Citrus Crop Water Requirements in Northern Zimbabwe: Significance of the Whole Season Irrigation Calendar

[a]Zirebwa, F.S., [b]Mashonjowa E., [b]Chipindu B., [b]Mhizha, T.

[a] Midlands State University, Department of Land and Water Resources Management, P. Bag 9055, Gweru, Zimbabwe

[b] University of Zimbabwe, Department of Physics, P.O. Box MP 167 Mount Pleasant, Harare, Zimbabwe

Corresponding Author: F.S. Zirebwa, zirebwasf@msu.ac.zw

Abstract

This study, carried out at Mazowe Citrus Estate, was aimed at developing drip irrigation guidelines for citrus in northern Zimbabwe in the form of irrigation calendars throughout the season. In order to achieve this, an automatic weather station was used to obtain the average ET_o values for the study site which were derived from micro climatic data. The ET_o trend for the study site was established from the FAO Penman Monteith equation using observed and historical climatic data. BUDGET (version 6.2), a soil water balance model was used to develop irrigation calendars using a fixed irrigation interval of one day. The irrigation calendars presents irrigation depths linked to the actual weather conditions throughout the season. The model was also used to simulate the soil water status after using the irrigation guidelines. The developed irrigation guidelines were compared with the grower's scheduling practise. There is a possibility that the grower was over irrigating based on simulated soil moisture conditions usually above the field capacity. High drainage losses of up to 1964 mm for the whole season were simulated compared to 381 mm for the irrigation scheduling guidelines. The grower's irrigation depths were found to be too high and therefore not compatible with a 1 day irrigation interval. Almost a third of the current irrigation depth was required under normal weather conditions. The excessive application of water might be associated with high drainage losses. Irrigation depth was reduced after considering the developed irrigation calendars. Taking into account the atmosphere's evaporative demand (the actual weather condition of the day) is an effective way of irrigation scheduling.

Keywords: *drip irrigation, calendar, Citrus*

1.0 Introduction

The recent uncertainties in the rainfall patterns of Southern Africa and the prevalence of drought in the region are the major driving factors that call for the efficient utilization of water resources. Climatic variability and change that result in increased evaporation rates coupled with reduced capacities of reservoirs in Zimbabwe due to siltation has recently led to increased pressure on the limited and diminishing water resources. Agriculture is the largest consumer of water in all regions of the world except Europe and North America and up to 70 % of water abstracted from rivers and ground water goes to irrigation (FAO, 2002; Lenntech, 2003). Water can be utilized efficiently in agriculture through properly designed irrigation schedules.

Irrigation scheduling is an important aspect of management that determines when to irrigate and how much water to apply. Application of the right amount of water at the proper time can influence fruit yield and quality. Crops require water in the root zone and any water applied should be equal to the water lost through evapotranspiration. The type of irrigation rather than scheduling mainly governs irrigation efficiency. Drip irrigation is more efficient than sprinkler irrigation and flood irrigation is the least efficient. All these irrigation types are in use in Zimbabwe but resources permitting, farmers should move to drip irrigation because of its high efficiency.

The citrus species are perennial in growth habit. The most common species are *Citrus sinensis* (sweet orange), *Citrus aurantium* (sour orange), *Citrus aurantifolia* (lime), *Citrus limon* (lemon) and *Citrus paradis* (grape fruit). In 2001, the world production of citrus was around 98.7 million tonnes of fresh fruit, 62 % of which were oranges (FAO, 2002). The production levels of citrus reflect that citrus production is one of the major agricultural activities contributing to the irrigation water demand. In Zimbabwe, an estimated 6000 hectares are under citrus cultivation (Ministry of Foreign Affairs, 2009).

The typical growth cycle of citrus fruit consists of the vegetative and fruit development growth stages. The vegetative and fruit development phases in citrus trees consist of bud break, flowering, fruit set, fruit growth, summer flush and autumn flush. Water application throughout the season should take into account the water requirements of these phases so as to enhance yield and fruit quality. More resources must be directed towards citrus production as it has potential to increase the country's revenue, since it is one of the major horticultural exports. The quality and quantity of produce can be drastically reduced when the trees are not receiving the right amount of water. Citrus production in Zimbabwe depends largely upon the availability of water for irrigation since rainfall occurs mainly during summer.

