance), whereas CWR reflects the volume of water that must be supplied to the crop to offset these losses (a positive water balance). Understanding this relationship forms the basis for water management strategies, enabling growers to optimize irrigation, conserve water resources, and improve onion production efficiency.

Onion (*Allium cepa L.*) seasonal water requirements are highly variable and influenced by several factors, including crop variety, planting density, agronomic practices, anticipated yield, soil and climate characteristics of the region, and the irrigation technique and scheduling method adopted [21; 254; 27]. Numerous studies across different agro-climatic regions have quantified these requirements, highlighting their variability.

For instance, lysimeter-based studies reported seasonal onion ETc values of 390 mm in the Central Rift Valley, Ethiopia [8], and 893 mm in Albacete, Spain [23]. Interestingly, the latter exceeded the theoretical ETc estimated using the FAO methodology. Stage-wise ETc measurements by [8] showed 51 mm during the initial stage (20 days), 140 mm in crop development (30 days), 145 mm at mid-season (30 days), and 54 mm in the late season (20 days). A review by [21] summarized that for yields between 35–45 t/ha, seasonal water requirements typically ranged between 350 and 550 mm [25; 33].

Experimental results from different regions further illustrate this variation: 337 mm using micro-sprinkler irrigation in Bulgaria [33], 597 mm under drip irrigation in Washington State (USA), 662 mm for drip-irrigated onions in Spain, and only 225–250 mm for yields of 10 t/ha in Eastern India [6]. In Texas (USA), seasonal ETc values across two years ranged between 362 and 438 mm [33]. Collectively, these studies indicate that onion water requirements span from 225 mm to 1040 mm, supporting yields between 10 and 77 t/ha, with irrigation efficiency and local conditions playing critical roles.

Comparable findings in other crops also highlight the importance of irrigation efficiency. For example, Giuliani [32] reported tomato crop water and irrigation requirements of 598 mm and 480 mm, respectively, while another study estimated seasonal tomato ETc at 584.0 mm and net irrigation water requirement at 340.7 mm [12].

In addition to water, temperature and soil conditions play a crucial role in onion cultivation. The optimal mean daily temperature ranges from 18–25°C, with 10–15°C at night being ideal for bulb development [37; 38]. Onions require well-drained sandy loam or clay loam soils to achieve optimal growth and yield.

Notably, water requirement patterns can be compared with other high-value crops. For instance, hot pepper (*Capsicum annuum L.*), another important commercial crop cultivated for fresh consumption, spice, and processing, demonstrates similar sensitivity to irrigation scheduling [29].

Green pepper (*Capsicum annuum L.*) originated in the Americas, but its cultivars are now widely grown across the globe due to their extensive use as both food and medicine [28; 31]. The crop performs well in soils with a pH range of 5.5 to 7.5 and thrives best at altitudes between 1,400 and 1,900 meters above sea level. For optimal growth and yield, it requires 600 to 1,200 mm of evenly distributed annual rainfall during the growing season. Warm climates favor its development, while proper soil drainage is essential, as waterlogging can cause leaf drop and yield reduction [37; 38].

In many production areas, farmers face persistent challenges in determining the optimal irrigation timing, quantity, and method under varying agroclimatic conditions. This issue is particularly critical in regions where agricultural water productivity remains low and food security is compromised due to high population growth and unsustainable water exploitation in both developing and developed countries [11].

Given these constraints, a clear understanding of crop water requirements is crucial for enhancing irrigation practices and maximizing water-use efficiency. This becomes even more significant in the context of climate variability and global water scarcity. To address this need, the CROPWAT model, developed by the FAO, has emerged as a valuable decision-support tool. It provides standardized calculations for reference evapotranspiration, crop water requirements, irrigation scheduling, and water-use planning, thereby aiding decision-making in regions with limited or fluctuating water availability. Under such challenging conditions, determining and validating the crop water requirements of key crops like tomato, onion, and hot pepper is essential for sustainable irrigation management, resource optimization, and ensuring stable agricultural productivity.

## Materials and Methods

### Description of the study area

The study was conducted in the Oda Bultum district, situated in the West Hararghe zone. Geographically, it lies between latitudes 08°30′0″N and 09°00′0″N, and longitudes 40°20′0″E to 40°40′0″E, approximately 404 kilometers east of Ethiopia's capital, Addis Ababa. The district receives an average annual rainfall ranging from 900 to 1,100 mm. Temperatures vary throughout the year, with average highs of 28°C, lows of 15°C, and a mean temperature of around 20°C. The predominant soil type in the area is sandy loam.

