Determination of the Effectiveness of Irrigation Scheduling Strategy using CROPWAT Model for Maize Crop: Case study in Perkerra Irrigation Scheme, Kenya

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Abstract: ***With the increasing climate change that results into unpredicted rainfall pattern that causes either severe drought and flood, there is need to adapt some irrigation scheduling strategies that will effectively and efficiently supply water to crops at the right time and in the right amount. This can be supplemented by harvesting the surplus rainwater when it floods then store it to be used in case the level supply goes down. By employing the correct irrigation scheduling strategy, the stored water or the minimal available water can be used increase productivity from a large portion of land. A CROPWAT model was applied in this research using maize crop as our main crop since maize is widely grown in Perkerra irrigation scheme. Weather elements from the nearby meteorological station were used to feed in the necessary data to obtain reference evapotranspiration. Crop water requirements, irrigation water requirement, and irrigation scheduling were estimated using the CROPWAT model while the soil texture, field capacity and the amount of available moisture before irrigation were done at the soil lab in Egerton University.***

Keywords: Irrigation scheduling, CROPWAT, Irrigation efficiency, Irrigation effectiveness, Scheduling strategies

1. Introduction

Poverty is drastically increasing in many parts of Kenya as water becomes scarce due to the population increase. This calls for urgent solutions in the agricultural sector. There is a need to formulate an irrigation technique so as to ensure that it has both a positive impact on reducing poverty by maximizing the limited water under climate change situation (Ngigi, 2002).

Climate change has resulted in droughts and floods in many regions. This has led to areduction in river flow or running dry during the dry season which makes irrigation during this time impossible. The compilation and scrutiny of data obtained from the nearby meteorological station for crop water requirement and crop productivity have a major factor in establishing irrigation schedule strategies which maximize use of water for crop production and the most appropriate strategies for water management. Therefore, adapting techniques that can enhance water use efficiency or plant crops that require a minimal amount of water when river levels are low is necessary (Kamble *et al*, 2013). Farmers tend to over-irrigate when there is enough water with the hope that it will improve crop yields. Instead, excess irrigation reduces the quality and quantity of the crop because the excess soil moisture usually causes diseases to crops, leaching of useful nutrients, reduce the effectiveness of pesticide, and wastage of water and energy in case water is being pumped (Ngigi, 2002).

The surplus water can then be used to expand the area under irrigation or increase the river flow downstream for other purposes thus increasing both production and the income to the farmers. In deriving irrigation schedule strategies, an adequate relationship between water required for irrigation purposes and for river environmental flows is paramount. Natural precipitation contributes to approximately 65% of global food production while irrigation water provides 35%. Irrigation is only done on 17% of the total land under agricultural activities (Smith, 2000)

For the sustainable development goals one (Zero poverty) and two (Zero hunger) to be accomplished, action should be taken to ensure sustainable growth in the agricultural section. Water is required for crop production. When crops are water stressed, their stomata close and the process of photosynthesis decline. Best growth can be achieved when crops have an equilibrium of soil moisture and air in the root zones in which the soil moisture requirement in any crop depends on the growth stage of crops (Kamble *et al.*, 2013).

The major problem of irrigated agriculture is the inefficiency of the water application techniques and scheduling. An estimated 40% of the water diverted from the source to be used for irrigation is wasted in the farm through surface runoff or deep percolation (Adeboye, Osunbitan, Adekalu, & Okunade, 2009).

Silts washed by surface run-off are usually deposited on the low areas in the field. This calls for frequent de-silting of these regions which is an extra task for the farm operators and a loss in terms of energy, cost, and time. These de-silted sediments though they are fertile, they are heaped in one area which becomes unbearable as they retard crops growth since they cover up crops and forcing them to fall down. The soil becomes waterlogged if the internal drainage is blocked that results in the drying of the roots and eventually crops die due to lack of oxygen (ICDC, 2008).

De-silting is being done more often so as to curb crops being swept or covered by silts. This reduces the time farm operators have for other farm activities such as herbicide application, weeding, and other irrigation management activities in the farm. This phenomenon has been observed in Perkerra Irrigation Scheme (PIS). PIS is a good representative of schemes with less supply of water for irrigation and rampant surface runoff which erodes top layer of the soil in Kenya.

