Original Research Article

Irrigation Schedules for Selected Food Crops Using Water Balance Book-Keeping Method

Mary Nkiru Ezemonye¹, Chukwudi Naemeka Emeribe²

¹*Department of Geography and Regional Planning, University of Benin, Benin City*

²*Environmental Pollution Remediation Unit, National Centre for Energy and Environment, University of Benin, Benin City*

Abstract

In the tropics, the water potential of a region cannot be adequately assessed from precipitation alone due to the seasonal character of rainfall and even more so owing to the changing climate scenario. It is therefore necessary that in any agro-climatological program, there must be a clear understanding of the actual amount of water that evaporates and transpires (AET), and the amount of water that would evaporate and transpire if water were always readily available (PET). This could be done through the method of the water balance. The present work examines the water budget of parts of the Imo river basin and its implications for improved crop production through supplementary irrigation schedules. It was observed, that the study area is already facing moisture-stress. This is because even during rainy months supplementary irrigation is required to compensate for the occasionally moisture deficit due to increased evapotranspiration. The study showed that cultivation of maize, rice and tomatoes can be carried out on an all-year-round basis under a scientific irrigation scheme. Thus the study provided farmers with guideline on the period and quantity of water required for supplementary irrigation, a development which will prevents wilting of plants before the application of needed water.

Keywords: crop production; consumptive use; water balance; supplementary irrigation.

INTRODUCTION

Over the years, Nigeria has witnessed rapid population growth and this naturally implies that growth in agricultural production including food products must be regularly maintained approximately in equilibrium with the ever growing population. For this to be possible, climatic conditions which are essential input factors for increased food production must be understood given that crops are sensitive to weather conditions both during their early and maturity stages. In addition, the impact of climate variability and climate change is expected to be felt differently at different scales. In relation to food security, the effect of dry spell occurrences during cropping seasons as a result of erratic rainfall patterns results in severe yield reductions in farming systems. In the tropic where rainfed agriculture is dominant, water is a major constraint to agricultural production (Ngigi, 2003). Moreover, Jackson (1977) has noted that the most common cause of crop death is insufficient water to replace loss by transpiration even when it is a temporary water deficit. A temporal water deficit is fatal to crop development especially during the vegetative and flowering stages of the crops.

The socio-economic consequences of low food crop yields in the tropics usually range from fluctuation in the prices of agricultural commodities to increasing poverty levels. Notwithstanding, it is possible to improve crop productivity even under the challenging conditions of climatic change

and variability. One way of achieving this is through a clear understanding of the actual amount of water that evaporates and transpires (AET), and the amount of water that would evaporate and transpire if water were always readily available (PET). This could be done through the method of the water balance bookkeeping. In the technique, attempt is made at providing information on all the aspects of the moisture relationship of an area including soil moisture storage, soil moisture deficits and surpluses, potential and actual evapo-transpiration. Such information is considered significant in agricultural development, monitoring climate change and providing farmers with the knowledge of when and how much water is needed for supplementary irrigation scheduling.

The study was made in an agrarian society and some food crops have been selected for design of supplementary irrigation schedules. These crops are maize, rice and tomatoes which serve as sources of food and income for the teaming population of the study area. These crops are influenced by seasonal variation in rainfall, a condition that may create the need for supplementary irrigation. Unfortunately, majority of the farmers in the study area do not know the amount of water supplied by rainfall during rainy season as to be sure of an estimated amount of water to be added through irrigation to compensate for any deficits. Thus, if irrigation is to be recommended in any part of the study area with the noted changing rainfall pattern, the problem of how much water is to be added and at what

stage of crop growth must be addressed scientifically and this is what this study addresses.

MATERIALS AND METHODS

Study area

The study was carried out in part of the Imo river basin. These include the Otamiri and Oramirukwa rivers. The area lies within latitudes $04^{\circ}45' \text{N}$ and $05^{\circ}32' \text{N}$ and longitudes $06^{\circ}56' \text{E}$ and $07^{\circ}35' \text{E}$ (Figure 1). The two rivers are major tributaries of the Imo River in Imo state and lie about 60 km north of the Atlantic Ocean and 70 km east of the River Niger.

