ISSN 0511-5728
The West Indian Journal of Engineering
Vol.37, No.2, January 2015, pp.31-36

Simulation of Irrigation Water Requirements of Some Crops in Trinidad Using the CROPWAT Irrigation Software

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(Received 13 June 2014; Revised 07 October 2014; Accepted 18 October 2015)

Abstract: *The Crop Water Requirements (CROPWAT) computer software package was used to design irrigation schedules during the dry season (February to May) for twelve (12) major farming locations in Trinidad. The irrigation schedules are for the nine major crops grown in different predominant soils in the selected locations. Crop and field parameters were obtained from published texts whereas the climatological data were obtained from the Water Resources Agency in Trinidad. The irrigation schedules using CROPWAT were planned in such a way that for the convenience of the farmer, the irrigation depth and irrigation interval were kept constant throughout the growing season for each crop and this value depended on the climatological situation or the water consumption pattern of the crops.*

Keywords: *Irrigation, Scheduling, Crop, Soil, Trinidad*

1. Introduction

Scientific irrigation scheduling is the best management practice needed for improving farm irrigation management (Simon et al., 1998). One of the objectives of irrigation management is to plan irrigation schedules, that is, to determine the correct water depth and interval of future irrigations in a locality so as to achieve optimal crop productivity (Evans et al., 1996). If water deliveries are untimely or not in desired volume, irrigation efficiency decreases. In Trinidad, the process of determining the artificial amounts of water needed by crops is seen as unimportant. The interaction of the authors with the farmers showed that they were either over-irrigating or under-irrigation their crops. Limited supply will lead to a reduction in yield whereas excess water results in percolation losses, leaching of nutrients and may cause temporary water-logging (Ekwue and Rigg, 2001).

Optimal irrigation practice requires accurate planning of the irrigation schedule. The challenge in irrigation scheduling is to achieve optimum yield with minimum water losses. Irrigation scheduling is normally achieved by observing the plants, keeping a water balance sheet, measuring the soil moisture content and using computer software (Evans et al., 1996; Goldsmith et al., 1988). The common computer software used in irrigation scheduling includes California Irrigation Management Information System, CIMIS (Allen et al., 2010), Crop Irrigation Water Requirements, CRIWAR (Lenselink and Jurriens, 1993), Irrigation Scheduling Information System, IRSIS (Raes et al., 1988a) and the Crop Water Requirements, CROPWAT (Smith, 1992) of the Food and Agriculture Organisation of the United Nations. Goldsmith et al. (1988) also developed a computer spreadsheet model for scheduling irrigation.

Information on the required depths and time of carrying out irrigation practice in different soils for different crops in many areas in Trinidad and the Caribbean region as a whole, is not readily available. Smith (1959) computed the irrigation needs of many Islands of the Caribbean region using the rainfall and evapotranspiration data. He did not actually produce irrigation schedules in these locations which require information about the weather, crop and field data. Ekwue and Rigg (2001) used IRSIS to schedule and evaluate irrigation patterns in the St. Mary Banana Estates in Jamaica. There is the need to extend this evaluation to other parts of the Caribbean region and beyond.

This paper reports the result of a study undertaken to collect, collate weather, crop and field data from 12 major farming locations in Trinidad in the Caribbean region in order to produce optimal irrigation schedules which will be used for the major crops grown in different soils.

2. Materials and Methods

A computer programme for irrigation planning and management, CROPWAT, was developed to plan irrigation schedules at field level (Smith, 1992). The version of CROPWAT used, CROPWAT 8.0 for Windows (FAO, 2013) calculates crop water requirements and irrigation requirements based on soil, climate and crop water using the procedures of Allen et al. (1998) and Dorrenbos and Kassam (1979).