Application of too much water has a less visual effect though it wastes fertilizer, soil, and water. Irrigating at a required proportion help in holding water and available useful nutrients in the root zone where crops can utilize them (Shock *et al.*, 2013).

2. Materials and Methods

2.1 History of establishment

Perkerra Irrigation Scheme is one of the seven public irrigation schemes under National Irrigation Board (NIB). Others include Bura, Ahero, South West Kano, Mwea, Bunyala and Tana Irrigation Scheme. It is in Baringo County in the western part of Kenya that was set up and funded by the Government with the overall aim of improving the livelihoods of farmers by enhancing their incomes through the practice of sustainable irrigated agriculture.

The Perkerra irrigation scheme was launched in 1952 and construction began in 1954 by the Mau Mau laborers because Margat town was one of the camps used for detaining colonial prisoners in the country at that time. (Roll-out, 2011)

The project was initiated in a region with a backdrop of extreme poverty of about 66% amongst its sparse population who experienced unreliable rainfall and frequent crop failures where agriculture (farming and pastoralism) is the mainstay of the people (Poverty Mapping exercise, 2003/2004).

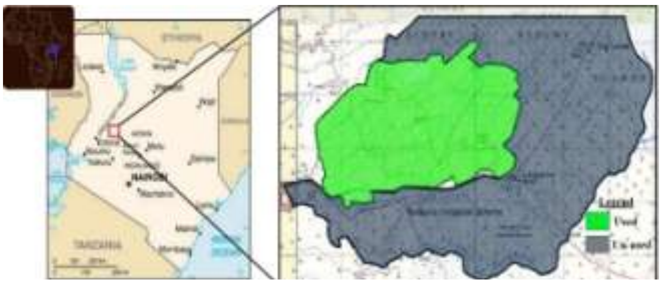

Figure 2.1: A map showing an area covered by Perkerra Irrigation Scheme

2.1.1 Beneficiaries

Beneficiaries are grouped into two broad categories; direct beneficiaries of about 13000 people and indirectly benefits the larger Baringo and part of Nakuru county by the marketing of the farm produce. The Perkerra irrigation scheme supports about 750 farm households where the large population is having 3 to 4 acres of farmland.

2.1.2 Water Resources

The sources of water in the area include; Lakes, boreholes, springs, and rivers. The district has two lakes which are Lake Baringo and Bogoria.The main rivers are Perkerra, Molo, Kerio, Loboi and Sugutaol Arabal. Due to technical and financial consideration, Perkerra river is the major source of water for the Irrigation Scheme. It allows water to flow via gravity through the scheme. The Perkerra River is the only perennial river in Baringo county that feeds the freshwater Lake Baringo. The Perkerra river supplies water to the Perkerra Irrigation Scheme in the Njemps flats near Marigat town. The river runs through a catchment area of 1,207 square kilometres. It rises in the Mau Forest on the western part of the Rift valley at 2,400 m, dropping down to 980 m at its mouth on the lake.

2.1.3 Population

The average population density is 120 people per square kilometre. There is an average growth rate of 3.6% compared to 2.4% for the country (Thom and Martin, 2016).

2.2 Determining the effectiveness of irrigation strategies using CROPWAT model for maize crop

A literature review was conducted on irrigation scheduling techniques and crop evapotranspiration. The field data collected during the review is presented as follows;

2.2.1 Data Collection

- Primary field data collection commenced with a reconnaissance survey of various sites and discussions with relevant government agencies. The collection was from frequent field observations, informant interviews, semi-structured interviews and focus group discussions.
- Canal water flow at the diversions discharge was taken at an interval which helped us in estimating the total volume of water that is being diverted by the irrigation scheme.
- Moisture contents of the soil of the selected irrigation fields before and after irrigation were determined by using the digital soil moisture meter and by taking soil samples at different depths of the soil profile.
- The Secondary data included crop types, area irrigated per crop per season, and cropping pattern.
- Meteorological data for each irrigation projects was obtained from the library, the internet, and the nearby meteorological station.