The mean monthly precipitation for Mazowe Citrus Estate (MCE) is less than the mean monthly potential evapotranspiration (ET) for eight months i.e. from April to November with an average of ninety-three rain days per year (Grieser, 2006). The climatic net primary production is precipitation limited. MCE is in the Natural Region II of Zimbabwe and is hence even better in terms of precipitation compared to the natural regions III, IV and V (Vincent and Thomas, 1960). For viable citrus production, the precipitation deficit has to be covered by irrigation since citrus are annual crops. There is need for irrigation for more than two thirds of the year. It is apparent that there is heavy reliance on irrigation and hence proper irrigation strategies have to be implemented for higher production as well as effective water management. Irrigation guidelines for citrus must take into account the variations in the evaporative demand of the atmosphere from day to day and even from season to season.

2.0 Materials and Methods

2.1 Study site

The study was carried out at Mazowe Citrus Estate (MCE), a commercial citrus producing estate in Zimbabwe (17.46°S, 31.00°E, 1189 m above sea level). Trees used for the study belong to the Palmer navel variety budded to a Troyer rootstock. The 5239 trees were planted in 2001 at an area of 8.6 hectares in Urrys section. The study site was situated on a gentle sloping terrain with dark red clayey loam soils in excess of 1 m depth (Hussein, 1982).

2.2 Microclimatic data collection

An Automatic weather station was used to monitor the microclimate of the orchard. The Automatic Weather Station and the orchard background are displayed in Figure 1. The climatic parameters that were observed include wind speed and direction, incoming solar radiation, Photosynthetically Active Radiation (PAR), net radiation, ground heat flux, air temperature and relative humidity and precipitation. A NR light net radiometer (Kipp and Zonen, Delft, The Netherlands) was used to measure net radiation and this was positioned horizontal to the ground at about 1.5 m.

Wind speed and direction were determined using a wind monitor consisting of a wind vane and a propeller (RM Young and Co., Traverse city, USA) fixed at 2 m height above the ground level. Air temperature and humidity were obtained using a temperature and relative humidity probe equipped with a capacitive relative humidity chip and a platinum resistance thermometer (model HMP 45 C, Campbell Scientific Limited, UK) inserted in a 12-plate Gill radiation shield at screen height approximately 1.5 m above the surface.

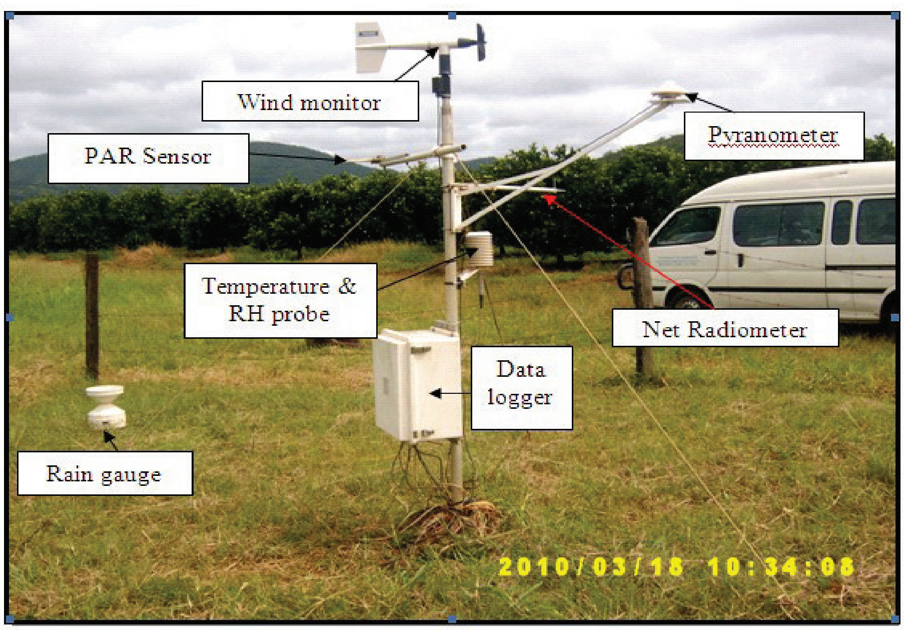


Figure 1: Automatic weather station to monitor orchard microclimate at the trial site at Mazowe Citrus Estate, Zimbabwe. The orchard can be seen in the background

The ground heat flux was measured using the ground heat flux plates inserted 10 cm and 25 cm below the surface. Precipitation was evaluated using a tipping bucket rain gauge. All sensors were connected to a CR23X data logger (Campbell Scientific Limited, UK) programmed with a scan interval of 5 seconds and all signals averaged every 15 minutes.

