E. Afri. Agri. For. J (2022,Volume 86, 1-2, Pg 40-48)

DETERMINATION OF IRRIGATION WATER REQUIREMENT OF TOMATO CROP IN RACHUONYO NORTH SUB CATCHMENT OF WESTERN KENYA USING CROPWAT MODEL

K.O. Owino[#], B.T. I. Ong’or and E. K. Kanda

Department of Civil and Structural Engineering, Masinde Muliro University of Science and Technology, P.O. Box 190 – 50100, Kakamega, Kenya

ABSTRACT

Irrigation water management is necessary for a successful irrigation system. Knowledge and tools on irrigation management is thus a requisite for profitable and sustainable use of the scarce water resources in Kenya. The study determined the irrigation water requirement of tomato (*Solanum lycopersicum* L.) crop in Rachuonyo catchment using CropWat model and the area climate, soils and tomato crop data. The study findings indicated that crop evapotranspiration (ET_c) and net irrigation water requirement (IR) of tomatoes in the study area was 584.0 mm season^{-1} and 340.7 mm season^{-1} , respectively. The seasonal water requirement for tomatoes growing in a smallholder farm of 0.607 ha farm in the area was found to be 2,297.97 m^3 season^{-1}. The study revealed that *CropWat* model coupled with accurate area climate, soils and crop data can be used as a reliable decision support tool for the management of irrigation water for the region.

Keywords: Irrigation water management, Crop water requirement, *CropWat,* Small-scale farmers

INTRODUCTION

The irrigation potential of Homa Bay County is 8,966 hectares and only 13.3% of the area is irrigated, due to lack of water supplies, inadequate rainwater harvesting (RWH) ,irrigation expertise, and socioeconomic constraints (CIDP, 2018). Rachuonyo North Sub County, Homa Bay is characterized by hot and dry weather with irregular rainfall patterns. The region receives low rainfall, ranging from 700 to 800 mm per year, which is often irregular (Opere *et al*, 2016). Crop failure is common among smallholder farmers in the region due to insufficient rainfall.

Small-scale farmers in the region have used a variety of techniques to build resilience. These include irrigation and the cultivation of drought-resistant and tolerant crops among others. The region is currently facing stiff competing water demands including irrigation, domestic and industrial demands. Water needs for irrigation is projected to be comparatively higher than other water demands hence decision makers in the region must equip themselves with the adequate and efficient decision support tools in order to make prudent decisions with regard to water allocation. Investment in water resources development and conservation as well as promotion of rainwater harvesting systems in the region is thus a necessity.

Irrigation refers to the process of artificially delivering water to crops for enhanced crop growth and yields (Sojka *et al*., 2002). It is required to supplement the natural water supply for enhanced economic benefit. Irrigation systems enable the farmer to supply water needs to the farm (Frenken and Gillet, 2012). The amount of water applied depends on; crop water requirement, soil properties, the extent of root development and the climatic conditions of the area.

Crop Water Requirements (CWR) is the amount of water required by crops to compensate for evapotranspiration losses from the crop field during a given period of time (Todorovic, 2006). It is sometimes referred to as crop evapotranspiration usually denoted by ET_c. The CWRs are always estimated under optimal conditions, uniform crop, actively growing and completely shading the ground in favorable soil conditions (Karara, 2018). The crop water needs depend on climate, crop type and the growth stages of the crop. ET_c can be calculated from the equation

$$ET_c = EK_o \, x \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

where, ET_o is the reference evapotranspiration and K_c is the crop co-efficient(MoWI, 2005).

[#] Corresponding author:odhiamboowino2016@gmail.com

Crop coefficients depend on the type of crop and their growth stages. The values are represented in the crop coefficient curve with K_c values at the initial, mid-season and the end of the late season of crop growth of considerable importance as outlined by Feleke (2015).