The data collected above was used in the development of the irrigation scheduling as follows;

2.2.2 Determination of the reference evapotranspiration

The reference evapotranspiration ETo was calculated by FAO Penman-Monteith method, using CROPWAT 8.0 developed by FAO. We used the meteorological data from the neighbouring meteorological station to estimate ETo. The Penman-Monteith equation integrated into the CROPWAT program is expressed as:

$$ETo = \frac{0.408\Delta(R_n - G) + \gamma \dfrac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)} \tag{2.1}$$

Where;
ETo = Reference evapotranspiration [mm/day]
Rn = Net radiation at the crop surface [MJ m^{-2} day^{-1}]
G = Soil heat flux density [MJ m^{-2} day^{-1}]
T = Daily air temperature at 2 m height [^oC]
u2 = Wind speed at 2 m height [m $s]^{-1}$
e_s = Saturation vapour pressure [KPa]
e_a = Actual vapour pressure [KPa]
$(e_s - e_a)$ = Saturation vapour pressure deficit [KPa]
Δ = Slope vapour pressure curve [KPa $^oC^{-1}$]
γ = Psychometric constant [KPa $^oC^{-1}$]

The reference evapotranspiration (ETo) is the only value that we determined using the meteorological data. Meteorological data used in the determination of ETo was latitude, longitude, and altitude of the station, maximum and minimum relative humidity, wind speed, sunshine hours and maximum and minimum temperature. ETo was calculated for every decade then expressed in a month (Zotarelli and Dukes, 2010).

2.2.3 The effective rainfall

The effective rainfall was calculated by CROPWAT using the United States Department of Agriculture (USDA) soil conservation service method as shown (Smith, 2000).

$$PE = 124.8P_{tot} \quad (2.2)$$

For P_{tot} < 250 mm

$$PE = 125 + 0.1P_{tot} \quad (2.3)$$

For P_{tot} > 250 mm

Where;
PE = effective rainfall, mm
P_{tot} = total rainfall, mm

2.2.4 Soil parameters

Soil characteristics required for the determination of crop water requirement include; available water content, total available water, depth of the plant root zone, depletion volume and readily available water which uses the equations below:

$$AWC = FC - WP \quad (2.4)$$

$$TAW = AWC \times R_d \quad (2.5)$$

$$RAW = p \times TAW \quad (2.6)$$

Where;
TAW = total available water capacity within the plant root zone (mm)
AWC = available water capacity of the soil, (m^3 /m^3)
Rd = depth of the plant root zone, (m)
p = an average fraction of TAW that can be depleted from the root zone before water stress.

The depth of the zone from which water uptake can occur, Rd, is calculated by assuming that maximum rooting depth coincides with the development of full canopy (Adeboye *et al*., 2009).

2.2.5 Crop data

Crop coefficient, planting date, and harvesting date are some of the crop data that was obtained from the PIS office for this research study. We majorly focused on maize in our study for its importance to the people of Marigat and in the larger population of Africa.

We obtained Crop coefficient values (Kc) for initial, mid and late growth stages from the available published data (FAO 1998)adjust them to the actual climatic condition of the site and then use them in our calculations.

FAO 56 was used to determine the length of each growth stage of the crop studied (Mark *et al*., 1992). These lengths and the total growing period for specific climate, location, and for varied crops are provided in FAO 56.

Table 2.1: The crop coefficient values for various crops (Allen et al., 1998)

Crop type	Kc Initial	Kc Development	Kc end
Maize	1.20	0.6	0.35
Onions	0.7	1.05	0.8
Watermelon	0.4	1.0	0.75

2.2.6 Crop evapotranspiration (ETc)

ETo obtained was multiplied by crop coefficient(Kc) to produce an estimate of actual crop evapotranspiration(ETc) as follows;

$$ETc = Kc \times ETo \quad (2.7)$$

Where;
ETc = Crop evapotranspiration
Kc = Crop coefficient
ETo = Reference crop evapotranspiration.

