Application of AquaCrop and CropWat Models for Estimating Crop Water Requirement and Irrigation Scheduling of Maize in Metekel Zone, Ethiopia

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ABSTRACT

The objective of the study was to compare AquaCrop Model with CropWat Model to estimate crop water requirement and irrigation scheduling of maize in the Metekel Zone. It also tries to compare the efficiency of Models for adoption in different situations in the study area. Crop water requirement and irrigation scheduling of maize in the study area were estimated using the CropWat Model based on soil, crop, and meteorological data. However, AquaCrop Model was based on soil, crop, and meteorological data including Co_2, groundwater, field management, and fertility management condition. From the study, it was observed that the maximum reference evapotranspiration in the study area was found to be 7.1 mm/day in Guba and the minimum reference evapotranspiration was 2.9 mm/day in the Bullen district. The maximum ETo in all districts was found to in March and the lowest in August. The maximum ETc of maize was found to be 702.4mm in the Guba district and the minimum ETc was found to be 572.6mm in Bullen district using CropWat but the effective rainfall for maize was determined as 185mm in the Wembera district. However, using the AquaCrop Model the maximum ETc of 565 mm was recorded in Guba but 425 mm was recorded as a minimum in the Wembera district for irrigated maize in the study area. From the study, it was observed that irrigation scheduling with a fixed interval of 10 days with 12 irrigation events performed best. Moreover, the result revealed that there was a strong relationship and a significant relation between the simulated and observed values for validation. The model performance indicators showed that AquaCrop Model was well simulated in all parameters considered. Therefore, AquaCrop Model was found to be the most suitable soil-water-crop-environment management Model. So future studies should focus on addressing deficit irrigation strategy with different field management conditions to improve agricultural water productivity under irrigated agriculture for the study area for major crops.

Keywords: AquaCrop, Deficit Irrigation, Depilation, Fixed interval, Irrigation events.

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1. INTRODUCTION

The demand for water has been the main limiting factor for crop production in much of the world where rainfall is not ample. The ever-increasing human population demands for a large quantity of crop yield (Lutaladio *et al*., 2009). Sustaining this population will require increased production of all crops. There is also a limited amount of arable land and the resources to produce food are becoming scarcer. As the population rises, the land will be scarce for agriculture. In other words, increased production comes from increased yields (Milander, 2015). Irrigation implies the application of water to crops in the right amount at the right time (FAO, 2005). Irrigation scheduling is important for developing best management practices for irrigated areas (Ali *et al*., 2011). There is considerable scope for improving water use efficiency for crops by proper irrigation scheduling governed by crop evapotranspiration (FAO, 1998). Allen *et al*., (1998) suggested that crop coefficient values need to be derived empirically from lysimetric data and local climatic conditions.

In the Metekel zone, almost all farmers are poor in water resource management and lack of experience and knowledge about how much and when to irrigate. Besides, no practices in the application of efficient irrigation water saving-strategies to tackle the shortage of rainfall and dry spell (Dessalegn *et al*., 2015). Therefore, there is a need to improve water use efficiency to obtain more crop production per drop of water with declining irrigation resources and uncertainty in the temporal and spatial distribution of rainfall. Among many, one of the mechanisms or strategies to improve crop productivity per unit of water under full irrigation is the use of Models to fill the gaps during dry spells (FAO, 1990). It was reported that crop water requirement and irrigation scheduling were determined by using CropWat for various crops in the study area.

The Model simulation is a simplification of the field processes, but it attempts to account for the most important factors that influence the Model's performance. Determination of crop water requirement and irrigation scheduling will provide information that increases water use efficiency and increases the productivity of maize crops in the study area. However, the performance of Models varies from one to another because of various factors. Therefore, evaluation and identification of the best Model for maximizing the efficiency of water use in crop production are unquestionable. Consequently, sustainable and effective utilization of scarce water resources may promote and contribute to poverty alleviation in the area and enhance food security through maximizing crop production of the farmers. The objective of this study was to compare and evaluate ETo, crop water requirement and irrigation scheduling for maize using CropWat and AquaCrop. Moreover, to recommend a better model that could be used to improve water productivity for sustainable agricultural production in the study area.

2. MATERIALS AND METHODS

2.1. Description of the study area

The study was conducted in the Metekel zone of Benishangul Gumuz Regional State, North-West of Ethiopia. It is the largest zone of the region covering an area of 3.3 million hectares. It consists of seven 7 districts: Wombera, Bullen, Manbuk, Debate, Mandura, Guba, and Pawe Woreda. The topography of the zone presents undulating hills slightly sloping down to low land Plateaus plateaus having varying altitudes from 600- 2800 m.a.s.l. The annual rainfall of the area is 900-1580mm. About 80 % of the zone is characterized by having a sub-humid and humid tropical climate (Solomon *et al*., 2014). The annual minimum and maximum temperature of the study area are 20^{o}C and 35^{o}C respectively. The soil type of the study area is characterized by heavy clay soil with an initial soil moisture depletion level range from 111 to 129 (mm/meter depth). The total available soil moisture level ranges 222 to 259 (mm/meter depth) varying with soil depth. The mean infiltration rate is 70 mm/day and the bulk density varies from 1.12 to 1.31gm/cm^{3} at the depth of 1.2 meters (Ashebir and Demeke, 2017). About 96.2% of the farmers practiced mixed crop-livestock production, while only 3.8% were involved in livestock production (Solomon *et al*., 2014).