2.3 The development of irrigation calendars

The irrigation scheduling guidelines were generated using BUDGET, (Version 6.2), a model developed by Raes (2005). BUDGET is composed of a set of validated sub routines (Figure 2) describing the various processes involved in water extraction by plant roots and soil – water movement in the absence of a water table. Infiltration and internal drainage are described by an exponential drainage function (Raes *et al.*, 1988 in Raes, 2005) that takes into account the initial wetness and the drainage characteristics of the various soil layers. Irrigation schedules were generated by time and depth criteria as described by Smith (1985) in Raes (2005) and used in the irrigation scheduling software packages Irrigation Scheduling Information Systems, IRSIS (Raes *et al.*, 1988) and CROPWAT (Smith, 1990 in Raes, 2005).

2.3.1 Model description

Budget is composed of a set of validated subroutines describing the various processes involved in water extraction by plant roots and water movement in the soil profile. By calculating the water content in the soil profile as affected by input and withdrawal of water during the simulation period, the program can design irrigation schedules and evaluate irrigation strategies.

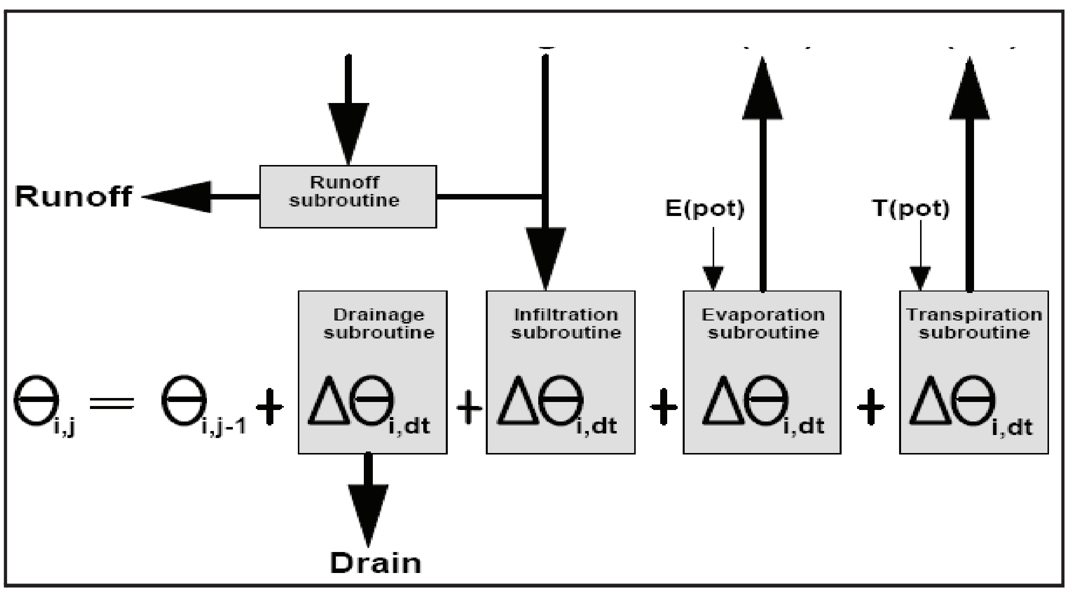


Figure 2: Calculation scheme of the budget model (Raes, 2005)

2.3.2 Input

The input into the model consists of the following parameters:

1. Daily or 10 day or monthly climatic data (ET_o and rainfall)
2. Crop parameters i.e. the parameters describing crop development and root – water uptake. This is done by the specification of the appropriate:
   - Class of crop type
   - Class of rooting depth
   - Class of sensitivity to water stress
   - Class of degree of ground cover at maximum crop canopy
   - And specifying the total length of the growing period
3. Soil parameters i.e. the identification of soil layers at the trial site and the corresponding specific characteristics.
4. Irrigation data i.e. irrigation intervals and water application depths or criteria to generate the irrigation schedules.
5. Initial soil water conditions in the soil profile.

An illustration of the BUDGET main menu showing all the input requirements of the model is shown on Figure 3.

