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Application of Aquacrop and CropWat Models for Estimating Crop Water Requirements and Irrigation Scheduling for Hot Pepper in Metekel Zone

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Abstract: The model simulation is a simplification of the field processes. In metekel zone understanding how much and when to irrigate their crops is proplems of farmers. Therefore, this study was conducted to determine the crop water requirement and irrigation scheduling of pepper for the study area to solve the problem. Crop, soil physical and chemical, collected long-term daily climatic and irrigation water quality data, used for crop water requirement and irrigation scheduling using CropWat and AquaCrop models. The result revealed that maximum Crop water requirementof pepper (799.9 mm) was estimated in Guba and minimum ETc pepper (632.2 mm) was estmimated in Bullen using CropWat Model. However, using AquaCrop model the maximum ETc of pepper (779.5 mm) and minimum ETc of pepper (591.3mm) was estimated in Wembera. Moreover, it observed that the irrigation scheduling with a fixed interval criterion for pepper 7 days with 21 irrigation events, has been determined. Among the performance indicators, root mean square error normalized values of pepper was 3.2%, and nash-sutcliffe efficiency index values of pepper was 0.99 and prediction error values of pepper were 0.02, -0.08, -0.06, 0.03, -0.07, in Pawe, Mandura, Guba, Bullen, Wembera respectively. This show that AquaCrop model used to simulate crop water requirements of pepper with relatively similar results as CropWat in Metekel zone.

Keywords: CropWat, Aquacrop Crop, Water Requirement, Climate Data

1. Introduction

1.1. Background

Crop water requirements vary in space and time [1]. The role of simulation models in understanding the processes in the soil-plant-atmosphere system has increased significantly in recent years [2]. Numerous models have been developed and used for simulation of water balance in the cropped field such as BUDGET [3] and CropWat [4].

Hot pepper (*Capsicum annuum L.*) belongs to the genus Capsicum and family Solanaceae [5]. The world average yield of pepper is 3.75 t/ha [6].

The water requirements for hot pepper production were 775 mm at Alemaya, 602 mm at Awassa, 613 mm at Bako, 517 mm at Melkassa and 629 mm at Zeway [7].

CropWat (currently in version 8) is a Windows computer program for the calculation of crop water requirements and irrigation requirements based on soil, climate and crop data. In addition, the program allows the development of irrigation schedules for different management conditions and the calculation of scheme water supply for varying crop patterns. CropWat 8.0 can also be used to evaluate farmers' irrigation practices and to estimate crop performance under both rainfed and irrigated conditions.

However, productivity of water use and to increasing efficiency and more accurate predictions are required for yield response under actual field conditions, AquaCrop allows more accurate modelling of actual crop growth and yield formation processes under various soil fertility, climate and water availability conditions [8].

AquaCrop is widely applicable due to the only use of the relatively small number of explicit parameters and mostly-intuitive input-variables that can be determined by simple methods. Besides, the calculation procedures are ground on the basic and often complex biophysical processes to guarantee an accurate simulation of the crop response in the plant-soil system [9].

The application of computer-based simulation models as tools for providing support for decision-making in agricultural research has increased tremendously in the last three decades [10]. Models are mathematical representations of mechanisms that govern natural phenomena that are not fully recognized, controlled, or understood. In order to study the responses of crops to soil fertility and environmental conditions, crop models are often used to complement field experiments.

Almost all farmers are poor in water resource management and lack of experience and knowledge about how much and when to irrigate efficiently for irrigation water saving-strategies in Metekel zone. This results soil erosion, in waterlogging, accumulation of salt, and loss of irrigation water resources. Therefore, there is a need to improve the water use efficiency and one of the strategies to improve crop productivity per unit of water under full irrigation is the employment of the aid of models to fill the gaps during dry spells.

1.2. Statement of the Problem

Information on appropriate time for irrigation application and the precise quantity of irrigation, which is the best application method available under given conditions are the key problem faced by farmers in the study area. Under such challenging conditions, advice on quantity and time of application of irrigation is nesessary. This in turn demands determination of the crop water requirements and irrigation scheduling of pepper.

1.3. Objective of the Study

The general objective of this study aims to determine crop water requirements for onion using different models to improve water productivity for sustainable agricultural production under irrigated agriculture. With the following specific objectives.

1) To compare the significance of AquaCrop and CropWat models for adoption at different situations in Metekel zone.
2) To develop irrigation scheduling for pepper using AquaCrop and CropWat model.

2. Materials and Methods

2.1. Study Area Description

The study was conducted in Metekel zone. It is the largest zone of Benishangul Gumuz Regional State, North-West of Ethiopia. It covers an area of 3,387,817 hectares consisting of seven districts: Pawe, Manbuk, Bullen, Wembera, Dibate, Mandura, and Guba, Woredas. The annual rainfall of the area is 900-1580mm and the topography of the zone have varying altitudes from 600- 2800 m.a.s.l. and. About 80% of the the study area is characterized by a sub-humid and humid tropical climate [11]. The surrounding of Metekel Zone has a wide climatic range within hot to warm moist lowlands and hot to warm -sub-humid lowlands agroecological zones. Farmers practice a mixed crop-livestock production system. Cereals (sorghum, maizeand finger millet) and oilseeds (sesame, soybean, and groundnut) are the most important food grains mainly cultivated in the zone. [12].