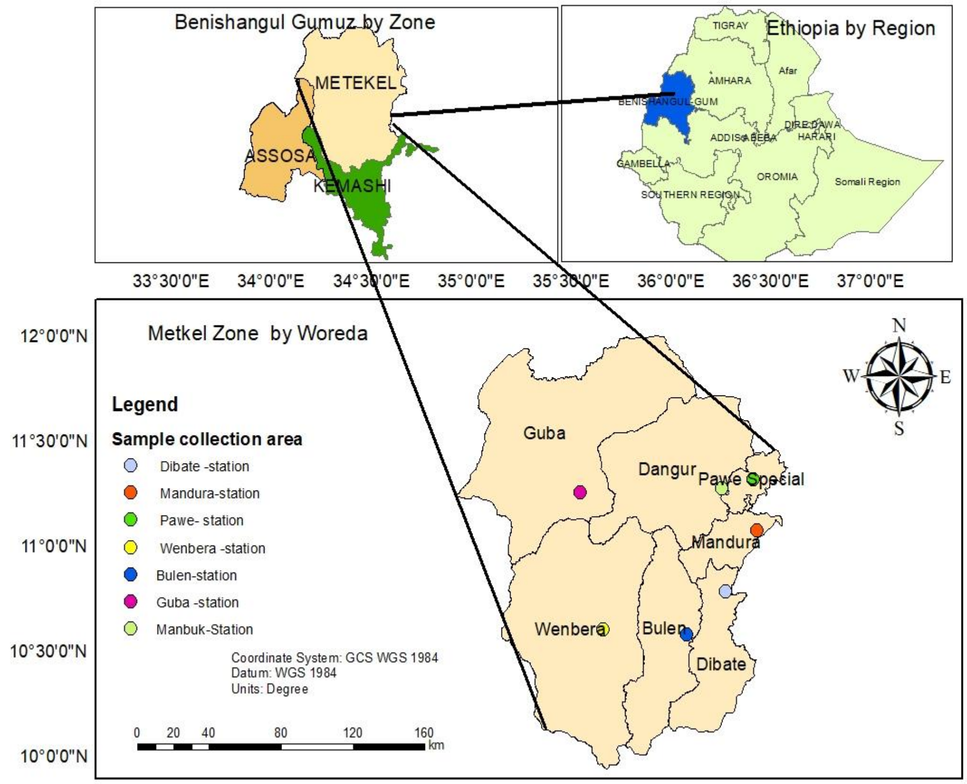

Figure-1: Location map of the study area

2.2. Crop water requirement

2.2.1. Crop and irrigation water requirements using CropWat Model

CropWat 8.0 was used to determine crop water requirement based on monthly ETo values. Besides; rainfall, crop type including cropping calendar and the required soil characteristics of maize were used for the study area. Crop coefficient (Kc) for every growth stage was adapted from Allen *et al*. (1998) whereas ETc was calculated by using equation (1). The irrigation requirement was calculated using equation (2).

$$\mathbf{ETc = ETo * kc} \quad \mathbf{(1)}$$

$$\mathbf{NIR = ETc - Pe} \quad \mathbf{(2)}$$

Where**,** ETc = crop evapotranspiration (mm), ETo = reference evapotranspiration (mm), Kc = crop factor, NIR = net irrigation water requirement (mm), ETc = crop water requirement (crop evapotranspiration) (mm), Pe = effective rainfall (mm).

The amount of water applied during an irrigation event (gross irrigation) was equal to the net irrigation required between irrigations and that needed for efficiencies in the irrigation system. In this study, water was assumed to be applied with precise measurements. As a result, there was no run-off and the only loss would be deep percolation and evaporation. Therefore, a higher value of application efficiency (60%) was adopted.

GIR =NIR / Ea **(3)**

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

2.2.2. Crop and irrigation water requirements using AquaCrop Model

As there was no shallow groundwater table, hence all stress indicators such as waterlogging stress, water shortage stress, air temperature stress, soil salinity stress) were assumed to be zero. Besides, no specific field management was considered. Then the net irrigation requirement and crop water requirement for furrow irrigation were calculated. The simulation period was adjusted and the soil water profile at % of RAW was considered as an initial condition without field observation..

To all test crops, crop evapotranspiration was calculated by multiplying the reference evapotranspiration (ETo) with the crop transpiration coefficient (KcTr). The water stress coefficient (Ks) is 1 when water stress does not induce stomatal closure. Crop transpiration was calculated using the following formula;

$$\mathbf{Tr = Ks * K_{cT}r * ETo} \qquad \mathbf{(4)}$$

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

The crop transpiration coefficient K_{cTr} was proportional to the green canopy cover (CC) as indicated by the following parameter:

$$\mathbf{K_{cTr} = K_{cTr,x} * K_c\ CC^{**}} \quad \textbf{(5)}$$

Where K_{cTr}, x is 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 depletion (% RAW) below which the soil water content in the root zone may not drop (0 % RAW corresponds to Field Capacity). The total amount of irrigation water required to keep the water content in the soil profile above the specified threshold was the net irrigation water requirement for the period. The net requirement didn't consider extra water that had to be applied to the field to account for conveyance losses or the uneven distribution of irrigation water on the field.

2.3. Irrigation scheduling

2.3.1. Irrigation scheduling using CropWat Model

Irrigation scheduling was worked out using CropWat 8.0 windows by selecting two scheduling criteria: fixing the interval and adjusting the depth to a constant value for no yield reduction and minimum water loss and 100% readily available soil moisture depletion.

2.3.2. Irrigation scheduling using AquaCrop Model

Generation of irrigation schedules using AquaCrop Model was computed by specifying back to field capacity and fixed net application depth criterion and fixed interval and allowable depletion (% of RAW) time criteria. By selecting the furrow irrigation method, irrigation events (when to irrigate and how much to irrigate) had been specified by considering irrigation water quality for maximum dry yield production and water productivity and minimum labor cost (irrigation event). The electrical conductivity (EC) of the irrigation water was used as an input to irrigation scheduling. However; in some cases, drainage water or other low-quality water might be used as an irrigation water source in the model. However, the input to the model depends on the accuracy of the lab analysis result.

2.4. Model calibration and simulations

After all, input data encoded - climatic, crop, management, and soil characteristics that described or defined the environment in which the crop was developed. Before the simulation, the simulation phase and the initial conditions at the beginning of the simulation were determined.

The user can track changes in the soil water and corresponding changes in the crop development, soil evaporation, transpiration, (ET) rate, biomass production, and yield when running simulation results of the simulation were stored in output files in spreadsheet format to retrieve the data for further processing and analysis. Furthermore, program settings permit the user to change default settings and reset to an individual’s default values once more.

Model Calibration for several crops was presented by Farahani *et al*., (2009); Garcia *et al.*, (2009); Geerts *et al*., (2009) Hsiao *et al*. (2009) and Heng *et al.* (2009) shown the AquaCrop Model performed well. The observed data set from the non-water stress conditions (that is full 100% ETc irrigation treatment) used for Model calibration. The observed crop characteristics namely; time to emergence, time to attain maximum canopy cover, time to flowering, and senescence and physiological maturity (in calendar days) were used. After the calibration process, the Model was validated from separated other treatment data except for 100% ETc (Yibrah *et al*., 2015).