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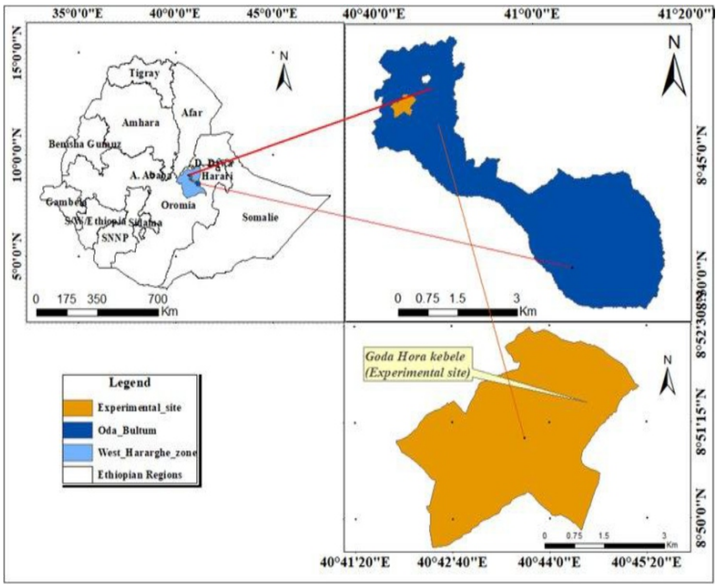


*Figure 1. Map of the study area*

### Data and effective rainfall

The collected meteorological data from 1991 to 2020 from the Ethiopian national meteorological agency were used as input for the CROPWAT 8model. Reference crop evapotranspiration and effective rainfall were determined using the formula below

$$\mathrm{ETo} = 0.408\Delta(\mathrm{Rn} - \mathrm{G}) + \gamma \frac{\frac{900}{\mathrm{T}+273}\mathrm{U2}(\mathrm{es}-\mathrm{ea})}{\Delta+\gamma(1+0.34\mathrm{U2})} \quad 1$$

Where, $ET_o$ = reference evapotranspiration, mm day$^{-1}$; Rn = net radiation at the crop surface, MJ m$^{-2}$d-1; G = soil heat flux density, MJ m$^{-2}$d$^{-1}$; T = mean daily air temperature at 2 m height, °C; $U_2$ = wind speed at 2 m height, ms$^{-1}$; $e_s$= saturation vapor pressure, kPa; $e_a$= actual vapor pressure, kPa; $e_s$-$e_a$= saturation vapor pressure deficit, kPa.

Precipitation Information and Assessment of Successful Precipitation. Correspondingly, environmental information for 30 years for month-to-month precipitation information was gathered from the Ethiopian National Meteorological Agency (ENMA). Compelling precipitation ($P_{eff}$) was resolved utilizing the Trustworthy downpour (FAO/AGLW recipe) strategy [40] and [4] as displayed in equations 2 and 3. The compelling precipitation was utilized to determine water system water requirement for the yields. CROPWAT provides various ways for calculating effective rainfall. For this study, the Dependable rain (FAO/AGLW formula) method is used and may be seen as follows:

$$\mathrm{Peff} = 0.5 * \mathrm{P} + \frac{-5}{3} \text{ for } \mathrm{P} \leq \frac{50}{3}\mathrm{mm} \quad 2$$

$$\mathrm{Peff} = 0.7 * \mathrm{P} + \frac{20}{3} \text{ for } \mathrm{P} > \frac{50}{3}\mathrm{mm} \quad 3$$

The reference evapotranspiration for specific agroecological units was calculated using the FAO Penman-Monteith method. This calculation was facilitated by the CROPWAT 8 decision support software, developed by the FAO Irrigation and Drainage Paper 56 [15]. The software considers factors such as soil type, climate, and crop data [17]. The crop coefficient (Kc) values corresponding to various growth stages were sourced from the FAO-56 guidelines. The CWR was calculated as follows:

$$\mathrm{ETc} = \mathrm{Kc} * \mathrm{ETo} \quad 4$$

**Required irrigation volume and timing plan**

Required irrigation volume and timing plan or Net irrigation requirement and irrigation Schedule Information on crop water system water prerequisites and water system time plans further develops water systems for executives in the field. Water system water the board is tied in with controlling the sum, timing, and pace of water system in a productive and arranged way.

The Required irrigation volume is the water amount expected for the development of the yield, or it is how much water is important to arrive at the field limit of the dirt. NIR relies upon the environment and editing design. Information on irrigation efficiency is essential for translating net irrigation requirements into gross irrigation demand. The different misfortunes, like overflow, leakage, vanishing, and permeation, happen during the application of a vehicle in a water system [28; 35; 3]. Tasks, like filtering, transplantation, and land planning, require specific measures of water. In this way, CWR incorporates ET, misfortunes during the utilization of water required for these reasons, as in equation 5.

$$\mathrm{NIR} = \mathrm{ETc} - \mathrm{Effrain} \quad 5$$

Irrigation scheduling involves identifying the appropriate quantity of water and the optimal timing for application. The CROPWAT model supports this process by estimating reference evapotranspiration (ETo), crop water requirements (CWR), and irrigation requirements (IRs), enabling the formulation of irrigation plans under varying management scenarios and water availability conditions [13].

