Estimation of Crop Water Requirements for Garden Pea, Sweet Pepper and Tomato using the CropWAT Model in Maragua Watershed, Murang'a County, Kenya

SUSAN MAINGI*, JACKLINE NDIIRI and BANCY MATI
Department of Soil, Water and Environmental Engineering
Jomo Kenyatta University of Agriculture and Technology
P.O. Box 62 000 – 00200, NAIROBI,
KENYA.

*Corresponding authors email: maingisusan@gmail.com; www.jkuat.ac.ke

Abstract: Kenya is a water scarce country and its water resources are limited. It is therefore significant to wisely utilize the little available water whether in agriculture or any other use. Agriculture being one of the key areas where water is a key input for growth, determination of crop water requirement is one of the key considerations for accurate scheduling of irrigation especially during the dry season when rains subside. This study was carried out to determine the crop water requirements and irrigation scheduling of garden peas, sweet pepper and tomatoes for the Kambirwa, Gituamba and Maragua ridge regions of Maragua watershed located in the Upper Tana Catchment. The crop water requirement for each of the crops was determined by FAO CROPWAT 8.0 model which is developed by the Food and Agricultural Organization (FAO), using 10 years climatic data which was obtained from Upper Tana meteorological station. The model is a computer based programme for the calculation of crop water and irrigation requirements from existing or new climatic and crop data. To determine the crop water requirements (CWR), reference crop evapotranspiration (ET_o) and crop factor (K_c) were used. The reference crop evapotranspiration (ET_o) was determined using meteorological data. The metrological parameters used are Maximum Temperature, Minimum Temperature, Wind Speed, Relative Humidity and Sunshine Hours and are considered as input and Reference Crop Evapotranspiration is considered as output. The study results showed that ET_0 varied from 3.01 to 5.10 mm/day and the effective rainfall varied from 8.0 to 154.4 mm. The crop water requirements for Garden pea, sweet pepper and tomato are 395.6, 460.1 and 432.7 mm/dec respectively. The irrigation requirements were 155, 187.7 and 158.7 mm/dec for garden pea, tomato, and sweet pepper respectively. The total gross irrigation mean and the total net irrigation mean are 190.9 mm and 133.7 for garden pea with two irrigation schedules,116.1 mm and 81.3 mm for tomato with six irrigation schedules and 67.2 mm and 47.0 mm for sweet pepper with six irrigation schedules. This study has proved that the CropWAT model is useful for calculating the crop irrigation needs which will help in proper management of water resources.

***Keywords*:** CropWAT; Irrigation schedules; Irrigation requirement; Crop water requirement

1. Introduction

Scarcity of water resources and the increasing war for water is likely to reduce its accessibility for irrigation since it is a major challenge in most parts of the world and life cannot go on without water [8]. Agriculture being the leading consumer of water in Kenya and accounting for over 70 % of the available water, the need for more efficient use of water in agriculture needs should be a top most priority [1]. As the world population increases, demand for food is also expected to escalate which means that agricultural production should be improved to feed the fast growing population [1][2]. As a result, competition for increasingly scarce land, water and energy resources is on the rise, further intensified by the threat of climate change [3]. Changes in climate is likely to affect smallholder farmers especially through increased crop failure. Acute water shortages are observed in many countries and there is no life without water. Even though the mean annual rainfall in Maragua is 1900mm, its distribution is uneven throughout the entire watershed leaving long dry spells which causes a long moisture stress period. This makes crop productivity either static or very low leading to low productivity. Since the past decades, irrigation has traditionally been the major source of water usage for agriculture. To cope with shortage of water, it is necessary to adopt water saving agriculture counter measures. The main objective of irrigation is to apply water to soil to meet crop evapotranspiration requirement when rainfall is insufficient, to raise crop till harvesting. Various studies carried out in various research institutions like Kenya Agricultural and Livestock Research organization (KALRO) on water management strategies among others have indicated that irrigated agriculture can enhance crop productivity in Kenya especially in areas with unreliable rainfall. Irrigated agriculture accounts for over 20 % of the total cultivated land and contributes to 40 % of the total world food production. It is highly productive and twice as much as rain fed agricultural production, hence tolerating more crop production escalation and divergence. This means that a better understanding of the interface between climate, water and crop growth needs to be a priority area in Kenya as water is always an essential input for crop production. With all this research in place, there has not been any specific information since crop data obtained for this purpose is general. It is therefore of great significance to have location specific scientific information on crop water requirements and irrigation scheduling of different crops since the available information does not cater for all different types of soils and climate of different agro-ecological zones. It is therefore of great significance to understand the water requirements of specific crops at different management levels within the irrigated area to accomplish effective irrigation management and efficiency [4]. Some studies carried out on such water parameters does not have specific details of areas like Maragua when water requirements are to be taken to regional levels. To achieve easy planning of water resources in such areas and to avoid general conclusion on crop water use, crop specific information is required with respect to soil, water and climate. Such information on crop water demand help determine water balance, crop water and irrigation requirements of different crops of the particular region under discussion. Crop simulation models are highly significant as they are able to predict yield responses to great weather variations. These models are able to predict the crop water needs for the crop to achieve optimum yields [5][6]. The crop water requirements are met from the effective rainfall, irrigation water applied and the available soil moisture. The potential evapotranspiration (ET_0) of a crop is the volume of water required to meet crop evapotranspiration requirements [7]. The crop irrigation water requirement is a difference between potential evapotranspiration (ET0) and effective precipitation (p). It also refers to the amount of water required to compensate the evapo-transpiration loss from cropped field. It depends on crop type, stage of growth and evaporation demand. Therefore, it is important that crop water requirement is obtained using combination of climate, soil and plant factors to distribute water resource and to improve water use efficiency and meet the crop water demand. Software modeling by programs like CROPWAT 8.0 is a significant practice used by Engineers and scientists for the assessment of crop evapotranspiration, CWR, and irrigation scheduling. This software was developed by the Food and Agriculture Organization (FAO) as tools to assist irrigation engineers and agronomists in performing the usual calculations for water irrigation studies and mainly in the management and design of irrigation schemes [9]. Murang'a County in Kenya lacks specific information of crop water requirements and irrigation scheduling hence this study attempted to compute the crop water requirements of the major crops mostly grown in this area and such was compared with available data to assess the applicability. In the present study, the irrigation water requirements and irrigation scheduling of some selected crops (garden pea, tomato and sweet pepper) in Maragua water shed were studied using the CROPWAT 8.0 model.

