

Simulation of Water Requirements and Irrigation Scheduling of Sorghum Crop

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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 research, sorghum crop rainfed region (Gadareef and Sennar) were 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. The model, that calculates evapotranspiration and crop water requirements, allows the development of recommendations for improved irrigation practices, the planning of irrigation schedules under varying water supply conditions and yields reduction under various conditions. For the purpose of this paper, the model was run for the specific weather conditions from 2000 to 2010. Simulation results analysis suggests that areas, where the sorghum water requirements exceeds the water supply, by application of adequate irrigation scheduling the yield losses can be significantly reduced. 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 sorghum at the right time reduced the loss of yield, under different scenarios.

Keywords – Model, CROPWAT, Sorghum, Climatic Water Deficit, Irrigation Schedule.

I. INTRODUCTION

Computer model simulation is an emerging trend in the field of water management. Water managers irrigation agronomists, engineers and researchers taking keen interest in model simulation for the easier solution of problems faced by them. CROPWAT is one of the models extensively used in the field of water management throughout the world. CROPWAT facilitate the estimate of the crop evapotranspiration, irrigation schedule, and agricultural water requirements with different cropping patterns for irrigation planning Models that adequately simulate the effects of water stress on yield can be valuable tools in irrigation management. These models can be used to optimize the allocation of irrigation water between different crops and/or the distribution of water during the crop season [1]. Sorghum [Sorghum bicolor (L.) Moench] is an indigenous crop to Africa, and though commercial needs and uses may change over time, sorghum will remain a basic staple food for many rural communities is of significant importance for countries like

Sudan, where rapid increase in population have increasing pressure on agricultural commodities.

Sorghum is one of the most important crops in irrigated semiarid areas of the world. It has high irrigation requirements and is very sensitive to water stress. Tariq and Jamal (2003) studied that optimal crop production demands decision-making processes of irrigation scheduling such as number of irrigation and their frequency to meet the crop requirement. Proper irrigation scheduling is essential for efficient use of water and crop production. Under scarce and costly water supplies, it may sometimes be advantageous to Sorghum has been reported to have high stress tolerance, including temperature, water and salt stresses [2]. The irrigation demand of sorghum crop is varied according to climatic condition but in Sudan it grow in rain season from (July to November).

Water requirement for sorghum under South African conditions (450–650 mm) per season depending on climate and length of growing period. [3] Beside soil moisture status the climate have also direct impact on plant growth and yield. The rate of water uptake required to sustain normal plant growth at any given time depends not only upon soil water status but also upon the atmospheric conditions and properties of the plants. So the CROPWAT is one of the computer models used to study climatic impact as well planning and management of irrigation scheduling in this study CROPWAT4 (Windows 4.3). This area, having long been the most important political and economic in East and central Sudan. The irrigation demand of sorghum crop is varied according to climatic condition but in Sudan it grows in rain season from (July to November). Now the area cultivated by sorghum 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.

The general objective: Apply CROPWAT model to Sorghum crop in Gdareef and Sennar Simulate results of various options for water supply and irrigation management conditions;

The specific of objectives of this study were to:

- 1- To estimate climatic water deficit.
- 2- To estimate the yield reduction of Sorghum under different rainfed and irrigated conditions.

II. METHODOLOGIES

A. Study Area

(14°02'N – 35°23' °E, 13.55 °N, – 33.6°E) for Gadareef and Sennar respectively (Fig. 1) It lies in the