## Results and Discussion

### Soil physicochemical property

*Table 1. Soil physical properties of the experimental site*

| Site | Depth (cm) | Bulk Density (g/cm³) | FC (%) | PWP (%) | Texture |
|---|---|---|---|---|---|
| Goda Hora | 0-40 | 1.24 | 40.1 | 28 | Sandy loam |

### Soil physical properties

The soil sample was collected before planting of onion, tomato, and hot Pepper. Laboratory analysis revealed that the texture falls within the sandy loam soil class at the Goda Hora site. The physicochemical characteristics are detailed in Tables 3 and 4. Table 1 displays the values for bulk density, moisture content at field capacity (FC), and permanent wilting point (PWP). At the initial locations within Goda Hora PA during 2023, the mean bulk density for the soil profile within the 0–40 cm layer was documented as 1.24 g/cm$^3$ and 1.18 g/cm$^3$ respectively [5]. Remember, since the effective root zone for these three crops is more than 40 cm, different studies support that more than 80% is effective in up to 40cm layer so these works are considered for up to 40 cm. Field capacity moisture levels reached up to 40.1%, while the permanent wilting point was measured at 28%. These values served as the basis for calculating irrigation depths, which were administered at the designated sites through the use of a Parshall flume.

*Table 2. Soil chemical properties of the experimental site*

| Site | Depth (cm) | EC (mmhos/cm) | pH | TN (%) | P (mg/kg) | K (mg/kg) | OC (%) | CEC (meq/100g) | Na (meq/100g) |
|---|---|---|---|---|---|---|---|---|---|
| Goda Hora | 0-40 | 1.7 | 7.5 | 0.27 | 92.4 | 491 | 0.59 | 25.1 | 0.9 |

### Soil's chemical characteristics

Soil pH values across the study area were 7.5, indicating slightly alkaline conditions, which are generally optimal for the cultivation of onion, tomato, and hot pepper. Soils with an alkaline pH (pH > 7.0) typically contain high levels of calcium; however, they are often prone to phosphorus (P) deficiency [22]. As highlighted in previous studies, soil pH plays a critical role in influencing the growth and productivity of tomato plants. Nevertheless, there is still limited research identifying the specific soil pH that is most favorable for tomato root development or the impact of pH on root structure formation.

The electrical conductivity (ECe) of the soils, measured at 25°C, ranged from 0.87 to 1.7 mmhos/cm, which is below the salinity threshold of 2 mmhos/cm, classifying these soils as non-saline. Furthermore, the soils contain medium to high levels of total nitrogen (N) [5].

The exchangeable sodium percentage (ESP), which indicates the proportion of the soil's cation exchange capacity occupied by sodium, was very low at 0.02% (Table 2) [5].

*Table 3. Input data for the CROPWAT model adopted from the FAO 56 guideline*

| Vegetables | RD (m) | p | Ky | Kc | | | CH (m) |
|---|---|---|---|---|---|---|---|
| Onion | 0.3-0.6 | 0.3 | 1.1 | 0.7 | 1 | 0.75 | 0.6 |
| Tomato | 0.7-1.5 | 0.4 | 1.05 | 0.4 | 1.15 | 0.8 | 0.6 |
| Pepper | 0.5-1 | 0.3 | 1.1 | 0.6 | 1.05 | 0.9 | 0.7 |

**RD- Root depth, p- Depletion fraction, Ky -yield response factor, Kc-crop coefficient, CH-Crop Height.**

*Table 4. Varieties and Growth developmental stage of onion, tomatoes and hot pepper*

| | | Crop Growth Stages | | | | |
|---|---|---|---|---|---|---|
| Crops | Variety used | Initial | Development | Mid | Late | Total (days) |
| Onion | Bombay Red | 30 | 40 | 40 | 15 | 135 |
| Tomato | Malka Salsa | 30 | 30 | 40 | 20 | 120 |
| Hot pepper | Marko Fana | 30 | 40 | 40 | 25 | 135 |

**Reference evapotranspiration**

Table 5 presents reference evapotranspiration (ETo) values for each month of the year. In March, the highest ETo is recorded at 4.38 mm/day, while January has the lowest values at 3.36 mm/day. These variations are influenced by weather conditions like air temperature, duration of sunlight, atmospheric moisture, and wind velocity influence the process. In the dry season, elevated temperatures combined with reduced humidity levels lead to higher rates of evapotranspiration. Conversely, in the rainy season, frequent rainfall and high relative humidity lead to lower $ET_o$ values. Overall, ETo is a climatic parameter affected by factors like temperature, solar radiation, and rainfall, resulting in significant variations within and between seasons. The findings align with [1; 40], who observed that ETo was almost lowest during the lowest of the rainy season and highest during the peak of the dry season.