The major climatic factors that affect the crop water needs include sunshine, temperature, humidity and wind speed. Crops require more water during hot and sunny weather conditions. Evapotranspiration rates are also high during windy conditions with low humidity (Hargreaves and Samani, 1985). The influence of climate on crop water needs is given by the reference crop evapotranspiration usually denoted by ET_o and is expressed in millimeters given time^{-1}. There are a number of methods for calculating the reference evapotranspiration. These include:

The FAO penman Monteith model

FAO recommends the use of FAO Penman Monteith formula that was developed in 1990 through a collaboration of International Commission on irrigation and drainage and the World Meteorological Organization The Equation is expressed as shown below:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \frac{\gamma 900}{T+273}U_2(e_s - e_a)}{\Delta + \gamma(1+0.34u_2)} \quad \text{.......2}$$

where, ET_o - Reference evapotranspiration [mm day^{-1}], R_n - Net radiation at the crop surface [MJ m^{-2} day^{-1}], G- Soil heat flux density [MJ m^{-2} day^{-1}], T - Mean daily air temperature at 2 m height [°C], u_2 - Wind speed at 2 m height [m s^{-1}], e_s - Saturation vapor pressure [kPa], e_a - Actual vapor pressure [kPa], e_s-e_a - Saturation vapor pressure deficit [kPa], Δ - Slope vapor pressure curve [kPa °C-1], γ - Psychometric constant [kPa °C^{-1}] (Allen *et al*, 1998).

The Radiation Method

If the climate data required for the Penman Monteith are not available for the needed time period, radiation method may be applied. The method was developed by Doorenbos and Prutt in 1977. It estimates crop water requirement based on solar radiation and air temperature data. It can be expressed by the formula;

$$ET_0 = -0.012 + [\frac{\Delta}{\Delta + \gamma}]b_r \frac{R_S}{\lambda} \quad \text{.......................3}$$

where, ET_o = evapotranspiration for clipped grass reference crop (in/d), Δ = slope of the vapor pressure curve (mb/°F), γ = psychometric constant (mb/°F), b_r = adjustment factor depending on the average relative humidity and daytime wind speed, R_s= incoming solar radiation (lang/d), λ = heat of vaporization of water (lang/in), (Allen *et al*, 1998)

FAO- Blaney – Criddle Method

It is also referred to the temperature method since it is based on estimation of crop water requirement solely on air temperature. It can be expressed by the following relationship:

$$ET_0 = c_e(a_t + b_t pT) \quad \text{...................................4}$$

where, ET_o = evapotranspiration for clipped grass reference crop (in/d), P = mean daily percent of annual daytime hours, T = mean air temperature for the period (°F), a_t and b_t = adjustment factors based on the climate of the region, c_e = adjustment factor, (Doorenbos and Pruitt, 1977).

Evaporation Pan Method

Crop water requirement can also be estimated by measuring the rate of evaporation from a shallow open faced pan of specific recommendations usually referred to as the class A Pan. The reference crop evapotranspiration can be approximated by the relationship;

$$ET_O = k_p E_{pan} \quad \text{...............................5}$$

where, ET_o = the evapotranspiration for a clipped grass reference crop (in/d), K_p= pan coefficient, E_{pan}= evaporation from the pan (in d^{-1}) (Doorenbos and Pruitt, 1977)

FAO Penman Montheith equation has been widely accepted for use in estimation of crop water requirement by the International Commission on Irrigation and Drainage as well as the World Meteorological organization since it has a broad theoretical base that accommodates small time periods (Allen *et a.,* 1998). However, climate data required for accurate prediction of ET_o is often lacking in many countries especially in Africa (Hargreaves and Samani, 1985). Important parameters in estimating ET_o are temperature and solar radiation. About 80% of the ET_o can be explained by temperature and solar radiation alone. A simple formula to estimate ET_o using minimum climatological data can be indicated by (Hargreaves and Samani, 1985) equation;

$$ET_O = (T\max - T\min)^{1/2} x 0.0135 x KT x R_a x (TC + 17.81) \quad ....6$$

where, *Tmax* = maximum temperature °C, *Tmin* = minimum temperature °C, TC = Average daily temperature °C, R_a= extraterrestrial radiation (mm/day), KT = empirical coefficient 0.162 for interior regions or 0.19 for coastal.

The net irrigation water requirement NIR is the depth or volume of water required for normal crop production over the whole cropped area excluding contribution from other sources. It can be calculated based on the (MoWI, 2005) relationship:

$$NIR = ET_{crop} - P_e - G_e - W_b (mm / period) \quad ....7$$

where, P_e is the effective rainfall (mm), G_e is the groundwater contribution (mm) and, W_b is the stored soil water contribution (mm).

The gross irrigation requirement accounts for losses of water incurred during conveyance and application to the crop field. These losses are expressed in terms of conveyance and application efficiencies. It can be calculated from the net irrigation requirements (MoWI, 2005) using the relationships;

$$IR = \frac{1(NIR)}{E_p(1 - LR)} \quad ....8$$

where, E_p is the project efficiency and LR is the leaching requirement.

