APPLICATION OF FAO-CROPWAT SOFTWARE FOR MODELLING IRRIGATION SCHEDULE OF RICE IN RWANDA

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Abstract

The overall objectives of the present research are the study of weather, soil, discharges in the irrigation channels crop water requirement and irrigation scheduling of rice in Muvumba-8 marshland of Nyagatare district in Rwanda. The specific objective is to study the crop water requirement and irrigation scheduling of rice in the marshland. The average infiltration rate of the soil in the experimental field was 12.8 mm/hour. The average discharge in the primary channel is 7.94 m^3/sec. The average reference crop evapotranspiration for the site was 3.89 mm/day. It varies from 3.51 to 4.38 mm/day. The maximum reference crop evapotranspiration was recorded in August and the minimum was May. The difference between maximum and minimum of reference crop evapotranspiration was observed to be 0.87 mm/day. CROPWAT derived the maximum effective rainfall of 80.3 mm in the month of October and the minimum of 20.9 mm during July. The total irrigation water requirement for rice crop for the season from Sept. to March was 412.7 mm. This low water requirement for rice is mainly due to higher effective rain fall in the experimental site from Sept to Dec. It was also inferred that the higher irrigation is needed from Dec to Feb because effective rainfall is lesser during that period. The moisture depletion pattern during the irrigation schedule varies from 59 to 71% with an average depletion of 64.8%. The net irrigation supplied to the field varies from 11.3 to 14.7 mm with an average net irrigation requirement 13.2 mm. The gross irrigation water requirement was varying from 16.2 to 21 mm with an average gross irrigation requirement of 18.96 mm. The average flow rate of water to the field was worked out to be 0.6 liter/sec/ha and it varies from 0.33 to 0.78 0.6 liter/sec/ha. The total gross irrigation was 906.9 mm and the total net irrigation was 634.8 mm.

Keywords: CROPWAT, rice field, water requirement, irrigation schedule.

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Introduction

Rwanda is a small, hilly, landlocked country in East Africa with the highest population density in Africa. Rwanda has a population of approximately 11.3 million people which is dominated by young people with a median age of 19 years and a population growth rate of 2.6%. The GDP of the economy is 4,685 Billion Rwanda Francs (at constant 2011 prices) with an average growth rate of 7.12% over the last 5 years (LMIS, Rwanda, 2018). The Muvumba P-8 marshland in Nyagatare district of Rwanda has a problem of lack of water during the dry season, flooding in some parts of the marshland during the peak rainy season and lack of management of available land and water resources for rice production. Hence, this paper brings out the modeling of CROPWAT 8.0 software (1992) developed by FAO to the Muvumba P-8 marshland. It will produce the modeling information like Crop Water Requirement and Irrigation Scheduling for rice.

Balder et al. (2004) stated that Alternate wetting and drying (AWD) irrigation has been widely implemented in many areas in China. In this water-saving technology, alternative flooded and non-flooded conditions are practiced in the field. CROPWAT was used in Kenya by Fredrick K. Karanja et al. (2015) and the results showed that an increase in temperature increases the percentage change in crop water use and the changes in rainfall did not appear to change the amount of water used by crops. CROPWAT program helps farmers as per Diku Abdulla et al.(2015) to assess the level of risk in their farm, based on crops they cultivate and hence agricultural advisory service people should be trained in using CROPWAT 8.0 program, since they will be considerably helpful to farmers in this way. CROPWAT was used to estimate the yield reduction caused by water stress and climatic impacts, which makes this model as a best tool for irrigation planning and management in maize as per Muhammad Nazeer (2009). Abdel-Kabirou Bouraima et al. (2015) stated that the CROPWAT was used to estimate the annual reference evapotranspiration of 1967 mm in Northern Benin and the lowest monthly value of annual reference evapotranspiration was 123 in August month. The crop evapotranspiration and the crop irrigation requirements were estimated at 651 mm and 383 mm respectively in rainy season and 920 mm and 1148 mm in dry season respectively.