2.5. Performance evaluation of Models

The output of a Model depends on the principle of the Model itself and the accuracy of the input data. Evaluation of Model performance should include both statistical criteria and graphical display. A Model is a good representation of reality only if it predicts an observable phenomenon with acceptable accuracy and precision (League and Green, 1991). Addicott and Whitmor (1987) concluded that any one method of measuring discrepancy between Model output and observed data alone might be misleading, but several methods used together could summarize the closeness of a Model’s estimates and measurements with the observed values. The following statistics and Model performance indicators were used to indicate overall Model performance: root mean square error

(RMSE), root mean square error normalized (RMSEN), Nash-Sutcliffe efficiency index (NSE), Model efficiency (ME), and prediction error (Pe) (Ali *et al*, 2004; Loague and Green, 1991).

Table-1: Statistical performance indicator of Models

No	Statistical indictors	Formulas	Agreements
1	Root Mean Square Error (RMSE)	RMSE= $\sqrt{\sum \frac{(Si-Oi)^2}{N}}$	It ranges from 0 to 1 the value 0 indicating good and the value 1 indicating poor Model performance.
2	Normalized Root Mean Square Error (NRMSE)	RMSEN= $\frac{1}{Oi}\sqrt{\sum \frac{(Si-Oi)^2 * 100}{N}}$	A Model can be considered excellent if NRMSE is <10%, good if between 10 and 20%, fair if between 20 and 30% and poor if >30 (Yibrah, 2015).
3	Nash-Sutcliffe Efficiency (NSE)	NSE= $1 - \frac{\sum_{i=1}^{N}(si-oi)^2}{\sum_{i=1}^{N}(oi-mo)^2}$	A plot of observed data versus simulated is that to fits the 1:1 line indicates a perfect match between the Model and the observations (Moriasi, et.al., 2007). A negative NSE occurs when the mean of the observations is a better prediction than the Model.
4	Model Efficiency (ME)	ME= $\frac{\sum_{i=1}^{N}(oi-\mathrm{mo})^2 - \sum_{i=1}^{N}(si-oi)^2}{\sum_{i=1}^{N}(oi-mo)^2}$	It acquires values from infinite negative to 1. The closer it gets to 1, the higher the robustness of the Model (Loague and Green 1991).
5	Prediction error (Pe)	Pe= $\frac{(\mathrm{Si}-\mathrm{Oi})}{\mathrm{Oi}} * 100$	Pe used to define the robustness of the Model as well as to predict the values. When Pe, approaches zero, they represent positive indicators of Model performance and used to evaluate the Model prediction error.

3. RESULTS AND DISCUSSION

3.1. Reference Evapotranspiration (ETo) of the study area

Long -term climatic data of the study area were analyzed and reference evapotranspiration (ETo) was calculated based on the FAO Penman-Monteith method (Allen *et al*., 1998) and the results are given in Figure-2.

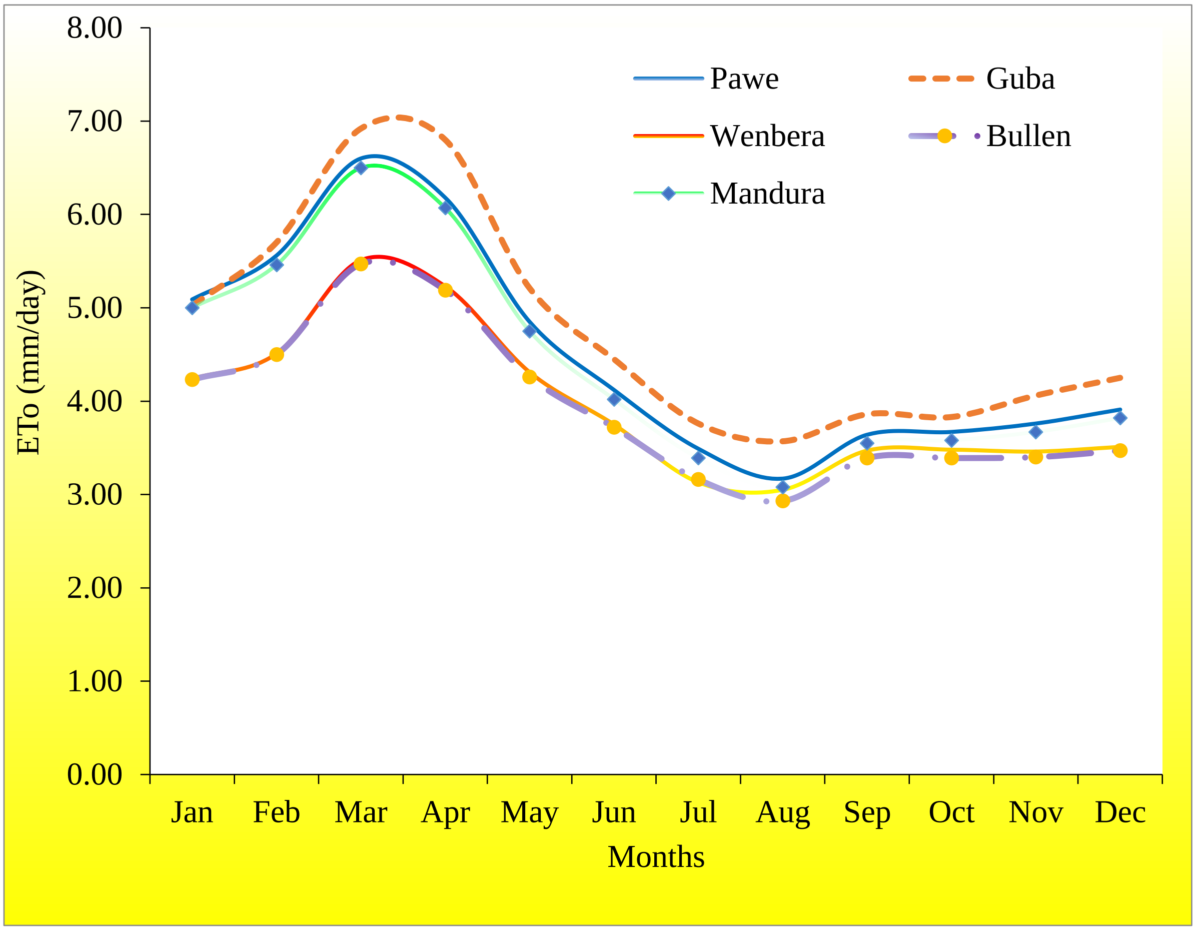

Figure- 2: Long term evapotranspiration (ETo) of the study areas (1987-2011)

