بسم الله الرحمن الرحيم

Sudan University of Science and Technology

College of Agricultural Studies

Department of Agricultural Engineering

Water Requirements and Irrigation Scheduling of Sugar Cane Using GIS and CropWat Model in Kenana- Sennar- New Halfa region

A research project Submitted to the Sudan University of Science and Technology in Partial Fulfiillment for the Requirement of the Degree of B.Sc. (Honors)in Agricultural Engineering

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August 2016

الآية

قال تعالى:

(أَوَلَمْ يَرَ الّذِينَ كَفَرُوا أَنّ السّمَوَاتِ وَالْأَرْضَ كَانَتَا رَتْقًا فَفَتَقْنَاهُمَا وَجَعَلْنَا مِنَ الْمَاءِ كُلّ شَيْءٍ حَيٍّ أَفَلَا يُؤْمِنُونَ)

صدق الله العظيم

سورة الأنبياء الآية (30)

Preface and Acknowledgments

The author wishes to express his sincere gratitude towards the following people.

The present thesis is submitted to Sudan University of science and Technology , College of Agricultural Studies , Department of Agricultural Engineering , as a final report in fulfilling the requirements for the BS.c Degree .

I take this opportunity to thank my supervisor, **Dr**. **Abbas Elshaikh Rahma Mohamed** for his considerate and close supervision, welcoming approach, and for providing moral as well as material support during the entire period of my study at Department of Agricultural Engineering and for his scientific guidance throughout the whole process of study. Many thanks to Colleagues at Sudan University of Science and Technology –College of Agricultural Studies who were always beside me to share my complaints of the daily routine and with whom I used to praise Allah.

Many thanks to all the friends from my Department who helped me either directly or indirectly with this study, and for their friendship and for creating a colorful learning atmosphere during the entire course.

I dedicate this work to my parents greatly; for their invaluable patience and prayer during my Study. I dedicate this research to my Aunt.

Thanks to my father and mother for grooming me to be the person that I am today. They are the best parents I know of in the world. Thanks to all my brothers and sisters, all my friends and relatives for their encouragement throughout the study. Above all, I would thank Allah for giving me health, strength and encouragement during all the ups and downs and for keeping my family and relatives healthy and in peace.

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Abstract

Due to the over use of available water resources, it has become very important to define appropriate strategies for planning and management of irrigated farmland. In this paper, Kenana –Sennar –New Halfa (Sugar cane) region was chosen as the case study area for its special political and economic status and its severe water problem. To achieve effective planning, the information about crop water requirements, irrigation withdrawals, soil types and climatic conditions were obtained in the study area. In the meantime, a GIS method was adopted, which extends the capabilities of the crop models to a regional level. The main objectives o f the study are: 1) to estimate the spatial distribution of the evapotranspiration of Sugar cane ; 2) to estimate climatic water deficit; 3) to estimate the yield reduction of Sugar cane under different rainfed and irrigated conditions. Based on the water deficit analysis, recommended supplemental irrigation schedule was developed using CropWat model. Compared to the rainfed control, the two or three times of supplemental water irrigated to Sugar cane at the right time reduced the loss of yield, under one scenario.

Keywords: **Sugar cane ; climatic water deficit; irrigation scheduling .**

CHAPTER ONE

INTRODUCTION

In the near future, irrigated agriculture will need to produce two-thirds of the increase in food products required by a large population increase (English *et al.*, 2002). The growing dependence on irrigated agriculture coincides with an accelerated competition for water and increased awareness of unintended negative consequences of poor design and management. Irrigation systems are selected, designed and operated to supply the individual irrigation requirements of each crop field on the farm while controlling deep percolation, runoff, evaporation and operational losses to establish a sustainable production process. Considering the stupendous task and constraint of time in developing the ultimate irrigation potential, it is necessary to use the modern methods of surveying and analysis tools. Remote sensing and Geographic Information System (GIS) with their capability of data collection and analysis are now viewed as efficient and effective tools for irrigation water management. The capability of GIS to analyze the information across space and time would help in managing such dynamic systems as irrigation systems.

Soil survey data and GIS are important tools in land use planning. Intertwined, they represent an invaluable and underutilized resource. Hazrat *et al*. (2003) found that the GIS is an important tool that can be used for optimal allocation of water resources of an irrigation project. Mean water balance components results for different months were stored in GIS databases, analyzed and displayed as the monthly crop water requirements maps.

Chowdary *et al*. (2008) showed that satellite remote sensing coupled with GIS offers an excellent alternative to conventional mapping techniques in monitoring and mapping of surface and sub-surface waterlogged areas. El Nahry *et al*. (2011) found that for center pivot irrigation under precision farming, remote sensing and GIS techniques have played a vital role in the variable rate of water applications that were defined due to management zone requirements. Fertilizers were added at variable rates.

Crop water requirements were determined in variable rate according to the actual plant requirements using SEBAL model with the aid of FAO CROPWAT model. used the soils information recompiled from an uncorrected aerial photographic base to a USGS topographic base map. Soils data were added to numerous other data layers and images.

The soil water and crop information required by the checkbook method and previously collected from field observations, was estimated by the soil water and nitrogen management model.

Geographic Information Systems has been used to improve the irrigation water manageme and for irrigation scheduling . have built a database program for enhancing irrigation district management to manage detailed information about district water management and to promote better on-farm irrigation practices. The application of GIS has become popular in water resources management due to its dynamic process to incorporate data and display results. GIS techniques are more time and cost efficient than the conventional field techniques and can be used to formulate a management plan much more efficiently and link land cover data to topographic data and to other information concerning processes and properties related to geographic location. The main objectives of the study are: 1) to estimate the spatial distribution of the evapotranspiration of Sugar cane ; 2) to estimate climatic water deficit.