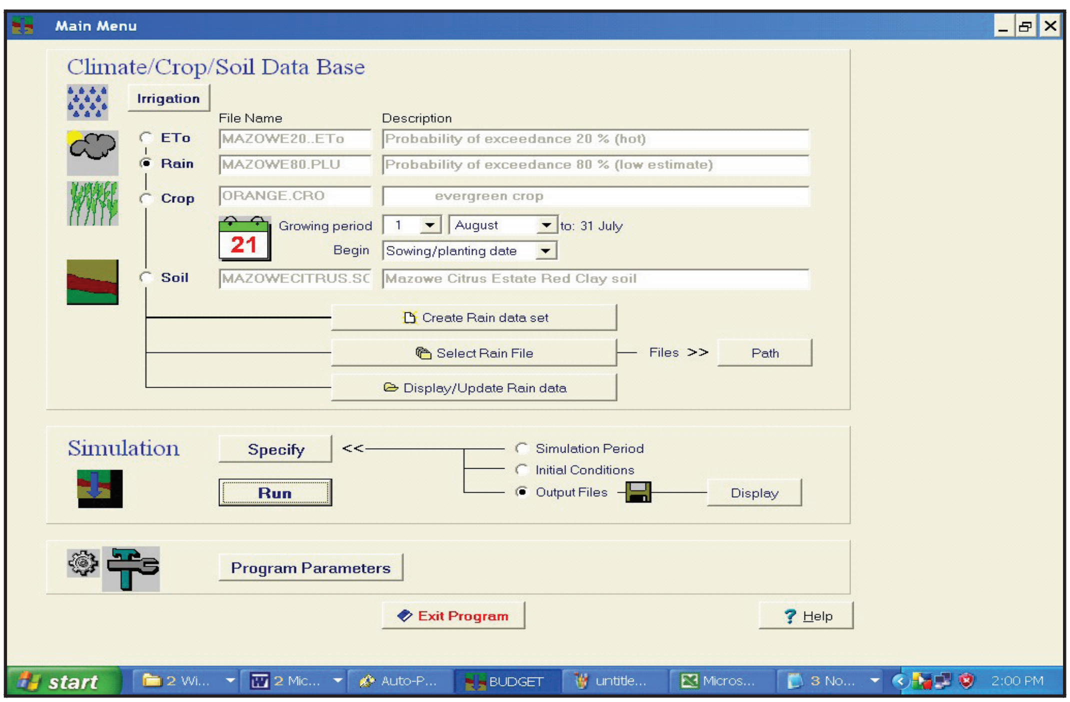


Figure 3: An illustration of the BUDGET main menu showing the model input requirements needed to run the model

2.3.3 Output

With the described input and for given initial conditions, BUDGET simulates the water uptake in the specified climate / crop / soil environment and for the specified irrigation option. During the simulation process, the variation of the soil – water content is visualised by displaying at the end of each day of the simulation period:

- The soil water content at different depths in the soil profile
- The water level in the soil – water reservoir
- The root zone depletion

At the end of the simulation process, BUDGET displays:

- The final soil moisture profile
- The total value for each of the parameters of the soil water balance
- The expected relative crop yield
- And the irrigation water requirement.

2.4 ET_o generation for the trial site

Average values for ET_o were obtained using historical and observed climatic data (2004 – 2009) of the trial site (from 15 minute averages). An AWS was used for the collection of climatic data. The FAO Penman Monteith equation was used for the computation of ET_o. The average ET_o values were regarded as the representative (normal) values for the study site. Increasing the normal ET_o values by 30% generated the hot environment for input into the model and the subsequent lowering of the normal ET_o values by 30% generated the cool environment.

2.5 Rainfall data

The mean monthly rainfall data for the study site was retrieved from the FAO LocClim model (version 1.0). The mean monthly rainfall totals were assumed to be the normal values for the study site. Raising the normal mean monthly rainfall totals by 30% generated the humid condition and a dry condition was established by lowering the normal values by 30 %.

2.6 Crop parameters

The citrus crop type is a perennial evergreen, which completely covers the ground at maximum crop canopy. After studying the growth cycle and water requirements of citrus, the following parameters (Table 1) were specified. The file used for the creation of a crop file in BUDGET is outlined in Figure 4.

Table 1: Citrus crop parameters that were used to run the model

Parameter	Description
Water stress	Sensitive to water stress with a soil water depletion fraction, p for non stress of 0.3
Growth stages and K_c coefficients	Four growth stages were specified i.e. initial, crop development, mid season and late season. The stage lengths are 70 days, 81 days, 120 days and 94 days respectively
Aeration stress	Crop stress as a result of deficient aeration conditions i.e. when soil water is greater than saturation (50 %).

Mulch	No mulching was considered.
Water extraction pattern	Throughout the root zone of 40 % in the first quarter, 30 % in the second quarter, 20 % in the third quarter and 10 % in the last quarter.
Partitioning of ET_{crop}	Potential soil evaporation was considered to be 10 % and potential crop transpiration 90 % of the total evapotranspiration.
Yield response	A yield response factor of 1.2 was used for all the growth stages.
Rooting depth	Rooting depth was considered to be up to 1 m for all the growth stages.