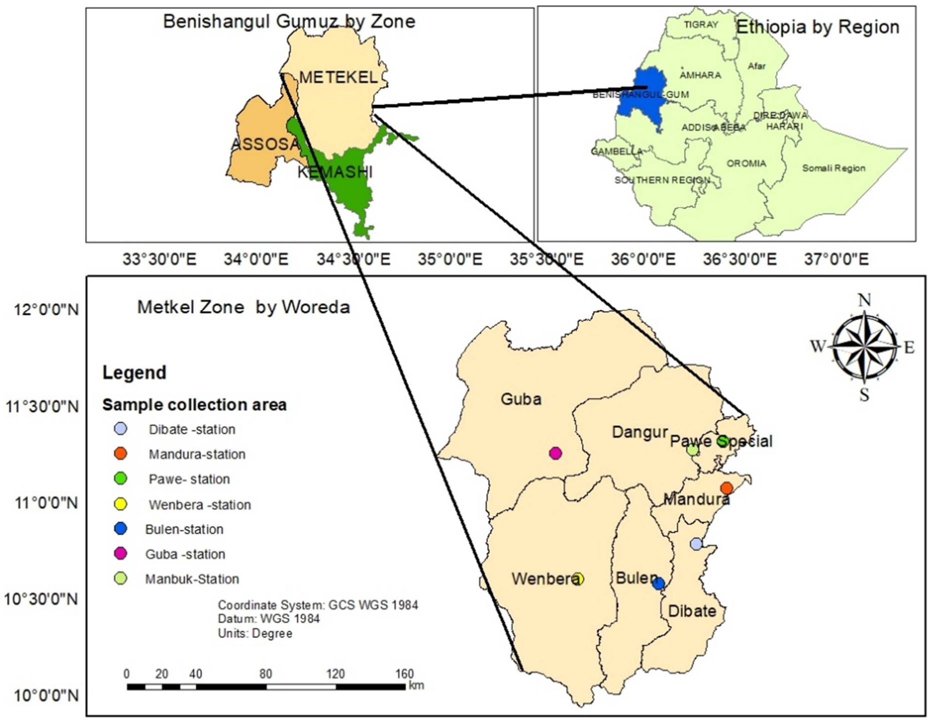

Figure 1. Location map of the study area.

The soil type of the study area is characterized by heavy clay soil with total available soil moisture level range 222-259 (mm/meter depth) and initial available soil moisture depletion level range 111-129 (mm/meter depth) varying with soil depth. The mean infiltration rate of the soil is 70 mm/day and the bulk density is varying from 1.12-1.31gm/cm3 across the depth of 1.2 meter. The annual maximum and minimum temperature of the study area is 35°C and 20°C respectively [13].

According Solomon et al. [11]. agricultural activities in the zone dominated by mixed crop-livestock production, which accounts 96.2% of the farmers and the rest 3.8% were involved only in livestock production.

2.2. Data Collection and Analysis

To run models various input data were collected from observations and measurements that were necessary to effect the specific area or location.

2.2.1. Climatic Data

Long-term monthly values of the weather variables such as minimum temperature and maximum, wind speed, relative humidity, sunshine hour, and rainfall collected from the National Metrological Agency (NMA).

The stations found in the study area are Mandura, Bullen, Pawe, Wembera, and Guba. normal ratio method for the normal annual climate exceeding 10% of the normal climate data of the station and simple arithmetic average procedure for the normal annual climate data at other stations that are within about 10% of the normal annual climate data were used for completing missing data a [14]. Double mass-curve method used to checked the consistency of the climate data set of the stations with about neighborhood stations from Metekel zone and Awi zone.

FAO CropWat model for window 8.0 and ETo calculator embedded in AquaCrop were used to determine ETo using the long term- climatic data of the area from the national meteorological station.

A fixed percentage method was used to account rainfall that effectively used by the crop after rainfall losses due to deep percolation and surface runoff.

AquaCrop requires the mean annual atmospheric CO_2 concentration ([CO_2]) for the adjustment of crop transpiration and biomass water productivity. The 'MaunaLoa.CO_2' file contains observed mean annual [CO_2] for the period 1902 till today. Reference CO_2 concentration (369.41 ppm) From Maunaloa.CO_2 database file.

2.2.2. Soil Sampling, Preparation, and Analysis

Undisturbed soil samples were taken from the field using core sampler of known volume and were collected from kebeles of each district at five soil depths (0-15 cm, 15-30 cm, 30-60 cm, 60 -90 cm, and 90-120 cm) for computing bulk density of soil at different depths. Soil samples and have been oven-dried at 105°C to obtain a constant weight.

The bulk density was calculated from the weight of the soil per unit volume of known core sampler which is expressed as in equation (1) and all analysis was conducted at Pawe Agricultural Research Center Laboratory.

$$\text{Pb} = \frac{\text{Ms}}{\text{Vt}} \tag{1}$$

Where, ρ_b is bulk density (g/c.m^3), Ms is mass of the dry soil (g), Vt is volume of core sampler (c.m^3).

Composite disturbed soil samples had been collected from different kebeles of the districts as at five soil depths (0-15 cm, 15-30 cm, 30-60 cm, 60 -90 cm, and 90-120 cm), texture analysis along with, analysis of soil texture, organic carbon, electrical conductivity (EC) and soil reaction (pH) soil had been done.

Particle size distribution was determined in the laboratory by the modified Bouyoucos hydrometer method [15]. Soil pH analysis was measured using a digital pH-meter and EC of soil analysis was measured using EC meter.

Field capacity (FC), permanent wilting point (PWP), total available water (TAW), hydraulic conductivity and soil water content at saturation (SAT), depend on soil textural class and were determined by soil-plant air-water (SPAW).

Maximum rain infiltration rate (mm/day), initial soil moisture depletion (%), and initially available soil moisture (mmm) total available soil moisture (mm/m), maximum rooting depth (m), used as an input.

2.2.3. Irrigation Water Sampling Preparation Analysis

Assessment of irrigation water quality is relevance to calculate the leaching raqurements of crops depending on there water quality tolerance threshold valus of crops.

Chemical characteristics of irrigation water (salt concentration of water and hydrogen ion concentration (PH) content) have been teste after water samples have been taken from water sources of irrigation in major irrigated areas. Collection and handling of irrigation water samples have been done following the procedure outlined by the US Salinity Laboratory Staff [16].

Acid-washed and rinsed polyethylene bottles (2-liters) were used to collect irrigation water samples. The samples have been transported to the laboratory and analyzed for their chemical composition immediately.

The irrigation water chemical properties have been determined at the Pawe Agricultural Research Center Soil and Water Laboratory. EC and pH of the water samples have measured in the laboratory within 24 hours using conductivity meter and a digital pH meter, respectively [17].

2.2.4. Crop Characteristics Data

Characteristics of pepper (growing stages, maximum rooting depth, crop coefficient, critical depletion infraction, yield response factor, crop height used as an input for CropWat and Calibrated and validated onion characteristics from the database have been used as input for the AquaCrop. These are dates of emergence, time to reach maximum (canopy cover, rooting depth), plant height, days of maturity dry biomass, harvest index, and total dry yield.

2.3. Crop Water Requirement

2.3.1. Crop and Irrigation Water Requirements Using Crop Wat Model

Crop water requirement computed using CropWat 8.0 and using monthly ETo values together, rainfall, crop characterand and the required soil characteristics as inputs.

Kc for every growth stage was adapted from Allen et al. (1998) and then, ETc was calculated.

$$ETc=kc * ETo \quad (2)$$

Where, ETc is crop evapotranspiration (mm), Kc is crop factor, ETo is reference evapotranspiration (mm).