*Table 5. Long-term monthly average climatic data*

| Month | $T_{min}$ oc | $T_{max}$ °c | RH % | Wind km/hr. | Sun hours | Rad MJ/m²/day | ETo (mm/day) |
|---|---|---|---|---|---|---|---|
| January | 11.3 | 28.1 | 74 | 69 | 6.8 | 17.7 | 3.36 |
| February | 12.9 | 29.7 | 76 | 85 | 8.3 | 21 | 4.12 |
| March | 13.9 | 30.1 | 69 | 87 | 7.7 | 21.2 | 4.38 |
| April | 14.3 | 29.5 | 70 | 91 | 6.6 | 19.7 | 4.19 |
| May | 14.4 | 28.2 | 90 | 65 | 7 | 19.8 | 3.87 |
| June | 14.3 | 27.9 | 65 | 45 | 6.8 | 19.1 | 3.76 |
| July | 14.6 | 26.8 | 70 | 42 | 6.2 | 18.3 | 3.58 |
| August | 14.4 | 26.8 | 75 | 41 | 6.5 | 19.2 | 3.71 |
| September | 13.8 | 27.0 | 74 | 40 | 6.5 | 19.3 | 3.71 |
| October | 11.9 | 27.6 | 80 | 42 | 6.4 | 18.4 | 3.51 |
| November | 10.5 | 28.0 | 85 | 55 | 8.1 | 19.7 | 3.61 |
| December | 9.90 | 27.6 | 88 | 56 | 9.4 | 20.8 | 3.62 |
| Average | 13 | 28.1 | 76 | 60 | 7.2 | 19.5 | 3.79 |

**Effective Rainfall**

The most noteworthy precipitation was reached at 161.7mm in September, and the least precipitation was around 12.2mm in December. At a similar time, the most elevated evapotranspiration was in March and January, respectively.

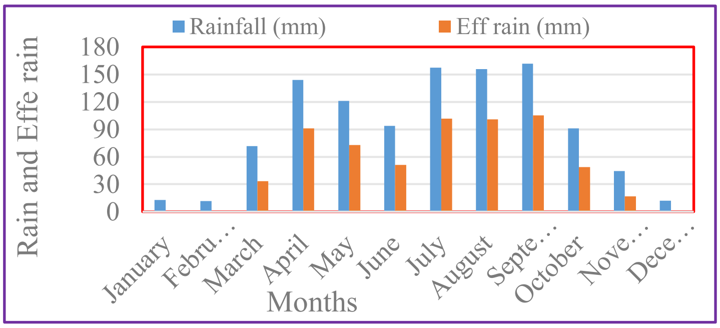


*Figure 2. Rainfall and effective rainfall*

**Seasonal irrigation water requirements of onion, tomatoes and hot pepper**

In our study area, the crop water requirement and irrigation water requirement for tomato were recorded as 412 mm and 358 mm, respectively. Based on previous studies, the estimated water requirement for hot pepper was 587.48 mm [19]. Similarly, at the Bontanga irrigation scheme, the crop evapotranspiration (ETc) for transplanted pepper over a 90–120 day period was reported as 580.7 mm, with a peak daily water requirement of 5.65 mm/day.

These findings are consistent with earlier reports [2], which indicated that the total water requirement of pepper ranges between 300 mm and 700 mm, depending on climatic conditions, crop season, and location. In our study area, the water demand for hot pepper in terms of crop and irrigation requirements was recorded as 412 mm and 358 mm, respectively.

**Crop water requirement, effective rainfall and irrigation requirements**

Findings presented in Table 6 demonstrated that when grown under irrigation during the off-season, onions, tomatoes, and hot peppers require Agricultural water needs, effective precipitation, and irrigation supply requirements of 409, 10.8, and 398mm, 412, 49.2, and 358mm, and 589.8, 167.5 and 4mm, respectively. This result is similar to [10], Irrigation scheduling for onion cultivation in Pawe was conducted using a soil refill approach to field capacity depth and a fixed 5-day interval for each growth stage. This method involved 19 irrigation events, meeting a net irrigation requirement of 448.5 mm and a total gross application of 748.1 mm, without causing any reduction in yield. Onion water requirement under rainfall needs for the full growth stage is 350 to 650 mm of water. Tomato water requirement under rainfall needs for the full growth stage over 600 to 650 mm of rainfall annually or irrigation water. These results are shown by [37; 38]. The corresponding irrigation amounts applied are around 360 mm, thus reinforcing that rational water management could be realized. In our study area irrigation requirement for tomatoes was 398mm. Hot pepper water requirement under rainfall needs for the full growth stage over 600 to 650 mm of rainfall annually or irrigation water. These results are shown by [37; 38].