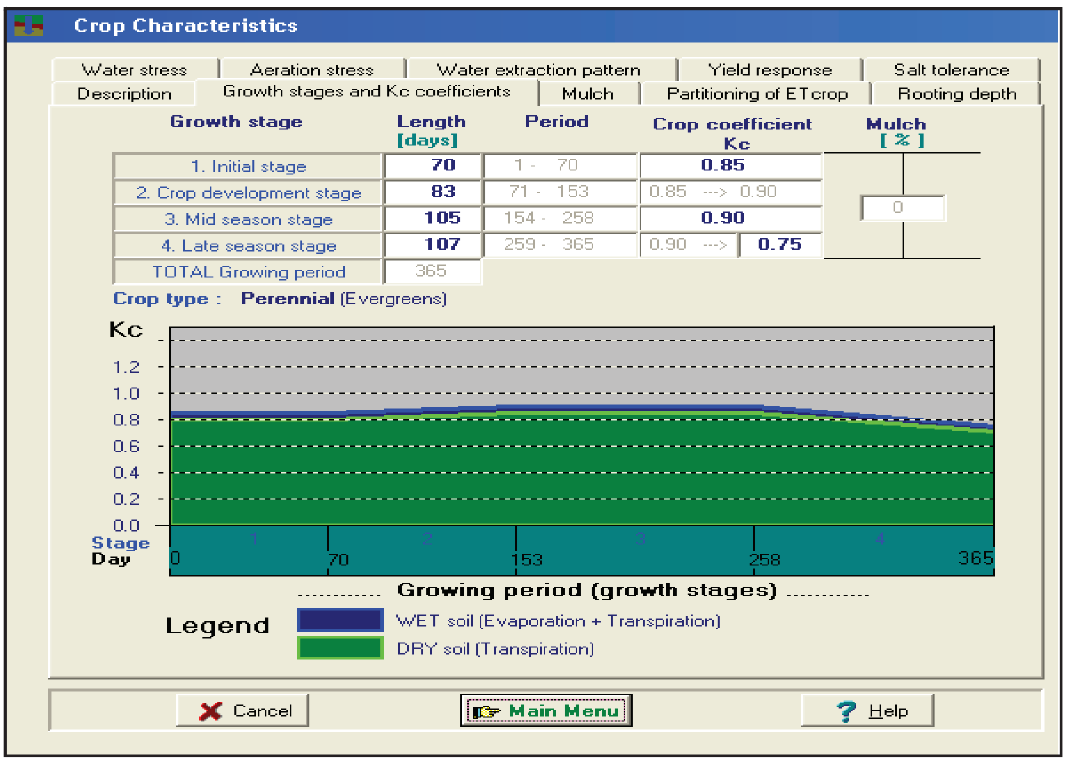


Figure 4: Creation of a crop file in BUDGET (Raes, 2005)

2.7 Soil parameters

Table 2 describes the soil properties at MCE that formed the basis for the creation of a soil file in BUDGET.

Table 2: Characteristics of the soil at Mazowe Citrus Estate (after Hussein, 1982)

Soil Property	Top soil	Sub soil
Sample depth (mm)	0 - 150	150 - 750
% Clay	63	81
pH ($CaCl_2$)	6.6	5.7
Bases exchangeable (me %)	27.5	15.9
Cation exchange (me %)	33.2	18.1
E / C value (%)	53	22
S / C value	44	20
Bulk density ($Kg.m^{-3}$)	1330	1350
Available Water Capacity (mm / 100 mm)	14.9	14.3

The topsoil layer i.e. a clay loam was considered to have a saturated hydraulic conductivity of 70 mm day^{-1}, a field capacity of 39.0 %, a wilting point of 23.0 % and a saturation point of 50 %. The bottom layer, a sandy clay was considered to have a saturated hydraulic conductivity of 75 mm day^{-1}, a field capacity of 39 %, a wilting point of 27 % and a saturation point of 50 %. No soil bunds were considered for the soils.

2.8 Irrigation data

Irrigation events were generated by specifying the two key irrigation parameters required for the generation of irrigation schedules i.e. time and depth criteria. A fixed irrigation interval of 1 day and irrigation amounts of back to field capacity were used for the generation of the irrigation schedules. An illustration of the BUDGET file used to specify irrigation parameters is displayed in Figure 5. The fraction of soil wetted using drip irrigation was assumed to be between 30 % and 40 %.