Hossain et al., (2017) stated that the model estimated mean annual reference evapotranspiration of rice crop, which was 1408 mm for western part of Bangladesh. The observed ETo values were higher during March to August and lower during September to February. The highest monthly ETo (175 mm) was in April and the lowest (70 mm) in December. Shah et al. (2015) stated that the CROPWAT was used to find out the crop water requirements for sorghum, which was 187.5 mm). The net irrigation requirements for sorghum at fixed interval per stage is 173.3 mm and four irrigation are on date 3-Sep, 28-Sep, 17-Nov, 17-Dec with varying depth of 9.6 mm, 3.9 mm, 111.4 mm, 48.4 mm respectively. Mehanuddin et al., (2018) observed that the Sugarcane crop in the developing stage it requires Net irrigation of 196.7 mm, Gross irrigation of 281.0 mm and flow of 0.66 L/s/ha. And at the 109th day of mid stage it requires Net irrigation of 196.8mm, Gross irrigation 281.1mm and Flow of 0.54 L/s/ha and at the 155th day of the mid stage it requires Net irrigation of 199.4mm, Gross irrigation of 284.9mm and Flow of 0.72 L/s/ha. Shakeel et al., (2017) mentioned that CROPWAT is a FAO model for irrigation management which integrates data on climate, crop and soil to assess reference evapotranspiration (ETo), crop evapotranspiration (ETc) and irrigation water requirements. develop irrigation schedules under various management conditions and scheme water supply. Proper and optimal scheduling of irrigation using CROPWAT 8.0 enabled the efficient water use to 70%. Hossain (2017) noted that the higher irrigation requirements during drier months of a season are explained by the severe drought condition and low relative humidity due to lack of rain and high temperatures, which led to increase evapotranspiration. Also observed that when the hottest period with the highest temperature prevailed, high evaporation occurred with rapid decrease in soil moisture implying the highest agricultural water requirement. The overall objectives of the present paper is to carry out simulation using CROPWAT 8.0 software to estimate the Crop Water Requirement (CWR) and Irrigation Scheduling (IS) in the rice field of Muvumba P-8 marshland in Rwanda

Materials and Methods

Site selection

The marshland of Muvumba P 8- site is located in Eastern Province of Nyagatare District and exactly lies in both Tabagwe and Rwempasha sectors. It has cultivable area of 1750 ha alongside Umuvumba River, starting at Gitengure Cell in Tabagwe Sector to Kazaza Cell in Rwempasha Sector, which is near the border of Republic of Uganda. The marshland has been developed since 2011 in order to increase the agricultural productivity. The rice has been selected as the crop to be grown in the developed marshland for the first time because of water availability.

Materials used in lab

During the analysis of soil texture the following materials were used: chemicals like sodium hexametaphosphate and hydrogen per oxide, amyl alcohol, sanbox, soil containers and electronic balance. The computer software which was used is CROPWAT Version 8.0 Software. According to FAO (1992), the CROPWAT version 8 was originally developed by the FAO to calculate rice and upland crops water requirements and irrigation scheme planning.

Soil texture

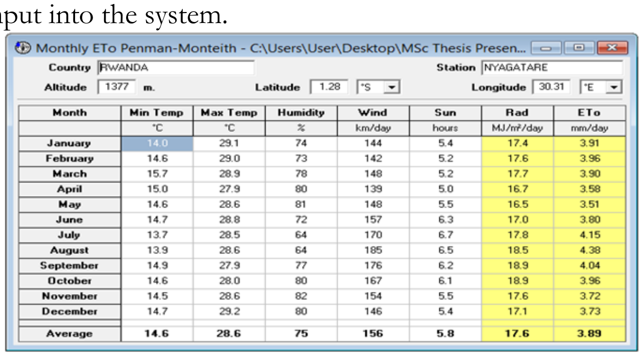
USDA texture triangle is used to classify the soil into twelve major soil texture classifications like sand, loamy sand, sandy loam, loam, silt loam, silt, sandy clay loam, clay loam, silty clay loam, sandy clay, silty clay, and clay. The USDA texture triangle chart was used to find out the soil texture of the experimental field based on the percentage of sand, silt and clay estimated in the laboratory.

Infiltration rate of the soil

The infiltration rate is the velocity or speed at which water enters into the soil. It is usually measured by the depth (in mm or cm) of the water layer that can enter the soil in one hour. The infiltration rate of the study area has been determined experimentally by the use of double ring infiltrometer. It consists of pouring water and put it at a level of 15 cm, which is the initial height of water. The water level after 10 to 15 min was recorded. After recording the final level of water, the ring is refilled to the initial level of 15 cm and the process continues like that until the constant change in water level is obtained. The constant water depletion obtained is called the infiltration rate

Input weather data fed into CROPWAT

The weather data from 1954 to 2017was collected with 15 years of missing data due to national disturbances. The mean monthly data were worked out from the daily data collected for 48 years. It includes the monthly averages of minimum and maximum temperature, rainfall, relative humidity, wind velocity, sunshine hours. These weather data were fed as input into the system.