As shown in Figure-2, the average ET_O value simulated using CropWat in the Pawe district was found to be 4.50 mm/day. The maximum value of ET_O was found to be 6.60 mm/day in March and the minimum ET_O was 3.17mm/day in August. The average ET_O value simulated using CropWat in the Mandura district was 4.51 mm/day. The average ET_O value simulated using AquaCrop in the Mandura district was 4.13 mm/day. The average ET_O value simulated using CropWat in the Guba district was found to be 4.79 mm/day. The maximum value of ET_O was found to be 6.92 mm/day in March and the minimum ET_O was 3.57 mm/day in August.

The average ET_O values simulated using CropWat in the Bullen district were found to be 3.93mm/day. The maximum values of ET_O were 5.47 mm/day in March and the minimum was 2.93 mm/day in August using CropWat.The average ET_O value simulated using CropWat in the Wembera district was found to be 3.97 mm/day. The maximum value of ET_O was found to be 5.51 mm/day in March and the minimum was 3.05 mm /day in August.

Table-2: Comparison of CropWat (CW) and AquaCrop (AqC) daily ETo (mm/day) of the study areas

Months	Pawe		Mandura		Guba		Bullen		Wombera	
	CW	AqC	CW	AqC	CW	AqC	CW	AqC	CW	AqC
January	5.09	5.20	5.00	4.00	5.02	5.10	4.23	4.30	4.24	3.20
February	5.56	5.70	5.46	5.10	5.70	5.90	4.50	4.60	4.51	4.00
March	6.60	6.80	6.50	6.30	6.92	7.10	5.47	5.60	5.51	5.20
April	6.18	6.20	6.07	6.10	6.80	6.90	5.19	5.20	5.23	5.20
May	4.85	4.70	4.75	4.80	5.21	5.10	4.26	4.20	4.31	4.30
June	4.12	4.00	4.02	4.10	4.45	4.30	3.72	3.60	3.75	3.80
July	3.49	3.40	3.39	3.50	3.76	3.70	3.16	3.10	3.13	3.20
August	3.17	3.20	3.08	3.20	3.57	3.60	2.93	2.90	3.05	3.10
September	3.64	3.70	3.55	3.50	3.86	3.90	3.39	3.40	3.47	3.30
October	3.67	3.70	3.58	3.30	3.83	3.80	3.39	3.40	3.48	3.10
November	3.76	3.70	3.67	2.90	4.06	4.10	3.40	3.40	3.46	2.60
December	3.91	3.90	3.82	2.70	4.25	4.30	3.47	3.50	3.51	2.40

As shown in Table-2, the average ET_O value simulated using AquaCrop *in Pawe* was found to be 4.52 mm/day. The maximum value of ET_O was found to be 6.80 mm/day in March and the minimum ET_O was 3.2 mm/day in August. The relative difference between average ETo values simulated using CropWat and AquaCrop was found to be small which was 0.02 mm/day. The climate parameters were collected from the Pawe Agricultural Research Center metrology station located at longitude 36.05^0 East, latitude 11.15^0 North, and altitude of 1120 meters above sea level.

The maximum value of ET_O in *Mandura* using AquaCrop, was 6.30 mm/day in March and the minimum ET_O was 3.20 mm/day in August. The relative difference between average ETo values simulated using CropWat and AquaCrop was found to be 0.38 mm/day. The climate parameters were collected from *Mandura* District Metrology Station located at longitude 36.32^0 East, latitude 11.06^0 North, and altitude of 1161 meters above sea level.

The average ET_O value simulated using AquaCrop was found to be 4.82 mm/day in the *Guba* district. The maximum value of ET_O was 7.1 mm/day in March and the minimum ET_O was 3.6 mm/day in August. The relative difference between average ETo values simulated using CropWat and AquaCrop was found to be 0.03 mm/day. The climate parameters were collected from the Guba distric*t* metrology station that was located at a longitude of 35.40^0 East, the latitude of 11.05^0 North, an altitude of 977 meters above sea level.

The average ET_O values simulated by AquaCrop in the Bullen district were found to be 3.93 mm/day. There was no difference between ET_O average values simulated using CropWat and AquaCrop. The maximum values of ET_O using AquaCrop and the maximum values of ET_O was 5.6 mm/day in March and minimum was 2.9mm /day in August, The climate parameters were collected from the Bullen district metrology station that was located at the longitude of 36.96^0 East, the latitude of 10.50^0 North, an altitude of 1323 meter above sea level.

The average ET_O value simulated using AquaCrop in the *Wembera* district was found to be 3.62 mm/day. The maximum values of ET_O were 5.2 mm/day in March and the minimum was 3.10 mm /day in August. The relative difference between average ETo values simulated using CropWat and AquaCrop was found to be 0.35 mm/day. The climate parameters were collected from Debre Zeit Metrology Station that was located at a longitude of 36.96^0 East, a latitude of 10.50^0 North, and an altitude of 1323 meters above sea level.

As General, the maximum reference evapotranspiration in the study area estimated using CropWat was found to be 6.92 mm/day in Guba, and minimum reference evapotranspiration was found to be 2.93 mm/day in the Bullen district. The maximum reference evapotranspiration in the study areas simulated using AquaCrop was found to be 7.1 mm/day in Guba and minimum reference evapotranspiration was found to be 2.9 mm/day in the Bullen district.

3.2. Irrigation water requirement

3.2.1. Irrigation water requirement of maize using CropWat Model

As shown in Table 3, since there was no determined crop coefficient, rooting depth, critical depletion, and yield response factor, so far for this area, the FAO recommended values for growth stages were used to calculate CWR and make irrigation scheduling. The local planting date of the crops was used for the computation.