CHAPTER TWO

LITERATURE REVIEW

2.1 Significance of Irrigation in Agriculture

Irrigation is a process that uses more than two-thirds of the Earth's renewable water resources and feeds one-third of the Earth's population (Stanhill 2002). Some 2.4 billion people depend directly on irrigated agriculture for food and employment. Irrigated agriculture thus plays an essential role in meeting the basic needs of billions of people in developing countries (FAO 1996). Although water resources are still ample on a global scale, serious water shortages are developing in the arid and semi-arid regions (Hall 1999). There is a need to focus attention on the growing problem of water scarcity in relation to food production. The World Food Summit of November 1996, drew attention to the importance of water as a vital resource for future development (FAO 1996). A major part of the developed global water resources is used for food production. The estimated minimum water requirement per capita is 1,200 m^3 annually (50m^3 for domestic use and 1,150 m^3 for food production) (FAO 1996).

Sustainable food production depends on judicious use of water resources as fresh water for human consumption and agriculture become increasingly scarce. To meet future food demands and growing competition for clean water, a more effective use of water in both irrigated and rainfed agriculture will be essential (Smith 2000). Options to increase water-use efficiency include harvesting rainfall, reducing irrigation water losses, and adopting cultural practices that increase production per unit of water. Irrigation is an obvious option to increase and stabilize crop production. Major investments have been made in irrigation over the past 30 years by diverting surface water and extracting groundwater. The irrigated areas in the world have, over a period of 30 years, increased by 25 % (mainly during a period of accelerated growth in the 1970s and early 1980s) (FAO 1993).

A major constraint to the understanding of the use of water is the difficulty associated with its measurement and quantification. Measurement and data collection of discharge in canals is difficult and fraught with potential errors.

Necessary conditions for the optimal performance of regional water delivery systems include well-defined water rights; infrastructure capable of providing the service embodied in the water rights, and assigned responsibilities for all aspects of system operation (Perry 1995). One or more of those conditions may be missing in some regional systems at the start of irrigation deliveries. In other systems problems may develop over time with changes in land ownership, cropping patterns, and the volume of water available for delivery in the system. Problems with cost recovery and inadequate maintenance also can reduce the efficiency of regional water-delivery systems.

Water use for crop production is depending on the interaction of climatic parameters that determine crop evapotranspiration and water supply from rain (Smith 2000). Compilation, processing, and analysis of meteorological information for crop water use and crop production are therefore key elements in developing strategies to optimize the use of water for crop production and to introduce effective water-management practices. Estimating crop water use from climatic data is essential to, better water-use efficiency Because most of the Earth’s irrigated land is in the underdeveloped world (where food, water, and skilled manpower are in short supply), it is important to use the simplest, cheapest, and most practical meteorological method to improve crop water-use efficiency in irrigation. Stanhill (2002) says that in these regions use of standard, correctly sited and maintained evaporation pans operating within a national network can provide the basis for a scheduling method in which the use of empirical crop coefficients is accepted. These coefficients reflect the local economic as well as agronomic, climatologic and hydrological (water quality) situation (Stanhill 2002). However, the literature often contradicts. Hillel (1997) said: “the use of ‘evaporation pans’ has several shortcomings.”

Smith (2000) stated that agro-meteorology would play a key role in the looming global water crisis. Appropriate strategies and policies need to be defined, including strengthening of national use of climatic data for planning and managing of sustainable agriculture and for drought mitigation. The limitations of currently available.

2.2 Reference Evapotranspiration

Several definitions of reference evapotranspiration ET_o have been formulated. Jensen (1993) defined ET_o as the rate at which water, if available, would be removed from the soil and plant surface. Pereira *et al*. (1999) stated that Duke simplified the definition of ET_o to “the water used by a well-watered reference crop, such alfalfa, which are desired (Jensen *et al.* 1990). fully covers the soil surface.” The modified Penman combination equation is used to compute ET_o, as it is considered to be a satisfactory estimation equation when daily estimates of ET_o

2.2.1 Use of FAO Penman-Monteith to Estimate Reference Evapotranspiration

This approach was introduced by Penman in 1948 to estimate open-water evaporation (Penman 1948); and extended by Monteith in 1965 to directly estimate evaporation from vegetation-covered surfaces (Monteith 1965). It is now the recommended method by the FAO to calculate reference crop evapotranspiration (Allen *et al.* 1998). Studies showed the superior performance of the Penman–Monteith approach, in both arid and humid climates, and convincingly confirmed the sound underlying concepts of the method. Based on these findings, the method was recommended by the FAO Panel of Experts for adoption as a new standard for reference crop evapotranspiration estimates (Hall 1999). The use of the Penman-Monteith equation in irrigation practice requires empirical coefficients to modify—in general to reduce but sometimes to increase—the estimates of reference crop evapotranspiration (Stanhill 2002).Reference evapotranspiration (ETo) is calculated based on the FAO Penman-Monteith method (Allen *et al.*, 1998) as: (2.1)

$$ETo = \frac{0.408\Delta(Rn - G) + \gamma(900/T + 273)U_2(ea - ed)}{\Delta + \gamma(1 + 0.34U_2)} \qquad \textbf{(2.1)}$$

where, ETo is reference evapotranspiration (mm/day),
Rn is net radiation at the crop surface
(MJ/m2/day),
G is soil heat flux density (MJ/m2/day),
T is mean daily air temperature at 2 m height (˚C),
u2 is wind speed at 2 m height (m/s),
es is saturation vapor pressure (kPa), ea is
actual vapor pressure (kPa), es
- ea is saturation vapor pressure deficit (kPa),
Δ is slope of vapor pressure curve (kPa/˚C),
γ is psychrometric constant (kPa**/˚C).**

Input data include monthly temperature (maximum and minimum), humidity, sunshine, and wind speed. Crop water requirements (ETc) over the growing season are determined from ETo and estimates of crop evaporation rates, expressed as crop coefficients (Kc), based on a wellestablished procedures. The updated values of crop coefficients are determined from Allen *et al*. (1998)

2.2.1.1Actual Crop Evapotranspiration

Procedures for estimating crop evapotranspiration have been well established by Doorenbos and Pruitt , using a series of recommended crop coefficient values (K_c) to determine ET_{crop} (ET_c) from reference evapotranspiration (ET_o), as follows:

$$ET_c = K_c * ET_o \tag{2.2}$$

This formula represents the single crop coefficient. Crop evapotranspiration (ET_c) refers to evapotranspiration of a disease-free crop, grown in very large fields, not short of water and fertilizer. Estimation of ET_c is essential for computing the soil water balance and irrigation scheduling. ET_c is governed by weather and crop condition (Smith, 2000).