2.2.7 Simulation of the irrigation water application using CROPWAT

After obtaining all the required data, they were used to calibrate the CROPWAT model to suit our study site (Perkerra Irrigation scheme). We then ran the model to get the results.

Crop water requirements (CWR) was calculated by CROPWAT from the above parameters (the effect of climate, the effect of the crop characteristics and the effect of local conditions and agricultural practices).

Table 2.2: Summary of the input data

Input			
Climate	Soil	Crop	Irrigation
Rainfall	Kc	Type of soil	System type
Maximum Temperature	Rooting depth		
Minimum Temperature	Planting date	Field capacity	efficiency
Wind speed	Harvesting date	Permanent wilting point	
Humidity	Length of each stage	Saturation capacity	
Sunshine hours	Critical depletion factor	Root depth	
	Infiltration rate		

Table 2.3: A summary of the output data

OUTPUT	
Reference crop evapotranspiration (mm/period) Average values of crop coefficient for each stage Irrigation requirements (mm/period)	Actual crop evapotranspiration (mm) Effective rain (mm/period) Readily available moisture(mm) Total available moisture

Daily soil moisture deficit (mm) Ratio of actual crop evapotranspiration to the maximum crop evapotranspiration (%) Estimated yields reduction due to crop stress (when ETc/ETm falls below 100%)	(mm) Crop water requirements (mm/period) Irrigation depth applied (mm) Irrigation interval (days) Lost irrigation (mm)

3. Results and Analysis

3.1 Determining the effectiveness of irrigation strategies using CROPWAT model for maize crop

3.1.1 Reference Crop evapotranspiration, ETo

Penman-Monteith method was used to compute ETo within CROPWAT environment. This method is recommended by FAO,1998 as it offers consistent result as compared to other methods. Figure 3.1 shows climatic data related to the project site at the PIS Project.

Monthly ETo Penman-Monteith - G:\Perkerra Data\MARIGAT.pen

Country: KENYA | Station: MARIGAT
Altitude: 1000 m. | Latitude: 0.50 °N | Longitude: 36.03 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	16.7	38.7	49	29	10.4	24.6	4.94
February	18.2	39.5	47	36	10.2	25.2	5.24
March	18.0	38.3	50	38	9.6	24.6	5.21
April	17.4	35.3	57	31	8.7	22.5	4.59
May	16.6	37.1	59	36	9.9	23.1	4.70
June	17.0	35.5	56	31	9.9	22.3	4.33
July	17.0	36.4	61	26	8.6	20.7	4.18
August	16.6	35.2	59	31	9.2	22.7	4.51
September	16.5	37.5	53	38	9.8	24.5	5.00
October	17.2	38.0	53	36	9.1	23.4	4.91
November	17.2	35.6	55	26	8.6	22.0	4.41
December	16.0	36.5	55	21	9.1	22.3	4.32
Average	17.0	37.0	54	32	9.4	23.2	4.69

Figure 3.1: Monthly weather variables and ETo calculation for PIS

The mean daily reference evapotranspiration (ETo) for PIS is 4.69 mm. The values are high in January to March and in September and October which are dry months. The values are low in the months of June, July, November, and December. The high ETo was experienced in the months where there was a low relative humidity combined with high temperatures. Inversely the low values of ETo were in the months that experienced some rainfall. This could be due to the high relative humidity and slightly low temperatures during the rainy season.

Perkerra scheme has low wind speed which makes it a light wind region

The mean monthly temperature of Perkerra is 26.3°C and the average ETo is 4.69mm/day. This makes Perkerra an arid and semi-arid region.

3.1.2 Rainfall

Monthly rainfall averages are used in the analysis to determine the fraction of rainfall that contributes toward the building of soil moisture content (effective rainfall). The highest monthly average is in the months of November and December and the lowest monthly average is in the month of January and March. FAO recommended formula Curve Number (CN) method for determination of the effective rainfall. The computation of the effective rainfall is presented in Figure 3.2.