2. Materials and methods

2.1 Description of the study area

This study was carried out in Maragua water shed in Murang'a County in Kenya focusing on three study farms which were representative of the entire county in terms of soils and topography (fig 1). The choice of the study farms were depended on the farmers' problems of water management with limited water resources in the particular area of study. The watershed has an area of 420 km^2 and lies within the Upper Tana catchment and situated between 0° 37' 12" to 0° 50' 0" S latitude and 36° 42' 0" to 37° 9' 0"E longitude. It originates from the Aberdare ranges and flows from the west towards the East with an altitude ranging from 1160m to 3769m. The watershed traverses Kigumo, Kiharu, Maragua, and Kahuro sub-counties in Murang'a County. The specific study farms were identified in Gituamba, Maragua ridge and Kambirwa regions which lies in Maragua watershed. The specific sites lies between (0° 44' 16" to 0° 46' 35" S latitude and 37° 09' 30" to 37° 14' 03" E Longitude). This area receives an average annual rainfall of 1164 mm out of which the longer rains come between March and May and the short rains between October and November. The general topography of the area is sloppy with some areas like Kambirwa with gentle slopes which are found on the lower eastern part of the watershed.

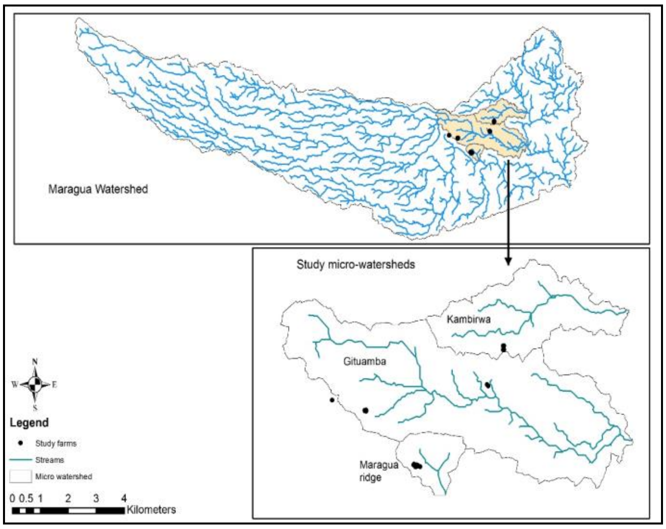

Figure 1: Study area showing the study farms

2.2 Meteorological data

The respective meteorological was collected from the Kenya meteorological station at Upper Tana station in Murang'a County. The data used for ET_0 computation was the meteorological data obtained from the station; for instance minimum and maximum temperatures (^{0}C), wind speed in km per day, the relative humidity in %, sunshine hours and the physical data such as altitude, latitude and longitude. The climatic data that was obtained from meteorological station were then adjusted into the format accepted by CROPWAT 8.0. The rainfall data collection which was obtained from rainfall records of 10 years (2008 - 2018) were used to allow for a calculation of rainfall likelihoods.

2.3 Crop data

The data for the crops grown in the study areas and their cropping patterns was obtained by means of a survey conducted on the farms. The crops which were observed in the field mainly grown under irrigation were tomatoes (*Solanum lycopersicum*), Sweet pepper (*Capsicum annuum)* and garden peas (*Pisum sativum*).The other crops majorly grown under rain fed conditions were beans and maize. Field observations, interviews with farmers were also used to aid in the assessment of the existing cropping patterns of the crops. The needed field information that was obtained was the growth stages of the three crops.

