Crop Water Simulation Using CropWAT Model for Climate Change Mitigation

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ORIGINAL RESEARCH

Abstract—Uncertainties caused by population increase and adverse climate change impact affect global food sufficiency and water availability. This can be tackled using crop models, an innovative, dynamic and robust approach. The study was conducted in the southwestern city of Ibadan, Oyo state, Nigeria. The study is aimed at determining the crop water requirement of *Corchorus Olitorus* and the feasibility of utilizing the CropWAT model for effective water management and mitigate climate change impact. An automatic weather station was used in obtaining meteorological data of the study area. Soil characteristics and the study crop growth parameters were determined through standard procedures. FAO recommended CropWAT model determine the potential evapotranspiration, crop growth co-efficient, irrigation requirement and water stress co-efficient. Data obtained indicated that crop growth coefficient ranged from 0.44-0.92, 1.53-2.68mm/day was obtained as the mean actual crop water use. Crop irrigation requirement showed a mean value ranging from 0.93-3.83mm/day. The simulated water use was efficient recording a deficit of zero. CROPWAT model showed ease in application and a high level of reliability in effective water management for climate change mitigation.

Keywords— CropWAT model, climate change, evapotranspiration, irrigation requirement, crop growth

1 Introduction

The study was conducted in the city of Ibadan, Oyo State, southwestern region of Nigeria. Changes in climate and other factors help in hindering global food security. This can be achieved by increasing competition and demand for limited natural resources. These undesirable effects can be managed by applying different types of scientific tools and methods which rely on different biophysical approaches using statistical or empirical models in estimating adverse climate change impact on crop production (Fermandez and Blanco, 2015). The study is aimed at determining the crop water requirement of *Corchorus Olitorus* and the feasibility of utilizing the CropWAT model to for effective water management and mitigate climate change impact. Adverse climate change impact has brought about a significant reduction in agricultural production due to shortage of water supply and harsh weather conditions which has drastically affected profit of farmers. Variability in climate is an important factor influencing crop growth and production even in locations with high technology and yield (Ehumadu *et al.*, 2024; Reddy *et al.*, 2000)

Presently, researchers are more focused on the consequence of climate change on crop production (Reddy et al., 2000). Water availability is a limiting factor for crop growth and achieving food security. Water management in agricultural production provides optimum yield while considering the crop water requirement (Ewemoje *et al*., 2010). Water scarcity cannot be achieved unless water demand fails to increase. However, when an irrigated farmland is increased more water is needed thus resulting in water scarcity. Therefore, it becomes important to develop possible sustainable strategies that will determine the impact of climate change on scare water resources and crop production (Fujihara *et al*., 2000). Crop modeling helps to simulate how crop yields changes when exposed to different conditions, either by making use of historical data or predicted data. This kind of research is usually influenced by other inseparable factors such as climatic characteristics e.g precipitation, wind, temperature, and solar radiation. This can be derived from models such as General Circulation Model. Other factors, which may include drought and heat tolerance can be incorporated. A lot of researches focus on climate stresses influenced by physiological traits which affect yield. Increased temperature and water shortages are major constraints to crop production Chetty, 2009). This scope of this research is mainly on how water limitations, and temperature affect crops (Araus *et al*., 2008; Barnabás *et al*., 2008). Crop physiology helps in improving our understanding of the factors that affect crop yield and how this plant response can be improved, using crop simulation models (Araus, 2008).

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The next component after proper understanding of the crop physiology is the crop models. Crop model are of two types namely; crop simulation models which are usually process-based and statistical models which are usually represented using regression equations. Process-based models use the behavior of specified agents in dynamic systems for its estimations (Chetty, 2009; Sims, 1986) while statistical models describe relationships among selected variables while considering others constant. Process-based models can be calibrated and validated using huge amount of data, this makes reduced form models a useful alternative (Chetty, 2009). Examples of process-based models include the Agricultural Production Systems Simulator Model (APSIM) (Keating *et al*., 2003), the Decision Support System for Agrotechnology Transfer (DSSAT) model (Hoogenboom *et al*., 2012; Jones *et al*., 2003), and the Global Agro-Ecological Zone (AEZ) modeling framework (Fischer *et al*., 2002, 2005). The Lund-Potsdam-Jena managed Land (LPJmL) model has also been used in more recent work (Blanco *et al*., 2014; Frank *et al*., 2014) and the General Large Area Model (GLAM) for annual crops (Challinor *et al*., 2010).