For a given climate, crop and field, it offers the possibilities of computing the net irrigation requirements and the optimal water distribution resulting in the highest yield under conditions of limited water. CROPWAT shows the consequences of the irrigation schedule in terms of water application efficiency and expected yield response. The main strength of the software is its ability to ease the calculation of alternative irrigation schedules, their consequences and the effect on the different entities of the soil water balance. The software was used to plan irrigation schedules of twelve (12) irrigation areas in Trinidad (see Table 1).

3. Simulation of Irrigation Schedules

To run CROPWAT, the following data has to be specified:

a. The climatological data which consist of the reference crop evapotranspiration (ET_0) and the rainfall data. For irrigation scheduling, Allen et al. (1998) suggested the use of monthly climatological normals of ET_o and monthly levels of rainfall that will be exceeded in 4 out of 5 years (80% dependable rainfall), termed effective rainfall. For this study, ET_o (see Table 2) was computed by CROPWAT using the Penman-Monteith method. The Penman-Monteith method is the one recommended by the International Commission for Irrigation and Drainage (ICID) and the Food and Agriculture Organisation (FAO) of the United Nations. Its use has also been found promising within the Caribbean region (Simon *et al.*, 1998). The weather data (air temperature, wind speed, humidity and radiation) used for the ET_o computation as well as mean monthly rainfall data were collected for the four weather stations from the Water Resources Agency in Trinidad. The four (4) weather stations are in close proximity to the 12 irrigation areas (see Table 1). The effective rainfall values (see Table 2) were computed from the rainfall values using empirical linear equation derived by Ekwue *et al.* (1997) for Trinidad.

b. The crop data consist of information about the length of crop development stages of the crop, the critical crop depletion factor (p-factor), the crop coefficient (K_c) and the crop yield response factor to water (K_y). The p-factor expresses the fraction of the soil water that can be extracted at the potential rate by the roots. It is given as the ratio between the readily available and the total available soil water. The data for the nine major crops used in this study (see Table 3) were extracted from the data presented by Allen et al. (1998) and Doorenbos and Kassam (1979). Planting date for the crops was put as February 1st, which is during the dry season when supplementary irrigation is needed in Trinidad.

Table 1. Weather stations and the irrigation areas

Weather Stations	Elevation (m)	Longitude (W)	Latitude (N)	Irrigation areas covered
Hollis Reservoir	150	61° 11’	10° 41’	Plum Mitan; Fishing Pond/Oroupouche
UWI Field Station	15	61° 23’	10° 58’	Aranguez; Macoya; Bamboo Settlement; Orange Groove
Navet Reservoir	122	61° 11’	10° 24’	Rio Claro; Tabaquite; Biche/Cuche
Piarco Met Office	11	61° 21’	10° 35’	Cunupia; Felicity; Maloney/Arouca

Table 2. Reference crop evapotranspiration, ET_o (mm/day); rainfall (mm) and effective rainfall (mm) of the various months for four weather stations near to the irrigation areas

Weather stations	January	Feb.	March	April	May	June	July	August	Sept.	Oct.	Nov	Dec.
Hollis Reservoir	*3.61 **191 ***131	3.87 132 84	4.71 107 64	4.20 134 85	4.45 195 134	3.97 334 245	4.38 349 257	4.68 346 255	4.37 218 152	3.95 285 206	3.50 380 282	3.44 355 262
UWI Field Station	3.79 85 46	4.38 51 19	4.79 32 4	5.03 51 19	4.87 93 52	4.34 160 106	4.15 210 146	4.14 237 168	4.28 161 107	4.03 183 124	3.72 203 140	3.57 134 85
Navet Reservoir	3.61 154 101	3.79 82 44	4.36 41 11	4.27 48 17	3.75 113 69	3.30 246 175	3.69 269 193	4.01 198 137	3.99 130 82	3.72 145 94	2.97 207 144	3.31 216 157
Piarco Met Office	4.27 81 43	4.88 60 26	5.33 35 6	5.60 53 21	5.27 125 78	4.50 200 138	4.41 217 152	4.47 231 162	4.56 142 92	4.23 162 107	3.90 197 136	3.77 148 97