2.2.1.1.2 Computerized Crop Water Use Simulations

Practical procedures and criteria need to be defined to enhance the introduction and application of effective water use practices for crop production. The introduction of computerized procedures linked to digital databases and geographic information systems (GIS) will greatly enhance the use of appropriate planning and management techniques for water use in irrigated and rainfed agriculture. Computerized procedures greatly facilitate the estimation of crop water requirements from climatic data and allow the development of standardized information and criteria for planning and management of rainfed and irrigated agriculture.

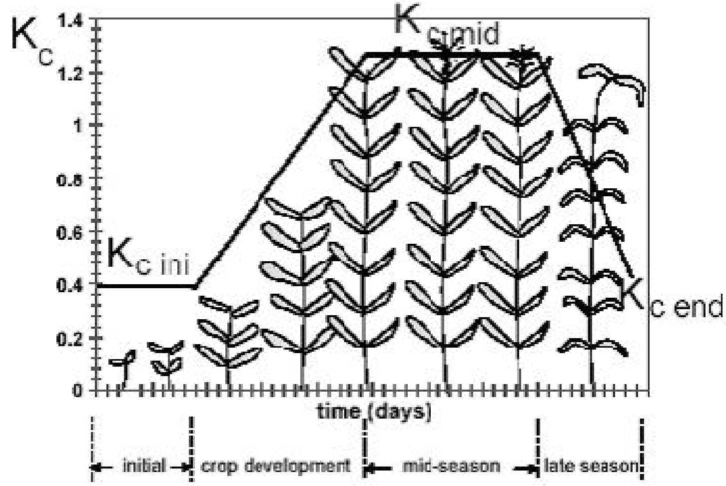


Figure 2. 1. Shows the crop coefficient divided in different stages according to crop development

The FAO-CROPWAT program (Smith 1992) incorporates procedures for reference crop evapotranspiration and crop water requirements and allows the simulation of crop water use under various climate (CLIMWAT 1994), crop and soil conditions. As a decision support system CROPWAT's main functions include: (1) the calculation of reference evapotranspiration according to the FAO Penman-Monteith method; (2) crop water requirements using revised crop coefficients (FAO Paper 56, compared to the data from FAO Paper 49) and crop growth periods; (3) effective rainfall and irrigation requirements; (4) scheme irrigation water supply for a given cropping pattern; (5) daily water balance computations (Smith 1992).

2.3 Sugar cane crop production areas in the world

Sugar cane is grown commercially in more than 58 countries, located mostly in the tropical region, including India, Brazil, Cuba, China, Mexico and the United States, Pakistan, Australia and Colombia. In Africa sugar cane planting in South Africa, Egypt, Mauritius, Natal and Sudan. The most important Arab countries that produce sugar cane are Egypt, Sudan and Morocco. And have reached the global area of sugar cane in the years 1999 and 2000 and 2001 about 19.405 million and 19.186 million and 19.245 million hectares, respectively. The global production stood at 1274697000 and 1258531000 and 1254857000 tons, respectively. Producing countries of Latin America about 50% of world production of sugar cane.

2.3.1 Sugar cane crop production areas in Sudan

In the Arab world, the average area of sugar cane in the period from 1985 to 1995 about 210,500 hectares and production is about 17,135,180 tons production areas in Sudan.

Then started experimental for the cultivation of sugar cane for sugar production in the early fifties in Mangala, but commercial production did not begin due to the economic situation in Sudan and its low prices worldwide.

Did not begin commercial production of sugar cane and sugar industry in Sudan, until in 1960 when Aljunied sugar factory was founded, which began production capacity of 60000 tons of sugar. And due to the success of Aljunied sugar factory established New Halfa Sugar Factory in 1965 with a capacity of 60000 tons also, in the seventies the sugar industry in Sudan, witnessed a big leap by establishing factories Sennar and Aslayah stone and Kenana, which started production in the seasons of 75 / 1976, 1979, 1980 and 1980 / 1981 by productivity energy reached 110,000 and 110,000 and 330,000 tons respectively. The average area of sugar cane in Sudan, about 117,464 feddan in the eighties, and 140,435 feddan in the nineties. In 2000 and 2001 the area amounted to 128,000 and 130,000 feddan, respectively. The total production of sugar cane reached 2860859 tons on average in the period from the mid seventies to mid eighties and 3252851 tons in the period from the mid-eighties to mid nineties.

2.3.2 Growth Stage of Sugar can

Sugar can a plant is considered as one of the most efficient convertor, of solar energy. It has five growth phases.

Plate 1. Germination phase

When cultivated commercially sugar cane is propagated only vegetatively by stem parts (Cuttings) or by whole stems

- Seed propagation is employed only in selection.
- Planting cuttings should have at least three budes.
- The sprouting phase (the beginning is marked by 10% and the complete stage by 75% of sprouts) is thought to commerce when two leaves appear is the stem.

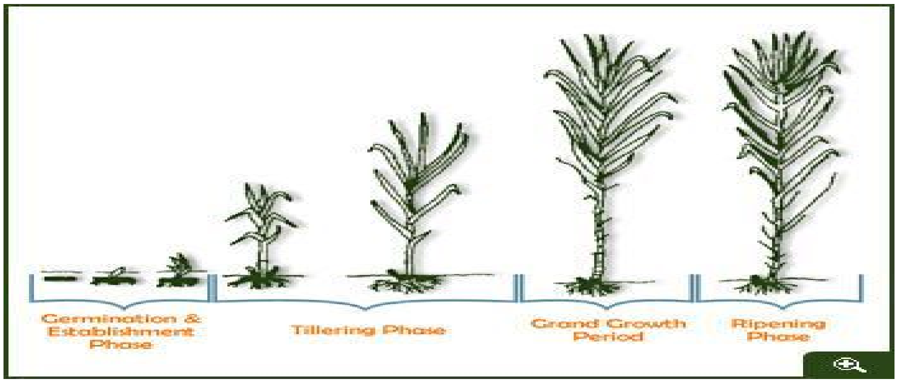


Plate 2. Tillering phase

Tillering of sugar cane in the tropics begins soon (in about 15-20 days) after the first sprouts appear.

