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Profit and Loss Irrigation Scheduling to Improve Water Production Efficiency

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Abstract: *Under the present irrigation system the rules applied for the network operation are not compatible with the problems of field irrigation; because the gross and net irrigation volumes applied depend mainly upon the field characteristics (furrow length and slope) and the pre-irrigation soil moisture content Also considering the climatic factors and the different phonological stages, the irrigation intervals need to be adjusted to meet the crop water requirements. A study was undertaken in Kenana Sugar Scheme, Sudan during 2013/2014 and 2014/2015 seasons. This paper outlines a simple irrigation control method it is dynamic , easy to use and has been sustained for a number of seasons. In this study, the irrigation scheduling spreadsheet developed by the irrigation and water management scientist was used to optimally maximize sugarcane crop water uptake and minimize water losses. To achieve these objectives, twelve commercial cane fields having different furrow lengths and slopes were chosen. The study shows that the Total Available Moisture ranged from 80 to 100 mm with an average of 87 mm. This represents the total amount of water that the soil can hold in the effective root zone. Typically the allowable depletion is taken to be 50% which means that an average of 43.5 mm of Readily Available Water in the soil is available to the crop. At peak demand (in March) this represents 5 days of available moisture before the crop will experience the onset of stress. The target irrigation depth is usually set to the Readily Available Water of the soil. Ideal the next irrigation event is triggered as the soil moisture reaches the refill point and the irrigation refills the soil to field capacity. This has implications for how much water can be applied during each event to avoid run off. Regarding the irrigation scheduling techniques for sugarcane, the specific objective would be achieved by providing the cane production management at Kenana sugar scheme with relevant information and the daily decision process to schedule irrigation effectively. The present study, results revealed that it is time to apply the proper irrigation scheduling by making use of the available soil-water-plant data collected from the commercial cane fields of Kenana sugar scheme. It is recommended that a detailed study and analysis of water use be done to quantify the impact of the approach on savings due to irrigation scheduling.*

Keywords: *Irrigation, Sugarcane, scheduling, Available water, Furrow, Application Efficiency, Percolation*

1. INTRODUCTION

Furrow irrigation involves supplying water at the high end of a furrow and gravity induces flow to the bottom end. The simplicity of irrigation with furrows contrasts with the study of furrow flow hydraulics and intake phenomena. Irrigation scheduling is the process of determining when to irrigate and how much to irrigate. The three ways to decide when to irrigatewas to measure soil-water estimate soil-water using and measure crop stress.

Although the talent of irrigating sugarcane crops is century's old, applying current technology to best advantage requires appropriate new skills. Water resources management should be concerned with careful and intensive use of relatively limited water supplies i.e. matching more closely irrigation volumes with crop water requirements in time and magnitude. Furrow irrigation is a method of applying water at a given rate into shallow evenly spaced canals **[1].** In furrow irrigation, the field divided into sectors each of 60 furrows in which irrigation water is applied. The furrows are filled to the desired depth of water and this water is retained until it infiltrates into the soil both vertically and horizontally. The gated pipe (hydro-flume) is defined as a closed conduct with a circular cross section with water flows in- side it (no free surface). The flows result from pressure difference between inlet and outlet and they affected by fluid properties and the flow rate. The gated pipe furrow irrigation system consists of relatively large diameter pipes of about 0.46 m (18 inches), with gates usually equipped on one side and corresponding to the furrow spacing. The hydro-flume is flexible so that no alluvial clings to its wall. The gated pipes as an improvement in furrow irrigation, in which the conventional head ditch and siphon are replaced by an above ground pipe. Gated-pipes are currently used extensively in sugarcane fields in Upper Egypt. **[2]** found that using gated-pipe to irrigate long furrow resulted in saving water by 20% and 38% and increasing its use efficiency by 58% and 17% for bean and peas, respectively. **[3]** stated that varying pipe slope, diameter, number of gates, gate area and mean outflow, affect uniformity of outflows. They added that for the entire typical gated-pipe situation analyzed, maximum flow uniformity is obtained with the pipeline slope uphill in the direction of flow.

In Sudan, the gated pipe furrow irrigation system was first introduced for vegetable production in a small scheme in Zaied Elkhair which is located on the eastern bank of the Blue Nile. In Kenana Scheme, the gated pipe was introduced in year 2003 to allow for more uniform irrigation. The system has high application efficiency when operated properly.