The irrigation requirement was calculated using the following equation.

$$NIR=ETc - Pe \quad (3)$$

Where, NIR is net irrigation water requirement (mm), ETc is crop water requirement (crop evapotranspiration) (mm), Pe is effective rainfall (mm).

The amount of water applied during an irrigation event (gross irrigation) was calculate using the following equation

$$GIR=NIR/ Ea \quad (4)$$

Where, GIR is gross irrigation requirement, NIR is net irrigation water requirement and Ea is water application efficiency =60%.

2.3.2. Crop and Irrigation Water Requirements Using AquaCrop Model

Net irrigation requirement and crop water requirement for furrow irrigation have been calculated Considering groundwater table, as no shallow groundwater table and no, all stress indicators, water shortage stress, waterlogging stress, soil salinity stress air temperature stress, have been considered as zero and considering no specific field management. The simulation period has been adjusted and soil water profile at % of RAW considered as an initial condition.

Crop transpiration has been calculated by the concept of the following formula

$$Tr=ETo *Ks* K_{cTr} \quad (5)$$

Where, ETo=the reference evapotranspiration, K_{cTr}=the crop transpiration coefficient, Ks=a water stress coefficient which is 1 when water stress does not induce stomatal closure.

The crop transpiration coefficient K_{cTr} is proportional to the green canopy cover (CC):

$$K_{cTr}=K_{cTr,\,x} * K_c\, CC^{**} \quad (6)$$

Where, K_{cTr}, x=the crop coefficient for maximum crop transpiration (determined by the characteristics that distinguish the crop with a complete canopy cover from the reference grass), and CC* the canopy cover adjusted for micro-advective effects.

The total amount of irrigation water required to keep the water content in the soil profile above the specified threshold is the net irrigation water requirement for the period. The depletion (% RAW) below which the soil water content in the root zone may not drop (0% RAW corresponds to Field Capacity). The net requirement does not consider extra water that has to be applied to the field to account for conveyance losses or the uneven distribution of irrigation water on the field.

2.4. Irrigation Scheduling

2.4.1. Irrigation Scheduling Using CropWat Model

Irrigation scheduling was conducted using fixing the interval time criterea and specify back to field capacity depth criteria with CropWat 8.0 windows.

2.4.2. Irrigation Scheduling Using AquaCrop Model

Generation of irrigation schedules using AquaCrop have been computed by specify back to field capacity depth criterion and fixed interval time criteria.

The electrical conductivity (EC) of the irrigation water was used as an input to irrigation scheduling and irrigation events (when to irrigated and how much to irrigate have been specified by selecting the furrow irrigation method Irrigation water quality was considering for maximum dry yield production and water productivity and minimum labor cost (irrigation event).

2.5. Performance Evaluation of Models

Model performance was evaluated using the following statistical parameters: Root mean square error (RMSE), root mean square error normalized (RMSEN), Nash-Sutcliffe efficiency index (NSE) prediction error, (Pe).

Root mean square error (RMSE):

Root mean square error (RMSE) was calculated as illustrated in (Equation 7) [18].

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(Si - Oi)^2} \quad (7)$$

Where, Si is predicted value, Oi is observed value, and N is the number of observations.

It ranges from 0 to 1 the value 0 indicating good and the value 1 indicating poor model performance. Ideally, the value of RMSE should be zero.

Root mean square error normalized (RMSEN):

The Normalized RMSE expressed in percent, was calculated as illustrated in (Equation 8) [18].

$$RMSEN=\frac{1}{Oi}\sqrt{\sum\frac{(Si-Oi)^2*100}{N}} \quad (8)$$

Where, Si is predicted value, Oi is observed value, and N is the number of observations.

A model can be considered as poor if NRMSE is larger than 30%, fair if NRMSE is between 20 and 30%, good if NRMSE is between 10 and 20%, excellent if NRMSE is smaller than 10%, [19].

Nash-Sutcliffe efficiency index:

The Nash-Sutcliffe coefficient of efficiency coefficient (NSE) calculated as (Equation 9).

$$NSE=1-\frac{\sum_{i=1}^{N}(si-oi)^2}{\sum_{i=1}^{N}(oi-mo)^2} \quad (9)$$

Where, Si is predicted value, oi is the observed value, N is the number of observations and Mo is the average of the observed values.

Nash-Sutcliffe is very commonly used, which means that there are a large number of reported values available [20].

Prediction error (Pe):

$$\frac{(Si-Oi)}{Oi} * 100 \tag{10}$$

Where, Si the is predicted value, Oi is observed value.

3. Results and Discussion

3.1. Climate Characterstics of the Study Areas

Climatic data of the study area were analyzed and reference evapotranspiration was estimated based on the FAO Penman-Monteith method [21] and the results shown in the following tables.

Table 1. *Long term evapotranspiration of the the study area (mm/day).*

Month	Pawe		Mandura		Guba		Bullen		Wembera	
	CW	AQ	CW	AQ	CW	AQ	CW	AQ	CW	AQ
January	5.09	5.2	5.10	4.00	5.02	5.10	4.23	4.30	4.24	3.20
February	5.56	5.7	5.56	5.10	5.70	5.90	4.50	4.60	4.51	4.00
March	6.6	6.8	6.60	6.30	6.92	7.10	5.47	5.60	5.51	5.20
Aprile	6.18	6.2	6.17	6.10	6.80	6.90	5.19	5.20	5.23	5.20
May	4.85	4.7	4.85	4.80	5.21	5.10	4.26	4.20	4.31	4.30
June	4.12	4	4.12	4.10	4.45	4.30	3.72	3.60	3.75	3.80
July	3.49	3.4	3.49	3.50	3.76	3.70	3.16	3.10	3.13	3.20
August	3.17	3.2	3.18	3.20	3.57	3.60	2.93	2.90	3.05	3.10
September	3.64	3.7	3.65	3.50	3.86	3.90	3.39	3.40	3.47	3.30
October	3.67	3.7	3.68	3.30	3.83	3.80	3.39	3.40	3.48	3.10
November	3.76	3.7	3.77	2.90	4.06	4.10	3.40	3.40	3.46	2.60
December	3.91	3.9	3.92	2.70	4.25	4.30	3.47	3.50	3.51	2.40
Avarage	4.5	4.52	4.51	4.13	4.79	4.82	3.93	3.93	3.97	3.62

**CW=CropWat, AQ=AqaCrop

As shown in Table 1, The minimum reference evapotranspiration was found to be 2.4 mm/day in Bullen district and the maximum reference evapotranspiration in was found to be 6.92 mm/day in Guba. Simulated using CropWat. The maximum reference evapotranspiration in the study areas simulating using AquaCrops was found to be 7.1 mm/day in Guba and minimum reference evapotranspiration was found to be 2.4 mm/day in Wembera district.