*Table 6.Crop water requirement, effective rainfall and irrigation requirement*

| Season | Crops | CWR (mm) | ER (mm) | IR (mm) |
|---|---|---|---|---|
| Off-season | Onion | 409 | 10.80 | 398 |
| | Tomato | 412 | 49.20 | 358 |
| | Hot pepper | 589.8 | 167.5 | 422.3 |

*Table 7. Crop water requirement for onion in off-season*

| Month | Decade | stage | Kc-Coef. | ETc mm/day | ETc mm/dec | Effective rain mm/dec | Irrigation Req mm/dec |
|---|---|---|---|---|---|---|---|
| Nov | 1 | Init | 0.70 | 1.02 | 10.2 | 0 | 10.2 |
| Nov | 2 | Init | 0.70 | 4.07 | 40.7 | 1.5 | 38.7 |
| Nov | 3 | Deve | 0.70 | 4.13 | 41.3 | 0 | 41.3 |
| Dec | 1 | Deve | 0.76 | 4.64 | 46.4 | 0.9 | 44 |
| Dec | 2 | Deve | 0.82 | 4.61 | 46.1 | 1.0 | 45.1 |
| Dec | 3 | Deve | 0.88 | 5.13 | 51.3 | 0.6 | 47.8 |
| Jan | 1 | Deve | 0.95 | 4.935 | 49.35 | 1.3 | 46.2 |
| Jan | 2 | Mid | 0.98 | 4.84 | 48.4 | 2.2 | 55.1 |
| Jan | 3 | Mid | 0.98 | 3.86 | 38.6 | 2.1 | 36.4 |
| Feb | 1 | Late | 0.86 | 3.65 | 36.5 | 1.2 | 33.3 |
| **Total** | | | | | **408.9** | **10.8** | **398.1** |

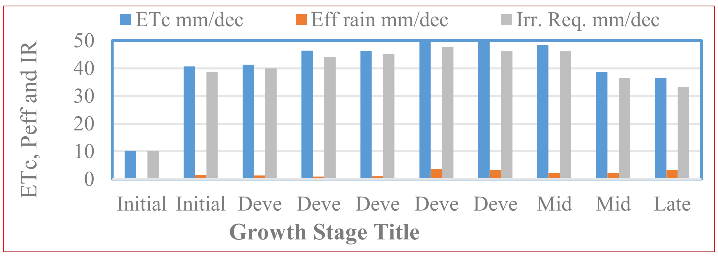


*Figure 3. ETc, Peff and irrigation requirement for onion*

*Table 8. Crop water requirement for tomato in off-season*

| Month | Decade | Stage | Kc-Coef. | ETc mm/day | ETc mm/day | Eff. Rain mm/dec | Irrigation Req mm/dec |
|---|---|---|---|---|---|---|---|
| Nov | 1 | Init | 0.4 | 1.4 | 5.6 | 2 | 4 |
| Nov | 2 | Init | 0.40 | 1.42 | 15.60 | 3.9 | 11.7 |
| Nov | 3 | Init | 0.40 | 1.43 | 14.30 | 3.6 | 10.7 |
| Dec | 1 | Deve | 0.43 | 1.54 | 15.40 | 2.9 | 12.6 |
| Dec | 2 | Deve | 0.65 | 2.15 | 21.50 | 3.2 | 18.3 |
| Dec | 3 | Deve | 0.85 | 2.83 | 28.30 | 6.1 | 22 |
| Jan | 1 | Deve | 0.97 | 3.51 | 35.10 | 0 | 30 |
| Jan | 2 | Mid | 1.13 | 3.99 | 43.90 | 7.9 | 36 |
| Jan | 3 | Mid | 1.14 | 3.87 | 38.70 | 2 | 36.7 |
| Feb | 1 | Mid | 1.14 | 3.74 | 37.40 | 5 | 32.4 |
| Feb | 2 | Mid | 1.14 | 4.06 | 44.70 | 4 | 40.7 |
| Feb | 3 | Late | 1.08 | 4.28 | 42.80 | 2 | 40.8 |
| Mar | 1 | Late | 0.93 | 4.00 | 40.00 | 3.5 | 36.5 |
| Mar | 2 | Late | 0.82 | 3.56 | 28.50 | 3.1 | 25.4 |
| **Total** | | | | | **411.7** | **49.2** | **357.8** |