Table-3: Crop characteristics and input data used for CropWat

Crop characteristics	**Growing stages**				**Total**
	Initial	**Development**	**Mid**	**Late**	
Kc	0.45		1.2	0.85	
Stages	20	35	40	30	125
Maximum rooting depth(m)	1.2		1		
Critical depletion (fraction)	0.55	0.55		0.8	
Yield response factor	0.4	0.4	1.3	0.5	1.25
Maximum crop height (m)		2			

Table-4: Simulated ETc and IR of maize in the study areas using CropWat

District	**ETc (mm)**	**ER (mm)**	**IR (mm)**
Pawe	680.4	12.4	667.5
Mandura	680.3	15.2	664.3
Guba	702.4	10.3	690.8
Bullen	572.6	21.3	539.9
Wembera	576.5	185	393

* ETC=Crop water requirement, ER =Effective rainfall, IR= Irrigation requirement

As shown in Table 4, the maximum seasonal irrigation requirement of maize was found to be 690.8 mm in the Guba district and a minimum irrigation requirement of 393 mm in the Wombera district. A relatively high amount of the required water was obtained by rain that occurred in December, January, February, and March in the Wembera district since this area was located at a high altitude and rainfall area. Seasonal effective rain (Pe) was185mm in the Wembera district. In Abshege Woreda, Gurage Zone, Ethiopia, the crop water requirement of maize was 423 mm depth of water for a growing period of 140 days was estimated using CROPWAT 8.0, while 101 mm would be required as supplementary irrigation depth (Solomon Abirdew *et al*, 2018). The total crop water requirement of maize was 535.60 mm in Tepi, Southwest of Ethiopia (BiniamYaziz and Tesfaye Tefera, 2016).

3.2.2. Irrigation Water Requirements of maize using the AquaCrop Model

Table-5: Crop characteristics & input parameters used as input for AquaCrop

Crop characteristics	**Descriptions**	**Input Parameter**
Initial canopy	Initial canopy cover (%)	0.29
	Canopy size seedling (c.m2/plant)	6.5
	Plant density (plants/ha)	44,444
Development	Maximum canopy cover (%)	90
	From day 1 after sowing to emergence (day)	8
	Maximum canopy(day)	50
	Senescence (day)	95
	Maturity (day)	125
Flowering and yield formation (root/tuber formation)	Length building up of harvest index (day)	52
	Duration of flowering (day)	13
	From day 1 after sowing to flowering(day), yield formation	68
Root deepening	Maximum effective root depth (m)	1.2
	From day 1 after sowing to maximum root depth (day)	97
	Average root zone expansion (cm/day)	1.1

As shown in Table 5, some characteristics of maize used as input for the AquaCrop Model were adopted from the reference manual developed by (Dirk *et al*., 2009) with minimum calibration.

Input parameters and characteristics for pepper ewere adopted from (John B., 2015) with minimum calibration. Most of the onion characteristics were also taken with minimum calibration as it has been reported by Marta , (2013).

Table-6: Simulated NIR, WP, and DY of maize in the study areas using AquaCrop

Parameters	**Districts**				
	Pawe	***Mandura***	***Guba***	***Bullen***	***Wombera***
NIR (mm)	673.1	569	618	548.8	309
ETC (mm)	593.9	502.1	565	484.6	425
DY (ton/ha)	11.349	12.013	12.013	11.738	12.167
WP (kg/m^3)	1.97	2.47	2.18	2.51	2.98
ETo (mm)	678.4	570.8	705.3	565.5	467.8
Rain (mm)	12.3	15	12.5	23.5	196.7

**Net=net irrigation requirement, ETc=CropWater requirement, DR=dry yield, Wp=water productivity, ETo=reference evapotranspiration.*

As shown in Table 6, the maximum net requirement of maize was found to be 673 mm in the Pawe district and the minimum net irrigation requirement was found to be 309 mm in the Wembera district.

3.4. Irrigation scheduling of maize under different districts

3.4.1. Irrigation scheduling of maize using CropWat Model

To carry out irrigation scheduling for selected crops using the CropWat Model has different options. These were irrigating at fixed intervals per stage time, irrigate at 100% critical depletion, and refill soil to 100% field capacity depth criteria. However, based on the research evidence and field data available in the study area irrigate at fixed intervals per stage time criteria was used. An irrigation efficiency of 60% was selected since the main irrigation application methods for the area is surface irrigation especially furrow irrigation.

Table-7: Irrigation scheduling of maize in the study area using irrigation at a fixed interval

Date	Stage	Pawe		Mandura		Guba		Bullen		Wombera	
		NIR (mm)	GIR (mm)	NIR (mm)	GIR (mm)	NIR (mm)	GIR (mm)	NIR (mm)	GIR (mm)	NIR (mm)	GIR (mm)
10-Dec	Initial	40.2	67	33.6	56	29.7	49.5	32.4	53.9	26	43.4
20-Dec	Initial	28.3	47.2	26.6	44.3	27.9	46.6	24.1	40.2	13.6	22.7
30-Dec	Dev	35.4	59	33.6	56	34.2	57.1	29.5	49.1	18	30.1
9-Jan	Dev	46.1	76.8	44.1	73.4	43.8	73	37.4	62.4	26	43.3
19-Jan	Dev	58.6	97.7	56.6	94.3	54.4	90.6	47.2	78.6	36.9	61.5
29-Jan	Mid	64.8	108	63.7	106.2	61.9	103.1	51.9	86.5	39.4	65.6
8-Feb	Mid	65.6	109.3	65.2	108.6	63.8	106.3	52.3	87.1	37.2	62.1
18-Feb	Mid	67.7	112.8	67.2	112	65.8	109.7	53.6	89.3	37.5	62.5
28-Feb	Mid	70.8	118	70.3	117.2	68.5	114.2	56.7	94.4	41.6	69.3
10-Mar	End	74.8	124.7	75.2	125.3	72.7	121.1	62.1	103.5	47.6	79.3
20-Mar	End	71.8	119.6	72.6	120.9	74.2	123.7	60.8	101.4	47.2	78.6
30-Mar	End	59.5	99.1	58.9	98.1	63.6	105.9	48.4	80.7	38.4	64.1
Total		**684**	**1139**	**668**	**1112**	**661**	**1101**	**556**	**927.1**	**409**	**683**