In 2001/02, the gated pipe furrow irrigation system was adopted in Kenana Scheme for irri- gating sugarcane in large scale. Until January, 2007 about 75% of the total area was serviced by the gated-pipe in place of the open field head ditch system with open canal. Recently (years 2004-2005), the gated-pipe was also adopted in some fields at Sudanese Sugar Company mainly, Asalayia Sugar Scheme. Irrigation practice in Kenana has subjected to many changes. In year 1981, the water indenting was basin on fixed days per cycle, and different sizes of siphon were used in the same field to maintain the cycle regardless of field gradient of furrow length. An irrigation system based on evapotranspiration (10 mm/day) was introduced in 1983. In 1987, an indenting system of irrigation based on the number of operating pumps was adopted. Recently, The individual fields were categorized into three groups according to their length, slops and soil classes as A, B and C system, which are irrigated every 12, 10 and 7 days respectively. The steeper the field, the shorter is the furrow length and the shorter is the irrigation cycle. Irrigation water is pumped from the White Nile into a main canal and distributed through secondary canals until it reaches an open field head ditch from which it is siphoned through a pipe into the furrows of the field. The Scheme is provided with a drainage net work. In year 2002, the open field head ditch system has been gradually changed to the closed system. The open field head ditch and siphons are replaced by an above ground flexible pipe (Hydro-flume) of 18 inch internal diameter, 100 meter long with adjustable gates spaced at 1.5 meter interval.

1.1 Justification of the study

Generally, irrigation events are triggered either according to the schedule or through physical inspection of the soil, but the theoretical basis for the irrigation scheduling method employed at kenana sugar scheme since 1980`s and before the project implementation was a fixed irrigation cycle times and not as per crop requirements. It is fairly inflexible system that can lead to over irrigation during the cropping cycle. Also the previous form of irrigation scheduling adopted under Kenana conditions was difficult since the total available moisture (TAM) of the soil and the application rates of the irrigation system were not known. **[4]** observed that the application of the scheduling method at Kenana Sugar Scheme varies between cane fields and within fields.

1.2 Objective of the study

The broad objective of the present study is to perk up the irrigation production efficiency (IPE) produced through improving on-farm water management and to improved flexibility in farm irrigation management via optimization of irrigation, water saving and improvement in cane yield. The specific objective is to assess the designed profit and loss irrigation scheduling model under the existing irrigation system of Kenana Sugar Scheme with regards to optimally control the soil moisture in the active root zone and maximizing cane and sugar yields.

1.3 Growing of sugarcane

Sugarcane is grown as an irrigated crop in Kenana Estate over an approximate area of 42437 hectare, out of which 8403 hectare is fallow land i.e. area under cane is 34034 hectare using ridge and furrow system. Planting always starts in June for the early maturing varieties i.e. about 2101 to 3361 hectare. The rest of the fallow land is planted in October after the rainy season, (4622 to 5042 hectare). The harvesting program is designed in the same sequence of planting for both plant cane and ratoon crop.

Generally, a cropping cycle starts with plant cane and may continue to the ninth ratoon according to the productivity of the particular field. Ratoons constitute more than 80% of the total area under cane.

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1.4 Water management and the irrigation Network

The irrigation network consists of six pumping stations situated along the main canal, with a total lift of 45 m above the White Nile level. Pumping stations one and two are designed to pump a maximum of 42 m^3s^{-1}. The other four stations are designed with less capacity because of the diversion of water to primary canals. Furrows run perpendicular to contour lines with lengths ranging from 300 to 2750 m.

[5] stated that frequency and depth of irrigation should vary with growth periods of the cane. He revealed that due to variations in the degree of field slope, furrow length, infiltration rate, the contact time of irrigation water and planting date, the first three irrigation cycles should be extended as below;

Irrigation number	Irrigation interval (days)
2nd. Irrigation cycle.	14 -- 21
3rd. irrigation cycle	10 -- 14
4th. Irrigation cycle	10 -- 14

1.5 Irrigation scheduling approach

Irrigation scheduling is the use of water management strategies to prevent over application of water while minimizing yield loss due to water shortage or drought stress. It is an extremely important management practice for irrigating many different crops grown under a wide range of soil conditions and production practices. Under Kenana conditions Abdel wahab (2000) stated that the profit and loss irrigation scheduling method depended on meteorological data for the scheduling. **[6]** confirm that monitoring the weather data can serve as an irrigation criterion in some situations. In principle, irrigation can be scheduled by monitoring the soil, the plant, and/or the microclimate. The profit and loss irrigation scheduling method commonly used in the Swaziland sugar industry to calculate or estimate soil moisture in the field using the total available moisture (TAM) of the soil, irrigation events, rainfall and the daily evapotranspiration (ET). The profit and loss irrigation scheduling method is similar to the water budgeting and the check-book methods.

1.5.1 Importance of irrigation scheduling

Irrigation scheduling requires knowledge of the soil-water status, the status of crop stress and the potential yield reduction if the crop remains in a stressed condition. Careful irrigation scheduling minimizes runoff and percolation losses, which in turn usually maximizes irrigation efficiency by reducing energy and water use. The amount of water lost through runoff and percolation processes is affected by irrigation system design and irrigation management.

