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Determination of Sorghum Optimum Sowing Date, Seasonal Variability of Biomass Production, And Water Use Efficiency in Agricultural Rain Fed Area in Sudan, Using AQUACROP Model

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ABSTRACT

This research aimed to determine sorghum optimum sowing date, seasonal variability of biomass production, and water use efficiency in agricultural rain fed area in Sudan using AQUACROP Model. The study selected five meteorological stations representing five different agro- ecological zones located in the north, middle and south of the Sudan namely Al-Dalang, Al- Damazin, Al-Gadaref, El-Obeied, and El-Fasher for the period 1979 to 2014. The results indicated that an increase in sorghum yield under historical climate conditions in the different studied stations is possible with early sowing. Stations with high rain fall (Al-Damazin, Al-Gadaref and Al-Dalang) showed little variations in inter-annual yields and inter-annual biomass yield. There was a big gap between actual and modeled water productivity showing that it is possible to introduce different means (water harvesting and improved cultural practices) to shorten this gap. The obtained WUE is lower in the driest regions (El-Fasher, and El-Obeied) and higher for those of high rain fall. To aid decision makers and crop growers in rain fed areas, a set of recommendations for policy making and future research were identified.

Keywords: *AQUACROP; benchmarking; water productivity; water use efficiency (WUE); Sorghum; rain fed; biomass yield.*

1. INTRODUCTION

With limited room for expansion of both agricultural land and the irrigated portion of the arable land from Nile Water (Rockström and Baron, 2007), additional food production will have to come from intensification of production in rain fed farming systems. Rockström *et al.* (2003) showed that it was possible to at least double rain fed staple food production by producing more ‘crop per drop’ of rainwater. It is therefore necessary to explore ways of increasing water use efficiency in rain fed agricultural systems.

Climate variability has been identified as the major constraint to agricultural production in dry land of Sudan, and hence reducing the risk associated with climate variability in the rain fed areas in the central clay plains of Sudan (Phillips *et al.,* 1998).

Despite contributing a large share of the annual grain output, rain fed production of rain fed Sorghum in Sudan is largely unstable (Mhizha, 2010).

AQUACROP (Raes *et al.,* 2009) is a crop water productivity model developed by the Land and Water Division of the Food and Agricultural Organization (FAO). It is a water-driven crop model to simulate yield response to water of several herbaceous crops. It is designed to balance simplicity, accuracy and robustness, and is particularly suited to address conditions where water is a key limiting factor for crop production. The AQUACROP model has been parameterized and validated for simulating crops yield response to water (Hsiao *et al.,* 2009; Heng *et al.,* 2009). Although AQUACROP is based on complex crop physiological processes, it uses a relatively small number of explicit and mostly intuitive parameters with simplicity and accuracy (Steduto *et al.,* 2009; Raes *et al.*, 2009). Some of the advantages of AQUACROP:

a) It is widely applicable with acceptable accuracy;
b) It requires only commonly available input (i.e. climate, soil, and crop and field data);
c) It allows easy verification of simulation results with simple field observations.

In an attempt to compare performance of AQUACROP, Crop System, and WOFOST Models, Todorovic *et al.,* (2009) simulated sunflower (*Helianthus annuus* L.) growth under different water regimes in a

Mediterranean environment. These three models differ in the level of complexity describing the crop development in the main growth modules driving the simulation of biomass growth, and in the number of input parameters. AQUACROP is exclusively based on the water-driven growth module, in which the transpiration is converted into biomass through water productivity (WP) parameter. He recommended that under conditions of limited input information and yield predictions under variable water supply situations, the AQUACROP model should be preferred over other models but still the use of simpler models should be encouraged.

Current crop simulation models can be used to capture and quantify the effects of weather extremes, hence compounding on the already existing uncertainty regarding the direction and magnitude of climate change (White *et al.,* 2011; Ramirez-Villegas *et al.,* 2013) consequently understanding of the impacts on crops and in the timing of crop adaptation strategies such as adjustments of planting dates and choice of crop cultivars can be improved. The main Applications of Aqua Crop model are:- Assessing water-limited, attainable crop yields at a given geographical location, As a benchmarking tool, comparing the attainable yields against actual yields of a field, farm, or region, to identify the yield gap and the constraints limiting crop production, Assessing rain fed crop production on the long term, Developing irrigation schedules for maximum production (seasonal strategies and operational decision-making), and for different climate scenarios and Scheduling deficit and supplemental irrigation .