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

As shown in Table 7, irrigation scheduling of maize in under the study areas using the fixed interval (10 days) per stage time criteria and refill soil to field capacity depth criteria had 12 irrigation events. The maximum gross and net irrigation requirements were 1139 mm and 684 mm respectively with no yield reduction was recorded in the Pawe district. However, the minimum (683 mm and 409 mm) were recorded in the Wombera district. Besides, the highest yield reduction (4.4%) was observed in the Guba district. This was due to the sandy soil texture of the area and the area need an irrigation schedule using short irrigation intervals and a small amount of water. Therefore, an irrigation interval of less than 10 days could be used by considering labor cost to reduce yield reduction. Research conducted in Vertisol in Metekel Zone, North-West of Ethiopia during the summer seasonal (January to May) indicated that CWR, IR, NIR, and GIR requirements of maize with total growth stages of 125 days were found to be 502 mm,486.8 mm 478.5 mm and 651.1 mm respectively and relatively high yield was recorded using irrigating at a fixed interval of 14 days per stage time criteria and refill soil to field capacity depth criteria. (Ashebir and Demeke, 2017).

3.4.2. Irrigation scheduling of maize using the AquaCrop Model.

Generating irrigation schedules is a practical mode for planning or evaluating a potential irrigation strategy. In this mode, AquaCrop will generate at run time irrigations according to the specified time and a depth criterion.

Table-8: Irrigation scheduling of maize in the study area at a fixed interval

Irrigation event	DAP	NAD (mm)					EC_W (ds/m)
		Pawe	*Mandura*	*Guba*	*Bullen*	*Wembera*	
1	10December	27.6	43.2	32.8	46.2	38.2	0.4
2	20 December	25.5	32.2	21.7	35.3	21.2	0.4
3	30 December	25.2	29.4	25.2	36.3	18.9	0.4
4	9 January	46.3	43.9	43.8	46.7	23.8	0.4
5	19 January	54.4	49.5	56.6	50.9	26.9	0.4
6	29 January	55.8	52.6	60.2	52.1	30.3	0.4
7	8 February	55.8	54.7	61.6	52.2	30.4	0.4
8	18 February	56.7	56.7	62.9	52.8	31.1	0.4
9	28 February	57.5	58.7	64.5	53.8	30.5	0.4
10	10 March	61.8	60.6	66.9	56.5	36.3	0.4
11	20 March	51.9	46.6	51	41.7	32.1	0.4
12	30 March	26.6	24.1	20.3	19.3	17.5	0.4
IR (mm)		655.1	552.3	567.5	534.8	337	
Rain (mm)		12.3	15	12.5	23.5	196.7	
ET_O (mm)		678.4	570.8	705.3	565.5	467.8	
DY (T/ha)		11.883	11.858	11.803	11.635	11.736	
Wp (kg. /m^3)		2.21	2.65	2.43	2.69	2.94	

*DAP=Days After Planting, NAD=Net application depth, IR=Irrigation requirement, ET_O =Reference evapotranspiration, DY= Dry yield, WP= water productivity, EC_{W}=Electrical conductivity of irrigation water.

As shown in Table 8, a fixed interval of 10 days and refill soil to field capacity depth criterion was selected. It had 12 irrigation events. The simulation indicated CWR of 655.1, 552.3, 567.5, 534.8 and 337 mm, 11.643, 11.858,11.803, 11.635, and 11.736 t/ha of maize can be produced in *Pawe, Mandura, Guba, Bullen, and Wembera* respectively. In Bushland the study that was conducted in 1989 shows that crop water requirement of maize simulated using AquaCrop was 598.0 mm in areas where measured crop water requirement of maize was 625.0 mm and in 1990 crop water requirement of maize simulated using AquaCrop was 730.8 mm in areas where the measured value was 778.3 mm. (Lee kheng Heng *et al*., 2009). During the 'driest' year, seasonal (March to mid-September) rainfall (138 mm) and ETo (682 mm) resulted in irrigation needs of onion in were found to be 286 mm and 360 mm for the sandy and sandy loam soils, respectively (Marta P., 2013).

3.5. Performance Evaluation of Models

Considering the districts as several observations RMSE values of maize when simulating crop water requirement was found to be 133.5. Considering the number of irrigation events as a some observations, the magnitude of root means square errors when simulating irrigation scheduling for maize in each irrigation event was found to be 4.09, 4.39, 4.26, 5.17, 3.12 in *Pawe, Mandura Guba Bullen,* and *Wembera* respectively as annexed under Table-1and 2.

Considering the districts as several observations RMSEN values of maize were found to be 20.74% and lied between 20% and 30 % when simulating crop water requirements and thus simulation was reasonable as indicated in section 2.5. When simulating irrigation scheduling for maize in each irrigation event, the magnitudes of all RMSEN values of maize were found to 7.18%, 7.88%, 7.74%, 9.08%, 9.13% in Pawe, Mandura, Guba, Bullen, and Wembera respectively. All values lied less than 10% and simulation was excellent in each district as annexed under table 2. The simulation was considered excellent if RMSEN was less than 10%; it would be good if it came between 10% and 20%; reasonable when it lied between 20% and 30%, and poor, if it was greater than 30% (Jamieson *et al*., 1991).

Nash-Sutcliffe efficiency index (NSE) total crop water requirements simulation was found to be 0.98 (i.e. close to one). This meant the Model simulation was in an acceptable range. The relative magnitude of the residual variance compared to the variance of the observations was small. When simulating irrigation scheduling for maize in each irrigation event, the magnitude of NSE to 0.1,0.12, 0.16, -0.44, -0.08 in *Pawe, Mandura, Guba, Bullen, and Wembera* respectively (annexed in table 1 and 2). All values were close to one and the simulation was accurate.

A magnitude of Model Efficiency (ME) simulation of irrigation scheduling for each event was found to be 0.1,0.12, 0.16, -0.44, and -0.08 in Pawe, Mandura, Guba, Bullen, and Wembera districts, respectively. The negative value of Model efficiency indicated overestimation, but positive values indicated underestimation. Ideally, Model efficiency (ME) would be zero. The Model efficiency of maize was 0.98 when simulating crop water requirements. When Pe approached zero, it represented positive indicators of model performance and are used to evaluate the Model prediction error. Pe was used to define the robustness of the Model as well as predict the values. when simulating total crop water requirements, Pe values of maize were found to be -0.13, -0.26, -0.19, -0.15, and -0.26 in Pawe, Mandura, Guba, Bullen, and Wembera respectively. when simulating total crop water requirements, Pe values, however, were found to be -0.2, -0.17, -0.14, -0.2, and -0.17 in Pawe, Mandura Guba Bullen, and Wembera, respectively (annexed in Table 1 and 2).