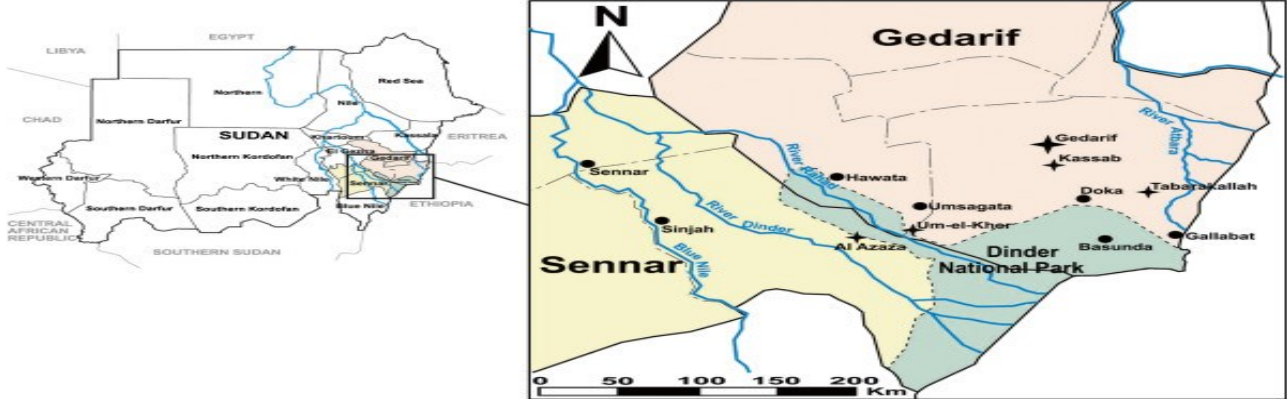


Fig. 1. Sketch of Gadareef and Sennar regions

B. Area Data

- Meteorological Data

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 2000 to 2010.

- Crop and Soil Data

For this study, sets of standard sorghum crop data that are included in the program were used. The crop coefficient (Kc) and crop yield data (Ky) have been updated by FAO. Sorghum crop was planted on 15th and 23rd of July, respectively. The crop is assumed to be planted all at the same time and cover 100% of the projected area. The model simulation requires soil data, such as: heavy soil, medium soil and light soil which is fulfilled by CROPWAT automatically having soil data option.

C. 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 reference evapotranspiration, crop water requirements and irrigation requirements in order to develop irrigation schedules under various management conditions and scheme water supply [4]. 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 [5]. 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

climate zone with hot-wet summer and cold-dry winter. The mean annual temperature is 18- 45 °C and the annual precipitation ranges from 325mm to most of which is flat to 644mm.

cropping pattern provided in the program [6], Studies have shown that the Penman-Monteith method is more reliable than methods that use less climatic data [7]. In this paper, the Penman-Monteith equation below was adapted as the sole means of calculating the reference evapotranspiration of sorghum.

$$ET_0 = \frac{0.408\Delta(Rn-G) + \gamma \left(\frac{900}{T} + 273 \right) U_2 (ea - ed)}{\Delta + \gamma (1 + 0.34 U_2)} \quad (1)$$

Where, ET₀ is the reference evapotranspiration (mm/a), R_n 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 of 2m (m/s), ed 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 [8]. ET_c can be calculated by Equation (2)

$$ET_c = K_c \times ET_0 \quad (2)$$

Where K_c is the crop coefficient.

The crop water requirement (ET_c) of sorghum was computed by multiplying the crop coefficient (K_c) with ET₀ at different growth stages. The K_c in various growing periods is: (0.50) in seedling stage (0.80); in development period (1.15); (0.66) in harvesting period (FAO, 1979).

$$WDR = [(ET_c - P)/ET_c] \times 100 \quad (3)$$

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

ETc is the crop water requirement (mm),
P is the difference between rainfall and runoff

III. RESULTS AND DISCUSSION

A. Crop Water Requirements

From the water requirement results computed by the evapotranspiration model, the peak period of Sorghum water use was from early (June) to late (July). The average

daily ETc was usually more than 4 mm. The calculated total sorghum ETc varied between 350mm and 620 mm in 2000-to 2010) with an average of 635 mm, which was less in wet years and more in dry years in region (Fig. 2). The variation trend of the ETc has two phases: in the first phase (2000-2005), the ETc curve is obvious highly fluctuating; in the second phase (2005 - 2010), the variation of ETc is comparatively gentle.