The model does not take into consideration such factors like pests, diseases and weeds

The objectives of this study were as follows:

1. To examine sorghum crop yield response and identify the adaptation options in the sorghum based cropping system using simulation modeling.
2. To determine sorghum optimum planting date.
3. To study seasonal variability of biomass production for five different climate regions.
4. To study rain fall water Use Efficiency (WUE) for regions of different climate element.

5. To calibrate and validate the results of the crop simulation model and simulation of the impacts of future climate change scenarios on sorghum productivity.
6. To evaluate the performance of a set of adaptation options such as changes in sowing date.

2. MATERIALS AND METHODS

Characteristics of the Study Area

The study selected five meteorological stations representing five different agro- ecological zones located in the north, middle and south of the Sudan, namely Al- Dalang, Al-Damazin , Al-Gadaref, El-Obeied, and El-Fasher (Table 1) .

(Table 1) shows climatic characteristics of the study area (humidity, max and min temperature, rain fall, sun shine hours and wind speed).

Table 1. Climatic characteristics of the study area

Station	**(average for period 1979-2014)**					
	Humidity (%)	**Min. Temp. (C°)**	**Max. Temp. (Co)**	**Annual Rainfall (mm)**	**Sunshine Duration (hours)**	**Wind Speed (km/d)**
Al-Dalang	**44.1**	**20.8**	**35.3**	**680.6**	**8.3**	**225.3**
Al-Gadaref	**42.4**	**21.4**	**36.8**	**612.0**	**9.1**	**231.7**
Al-Damazin	**47.7**	**20.7**	**35.8**	**698.2**	**8.1**	**218.8**
El-Obeied	**34.6**	**20.0**	**34.7**	**329.0**	**9.2**	**312.2**
El-Fasher	**31.2**	**17.2**	**34.7**	**193.3**	**9.3**	**180.2**

Types and Sources of Climatic Data

The weather data required by AQUACROP are the daily values of minimum and maximum air temperature, reference evapotranspiration, rainfall and solar radiation (Raes *et al.*, 2009, Steduto *et al.*, 2009). If daily climatic data is not available, 10- day and monthly data can be used as input.

The standard procedure is to calculate daily reference evapotranspiration (ETo) following the FAO Penman–Monteith equation (Allen *et al.*, 1998).

Observed data was provided by the Sudan Meteorological Services Department (SMSD), as well as downscaled Global Climate Model data (GCM) and the daily Satellite data (air temperature, precipitation, wind and relative humidity) have also been downloaded from *http://globalweather.tamu.edu/#* website in CSV[1] file format for a given location, (South Latitude (12), West Longitude (31), North Latitude (16), East Longitude (34)) and time period, (1/1/1979 to 12/31/2014). The numbers of downloaded weather stations were made for each one of the five cities.

Soil Data

The required input soil parameters for AQUACROP are the soil texture data (sand, clay, loam, in %), saturated hydraulic conductivity (Ksat), volumetric water content at saturation (θsat), field capacity (θFC), and permanent wilting point (θPWP).These parameters were derived from field measurements.

Crop Yield Data

Sorghum yield data for period 1979 - 2014 was collected from the Federal Ministry of Agriculture for each one of the 5 cities. For the purpose of AQUACROP simulation, time to emergence, maximum canopy cover, and start of senescence were based on field observations.

Crop Parameters

initial, final and rate of change in %; canopy cover; initial, final and rate of deepening in root depth; biomass water productivity; harvest index; typical management conditions such as irrigation dates and amounts, sowing and harvest dates, mulching …etc.) and details of the crop model that include: phonology, growth and water balance are contained in FAO (2009).

Management

- Irrigation type. Soil fertility.
- Field; b. Mulches; c. Field surface practices.
- Surface runoff soil bund occurrence.

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[1] The CSV (“Comma Separated Value”) file format is often used to exchange data between disparate applications.

Simulation Data

- Simulation period (linked to growing season).
- Initial condition: Initial soil water content soil layer thickness soil salinity (Specified for specific layer).