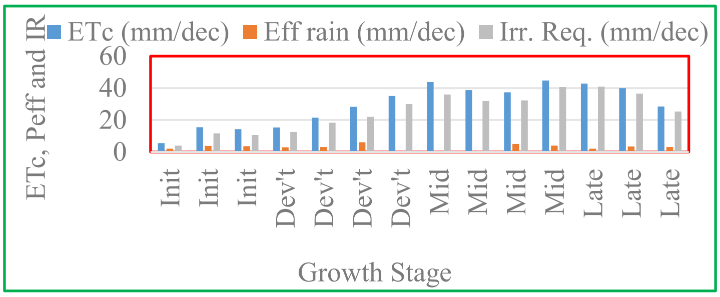


*Figure 4. ETc, Peff and irrigation requirement for tomato*

*Table 9. Crop water requirement for hot pepper in off-season*

| Month | Decade | Stage | Kc-Coef. | ETc (mm/day) | ETc (mm/day) | Eff rain (mm/dec) | Irr. Req (mm/dec) |
|---|---|---|---|---|---|---|---|
| Nov | 1 | Init | 0.6 | 2.23 | 20.0 | 32.9 | 0.0 |
| Nov | 2 | Init | 0.6 | 2.23 | 22.3 | 38.0 | 0.0 |
| Nov | 3 | Init | 0.6 | 2.19 | 21.9 | 30.8 | 0.0 |
| Dec | 1 | Deve | 0.6 | 2.36 | 23.2 | 21.8 | 1.5 |
| Dec | 2 | Deve | 0.77 | 2.71 | 26.7 | 15.1 | 11.6 |
| Dec | 3 | Deve | 0.89 | 3.15 | 34.2 | 11.9 | 22.3 |
| Jan | 1 | Deve | 1.01 | 3.59 | 35.6 | 8.7 | 26.9 |
| Jan | 2 | Mid | 1.05 | 3.77 | 37.7 | 4.9 | 32.8 |
| Jan | 3 | Mid | 1.04 | 3.78 | 37.8 | 3.2 | 34.5 |
| Feb | 1 | Mid | 1.04 | 3.78 | 37.8 | 0.1 | 37.7 |
| Feb | 2 | Mid | 1.04 | 3.79 | 37.9 | 0.0 | 37.9 |
| Feb | 3 | Mid | 1.04 | 3.70 | 40.7 | 0.0 | 40.7 |
| Mar | 1 | Mid | 1.04 | 3.50 | 35.4 | 0.0 | 35.4 |
| Mar | 2 | Mid | 1.04 | 3.41 | 34.1 | 0.0 | 34.1 |
| Mar | 3 | Mid | 1.04 | 3.71 | 40.8 | 0.0 | 40.8 |
| Apr | 1 | Mid | 1.04 | 4.04 | 40.4 | 0.0 | 40.4 |
| Apr | 2 | Late | 1.04 | 4.31 | 43.1 | 0.0 | 43.1 |
| Apr | 3 | Late | 1.04 | 4.40 | 35.2 | 0.1 | 35.1 |
| Total | | | | | **589.8** | **167.5** | **422.3** |

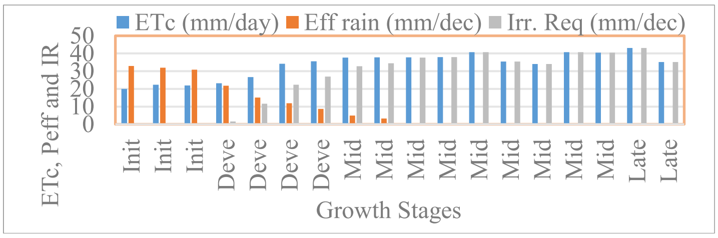


*Figure 5. ETc, Peff & irrigation requirement for hot pepper*

## Net irrigation requirement and irrigation schedule for onion

For calibration of crop water requirement (CWR), gross and net irrigation were done depending on the FAO 56 paper guideline. The results of gross and net irrigation calibrated at Oda Bultum for the major vegetable crops onion, tomato, and pepper, were 588 and 407.6, 518 and 363, 905.4 and 633.9mm, respectively. Field crop irrigation schedules are presented in Table 10 and depicted in Figure 6. for the onion crops. The yield obtained from this field research for the onion Bombay red variety was 300 qt/ha. This yield obtained is similar to [37; 38].

*Table 10. Irrigation scheduling, net and gross irrigation and flow of irrigated water for onion*

| Day | Stage | Rain (mm) | Net Irrigation (mm) | Gross Irrigation (mm) | Flow (l/s/ha) |
|---|---|---|---|---|---|
| 07 | Init | 0.0 | 10 | 34.3 | 0.40 |
| 13 | Init | 0.0 | 20 | 34.3 | 0.40 |
| 20 | Dev | 0.0 | 30 | 35.4 | 0.41 |
| 27 | Dev | 0.0 | 39 | 33.7 | 0.43 |
| 35 | Dev | 0.0 | 48 | 35.9 | 0.46 |
| 43 | Dev | 12.2 | 56 | 34.3 | 0.50 |
| 53 | Dev | 9.8 | 63 | 32.5 | 0.54 |
| 64 | Mid | 0.0 | 70 | 33.9 | 0.56 |
| 80 | Mid | 7.1 | 77 | 33.0 | 0.55 |
| 98 | Mid | 0.0 | 84 | 33.7 | 0.56 |
| 116 | End | 0.0 | 91 | 32.3 | 0.53 |
| 135 | End | 0.0 | 0 | 34.3 | 0.40 |