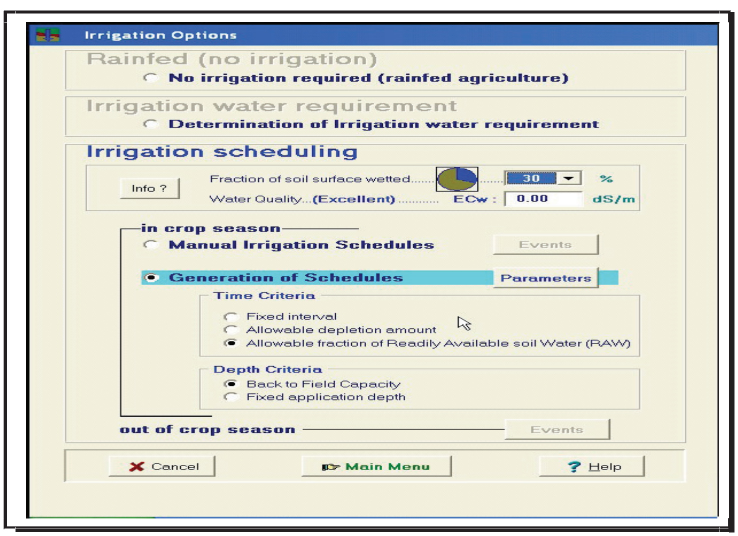


Figure 5: A BUDGET file outlining the irrigation options used for the generation of irrigation schedules

3.0 Results

3.1 Mean Reference Evapotranspiration

The irrigation guidelines were developed after evaluation of the crop water requirements of the citrus trees at the study site. This was done through the determination of the monthly average ET_o values from climatic parameters of the study site. The climatic parameters under consideration were the wind speed, solar radiation, net radiation, relative humidity, air temperature, vapour pressure deficit and the soil heat flux. ET_o values were slightly above 4 mm a day from January to April. During winter (May to early August), ET_o was low i.e. around 3 mm a day. Peak values were observed in summer especially in October with values greater than 5 mm a day. The trend shown in Figure 6 reflects that there was little variation (about 2 mm a day) in ET_o values throughout the year.

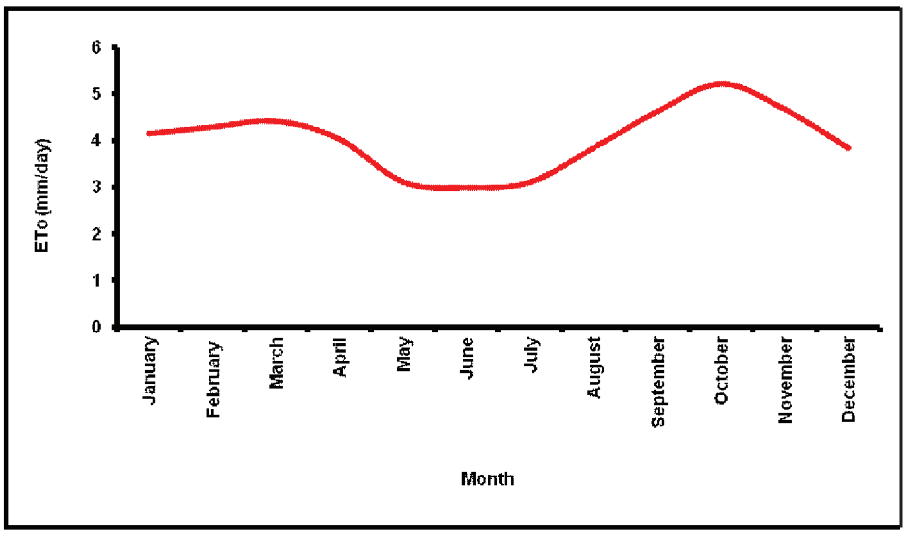
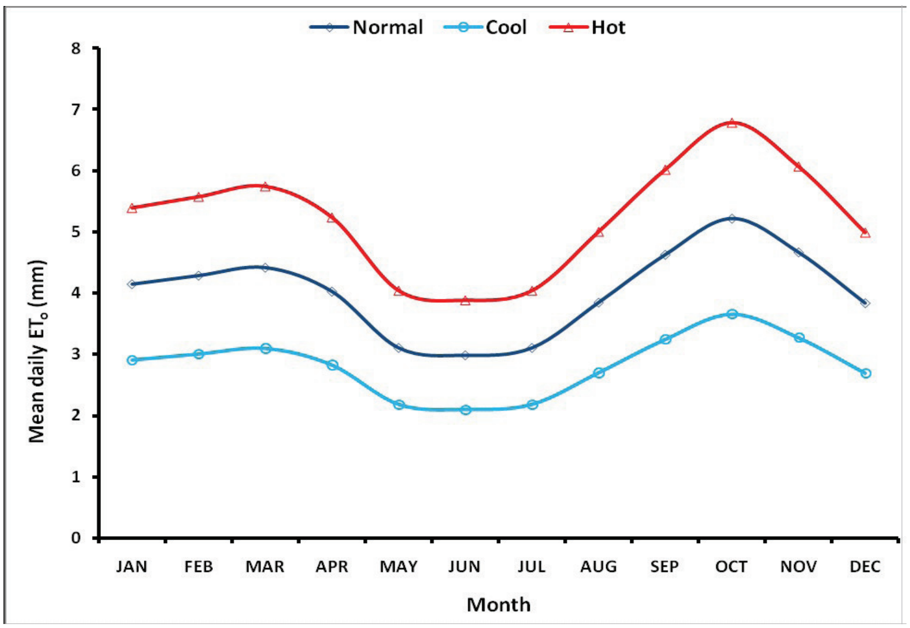