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Country RWANDA — Station NYAGATARE

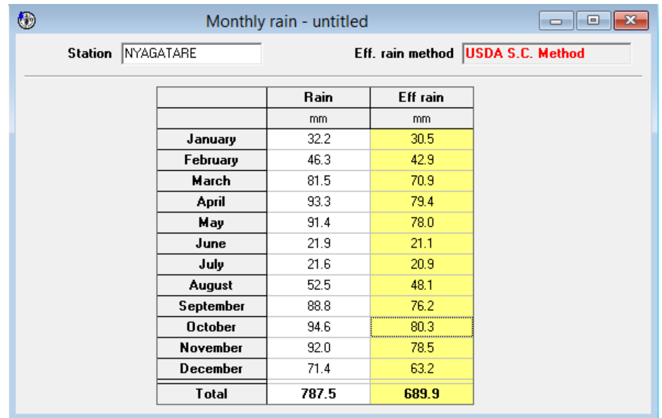
Altitude 1377 m. — Latitude 1.28 °S — Longitude 30.31 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	14.0	29.1	74	144	5.4	17.4	3.91
February	14.6	29.0	73	142	5.2	17.6	3.96
March	15.7	28.9	78	148	5.2	17.7	3.90
April	15.0	27.9	80	139	5.0	16.7	3.58
May	14.6	28.6	81	148	5.5	16.5	3.51
June	14.7	28.8	72	157	6.3	17.0	3.80
July	13.7	28.5	64	170	6.7	17.8	4.15
August	13.9	28.6	64	185	6.5	18.5	4.38
September	14.9	27.9	77	176	6.2	18.9	4.04
October	14.6	28.0	80	167	6.1	18.9	3.96
November	14.5	28.6	82	154	5.5	17.6	3.72
December	14.7	29.2	80	146	5.4	17.1	3.73
Average	14.6	28.6	75	156	5.8	17.6	3.89

Figure 1 Feeding of input weather data into CROPWAT

Input soil data fed into CROPWAT

The soil data like 1) soil type 2) total available soil moisture (difference between field capacity and wilting point) 3) maximum rain infiltration rate and 4) maximum rooting depth were fed as input to the CROPWAT software as shown below.

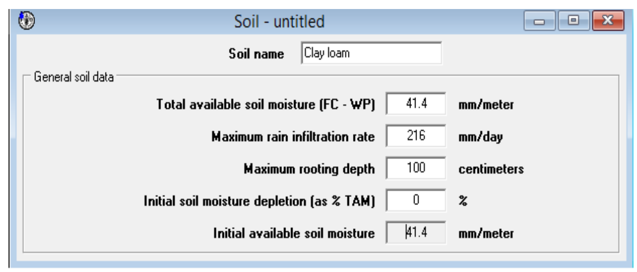


Monthly rain - untitled

Station NYAGATARE — Eff. rain method USDA S.C. Method

	Rain	Eff rain
	mm	mm
January	32.2	30.5
February	46.3	42.9
March	81.5	70.9
April	93.3	79.4
May	91.4	78.0
June	21.9	21.1
July	21.6	20.9
August	52.5	48.1
September	88.8	76.2
October	94.6	80.3
November	92.0	78.5
December	71.4	63.2
Total	787.5	689.9

Figure 2 Feeding input rainfall data into CROPWAT



Soil - untitled

Soil name Clay loam

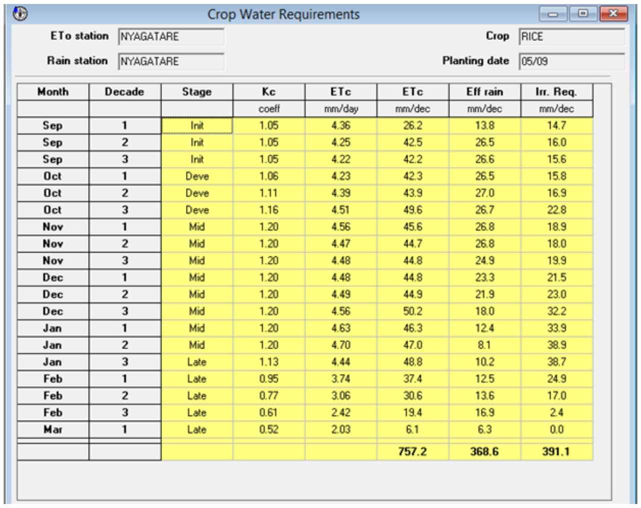
General soil data

Total available soil moisture (FC - WP)	41.4	mm/meter
Maximum rain infiltration rate	216	mm/day
Maximum rooting depth	100	centimeters
Initial soil moisture depletion (as % TAM)	0	%
Initial available soil moisture	41.4	mm/meter

Figure 3 Feeding input soil data into CROPWAT

Outputs received from CROPWAT

The crop water requirement of rice was computed by the software after getting the rice crop and the date of transplantation from the user. The outputs includes the different stages of the crop, crop coefficient (Kc), reference crop evapotranspiration for rice, effective rainfall and irrigation requirement as shown below.