- The secondary sprouts are formed from underground buds.
- In early ripening varieties of sugar cans, tillering lasts for 4-6 months, and finishes after the row contact.
- In the late ripening varieties of sugar cane tillering lasts long as 6-8 months.
- Every new sprout appears in 2 to 4 days.
- Under field cultivation each plant develops:

(a) In the strong- bushy varieties 20 to 40 sprouts.

(b) In medium bushy 15 to 25 sprouts.

(c) And in weakly bush 8 to 12 sprouts.

Plate 3. Grand Growth Phase

This stage lasts for 5 to 8 months sugar cane plants normally vegetate at this stage if properly supplied with heat and moisture.

- Grand growth phase starts from 120 days after planting and lasts up to 270 days in a 12 month crop. During the early period of this phase tiller stabilization takes place. Out of the total tillers produced only 40-50% survives by 150 day to form millable can.
- Most important phase of the crop where in the actual cane formation elongation and thus yield build up takes place

- Leaf production is frequent and rap during this phase with LAI reaching around 6-7.
- Under favorable conditions stalks grow rapidly almost 4-5 internodes per month.

Plate 4. Maturation and Ripening

- This phase lasts for about three months.
- Its maturation is determined by a definite sucrose level in the stems (up to 14-16% stem mass) and a low level of reducing sugar.

In tropics, by harvesting time the sugar cane stem accumulate on the average up to 14-16% sugar in subtropics 8-12% sugar.

2.3.2 Deficit Irrigation (DI):

Isa watering strategy that can be applied by different types of irrigation application method. The correct application of DI requires thorough understanding of the yield response to water (crop sensitivity to drought stress) and of the economic impact of reductions in harvest (Englih, M.,1990).In regions where water resources are restrictive it can be more profitable for a farmer to maximize crop water productivity instead of maximize the harvest per unit land(Fereres,E,Soriano,M.A.,2000) . The saved water can be used for other purposes or to irrigate extre units of land(Geerts, S,Raes,D.,2009) . DI is sometimes referred to as regulated DI. Deficit Irrigation is an optimization strategy in which irrigation is applied during drought- sensitive growth stages of crop outside these periods. Irrigation is limited or even unnecessary supply of water. Water restriction is limited to drought tolerant phonological stages, often the vegetative stages, and the late ripening period. Total irrigation application is therefore not proportional to irrigation requirements throughout the crop cycle while this inevitably results in plant drought stress and consequently in production loss, DI maximizes irrigation water productivity, which is the main limiting factor (English, 1990).

In other words DI aims at stabilizing yields and at obtaining maximum crop water productivity rather than maximum yield (Zhang and Oweis, 1998).

2.4 Application of GIS to Irrigation Management

GIS have potentially considerable application to irrigation water management, especially in regions where there are poorly defined procedures for irrigation water management data collection, processing and analysis. The possibility of using GIS to identify crop areas, plan irrigation schedules and quantify performance offer exciting possibilities for research (Ray and Dadhwal 2001).

The tools necessary to create a good GIS in irrigation are the availability of weather data and how it is spatially distributed over the study area. Also important are the techniques to be used to interpolate the climatic data, evapotranspiration, and other calculated variables.

The availability of weather data of acceptable spatial resolution for large-scale irrigation scheduling is an important factor to consider in planning the development and management of irrigation information systems throughout the world (Hashmi *et al*. 1994). The spatial distribution of the available weather data is important. It is of special concern in developing countries where the availability of weather stations is limited. The recommended maximum distance between points (weather stations) for least dense networks is 150–200 km, for the intermediate network, 50–60 km for the densest network, 30km (Gandin 1970). Once the data is collected and analyzed using statistics, a surface map can be created using GIS. There are many interpolation methods; however, inverse-square-distance interpolation technique appears to be the most accurate method of interpolation irrespective of number of data points. Hashmi *et al*. (1994) has also used the inverse-square-distance approach to interpolate ET values.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Study Area

The projects are located in N 15°28 E 35°34.3, N 14°51.55 E 33°15.62 was chosen as a typical study area, which includes（Sennar, Kenana and New Halfa）(Fig. 1).It is covers of an area approximately(140,435 feddan)It lies in the climate zone with hot-wet summer and cold-dry winter. The mean annual temperature is 27-42C , and the annual precipitation ranges from200-600mm. Now this area is severely short of water resources due to fast economic development and the waste of water in agriculture. Water availability has been one of the main factors limiting economic development and agricultural productivity in this .area. Water management, especially agricultural irrigation water management has become an extremely essential measure to take in this area..

Figure 3. 1. Sketch of area Study

3.2 Methodology

The data we use in this study are mainly meteorological data, including monthly solar radiation, precipitation relative humidity, sunshine time, average yearly air temperature, minimum air temperature, maximum air temperature and wind speed from 20051 to 2010 in 3 meteorological stations. Arc/Info grid spline method is used to interpolate the point climate data into the 1km×1km grid data. Then the grids are converted from geographic projection to Albers Conic Equal-Area projection.