The project efficiency E_p is calculated from (MoWI, 2005) using the relationship;

$$E_P = E_a x E_c \quad ....9$$

where, E_a is the application efficiency and $E_c$is the conveyance efficiency.

E_a field applications range from,0.55 – 0.75 Surface irrigation,0.60 – 0.85 Sprinkler irrigation,0.75 -0.90 Drip irrigation, (MoWI, 2005)

Scheme water requirement is the total amount of water that needs to be supplied for an area. It can be calculated from (MoWI, 2005) by the formula;

$$V = 10 x A x IR \quad ....10$$

where,V is the scheme water requirement (m^3/period), A is the area in hectares and IR is the gross irrigation water requirement (mm $period^{-1}$).

The FAO Penman Monteith has been simplified for use in a computer programe known as CropWat that was developed by the FAO Land and Water Development Division in 1992.

The CropWat Model

CropWat is a decision support tool developed by FAO Land and Water Development Division in 1992. It enables the calculation of reference evapotranspiration, crop water requirements and crop irrigation water requirements. The calculation of reference evapotranspiration, ET_o is based on the FAO Penman Monteith method and requires input data of temperature, humidity, sunshine and wind speed.

Crop water requirements require inputs of crop, climate and soils data. It can be determined from the ET_o, rainfall and the crop coefficients K_c that have been determined using established procedures. For irrigation scheduling, the model require data on soil type, maximum rooting depth, total available soil moisture and the soil moisture depletion. Once the input data is entered, the *CropWat* automatically calculates ET_o and CWR and displays results in tables or graphs.

MATERIALS AND METHODS

Study area

The research was conducted in Rachuonyo North Sub County, Homa Bay (Figure1), which is located at 3.795°S and 34.6567°E. The County consists of seven administrative entities that include: West Rachuonyo, North Rachuonyo, Central Rachuonyo, Kendu Bay Town, Wang'chieng, Kanyaluo, and Kibiri. The area occupies around 435.4 km² with an average population of 178,686

(GoK, 2019). The Lower Midland (UM4) agro-ecological zones encompass the region. It has two rainy seasons: long rains between March and June and short rains between August and November. Rainfall varies between 700 and 1800 millimeters, with an average of 949 millimeters.

The temperature ranges from 17.1 to 34 °C. The region has recently experienced significant rainfall variability, which has been marked by years of drought (Opere *et al.,* 2016). The average farm sizes are 0.607028 ha for small scale farmers and 4.04686 ha for the large scale farmers.

Data Collection

Data samples were collected in line with the requirement of *CropWat* Model. Rainfall data, maximum and minimum temperature, relative humidity, wind velocity and solar radiation hours were used to calculate the monthly ET_o. This was input into the *CropWat* model to calculate the Potential Evapotranspiration. Tomato crop was identified as the most preferred horticulture crop in the area. Data collected include the crop co-efficient (K_c) of crop height based on guidelines of Feleke (2015). Rooting depth, length of crop development and critical depletion fraction for tomato crop was chosen according to the recommendation of Savva and Fenken (2002). Soils data on soil type and infiltration rates were chosen as per the guidelines of Ministry of Water and Irrigation design manual (MoWI, 2005) and the available soil moisture as per the guidelines adopted from Newman *et al.*(2015). These were input into the CropWat Model to calculate the net irrigation water requirement.

Min. of Agr. and GTZ: R. Jaetzold 09, GIS-Cartogr.: B. Girkens

Figure 1. Map showing location of the study area in Homa Bay County, Kenya)

Data sources and data frame

Rainfall, temperature, wind velocity, relative humidity and solar radiation data were obtained from SWAT GLOBAL with a time frame ranging from 1st January, 1979 to 31st July, 2014. The monthly averages of rainfall, minimum temperature, maximum temperature, relative humidity, wind velocity and sunshine hours were calculated from the data and used as input into the *CropWat* Model.

Data Processing and Analysis

The seasonal irrigation water requirement for tomatoes was determined in *CropWat* model using the soils data, crop data and the average monthly climatic data for the study area as indicated in Figure 2.