In previous related studies, Lidiane *et al.* (2023), calibrated the CROPWAT model with the intent to simulate a rain fed and irrigated soybean production systems. The study relied on the use of climatic and soil data from the region which is located south of Mato Grosso do Sul, Brazil. This was done for a period of nine agricultural years. Surendran *et al.* (2015), undertook the modelling of crop water requirement for sustainable water resource management in Palakkad district of Kerala, India using FAO recommended CROPWAT model. The study considered crops like banana, cotton, tea, vegetables, rice, coconut, coffee, etc. Abdelkader (2023), estimated the crop water requirement of tomato in Algeria using CROPWAT model. The results obtained from the study showed the relation between variations in climatic characteristics, crop water requirement (ETc), reference evapotranspiration (ETo), and irrigation demand of tomato at two different locations namely; Oran and Algiers both in Algeria. The study was helpful for proper irrigation planning and water management. Crop modeling emphasis on the biophysical aspects of variations in climate and its effect on crop yield, and how sustainable adaptation strategies can be incorporated in maintaining food security and minimizing undesirable outcomes. These studies tend to focus on the effect of these variations on yield of *Corchorus Olitorus.*

2.0 MATERIALS AND METHODS

2.1 STUDY SITE, EXPERIMENTAL DESIGN AND LAYOUT

The study was carried out at the Crop Garden of the Department of Crop Protection and Environmental Biology located at 3º89' E and 7º45' N with elevation of 223.5±12.0 m above sea level. The research was conducted during the dry seasons and irrigated according to the field capacity of the soil. The net area of land used for the experimental study is 1ha.

2.2 THE STUDY CROP

Corchorus olitorus is an important leaf vegetable cultivated for its mucilaginous foliage. The leaf is a rich source of many minerals, vitamins and antioxidants. Consumption of *C. olitotius* is important on wellness of gut system owing to its high concentration of dietary fibre. The leaves are rich in protein, iron, calcium, thiamine, niacin, riboflavin, folate and dietary fibre (Palada and Chang, 2003). Besides, Jute plants purifies the atmosphere by absorbing large quantity of CO_2, which unarguably can be regarded as one the major causes of the earth greenhouse effect. Jute plant theoretically, ingest CO_2 within the range of 15 tonnes from the air and releases close to 11 tonnes of oxygen in hundred days of its growing season. Data has shown that CO_2 consumption rate by jute is greater than what is obtained for tree crops (Anwar, 2007). The importance of *C. olitorius* both as leaf vegetable and air cleaner are directly linked to its photosynthetic ability.

The field was cleared and beds of 1 m x 1 m each were with a spacing of 1 m between each bed. Seeds of *Corchorus olitorius* were sown at the rate of 3 g per m^2 using broadcasting method. After emergence, the seedlings were thinned to a spacing of 30 cm x 10 cm to give a plant population of 300,000 plants per hectare. Drip irrigation method was adopted on a 2-day basis for supplying water at the pre-determined depth based on volume/unit area. The vegetable is an important crop in the southwestern region of Nigeria where almost every home find it difficult to do without. The yield of the crop has been declining over the years as a result of water scarcity during the dry season. Hence the need for proper water management practices using crop models.

2.3 METEOROLOGICAL PARAMETERS

The climatic characteristics (Max. and Min. Temperature, Humidity, Wind speed, Sunshine hours, rainfall) of the study area was determined using data from an automatic weather stations (Marshal, 1988). The parameters used for calculating the potential evapotranspiration include the

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longitude and latitude of the study station and the climatic parameters.

2.4 SOIL CHARACTERISTICS

The parameters considered in the CropWAT model under soil characteristics are maximum infiltration rate, percentage initial soil moisture depletion, initial available soil moisture, maximum rooting depth, total available soil moisture and soil name.

2.5b Soil characteristics such as field capacity, wilting point, infiltration rate, soil moisture depletion, available soil moisture was carried out using standard procedures (Cornejo, 2003). The crop characteristics like the crop growth stages in days, crop height, root depth, yield response factor (Ky), planting date and harvest date was determined using standard procedures and relevant equations (Cornejo, 2003). The crop was harvested 10 weeks after planting. The CropWAT model was used to determine the irrigation requirement, water stress coefficient, yield reduction.