2.4 Determination of crop growth stages

Stages of plant growth were used in determining water requirement of the crop. This was achieved by recording planting dates and carefully monitoring the stages of development up to the harvesting date for the three selected crops. This was done by observation method where the changes from one stage were observed and recorded together with the number of days per stage.

Crop coefficient (Kc): this is the ratio of the crop ET_c to the reference ET_o, and represents an integration of the effects of four primary characteristics that distinguish the crop from reference grass i: e Crop height. Albedo of the crop-soil surface, Canopy resistance, Evaporation from soil, especially exposed soil [21]. In developing the crop coefficients for the growing season, different stages of crop development were considered; initial stage, development stage, mid-season and late season stage. Below is a description of the behavioral changes of the crops at each stage.

Initial stage: This starts from germination and early growth when the soil surface is not or is hardly covered by the crop (groundcover less than10%).
Development stage: This begins from the end of initial stage to attainment of effective full groundcover (groundcover approx. 70-80%).
Mid-season: This begins from attainment of effective full groundcover to time of start of maturing.
Late season stage: This begins from end of mid-season stage until full Maturity harvest.

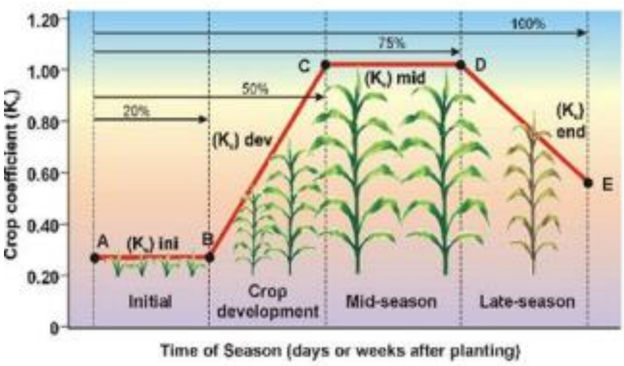

Figure 2: Crop Coefficient (Kc)

2.5 Soil data

The data utilized on the soil characteristics was acquired through laboratory soil analysis done on the soil samples collected from the three study sites. The soil samples were collected using an auger which was analyzed at National Agricultural Research Laboratories (**NARL**) in Kabete. The analyzed results included soil texture, bulk density, and total available water were then used as input into the CROPWAT 8.0 program, and saved. Crop and irrigation water needs were then calculated using the model for the majorly observed high value crops.

2.6 Determination of crop water requirement

This was achieved by use of FAO-CROPWAT model applying the appropriate procedures described by FAO in land and water development division [10]. Data requirements for the model included: crop data which included the respective planting and harvesting dates, Kc, growth stages, critical depletion and yield response factor. Soil data including Total Available Water (TAW), maximum infiltration rate, maximum rooting depth and initial soil moisture depletion and finally climate data which required total monthly precipitation (P),effective precipitation reference evapotranspiration (ET_0) and monthly average maximum and minimum temperature, Wind speed, radiation and sunshine hours. The soil and crop data were collected from the field where the particular crops under observation were grown. Crop coefficient values (Kc) were taken from the already published data. Kc values for initial, mid and late growth stages of annual and seasonal crops are used.

2.7 CropWAT 8.0 model description

The CROPWAT software is a decision support system developed by the Land and Water Development Division of the FAO [12]. Its main functions are to calculate reference evapotranspiration, crop water requirements and crop irrigation requirements. This enhances development of irrigation schedules under various water management conditions and scheme water supply and to evaluate rain fed production, drought effects and efficiency of irrigation practices. It uses the FAO Penman-Monteith method for calculating reference crop evapotranspiration whose estimate is used in crop water requirements and irrigation scheduling calculations. CROPWAT calculates the irrigation water requirements per a certain period either daily or weekly or as required by cropping pattern in an irrigated area, for various stages of crop development throughout the crops growing season. It uses techniques for predicting yields when all the meteorological, soil and crop parameters are known. This approach allows estimation of ET_a and K_s, from the ratio of actual to potential yield. The CROPWAT program was utilized in this study to estimate the crop water requirement and irrigation scheduling of each of the crops. The climatic data like Min-Max Temperature, Relative Humidity and Wind Speed and Sunshine hours are used for the calculations. Conversions for all the obtained data were done in order to adjust the data into the format accepted by CROPWAT 8.0 [15].

a. FAO Penman-Monteith Approach: Standard method for the computation of ET_o from meteorological data. This method to estimate ET_O is expressed as:

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

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 air temperature at 2 m height [°C],
u_2 wind speed at 2 m height [m s^{-1}],
e_s saturation vapour pressure [kPa],
e_a actual vapour pressure [kPa],
e_s - e_a saturation vapour pressure deficit [kPa],
D slope vapour pressure curve [kPa °C^{-1}],
g psychrometric constant [kPa °C^{-1}].

b. Crop Evapotranspiration (ETc): This is the amount of water required by the crop during the growing season. It is usually determined by the crop coefficient approach whereby the effect of the various weather conditions are incorporated into ET_o and the crop characteristics into the Crop coefficient. It is expressed as;

$$ET_c = K_c * ET_0 \quad (2)$$

3. Results and discussion

3.1 Crop data

The crops under observation during the study period were garden pea (*Pisum sativum*), sweet pepper (*Capsicum annuum*) and tomato (*Lycopersicum esculentum*). The various lengths of growth stages are shown in the table 1. The length of the growing season depends on rainfall, evaporation and temperature, soil factors and crop factors [5]. Among the crops under study, sweet pepper took the longest time of 115 days from planting date to harvest, tomato took 100 days and garden pea took 90 days. The crops were observed under four stages of growth, namely; Initial, development, mid-season and late season stages.