RESULTS AND DISCUSION

The amount of water supplied by an irrigation system to a farm depends on the crop water requirements, soil properties, the growth stage of the crop and the climatic conditions of the area. Tomato was the most preferred horticulture crop by the smallholder irrigation farmers in the region. The irrigation water requirement was established for tomatoes according to the steps outlined in Figure 2. FAO Penman Montheith formula was used to estimate the reference ET_o using the *CropWat* Model and the obtained area climate data. The results of ET_o simulation are as shown in Table 1. Effective precipitation was calculated in *CropWat* from the area average monthly rainfall (Table II).

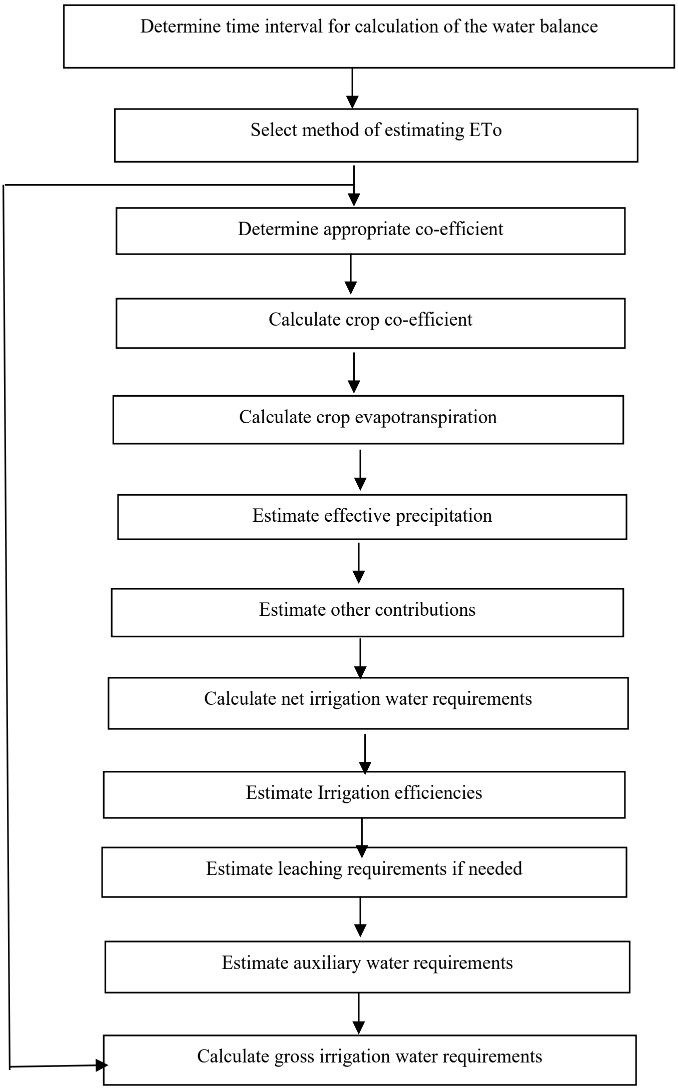


Figure 2. Flow chart for calculation of irrigation water requirement

TABLE I- RESULTS OF ET_O ESTIMATION OBTAINED FROM CROPWAT MODEL FROM RACHUONYO NORTH.

Monthly ET_o: Penman- Monteith

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	Km/day	Hrs	MJ/m2/day	Mm/day
Jan	15.6	31.2	57	12	12.5	27.8	4.86
Feb	15.9	31.2	58	12	12.5	28.8	5.12
Mar.	16.5	30.7	61	11	12.5	29.1	5.25
Apr.	16.6	29.3	65	10	12.5	28.3	5.05
May	16.2	28.8	68	9	12.5	26.9	4.7
Jun	15.1	28.6	66	9	12.5	25.9	4.38
Jul	14.9	28.5	64	10	12.5	26.3	4.42
Aug	14.8	28.8	64	10	12.5	27.6	4.72
Sep	14.8	29.7	59	11	12.5	28.7	4.95
Oct	15.5	30.4	57	11	12.5	28.7	5
Nov	15.9	30.1	61	11	12.5	27.9	4.89
Dec	15.5	30.2	59	11	12.5	27.4	4.72
Avarage	15.6	29.8	62	11	12.5	27.8	4.84

(Odhiambo, 2021)

TABLE II- RESULTS OF CALCULATION OF EFFECTIVE PRECIPITATION IN RACHUONYO NORTH USING EFFECTIVE RAIN METHOD (USDA S.C METHOD).