Crop Water Requirements

ETo station NYAGATARE | Crop RICE
Rain station NYAGATARE | Planting date 05/09

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Sep	1	Init	1.05	4.36	26.2	13.8	14.7
Sep	2	Init	1.05	4.25	42.5	26.5	16.0
Sep	3	Init	1.05	4.22	42.2	26.6	15.6
Oct	1	Deve	1.06	4.23	42.3	26.5	15.8
Oct	2	Deve	1.11	4.39	43.9	27.0	16.9
Oct	3	Deve	1.16	4.51	49.6	26.7	22.8
Nov	1	Mid	1.20	4.56	45.6	26.8	18.9
Nov	2	Mid	1.20	4.47	44.7	26.8	18.0
Nov	3	Mid	1.20	4.48	44.8	24.9	19.9
Dec	1	Mid	1.20	4.48	44.8	23.3	21.5
Dec	2	Mid	1.20	4.49	44.9	21.9	23.0
Dec	3	Mid	1.20	4.56	50.2	18.0	32.2
Jan	1	Mid	1.20	4.63	46.3	12.4	33.9
Jan	2	Mid	1.20	4.70	47.0	8.1	38.9
Jan	3	Late	1.13	4.44	48.8	10.2	38.7
Feb	1	Late	0.95	3.74	37.4	12.5	24.9
Feb	2	Late	0.77	3.06	30.6	13.6	17.0
Feb	3	Late	0.61	2.42	19.4	16.9	2.4
Mar	1	Late	0.52	2.03	6.1	6.3	0.0
					757.2	368.6	391.1

Figure 4 Output of Crop Water requirement of rice

Output of crop stages and crop coefficient values

The software produced the outputs like the number of days of different stages of the crop like 1) initial stage 2) development stage 3) mid-season stage 4) late season stage and 5) total duration of the crop. It also produces the different crop coefficient values (Kc) for different stages as shown below.

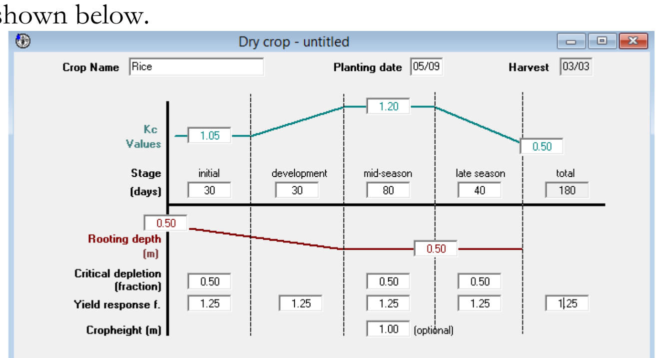
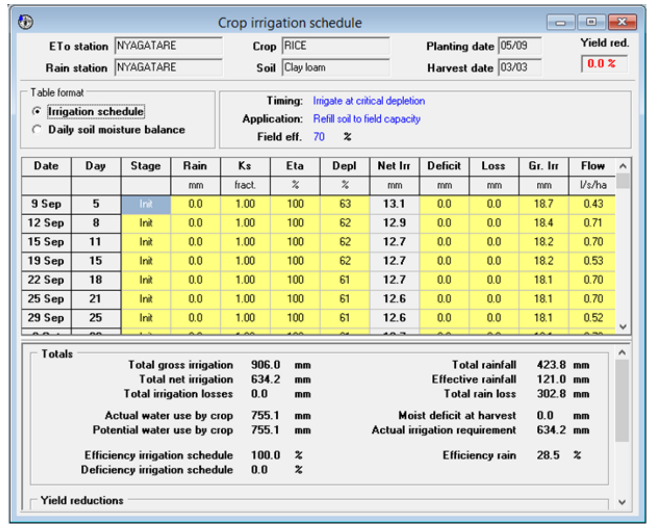


Figure 5 Output of crop coefficient values for different stages

Output of Irrigation scheduling of rice

The software produced the outputs like the irrigation schedule with every 3 days. It includes the 1) Net irrigation 2) Gross irrigation and 3) flow rate in liter /sec/ha for different days of irrigation.



Crop irrigation schedule

ETo station NYAGATARE | Crop RICE | Planting date 05/09 | Yield red.
Rain station NYAGATARE | Soil Clay loam | Harvest date 03/03 | 0.0 %

Table format: Irrigation schedule / Daily soil moisture balance

Timing: Irrigate at critical depletion
Application: Refill soil to field capacity
Field eff. 70 %