Notes: *Reference crop evapotranspiration, ET_o **Rainfall, R ***Effective Rainfall = -22.1 + 0.75 R. Values are averages for the periods 2001 to 2012.

c. The crop data consist of information about the length of crop development stages of the crop, the critical crop depletion factor (p-factor), the crop coefficient (K_c) and the crop yield response factor to water (K_y). The p-factor expresses the fraction of the soil water that can be extracted at the potential rate by the roots. It is given as the ratio between the readily available and the total available soil water. The data for the nine major crops used in this study (see Table 3) were extracted from the data presented by Allen et al. (1998) and Doorenbos and Kassam (1979). Planting date for the crops was put as February 1st, which is during the dry season when supplementary irrigation is needed in Trinidad.

d. The field data comprise the soil water content at field capacity and at the permanent wilting point together with the basic infiltration rate. The field data (see Table 4) for the 10 typical soil textures found in the different locations used in this study were taken from data presented by Brown and Bally (1976).

Table 3. Crop data for the nine major crops grown in Trinidad

Crops	Critical crop depletion fraction, p	Rooting depths (cm)	Crop growth periods (days)			
			Initial	Crop development	Mid-season	Late-season
Water melons	0.40	130	Days: 25 $^{*}K_c$: 0.50 $^{**}K_y$:0.50	35 - 0.60	40 1.05 1.10	20 0.75 0.80
Pumpkin	0.35	130	Days: 20 K_c: 0.60 K_y: 0.20	30 - 0.40	30 1.00 0.45	20 0.80 0.60
Egg plant	0.40	110	Days: 30 K_c: 0.60 K_y: 1.40	45 - 0.60	40 1.05 1.20	25 0.90 0.60
Cucumbers	0.50	100	Days: 20 K_c: 0.60 K_y: 0.20	30 - 0.40	40 1.05 0.45	15 0.90 0.60
Tomatoes	0.40	100	Days: 30 K_c: 0.60 K_y: 0.50	40 - 0.60	45 1.15 1.10	30 0.80 0.80
Sweet peppers	0.30	80	Days: 30 K_c: 0.60 K_y: 1.40	35 - 0.60	40 1.05 1.20	20 0.90 0.60
Cabbage	0.45	50	Days: 40 K_c: 0.70 K_y: 0.20	60 - 0.40	50 1.05 0.45	15 0.95 0.60
Cauliflower	0.45	50	Days: 35 K_c: 0.70 K_y: 0.20	50 - 0.40	40 1.05 0.45	15 0.95 0.60
Lettuce	0.30	40	Days: 20 K_c: 0.70 K_y: 0.20	30 - 0.40	15 1.00 0.45	10 0.95 0.60

Notes: * K_c is crop factor; ** K_y is crop yield response factor

Table 4. Field data for the soil types in different irrigation areas

Weather stations	Irrigation areas	Soil types	Field capacity, % by mass	Permanent wilting point, % by mass	Bulk density (g/cm^3)	Infiltration rates (mm/d)
Hollis Reservoir	Fishing Pond/Oroupouche	Sangre Grande Silty clay	36	24	1.32	264
	Plum Mitan	Navet clay	33	24	1.20	228
UWI Field Station	Orange Groove	Sandy clay loam	29	13	1.28	547
	Macoya					
	Bamboo Settlement					
	Aranguez	Clay	33	14	1.25	204
Navet Reservoir	Rio Claro	Ecclesvile clay loam	36	18	1.14	298
	Biche/Cuche	Navet clay	33	24	1.20	228
	Tabaquite	Brasso clay	35	17	1.15	228
Piarco Met Office	Cunupia	Cunupia silty clay	36	24	1.32	254
	Felicity	Felicity clay loam	30	22	1.38	298
	Maloney/Arouca	Clay loam	22	10	1.38	298

With the weather, crop and soil data specified for the different locations, the irrigation schedules were determined for the 80% dependable rainfall. In order to obtain an easy and manageable schedule for farmers, the time criterion in the CROPWAT software was set to "fixed interval" while the depth criterion was set at "fixed depth" for periods of the irrigation season. The following approach was used. First a constant irrigation depth was selected based on the soil type and the rooting depth of the crop. In all the cases, it was found that the interval between irrigations could be kept constant for the whole irrigation season, without inducing deep percolation or crop stress.