4. CONCLUSIONS AND RECOMMENDATIONS

This study was aimed at comparing estimation methods of crop water requirement and irrigation scheduling for major crops using different models and comparing the significance of Models for adoption at different situations in the Metekel Zone. It was observed that the maximum reference evapotranspiration in the study area was found to be 7.1 mm/day in Guba and the minimum reference evapotranspiration was 2.9 mm/day in the Bullen district. In all cases, the maximum ETo in all districts was found to be in March and the low in August. The maximum ETc was found to be 702.4mm in the Guba district and the minimum ETc was found to be 572.6mm in Bullen district using CropWat but the effective rainfall (Pe) was determined as 185mm in the Wembera district. However, using the AquaCrop Model the maximum ETc recorded for maize was 565 mm in *Guba* but a minimum of 425 mm, was recorded in the *Wembera* district. The study revealed that the irrigation scheduling with a fixed interval criterion for maize 10 days with 12 irrigation events has been determined. It was observed that there was a strong and significant relationship between the simulated and observed values for validation. Hence, Normalized Root Mean Square Errors (NRMSE), Model by Nash-Sutcliffe efficiency (NSE), Prediction error (Pe), and Model efficiency (ME) showed that the Model was well simulated in all parameters considered as it was annexed under table-1 and 2.

Irrigation scheduling using the AquaCrop Model was found to improve water productivity in this study. Thus, it was recommended to use the AquaCrop Model in the development plan through developing appropriate packages and extension guidelines in agricultural water management. It was recommended also that farmers and end-users should adopt fixed irrigation intervals for irrigated maize in the study area to save water, time, labor, and energy during irrigation.

REFERENCES

Addicott, T.M. and Whitmor, A.P. 1987. Computer simulation of changes in soil mineral nitrogen and crop nitrogen during autumn, winter, and spring. J. Agric. Sci. Cambridge, 109: 141-157.

Ali, M.H., Amin, M.G.M. and Islam, A.K.M.R. 2004. Comparison of various methods for estimating reference crop evapotranspiration. J. Bangladesh Agril, Uni. 2(2): 313-324.

Ali, M.H., Paul, H. and Haque, M.R. 2011. Estimation of evapotranspiration using a simulation Model. *J. Bangladesh Agril. Univ*, 9(2): 257–266.

Allen, R.G., Periera, L.S., Raes, D. and Smith, M. 1998. Crop evapotranspiration. Guidelines for computing crop water requirements (FAO Irrigation and Drainage Paper no. 56, p. 300). Rome.

Ashebir Haile and Demeke Tamene. 2017. Determination of Optimum Irrigation Scheduling and Water Us Efficiency for Maize Production in North-West Ethiopia. Journal of Natural Sciences Research, volume. 7. no. 21. PP 22-27.

Biniam Yaziz and Tesfaye Tefera . 2016. Determination of Optimal Irrigation Scheduling for Maize (Zea mays) at Teppi, Southwest of Ethiopia. International Journal of Research and Innovations in Earth Science Volume 3, Issue 5, ISSN (Online): 2394-1375.

Dessalegn, Dagnew C, Guzman, Christian D, Zegeye, Assefa D, Tibebu, Tigist Y, Getaneh, Menelik, Abate, Solomon, Steenhuis, Tammo S. 2015. Impact of conservation practices on runoff and soil loss in the sub-humid Ethiopian Highlands: The Debre Mawi watershed. Journal of Hydrology and Hydromechanics, 63(3), 210-219.

Dirk RAES, Pasquale STEDUTO, Theodore C. HSIAO, and Elias FERERES. 2009. calibration and validation of crops. reference manual. Reference Manual, Annexes – AquaCrop,

FAO (Food and Agriculture Organization). 2005. Irrigation water requirements: Irrigation Potential in Africa: A-Basin Approach, Chapter 5, FAO Corporate Document Repository, FAO, Rome, Italy.

FAO (Food and Agriculture Organization). 1998. Crop evapotranspiration by R. Allen, L.A. Pereira, D. Raes and M. Smith. FAO Irrigation and Drainage Paper No. 56.

FAO (Food and Agriculture Organization). 1990. Crop water information: potato. Accessed at cropinfo_potato.html. Development Division, Rome, Italy. http://www.fao.org.

Farahani, H. J., Izzi, G., & Oweis, T. Y. (2009). Parameterization and evaluation of the AquaCrop Model for full and deficit irrigated cotton. Agronomy Journal, 101(3), 469-476.

García-Vila, M., Fereres, E., Mateos, L., Orgaz, F., & Steduto, P. 2009. Deficit irrigation optimization of cotton with AquaCrop. Agronomy Journal, 101(3), 477-487.

Geerts, S., Raes, D., Garcia, M., Miranda, R., Cusicanqui, J. A., Taboada, C., ... & Mamani, J. 2009. Simulating yield response of quinoa to water availability with AquaCrop. Agronomy Journal, 101(3), 499-508.

Heng, L. K., Hsiao, T., Evett, S., Howell, T., & Steduto, P. 2009. Validating the FAO AquaCrop Model for irrigated and water-deficient field maize. Agronomy Journal, 101(3), 488-498.

Hsiao, T.C., L.K., Heng, P., Steduto, B. Rojas-Lara, D. Raes & E. Fereres. 2009. AquaCrop-The FAO crop Model to simulate yield response to water: III. Parameterization and testing for maize. Agron. J.101: 448-459.

Jamieson, P. D., Porter, J. R., & Wilson, D. R. 1991. A test of computer simulation Model ARC-WHEAT 1 on wheat crops grown in New Zealand. Field Crops Research,

John B. Zayzay, Jr. 2015. validation of the FAO AquaCrop Model for irrigated hot pepper (capsicum frutescens var legon 18) in the coastal savannah ecological zone of Ghana. A Thesis Submitted to the Department of Agricultural Engineering, School of Agriculture, College of Agriculture and Nature Sciences, University of Cape Coast.