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
9 Sep	5	Init	0.0	1.00	100	63	13.1	0.0	0.0	18.7	0.43
12 Sep	8	Init	0.0	1.00	100	62	12.9	0.0	0.0	18.4	0.71
15 Sep	11	Init	0.0	1.00	100	62	12.7	0.0	0.0	18.2	0.70
19 Sep	15	Init	0.0	1.00	100	62	12.7	0.0	0.0	18.2	0.53
22 Sep	18	Init	0.0	1.00	100	61	12.7	0.0	0.0	18.1	0.70
25 Sep	21	Init	0.0	1.00	100	61	12.6	0.0	0.0	18.1	0.70
29 Sep	25	Init	0.0	1.00	100	61	12.6	0.0	0.0	18.1	0.52

Totals

Total gross irrigation	906.0	mm	Total rainfall	423.8	mm
Total net irrigation	634.2	mm	Effective rainfall	121.0	mm
Total irrigation losses	0.0	mm	Total rain loss	302.8	mm
Actual water use by crop	755.1	mm	Moist deficit at harvest	0.0	mm
Potential water use by crop	755.1	mm	Actual irrigation requirement	634.2	mm
Efficiency irrigation schedule	100.0	%	Efficiency rain	28.5	%
Deficiency irrigation schedule	0.0	%			

Yield reductions

Figure 6 Output of Irrigation Scheduling of rice

Reference evapotranspiration (ETo) and Effective rainfall at the site

Reference evapotranspiration is the evapotranspiration from a reference surface and not water surface. The software gave the reference evapotranspiration when the input data like altitude, latitude, longitude, country, station minimum and maximum temperature, relative humidity, wind velocity and sunshine hours. Effective rainfall was received by entering the monthly rainfall.

Net Irrigation Requirement at the site

Net Irrigation Requirement (NIR) is different from the Crop Water Requirement (CWR). CWR is the water used by the plant for its growth, evapotranspiration and water loses during land preparation and transplantation etc., whereas NIR is the irrigation water supplied to the field so that the crop gets its full CWR and it did not include any water losses in the process of irrigation.

CROPWAT 8.0 software gave the output of rice water requirement using the following formula.

ETc = Kc x ETo Where ETc = Crop evapotranspiration, mm; Kc = Crop coefficient
ETo = Reference evapotranspiration, mm

CROPWAT 8.0 software also gives the output of Net Irrigation Requirement (NIR) for rice using the following formula.

$IR_n = \sum_{t=0}^{T}(Kc.ETo - Peff)$

Where IR_n = Net irrigation requirement, mm; ETo = Reference evapotranspiration, mm

$Peff$ = Effective dependable rainfall, mm; Kc = Crop coefficient;
T= Total Growing Period of Crop

Irrigation schedule for the site

Irrigation scheduling gives the time to irrigate and how much water to be supplied in each irrigation. The software was built to work out the irrigation scheduling by keeping the irrigation efficiency of 70%. CROPWAT 8.0 software gives the output of irrigation schedule for 180 days, which is the duration of rice crop in the experimental region of Rwanda.

Results and discussion

This section gives the results and discussion about the infiltration rate of the soil and the modeling of the CROPWAT software for water requirement and irrigations scheduling.

Infiltration rate of soil

The infiltration rate is the speed at which water enters into the soil. It is usually measured by the depth in mm or cm of the water layer that can enter the soil in one hour. Table 1 shows the results obtained during the experiment.

Table 1Infiltration rate of soil in experimental plots

Time, min	Infiltration test in plot 1				Infiltration test in plot 2				Infiltration test in plot 3			
	Water level in cm			Infiltration rate	Water level in cm			Infiltration rate	Water level in cm			Infiltration rate
	Before filling	After filling	Depth of water	cm/hour	Before filling	After filling	Depth of water	cm/hour	Before filling	After filling	Depth of water	cm/hour
0	-	15.00			-	15.00			-	15.00		
10	7.30	15.00	7.70	46.20	11.50	15.00	3.50	21.00	12.20	15.00	2.80	16.80
20	8.60	15.00	6.40	19.20	12.00	15.00	3.00	9.00	12.70	15.00	2.30	6.90
30	9.20	15.00	5.80	11.60	11.40	15.00	3.60	7.20	12.10	15.00	2.90	5.80
45	9.30	15.00	5.70	7.60	10.95	15.00	4.05	5.40	11.65	15.00	3.35	4.47
60	10.00	15.00	5.00	5.00	11.00	15.00	4.00	4.00	11.70	15.00	3.30	3.30
75	10.50	15.00	4.50	3.60	10.50	15.00	4.50	3.60	11.20	15.00	3.80	3.04
90	11.00	15.00	4.00	2.67	12.00	15.00	3.00	2.00	12.70	15.00	2.30	1.53
100	11.30	15.00	3.70	2.22	13.00	15.00	2.00	1.20	13.45	15.00	1.55	0.93
120	10.00	15.00	5.00	2.25	13.20	15.00	1.80	0.90	13.63	15.00	1.37	0.69
150	9.38	15.00	5.62	2.25	12.75	15.00	2.25	0.90	13.30	15.00	1.75	0.70
180	8.25	15.00	6.75	**2.25**	12.30	15.00	2.70	**0.90**	12.90	15.00	2.10	**0.70**