Table 2. *Long term rain fall data and effective rainfall (mm) of the study area.*

Mouth	pawe		Mandura		Guba		Bullen		Wembera	
	p	pe	p	pe	p	pe	p	pe	p	pe
January	0.7	0.7	1.6	1.6	0	0	3.5	3.5	42.8	39.9
February	0.6	0.6	2	2	7.1	7	2.6	2.6	49.3	45.4
March	7.8	7.7	7.2	7.1	6.1	6	4.5	4.5	45.1	41.8
April	27.8	26.6	38	35.7	42	39.2	72.4	64	53.6	49
May	93.2	79.3	126.7	101	230.8	145.6	153.1	115.6	75.8	66.6
June	289.8	154	270.1	152	212.9	140.4	261.8	151.2	78.6	68.7
July	361.4	161.1	494.1	174.4	326.5	157.7	284.4	153.4	82	71.2
August	396.3	164.6	362.8	161.3	299.8	155	373.4	162.3	85	73.4
September	261.1	151.1	267.6	151.8	250.2	150	278.8	152.9	75	66
October	132.6	104.5	60.5	54.6	156.7	117.4	124.6	99.8	79	69
November	14.4	14.1	19	18.4	13.2	12.9	16.9	16.4	72	63.7
December	0.7	0.7	1.2	1.2	0.7	0.7	4.5	4.5	53	48.5
Total	1586.4	865	1650.8	861.1	1546	931.9	1580.5	930.7	791.2	703.4
Average	132.2	72	137.6	71.5	128.8	77.6	131.7	77.5	65.9	68.6

*P=Rain fall, Pe=Effective rainfall.

As shown in Table 2, Part of the rainfall that infiltrated into the soil called effective rainfall became available for crop groth in mm. Effective rainfall values used to simulate net irrigation requirements when irrigation scheduling developed using CropWat model and the rain fall values used to simulate the water balance in soil profile when irrigation scheduling developed using AquaCrop.

The rain fall values in wembera district was relatively higher than the other districts during growing season of the sumulation period that results higher effective rain fall.

3.2. Soil Profile Characteristics of the Study Areas

The total available soil moisture content of soil on a volumetric percentage basis easily converted to mm of water per meter of soil depth by multiplying by 1000 mm/meter and then dividing by 100 to remove the percentage is a preferable unit for irrigation management.

As shown in Table 3, the soil moisture contents on a volume basis in Pawe district were in the range of 25.11% and 27.66%, and 36.8% and 44.18%, respectively at permanent welting *point and field and the average total available soil moisture content was 144.12 mm/m.*

Table 3. *Soil sample analysis in Pawe district.*

Depths (cm)	Sand (%)	Silt (%)	Clay (%)	TAW (mm/m)	PWP	FC	SAT	Ksat (mm/day)	Textural class
					Volume in %				
0-15	22	10	68	179.5	27.66	45.61	48	300	Sity loam
15-30	14	18	68	116.9	25.11	36.8	48.9	270.5	Sity loam
30-60	18	14	68	126.7	26.37	39.04	48.5	288.1	Sity loam
60-90	24	12	64	129.6	26.94	39.9	47.7	307.7	Sity loam
90-120	22	12	66	167.9	27.39	44.18	48	300	Sity loam
ATASM (mm/m)	144.12								
MIR (mm/day)	70								
MRD (c.m)	120								

* ATASM=Average total available soil moisture, MIR=Maximum infiltration rate, MRD=Maximum rooting depth.

Table 4. *Soil sample analysis in Mandura district.*

Depths (cm)	Sand (%)	Silt (%)	Clay (%)	TAW (mm/m)	PWP	FC	SAT	Ksat (mm/day)	Textural class
					Volume in %				
0-15	38	24	38	127	23.5	36.2	46.4	61	Clay loam
15-30	36	26	38	129	23.5	36.4	46.7	67.1	Clay loam
30-60	40	26	34	128	21.3	34.1	45.9	91.1	Clay loam
60-90	35	15	50	119	30	41.9	47.7	12.2	clay
90-120	37	15	45	119	29	40.9	47.2	12.2	Clay
ATASM (mm/m)	124.4								
MIR (mm/hr)	76								
MRD (c.m)	120								

* ATASM=Average total available soil moisture, MIR=Maximum infiltration rate, MRD=Maximum rooting depth.

From Table 4, the soil moisture contents on a volume basis in Mandura district were in the range of 21.3% and 30%, and 41.9%, and 34.1%, respectively at PWP and FC and the average total available soil moisture was 124.4 mm/m.

Table 5. *Soil sample analysis in Guba district.*

Depths (cm)	Sand (%)	Silt (%)	Clay (%)	TAW (mm/m)	PWP	FC	SAT	Ksat (mm/day)	Textural class
					Volume in %				
0-15	68	12	20	87	13.8	22.5	43.1	493.8	Sandy loam
15-30	65	19	16	95	11.5	21	44	280.4	Sandy loam
30-60	66	14	20	91	13.8	22.9	43.3	487.7	Sandy loam
60-90	65	12	23	85	15.5	24	43	347.5	Sandy lay loam
90-120	68	10	22	88	14.9	23.7	42.9	402.3	Sandy loam
TASM (mm/m)	89.2								
MIR (mm/hr)	90								
MRD (c.m)	120								

* ATASM=Average total available soil moisture, MIR=Maximum infiltration rate, MRD=Maximum rooting depth.

From Table 5, the average total available soil moisture was 89.2 mm/m. The soil moisture contents in Guba were in the range of 11.5% and 15.5%, and 21 and 24%, respectively at PWP and FC on a volume basis.

Table 6. *Soil sample analysis in Bullen district.*

Depths (cm)	Sand (%)	Silt (%)	Clay (%)	TAW (mm/m)	PWP	FC	SAT	Ksat (mm/day)	Textural class
					Volume in %				
0-15	20	40	40	144	24.3	38.7	49.9	85.3	Silty clay
15-30	25	37	38	142	22.8	37	48.5	85.3	Clay loam
30-60	26	37	37	141	17	31.1	46.5	91.4	Clay loam
60-90	26	36	38	139	17	30.9	46.2	85.3	Clay loam
90-120	24	36	40	142	15.5	29.7	45.9	79.2	Clay
TASM (mm/m)	141.6								
MIR (mm/hr)	74								
MRD (c.m)	120								

* ATASM=Average total available soil moisture, MIR=Maximum infiltration rate, MRD=Maximum rooting depth.