3.3 Methods

CropWat for Windows is a decision support system developed by the Land and Water Development Division of FAO, with the assistance of the Institute of Irrigation and Development Studies of Southampton of UK and National Water Research Center of Egypt. The model carries out calculations for referenceevapotranspiration, crop water requirements and irrigation requirements in order to develop irrigation schedules un various management conditions and scheme water supply (FAO,1992). It allows the development for improved irrigation practices, the planning of irrigation schedules and the assessment of production under rainfed conditions or deficit irrigation. CropWat for Windows uses the FAO Penman-Monteith method for calculation reference crop evapotranspiration (Allen *et al.*, 1998). The development of irrigation schedules and evaluation of rainfed and irrigation practices are based on a daily soil-moisture balance using various options for water supply and irrigation management conditions. Scheme water supply is calculated according to the cropping pattern provided in the program (Clarke *et al.*, 1998; Smith, 1992). Studies have shown that the Penman-Monteith method is more reliable than methods that use less climatic data (Jensen *et al.*, 1990). In this paper, the Penman-Monteith equation below was adapted as the sole means of calculating the reference evapotranspiration of sugar cane.

$$ETo = \frac{0.408\Delta(Rn - G) + \gamma(900 / T + 273)U_2(ea - ed)}{\Delta + \gamma(1 + 0.34U_2)} \qquad (3.1)$$

where, $ET0$ is the reference evapotranspiration (mm/a),

Rn is the net radiation (MJ/(m2·d)),

G is the soil heat flux density (MJ/(m2·d)),

$U2$ is the wind speed at a height of2m (m/s),

es is the saturated vapor pressure (kPa).

ea is the actual vapor pressure of the air at standard screen height (kPa),

γ is the psychrometer constant (kPa/°C),

Δ is the slope of the saturation vapor pressure curve between the average air temperature and dew point

(kPa/°C),

T is the mean daily air temperature (°C).

*ET*c is termed as the crop water requirement (CWR) (mm/a). It is defined as the depth of water needed to meet the water loss through evapotranspiration of a disease free crop, growing in fields under non-restricting soil conditions including soil water and fertility and achieving full production potential under the given growing environment (Doorenbos and Pruitt, 1977; Doorenbos and Kassam, 1979). *ET*c can be calculated by Equation (2)

$$ET_c = K_c * ET_o \qquad (3.2)$$

Where *K*c is the crop coefficient. The crop water requirement (*ET*c) of sugar cane was computed by multiplying the crop coefficient (*K*c) with *ET*0 at different growth stages. The *K*c in various germination periods is 0.40 in tellering stage (1.25) in grand or boom period (0.75) in last stage maturity period (0.4) (FAO, 1979).

$$WDR=(ET_c - P)/ET_c \times 100\% \qquad (3.3)$$

Where *WDR* is the water deficit ratio (%),

*ET*c is the crop water requirement (mm),

P is the difference between rainfall and runoff

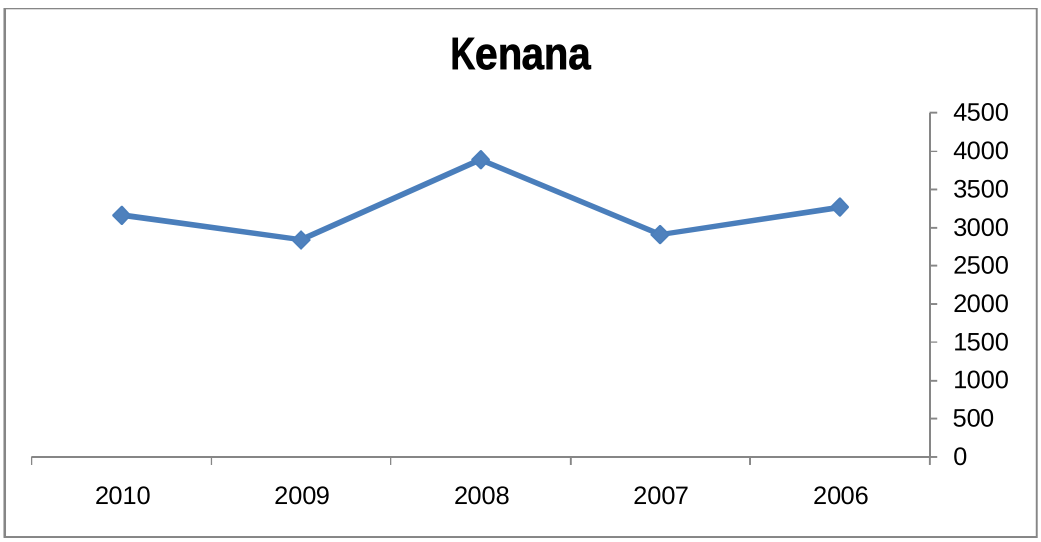
The spatial distribution of sugar cane evapotranspiration (*ET*c) in different stages of growing season was estimated by two steps..

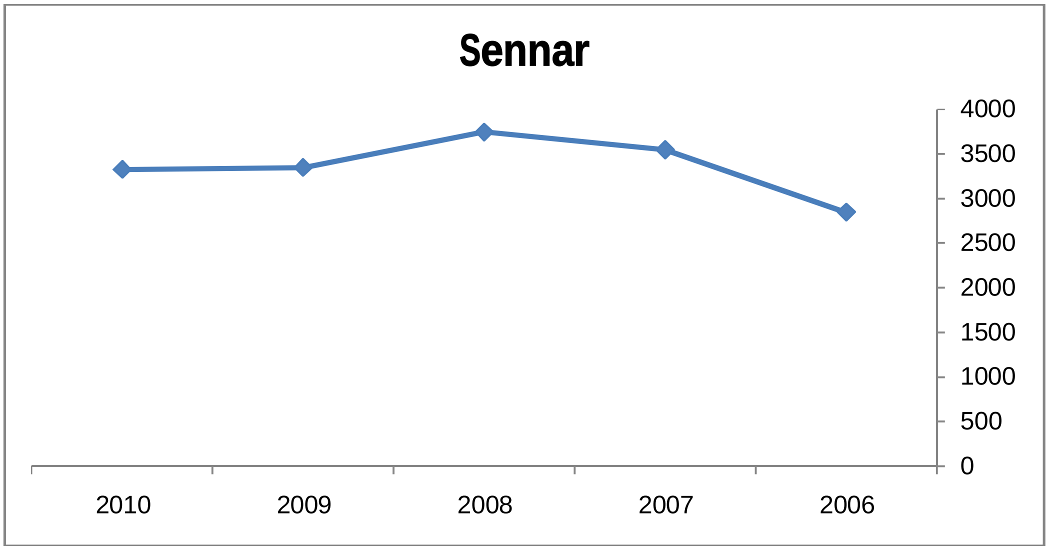
CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Crop water requirements

From the water requirement results computed by the evapotranspiration model, the peak period of suagr cane water use was from early July to late Augest . The average daily ETc was usually more than 8mm. The calculated total sugar cane ETc varied between 2000mm and 3500mm in 2005-2010, with an average of 2750. mm (Fig. 4.1).