Lee,K. H.,Theodore, H., Steve E.,Terry, H., And Pasquale, .2009. Validating The FAO AquaCrop Model for Irrigated and Water Deficit Field Maize. Agronomy Journal, Volume 101, Issue 3: pp 488-498.

Loague, K. and Green, R.E. 1991. Statistical and graphical methods for evaluating solute transport Models: Overview and application. J. Contam. Hydrol, 7: 51-73.

Lutaladio, N., Ortiz, O., & Caldiz, D. (2009). Sustainable potato production. Guidelines for developing countries. Food and Agriculture Organization.

Marta Perez Ortola. 2013. Modeling the impacts of in-field soil and irrigation variability on onion yield. School of applied science.

Milander J., Charles Wortmann, Charles Shapiro1, Tim Shaver, Micael Mainz. 2015. Soil Test P Level and Tillage Effect on Corn Yield.

Moriasi, D. N., Arnold, J. G., Van Liew, M. W., Bingner, R. L., Harmel, R. D., & Veith, T. L. .2007. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Transactions of the ASABE, 50(3), 885-900.

Solomon Zewdu Altaye, Binyam Kassa, Bilatu Agza, Ferede Alemu and Gadisa Muleta. 2014. Smallholder cattle production systems in Metekel zone, Northwest Ethiopia. Research Journal of Agriculture and Environmental Management. Vol. 3(2), pp. 151-157.

Yibrah G, Araya B, Amsalu N. 2015. Performance of AquaCrop Model in Predicting Tuber Yield of Potato (Solanum tuberosum L.) under Various Water Availability Conditions in Mekelle Area, Northern Ethiopia. Journal of Natural Sciences Research www.iiste.org ISSN 2224-3186 (Paper) ISSN 2225-0921 (Online) Vol.5, No.5, World Scientific News 12 (2015) 100-110.

APPENDICES

Table-1. Performance Evaluation of Models to Simulate CWR for maize in different districts.

District	Si	Oi	(Si-Oi)	(Si-Oi)/Oi	(Si-Oi)^2	(Oi- $\bar{Oi}$)	(Oi- $\bar{Oi}$)^2
Pawe	593.9	680.4	-86.5	-0.12713	7482.25	37.96	1440.962
Mandura	502.1	680.3	-178.2	-0.26194	31755.24	37.86	1433.38
Guba	565	702.4	-137.4	-0.19562	18878.76	59.96	3595.202
Bullen	484.6	572.6	-88	-0.15368	7744	-69.84	4877.626
Wenbera	425	576.5	-151.5	-0.26279	22952.25	-65.94	4348.084
Sum	2570.6	3212.2	-641.6	-1.00116	88812.5	37.96	6603666
Mean	514.12	642.44	-128.32	-0.20023	17762.5	37.86	1440.962
RMSE			**133.5**				
NRMSE (%)			**20.7**				
NSE			**0.98**				
ME			**0.99**				
Pe			**-0.2**				

Table-2. Performance Evaluation of Models to Simulate Irrigation Scheduling of maize under different districts of study areas.

Maize	**Pawe**			**Mandura**			**Guba**			**Bullen**			**Wombera**		
DAP	**Oi**	**Si**	**$(Si-Oi)^2$**	**Oi**	**Si**	**$(Si-Oi)^2$**	**Oi**	**Si**	**$(Si-Oi)^2$**	**Oi**	**Si**	**$(Si-Oi)^2$**	**Oi**	**Si**	**$(Si-Oi)^2$**
10-Dec	40.20	27.60	158.76	33.60	43.20	92.16	29.70	32.80	9.61	40.20	46.20	36.00	26.00	38.20	148.84
20-Dec	28.30	25.50	7.84	26.60	32.20	31.36	27.90	21.70	38.44	28.30	35.30	49.00	13.60	21.20	57.76
30-Dec	35.40	25.20	104.04	33.60	29.40	17.64	34.20	25.20	81.00	35.40	36.30	0.81	18.00	18.90	0.81
9-Jan	46.10	46.30	0.04	44.10	43.90	0.04	43.80	43.80	0.00	46.10	46.70	0.36	26.00	23.80	4.84
19-Jan	58.60	54.40	17.64	56.60	49.50	50.41	54.40	56.60	4.84	58.60	50.90	59.29	36.90	26.90	100.00
29-Jan	64.80	55.80	81.00	63.70	52.60	123.21	61.90	60.20	2.89	64.80	52.10	161.29	39.40	30.30	82.81
8-Feb	65.60	55.80	96.04	65.20	54.70	110.25	63.80	61.60	4.84	65.60	52.20	179.56	37.20	30.40	46.24
18-Feb	67.70	56.70	121.00	67.20	56.70	110.25	65.80	62.90	8.41	67.70	52.80	222.01	37.50	31.10	40.96
28-Feb	70.80	57.50	176.89	70.30	58.70	134.56	68.50	64.50	16.00	70.80	53.80	289.00	41.60	30.50	123.21
10-Mar	74.80	61.80	169.00	75.20	60.60	213.16	72.70	66.90	33.64	74.80	56.50	334.89	47.60	36.30	127.69
20-Mar	71.80	51.90	396.01	72.60	46.60	676.00	74.20	51.00	538.24	71.80	41.70	906.01	47.20	32.10	228.01
30-Mar	59.50	26.60	1082.41	58.90	24.10	1211.04	63.60	20.30	1874.89	59.50	19.30	1616.04	38.40	17.50	436.81
Sum	683.60	545.10	2410.67	667.60	552.20	2770.08	660.50	567.50	2612.80	683.60	543.80	3854.26	409.40	337.20	1397.98
Mean	56.97	45.43	200.88	55.63	46.02	230.84	55.04	47.29	217.73	56.97	45.32	321.18	34.12	28.1	116.49
N	12	12		12	12		12	12		12	12		12	12	
RMSE			4.09			4.39			4.26			5.17			3.12
NRMSE (%)			7.18			7.88			7.74			9.08			9.13
NSE			0.10			0.12			0.16			-0.44			-0.08
ME			0.10			0.12			0.16			-0.44			-0.08
Pe			-0.2			-0.17			-0.14			-0.2			-0.17