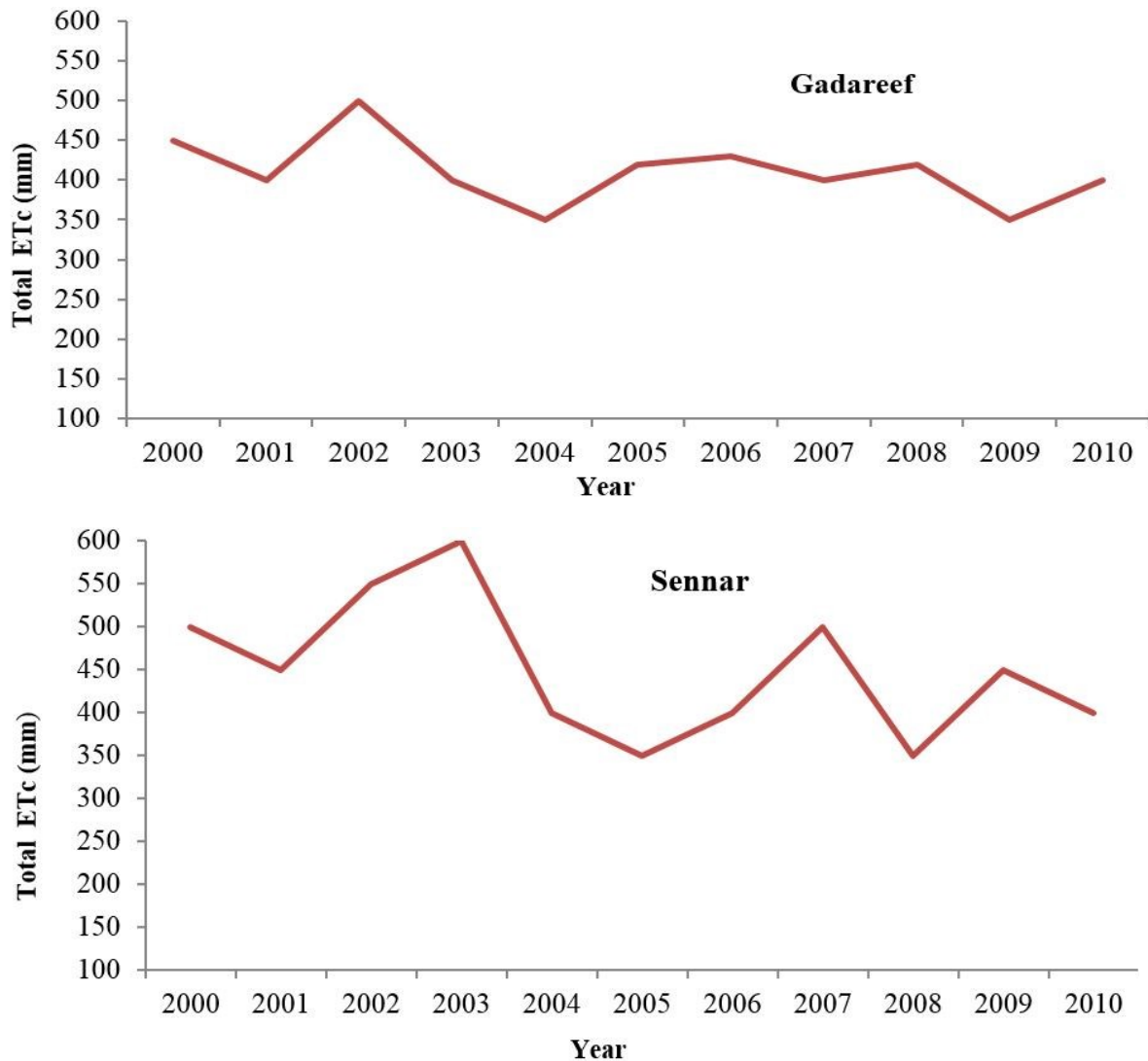


Fig. 2. Total Etc of Sorghum in Gadareef and Sennar regions in 2000–2010.

B. Crop Water Deficit

The average water deficit of Sorghum from natural precipitation was (25.5. – 56.9.mm) in the first stage in(2000 - 2010), while its ETc is mm77.1- 85.8 (Table1). During 2001–2010, there are 6 times of water deficit occurring in the seeding stage, 2 times, there are 2 times of deficit in the development stage, 2 times of deficit in the late stage. The serious water deficit in the seeding stage is the primary reason for low sorghum yield in this area, since the water deficit is from 33.1 % to 66.2% of ETc. So the crop yield may obviously increase if irrigation water is supplied during the critical growth stage.

Water Requirements and Irrigation Scheduling of SORGHUM Using Crop Wat Model.

C. 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 paper, we analyze two scenarios. The first is under fortnightly precipitation condition and the second is under triweekly precipitation condition.

Under these weather situations if sorghum has not obtained enough water, the production will drop heavily or three times under the two scenarios. the irrigation schedule for Sorghum was planned for two or three times under the two scenarios.

