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A single onion crop water requirement and irrigation schedule validation by the integration of Arc GIS Tool and CROPWAT 8.0 model: Case study in Fogera, Libokemkem, and Dera districts, Amhara region, Ethiopia

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Abstract
The motivation for this research has been enhanced to increase agricultural productivity and improve the living standards of the community in the sub-tropical part of Ethiopia. The CROPWAT 8.0 FAO simulation model is carried out to determine the proper water and nutrient use in all onion crop growing seasons. The objective of the present study is to determine the onion crop water requirement (CWR) and irrigation scheduling (IRS) by using four significant input parameters: reference evapotranspiration (ET_O), crop, rain, and soil data. The average crop evapotranspiration (ET_C) values for all growing seasons are 27.2mm/dec (initial stage), 88.4mm/dec (developing stage), 136.7mm/dec (middle stage) and 129.2mm/dec (late season). Whereas the average crop coefficient (K_C) values were found to increase from the initial to final stage (0.7 to 3.56). Finally, the crop water requirement (CWR) of the onion crop is very high (mid-season), high (late-season), medium (developing season) and low (late-season). As a consequence of the yield reduction in onion crops were 4.3% (stage-A), 7.1% (stage-B), 9.4% (stage-C), and 4.7% (stage-D). Due to this, the high depletion value is recorded in the mid-growth season, while the low depletion value has been recognized in the late growth season as well.

Keywords: CROPWAT 8.0, reference evapotranspiration, crop water requirement and irrigation schedule

Introduction

This study is enhanced to increase the agricultural productivity in the sub-tropical region of Ethiopia. The motivation of this research is afford to transfer agricultural productivity to industrial linkage. Therefore, it is to improve the living standards of the community in low income countries to reduce poverty and migration. Moreover the impact of climate change and the growth of the population have been the main driving factors behind the reduction in agricultural productivity in this study area [1-4]. Due to this connection, onion Crop productivity is highly affected by growth of population and metrological variability, including increasing temperature and precipitation regimes [1-4]. As the result, the drip irrigation application technology is required to establish the economic standard of the community as well as helth care improvement [5]. Still, today, agricultural activity is traditional in the study area and the onion crop production is insufficient for food security. Therefore, new technology is required to improve the productivity of the onion crop as well. So that CROPWAT 8.0 for window-supporting computer program is designed to simulate the proper water and nutrient use in onion crop growing in drip irrigation application. Furthermore, this software enables us to inquire about the onion crop's water requirement balance in the drip irrigation system. As a result, drip irrigation application has made agricultural practice simple and effective, allowing farmers to grow sustainable food per hector while producing high quality and quantity of onion crops. The main objective of this investigation is to determine the onion crop water requirement (CWR) and irrigation schedule (IRS) in order to increase the yield of onion crops in alluvial plain sediment of sub-tropical part of the country [6]. This alleviates the impact of drought and climate change on food production and supports the rural community by reducing poverty and migration to the cities.

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Description of the study area
This area is conducted at downstream of Rib irrigation dam in south Gonder district of Fogera, Libokemkem and Dera woreda, which is upper blue Nile and lake Tana basins. As Ethiopia metrological agency provided that the study area is grouped under sub- tropical part of Ethiopia which is emplaced under alluvial plain formed by sediments left by flowing from water. Irrigation suitability of onion crop has been improved by drip irrigation application in dry season period of Ethiopia in those districts. Annual average max and min temperature of the study area is 27.3 °c and 13.3°c respectively, while the annual precipitation and effective rain is 1132.0 mm and 623.1 mm respectively.