All these input data were used in the model to predict the yield, water productivity, and biomass and harvest inde**x** of Sorghum. However, the model should be recalibrated and revalidated using the data acquired from field experiments for its further use.

Data Analysis

AQUACROP Yield Prediction Model

AQUACROP model is based on the crop growth and production that driven by the amount of water used through consumptive use of the plant. Among the empirical function approaches, FAO Irrigation and Drainage Paper No. 33 (Doorenbos and Kassam, 1979) represented an important one to determine the yield of field, vegetable and tree crops response to water, through the following equation:-

$$\left(\frac{Y_x-Y}{Y_x}\right) = K_y\left(\frac{ET_x-ET}{ET_x}\right) \quad \text{--------------------Eq.1}$$

Where, Yx and Y are the maximum and actual yield, ETx and ET are the maximum and actual evapotranspiration, and Ky is the proportionality factor between relative yield loss and relative reduction in evapotranspiration. There was a constant scientific and experimental progress in crop-water relations from 1979 till date, which led to a revision framework that treats separately field crops from tree crops. For the field crops, it was suggested to develop a model of proper structure and conceptualization that would evolve from Eq.1 and be designed aerations in yields and a trend towards lower yields. These results seem to suggest that depending on the onset of rain fall, adapting sowing dates may be effective in counteracting adverse climatic effects as shown by the slight increases in median yields compared to yields from baseline.

For planning, management and scenario simulations, the result is the Aqua Crop model which differs from the main existing models for its balance between accuracy, simplicity and robustness. Aqua Crop is a

FAO's crop water productivity simulation model. AQUACROP evolves from the previous Doorenbos and Kassam (1979) approach (Eq. 1) by separating (i) the ET into soil evaporation (E) and crop transpiration (Tr) and (ii) the final yield (Y) into biomass (B) and harvest index (HI). The separation of ET into E and Tr avoids the confusing effect of the non-productive consumptive use of water (E), especially during incomplete ground cover. The separation of Y into B and HI allows the distinction of the basic functional relations between environment and B from those between environment and HI and also avoids the confusing effects of water stress on B and on HI. The changes led to the following equation for the Aqua Crop model:-

$$B = WP \times \sum T_r \text{-------------------------------Eq.2}$$

Where, Tr is the crop transpiration (in mm) and WP is the water productivity parameter (kg of biomass per m2 and per mm of cumulated water transpired over the time period in which the biomass is produced). The main change from Eq. 1 to AQUACROP is in the time scale used for each one. In the case of Eq. 1, the relationship is used seasonally or for long periods (of the order of months), while in the case of Eq. 2 the relationship is used for daily time steps, a period that is closer to the time scale of crop responses to water deficits.

3. RESULTS AND DISCUSSIONS

Determining the Optimal Planting Date

Adjustment of sowing dates for sorghum as one of the adaptations in future climate change scenarios was tested in the modeling framework through shifting by either bringing forward or delaying sowing within a regular interval (Do-15, Do+15 days) with respect to the baseline case, Do being the normal sowing date .

Results from the adjustments are shown in Figure 1 and indicate increase in sorghum yields under historical climate when early sowing is considered in almost all stations. Decrease in yield with late sowing may be due to incidence of low early rains (rains coming late). In stations with high rains (Al-Dalang, Al-Damazin and Al-Gadaref) it is preferred to sow early to benefit from the probable early rains. This result is in agreement with Rinaldi (2004); Heng *et al.*(2009); Asseng *et al.* (2011) who used AQUACROP to determine the optimal sowing date in relation to initial soil water to maximize wheat grain yields. Table 2 shows the average Potential model yield for the different sowing dates for each one of the five stations (kg/fed). It is evident from the table that the date with maximum yield for El-Obeied, Al-Damazin, El-Fasher, Al-Gadaref, and Al-Dalang are 1-July, 15–June, 15-July, 15-June, and 15-June respectively.