Table 1: Lengths of Crop developmental growth stages for the three crops in the study

Crop	Crop growth periods (days)				
	Total growing season (days)	Init. (L_{ini})	Dev. (L_{dev})	Mid (L_{mid})	Late (L_{late})
Garden pea (*Pisum sativum*)	90	15	25	35	15
Sweet pepper (*Capsicum annuum*	115	20	35	40	20
Tomato (*Lycopersicum sculentum*)	100	20	25	30	25

3.2 Climatic data

The climatic data and the potential evapotranspiration for the three crops are presented in Table 2 and Table 3. The ET_o on average was 3.84 mm/day for Kambirwa and 3.85 mm/day for Gituamba and Maragua ridge, while wind speed was 103 km/ day for all sides. For Gituamba and Maragua ridge the climatic factors were almost similar since the attitude was nearly at the same level. The average sunshine hours were 6.7. This meant that the sky was cloudy at most times of the day in all sites. The minimum and maximum temperatures were 11.7 °C and 28 °C which was ideal for optimal growth of all the crops studied under the prevailing rainfall and other climatic factors. The two tables (2 and 3) also show the total effective rainfall of the study areas which was 842.6mm.

Table 2. Climate characteristics, rainfalls, and ET_0 of Kambirwa in Maragua watershed

Month	Min Temp °C	Max Temp °C	Humidity%	Wind km/day	Sun hours	Rad MJ/m²/day	ETo mm/day	Rain mm	Eff Rain mm
January	11.2	28.5	71	116	9.7	23.5	4.51	58	52.6
February	11.4	30	62	142	9.5	24.1	5.06	71	62.9
March	12.2	30.2	57	105	7.2	20.8	4.55	87	74.9
April	12.6	28.6	72	111	6.7	19.5	4.06	294	154.4
May	12.2	27.4	84	61	5.7	17	3.28	135	105.8
June	11.2	26.4	83	45	5.8	16.6	3.07	4.2	4.2
July	10.7	25.2	72	58	3.8	14	2.76	8.3	
August	10.5	25.4	67	64	4.2	15.2	3.02	8.1	8.2
September	10.8	27.7	66	109	6.1	18.8	3.89	30.1	8
October	11.9	29.1	75	142	7.4	20.7	4.27	62.1	28.7
November	13.7	29.4	82	115	6.5	18.8	3.85	221.2	55.9
December	11.6	27.6	85	168	7.2	19.5	3.8	225.1	142.9
Total								1204.1	144
Average	11.7	28	73	103	6.7	19	3.84		842.6

Table 3 Climate characteristics, rainfalls, and ET_0 of Gituamba and Maragua ridge in Maragua watershed

Month	Min Temp°	Max Temp°C	Humidity%	Wind km/day	Sun hour	Rad MJ/m²/day	ETo mm/day	Rain mm	Eff rain mm

	C				s				
January	11.2	28.5	71	116	9.7	23.8	4.59	58	52.6
February	11.4	30	62	142	9.5	24.2	5.1	71	62.9
March	12.2	30.2	57	105	7.2	20.8	4.56	87	74.9
April	12.6	28.6	72	111	6.7	19.4	4.04	294	154.4
May	12.2	27.4	84	61	5.7	16.8	3.24	135	105.8
June	11.2	26.4	83	45	5.8	16.3	3.02	4.2	4.2
July	10.7	25.2	72	58	3.8	13.8	2.72	8.3	8.2
August	10.5	25.4	67	64	4.2	15.1	2.99	8.1	8
September	10.8	27.7	66	109	6.1	18.7	3.89	30.1	28.7
October	11.9	29.1	75	142	7.4	20.9	4.31	62.1	55.9
November	13.7	29.4	82	115	6.5	19	3.91	221.2	142.9
December	11.6	27.6	85	168	7.2	19.8	3.86	225.1	144
Total								1204.1	842.6
Average	11.7	28	73	103	6.7	19.1	3.85		