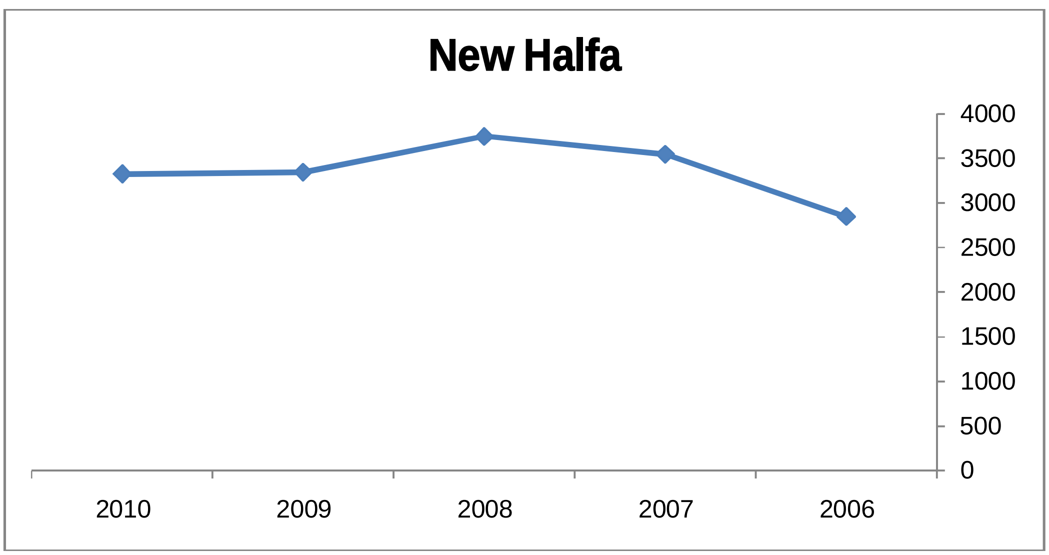


Fig. 4.2 Total ETc of Sugar cane in Knana- Sennar – New Halfa region in 2006–2010

4.2 Spatial distribution of *ET*c and climate water deficits

The spatial distribution of sugar cane evapotranspiration (*ET*c) in different stages of growing season was estimated by two steps. First, DEM-based and GIS-assisted methods were employed to estimate the spatial distribution of reference crop evapotranspiration (*ET*0) according to Penman-Monteith model. Then, sugarcane evapotranspiration (*ET*c) of different stages of growing season was calculated by *ET*0 and crop coefficient (*K*c) (Fig. 3).

Figure 3 shows that *ET*c value has temporal variation during growing seasons. Highest value of *ET*c appears in the （Grand period or boom stage (17 SEP - 1 JUL) which is varied from 903mm to 1676mm, and lowest *ET*c is seen in the germination stage (15 JUL -10 AUG) which is varied from 92mm to 545mm.

4.3 Long-term crop water deficits

The average water deficit of suger cane from natural precipitation was 125.5–325.5mm in the first stage in

2005–2010 in sugar cane region , while its *ET*c is 364.4–545.5mm (Table1).

Table 4. 1.Water Requirements and Irrigation Scheduling of sugar cane Using GIS and CropWat Model Average water deficit of suger cane in 2005–2010.

Growth Stages	Period		Halffa	Sennar	Kenana
Germnation	**15july-10august**	ETC mm	418.32	545.50	364.40
	(stage1)	P mm	292.75	220.00	171.20
		ETC-P	125.57	325.50	193.20
		WDR(%)	30.02	59.67	53.00
Tillering	**10Augest-17Septmber**	ETC mm	509.88	559.60	449.90
	(stage2)	P mm	565.50	902.00	153.80
		ETC-P	-55.62	-342.40	296.10
		WDR(%)	-10.91	-61.19	65.81
Grand or boom	**17Septmber-1July**	ETC mm	903.11	1001.40	116.94
	(stage3)	P mm	6.10	870.60	173.80
		ETC-P	897.01	130.80	-56.86
		WDR(%)	99.32	13.06	48.60
Maturity	**1July-8Augest**	ETC mm	1019.70	1299.15	594.30
	(stage4)	P mm	420.52	331.50	146.30
		ETC-P	599.18	967.65	448.00
		WDR(%)	58.76	74.48	75.38

During 2005–2010, there are (10) times of water deficit occurring in the germination stage, there are (3) times of deficit in thetillering(1) stage, times of deficit in the grand and boom(3) and (3)in the maturity stages. The serious water deficit in the seeding stage is the primary reason for low cane yield in this area, since the water deficit is from 13.06% to 99.32% of ETc. So the crop yield may obviously increase if irrigation water is supplied during the critical growth stage.