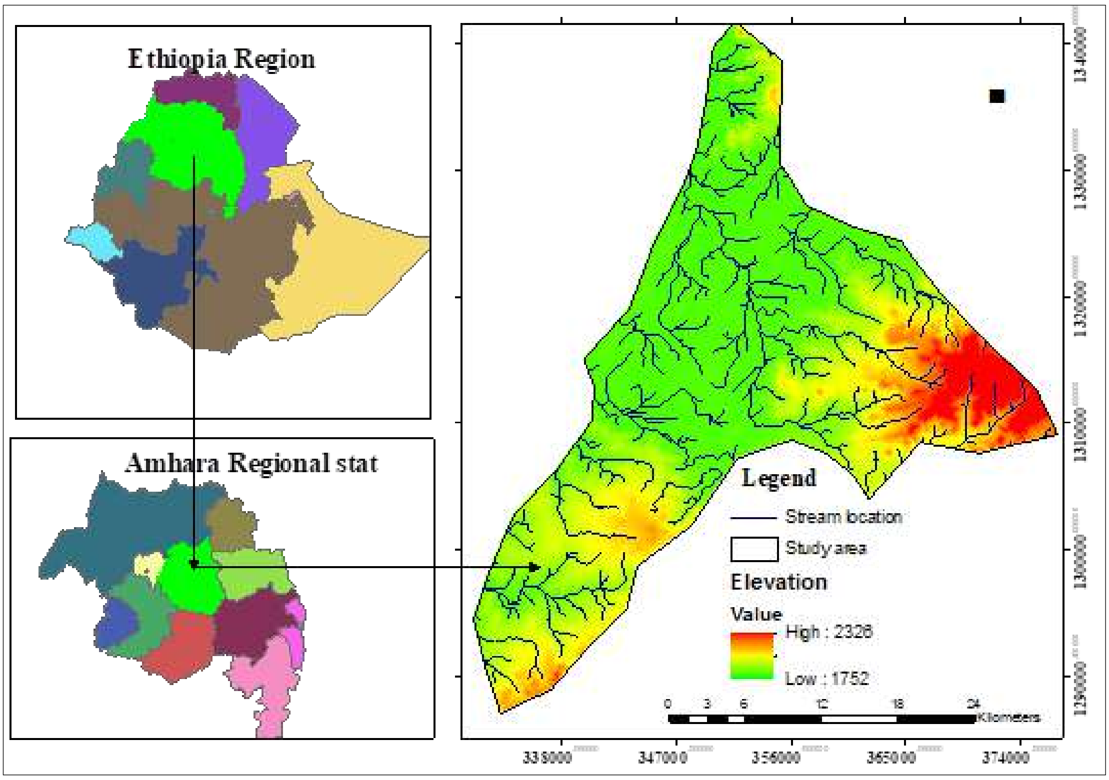


Fig 2: Location map of the study area

Methodology

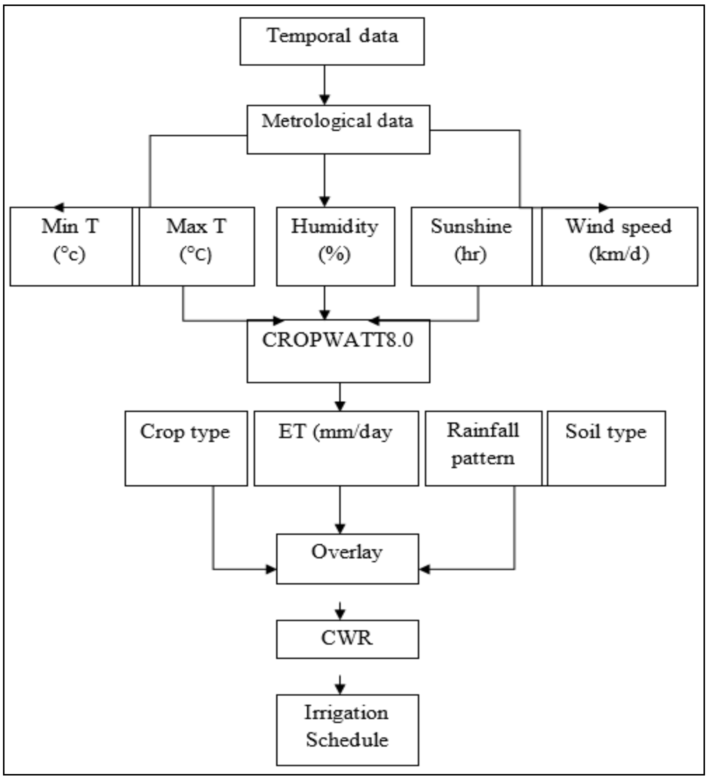


Fig 2: Frame work of the methodology

Data collection mechanism

This investigation utilized four significant parameters (climate/ET_O, rain, crop, and soil) to determine the crop water requirement and irrigation schedule of the onion crop. Climate/ET_O was calculated in the CROPWAT 8.0 model using penman Monteith methods from temporal metrological data of Max and Min temperatures (°C), humidity (%), wind (km/day), and sunshine (hours), while the soil data was determined using GIS from the Ethiopian International Geological Survey (EGGS). The spatial distribution of rain fall data has to be collected from the Amhara regional state metrological agency, while crop type data are collected from FAO irrigation and drainage paper No. 24, which provides general length for the four distinct growth stages and the total growth period of various types of climates and locations.