3.3 Crop Water Requirement of garden pea, sweet pepper and Tomatoes

The crop water requirements and crop evapotranspiration are closely clinked to each other since both have an equal amount of water. The difference between them is that crop evapotranspiration represents the water losses that occurs, while the crop water requirement indicates the amount of water that should be supplied accounting for the water losses. In fact, this amount of water corresponds to the effective irrigation water supply to a certain crop in order to reach the maximum yield. Consequently, the estimation of crop evapotranspiration precedes the estimation of crop water requirements where latter usually represents the values of crop evapotranspiration accumulated over some period of time [20]. The tables 3.3a, b and c shows the crop water requirement and the irrigation requirement of the three different crops during the study period. From the results, in Table 4, 5 and 6 the Kc at initial stage was the lowest, and began to increase at the development stage then was highest at lid season stage and then began to decrease at the late season stage. The Kc at this stage was lower as compared with the other stages since this was just at initial stage of canopy formation so there was much water requirement. This is explained by the fact that when atmospheric evaporation demand is on the higher side the soil dries very fast and therefore the crop coefficient is low [2]. ET_c is seen to be low at the initial stage of growth cutting across all crops. The ETc begins to rise at the development stage and maintains the high levels at the mid-season stage and goes down at the late season stage. The high ETc in development and mid-season stage is explained by effective full groundcover approx. 70-80% and also rapid growth and therefore requires a lot of water since it is the time the ground is shaded and transpiration is more than evaporation in the plant due to increased canopy [12]. The late season stage has lower values of both Kc and ETc since the crops begin to shed their leaves leading to less ground cover, hence less water requirements. The ETc values for the garden pea, sweet pepper and tomato were **395.6, 460.1 and 432.7** mm/dec respectively which is within the range provided by FAO, 2008. The irrigation requirements were **155, 187.7 and 158.7** mm/dec for garden pea, tomato, and sweet pepper respectively. The results indicate increasing ETc throughout the growth stages which is high at the mid-season stage and starts to decrease slightly at the later stages.

.

Table 4. Crop water requirement (ETc) for garden pea in kambirwa

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Jan	2	Init	0.5	2.29	2.3	1.3	2.3
Jan	3	Init	0.5	2.38	26.1	15.5	10.6
Feb	1	Deve	0.57	2.86	28.6	19.8	8.9
Feb	2	Deve	0.83	4.32	43.2	20.9	22.2
Feb	3	Deve	1.07	5.32	42.6	22.3	20.3
Mar	1	Mid	1.16	5.5	55	21.5	33.5
Mar	2	Mid	1.16	5.29	52.9	21.8	31.1
Mar	3	Mid	1.16	5.08	55.9	31.7	24.3
Apr	1	Late	1.15	4.85	48.5	46.7	1.8
Apr	2	Late	1.12	4.5	40.5	51.8	0
					395.6	**253.1**	**155**

Table 5. Crop water requirement for tomato in Maragua ridge

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Jan	2	Init	0.6	2.75	24.8	11.5	12
Jan	3	Init	0.6	2.86	31.4	15.5	15.9
Feb	1	Deve	0.72	3.62	36.2	19.8	16.4
Feb	2	Deve	0.95	4.94	49.4	20.9	28.5
Feb	3	Mid	1.14	5.66	45.3	22.3	23
Mar	1	Mid	1.16	5.52	55.2	21.5	33.7
Mar	2	Mid	1.16	5.31	53.1	21.8	31.3
Mar	3	Late	1.15	5.05	55.5	31.7	23.8
Apr	1	Late	1.03	4.32	43.2	46.7	0
Apr	2	Late	0.88	3.56	35.6	57.5	0
Apr	3	Late	0.8	3.03	3	5	3
					432.7	**274.1**	**187.7**

Table 6. Crop water requirement for Sweet pepper in Gituamba

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Jan	1	Init	0.6	2.61	2.6	2.4	2.6
Jan	2	Init	0.6	2.75	27.5	12.7	14.8
Jan	3	Deve	0.6	2.87	31.6	15.5	16.1
Feb	1	Deve	0.7	3.48	34.8	19.8	15
Feb	2	Deve	0.82	4.29	42.9	20.9	22
Feb	3	Deve	0.94	4.7	37.6	22.3	15.3
Mar	1	Mid	1.04	4.92	49.2	21.5	27.7

Mar	2	Mid	1.05	4.79	47.9	21.8	26.1
Mar	3	Mid	1.05	4.61	50.7	31.7	19
Apr	1	Mid	1.05	4.43	44.3	46.7	0
Apr	2	Late	1.03	4.18	41.8	57.5	0
Apr	3	Late	0.96	3.64	36.4	50.1	0
May	1	Late	0.91	3.19	12.8	16.9	0
					460.1	339.8	158.7

Init = initial; Deve = development; Mid = Mid-season; Late = Late season stage; Eff = effective rain, Irr. Req = irrigation requirements, Kc = crop coefficient, ETc = crop evapotranspiration

3.4 Net Irrigation Requirement (NIR) and Irrigation Schedule

In order to improve irrigation water management in the field the knowledge of irrigation water requirements and irrigation time scheduling is key [17]. The CROPWAT model provides agriculturists with the opportunity to design an indicative irrigation schedules and its impact over crop yields, Evaluate field irrigation program in terms of efficiency of water use and yield reduction and Simulate field irrigation program under water deficiency conditions, rain-fed conditions, and supplementary irrigation. Irrigation water management is simply monitoring the amount, timing, and rate of irrigation in an effective and strategic manner to minimize wastage of water or over irrigating the crops [13][18]. Tables 7, 8 & 9 and Figures 3, 4 & 5 illustrate the field crop irrigation schedules for the garden pea, tomato and sweet pepper grown in the study areas. The total gross irrigation mean and the total net irrigation for garden pea are **190.9 mm** and **133.7** with two irrigation schedules, **116.1 mm** and **81.3 mm** for tomato with six irrigation schedules and **67.2 mm** and **47.0 mm** for sweet pepper with six irrigation schedules.