As shown in Table 6, the average total available soil moisture was 141.6 mm/m. The soil moisture contents in the Bullen district were in the range of 15.5% and 24.3%, and 29.7% and 38.7%, respectively at PWP and FC on a volume basis.

Table 7. *Soil sample analysis in Wembera district.*

Depths (cm)	Sand (%)	Silt (%)	Clay (%)	TAW (mm/m)	PWP	FC	SAT	Ksat (mm/day)	Textural class
					Volume in %				
0-15	23	29	48	135	28.7	41.3	50.1	35.576	clay
15-30	20	34	46	132	27.5	40.7	50.5	54.864	clay
30-60	28	25	47	126	28.2	40.8	49	30.48	clay
60-90	23	35	42	136	25.5	39.1	49.5	67.056	clay
90-120	23	36	43	135	26	39.5	49.6	60.96	clay
TASM) mm/m)	132.8								
MIR (mm/hr)	45								
MRD (c.m)	120								

* ATASM=Average total available soil moisture, MIR=Maximum infiltration rate, MRD=Maximum rooting depth.

As shown in Table 7, the soil moisture contents on a volume basis in Wembera were in the range of 25.5% and 28.7%, and 39.1% and 41.3% respectively at PWP and FC and the average total available soil moisture was 132.8 mm/m.

The values of saturated hydraulic conductivity, soil moisture contents at permanent welting point, field capacity and saturation and total available soil moisture depend soil textural class.

Generally all soil textural class could be found in each districtes. The soil analysis results shoun in the above tables (from table 3-7) represents only areas where irrigation practice observed by smallholder farmers, small irrigation shems, around perennial rivers that are serving as irrigaton water source.

The soil textural class sampled and analysis around the study areas ranges from light (sandy loam) in Guba to clay soil texture in Mandura, Bullen and Wembera.

Irrigation water quality of the study areas

Assessment of electrical conductivity or Salinity values of irrigation water have been conducted to calculate leaching requitement and identify effect of salinity stress if the salinity values grater than threshold salinity values of pepper.

Table 8. *Irrigation water quality results of the study area.*

Name of rivers (irrigation water source)	Hydrogen ion concentration (PH)	electrical conductivity (CE_w)
Midimida	7.64 moles per liter	0.273ds/m
Changure	7.43 moles per liter	0.41ds/m
Abat Beles	7.69 moles per liter	0.36ds/m
Gilgel Beles	7.47 moles per liter	0.466ds/m
Baguna	7.83 moles per liter	0.521ds/m
Libite	7.7 moles per liter	0.511ds/m
Average	7.63 moles per liter	0.4235 ds/m

* $\mu s/cm$`=Micro Siemens per centimeter.

As shown in Table 8, the electrical conductivity of irrigation water ranged from 0.273 ds/m to 0.521 sd/m and the average electrical conductivity were 0.4235 Sd/m and hydrogen ion concentration of irrigation water ranged from 7.43 moles per liter to 7.83 moles per liter and average hydrogen ion concentration was 7.63 moles per liter. The nature of sampled rivers was perennial, representative, and cross many districts in the zone.

3.3. Characteristics of pepper Used as Input

Information on, the local transplanting date onion, which was around December first had been collected from farmers experience around the study area and used for the computation of crop water requirement and to made irrigation scheduling using both CropWat and AquaCrop model.

Table 9. *Characteristics of pepper used as input for CropWat.*

Crop characteristics	Growing stages				Total
	Initial	Development	Mid	Late	
kc	0.6	0.6-0.75	1.05	0.98	
stage	30	40	45	35	150
Rooting depth	0.25		0.8		
Critical depletion (fraction)	0.2	0.3		0.5	
Yield response factor	1.4	0.6	1.2	0.6	1.11
Crop height		0.7 (optional)			

As shown in Table 9, Since there was no determined rooting depth, critical depletion, crop coefficient, and yield response factor, for this area, the FAO recommended values for the pepper growth stages are used to simulate crop water requirement and to made irrigation scheduling.

Table 10. *Characteristics of pepper used as input for AquaCrop.*

Initial canopy	Initial canopy cover (%)	0.83
	Canopy size seedling (c.m^2/plant)	15
	Plant density (plants/ha)	55,556
Development	Maximum canopy cover (%)	78
	From day 1 after sowing to emergence (day)	7
	Maximum canopy (day)	68
	Senescence (day)	90
	Maturity (day)	150
Flowering and yield formation (root/tuber formation)	Length building up of harvest index (day)	110
	Duration of flowering (day)	
	From day 1 after sowing to flowering (day), yield formation	63
Root deepening	Maximum effective root depth (m)	0.8
	From day 1 after sowing to maximum root depth (day)	50
	Average root zone expansion (cm/day)	1.4

Most of the pepper characteristics have been taken with minimum calibration [22].

3.4. Crop and Irrigation Water Requirements

3.4.1. Crop and Irrigation Water Requirements with CropWat Model

Equation (2) used to calculate crop water requirements using CropWat model.

Table 11. *Simulated ETc and IR of pepper in the study areas using CropWat.*

	Districts				
	Pawe	***Mandura***	***Guba***	***Bullen***	***Wembera***
ETC (mm)	762.4	760	799.9	632.2	636.1
ER (mm)	35.4	46.1	51	76.5	223.2
IR (mm)	725.6	712.1	746.7	553	411.1

* ETC=crop water requirement, ER=Effective rainfall, IR=Irrigation requirement.

As shown in Table 11, The minimum irrigation requirement of pepper was found to be 411.1 mm in Wembera district. The maximum seasonal irrigation requirement of pepper was found to be 746.7 mm in Guba district. Relatively height amount of the required water was satisfied by seasonal effective rain (Pe) with 148 mm in Wembera district.

In Melkasa, Ethiopia, the average seasonal ETc of pepper was found to be 526.06 mm with 42.3 mm, 127.7 mm, 255.9 mm, and 100.7 mm of water calculated for initial, crop development, mid-season, and late-season stages, respectively [23].

3.4.2. Crop and Irrigation Water Requirements Using the AquaCrop Model

The irrigation requirement using AquaCrop simulation is the total simulated irrigation depth considering the water balance on effective root depth of the soil profile. The actual evapotranspiration (ET) throughout the growing season were then determined based on equation (5) using AquaCrop model.