Figure 6: The average (2005 – 2009) annual variation of ET_o calculated using the FAO Penman – Monteith equation

3.2 Climatic scenarios

Irrigation calendars were developed considering the probable climatic scenarios for the study site. The climatic parameters used were the ET_o and rainfall. ET_o integrates solar radiation, net radiation, relative humidity, wind speed, vapour pressure deficit and soil heat flux. The climatic scenarios are displayed in Figures 7 and 8. The normal condition was regarded as the mean monthly values for the study site and these are expected for 'normal' seasons.

A hot season (high estimate) was assumed to have ET_o values that are 30 $\%^+$ higher than the average values where as a cool season (low estimate) was assumed to have ET_o values that are 30 $\%^+$ lower than the average. A humid scenario (high estimate) was considered to have rainfall values that are 30 %+ greater than the average rainfall and consequently a dry season (low estimate) was assumed to have rainfall values that are 30 %+ lower than the average rainfall values. There is however no difference in rainfall amount for the three rainfall scenarios from May to September because this is a dry period.



7: Mean daily ET_o of MCE for the cool, normal and hot scenarios.

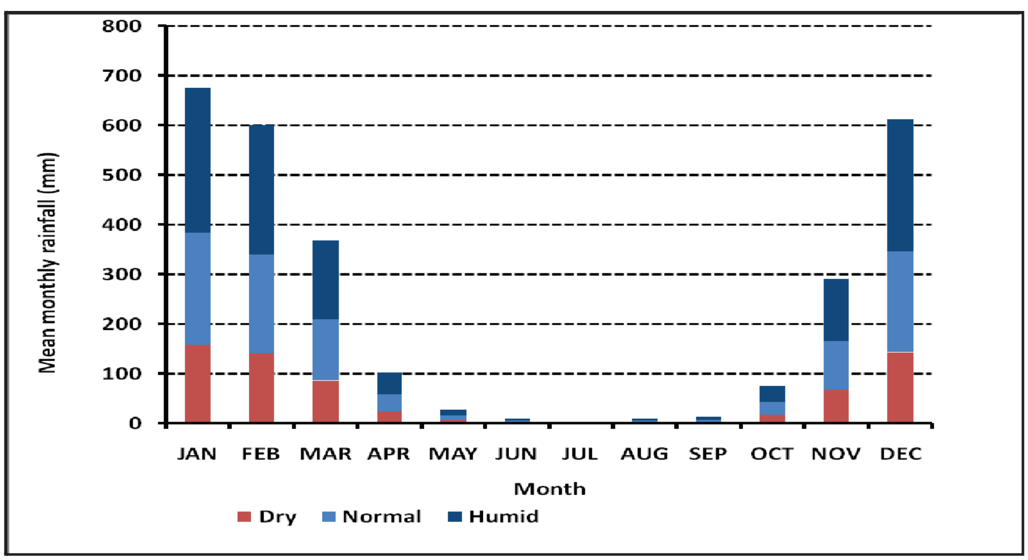


Figure 8: Mean monthly rainfall totals of MCE for the dry, normal and humid scenarios

3.3 Irrigation calendars

Irrigation calendars were produced for a citrus growing season beginning during the first decade of August. A fixed irrigation interval of one day was used. This was done for operational purposes. An irrigation interval of more than one day results in longer irrigation duration and this is usually not practical. Depending on the drip line specifications, the irrigation duration may be very long and usually disrupted by power cuts in Zimbabwe. With shorter irrigation duration, irrigation can be timed to periods where there will be uninterrupted power supplies.

Irrigation amounts shown in the calendars were based on a depth criterion of back to FC. The initial soil water content was assumed to be at FC. The irrigation calendar for the whole season was divided into three segments (Figures 9, 10 and 11) for the first trimester, second trimester and third trimester of the citrus growing season respectively.

The calendars show irrigation depth instead of duration because of the differences in the design of drip lines. Irrigation duration is affected by the drip line emitter discharge and emitter spacing. The determination of irrigation duration for specific emitter discharge and spacing is shown in the Appendix. The irrigation calendars (Figures 9 – 11) presents guidelines to adjust the irrigation depth to the varying weather conditions throughout the season. The guidelines are based on information concerning the actual weather condition and the crop response to water.