Table 1. Average water deficit of Sorghum in 2000–2010

| Growth stage | | Gadareef | Sennar |
|----------------------------------------|------------|----------|--------|
| (Seeding stage) 2 Jul. –1 Aug. | ETc (mm) | 77.1 | 85.8 |
| | P (mm) | 51.6 | 29.0 |
| | ETc–P (mm) | 25.5 | 56.9 |
| | WDR(%) | 33.1 | 66.2 |
| (Development stage) 2 Aug. – 1 Sep. | ETc (mm) | 109.5 | 125.7 |
| | P (mm) | 87.6 | 65.9 |
| | ETc–P (mm) | 21.9 | 59.8 |
| | WDR(%) | 0.2 | 0.5 |
| (Middle stage) 2 Sep. – 1 Oct. | ETc (mm) | 138.8 | 140.0 |
| | P (mm) | 181.2 | 201.9 |
| | ETc–P (mm) | 42.4– | 61.9– |
| | WDR(%) | 30.5– | 44.2– |
| (Late stage) 2 Oct. – 2 Nov. | ETc (mm) | 16.3 | 18.3 |
| | P (mm) | 15.8 | 13.2 |
| | ETc–P (mm) | 0.5 | 5.1 |
| | WDR(%) | 2.9 | 28.0 |
| (Whole stage) | ETc (mm) | 431.7 | 462.2 |
| | P (mm) | 433.2 | 417.0 |
| | ETc–P (mm) | 1.5– | 45.2 |
| | WDR(%) | 0.4– | 9.8 |

Table 2. Irrigation scheduling in Gadareef (fortnightly precipitation) (mm)

| Date | TAM | RAM | Total rainfall | SMD (No Irr.) | SMD (Irr.) | Net Irr. | Lost Irr. |
|---------|-------|------|----------------|---------------|------------|----------|-----------|
| 28 Jul. | 54.9 | 27.5 | 15.6 | 3.6 | 3.6 | | |
| 11 Aug. | 74.2 | 37.1 | 25.3 | 1.4 | 1.4 | | |
| 25 Aug. | 93.5 | 46.8 | 39.7 | 2.8 | 2.8 | | |
| 8 Sep. | 112.8 | 56.4 | 55.1 | 12.4 | 12.4 | | |
| 22 Sep. | 128.0 | 64.0 | 67.4 | 39.6 | 39.6 | 40.0 | 0.00 |
| 6 Oct. | 128.0 | 64.0 | 73.4 | 60.3 | 30.7 | 30.0 | 0 |
| 20 Oct. | 128.0 | 64.0 | 71.5 | 68.2 | 28.3 | 10 | 0 |
| 3 Nov. | 128.0 | 71.7 | 61.9 | 68.8 | 39.5 | 0 | 0 |
| 17 Nov. | 128.0 | 89.6 | 46.8 | 65.4 | 41.9 | 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 3. Irrigation scheduling in Gadareef (triweekly precipitation) (mm)

| Date | TAM | RAM | Total rainfall | SMD (No Irr.) | SMD (Irr.) | Net Irr. | Lost Irr. |
|---------|-------|------|----------------|---------------|------------|----------|-----------|
| 4 Aug. | 61.8 | 30.9 | 16.8 | 1.7 | 1.7 | | |
| 25 Aug. | 94.4 | 47.2 | 53.7 | 2.1 | 2.1 | | |
| 15 Sep. | 126.9 | 63.5 | 102.4 | 28.1 | 28.1 | 40 | 11.9 |
| 6 Oct. | 144 | 72 | 130.4 | 75 | 58.1 | 60 | 1.9 |
| 27 Oct. | 144 | 72 | 119.9 | 90.3 | 57.6 | 60 | 2.4 |
| 17 Nov. | 144.0 | 90.7 | 78.6 | 91.8 | 44.2 | | |

Table 4. Irrigation scheduling in Sennar (fortnightly precipitation) (mm)

| Date | TAM | RAM | Total rainfall | SMD (No Irr.) | SMD (Irr.) | Net Irr. | Lost Irr. |
|---------|-------|-------|----------------|---------------|------------|----------|-----------|
| 28 Jul. | 76.4 | 38.2 | 4.7 | 22.1 | 22 | | |
| 11 Aug. | 103.2 | 51.6 | 14.4 | 27.8 | 27.8 | | |
| 25 Aug. | 130.2 | 65 | 32 | 2.8 | 30.1 | | |
| 8 Sep. | 156.9 | 78.5 | 51.5 | 12.4 | 44.4 | | |
| 22 Sep. | 178.0 | 89.0 | 66.9 | 39.6 | 31.3 | 60.0 | 15.6 |
| 6 Oct. | 178.0 | 89.0 | 73.6 | 60.3 | 33.2 | 30.0 | 0 |
| 20 Oct. | 178.0 | 99.7 | 69.9 | 68.2 | 50.1 | 10 | 0 |
| 3 Nov. | 178.0 | 71.7 | 56.9 | 68.8 | 70.2 | 0 | |
| 17 Nov. | 178.9 | 124.6 | 39.0 | 65.4 | 73.4 | 0 | |