[7] revealed that by applying profit and loss irrigation scheduling practices the quantity of water pumped can often be reduced without reducing yield. Studies have shown that irrigation scheduling using profit and loss irrigation scheduling method can save 15 to 35 percent of the water normally pumped without reducing yield **[8]**.

1.6 Relating soil-water to plant stress

In irrigation scheduling, soil moisture data is used as a proxy for plant stress. In other words, a certain level of soil moisture deficit is chosen as the point at which the crop starts to suffer from stress due to insufficient water availability The amount of water that should be applied with each irrigation depends primarily on the soil and the amount of water it can retain for plant use, referred to as *plant-available water* (PAW). The amount of water removed from the soil by the plant since the last irrigation or rainfall is referred to as the *depletion volume.* **[9]** stated that sugarcane crop will start to stress, with potential yield reduction when they reach the refill point and will die when they reach the wilting point. Sugarcane crop typically use most soil moisture in the top of the soil profile and proportionally less, deeper in the profile. Moisture is generally obtained from the top of the profile first, although on some occasions this may not occur. For example a rainfall event may cause temporary water-logging at the soil surface whilst water extraction continues at depth.

Recently, scheduling techniques have been developed that are based on the moisture status or stress condition of the crop. For example, to predict crop stress by infrared thermometry, the temperature of the crop's leaves is related to transpiration rate. Remote sensing of crop stress using infrared satellite imagery is another method being evaluated. Although these methods hold promise for the future, most of the work on them has been conducted in arid regions. The most reliable method currently available for estimating when to irrigate is based on allowable depletion of PAW. The basic assumption is that crop yield or quality will not be reduced if crop water use is less than the allowable depletion level. In Kenana sugar scheme, 60 percent depletion of PAW is recommended for the heavy clay soil. However, allowable depletion may range from 40 percent or less during the early growth stages.

2. MATERIALS AND METHODS

2.1. Site Specification

2.1.1. Location

Kenana Sugar Estate is located in an arid continental climatic zone in the Sudan (East Africa) on the east bank of the White Nile River, 240 Km. south of Khartoum and 30 km South of Rabak town and coordinates 13.10 North and 32,40 East . The climate is arid with a rainy season extended from mid July to mid October and a mean annual rainfall of about 341mm (for the period from 1977 to 2015) .There is a cold dry season (March – mid July) with average temperature enables optimum growth of sugarcane. The mean annual temperature is 28.70 Deg C. The mean maximum temperature is over 40^{o} C for April and May with absolute maximum of about 45^{o} C for these months. The mean minimum temperature is 17.6^{o} C in December with an absolute minimum of 10 ^{o}C. The daily evaporation rate varies from 5 mm/day in August to 16 mm/day in March – April.

2.2. Area of the Scheme

Kenana Sugar Estate is considered to be one of the largest single estates in the world covering an area of 42,400 hectares of cane. It is irrigated from the White Nile River by lift irrigation. The potential yield of the estate is about four million ton of cane.

2.3. Topography

The Estate area slopes downwards towards the White Nile River with an average land slope of 0.5 meter per kilometer. From its Western boundary to the river elevations range from 390 ms to 429 ms above sea level. The Estate area is divided in two by a ridge running from North east to South-west from elevation 424 meter to 410 meter and is deeply incised by two drainage channels which are separated by a ridge. The governing slopes are about 45 degrees to the direction of the drainage channels. The cross contour grades range from 1:25 to 1:1000 with the majority of areas around 1:500

2.4. Soil

The soil of the Estate consists mainly of sediments of the Blue Nile mostly derived from the basic rocks of the Ethiopian Highlands and forms a part of the extensive central clay plain of the Sudan. Kenana soil is classified as Vertisols of the Central Clay plain (Dinder series) that crack widely and have a high Base Exchange capacity. Soil characteristics of the surface layer (0 – 60 cm) were 65 to 75% clay. Dark in color, very fine fraction was dominated by montmorillonite that gradually decreased with depth.

The soils are fairly uniform, self mulching clays. The surface crack is developed with cracks up to 5 cm. wide down to about 60 cm. A massive horizon below 60 –75 cm. deep has fewer cracks than the top layer. Irrigation and rain water enter the soil through the cracks resulting in the swelling of the soils and closing of the cracks after saturation. Very little further water can gain entry and thus development of water table does not arise easily. The topsoil is alkaline clay, containing 40 to 60% clay and 10 to 30% sand, with sub-soils somewhat heavier. Over 90 percent of the soil has a P.H value in the range of 7.5 to 8.5. About 97% of the topsoil (0-25 cm) has low EC (electro-conductivity) values of less than 2 mmho/cm increasing to 4 mmho/cm in the sub-soils (75 -100 Cm).