The combined effects of the tropical continental (cT) air mass which originates in the Sahara desert and blows as the dry northeast trade wind, and the tropical maritime (mT) air mass which originates from the south Atlantic Ocean, in response to the movement of the ITD control the rainfall over southeastern Nigeria. Rainfall decreases from the southern

extremity northwards over the study area. There is normally a long rainy season from April to October, with a break in between the rainfall regime. This break is mostly in July or August and is referred to as the August break or the “little dry season”. The dry season proper lasts between November and March (Ilesanmi, 1972). Annual temperature is usually above 27°C , and increases southwards. Both the mean daily maximum and mean annual maximum temperatures increase from the coast towards the interior because of the moderating influence of the sea.

Data collection

Meteorological data used in this study were collected from the Nigerian Meteorological Agency (NIMET), Federal Ministry of Aviation, Oshodi, Lagos. The data covered a period of 26 years (1984-2010), for the following variables: minimum and maximum temperature, relative humidity, wind speeds, rainfall. Data analyses involved comparisons using the standard Meteorological procedure of means of the selected parameters and the use of statistics.

Figure 1. Map of Imo State showing the study area

Evapotranspiration and soil-moisture storage

Actual evapotranspiration (AET) is derived from potential evapotranspiration (PET), P_{total} , soil-moisture storage (ST), and soil-moisture storage withdrawal (STW). Monthly PET is estimated from mean monthly temperature (T) and is defined as the water loss from a large, homogeneous, vegetation-covered area that never lacks water (Thornthwaite, 1948; Mather, 1978). Thus, PET represents the climatic demand for water relative to the available energy. In this study, PET was calculated by using the Hamon equation (Hamon, 1961):

$$PET_{Hamon} = 13.97 \times d \times D2 \times Wt \quad (1)$$

where PET_{Hamon} is PET in millimeters per month, d is the number of days in a month, D is the mean monthly hours of daylight in units of 12 hrs, and Wt is a saturated water vapor density term, in grams per cubic meter, calculated by:

$$W_t = \frac{4.95 \times e^{0.062 \times T}}{100} \quad (2)$$

where T is the mean monthly temperature in degrees Celsius (Hamon, 1961).

When P_{total} for a month is less than PET , then AET is equal to P_{total} plus the amount of soil moisture that can be withdrawn from storage in the soil. Soil-moisture storage withdrawal linearly decreases with decreasing ST such that as the soil becomes drier, water becomes more difficult to remove from the soil and less is available for AET . STW is computed as follows:

$$STW = ST_{i-1} - \left[\text{abs}(P_{total} - PET) \times \left(\frac{ST_{i-1}}{STC} \right) \right] \quad (3)$$

where ST_{i-1} is the soil-moisture storage for the previous month and STC is the soil-moisture storage capacity. An STC of 150 mm works for most locations (McCabe and Wolock, 1999; Wolock and McCabe, 1999).

If the sum of P_{total} and STW is less than PET , then a water deficit is calculated as $PET - AET$. If P_{total} exceeds PET , then AET is equal to PET and the water in excess of PET replenishes ST . When ST is greater than STC , the excess water becomes surplus (S) and is eventually available for runoff.

Estimating irrigation needs of crops

To ascertain if monthly supplementary irrigation for any of the selected crops is required within the basin, Baier and Russello (1968) equation for estimating supplementary irrigation need was used. The equation is given as

$$IR = (PET + CU) - R \text{ mm month}^{-1} \quad (4)$$

Where: IR = supplementary irrigation in mm;

PET = potential evapotranspiration (mm);
 CU = consumptive water need (mm); and
 R = rainfall (mm).

This equation was adopted in this study. The climate water demand (PET) of the basin was added to the consumptive water use of that month (CU) and then subtracted from the month's rainfall value. If the rainfall amount for that period does not satisfy both the climatic water need (PET) and crop consumptive water use, irrigation is recommended. Consumptive water uses of the selected crops in the study area are shown in Table 1.

Table 1. Crop Consumptive Water Use and Length of Growth

Crop	Length of growth (month)	Consumptive water use (mm)
Rice (<i>Oryza sativa</i>)	5	1000
Maize (<i>Zea mays</i>)	4	1200
Tomatoes <i>Lycopersicon_esculentum</i>	3	600

Adopted from FAO (1986)

Irrigation schedule for selected crops in the study area

Israelsen and Hansen (1962) suggested that about 40-60% of water consumed by a crop takes place during the flowering stage, while the remaining percentage is shared between the vegetative and harvesting stages, with the vegetative stage utilizing more than the harvesting stage. The authors suggested some ratios of 6:15:4; 7:10:3 and 4:5:3 for obtaining the amount of water needed by maize, rice and tomatoes, respectively, at different stages of their growth. These ratios were adopted in designing the supplementary irrigation schedules in the study area (Tables 2, 3 and 4).