In the figures 3, 4 & 5, (TAM) is the total available moisture or the total amount of water available to the crop. The (RAM) is the readily available water or the portion of (TAM) that the plant can get from the root zone without facing water stress.

Table 7. Irrigation schedules for Garden pea

Date	Day	Stage	Rain mm	Ks fract	Eta %	Depl %	Net Irr mm	Deficit mm	Loss mm	Gr. Irr mm	Flow l/s/ha
10-Feb	31	Dev	0	1	100	75	133.7	0	0	190.9	0.71
10-Apr	End	End	0	1	0	62					

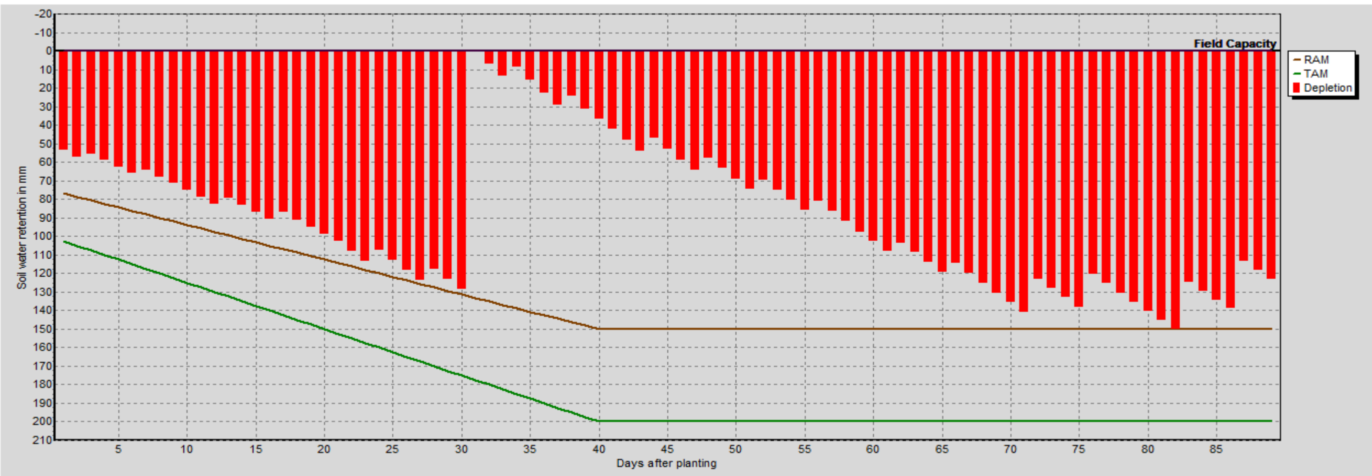

Figure 3: Field crop water schedules for Garden pea

Table 8. Irrigation schedules for tomato

Date	Day	Stage	Rain mm	Ks fract	Eta %	Depl %	Net Irr mm	Deficit mm	Loss mm	Gr. Irr mm	Flow l/s/ha
11-Jan	1	Init	0	0.71	71	54	28.7	0	0	41	4.74
19-Jan	9	Init	0	1	100	32	25.7	0	0	36.6	0.53
31-Jan	21	Dev	0	1	100	33	39.4	0	0	56.3	0.54
20-Feb	41	Dev	0	1	100	41	75.9	0	0	108.4	0.63
16-Mar	65	Mid	0	1	100	41	81.3	0	0	116.1	0.56
20-Apr	End	End	0	1	0	5					