2.5. Implementation of irrigation scheduling model

The project was first implemented in the mid-2012/13 crop season, and was effectively run with objective of evaluating the irrigation scheduling model for two growing seasons (from 2013/14 to 2014/15) and the method used at the outset are still in practice, The irrigation scheduling techniques were applied to only 12 cane fields of Kenana scheme. These fields were selected for the implementation and verification of the developed profit and loss irrigation scheduling model, then scheduling began to expand to include other fields of the scheme. The technology was fully implemented by the third year. The project was formally evaluated at the end of each year. Each field was scheduled with the aid of a simple computer irrigation scheduling spreadsheet, where the collected data were manipulated in these spreadsheets template as shown in Table 1.

2.6. Data Collection

2.6.1. Soil Data

Soil samples for gravimetric moisture determination were collected at furrow top, middle and bottom for the determination of the soil moisture deficit prior to the irrigation **and t**he crop water requirements. The amount of water required for irrigating sugarcane plants were then calculated according to its phenological stages. The acceptable allowable depletion (the net amount of water to be replaced), the soil saturation point, field capacity, wilting point and available water (W/W %) were also estimated by using the core method. The field capacity and wilting point was determined using pressure extractor with regulated air pressure, **[10].** For each field the total available moisture (TAM), and hydro-flume discharge was measured and the irrigation inlet time (time that hydro-flume is open) was recorded and used as an input data. In the developed profit and loss irrigation scheduling model it was assumed that there was no deep percolation or storage above field capacity. Excess soil moisture above field capacity was assumed to run out of the field.

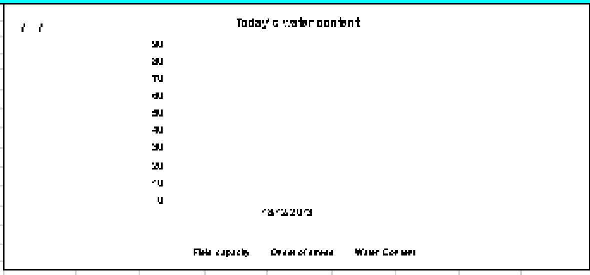
2.6.2. Soil physical and chemical analysis

Soil samples were taken from the soil profiles marked as: 0 - 20, 20 - 40, 40 - 60 and 60 - 80 cm. Three samples were then analyzed to obtain the particle size distribution, soluble cations and anions, cation exchange capacity, pH, organic matter, total carbonate and electric conductivity (EC). The international method was used to obtain the particle size distribution of soil samples **[11].** The chemical analyses of soil samples were carried out according to **[12].** Soil mechanical analysis, chemical and physical properties of the experimental sites are presented in Tables 2a and 2b.

Table 1: *Example of irrigation scheduling using profit and loss approach*

FIELD 22113

Kenana Sugar Company	
AREA : Profit and Loss Irrigation Scheduling	
Row spacing [m]	1.5
Field length [m]	1150
Hydroflume discharge [l/s]	3
Plantation date	13/11/2012
TAM [mm]	85
Allowable depletion	50%
RAW [mm]	42.5
Irrigation inlet time for target [h]	7
Initial starting moisture [mm]	0



Summary [mm]	
Irrigation applied	2610.8
Run off	1027.1
ETo	2281.4
ETc	2201.6
Rain	321.0