Table 1 shows that the infiltration rate of the plot 1, plot and plot 3 are 2.25, 0.90 and 0.70 cm/hour respectively. The average infiltration rate of the experimental field at Muvumba P-8 marshland was 1.28 cm/hour or 12.8 mm/hour. It means that a water layer of 12.8 mm on the soil surface will take one hour to infiltrate. The class of infiltration of the experimental plot was based on Majumdar (2000). As per the infiltration test, the average infiltration rate of the experimental field at Muvumba P-8 marshland was 1.28 cm/hour. As per Majumdar (2000) classification of infiltration rate of the soil, the experimental plot at Muvumba P-8 marshland was of moderately slow infiltration rate.

3.2 Estimation of crop water requirement and irrigation requirements in the site

The software CROPWAT 8.0 developed by FAO was used to find out the crop water requirements, irrigation requirements of rice and irrigation schedule in P-P Muvumba marshland using the input data like soil, climate and crop data

3.2.1 Reference evapotranspiration and Effective rainfall at the site

Reference evapotranspiration is the evapotranspiration from a reference surface and not water surface. It is closely showing the evapotranspiration of alfalfa grass based on physical, physiological and aerodynamic parameters. When rainfalls, part of the rainwater goes as runoff and another part of the water percolates down ward. The remaining part of water s stored in the root zone is called effective rainfall. The ETo and effective rainfall for different months are shown below.

Table 2 Reference evapotranspiration (ETo) at the site

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean\total
ETo, mm\day	3.91	3.97	3.89	3.57	3.51	3.80	4.15	4.38	4.04	3.96	3.72	3.73	3.89 (mean)
Effect.RF, mm\month	30.5	42.9	70.9	79.4	78.0	21.1	20.9	48.1	76.2	80.3	78.5	63.2	689.9 (total)

Table 2 shows that the mean ETo for the P-8 Muvumba site was 3.89 mm/day. It varies from 3.51 to 4.38 mm/day. The maximum ETo was in August and the minimum was recorded in the month of May. The difference between maximum and minimum of ETo was 0.87 mm/day. Maximum effective rainfall of 80.3 mm was observed in the month of October and the minimum of 20.9 mm was during July. It shows that July is the driest month, which needs more irrigation and the high rainfall was in October.

Table 3 Crop Water Requirement of rice

Month	Decade	Stage of crop	Kc	ETc mm/day	ETc mm/dec	Effective Rain mm/dec	Net Irrigation requirement mm/dec
Sep	1	Initial	1.05	4.36	26.2	13.8	14.7
Sep	2	Initial	1.05	4.25	42.5	26.5	16
Sep	3	Initial	1.05	4.22	42.2	26.6	15.6
Oct	1	Develop	1.06	4.23	42.3	26.5	15.8
Oct	2	Develop	1.16	4.39	43.9	27	16.9
Oct	3	Develop	1.20	4.51	49.6	26.7	22.8
Nov	1	Mid	1.20	4.56	45.6	26.8	18.9
Nov	2	Mid	1.20	4.47	44.7	26.8	18
Nov	3	Mid	1.20	4.48	44.8	24.9	19.9
Dec	1	Mid	1.20	4.48	44.8	23.3	21.5
Dec	2	Mid	1.20	4.49	44.9	21.9	23
Dec	3	Mid	1.20	4.56	50.2	18	32.2
Jan	1	Mid	1.20	4.63	46.3	12.4	33.9
Jan	2	Mid	1.20	4.70	47	8.1	38.9
Jan	3	Late	1.13	4.44	48.8	10.2	38.7
Feb	1	Late	0.95	3.74	37.4	12.5	24.9
Feb	2	Late	0.77	3.06	30.6	13.6	17
Feb	3	Late	0.61	2.42	19.4	16.9	24
Mar	1	Late	0.52	2.03	6.1	6.3	0
Total irrigation water requirement for rice for the season (Sep. to March)							412.7

3.3 Net Irrigation Requirement at the site

Net Irrigation Requirement (NIR) is different from the CWR. CWR is the water used by the plant for its growth, evapotranspiration and water loses during land preparation and transplantation etc., whereas NIR is the irrigation water supplied to the field so that the crop gets its full CWR and it did not include any water losses in the process of irrigation. The Crop Water Requirement of rice was given as output by the system and is shown Table 3.Table 3 shows that the total irrigation water requirement for rice crop for the season from Sep. to March was 412.7 mm. This low water requirement for rice is mainly due to higher effective rain fall in the experimental site from Sept to Dec.Higher irrigation is needed from Dec to Feb because effective rainfall is lesser during that period.