3.0 RESULTS AND DISCUSSIONS

The weather data showed that increase in temperature of Ibadan, south western region of Nigeria was due to climate change. This had led to a significant reduction of available water supply for plant growth due to an increase in the rate of evaporation from soil surface, reduced rainfall, and dryness of the soil resulting to increase of soil water holding capacity. Figure 1 shows the irrigation scheduling graph which estimates the simulated soil water retention capacity. The soil water depletion varied slightly, however it increased during the late stage of the plant. The readily available water increased slightly, compared to the total available water which increased significantly indicating that water losses was experienced greatly within this period which is in

2.5 DATA COLLECTION PROCEDURE

The actual amount of water needed to be applied to the plant was obtained by dividing the potential evapotranspiration (using the CropWAT model) by the crop coefficient (Kc) values (Allen *et al*, 2006).
Soil

tandem with the soil water depletion. Figure 2 and Table 1 shows the usage of CropWAT model in predicting the evapotranspiration and irrigation requirement to reduce wastage that might add to the cost of crop production and reduce water efficiency. The result shows the crop water requirement increasing as the crop growth stage moves from initial to the beginning of the late stage, however, a reduction was experienced as harvesting date was approached. The values of the crop growth coefficient obtained after simulation was close to the value obtained from the field. This proves that the simulation model adopted for this study is reliable. The crop growth coefficient helps in identifying the closeness of crop water loss to water gained.

Table 2 shows the simulated water stress coefficient (Ks), water depletion and flow, which is influenced by the soil characteristics, climatic conditions and the type of crop cultivated. The water stress coefficient (Ks) identify the water status of the plant. Ks of 100% implies that the plant is well watered and vice versa. Water depleted from the soil is not available for the plant. The amount of water depleted from the root zone decrease from the initial growth stage to maturity stage. This points out to the fact that water application at the initial stage of planting should be adequate for the plant to growth properly. The initial stage of crop growth indicates that the plant was not well watered and the level of water depletion was high compared to other methods.

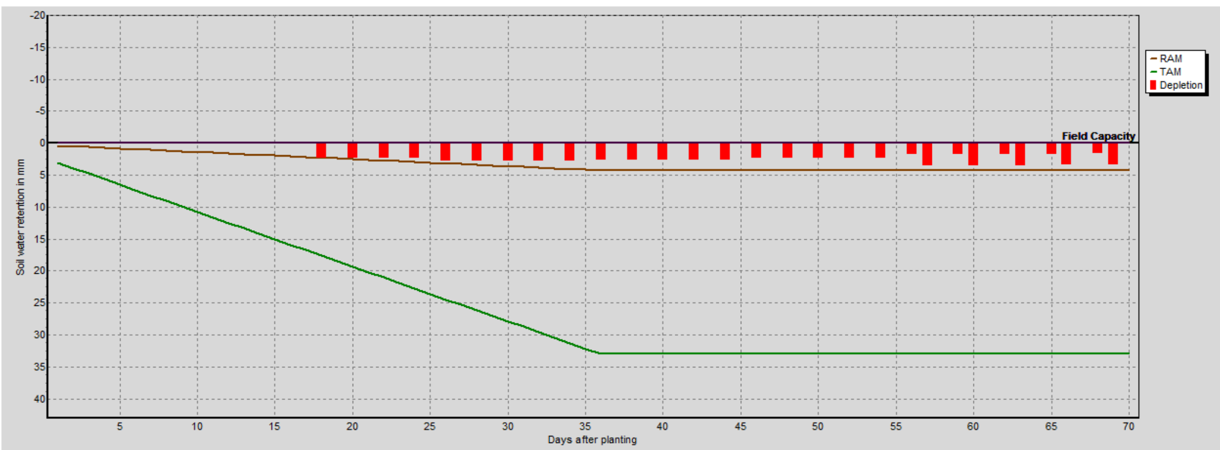

Figure 1: Simulated soil water retention in mm from planting to harvest

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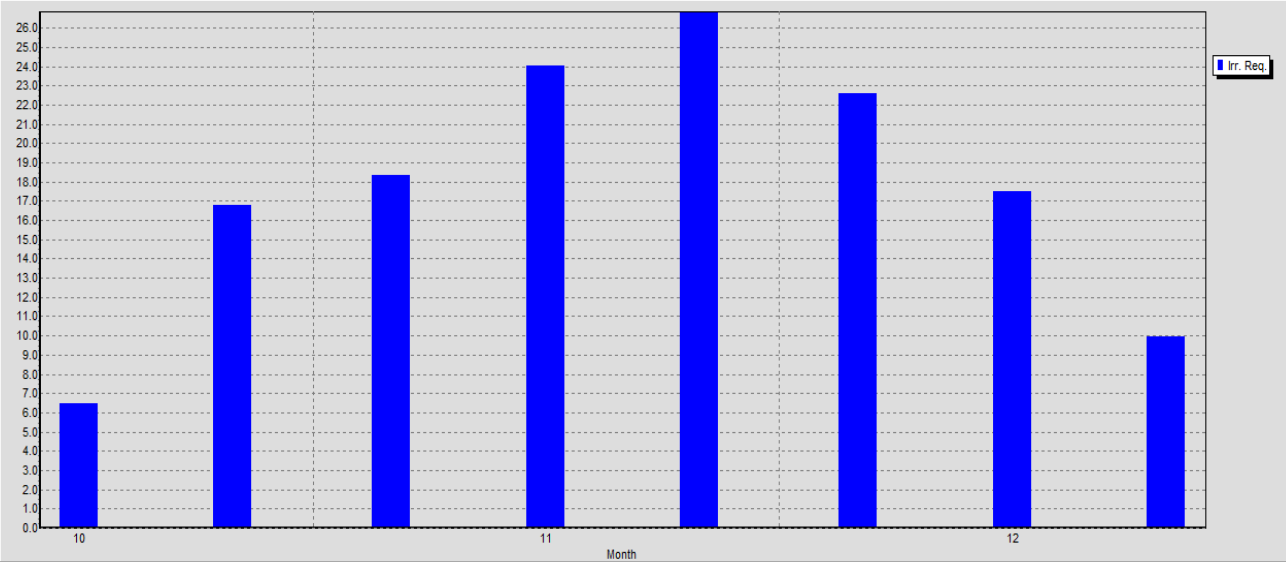