Table 12. *Simulated ETc and IR of pepper in the study areas using AquaCrop.*

Parameters	**Districts**				
	Pawe	***Mandura***	***Guba***	***Bullen***	***Wembera***
TIR (mm)	678.1	648.6	703.4	587.9	414.7
ET_C (mm)	779.5	698.2	749.6	653.9	591.3
ETo (mm)	832.4	722.7	877	694.8	571.1
Rain (mm)	36.8	48.5	47.3	86.2	241.0

TIR=Total irrigation requirement, ETc=crop water requirement, ETo=reference evapotranspiration,

This total simulated irrigation requirements shown in Table 12, used to generating irrigation scheduling according to the specified time, a fixed interval and bring the soil water content in the root zone at field capacity depth criteria.

The maximum total irrigation requirement and crop water requirement of pepper were found to be 911 and 825.1mm respectively in *Guba* district and the minimum total irrigation requirement and crop water requirement were found to be 597.4 and 615.4 mm in *Wembera* district.

3.5. Irrigation Scheduling

3.5.1. Irrigation Scheduling of Onion Using CropWat Model

CropWat model has different options to carry out irrigation scheduling. However, based on the research evidence and field data available in the study area refill soil to field capacity depth criteria and irrigate at fixed interval per stage time criteria a were used. Since main irrigation application methods for the area is surface irrigation, irrigation efficiency of 60%

was considered.

Table 13. *Irrigation scheduling of pepper in Pawe using irrigate at a fixed interval.*

Irrigation events	**Date**	**Day**	**Stage**	**NIR (mm)**	**GIR (mm)**
1	7 December	7	Initial	14.7	24.5
2	14 December	14	Initial	15.7	26.2
3	21 December	21	Initial	16.2	26.9
4	28 December	28	Initial	17.7	29.5
5	4 January	35	Development	20.2	33.6
6	11 January	42	Development	23	38.3
7	18 January	49	Development	28	46.6
8	25 January	56	Development	32	53.3
9	1 February	63	Development	34.4	57.3
10	8 February	70	Development	39.1	65.2
11	15 February	77	Mid	40.9	68.1
12	22 February	84	Mid	42.2	70.4
13	1 March	91	Mid	44.1	73.5
14	8 March	98	Mid	45.5	75.8
15	15 March	105	Mid	47.7	79.5
16	22 March	112	Mid	48	80.1
17	29 March	119	End	46.2	77
18	5 April	126	End	44.3	73.8
19	12 April	133	End	43.2	72
20	19 April	140	End	41.1	68.5
21	26 April	147	End	33.4	55.7
Total			717.6		1195.8

*NIR=net irrigation requirement, GIR=Gross irrigation requirement.

As indicated in Table 13, The total gross and net irrigation requirements of pepper in *Pawe* district were found to be 1195.8 mm and 717.6 mm respectively with a yield reduction of 0.5%.

Irrigation scheduling of pepper using the fixed interval (7 days) per stage time criteria and refill soil to field capacity depth criteria in *Paw*e had 21 irrigation events.

The minimum net and gross irrigation requirement were found to 14.7 mm and 24.5 in the first irrigation event respectively and the maximum net and gross irrigation requirement reach up to 48 mm and 80.1 mm at the end of mid stage respectively.

Table 14. *Irrigation scheduling of pepper in Mandura using irrigate at a fixed interval.*

Irrigation events	**Date**	**Day**	**Stage**	**NIR (mm)**	**GIR (mm)**
1	7 December	7	Initial	14	23.4
2	14 December	14	Initial	15.5	25.8
3	21 December	21	Initial	16	26.7
4	28 December	28	Initial	17.5	29.2
5	4 January	35	Development	19.9	33.2
6	11 January	42	Development	22.7	37.9
7	18 January	49	Development	27.4	45.7
8	25 January	56	Development	31.5	52.5
9	1 February	63	Development	34	56.6
10	8 February	70	Development	38.4	64.1
11	15 February	77	Mid	40.3	67.1
12	22 February	84	Mid	41.6	69.3
13	1 March	91	Mid	43.2	72.1
14	8 March	98	Mid	45	75.1
15	15 March	105	Mid	47.1	78.4
16	22 March	112	Mid	47.4	78.9
17	29 March	119	End	45.3	75.5
18	5 April	126	End	43	71.6
19	12 April	133	End	41.7	69.5
20	19 April	140	End	39	65
21	26 April	147	End	30.1	50.2
Total			700.6		1167.8

* NIR=Net irrigation requirement, GIR=gross irrigation requirement.

In Table 14, irrigation scheduling of pepper in *Mandura* using the fixed interval (7 days) time criteria and refill soil to field capacity depth criteria had 21 irrigation events. The total gross and net irrigation requirements were found to be 1167.8 mm and 700.6 mm respectively.

The yield reduction was high (1.5%) due to heavy soil texture of the district, but soil requirement of pepper is light to medium textural soil, that is well- drained and aerated as shown in table 4.

The minimum net and gross irrigation requirement were found to 14 mm and 23.4 mm in the first irrigation event respectively and the maximum net and gross irrigation requirement reach up to 47.4 mm and 78.9 mm at the end of mid stage respectively.

Table 15. *Irrigation scheduling of pepper in Guba using irrigate at a fixed interval.*

Irrigation events	Date	Day	Stage	NIR (mm)	GIR (mm)
1	7 December	7	Initial	14.5	24.1
2	14 December	14	Initial	15.8	26.4
3	21 December	21	Initial	16.6	27.6
4	28 December	28	Initial	17.7	29.5
5	4 January	35	Development	19.8	33
6	11 January	42	Development	22.1	36.8
7	18 January	49	Development	26.2	43.6
8	25 January	56	Development	30	50
9	1 February	63	Development	32.6	54.4
10	8 February	70	Development	35.9	59.9
11	15 February	77	Mid	38	63.3
12	22 February	84	Mid	39.2	65.4
13	1 March	91	Mid	41.1	68.5
14	8 March	98	Mid	43.2	72
15	15 March	105	Mid	45.2	75.4
16	22 March	112	Mid	45.6	76
17	29 March	119	End	44.3	73.8
18	5 April	126	End	44.5	74.1
19	12 April	133	End	44.8	74.7
20	19 April	140	End	44.5	74.1
21	26 April	147	End	29.8	49.7
Total				691.4	1152.3

** NIR=Net irrigation requirement, GIR=gross irrigation requirement.*

As shown in Table 15, irrigation scheduling of pepper in *Guba* using a fixed interval (7 days) per stage time criteria and refill soil to field capacity depth criteria had 19 irrigation events had the total gross and net irrigation requirements of 1152.3 mm and 691.4 mm respectively.