Month		August			September			October			November		
Decade (10 days)		1	2	3	1	2	3	1	2	3	1	2	3
Actual weather condition	Hot and dry	3.8 mm		4.4 mm		4.9 mm		5.2 mm			4.6 mm		
	Dry	3.7 mm		4.2 mm	5.0 mm					4.4 mm	3.6 mm	3.0 mm	2.3 mm
	Normal	3.0 mm	3.5 mm		3.8 mm					3.2 mm	2.4 mm	1.9 mm	1.2 mm
	Humid	2.2 mm			2.6 mm				2.2 mm		1.2 mm	0 mm	
Growing stage		1 Bud break, Shoot elongation, Flowering, Fruit set begins							2 Flowering, Fruit set, Fruit growth (cell division)				
Sensitivity to water stress		Very sensitive							Very sensitive				
Irrigation interval is 1 day													

Figure 9: Irrigation calendar for the first trimester of citrus production. 1 and 2 are the initial and crop development stages respectively.

Month		December			January			February			March		
Decade (10 days)		1	2	3	1	2	3	1	2	3	1	2	3
Actual weather condition	Hot and dry	4.2 mm	3.6 mm		4.6 mm								
	Dry	1.8 mm	1.0 mm				1.8 mm			1.2 mm	3.0 mm		
	Normal	0 mm									1.5 mm		2.0 mm
	Humid	0 mm											
Growing stage		2 Fruit let drop (Fruit set), cell expansion			3 Cell expansion								
Sensitivity to water stress		Very sensitive			Moderate sensitivity								
Irrigation interval is 1 day													

Figure 10: Irrigation calendar for the second trimester of citrus production. 2 and 3 refers to the crop development and mid season stages respectively.

3.4 Comparison of the irrigation guidelines with the grower's practice

The comparison of the soil water status was done under normal weather conditions only and this serves as a guideline for all weather conditions. After receiving the same total annual rainfall amount of 926.6 mm, the projected drainage losses, water deficiency and irrigation requirements are outlined in Table 3. The grower's practice total irrigation amount was excessive and approximately only a third (of 2322 mm) was required for the whole season. The application of excess water is the major cause of the high drainage losses beyond the root zone under the grower's practice. The drainage losses could be reduced if the irrigation guidelines are implemented.

Table 3: Irrigation requirements, drainage losses and water deficiency under normal conditions for irrigation scheduling guidelines and grower's practice.

Scheduling Method	Total Rainfall	Total Irrigation	Total Drainage Losses	Drainage loss duration	Total water deficiency	Water Deficiency duration
	(mm)	(mm)	(mm)	(days)	(mm)	(days)
Guideline	926.6	709.5	381	150	-	-
Grower's practice	926.6	2322	1963.9	290	275.1	49*

* From first decade of March to second decade of April.

These high drainage losses cause the leaching of plant nutrients and consequently affect fruit yield and quality. There are however, drainage losses of 381 mm under the irrigation scheduling guidelines. These losses are experienced during the rain season where there is uncontrolled input of water into the soil system. With proper scheduling, about 1582.9 mm would have been saved. The drainage losses can be even higher under cool and humid conditions. For nearly 290 days, there will be drainage losses considering the grower's scheduling practices compared to almost 150 days for the irrigation scheduling guidelines. Water deficiency of about 275 mm may be experienced from the first decade of March to the second decade of April. This deficiency coincides with the cell expansion to maturation stages that are moderately sensitive to water stress and hence does not affect yield and growth. It is actually a form of regulated deficit irrigation. Under hot and dry and dry conditions, this deficiency can lead to reduction in fruit quality and yield.

4.0 Conclusions and Recommendations

The irrigation depth varies significantly during each day after considering the actual weather condition. It is essential to take into account the actual weather condition for a particular day for efficient irrigation scheduling. A variation in irrigation depth of up to 3 mm day^{-1} is possible if the actual weather condition is not taken into consideration. This results in both unregulated water deficit and over irrigation. The seasonal or monthly irrigation scheduling guidelines (blanket recommendations) should therefore be replaced by the developed irrigation calendars. During the rain season, irrigation can only be terminated under normal and humid weather conditions only. During the dry weather conditions, irrigation depth can only be reduced during the rain season. If the weather is hot and dry, irrigation is required throughout the season even during the rainfall season. The grower's irrigation scheduling practices usually resulted in soil moisture conditions above the FC. The irrigation depths are not compatible with a 1 day irrigation interval. Almost a third of the current irrigation depth is required under normal weather conditions. The excessive application of water results in high drainage losses.

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