	Date	Irrigation inlet time [hours]	Irrigation applied [mm]	LTM ET [mm]	Actual ETo [mm]	kc	Rain [mm]	ETc [mm]	Opening balance [mm]	Closing balance [mm]	Run off [mm]	Closing balance after runoff [mm]
1	13/12/2012	16	100.2	5.2		0.40	0.0	2.1	0.0	98.1	13.1	85.0
2	14/12/2012		0.0	5.2		0.40	0.0	2.1	85.0	82.9	0.0	82.9
3	15/12/2012		0.0	5.2		0.40	0.0	2.1	82.9	80.8	0.0	80.8
4	16/12/2012		0.0	5.2		0.40	0.0	2.1	80.8	78.7	0.0	78.7
5	17/12/2012		0.0	5.2		0.40	0.0	2.1	78.7	76.6	0.0	76.6
6	18/12/2012		0.0	5.2		0.40	0.0	2.1	76.6	74.5	0.0	74.5
7	19/12/2012		0.0	5.2		0.40	0.0	2.1	74.5	72.4	0.0	72.4
8	20/12/2012		0.0	5.2		0.40	0.0	2.1	72.4	70.3	0.0	70.3
9	21/12/2012		0.0	5.2		0.40	0.0	2.1	70.3	68.2	0.0	68.2
10	22/12/2012		0.0	5.2		0.40	0.0	2.1	68.2	66.2	0.0	66.2
11	23/12/2012		0.0	5.2		0.40	0.0	2.1	66.2	64.1	0.0	64.1
12	24/12/2012		0.0	5.2		0.40	0.0	2.1	64.1	62.0	0.0	62.0
13	25/12/2012		0.0	5.2		0.40	0.0	2.1	62.0	59.9	0.0	59.9
14	26/12/2012		0.0	5.2		0.40	0.0	2.1	59.9	57.8	0.0	57.8
15	27/12/2012		0.0	5.2		0.40	0.0	2.1	57.8	55.7	0.0	55.7
16	28/12/2012		0.0	5.2		0.40	0.0	2.1	55.7	53.6	0.0	53.6
17	29/12/2012		0.0	5.2		0.40	0.0	2.1	53.6	51.5	0.0	51.5
18	30/12/2012		0.0	5.2		0.40	0.0	2.1	51.5	49.4	0.0	49.4
19	31/12/2012		0.0	5.2		0.40	0.0	2.1	49.4	47.3	0.0	47.3
20	01/01/2013		0.0	5.5		0.40	0.0	2.2	47.3	45.1	0.0	45.1
21	02/01/2013		0.0	5.5		0.40	0.0	2.2	45.1	42.9	0.0	42.9
22	03/01/2013		0.0	5.5		0.40	0.0	2.2	42.9	40.7	0.0	40.7
23	04/01/2013		0.0	5.5		0.40	0.0	2.2	40.7	38.5	0.0	38.5
24	05/01/2013		0.0	5.5		0.40	0.0	2.2	38.5	36.3	0.0	36.3
25	06/01/2013		0.0	5.5		0.40	0.0	2.2	36.3	34.1	0.0	34.1
26	07/01/2013		0.0	5.5		0.40	0.0	2.2	34.1	31.9	0.0	31.9
27	08/01/2013		0.0	5.5		0.40	0.0	2.2	31.9	29.7	0.0	29.7
28	09/01/2013		0.0	5.5		0.40	0.0	2.2	29.7	27.5	0.0	27.5
29	10/01/2013		0.0	5.5		0.40	0.0	2.2	27.5	25.3	0.0	25.3
30	11/01/2013		0.0	5.5		0.40	0.0	2.2	25.3	23.1	0.0	23.1
31	12/01/2013		0.0	5.5		0.40	0.0	2.2	23.1	20.9	0.0	20.9
32	13/01/2013	12	75.1	5.5		0.66	0.0	3.6	20.9	92.4	7.4	85.0
33	14/01/2013		0.0	5.5		0.66	0.0	3.6	85.0	81.4	0.0	81.4
34	15/01/2013		0.0	5.5		0.66	0.0	3.6	81.4	77.7	0.0	77.7
35	16/01/2013		0.0	5.5		0.66	0.0	3.6	77.7	74.1	0.0	74.1
36	17/01/2013		0.0	5.5		0.66	0.0	3.6	74.1	70.4	0.0	70.4
37	18/01/2013		0.0	5.5		0.66	0.0	3.6	70.4	66.8	0.0	66.8
38	19/01/2013		0.0	5.5		0.66	0.0	3.6	66.8	63.1	0.0	63.1
39	20/01/2013		0.0	5.5		0.66	0.0	3.6	63.1	59.5	0.0	59.5
40	21/01/2013	12	75.1	5.5		0.66	0.0	3.6	59.5	131.0	46.0	85.0
41	22/01/2013		0.0	5.5		0.66	0.0	3.6	85.0	81.4	0.0	81.4
42	23/01/2013		0.0	5.5		0.66	0.0	3.6	81.4	77.7	0.0	77.7
43	24/01/2013	12	75.1	5.5		0.66	0.0	3.6	77.7	149.2	64.2	85.0
44	25/01/2013		0.0	5.5		0.66	0.0	3.6	85.0	81.4	0.0	81.4
45	26/01/2013		0.0	5.5		0.66	0.0	3.6	81.4	77.7	0.0	77.7
46	27/01/2013		0.0	5.5		0.66	0.0	3.6	77.7	74.1	0.0	74.1
47	28/01/2013		0.0	5.5		0.66	0.0	3.6	74.1	70.4	0.0	70.4
48	29/01/2013		0.0	5.5		0.66	0.0	3.6	70.4	66.8	0.0	66.8

Table 2a: *Physical properties of Kenana soil*

Soil depth (cm)	Mechanical analysis			Field capacity	Saturation	Permanent wilting point	Bulk density
	Sand	Silt	Clay				
	(%)						(gram/cm³)
0 - 20	11	24	65	46	70	20	1.16
20 - 40	10	22	68	44	66	18	1.25
40 - 60	09	22	69	41	67	21	1.23
60 - 80	09	20	71	42	69	19	1.29