The yield reduction of pepper was also high (7.7%) since soil texture of the district was sandy as shown in Table 5, that need irrigation schedule using short irrigation intervals and small amount of water. So irrigation interval less than 7 days can be use by considering labor cost to reduce yield reduction.

The minimum net and gross irrigation requirement were found to 14.5 mm and 24.1 mm in the first irrigation event respectively and the maximum net and gross irrigation requirement reach up to 45.6 mm and 76 mm at the end of mid stage respectively.

Table 16. *Irrigation scheduling of pepper in Bullen using irrigate at a fixed interval.*

Irrigation events	Date	Day	Stage	NIR (mm)	GIR (mm)
1	7 December	7	Initial	11.8	19.7
2	14 December	14	Initial	13.9	23.2
3	21 December	21	Initial	14.2	23.7
4	28 December	28	Initial	14.6	24.3
5	4 January	35	Development	16.8	28
6	11 January	42	Development	18.8	31.4
7	18 January	49	Development	22.2	37.1
8	25 January	56	Development	25.8	43.1
9	1 February	63	Development	27.6	46.1
10	8 February	70	Development	30.9	51.4
11	15 February	77	Mid	32.6	54.3
12	22 February	84	Mid	33.7	56.2
13	1 March	91	Mid	35.7	59.6
14	8 March	98	Mid	38.5	64.2
15	15 March	105	Mid	40.6	67.6
16	22 March	112	Mid	41	68.3
17	29 March	119	End	38	63.4
18	5 April	126	End	30.7	51.2
19	12 April	133	End	32.4	54
20	19 April	140	End	25	41.6

Irrigation events	Date	Day	Stage	NIR (mm)	GIR (mm)
21	26 April	147	End	19.3	32.2
Total				564.1	940.6

* NIR=Net irrigation requirement, GIR=gross irrigation requirement.

As shown in Table 16, Irrigation scheduling of pepper in *Bullen* using the fixed interval (7 days) per stage time criteria and refill soil to field capacity depth criteria had 21 irrigation event and had the total gross irrigation and net irrigation reqiuirement of 940.6 mm and 564.1 mm respectively and the yield reduction of was 0.1%.

The minimum net and gross irrigation requirement were found to 11.8 mm and 19.7 mm in the first irrigation event respectively and the maximum net and gross irrigation requirement reach up to 41 mm and 68.3 mm at the end of mid stage respectively.

Table 17. *Irrigation scheduling of pepper in Wembera using irrigate at a fixed interval.*

Irrigation events	Date	Day	Stage	NIR (mm)	GIR (mm)
1	7 December	7	Initial	2.1	3.5
2	14 December	14	Initial	6.1	10.1
3	21 December	21	Initial	10.7	17.8
4	28 December	28	Initial	5.4	9
5	4 January	35	Development	10.1	16.9
6	11 January	42	Development	14.1	23.6
7	18 January	49	Development	13.3	22.2
8	25 January	56	Development	19.2	32
9	1 February	63	Development	24.3	40.5
10	8 February	70	Development	19.3	32.1
11	15 February	77	Mid	24.6	40.9
12	22 February	84	Mid	29.4	49
13	1 March	91	Mid	28.3	47.1
14	8 March	98	Mid	25.8	43
15	15 March	105	Mid	33.6	56.1
16	22 March	112	Mid	35.4	59
17	29 March	119	End	32.8	54.6
18	5 April	126	End	30.9	51.5
19	12 April	133	End	32.6	54.4
20	19 April	140	End	28.5	47.4
21	26-Apr	147	End	24.6	41
Total				451.1	751.7

* NIR=Net irrigation requirement, GIR=gross irrigation requirement.

As indicated in Table 17, irrigation scheduling of pepper using the fixed interval (7 days) per stage time criteria and refill soil to field capacity depth criteria in *Wembera* had 21 irrigation events and had the total gross and net irrigation requirements of 751.7 mm and 451.1mm respectively with yield reduction of 0.0%.

The minimum net and gross irrigation requirement were found to 2.1 mm and 3.5 mm in the first irrigation event respectively and the maximum net and gross irrigation requirement reach up to 35.4 mm and 59 mm at the end of mid stage respectively.

Generally hiegh gross and net irrigation requerements for pepper needed at the end of mid stages and small gross and net irrigation requerements needed at beginning of initial stages.

3.5.2. Generating Irrigation Scheduling Using the AquaCrop Model

AquaCrop Generating irrigation scheduling according to the specified depth and time criterion. AquaCrop model has different options like CropWat to carry out irrigation scheduling. However, based on the research evidence and field data available in the study area refill soil to field capacity depth criteria and irrigate at fixed interval per stage time criteria a were used.

Table 18. *Generated irrigation scheduling of pepper in the study area at a fixed interval.*

Irrigation event	DAP	IR (mm)					ECw (ds/m)
		Pawe	*Mandura*	*Guba*	*Bullen*	*Wembera*	
1	7 December	14.6	17.3	15.7	19.5	9.3	0.4
2	14 December	13.1	13.9	13.9	16.6	9.9	0.4
3	21 December	13.6	14.5	14.5	17.5	10.5	0.4
4	28 December	12.8	14.3	13.6	18.1	11.2	0.4
5	4 January	18.5	19	17.1	21.5	14.1	0.4
6	11 January	25.4	23.7	23.7	25.9	16.9	0.4
7	18 January	31.8	27.6	31.4	28.9	17.3	0.4

Irrigation event	DAP	IR (mm)					ECw (ds/m)
		Pawe	*Mandura*	*Guba*	*Bullen*	*Wembera*	
8	25 January	35	30.1	35.2	30.5	19.4	0.4
9	1 February	36.7	32.3	37.5	31.1	19.7	0.4
10	8 February	38.3	34.1	39.1	31.3	19.7	0.4
11	15 February	39.2	36.1	40.5	32.2	21	0.4
12	22 February	40.2	37.9	41.8	33.2	21.9	0.4
13	1 March	41.3	39.7	43.2	34.7	22.5	0.4
14	8 March	46.2	43.4	47.8	39.9	30	0.4
15	15 March	45.2	43.4	47.5	38.6	29.9	0.4
16	22 March	44.3	42.9	46.6	37.7	29.7	0.4
17	29 March	42.6	41.3	44.9	35.4	28.9	0.4
18	5 April	40	39.1	44.2	30.2	24.4	0.4
19	12 April	36.9	36.7	41.7	25.9	21.4	0.4
20	19 April	33.3	33.4	36.7	21.5	19.2	0.4
21	26 April	28.8	27.9	26.8	17.7	17.9	0.4
TIR (mm)		678.1	648.6	703.4	587.9	414.7	
DY (T/ha)		13.686	13.693	13.686	13.693	13.693	
Wp (k.g/m^3)		1.91	1.96	1.83	2.09	2.32	

*DAP=Days after planting, IR=Irrigation requirement, TIR=Total irrigation requirement, DY=Dry yield, WP=Water productivity, EC_W=Electrical conductivity of irrigation water.