As an example, for the scheduling of irrigation of tomato grown on clay soil in Aranguez (see Table 5), after entering the constant depth and interval of irrigation, the irrigation simulation was carried out. The diagram obtained for the root zone depletion of water for the crop was examined. Irrigation is ideal when the water depletion levels fall between the readily available water and the field capacity as shown in Figure 1. The table of expected yield response within the software was checked to ensure that at the different growth stages of the crop, the yield response was 100% or very close to it. The table on irrigation efficiency was also checked to make sure that irrigation efficiencies were very close to 100%. Depending on the results of the simulations, the schedule could be adapted and tested again until ideal root zone depletion pattern similar to that in Figure 1 was obtained.

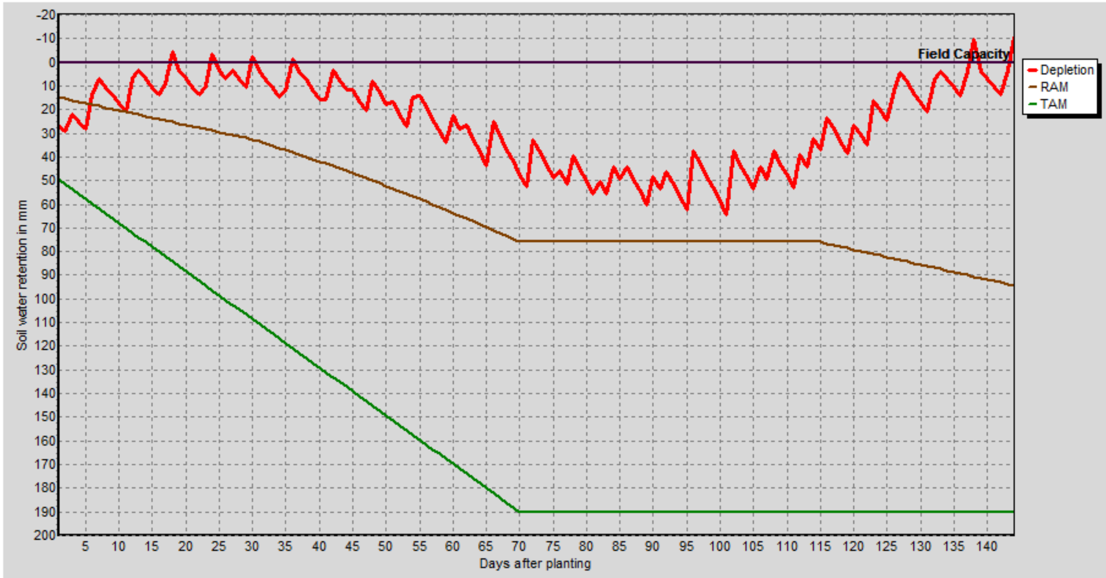
4. Discussion of Simulation Results

The irrigation schedules designed for the crops grown in different soils in the twelve locations in Trinidad are summarised in Table 5. For all schedules derived, the irrigation depth was kept constant throughout the growing season and the irrigation interval was also kept constant. The depth of water chosen for simulation was a function of the root zone depth of the crop as well as the water storage capacity of the soil.