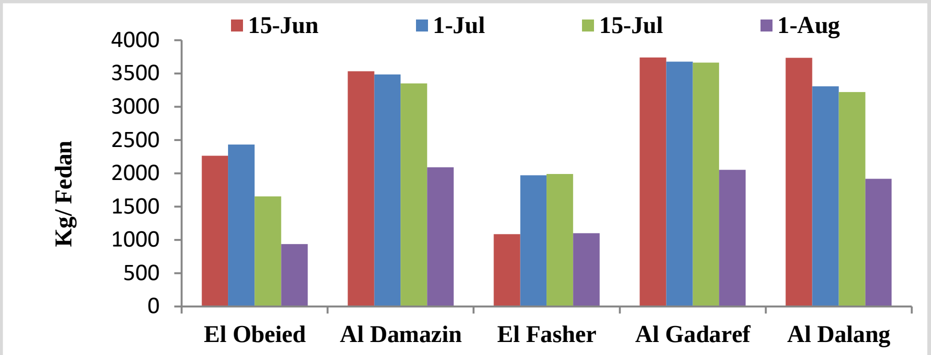


Figure 1. Sorghum Grain yield due to changes in sowing dates in the different stations

Table 2. Average Potential model yield for the different sowing dates for each one of the five stations (kg/fedan).

Station	15-Jun	1-Jul	15-Jul	1-Aug
El-Obeied	2266	2435	1652	938
Al-Damazin	3536	3485	3350	2092
El-Fasher	1086	1969	1992	1100
Al-Gadaref	3741	3677	3667	2051
Al-Dalang	3737	3311	3222	1917

Seasonal Variability of Sorghum Yield for different climate regions

Stations with high rain fall (Al-Damazin, Al-Gadaref and Al-Dalang) show little variations in inter-annual yields but with a tendency towards high yields. Contrastingly, El-Obeied and El-Fasher show wide variations in yields and a trend towards lower yields (Fig 2). These results seem to suggest that depending on the onset of rain fall, adapting sowing dates may be effective in counteracting adverse climatic effects as shown by the slight increases in median yields compared to yields from baseline crop and

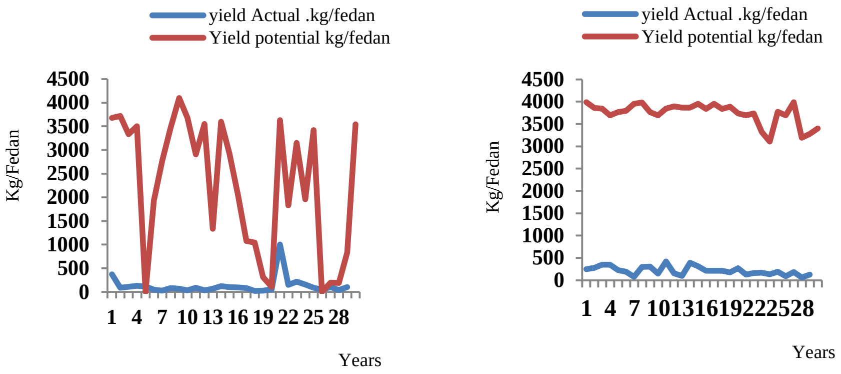
Millet crops. However the erratic nature of rainfall, characteristic of semi-arid areas (which unfortunately cannot be captured by the model) tend to shorten the planting window, such that a delay of two weeks in sowing may cause significant reduction in yields due to shortening of the length of growing period (yield decrease by 43% when sowing date is delayed from 15July (the recommended date by ARC) to 1st of August. This result is in agreement with wheat yield reported by Stapper and Harris (1989). This may be due to effects of initial soil water stored from onset of early summer rainfall be able to influence early establishment of the crop and can contribute to water use and yield later in the season, in particularly in low rainfall seasons Hadjichristodoulou and Photiades (1977); Anderson and Smith (1990) and Connor *et al.* (2008).