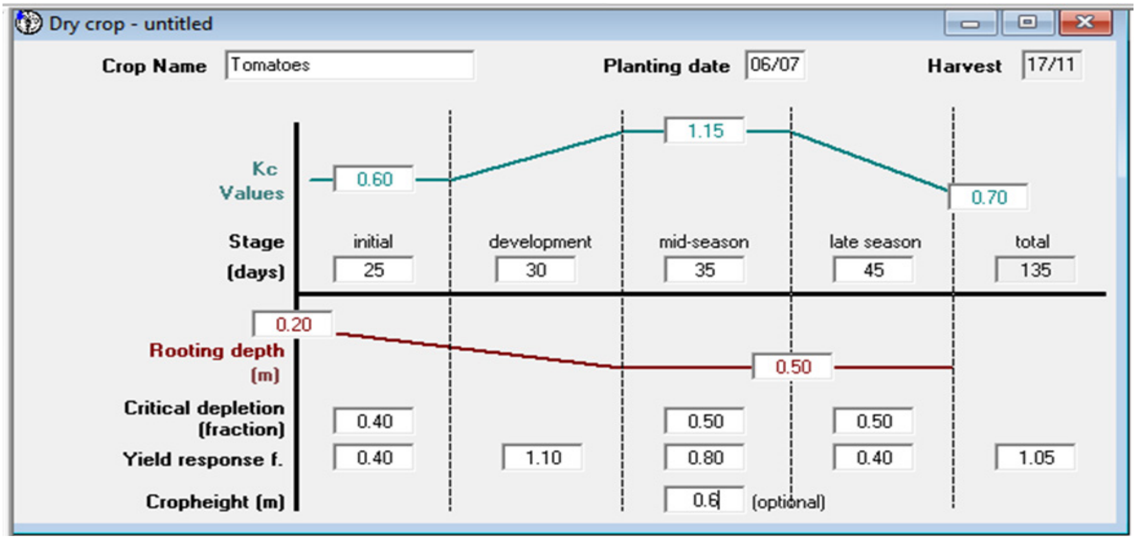
Month	**Rainfall**	**Effective Rainfall**
	mm	
January	32.8	31
February	50.2	46.2
March	115.1	93.9
April	230.1	145.4
May	253.2	150.3
June	119.7	96.8
July	40.2	37.6
August	51.2	55.2
September	48.7	44.9
October	41.2	38.5
November	103.9	86.6
December	64.9	58.2
Total	1161.2	884.6

(Odhiambo, 2021)

The crop coefficient (*Kc*) at different crop development stages, rooting depth and the critical depletion period for tomatoes were selected based on Feleke (2015). The length of crop development stages, yield response and crop height were chosen for tomatoes according to the guidelines by Savva, (2002). These were input into the *CropWat* model as indicated in Figure 3.

According to the generalized soil map of Kenya, the region has acrylic and luvisols types of soils generally classified under clay loam. Based on the guidelines of Feleke (2015) tomatoes was found to have a maximum crop height of 0.6m and a range of between 0.7m to 1.5m rooting depth in deep well drained soils. The average water infiltration rate in clay loam soils was 8mm per hour (MoWI, 2005). The available soil moisture from the soil was identified based on a guide by Newman *et al*. (2015) for clay loam as 200mm meter^{-1} of soil. Initial available soil moisture was calculated from the initial soil moisture depletion from Savva and Fenken (2002) at 40% and was found to be 120mm per meter. These data were entered in *CropWat* model (Figure 4) for calculation of irrigation water requirement results (Table III).