The crops with deep root systems like the tomatoes with maximum root depth of 100 cm (see Table 3) could be applied larger depths of water (up to 17 mm of water, see Table 5) without causing water-logging, especially if they are grown in clay soils which have large water storage capacity. This was shown by the larger difference between the values of field capacity and the permanent wilting point (see Table 4). The irrigation interval in such cases is large (i.e., 6 days), meaning that irrigation would be applied less often.

Table 5. Irrigation scheduling parameters for the different irrigation areas

Weather stations	Irrigation areas	Crops	Irrigation water requirements (mm)	Irrigation scheduling parameters	
				Depth (mm)	Interval (days)
UWI Field Station	Aranguez clay	Tomato	422	17	6
		Sweet pepper	380	10	3
		Cabbage	390	9	3
	Macoya sandy clay loam	Egg plant	380	17	5
		Tomato	422	17	5
		Cabbage	390	9	3
	Orange Grove sandy clay loam	Pumpkin	326	17	5
		Tomato	422	17	5
		Egg plant	381	17	5
	Bamboo Settlement sandy clay loam	Sweet pepper	380	10	3
		Cabbage	390	9	3
Hollis Reservoir	Plum Mitan clay	Tomato	111	6	6
		Pumpkin	94	9	6
		Water melon	92	9	6
	Fishing Pond/North Oroupouche silty clay	Tomatoes	111	9	6
		Pumpkin	94	9	6
Navet Reservoir	Rio Claro clay loam	Water melon	255	14	6
		Pumpkin	250	14	6
		Cucumber	259	14	6
	Biche/Cuche clay	Water melon	255	15	6
		Cucumber	259	16	6
		Pumpkin	250	18	6
	Tabaquite clay	Cauliflower	272	8	3
		Pumpkins	250	15	6
Piarco Met Office	Cunupia silty clay	Sweet pepper	419	11	3
		Pumpkins	375	20	5
	Felicity clay loam	Tomatoes	460	20	5
		Cucumber	389	17	4
	Maloney/Arouca clay loam	Cauliflower	429	10	3
		Lettuce	393	9	3



Notes: RAM: Readily available moisture; TAM: Total available moisture

Figure 1. Simulation results for irrigation of tomatoes grown in Aranguez clay soil

On the other hand, shallow rooted crops like cabbage with maximum root depth of 0.5 m (see Table 3) could only be applied 9 mm of irrigation water at a time if grown in the same clay soil (see Tables 5). Irrigation in this case is more often (i.e., 3 days).

5. Conclusions

It has been shown that the CROPWAT software package is an easy tool to generate the optimal irrigation pattern of crops in Trinidad. Another similar software, Irrigation Scheduling Information Systems (IRSIS), has been used to schedule irrigation projects in France, Brazil and Jamaica by Raes *et al.* (1988b), De Goes et *al.* (1992) and Ekwue and Rigg (2011), respectively. Goldsmith et al. (1988) also described the use of a computer spreadsheet model to produce irrigation schedules for smallholder farmers in Zimbabwe and Thailand. The main strength of the CROPWAT software is that each of the designed schedules could be evaluated in terms of crop response and deep percolation losses. The criterion used for the planning of the irrigation schedules is a constant irrigation depth, since farmers are more apt in managing a constant depth rather than a variable depth (Sagardoy, 1982). The irrigation interval was also kept constant since the variations in the weather and water consumption pattern of the crops were not enough to make the need to vary if necessary.

Future studies should test the efficiency of these optimally derived irrigation schedules in the field. Meanwhile these produced schedules could be utilised and may be further refined for specific situations of the "dry year" or "wet year" as specified by Ekwue and Rigg (2001). Smith (1986) and Goldsmith et al. (1988) stated that computer based simulations similar to the ones produced in this paper using CROPWAT could be utilised in the training of irrigation and soil management professionals. Hypothetical simulations of an irrigation system could be used to show managers in the Caribbean and other regions, the consequences of their decisions and how different groups of crops, water and weather situations interact with one another to affect crop yields and soil conditions (Goldsmith et al., 1988).

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