3.4 Irrigation schedule for the site

Table 4. Irrigation schedule for the experimental site

Date	Days	Stage	Ks Fract	Eta %	Depl %	Net Irr, mm	Deficit, mm	Loss, mm	Gr. Irr, mm	Flow l/s/ha
09-Sep	5	Initi	1.00	100	64	13.1	0.0	0.0	18.7	0.43
12-Sep	8	Initi	1.00	100	63	12.9	0.0	0.0	18.4	0.71
15-Sep	11	Initi	1.00	100	62	12.7	0.0	0.0	18.2	0.70
19-Sep	15	Initi	1.00	100	62	12.7	0.0	0.0	18.2	0.53
22-Sep	18	Initi	1.00	100	62	12.7	0.0	0.0	18.1	0.70
25-Sep	21	Initi	1.00	100	62	12.6	0.0	0.0	18.1	0.70
29-Sep	25	Initi	1.00	100	62	12.6	0.0	0.0	18.1	0.52
02-Oct	28	Initi	1.00	100	62	12.7	0.0	0.0	18.1	0.70
05-Oct	31	Dev.	1.00	100	62	12.7	0.0	0.0	18.1	0.70
09-Oct	35	Dev.	1.00	100	62	12.7	0.0	0.0	18.1	0.52
12-Oct	38	Dev.	1.00	100	63	13.0	0.0	0.0	18.6	0.72
15-Oct	41	Dev.	1.00	100	64	13.2	0.0	0.0	18.8	0.73
19-Oct	45	Dev.	1.00	100	64	13.2	0.0	0.0	18.8	0.54
22-Oct	48	Dev.	1.00	100	65	13.4	0.0	0.0	19.1	0.74
25-Oct	51	Dev.	1.00	100	66	13.5	0.0	0.0	19.3	0.74
29-Oct	55	Dev.	1.00	100	66	13.5	0.0	0.0	19.3	0.56
01-Nov	58	Dev.	1.00	100	66	13.6	0.0	0.0	19.4	0.75
05-Nov	62	Mid	1.00	100	67	13.7	0.0	0.0	19.5	0.57
09-Nov	66	Mid	1.00	100	67	13.7	0.0	0.0	19.5	0.57
12-Nov	69	Mid	1.00	100	66	13.5	0.0	0.0	19.3	0.74
15-Nov	72	Mid	1.00	100	65	13.4	0.0	0.0	19.1	0.74
19-Nov	76	Mid	1.00	100	65	13.4	0.0	0.0	19.1	0.55
22-Nov	79	Mid	1.00	100	65	13.4	0.0	0.0	19.2	0.74
25-Nov	82	Mid	1.00	100	65	13.4	0.0	0.0	19.2	0.74
29-Nov	86	Mid	1.00	100	65	13.4	0.0	0.0	19.2	0.55
02-Dec	89	Mid	1.00	100	65	13.4	0.0	0.0	19.2	0.74
05-Dec	92	Mid	1.00	100	65	13.4	0.0	0.0	19.2	0.74
09-Dec	96	Mid	1.00	100	65	13.4	0.0	0.0	19.2	0.56
12-Dec	99	Mid	1.00	100	65	13.4	0.0	0.0	19.2	0.74
15-Dec	102	Mid	1.00	100	65	13.5	0.0	0.0	19.2	0.74
19-Dec	106	Mid	1.00	100	65	13.5	0.0	0.0	19.2	0.56
22-Dec	109	Mid	1.00	100	66	13.6	0.0	0.0	19.4	0.75
25-Dec	112	Mid	1.00	100	67	13.7	0.0	0.0	19.5	0.75
29-Dec	116	Mid	1.00	100	67	13.7	0.0	0.0	19.5	0.57
01-Jan	119	Mid	1.00	100	67	13.7	0.0	0.0	19.6	0.76
05-Jan	123	Mid	1.00	100	68	13.9	0.0	0.0	19.8	0.57
09-Jan	127	Mid	1.00	100	68	13.9	0.0	0.0	19.8	0.57
12-Jan	130	Mid	1.00	100	68	14.0	0.0	0.0	20.0	0.77
15-Jan	133	Mid	1.00	100	69	14.1	0.0	0.0	20.2	0.78
19-Jan	137	Mid	1.00	100	71	14.7	0.0	0.0	21.0	0.61
22-Jan	140	Mid	1.00	100	66	13.6	0.0	0.0	19.4	0.75
25-Jan	143	End	1.00	100	65	13.4	0.0	0.0	19.1	0.74
29Jan	147	End	1.00	100	65	13.4	0.0	0.0	19.1	0.55
01-Feb	150	End	1.00	100	62	12.7	0.0	0.0	18.1	0.70
05-Feb	154	End	1.00	100	65	11.3	0.0	0.0	16.2	0.47
09-Feb	148	End	1.00	100	65	11.3	0.0	0.0	16.2	0.47
15-Feb	164	End	1.00	100	59	12.1	0.0	0.0	17.3	0.33
20-Feb	169	End	1.00	100	61	12.5	0.0	0.0	17.8	0.41
03-Mar	End	End	1.00	0	0					
IRRIGATION SCHEDULE AND RAINFALL										