Soil depth (cm)	Mechanical analysis			Field capacity	Saturation	Permanent wilting point	Bulk density
	Sand	Silt	Clay				
	(%)						(gram/cm³)
0 - 20	11	24	65	46	70	20	1.16
20 - 40	10	22	68	44	66	18	1.25
40 - 60	09	22	69	41	67	21	1.23
60 - 80	09	20	71	42	69	19	1.29

Soil depth (cm)	Mechanical analysis			Field capacity	Saturation	Permanent wilting point	Bulk density
	Sand	Silt	Clay				
	(%)						(gram/cm³)
0 - 20	11	24	65	46	70	20	1.16
20 - 40	10	22	68	44	66	18	1.25
40 - 60	09	22	69	41	67	21	1.23
60 - 80	09	20	71	42	69	19	1.29

Table2b: *Chemical properties of Kenana soil*

Soil depth (cm)	pH 1: 5 Soil:H_2O	EC_e ds m^{-1}	$CaCO_3$	N	Organic carbon	Exchangeable		CEC	ESP
						Na	K		
			(%)			C mol(+) kg^{-1}soil			
0 - 20	7.5	0.45	0.6	0.008	1.00	0.01	1.4	82	0.0
20 - 40	7.9	0.26	1.4	0.054	0.96	0.04	0.4	86	0.0
40 - 60	8.1	0.29	1.1	0.038	0.68	2.2	0.6	84	3.0
60 - 80	8.3	0.33	1.3	0.031	0.57	3.6	0.3	88	5.0
80 - 100	8.5	0.54	2.3	0.016	0.40	0.40	0.2	89	7.5

2.6.3. Sugarcane crop Data:-

In the present study the sugarcane crop coefficients for each growth stage and the daily reference evapotranspiration (ETo) and rainfall data were computed using the local climatic data and Penman-Monteith approach (Table 3).

2.7. Methodology: -

To commence, four main interacting scheduling principles were implemented and agreed on; firstly exploit plant available water (PAW) in the soil profile to maximize use of rainfall and optimize irrigation. Then deplete as much as possible to maintain PAW above liberally obtainable level by means of profit and loss irrigation scheduling spreadsheet. Assume that 50% of the total available moisture (TAM) was freely available and could be depleted without causing yield loss. Provide adequate water to satisfy the sugarcane water demands (evapotranspiration). Then the following irrigation event data and climate data as designed by the author were entered into the profit and loss irrigation scheduling spreadsheet model:

1. Enter the relevant data in the cells shaded light blue. These will be specific for each field.

2. Enter irrigation inlet time in hours in the light yellow shaded cells.

3. Enter the actual daily ETo in mm/day in the light yellow shaded cells.

4. Enter the actual rainfall in mm/day in the light yellow shaded cells

5. You can jump to today's date by clicking the Go to today button

6. The closing balance will show the closing soil moisture level. Green means good, orange means stress.

7. The values of the long term mean of the reference evapotranspiration (LTM, ETo) in mm/day were calculated and used to predict future moisture levels.

8. Crop coefficients which are used to convert the weather derived Reference Evapotranspiration (ET_0) to an estimate

of crop evapotranspiration (ET_c) using the following formula:

$$ET_c = K_c \times ET_0$$

are automatically calculated based on month as per table on constants worksheet.

3. RESULTS AND DISCUSSION

3.1. Measuring Soil-Water for Irrigation Scheduling

Generally, the profit and loss approach to irrigation scheduling involves a daily accounting of water withdrawals and additions to the effective root zone. The additions include rainfall and irrigation amounts and the withdrawals include crop water use, runoff, and percolation.

In the present study the total available moisture (TAM) of Kenana cane fields were determined and found to be ranged from 80 to 100 mm with an average of 87 mm. This represents the total amount of water that the soil can hold in the effective root zone. Typically the allowable depletion was taken to be 50% which means that an average of 43.5 mm of Readily Available Water (RAW) in the soil is available to the crop. At peak demand (in March) this represents 5 days of available moisture before the crop will experience the onset of stress. The target irrigation depth is usually set to the RAW of the soil. Ideal the next irrigation event is triggered as the soil moisture reaches the refill point and the irrigation refills the soil to field capacity. This has implications for how much water can be applied during each event to avoid run off

3.2. Influence of Rainfall

The total rainfall received during the first season of the study approximates to about 325.5 mm, is lower in comparison to both total rainfalls received during 2014, (520.5 mm) and the general Kenana rainfall average, (380 mm). No doubt such decrease in amounts of rains received will affect sugarcane growing unless sufficient irrigation water is supplied. **[13]** stated that measurement of rainfall and irrigation amounts is essential to maintain water content for irrigation scheduling. Efficiently and effectively supplementing rainfall is one of the greatest challenges to irrigation scheduling in agriculture regions, because irrigation frequency and the amount of water to apply are strongly influenced by seasonal rainfall. Accordingly, the weekly, monthly, and annual variability in rainfall must be taken into account when making irrigation decisions.