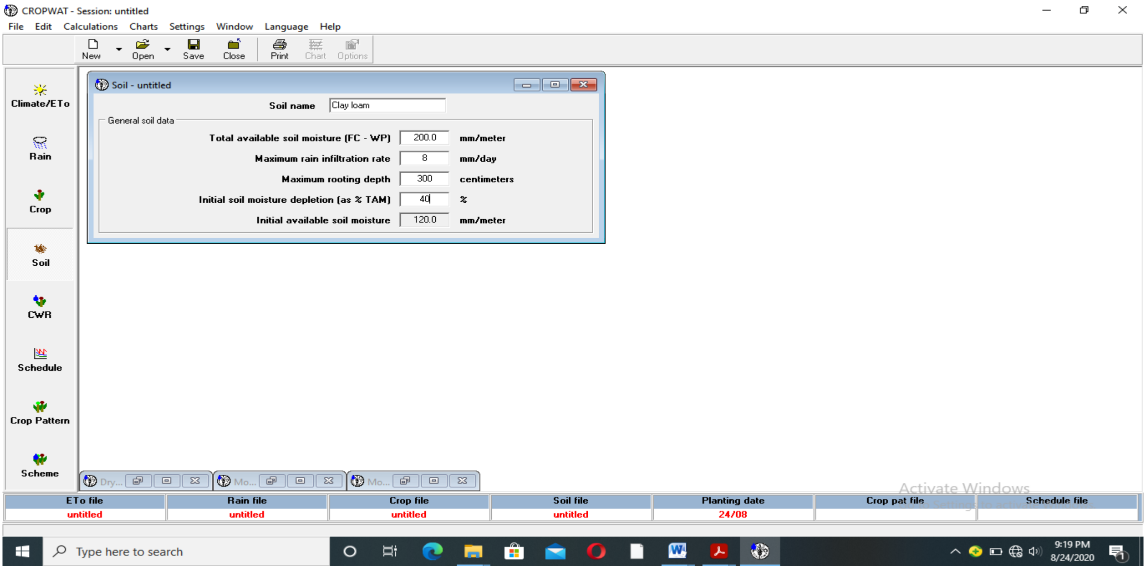
The crop water demand was determined for tomatoes growing in a smallholder farm with a reccommended water use technology. Integration of rainwater harvesting



Crop Name: Tomatoes
Planting date: 06/07
Harvest: 17/11

Stage	initial	development	mid-season	late season	total
Kc Values	0.60		1.15	0.70	
Stage (days)	25	30	35	45	135
Rooting depth (m)	0.20		0.50		
Critical depletion (fraction)	0.40		0.50	0.50	
Yield response f.	0.40	1.10	0.80	0.40	1.05
Cropheight (m)			0.6		

Figure 3: Input of crop data into *CropWat* Model



Soil name: Clay loam

General soil data

Total available soil moisture (FC - WP): 200.0 mm/meter
Maximum rain infiltration rate: 8 mm/day
Maximum rooting depth: 300 centimeters
Initial soil moisture depletion (as % TAM): 40 %
Initial available soil moisture: 120.0 mm/meter

ETo file	Rain file	Crop file	Soil file	Planting date	Crop pat file	Schedule file
untitled	untitled	untitled	untitled	24/08		

Figure 4 : Soils and Crop data input into *CropWat* Model

with an an approriate water saving technology such as drip irrigation was proposed for the area. From the results (Table III) , effective rainfall was lower than the crop water requirement during the whole growing season hence supplimental irrigation was required. The result also showed that tomatoes required high amounts of water during the dry period when the effective rainfall was low than when there was more rainfall.

The values of ET_c and *IR* varied throughout the crop growing stages depending on the changing climatic conditions as determined by the respective ET_o and soil conditions. The average ET_c and *IR* for tomatoes during the season was found to be 584.0mm season^{-1} and 340.7mm season^{-1} , respectively. For drip irrigation with no conveyance losses, the irrigation efficiency can be assumed to be 90% (MoWI, 2005). The seasonal gross irrigation requirement for tomatoes was estimated from equation 8 and found to be 378.56 mm season^{-1}. The scheme water requirement for tomatoes in a typical smallholder farm of 0.607 ha farm size in Rachuonyo North was estimated based on equation 10 and found to be 2,297.97 m^3 season^{-1}.

TABLE III- DETERMINED IRRIGATION WATER REQUIREMENT FROM CROPWAT MODEL ACROSS DECADES IN RACHUONYO NORTH.

Planting date 24/08 Crop: Tomatoes

Month	Decade	Stage	K_c Coefficients	ET_c mm/day	ET_c mm/dec	Effective Rain mm/dec	Irri. Req mm/dec
Aug	3	Init	0.6	2.88	23	13.2	14
Sep	1	Init	0.6	2.92	29.2	16	13.2
Sep	2	Dev	0.61	3.02	30.2	14.8	15.4
Sep	3	Dev	0.75	3.7	37	14.2	22.9
Oct	1	Dev	0.92	4.57	45.7	11.8	33.8
Oct	2	Mid	1.08	5.39	53.9	10.3	43.6
Oct	3	Mid	1.11	5.52	60.8	16.5	44.3
Nov	1	Mid	1.11	5.48	54.8	25.9	28.9
Nov	2	Mid	1.11	5.44	54.4	32.5	21.9
Nov	3	Late	1.07	5.16	51.6	28.1	23.5
Dec	1	Late	0.97	4.62	46.2	22.5	23.7
Dec	2	Late	0.87	4.09	40.9	19.3	21.6
Dec	3	Late	0.76	3.63	40	16.3	23.6
Jan	1	Late	0.68	3.29	16.4	6	10.4
					584	247.5	340.7