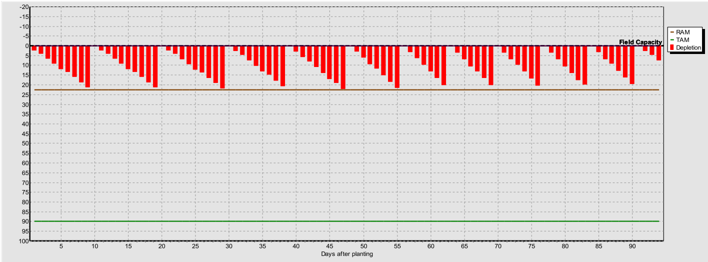

*Figure 6. Irrigation schedules for onion*

## Net irrigation requirement and irrigation schedule for tomato

Table 11 and Figure 7 present the irrigation schedules for tomato field crops, including both total gross and net irrigation amounts of 518 and 363 mm for tomatoes in the study areas. The yield obtained from this field research for the Melka salsa Tomato variety was 428.5 qt/ha. This variety has a potential of up to 430 t/ha. This yield obtained is similar to those [37; 38]. According to the result of [7], Melka salsa variety has a total fruit yield obtained in the field of the study area was 614 qt/ha.

*Table 11. Irrigation scheduling, net and gross irrigation and flow of irrigated water for tomato*

| Days | Growth Stage | Rain (mm) | Net Irrigation (mm) | Gross Irrigation (mm) | Flow (l/s/ha) |
|---|---|---|---|---|---|
| 1 | Initial | 0 | 28.13 | 40.15 | 0.4 |
| 6 | Initial | 0 | 28.13 | 40.15 | 0.4 |
| 13 | Dev | 0 | 28.93 | 41.25 | 0.41 |
| 21 | Dev | 0 | 27.73 | 39.55 | 0.39 |
| 31 | Dev | 0 | 29.33 | 41.75 | 0.41 |
| 43 | Mid | 12.2 | 28.13 | 40.15 | 0.4 |
| 56 | Mid | 9.8 | 26.83 | 38.35 | 0.39 |
| 70 | Mid | 0 | 27.83 | 39.75 | 0.39 |
| 85 | Mid | 7.1 | 27.23 | 38.85 | 0.39 |
| 99 | Mid | 0 | 27.73 | 39.55 | 0.40 |
| 112 | Mid | 0 | 26.73 | 38.15 | 0.38 |
| 120 | End | 0 | 28.13 | 40.15 | 0.40 |

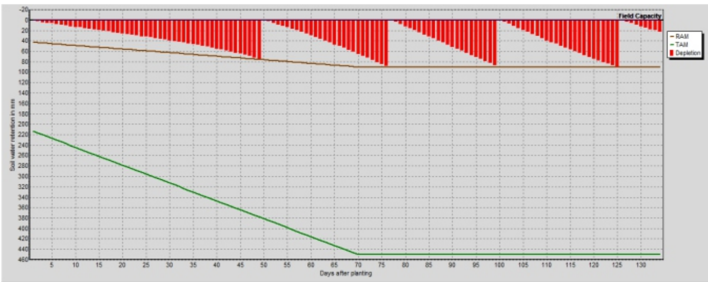

*Figure 7. Irrigation schedules for tomato*

## Net irrigation requirement and irrigation schedule for hot pepper

Table 12 and Figure 8 illustrate the timetables for irrigating field-grown crops for hot pepper crops. The total gross irrigation mean and the total net irrigation mean are 905.4 and 633.9 mm for peppers. According to the result of [37;38], similar results to the production of peppers. Marako Fana variety was grown in an open field and showed tolerance to viral diseases. The fruit transitions from green to yellow as it approaches its maturity stage of 120 to 135 days after transplanting and yields at an open field of 150 to 250 qt/ha. Marko Fana variety has a total fruit yield obtained was 245 qt/ha in the study area.

*Table 12. Irrigation scheduling, net, gross irrigation and flow of irrigated water for peppers*

| Day | Stage | Rain (mm) | Net Irrigation (mm) | Gross Irrigation(mm) | Flow (L/s/ha) |
|---|---|---|---|---|---|
| 06 | Init | 0.0 | 12.4 | 17.7 | 0.34 |
| 12 | Init | 0.0 | 19.0 | 27.2 | 0.35 |
| 19 | Init | 0.0 | 32.4 | 46.2 | 0.33 |
| 26 | Dev | 0.0 | 50.7 | 72.4 | 0.40 |
| 34 | Dev | 0.0 | 65.0 | 92.9 | 0.54 |
| 42 | Mid | 0.0 | 63.9 | 91.3 | 0.59 |
| 52 | Mid | 1.3 | 64.1 | 91.6 | 0.59 |
| 63 | Mid | 0.0 | 63.2 | 90.3 | 0.58 |
| 79 | Mid | 0.0 | 66.2 | 94.5 | 0.55 |
| 97 | Mid | 0.0 | 63.4 | 90.6 | 0.62 |
| 115 | Mid | 0.0 | 67.4 | 96.2 | 0.7 |
| 135 | End | 0.0 | 66.2 | 94.5 | 0.68 |