Monthly rain - G:\Perkerra Data\MARIGAT.cli

Station: MARIGAT | Eff. rain method: USDA S.C. Method

	Rain	Eff rain
	mm	mm
January	1.0	1.0
February	2.3	2.3
March	1.4	1.4
April	3.5	3.5
May	3.4	3.4
June	14.7	14.4
July	28.6	27.3
August	8.0	7.9
September	16.7	16.3
October	21.9	21.1
November	59.5	53.8
December	54.4	49.7
Total	215.4	202.0

Figure 3.2: Monthly rainfall and effective rainfall

From FAO irrigation and drainage paper No 56, compared to the rainfall data of Perkerra as shown in Figure 4.2, it is clear that in the first quarter of the year the rain is less than 3 mm which implies that it is a very light shower (drizzle). The rainfall is more than 10 mm (medium shower) from June to October excluding the month of August which is a light shower. November and December have a rainfall more than 40 mm which is a heavy rainfall (rainstorms). Rainfall is insufficient in the better part of the year which implies that irrigation is required throughout the growing season.

3.1.3 Actual crop evapotranspiration, ETc

The crop evapotranspiration of maize was found to be **558.2 mm** in the whole season. ETc was more during the dry months than the rainy months. This is because crops lose more water in the dry season and therefore need more water to replace the lost ones than those grown during the rainy season. The ETc is a function of the temperature and rainfall and varies greatly with the crop growth stage as presented in Figure 3.3.

Crop Water Requirements

ETo station: MARIGAT | Crop: MAIZE (Grain)
Rain station: MARIGAT | Planting date: 01/11

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Nov	1	Init	0.30	1.38	13.8	15.4	0.0
Nov	2	Init	0.30	1.33	13.3	19.6	0.0
Nov	3	Deve	0.33	1.46	14.6	18.6	0.0
Dec	1	Deve	0.54	2.34	23.4	18.4	5.0
Dec	2	Deve	0.75	3.30	33.0	18.7	14.3
Dec	3	Deve	1.00	4.50	49.4	12.5	36.9
Jan	1	Mid	1.19	5.58	55.5	1.0	54.5
Jan	2	Mid	1.20	5.92	59.2	0.8	58.2
Jan	3	Mid	1.20	5.98	65.8	0.1	65.7
Feb	1	Mid	1.20	6.14	61.4	0.7	60.7
Feb	2	Late	1.19	6.25	62.5	0.8	61.7
Feb	3	Late	1.02	5.32	42.6	0.7	41.9
Mar	1	Late	0.76	3.98	39.8	0.5	39.3
Mar	2	Late	0.48	2.45	24.9	0.4	24.5
					558.2	107.5	462.8

Figure 3.3: Monthly actual crop evapotranspiration and irrigation requirement

3.1.4 Crop data

Crop coefficient, Kc; rooting depth; length of plant growth stages; planting date, and allowable depletion were entered in the CROPWAT for the crop. Crop coefficient, Kc for a variety of crops for their various growth stages were obtained from FAO manual 56. Crop characteristics for maize crop were obtained as in Figure 3.4.

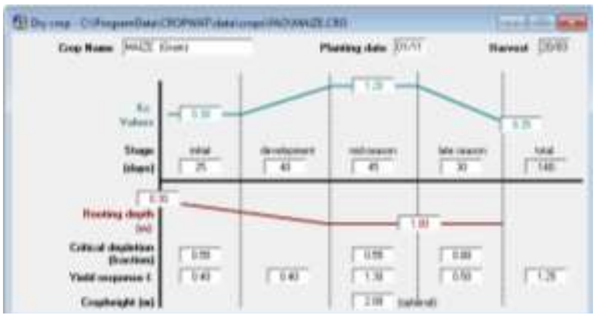

Figure 3.4: Crop characteristics for maize

3.1.5 Soil type

There are two types of soil in the study area. Silt loam and sandy loam but the predominant soil in the scheme is of silt loam. This was obtained from the record books and also done practically in the laboratory. It is assumed that soil moisture at the beginning of crop growth is zero in order to account for initial irrigation required to prepare the soil before seeds are dispersed in the field.

$$AWC = FC - WP$$

Rooting depth of maize from FAO 56 is 0.90m
Available moisture content of the silt loam is 208mm/m

$$AW = AWC \times Rd$$

Therefore; $= 208mm/m \times 0.90m$

$$= 187.2mm$$

Depletion factor of maize is 50%

$$RAW = p \times TAW$$

$$= {}^{50}\!/_{100} \times 187.2$$

$$= 93.6mm$$

The values calculated above was then fed into CROPWAT 8.0 as presented in Figure 3.5.