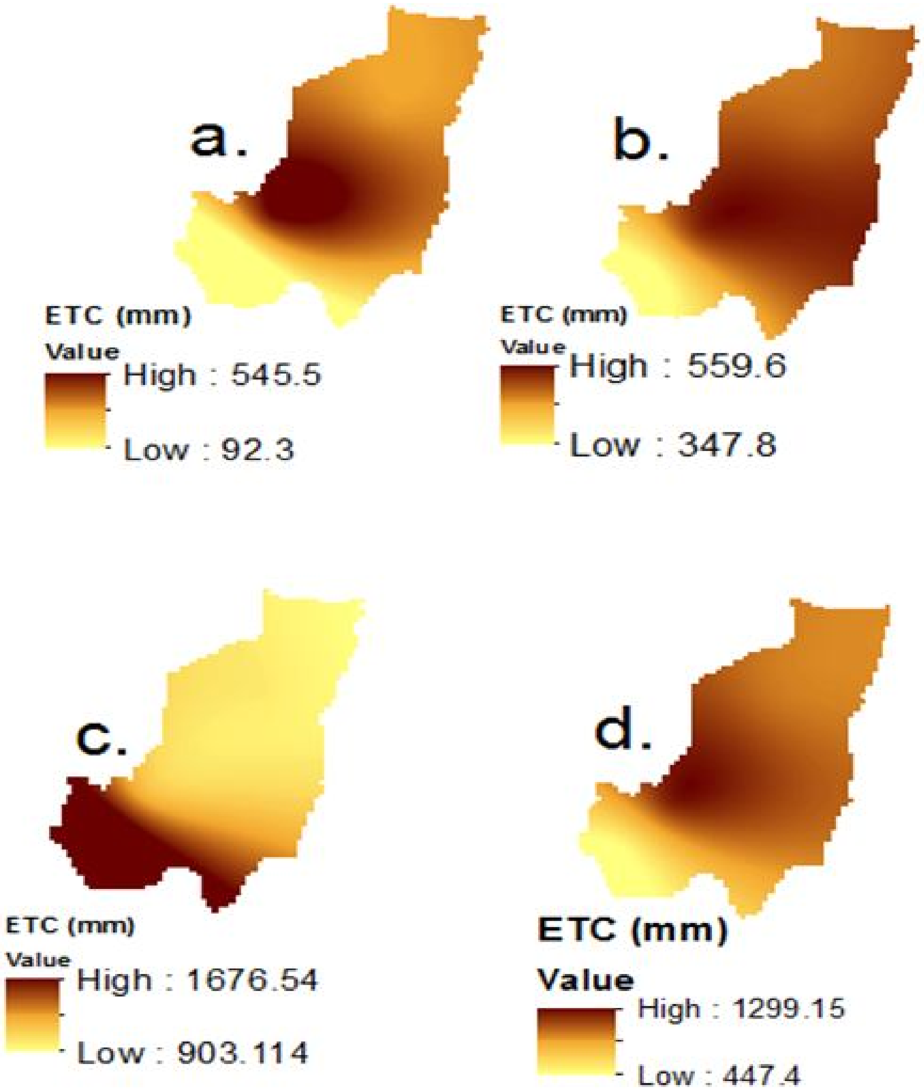


Figure 4.1. Spatial distribution of ETc in aljnead , Kynana and Sennar in 2005-2010 a. Germination (15 JUL - 10 AUG) b. Tillering (10 AUG - 17 SEP) c. Grand period or boom stage (17 SEP - 1 JUL) d. Maturity (1 JUL - 8 AUG)

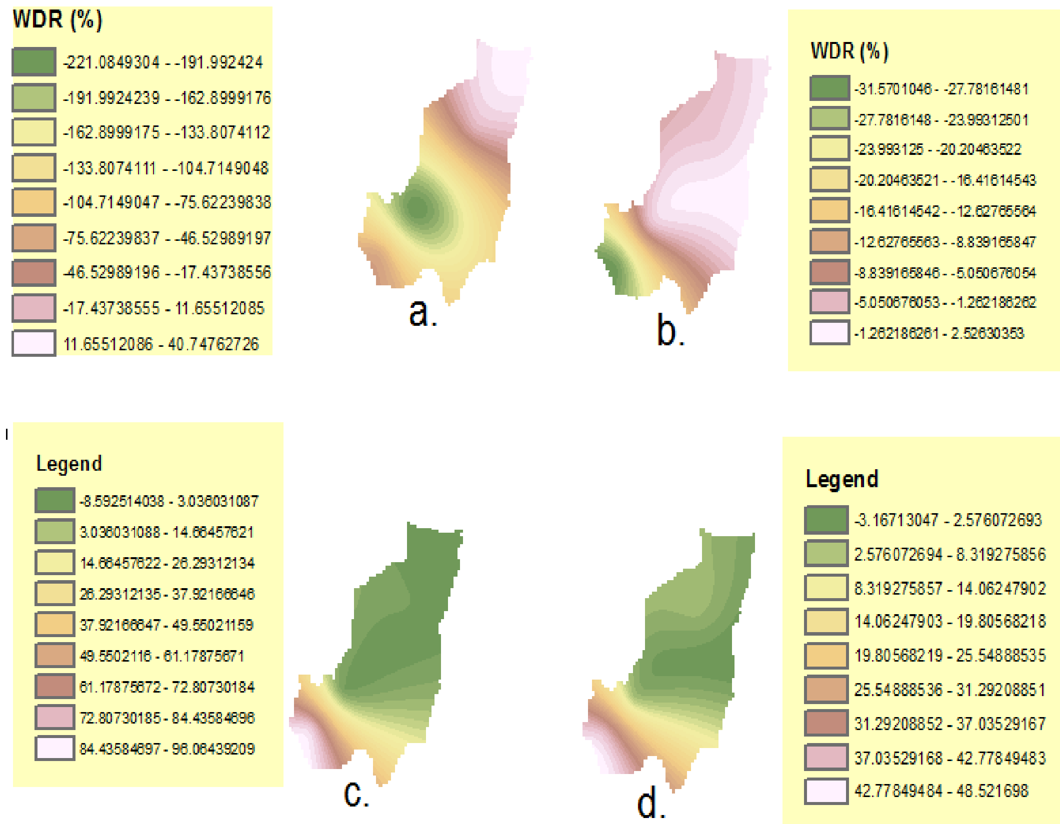


Figure 4. 2. Spatial distribution of WDR in aljnead , Kynana and Sennar in 2005-2010 a. Germination (15 JUL - 10 AUG) b. Tillering (10 AUG - 17 SEP) c. Grand period or boom stage (17 SEP - 1 JUL) d. Maturity (1 JUL - 8 AUG)

Figure 4.3 shows the spatial distribution characteristic of water deficit in different growing stages. In the first stage (Fig. 4a, germination) ,Fig. 4c, grand or boome stage and four stages (Fig. 4d), and maturity stages), the average water deficit of sugar cane very high in the whole area, since there is little rainfall in the three stages. In order to reduce the loss of production, farmers should irrigate once or twice in this period. In the second stages (Fig. 4bTillering stage;), the water deficit was different in different areas: water deficit ratio (*WDR*), which is about 65%; in kenana area.