Table 2. Consumptive water use per stage of growth for maize

Months	1 st	2 nd and 3 rd	4 th
Parameter			
Growing stage	Vegetative	Flowering	Harvesting
Consumptive use per stage (mm)	288	720	192
Consumptive use = 1200 mm			
Length of growth = 4 months			
Ratio per stage = 6:15: 4			

Source: author's field work (2011)

RESULTS

The mean result of the water balance of the study area (1982-2010) utilizing the evapotranspiration method of

Table 3. Consumptive water use per stage of growth for rice

Months Parameter	1 st and 2 nd	3 rd and 4 th	5 th
Growing stage	Vegetative	Flowering	Harvesting
Consumptive use per stage (mm)	350	500	150
Consumptive use = 1000 mm			
Length of growth = 5 months			
Ration per stage = 7: 10: 3			

Source: author's field work (2011)

Table 4. Consumptive water use per stage of growth for tomatoes

Months Parameter	1 st	2 nd	3 th
Growing stage	Vegetative	Flowering	Harvesting
Consumptive use per stage (mm)	200	250	150
Consumptive use = 600 mm			
Length of growth = 3 months			
Ration per stage = 4: 5: 3			

Source: author's field work (2011)

Hamon (1961) is presented as Figure 2. From the figure, it is observable that the study area has an annual precipitation value of 1673.9 mm with marked variation between wet season and dry season precipitation. With a range of 330.3 mm, the lowest precipitation value was recorded in January (4.7 mm) while August witnessed the highest precipitation value of 335 mm. Low values of precipitation are recorded

from November up to March with January, December and February having the lowest values of 4.7 mm, 5.6 mm and 6.4 mm, respectively.

It is noteworthy that the monthly precipitation values are more variable than those of potential evapotranspiration. Within the months of high precipitation (May to September), monthly precipitation values are greater than those of potential water needs of crops and consequently soil moisture storage tends to rise reaching saturation point between August and September. October is the first month when the climatic water needs (PET) exceeds the supply of water from precipitation leaving a monthly moisture storage value of 237.3 mm. The months of May and June are the months with considerable soil moisture storage for commencement of planting.

In Tables 2-4, estimates of irrigation needs per crop stage of growth are presented. Maize has a consumptive water use of 1200 mm and a growing season of 4 months. By considering the length of growth and employing the ratio of 6:15:4 for vegetative, flowering and harvesting stages, approximate amounts of additional water needed for maize cultivation for each stage were estimated as 288 mm in the first month, 720 mm between second and third months and 192 mm in the fourth month, respectively (Table 2).

In the case of rice with a consumptive water use of 1000 mm and length of growth of 5 months, using the ratio of 7:10:3, the specific amounts of additional water needed per stage (vegetative, flowering and harvesting) were determined as 350 mm between the first and second months, 500 mm in the third and fourth months and 150 mm in the last month, respectively (Table 3).

Tomato with a consumptive water use of 600 mm has

Figure 2. Mean values of the water balance components of the study area (mm)

P = precipitation; PET= Potential Evapotranspiration; ST= moisture storage; Δ ST= Change in storage; AE = Actual Evapotranspiration; DEF= Deficit; Sur= Surplus

a growing length of 3 months and a ratio of 4:5:3. The consumptive water use per stage of tomato were determined as 200 mm, 250 mm and 150 mm for vegetative, flowering and harvesting stage, respectively. The uniqueness of tomato in the region is that farmers can carry out cultivation more than twice per annum (Table 4).

The irrigation schedules for selected crops are presented in Tables 5-7. In the first growing season of maize (from April to July), the month of April has the highest irrigation need, followed by the months of May and June, with irrigation needs (IR) of 300.8 mm, 290.6 mm and 276.9 mm, respectively. July has the lowest irrigation need of 74.9 mm. Total irrigation water need for the first growing season of maize (growing, flowering and harvesting stages) is 943.2 mm. In the second growing season (October to January), a total water need for irrigation is 1523.4 mm. The months of December and January recorded the highest amounts of irrigation water needs of 476.6 mm and 439.3 mm, respectively (Table 5).

In the first growing season of rice (April to August), supplementary irrigation is needed in all the months with the

exception of August, when the basin attains saturation. April and June recorded the highest amounts of water needs of 187.8 mm and 166.9 mm. The total water need for irrigation for the first growing season is estimated as 592.3 mm. In the second growing season (October to February) a total of 1446.4 mm water is needed for effective rice cultivation spread between growing, flowering and harvesting stages. Within the second growing season, January and December recorded the highest water needs for irrigation of 371.3 mm and 366.6 mm, respectively (Table 6).