Table 5 Irrigation scheduling in Sennar (triweekly precipitation) (mm)

| Date | TAM | RAM | Total rainfall | SMD (No Irr.) | SMD (Irr.) | Net Irr. | Lost Irr. |
|---------|-------|-------|----------------|---------------|------------|----------|-----------|
| 4 Aug. | 76.4 | 38.2 | 10.1 | 16.7 | 16.7 | | |
| 25 Aug. | 116.7 | 58.3 | 41 | 11.4 | 11.4 | | |
| 15 Sep. | 156.9 | 78.5 | 83.5 | 45.4 | 45.4 | 60 | 14.6 |
| 6 Oct. | 178 | 89 | 108.6 | 98 | 67.1 | 60 | 0 |
| 27 Oct. | 178 | 89 | 100.4 | 115.6 | 68.6 | 30 | 0 |
| 17 Nov. | 178.0 | 112.1 | 65.4 | 118.1 | 81.7 | | |

Table 6. Effect of rain fed and optimal irrigation on total Sorghum yield reduction in different weather conditions.

| Site | Option | Net Irr.(mm) | Lost Irr.(mm) | Yield red. (%) |
|----------|----------------------------------------|--------------|---------------|----------------|
| Gadareef | Fortnightly precipitation (rainfed) | - | - | 16.2 |
| | Triweekly precipitation (rainfed) | - | - | 35.9 |
| | Fortnightly precipitation (irrigation) | 80 | 0.4 | 0.2 |
| | Triweekly precipitation (irrigation) | 150 | 9.1 | 4.1 |
| Sennar | Fortnightly precipitation (rainfed) | - | - | 15.7 |
| | Triweekly precipitation (rainfed) | - | - | 29.2 |
| | Fortnightly precipitation (irrigation) | 100 | 14.6 | 0.1 |
| | Triweekly precipitation (irrigation) | 150 | 15.6 | 0.6 |

In the rain fed conditions (fortnightly precipitation and triweekly precipitation), the calculated soil moisture deficit shows the effect of rainfall only. Due to the small amount of precipitation during maize seeding season, the soil moisture deficit reaches the limit of the readily available moisture in the first ten days of June in the area. Beginning from June the soil moisture deficit goes up to the limit of total available moisture. In this case, the Sorghum has a yield reduction, which is estimated to be 16.2 % (fortnightly precipitation), 35.9% (triweekly precipitation) for Gadareef and 15.7% (fortnightly precipitation), 29.2% (triweekly precipitation) for Sennar. In irrigation scheduling for maize at two sites, the daily soil moisture balance option was selected to show the status of the soil every day, the soil moisture Gadareef in the growing season and estimated total yield reduction. First, we will analyze the irrigation scheduling under the fortnightly precipitation scenario. Table 2 and Table 4 show soil moisture changes during the Sorghum growing season in Gadareef and Sennar 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.

IV. CONCLUSIONS

The model CROPWAT can appropriately estimate the yield reduction caused by water stress and climatic impacts, which makes this model as a best tool for irrigation planning and management in sorghum. The sorghum has seasonal water deficits, especially serious in (seeding 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 meantime, precise supplemental irrigation schedules were recommended in different weather conditions (the fortnightly precipitation and the triweekly precipitation). Under the fortnightly precipitation scenario, in Gadareef irrigation was recommended three

times in its growth period: 2 July, 16 July and 30 July respectively. In Sennar irrigation was also June, 2 July and 16 July respectively. Under the triweekly precipitation scenario, irrigation was recommended three times in the area during the growing season: one at elongation stage one at booting and heading stage, and one in the milk stage. These timely and limited irrigations will result in significantly higher yields compared to the rainfed control. Precise water harvesting techniques as supplemental irrigation in critical growth periods is valuable for reducing the loss of Sorghum production especially during the dry years.

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