4.4 Irrigation schedule

In order to compute the irrigation schedule using the CropWat model, the information on soil type, such as total available moisture, readily available moisture and initial available moisture are also required. The results are as follows. In dry years, it needs irrigation to minimize the loss of production. So in the study we analyze one scenarios: Under fortnightly precipitation condition and under these weather situations if the sugar cane has not obtained enough water, the production will drop heavily. The irrigation schedule for sugar cane was planned for two or three times under the one scenario. The irrigation scheduling in Kennan , Sennar and New Halfa in Tables 2-4

Table 4.2. Irrigation scheduling in Kenana Region (fortnightly precipitation)

Date	ATM	RAM	Total rain fall	SMD(NoIrr)	SMD(Irr)	Net(Irr)	Lost Irr
7\May	270	162	1.03	86.43	8	70.4	0
21\May	270	162	1.23	108.8	8.7	68.9	0
4\Jun	270	162	3.6	65.6	0	0	0
18\Jun	270	162	9.6	46.7	0	0	0
2\Jul	270	162	21.7	62.1	0	0	0
16\Jul	270	162	13.8	15.9	0	0	0
30\Jul	270	162	10.7	2.13	0	0	0
13\Aug	270	162	10.1	2	0	0	0
27\Aug	270	162	11.6	5.6	0	0	0

Notes: SMD—soil moisture deficit;
RAM—readily available moisture;
TAM—total available moisture;

Net Irr.—irrigation depth applied;

Lost Irr.—irrigation water that is not stored in soil; The same in the below tables

Table 4.3.Irrigation scheduling in Sennar Region (fortnightly precipitation)

Date	ATM	RAM	Total rain fall	SMD(NoIrr)	SMD(Irr)	Net(Irr)	Lost Irr
7\May	270	162	0	104.22	8.8	104.22	0
21\May	270	162	2.62	82.18	4.6	64.16	0
4\Jun	270	162	0.42	104.06	6.4	86.28	0
18\Jun	270	162	1.58	98.32	6.2	85.62	0
2\Jul	270	162	0	107.88	8.4	107.88	0
16\Jul	270	162	2.08	57.62	4	43.4	0
30\Jul	270	162	5.22	33.4	10.42	0	0
13\Aug	270	162	7.26	36.76	0	0	0
27\Aug	270	162	2.22	68.94	4.4	41.46	0

Table 4.4. Irrigation scheduling in New Halfa Region (fortnightly precipitation)

Date	ATM	RAM	Total rain fall	SMD(NoIrr)	SMD(Irr)	Net(Irr)	Lost Irr
7\May	270	162	0.16	95.58	8.4	85.48	0
21\May	270	162	0.32	98.7	8.4	85.3	0
4\Jun	270	162	3.56	95.1	8.8	83.3	0
18\Jun	270	162	1.5	73.3	3.6	43.3	0
2\Jul	270	162	2.02	66.92	2	20	0
16\Jul	270	162	3.14	61.94	2	20.4	0
30\Jul	270	162	4.92	63.34	22.5	42.6	0
13\Aug	270	162	2.94	77.54	25.7	67.3	0
27\Aug	170	162	3.34	38.84	10	60.32	0

In irrigation scheduling for Sugar cane at three sites, the daily soil moisture balance option was selected to show the status of the soil every day, the soil moisture changes in the growing season and estimated total yield reduction. First, we will analyze the irrigation scheduling under the fortnightly precipitation scenario. Table 2, Table 3 and Table 4 shows soil moisture changes during the Sugar cane growing season in Kenana, Sennar and New Halafa sites using the scheduling criteria: irrigating at fixed intervals of 14 days and variable depths (the soil is returned exactly to field capacity with no or less excess irrigation), when the soil moisture deficit reaches the readily available moisture.. Scheduling option with 2 times of irrigation of 70.5mm (7May), 68.9mm (21 May) at Kenana can be applied when soil moisture deficit falls below the readily available moisture, which seems to be the most suitable option will be the best choice (Table 2) .

According to the analysis. In Sennar , scheduling with seven times of irrigation of 104.2 mm (7 May), 64.1mm (21May) and 86.2mm (4 June) , 85.6mm(18June), 107.8 mm(2July) , 43.4mm(16July) and 41.4 mm(27August) seems to be the best option Table 2). In New Halfa , scheduling with nine times of irrigation of 85.4mm (7 May) , 85.3mm (21 May) , 83.3mm(4June) , 34.3 mm(18June) , 20.0mm (2July) , 20.4mm (16 July) , 42.6mm(30 July), 67.3mm (13 August)and 60.3 mm (27August) (Table 6).

CHAPTER FIVE

CONCLUSIONS AN RECOMMENDATION

The Sugar cane region has seasonal water deficits, especially serious in Sugar cane (germination stage), which is the dominating reason for the low yield per unit area in this region. To remedy the water deficits during its critical growth periods and avoid the waste of water in the mean time, precise supplemental irrigation schedules were recommended in different weather conditions (the fortnightly precipitation).

Under the fortnightly precipitation scenario, in Kenana irrigation was recommended two times in its growth period: 7May and 21May respectively. In Sennar irrigation was also recommended seven times:

7 May, 21May, 4June, 18June, 2July , 16July and 27 August respectively. In New Halfa irrigation was recommended nine: 7May, 21May, 4June, 18June, 2July , 16 July, 30 July, 13 August and 27 August.

Precise supplemental irrigation in critical growth periods is valuable for reducing the loss of spring maize production, especially during the dry years.

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