The irrigation schedule for tomato in the study area as depicted in Table 7 which shows that in the first growing season, April recorded the highest amount of water need. In the second growing season, December recorded highest while in the third growing season February recorded the highest. There is variation in the total amounts of water needed between the three seasons of tomato growing from 460.3 mm (first growing season), 579.8 mm (second growing season) and 895.4 mm for the third growing season. More water, however, is needed during the third growing season.

Table 5. Irrigation schedule for maize in the study area

Season	Month	PET (mm)	CU (mm)	R (mm)	IR (mm)	Total water for irrigation (mm)
1 st growing season	April	140.8	288	128	300.8	943.2
	May	139.6	360	209	290.6	
	June	140.9	360	224	276.9	
	July	136.7	192	254	74.9	
2 nd growing season	Oct	136.3	288	130	294.3	1523.4
	Nov	103.9	360	24.7	439.2	
	Dec	122.2	360	5.6	476.6	
	Jan	126	192	4.7	313.3	

Source: author's field work (2011)

Table 6. Irrigation schedule for rice in the study area

Season	Month	PET (mm)	CU (mm)	R (mm)	IR (mm)	Total water for irrigation (mm)
1 st growing season	April	140.8	175	128	187.8	592.3
	May	139.6	175	209	105.6	
	June	140.9	250	224	166.9	
	July	136.7	250	254	132.7	
	August	138.5	150	335	-	
2 nd growing season	Oct	136.3	175	130	181.3	1446.4
	Nov	103.9	175	24.7	254.2	
	Dec	122.2	250	5.6	366.6	
	Jan	126	250	4.7	371.3	
	Feb	129.4	150	6.4	273	

Source: author's field work (2011)

Table 7. Irrigation schedule for tomato in the study area

Season	Month	PET (mm)	CU (mm)	R (mm)	IR (mm)	Total water for irrigation (mm)
1 st	April	140.8	200	128	212.8	460.3
	May	139.6	250	209	180.6	
	June	140.9	150	224	66.9	
2 nd	Oct	136.3	200	130	206.3	579.8
	Nov	103.9	250	24.7	106.9	
	Dec	122.2	150	5.6	266.6	
3 rd	Jan	126	200	4.7	321.3	895.4
	Feb	129.4	250	6.4	373	
	March	146.6	150	95.5	201.1	

Source: author's field work (2011)

DISCUSSION

From the water balance analyses of the study area (Figure 2), the basin has four months of soil moisture recharge (March -July) while saturation point is reached in August and maintained through September. From the months of October to December when monthly values of PET are greater than those of atmospheric water supply (rainfall), water is withdrawn from the basin, paving way for moisture deficit. The study area generally experiences moisture deficit from January to early March with an annual moisture deficit value of 312.5 mm. Some previous rainfall reports have confirmed similar trends in rainfall and soil moisture patterns over southern Nigeria (Olaniran, 1990, 1991; Jayeoba, 2011).

The study also shows that May and June are the months with considerable soil moisture storage to support adequate crop yields. Furthermore, because rainfall is observed to begin in the basin from March, crops planted before the months of May and June may suffer water stress during the vegetative stage due to the pattern of soil moisture shortage. The rainfall of May and June are however considered suitable for plantation as soil moisture storage is adequate for crop use.

Even during the rainy months in the study area, our investigation showed that supplementary irrigation is needed to compensate for the occasionally deficit due to increased rate of evapo-transpiration over the basin. The study has also shown that the cultivation of maize, rice and tomato can be carried out more than once in a year under a scientific irrigation scheme. This confirms results of study by Agele et al. (2013) in southern Nigeria and Araya and Stroosnijder (2011) for the humid tropical environment.

The irrigation schedule for maize in the study area (Table 5) shows that for an effective cultivation of maize with greater yields twice yearly, supplementary irrigation is needed for the two growing seasons especially during the

second growing season (from October to January) when the soil moisture storage of the basin is below the basin field capacity of 250 mm.

With the exception of August (Table 6), supplementary irrigation is needed for the cultivation of rice in all the months of the first growing season with April and June requiring the highest amount of water. In the month of August, the soil of the basin is already at field capacity and so no additional water is required. However, in the second growing season (October to February) when the soil moisture storage of the basin falls below the field capacity more water is needed for irrigation for effective rice cultivation.