Figure 1 illustrates the annual variation in rainfall at Kenana sugar scheme during the period of the investigation. It was noticed that About 90% of the total rainfalls occur during the June-September period, most of it in July – August, the mean annual rainfall is about 300 mm Normally, the average rainfall during the growing season was not adequate and less than the cumulative consumptive use for the sugarcane crop and irrigation was needed. These data illustrate that the timing of rains is more important to irrigation decisions than the total amount of rainfall.

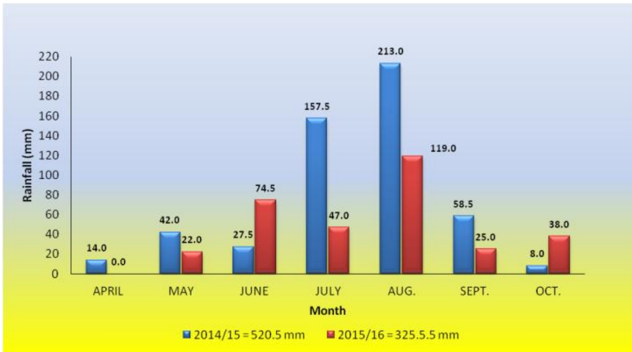


Figure 1: *Monthly rainfall during 2013/14 and 2014/15 crop seasons compared to average*

3.3. Soil moisture characteristic curve

Figure 2 showed the calibration curve of the soil moisture content versus soil moisture tension reading (tension) which is called the water retention curve that reflect the relationship between the water content, θ, and the soil water potential, ψ, and is also called the soil moisture characteristic. It is used to predict the soil water storage, water supply to the plants (field capacity) and soil aggregate stability. The result of the general features of a water retention curve (figure,) showed that at matric potentials close to zero, a soil is close to saturation, and water is held in the soil primarily by capillary forces. As the soil moisture content, θ decreases, binding of the water becomes stronger

[14] stated that the water holding capacity of any soil is due to the porosity and the nature of the bonding in the soil. I n the present study result revealed that the field capacity of Kenana soil is normally interpreted to be the point at which the rate of decrease of water content versus tension flattens out, in this case, about 33 cent-bars. Similar result was reported in Lajas Valley by **[15].** Who stated that clay soils, with adhesive and osmotic binding, will release water at lower (more negative) potentials

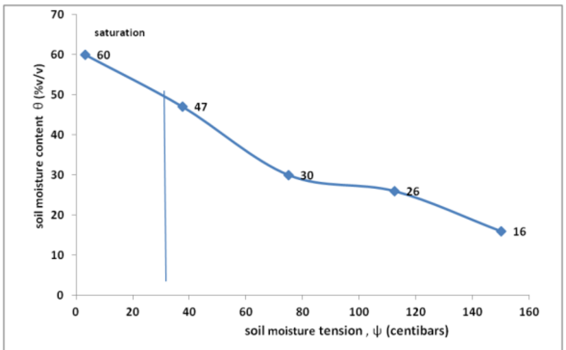


Figure 2 : Soil moisture characteristic curve

3.4. Crop coefficients (kc)

Before the crop reached its full canopy, the crop coefficient (kc) increased up to more than unity and then decreased reaching a minimum value of 0.6 at maturity stage (Table 3) . The same trend was reported by **[16]** at Kenana Scheme.

3.5. Crop water requirements (CWR)

Table 1 shows the mean monthly crop water requirements (CWR) for the experimental site. Results indicated that the crop water requirements increased gradually with plant development and then declined at the late growth stage. Similar results were reported by **[17]** at Guneid Research Station. ----revealed that the daily crop water use will vary depending upon the weather conditions for each day (evaporative demand) as well as the difficulty with which the crop can extract moisture from the soil. When the sugarcane crop reaches the refill point and moisture stress starts to occur, the daily water use declines.