(Odhiambo, 2021)

CONCLUSION AND RECOMMENDATIONS

The average ET_c and *IR* of tomatoes in the study area was found to be 584.0 and 340.7 mm season^{-1} , respectively. The seasonal water requirement for tomatoes growing in a typical smallholder farm of 0.607 ha farm size in the area was found to be 2,297.97 m^3 season^{-1}. The study revealed that *CropWat* model coupled with accurate area climate, soils and crop data can be used to reliably establish the irrigation water requirement for the region.

The study therefore recommends *CropWat* model as a suitable decision support tool for policy makers and investors on irrigation and water resources in the region with regard to irrigation water management. It further recommends that governments and other development agencies needs to invest in training and awareness creation on effective irrigation water management and rainwater harvesting techniques for smallholder farmers of the area.

REFERENCES

Allen, R. G., Pereira, L. S., Raes, D. and Smith, M. (1998). FAO Irrigation and drainage paper No. 56. Rome: Food and Agriculture Organization of the United Nations, 56(97), e156..

County Government of Homa Bay. Homa Bay__ CIDP_2018-2022_County-Integrated Development-Plan.pdf. https://roggkenya.org/wp-content/uploads/docs/CIDPs/Kakamega__CIDP_2018-2022_County-Integrated-Development-Plan.pdf

Cropwat, F. A. O. (1992). A computer program for irrigation Planning and Management, By M. Smith. FAO Irrigation and Drainage Paper, (46).

Doorenbos, J. (1977). Guidelines for predicting crop water requirements. *FAO irrigation and drainage paper,* 24, 1-179.

Feleke, M. M. (2015). Alternatives to improve major properties of the irrigated soils in the melkassa agricultural research centre (marc), Ethiopia, with special emphasis on organic matter and water holding capacity.

Frenken, K. and Gillet, V. (2012). Irrigation water requirement and water withdrawal by country. FAO, Rome, Italy.

GoK, (2019). Kenya Population and Housing report http://housingfinanceafrica.org/app/uploads/VOLUME-I-KPHC-2019.pdf

Hargreaves, G.H. and Z.A. Samani (1985). Reference crop evapotranspiration from temperature.Transaction of ASAE 1(2):96-99. Hargreaves, G.H. (1994). Retrieved from:http://www.zohrabsamani.com/research_material/files/Hargreaves- samani.pdf

Karara G. K. (2018). Assessment of Rainwater Harvesting Potential for Irrigation in Nyeri, Kenya. A thesis submitted for Award of MSc. in Soil and Water Engineering in the school of Environmental and Bio systems engineering at Jomo Kenyatta University of Agriculture and Technology

Ministry of Water and Irrigation (MoWI) (2005). Practice Manual for water supply services in Kenya

Onwuegbunam, D. O., Zakka, E., Onwuegbunam, N. E., Danbaki, C. and Bolaji, W. (2020). Soil wetting pattern of sandy loam soil in response to drip irrigation running time. Fudma journal of SCIENCES-ISSN: 2616-1370, 3(4), 529-534.

Newman, L., Powell, L. J. and Wittman, H. (2015). Landscapes of food production in agriburbia: Farmland protection and local food movements in British Columbia. Journal of Rural Studies, 39, 99-110.

Opere E. Juma S. and Sitienei B. (2016). Trends in Monthy Rainfall and Temperature in Rachuonyo North Sub County, Kenya. *Ethiopian Journal of Environmental Studies & Management.* https://www.researchgate.net/publication/311257672Odhiambo 2021….

Sojka, R. E., Bjorneberg, D. L. and Entry, J. A. (2002). Irrigation: An historical perspective.

Savva A. P. and Fenken K. (2002). *Crop water requirements and irrigation scheduling.* Irrig Man. 4:1–121.

Todorovic, Mladen. (2006). Crop Water Requirements. 10.1002/047147844X.aw59.