Water is needed in all the seasons and months for effective tomato yields as shown in Table 7. Variation, however, exists in the amount needed per growing season. January to March (3rd growing season) are noted as the greatest water demand periods with the first growing season (April - June) having the least need for supplementary irrigation. The period July to September is exempted in the schedule for tomato planting because of the adverse effects of the heavy rains of these months on the tomato fruits.

CONCLUSION

The study has shown that the water potential of a region is the result of interactions between rainfall and the evapo-transpiration of the area. The seasonal character of rainfall over the basin with associated changes in soil moisture storage has a lot of implications for effective crop production. As a result, the seasonal fluctuations in the moisture supply of the study area must be understood so as to be able to address the issues of when and how much water is needed for supplementary irrigation in the basin.

The study also showed that even in the rainy months, supplementary irrigation is required in the basin to maintain adequate crop yields and an all-year round cultivation to meet

the food needs of the teaming population of the study area. As temperature is predicted to rise due to global warming, this may result in increased evapotranspiration rate over the study area leading to greater soil moisture deficit and crop water stress (CWS).

There is dare need for farmers in the study area to plan for future agricultural operations especially under the increasing weather variability. For example, they can predict without much error, the water need for a growing season and make necessary arrangements in time by way of sourcing for alternative options of providing water for periods of deficit. Furthermore, all-year-round agriculture can be targeted to increase the farmers' income and guarantee constant supply of these essential food crops to the market and thus help eliminate seasonal price fluctuations which tend to characterize food marketing system in the study area.

REFERENCES

- Agele S., Agbona A., Balogun C. (2013): Water use, growth and yield of fadama-grown pepper (*Capsicum annum* L.) as affected by mulching and drip irrigation in a humid zone of Nigeria: *Scientia Agriculturae* 4: 5-12.
- Araya A., Stroosnijder L. (2011): Assessing drought risk and irrigation need in northern Ethiopia. *Agricultural and Forest Meteorology* 151: 425-436.
- Baier W., Russelo D.A. (1968): A computer program for estimating risks of Irrigation Requirements from Climatic Data: Technical Bulletin 59, Agro-Meteorological Section, Plant Research Institute, Canadian Department of Agriculture, Ottawa, pp. 1-48.
- FAO (1986): Irrigation Water Management: Irrigation Water Needs, Publications Division, Food and Agriculture Organization of the United Nations: Rome, Italy
- Hamon W.R. (1961): Estimating potential evapotranspiration: *Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers* 87: 107-120.
- Ilesanmi O.O. (1971): An empirical formulation of an ITD rainfall model for the Tropics: A case study of Nigeria. *Journal of Applied Meteorology* 10: 882-891.
- Israelsen O.W, Hansen V.E. (1962): *Irrigation Principles and Practices*, John Wiley and Sons. Inc, New York.
- Jackson I. J. (1977): *Climate, Water and Agriculture in the Tropics*. Longman Inc, New York.
- Jayeoba O.J. (2011): Spatial and Temporal variability of surface soil moisture content of an alfisol as influenced by tillage operations in Oyo State, Southwestern Nigeria. *Indian Journal of Science Research* 2: 17-20.
- Mather J.R. (1978): *The climatic water balance in environmental analysis*: Lexington, Mass., D.C. Heath and Company, 239 p.
- McCabe G.J., Wolock D.M. (1999): Future snowpack conditions in the western United States derived from general circulation model climate simulations: *Journal of the American Water Resources Association* 35: 1473-1484.
- Ngigi S.N. (2003): Rainwater harvesting for improved food security: Promising technologies in the Greater Horn of Africa: Greater Horn of Africa Partnership, Nairobi, Kenya. 266 p.
- Olaniran O. J. (1990): Changing patterns of rain-days in Nigeria. *GeoJournal* 22: 99 -107.
- Olaniran O. J. (1991): Rainfall anomaly patterns in dry and wet years over Nigeria: *International Journal of Climatology* 11:177-204.
- Thornthwaite C.W. (1948): An Approach toward a Rational Classification of Climate: *Geographical Review* 38: 55-94.
- Wolock D.M., McCabe G.J. (1999): Effects of potential climatic change on annual runoff in the conterminous United States: *Journal of the American Water Resources Association* 35:1341-1350.

Received: March 25, 2014

Accepted after revisions: September 1, 2014

Corresponding author:

Mary N. Ezemonye

Department of Geography and Regional Planning

University of Benin, Benin City

E-mail: ezemonyemary@yahoo.com

Phone: +234 8033418529