Table 3: *Mean monthly evapotranspiration (ETo) calculated according to Penman Monteith in Kenana Scheme (2013/14 – 2014/15)*

Month	ETo (mm/day)	Kc	CWR (mm/day)	Days of month	CWR (mm/month)	Rainfall (mm/month)
Nov.	5.2	0.6	3.1	30	94	00
Dec.	5.4	0.6	3.2	31	100	00
Janua	5.1	0.8	4.1	31	126	00
Feb.	5.8	1.1	6.4	28	179	00
March	6.4	1.3	8.3	31	258	00
April	6.8	1.2	8.2	30	245	14
May	6.2	1.0	6.2	31	192	42
June	5.7	1.0	5.7	30	171	28
July	4.8	1.0	4.8	31	149	158
Aug.	4.2	1.0	4.2	31	130	213
Sept.	4.9	1.0	4.9	30	147	59
Oct.	5.0	0.9	4.5	31	140	08
Total Growth	irrigation	requirement	(mm/season)		1931	522

3.7. Determining when to irrigate?

In the obtained water balance chart (Figure 3). Above green zone shows runoff, green zone is adequate moisture, and orange zone is stress. When to irrigate? When the blue line in the chart (Figure 3) is predicted to reach the top of the orange zone. This is to be confirmed with physical check. Meaning that irrigation is scheduled when the soil-water content in the effective root zone is near the allowable depletion volume.

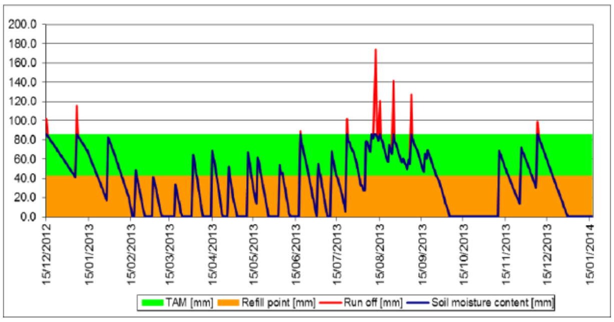


Figure 3: *The soil water balance chart for field 32112.*

3.8. Determining How Much to Irrigate?

The amount of irrigation water needed to satisfy crop demand or how much to apply is equivalent to the depleted volume or the net amount of water to be replaced. Additional water must be applied to account for irrigation inefficiencies so that the net amount reaches the root zone. **[18]** revealed that sufficient irrigation water should be applied to replace the depleted plant available water within the root zone and to allow for irrigation inefficiencies, because under adequate moisture conditions, water uptake by the sugarcane crop is about the same as its root distribution. Thus, about 70% of the water used by a crop is obtained from the effective root depth which represents the upper half of the root zone where the irrigation amounts should be computed to replace the depleted plant available water within the effective root zone.

Results of table 4 showed the summary of irrigation events for the twelve cane fields that selected for the assessment of the profit and loss irrigation scheduling approach. It was observed that correct irrigation water volumes were applied timeously during irrigation events on the commercial cane fields that having different furrow lengths and slopes. This practice could have had a positive impact in the yield increases as it appeared to be case in the two consecutive years of implementing the irrigation scheduling tools.

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Table 4: *Summary of irrigation events for the twelve fields*

Field Number	TA	# irrigatio	rrigatio n	Rainfa	Tota l	Ru	Run off %	Run off %
	mm		mm	mm	mm	m m		
11101	100	18	1 632	362	1	28	17%	14%
12103	90	12	718	422	1	17	24%	15%
21102	86	28	1 620	321	1	27	17%	14%
21113	85	34	2 611	321	2	1	39%	35%
32107	84	17	1 548	296	1	35	23%	19%
32112	86	22	1 571	296	1	31	20%	17%
41107	80	20	1 578	306	1	39	25%	21%
42113	88	21	1 421	342	1	25	18%	15%
51211	84	17	1 136	418	1	39	34%	25%
51215	84	16	1 649	418	2	54	33%	26%
61104	90	24	1 526	448	1	33	22%	17%
61113	85	20	1 830	448	2	57	31%	25%
Average	87	21	1 570	367	1	41	25%	20%
Minimu	80	12	718	296	1	17	17%	14%
Maximu	100	34	2 611	448	2	1	39%	35%

4. CONCLUSIONS

In the present study irrigation scheduling practice had been carried out during the assessment period most effectively based on the sugarcane crop water requirements. Regarding the irrigation scheduling techniques for sugarcane, the specific objective would be achieved by providing the cane production management at Kenana sugar scheme with relevant information and the daily decision process to schedule irrigation effectively.

The total available moisture (TAM) was measured for each selected field in which profit and loss irrigation scheduling was practiced. These fields were re-designed to ensure that they were operated according to the best practices.

RECOMMENDATIONS

A simple profit and loss approach for scheduling irrigation was implemented and verified in the present study, results revealed that it is time to apply the proper irrigation scheduling by making use of the available soil-water-plant data collected from the commercial cane fields of Kenana sugar scheme. It is recommended that a detailed study and analysis of water use be done to quantify the impact of the approach on savings due to irrigation scheduling.

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