Figure 2: Simulated crop water requirement in mm from planting to harvest

Table 1: Simulated Crop Coefficient (Kc), Evapotranspiration (ETc) and Irrigation Requirement

Month	Decade	Stage	Kc CropWAT	Kc Field	ETc mm/day	ETc	Eff. Rain	Irrigation Requirement
Oct	2	Init	0.44	0.43	1.62	6.5	0.0	6.5
Oct	3	Init	0.44	0.44	1.53	16.8	0.0	16.8
Nov	1	Deve	0.57	0.61	1.84	18.4	0.0	18.4
Nov	2	Deve	0.80	0.81	2.40	24.0	0.0	24.0
Nov	3	Late	0.92	0.98	2.68	26.8	0.0	26.8
Dec	1	Late	0.82	0.89	2.26	22.6	0.0	22.6
Dec	2	Late	0.67	0.61	1.75	17.5	0.0	17.5
Dec	3	Late	0.55	0.61	1.65	9.9	0.0	9.9
						142.5		142.5

The net irrigation was lowest at the initial stage of the crop development. It was highest at the Mid-level stage. Water deficit or loss were not observed in the simulation. The gross irrigation requirements of the crop were greater than the net irrigation obtained from the simulation model, the difference ranged from 0.8-1.0mm. The development stage showed a difference irrigation of 1.0-2.4mm while the Mid and End stage showed a difference of 2.2mm and 2.0-2.3mm, respectively. Table 2 simulates a scenario of an idea situation where other variables limiting the full utilization of the water supplied were not factored. The level of water depletion was highest at the initial stage and lowest at the Mid and End stage which had equal values. ETa obtained from the Development stage to the End stage were 100. This implies that the simulated crop got all the needed amount of water needed for proper plant growth and development. Table 2 showed that rain fell water was not considered in the simulation process. The crop is expected to have grown through water supplied from artificial sources. The maximum crop yield was obtained when soil water was at field capacity. Yield reductions were recorded for soil moisture contents below field capacity.

This study shows that due to the physiological nature of the study crop and the soil, an average water loss of about 30% occurs at all growth stages of the crop. This implies that if the needed 70% of irrigated water is applied directly to the plant through the soil, optimum yield will be achieved.

4.0 CONCLUSIONS

The results from the crop simulation model are based on soil water balance influenced by climate change i.e temperature variations, soil and the type of crop for prudent management of scare water resources to guarantee water use efficiency. Climate change had adversely affected crop production due to changes in rainfall pattern which has drastically affected the availability of water thus, reducing crop yield. The model successfully aided in optimizing usage of scarce water resources and avoiding wastages through proper irrigation scheduling. This model does not consider the

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effect of pest and diseases on the crop which is usually unpredictable mathematically in scale. It also does not consider the constituent nutrients effect on the plant. This work helps in identifying the crop water requirement and irrigation requirement of the study crop to avoid wastes due to scare water supply occurring due to climate change. This simulation model was effective in predicting the potential evapotranspiration, crop water requirement and irrigation requirement. The soil should be properly tilled for proper seed germination and water retention. Proper cultural management practices to avoid pest and diseases and adequate water harvesters should be installed. The effective usage of CropWAT Model irrigation water requirement analysis should be encouraged to guarantee water use efficiency. In mitigating climate change impact the use of simulation models as a veritable tool in analysing and predictions of possible plant growth and water use efficiency outcomes should be encouraged.

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