Discussion of parameter

Analysis of evapotranspiration (ET_O)

In a drip irrigation system, evapotranspiration (ET_O) is one of the most basic parameters to determine the onion crop's water requirement and irrigation schedule (IRS) [7]. Evapotranspiration has been simulated by the CROPWAT 8.0 model in the FAO Penman-Monteith formula and requires radiation, air temperature, air humidity, and wind speed data as shown in table 1 [8]. Therefore, the amount of onion crop water in the root zones of the soil could be determined from evapotranspiration [9–10]. Thus, the FAO penman-Monteith formula is considered on the physical principles applied by Penman with an enhanced physical representation of the water loose from the vegetation [11-13]. Due to the original Penman-Monteith equation and the equations of aerodynamic and canopy resistance, the FAO Penman-Monteith equation is:

$$ET_o = \frac{0.408\Delta\left(Rn-G\right)+\gamma\frac{900}{T+273}U_2\left(es-ea\right)}{\Delta+\gamma\left(1+0.34U_2\right)} \quad (1)$$

Where,

ET_O = reference evapotranspiration (mm/day)

es = the saturated vapor pressure (kpa)

ea = the actual vapor pressure of the air at standard screen height (kpa)

Rn = the net radiation (MJ/ (m2//day))

G = the soil heat flux density (MJ/ (m2/day)), is the psychomotor constant (kpa/Co)

T = the mean daily air temperature (C°).

Table 1: shows monthly ET_O Penman-Monteith metrological data in Addis Zemen station, Amhara region Ethiopia with (37.46°E longitude, 12.07°N latitude and 1975 altitude) 2013 EC.

Month	Min Temp	Max Temp	Humidity	Wind	Sunshine	Radiation	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	9.9	27.8	52	164	8.2	18.9	3.88
February	10.9	29.5	49	164	9.2	21.8	4.52
March	11.9	29.8	46	164	9.1	23.0	4.98
April	12.1	29.3	47	129	8.3	22.3	4.75
May	12.1	29.5	56	164	6.8	19.8	4.47
June	12.0	26.9	70	164	5.6	17.7	3.75
July	12.2	23.8	79	103	2.1	12.5	2.64
August	12.0	24.0	79	86	2.3	12.9	2.64
September	11.6	25.2	75	103	6.7	19.4	3.59
October	10.8	27.2	65	138	8.4	20.9	3.97
November	10.4	27.3	59	138	9.1	20.4	3.85
December	10.3	27.6	55	120	8.7	19.1	3.60
Average	**11.3**	**27.3**	**61**	**136**	**7.0**	**19.1**	**3.89**

Rain fall analysis

Recently, the agricultural activity of the study area has been adopted under a rain-fed farming system [14–15]. Hence, the natural rain fall pattern of the study area is erratic and unreliable for crop production [16–17]. Furthermore, it seems that there is a significant relationship between climate and agricultural production in terms of the timing, variability, and quantity of seasonal and annual rain fall [29, 19]. Due to this, drought is a major cause of food insecurity and famine in the study area [20-21]. As a result, irrigation application is the only solution to reduce food insecurity. The USDA Soil Conservation Service (SCS) method was used for determining effective rainfall required to calculate the crop water requirement in the CROP WAT 8.0 model. The effective rain fall can be computed as:

$$\mathbf{P_{eff} = ET_C - CWR} \quad (2)$$

Where,

ETc = Crop evapotranspiration (mm/dec)

Kc = Crop coefficient,

ET_0 = Reference evapotranspiration (mm/day)

CWR = Crop water requirement (mm/dec)

Peff = Effective rainfall (mm/dec)