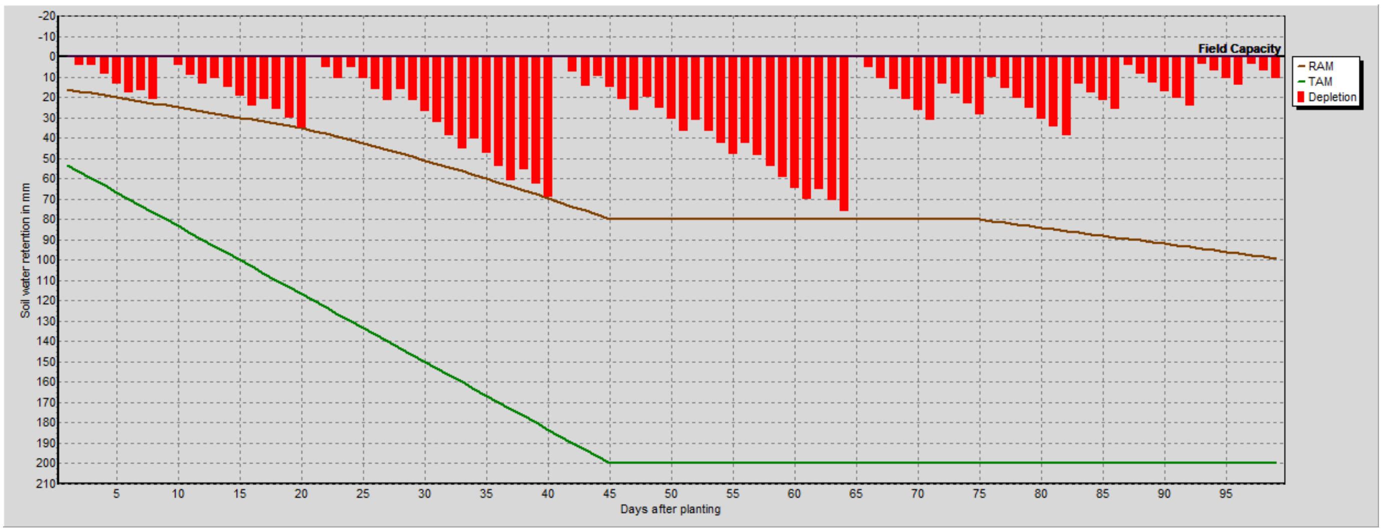

Figure 4: Field crop water schedules for tomato

Table 9: Irrigation schedules for Sweet pepper

Date	Day	Stage	Rain mm	Ks fract	Eta%	Depl %	Net Irr mm	Deficit mm	Loss mm	Gr. Irr mm	Flow l/s/ha
19-Jan	9	Init	0	1	100	23	14	0	0	20	0.26
30-Jan	20	Init	0	1	100	20	16.3	0	0	23.3	0.25
12-Feb	33	Dev	0	1	100	24	24.8	0	0	35.5	0.32
26-Feb	47	Dev	0	1	100	29	37.5	0	0	53.5	0.44
12-Mar	61	Mid	0	1	100	33	47	0	0	67.2	0.56
5-May	End	End	0	1	0	4					