As shown in Table 18, to generate irrigation scheduling of pepper, a fixed interval of 7 days' time criterion, and refill soil to field capacity depth criteria which had 21 irrigation events has been selected. The simulation indicated that with TIR of 678.1 and 703.4 mm, the markatable yield of 13.686 T/ha of pepper can be produced in *Pawe* and *Guba* respectively and with TIR of 648.6, 587.9 and 414.7 mm, the marketable yield of 13.693 T/ha of pepper can be produced in *Mandura, Bullen*, and *Wembera* respectively.

Research conducted in the Coastal Savannah Ecological Zone of Ghana in 2014 indicated that the measured water requirement of pepper was found to be 318.30 mm where simulated was 321.0 mm in areas where ETo value and total growing stages 339.40 mm and 112 days respectively [22].

Threshold soil salinity and water salinity value in dS/m of pepper is 1.5 and 1.0 respectively. Water salinity of the study area (0.4dS/m) as shown in Table 8 is lower than the threshold values, so water salinity value in irrigation scheduling of pepper should be considered as zero.

3.6. Performance Evaluation of Models

Performance evaluation was calculated considering and simulated crop water requirement values of AquaCrop as simulated values (Si), and simulated crop water requirement values of CropWat as observed values (Oi) and the districts as a number of observations (N).

Table 19. *Performance evaluation considering the districts as a number of observations.*

Parameter	Pepper
Root mean square error	23.62.
Root mean square error normalized (%)	3.2%
Nash-Sutcliffe coefficient of efficiency coefficient	0.99
Prediction Error	0.32

RMSE provides information on the short-term performance of a model by allowing the term by term comparison of the actual difference between the simulated and the measured value.

In this study case, RMSE provides information comparison of the actual difference between the simulated values of AquaCrop and simulated values of CropWat.

According to Jamieson et al. [24] the simulation is considered and poor when it is greater than 30%, reasonable when it comes between 20% and 30%, good if it comes between 10% and 20% and excellent if RMSEN is less than 10%.

When NSE<0.5 simulation is an unsatisfactory fit, When NSE=0.5 to 0.64 simulation is a satisfactory fit, When NSE=0.64 to 0.74 simulation is a good fit, When NSE>0.75 simulation is a very good fit, When NSE=1.0, simulation is the perfect fit [20].

When Pe, approaches zero, they represent positive indicators of model performance and used to evaluate the model prediction error. Pe used to define the robustness of the model as well as to predict the values.

As shown in Table 19, Considering the districts as a number of observations, RMSE values for pepper when simulating crop water requirement was fund to be 23.62. and the simulation was poor.

Considering the districts as a number of observations, RMSEN values for pepper the values was 3.2%% lied less than 10% and the simulation was excellent.

Considering the districts as a number of observations, simulating crop water requirements using AquaCrop in all district for pepper was founed to be a very good fit (NSE>0.75) (NSE=0.99, pepper) with simulating crop water requirement using CropWat and the average pe values for pepper when simulating crop water requirements were found to be 0.32.

Generally from the overall model performance indicators indicated that AquaCrop model can simulate crop water requirements and irrigation application deths almost with similar result as CropWat model.

4. Conclusion and Recommendations

4.1. Conclusion

The objective of the study was to compare the significance of models for adoption at different situations in the study area and to simulate water requirement and irrigation scheduling for pepper.

Based on crop, soil, and meteorological data CO_2, groundwater, field management, and fertility status Crop water requirement and irrigation scheduling of pepper in selected districts of Metekel zone were estimated using using AquaCrop and CropWat.

(Normalized Root mean square errors (NRMSE), Prediction error (Pe), model by Nash-Sutcliffe efficiency (NSE)) were used to show relationship between simulated results of CropWat usingand the simulated results of AquaCrop.

The seasonal crop requirement of pepper were found to be 762.4 mm, 760 mm, 799.9 mm, 632.2 mm, 636.1 mm using Cropwat and 779.5 mm, 698.2 mm, 749.6 mm, 653.9 mm, and 591.3mm using AquaCrop in *Pawe, Mandura, Guba, Bullen and Wembera* respectively.

This study also shown that there was a strong close relation between simulated crop water requirement values of CropWat and the simulated crop water requirement values of AquaCrop. Hence Model performance indicators showed that the models well simulated in all districtes.

It has been observed shown that the appropriate irrigation interval at initial developments mid and late growth stages should be identified for ease of work to the users.

4.2. Recomendations

The developed irrigation schedule both using AquaCrop and CropWat should be validated and calibrated in all soil textural classes in each district of the study areas.

It is recommended that end-users and farmers should adopt fixed irrigation intervals to save time, energy water, and labor during irrigation water application of onion in the study area.

AquaCrop model should be adopted to compare attainable and actual yields in a field, farm, or a region and to simulate water productivity simultaneously, simulating crop water requirement and irrigation application depth and to improve water productivity.

Therefore, AquaCrop model should recommended due to its merit that easy for an application, a user friendly, accuracy and robustness and address the conditions where water is a key limiting factor for crop production.

It is also recommended that farmers and end-users should adopt AquaCrop as a planning tool or to assist in management decisions for both rainfedand irrigated agriculture and thus advisable to use the this model in to the development action at scale through developing appropriate pakcages and extension quidelines.

Abbreviation

ETC: Crop water requirement; IR: Irrigation requirement; GIR: Gross irrigation requirement; NIR: net irrigation requirement: IR: Irrigation requirement; DY: Dry yield; TIR: Total irrigation requirement; WP: Water productivity; EC_W: Electrical conductivity of irrigation water; DAP: Days after planting.

Conflict of Interest

The authors declare that they have no conflict of interests.

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