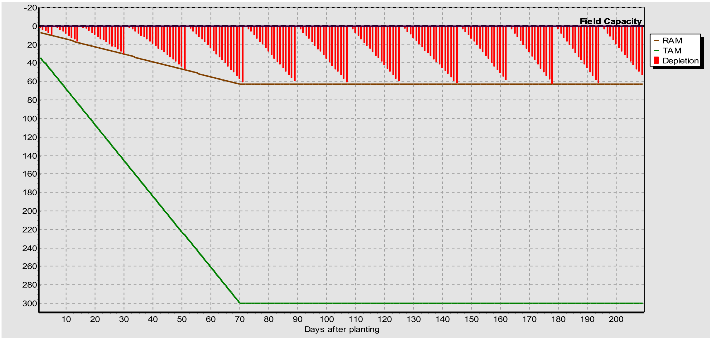


*Figure 8. Irrigation schedules for hot pepper*

### Monthly average maximum and minimum temperature and reference evapotranspiration

According to Figure 9, the reference evapotranspiration (ETo) was assessed for each month of the year, revealing that the highest ETo occurred in March (4.38 mm/day), while the lowest was observed in January (3.36 mm/day). These findings suggest that crop water demand is elevated during months with higher ETo values. Additionally, the peak temperature was recorded in March at 29.8 °C, followed closely by February at 29.7 °C. In contrast, the lowest temperatures were noted during December, November, and January.

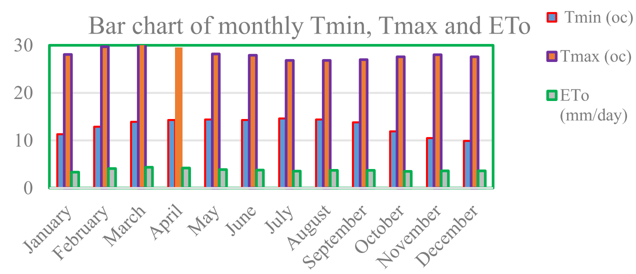


*Figure 9. Bar chart showing long-term average monthly $T_{min}$, $T_{max}$ and $Et_o$.*

### Water needs, rainfall contribution, and irrigation demand for onion, tomato, and hot pepper cultivation

Onion, tomato and hot pepper were shown crop water requirements, effective rainfall and irrigation requirements, during the off-season under irrigation as indicated by bar graph 10.

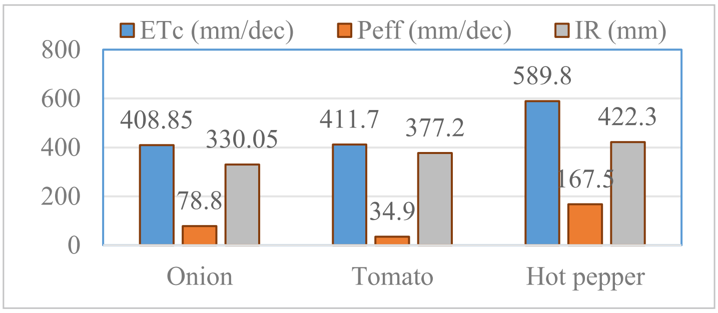


*Figure 10. Bar chart showing the crop water need, effective rainfall, and irrigation need*

### Validations of crop water requirement for onion, tomato and hot pepper

The management of water application volume and efficient application of water is known as irrigation scheduling. With a 60% field irrigation application efficiency for CROPWAT under surface irrigation at study areas, the gross irrigation depth was evaluated for this investigation. This study examines the effects of CROPWAT-based irrigation scheduling and crop water requirement practices on the yield and water use efficiency of onions, tomatoes, and hot peppers. During the validation periods in the research location, the determined water demand for crops and associated irrigation needs for onions, tomatoes, and hot peppers were verified to be 409 and 398 mm, 412 and 358 mm, and 589.8 and 422.3 mm, respectively.

## Conclusion

It is easily evident from using the FAO CROPWAT 8.0 model that the irrigation needs and scheduling for the crops were unique to the local research area because of the province's seasonal and biological characteristics. The findings of the study contribute to a deeper understanding of crop water needs, which consequently help to improve irrigation water in agricultural fields. Consequently, the crop water need of onion with a developing time of 135 days to development requires 409 mm of water during the slow time of year, with a water system necessity of 398 mm. Crop water need of tomato with a developing time of 120 days to development requires 412 mm of water at a slow time of year, with water system necessity of 358 mm. Hot peppers with a developing time of 135 days require 589.8 mm depth of water at a slow time of year, with water system necessity of 422.3mm.

## Recommendation

In this research, it is inferred that reference harvest evapotranspiration, viable precipitation, yield water necessity and water system requirements were assessed utilizing CROPWAT 8 programming with the contribution of climatic information. Results on ETc and IR gave functional evaluation to water system planning. These outcomes can be utilized for the most proficient water use. In areas with restricted water assets, the CROPWAT can help with deciding the yield of water requirements and water systems for field crops. This study could act as an aid for settling on decisions with irrigation water management, saving in the research area.

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**Conflict of interest**

The authors affirm that there are no conflicts of interest to disclose.

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