Irrigation scheduling gives the time to irrigate and how much water to be supplied in each irrigation. The software was built to work out the irrigation scheduling by keeping the irrigation efficiency of 70%. The effect of irrigation schedule is shown in Table 4.

Table 4 brings out the following facts through the modeling of CROPWAT 8.0 software. The date of planting of rice was on 5 September of the year and the crop was harvested on 3 March and the duration of the crop was 180 days. There were three stages of the crop namely initial stage, development stage, mid stage and harvesting end stage. The water stress coefficient (Ks) was assumed to be 1 and the actual evapotranspiration (ETa) was assumed as 100% during the entire cropping season. The moisture depletion pattern during the irrigation schedule varies from 59 to 71% with an average depletion of 64.8%. The net irrigation supplied to the field varies from 11.3 to 14.7 mm with an average net irrigation requirement 13.2 mm. There was no deficit of irrigation to the crop and hence it was marked as 0 mm during the entire cropping schedule. There was no loss of water and hence it was marked as 0 mm during the entire cropping schedule. The gross irrigation water requirement was varying from 16.2 to 21 mm with an average gross irrigation requirement of 18.96 mm. The average flow rate of water to the field was worked out to be 0.6 liter/sec/ha and it varies from 0.33 to 0.78 0.6 liter/sec/ha.

CROPWAT 8.0 also gave information like the total gross irrigation was 906.9 mm and the total net irrigation was 634.8 mm. Similarly, total rainfall during the season was 423.8 mm and the effective rainfall during the season of Sep to March was 121.7 mm. It was observed that irrigation efficiency of the modeling was 100% and the efficiency of rain was 28.7%.

Conclusion

The simulation study of estimation of crop water requirement and irrigation scheduling was conducted using CROPWAT 8.0, the conclusions are summarized hereunder. The soil texture from top of the soil up to 45 cm depth was same as sandy clay loam but after 45 to 60 cm, it was clay loam texture. Average infiltration rate of the soil in the experimental field was 12.8 mm/hour. It means that a water layer of 12.8 mm on the soil surface will take one hour to infiltrate. As per Majumdar (2000) classification of infiltration rate of the soil, the marshland was found to have moderately slow infiltration rate. Hence, the percolation loss of water will be minimum. Average reference crop evapotranspiration (mean ETo) for the P-8 Muvumba site was 3.89 mm/day. It varies from 3.51 to 4.38 mm/day. The maximum ETo was in the August and the minimum was in May. The difference between maximum and minimum of ETo was 0.87 mm/day. Maximum effective rainfall of 80.3 mm was in October and the minimum of 20.9 mm was during July. It shows that July is the driest month, which needs more irrigation and the high rainfall was in October. It was that the total irrigation water requirement for rice crop for the season from Sept. to March was 412.7 mm. This low water requirement for rice is mainly due to higher effective rain fall in the experimental site from Sept to Dec. It was also inferred that the higher irrigation is needed from Dec to Feb because effective rainfall is lesser during that period.

The moisture depletion pattern during the irrigation schedule varies from 59 to 71% with an average depletion of 64.8%. The net irrigation supplied to the field varies from 11.3 to 14.7 mm with an average net irrigation requirement 13.2 mm. The gross irrigation water requirement was varying from 16.2 to 21 mm with an average gross irrigation requirement of 18.96 mm. The average flow rate of water to the field was worked out to be 0.6 liter/sec/ha and it varies from 0.33 to 0.78 0.6 liter/sec/ha. It was found from simulation that the total gross irrigation was 906.9 mm and the total net irrigation was 634.8 mm. Similarly, total rainfall during the season was 423.8 mm and the effective rainfall during the season of Sept. to March was 121.7 mm. Irrigation efficiency of the simulated model was 100% and the efficiency of rain was 28.7% in the Muvumba marshland of Rwanda. The researcher recommends that there is a need to motivate future researchers especially students to undertake the similar initiatives for adding more researches about similar modeling and simulation subjects because it will combat the problem of low rainfall hence productivity of agricultural outputs will be increased.

Acknowledgement

I acknowledge the help rendered by Department of Agricultural Mechanization and
Swedish Agricultural University for the support in data collection in the field and analysis.

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