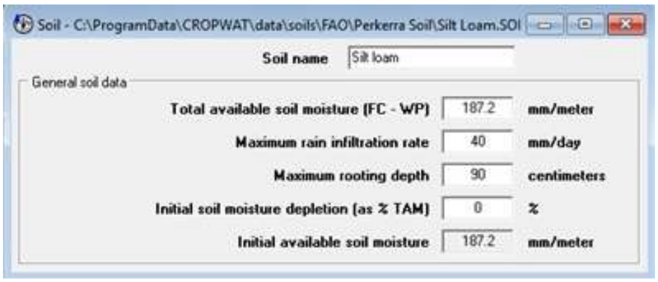

Figure 3.5: Soil characteristics

3.1.6 Irrigation Scheduling for Maize crop

Water application is scheduled to take place at the wilting point where the soil is irrigated to Field Capacity. Irrigation schedule for maize crop was calculated when initial soil moisture depletion set at 0% in order to obtain a yield reduction of 0% as shown in Figure 3.6.

Figure 3.6: Irrigation Scheduling for the maize crop in PIS

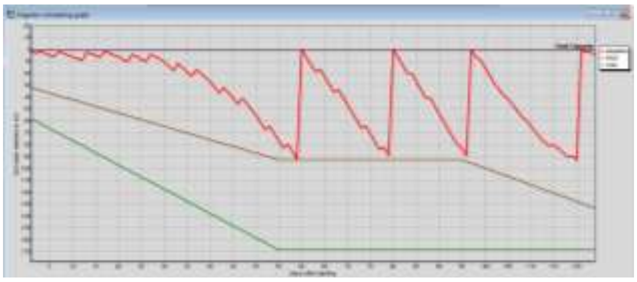

Figure 3.7: Graphical representation of the Irrigation Requirement for maize in PIS

Comparison of the total gross irrigation, actual evapotranspiration and irrigation requirement from CROPWAT with respect to the planting month in PIS is tabulated in Table 3.1. This can be used to calibrate the CROPWAT to suit the optimal irrigation schedule for the PIS.

Table 3.1: Comparison of the total gross irrigation, actual evapotranspiration and irrigation requirement from CROPWAT with respect to the planting month in PIS

Planting month	November	October	September
Total gross irrigation (mm)	549	406.7	408.5
Actual evapotranspiration (mm/season)	558.2	534.8	526.5
Irrigation requirement(mm/season)	462.8	362.4	356.4

4. Conclusion and Recommendation

In particular, regions where there is enough water for irrigation, that is near the diversion that leads to the secondary canals, farmers have a tendency of over irrigating crops to prevent crop yield reduction which is totally not the case. The results of irrigation scheduling project done from CROPWAT have proved that water applied to crops can be declined and in most scenarios, enhance crop yields. When the irrigation scheduling using CROPWAT is adapted to the current scenario where farmers apply water after every 2-3 days, a lot of water will be saved by more than 100% i.e. 660.6mm. The excess water can then be used to increase the area under irrigation.

From the tabulated results of the total gross irrigation, actual evapotranspiration, and irrigation requirement, it is clear that when planting date is shifted from November to September, less water will be required. The water saved will be approximately 140.5mm. This is because maize requires more water during development and middle stage of growth, which can be supplemented by the rain that is available from September all the way to December.

Irrigation scheduling practice using CROPWAT that incorporates weather variables, crop evapotranspiration, crop coefficient and soil water balance can be combined with soil moisture sensors to boost the application of water to the crops. More studies should be done to find a way of incorporating soil sensors with CROPWAT. This is necessary because rainfall pattern keeps on changing.

More research should be done on how to curb the silt in the abstracted water so as to help PIS to change from the furrow irrigation system to sprinkler or trickle irrigation because more water can be saved from these methods as compared to the current method.

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