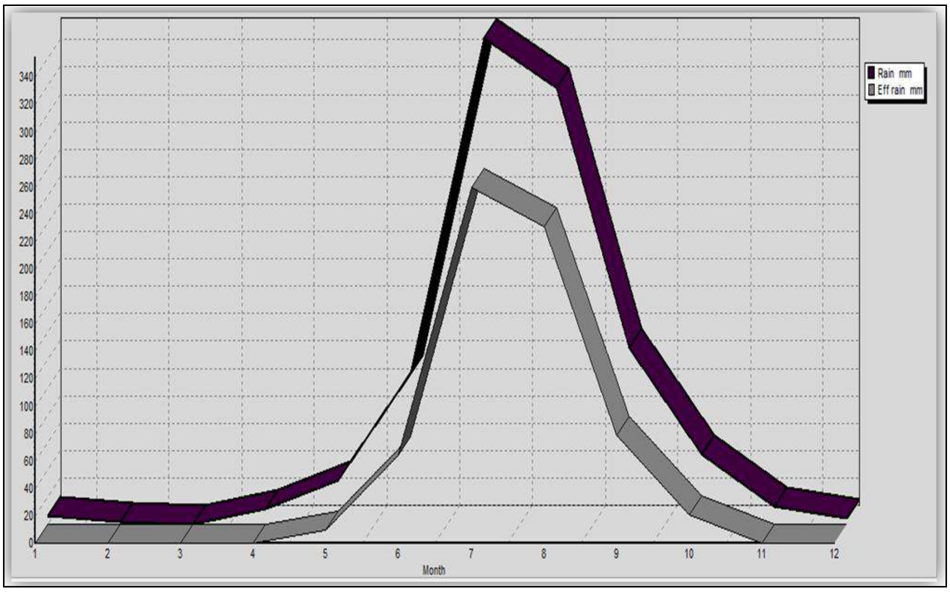


Fig 3: Rain & Eff rain fall variability of the study area

Soil Analysis

Soil is one of the most significant data points in the CROPWAT 8.0 model to determine the onion crop water requirement and irrigation schedule in Fogera, Dera, and Libokemkem districts [22]. However, the most suitable soil for onion crop production is deep, friable loam and alluvial soils with good drainage, moisture holding capacity, and sufficient organic matter [23]. As a result, the soil characteristics of the study area are clay with sand, silt including friable loam and alluvial soils [23].

Table 2: shows the general soil data of the study area

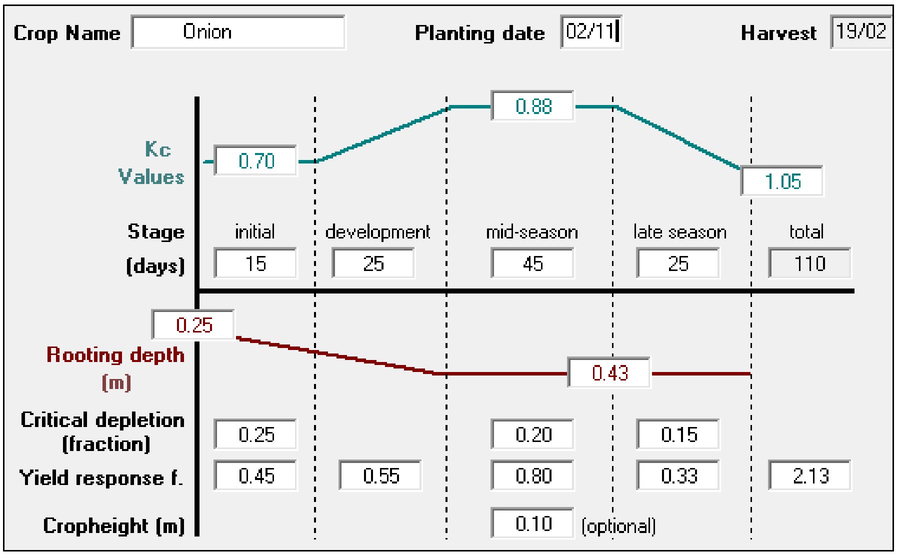
Soil name	Clay soil	
General soil data		
Total available soil moisture (FC - WP)	100.0	mm/meter
Maximum rain infiltration rate	36	mm/day
Maximum rooting depth	26	centimeters
Initial soil moisture depletion (% TAM)	0	%
Initial available soil moisture	100.0	mm/meter

Source: FAO CROPWAT Model 8.0

Crop Analysis

Onion crop analysis is used to calculate the crop water requirement and irrigation schedule. Despite the fact that this application includes general onion crop data as shown in table 3, Those are yield reductions due to pressures such as crop coefficient, length of growing season, critical depletion level, and yield response factor [24].