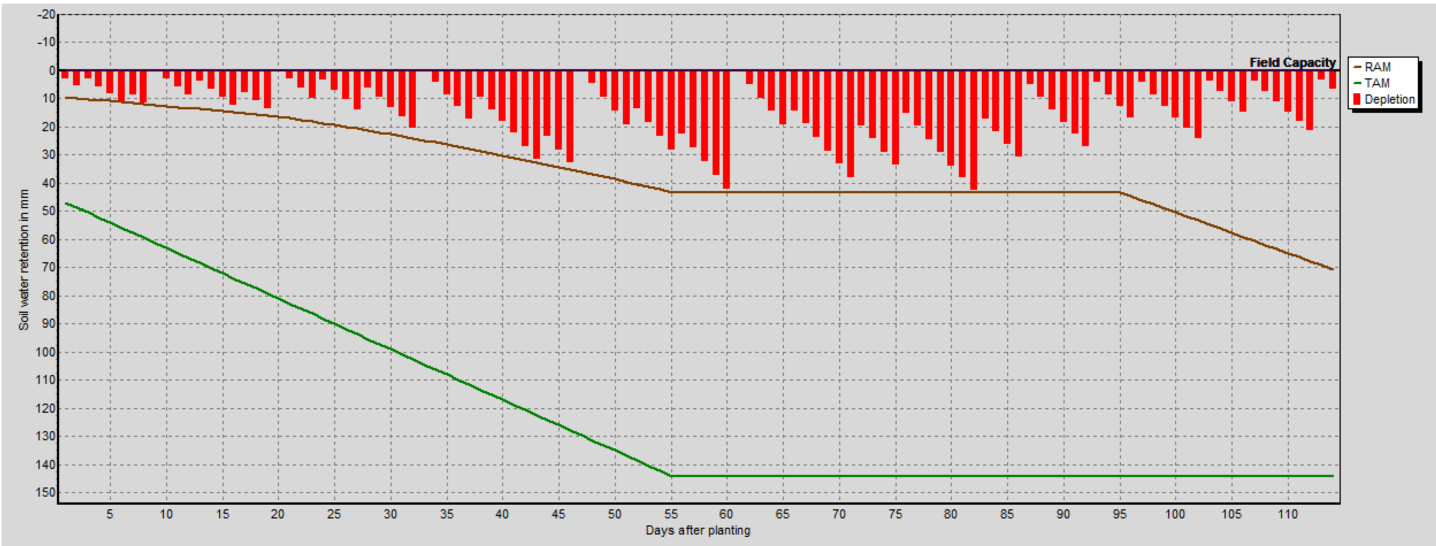

Figure 5: Field crop water schedules for sweet pepper

4. Conclusion

From this study, CROPWAT 8.0 Software can be used to estimate reference Crop Evapotranspiration, Effective Rainfall, Crop water requirement and Irrigation water requirement with the input of climatic data like maximum and minimum temperature, relative humidity, wind speed and sunshine hours and rainfall. Using the FAO CROPWAT 8.0 model used in this study, it can be observed that crop water requirements and schedules were specific to the study area due to the nature of the watershed and Murang'a County as a whole. Among the three crops under study, sweet pepper had the highest amounts of evapotranspiration and water requirements and more frequent irrigation schedules than the other two crops. The ETc values for the garden pea, sweet pepper and tomato were **395.6, 460.1 and 432.7** mm/dec respectively which is within the range provided by FAO, 2008. The irrigation requirements were **155, 187.7 and 158.7** mm/dec for garden pea, tomato, and sweet pepper respectively. The study results enhance a deeper understanding of the water requirements of some major crops in Murang'a County specifically in Maragua where the study was carried out. The results will support improvement of water use by the farmers as well as water management and productivity through policies that can arise from these findings. The use of scientific tools like CROPWAT model can assess the Crop Water Requirements with a high degree of accuracy and suggest the cropping pattern and crop rotation that farmers can readily accept. The results of this study are useful in water resource planning hence helping in saving a lot of water in meeting crop water requirements. They can also be used to guide farmers to select the amount and frequency of irrigation for the crops being studied.

References

[1] Conforti, P., Food and Agriculture Organization of the United Nations, & Food and Agriculture Organization of the United Nations. *Looking ahead in world food and agriculture: Perspectives to 2050*. Rome: Food and Agriculture Organization of the United Nations, 2011.

[2] Burdack, D., *Water management policies and their impact on irrigated crop production in the Murray-Darling basin, Australia*. Potsdam: Univ. Press. 2014.

[3] InGleick, P. H. *The World's Water*. Washington: Island Press, 2011.

[4] Majumdar, D. K. *Irrigation water management: Principles and practice*. New Delhi: Prentice-Hall of India, 2004.

[5] Mohanty, M. S. *Crop growth simulation modelling and climate change*. Jodhpur: SCIENTIFIC PUBLISHER (IND., 2015.

[6] Wallach, D., Makowski, D., Jones, J. W., & Brun, F. *Working with Dynamic Crop Models: Methods, Tools and Examples for Agriculture and Environment*. San Diego: Academic Press [Imprint. 2014.

[7] In Jensen, M. E., In Allen, R. G., American Society of Civil Engineers, & Environmental and Water Resources Institute (U.S.).. *Evaporation, evapotranspiration, and irrigation water requirements*. 2016.

[8] UNESCO. *Nature-based solutions for water*, 2018.

[9] Nayak, T & Choudhary, Mahendra & Pandram, V. Modelling the Crop Water Requirement Using CROPWAT: A Case Study of Samrat Ashok Sagar (Halali) Project Command. 10.13140/RG.2.1.4831.0164., 2016.

[10] FAO. Global map of monthly reference evapotranspiration –GeoNetwork: grid database, Food and Agriculture Organization, Rome, 2008.

[11] AQUASTAT. FAO's Information System on Water and Agriculture. 2009.

[12] Savva, A. P., Frenken, K., Food and Agriculture Organization of the United Nations., & Food and Agriculture Organization of the United Nations.. *Irrigation manual: Planning, development, monitoring and evaluation of irrigated agriculture with farmer participation = Manuel d'irrigation: planification development, suivi et évaluation de l'agriculture irriguée avec la participation des paysans*. Rome: FAO, 2010.

[13] Food and Agriculture Organization of the United Nations. *Guidelines on irrigation investment projects*, 2018.

[14] Ali, M. & Mubarak, S., Effective Rainfall Calculation Methods for Field Crops: An Overview, Analysis and New Formulation. Asian Research Journal of Agriculture. 7. 1-12. 10.9734/ARJA/2017/36812., 2017.

[15] Matthews, R. B., & Stephens, W., *Crop-soil simulation models: Applications in developing countries*. Wallingford, Oxon, UK: CABI Pub, 2002.

[16] Carr, M. K. V., Lockwood, R., & Knox, J. W. *Advances in irrigation agronomy: Plantation crops*. Cambridge: Cambridge University Press, 2012.

[17] Hatfield, J. L., Fleisher, D. H., American Society of Agronomy, Crop Science Society of America, & Soil Science Society of America, *Improving Modeling Tools to Assess Climate Change Effects on Crop Response*. Madison, Wisconsin: American Society of Agronomy, Crop Science Society of America, Soil Science Society of America. 2016.

[18] Ali, M. H., *Fundamentals of irrigation and on-farm water management*. New York: Springer, 2010.

[19] Food and Agriculture Organization of the United Nations. *The state of food and agriculture, 2017*.

[20] Todorovic, M. Crop water requirements. In: Water Encyclopedia: Surface and Agricultural Water (Jay H. Lehr, Jack Keeley, Eds.), AW-59, p. 557-558, John Wiley & Sons Publisher, USA, 2005.

[21] R.G. Allen, L.S. Pereira, D. Rase, Smith, “Crop evapotranspiration: Guidelines for computing crop requirements. Irrigation and Drainage paper No 56”, FAO Rom, Italy1998.