Table 3: Shows the onion crop input data in the study area



Source: FAO CROPWAT 8.0 model, smith and Munoz, 2002

Result and discussion

The CROPWAT 8.0 model needs daily data on minimum and maximum temperatures, humidity, wind speed, and sunshine hours, as well as monthly data on rainfall, crop data (i.e. planting date, crop coefficient values for four different growth phases and the number of days under each growth stage, rooting depth, critical depletion fraction, yield response factor, and crop height), and soil data (i.e. total available soil moisture and initial soil moisture depletion) to determine the crop water requirement and irrigation schedule of an onion crop in the study area.

Crop Evapotranspiration (ET_C)

The FAO CROP WAT8.0 model requires the crop coefficient (K_C) and reference evapotranspiration to determine the crop evapotranspiration (ET_C). The magnitude of crop evapotranspiration has varied through all growth stages. As a result, the average ET_C value of the onion crop under all growth stages is 27.2 mm/dec (initial stage), 88.4 mm/dec (crop development stage), 136.7 mm/dec (mid season stage) and 129.2 mm/dec (late season stage). In contrast, onion crop evapotranspiration is low in the early growth stage and follows through to the late growth stage, owing to low canopy cover in the early stage and a cessation of leaf growth in the late stage [25]. The high value of onion crop evapotranspiration is at the middle growth stage. This indicates that the crop water requirement is high at the middle growth stage due to fully developed crop canopies and high evaporative losses of the crops. Crop evapotranspiration (ET_C) is computed under standard conditions.

$$ET_c = K_c * ET_o \tag{3}$$

Where,
ET_C = Crop evapotranspiration (mm/dec)
K_c = crop coefficient
ET_O = reference evapotranspiration (mm/day)

Onion crop coefficient (Kc)

Using water balancing methods, the average Kc value created during the crop growing season fluctuated and was shown to increase with each growth stage. The average stage-wise measured Kc values for the onion crop season increased from 0.7 to 3.56 as the crop progressed from early to late growth stages. During the early phases of growth, the average Kc value was low, and during the mid-season stages, it was high. The crop's mid-season stage (Kc_{initial}) values are frequently higher than those of other established stages [26]. As a result, the highest value of Kc was obtained in the middle of the season ($K_{C\ \text{middle}}$), when the crop had attained its peak value of leaf area index and maximum canopy cover, resulting in increased crop evapotranspiration [27].

Onion crop water requirement (OCWR)

However, an FAO-designed CROPWAT 8.0 simulation model was used to determine the onion crop's water requirements. Furthermore, depending on the location, climate, soil type, calvation method, effective rain, and total water required, crops have different water requirements. Crop growth is not evenly distributed throughout its life cycle. As a result, the crop water requirement (CWR) is low at the beginning (starting stage), medium in the middle (developing stage), extremely high in the middle (mid season stage), and very high in the end (end of season stage) The onion crop is particularly sensitive as a result of the drip irrigation application and requires a suitable amount of water in the mid and Slate growth seasons to fulfill its full production potential in a given environment. The following formula can be used to calculate crop water requirements:

$$CWR = ET_c - P_{eff} \tag{4}$$

Where,
CWR = crop water requirement (mm/dec)
ET_C = crop evapotranspiration (mm/dec)
P_{eff} = effective rainfall (mm/dec)

Drip irrigation scheduling on onion crop

This research improved the CRPWAT8.0 simulation model for drip irrigation scheduling of onion crops grown during the dry season (November 02/11/2021 – April 19/02/2022). In the research area, onion crop yield redaction varies over the growing season. According to this research, crop evapotranspiration and soil quality have an impact on onion

crop yield redaction, as shown in Figure 4. The yield redaction of onion crop is around 4.3 percent (A), 7.1 % (B), 9.4 % (C), and 4.7 % (D) as a result of this experiment (D). As a result, in order to produce a good yield of onion crop, irrigation water is required more in the production stage of (Development-stage) and (Mid-season).
Figure 4 shows how crop onion yield redaction is influenced by crop evapotranspiration. As a result, crop evapotranspiration controls the sensitivity of onion yield redaction (ETC). In the research location, however, soil depletion has a negative impact on onion crop productivity. Furthermore, as illustrated in Figure 3, soil depletion is greatly accelerated in the mid-season due to high crop evapotranspiration (ETC). In the Lat and Dve -seasons, however, minor soil depletion has been seen. As a result, irrigation water is required to obtain high quality and quantity onion crop products while also maintaining the moisture content of the crop root soil.

Table 4: Scheduling of drip irrigation CROPWAT 8.0 simulation summery in the study area

Irrigation total summery	Result	Units
Total gross irrigation	421.8	mm
Total net irrigation	295.3	mm
Actual water use by crop	330.8	mm
Potential water use by crop	377.9	mm
Efficiency irrigation schedule	100	%
Deficiency irrigation schedule	12.5	%
Total rain fall	24.7	mm
Effective rain fall	22.6	mm
Total rain fall	2.1	mm
Moist deficit at harvest	12.9	mm
Actual irrigation requirement	355.3	mm
Efficiency rain Irrigation loss	91.4 0.0	% mm

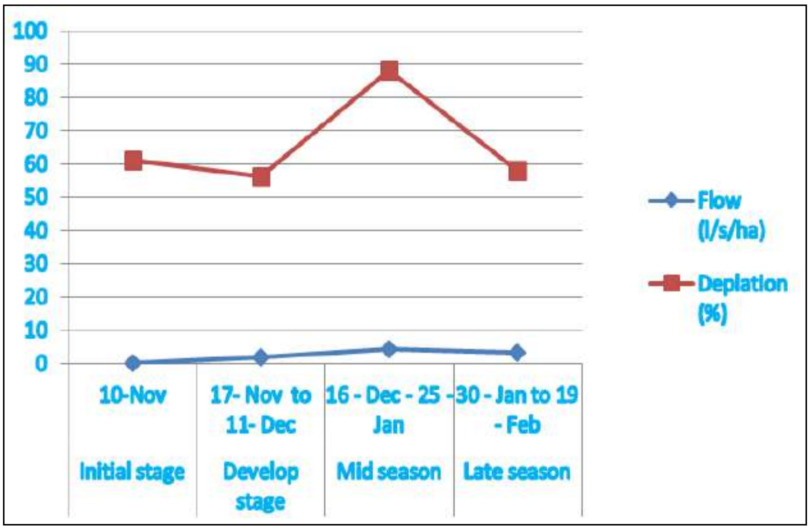
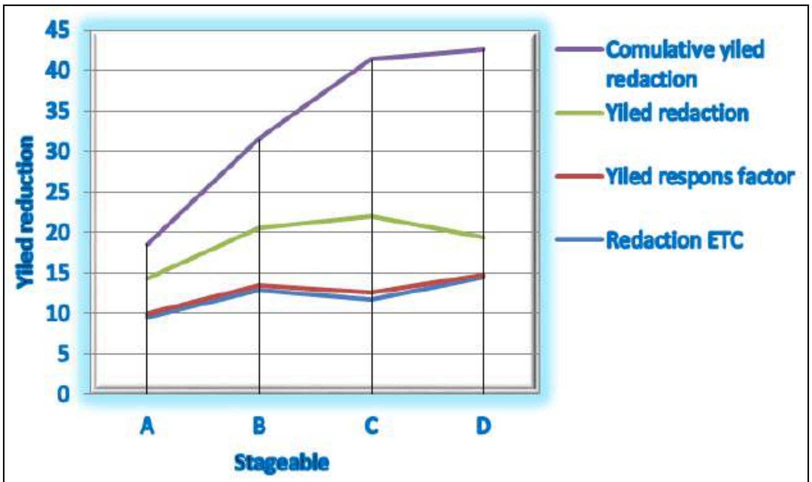


Fig 3: Irrigation schedule graph of the study area



Where, A, B, C and D are indicates crop growth stage

Fig 4: Irrigation reduction graph of the study area

Conclusions

Today, agriculture is an essential application to reduce food insecurity globally. The FAO CROPWAT 8.0 simulation model was enhanced for drip irrigation for onion crops in clay and alluvial soil under sub-tropical climate conditions. This study has used four different input parameters: reference evapotranspiration (ET_O), rain fall data, crop data, and soil data in the study area. The total actual water use by crop and potential water use by onion crop were found to be 330.8mm and 377.9mm, respectively, in 2021 and 2022 under drip irrigation application. Total gorse and total net irrigation, on the other hand, were found to be 421.8mm and 295.3mm, respectively. The yield redaction of the onion crop is highly sensitive in the early and mid-growth seasons. In addition to that, the depletion of the soil in all growth seasons is highly recognized in the mid and initial growth seasons as well. The onion crop will be planted and harvested from October 2, 2021 to January 19, 2022.

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