Seasonal Variability of Biomass Production for different climate regions

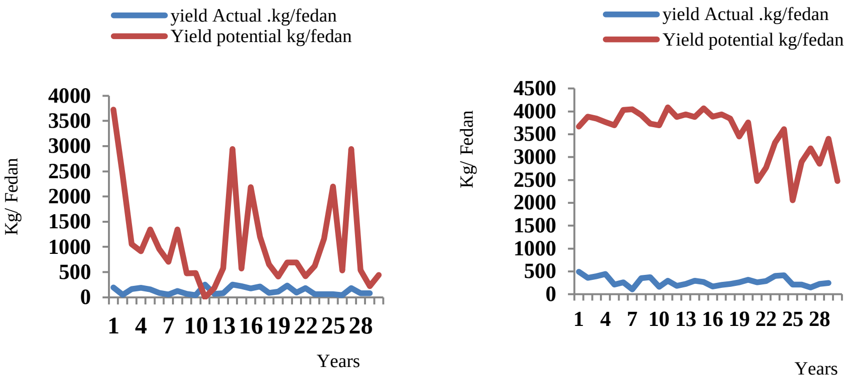
Figure 3 shows the inter-annual variability, of biomass yield in the five stations (ton/ha). The figure shows that the variability of both grain yield and biomass follows the same trend. It is also evident that much inter-annual variability is in El-Fasher and El-Obeied stations. These stations are characterized with late and low rain fall amount. In contrast less inter-annual variability is found in the other stations with higher rain fall amount.

Determination of Rain fall water Use Efficiency (WUE)

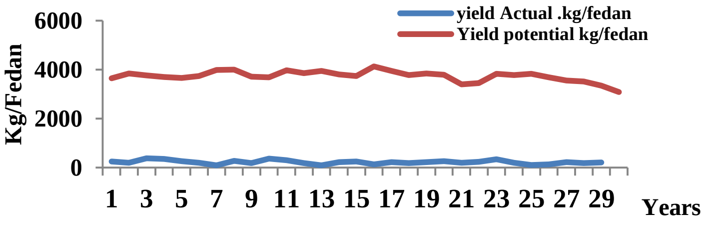
Figure 4 shows the variability of Water use efficiency (WUE) for different climatic regions. The figure indicates that: the obtained WUE is lower in the driest regions of El-Fasher, El-Obeied while it is medium and equal for Al-Gadaref and Al-Dalang and higher for Al-Damazin. This may be attributed to availability of water at crop critical growth stages; where the crop is sensitive to presence of high rain water at the early initial stage and sensitive to water shortage at flowering stage.



El-Obeied **Al-Gadaref**

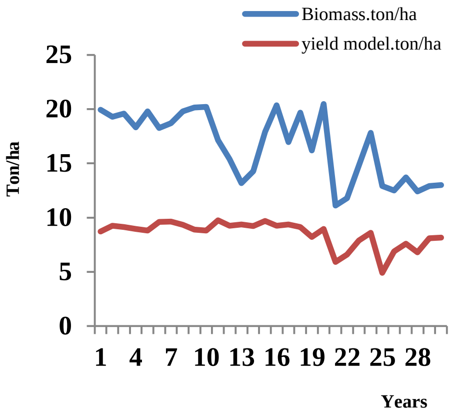


El-Fasher **Al-Damazin**

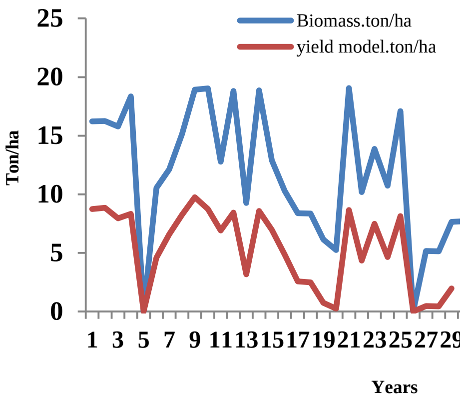


Al-Dalang

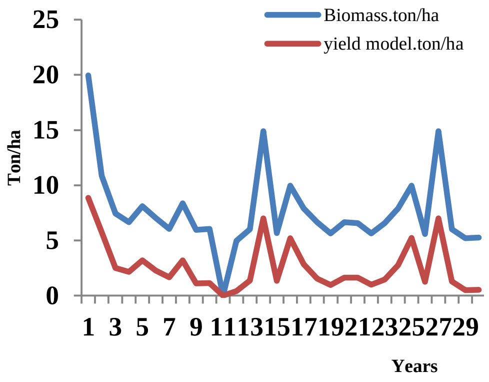
Figure 2. Inter-annual variability, of Sorghum yield in each station (Kg/fedan)



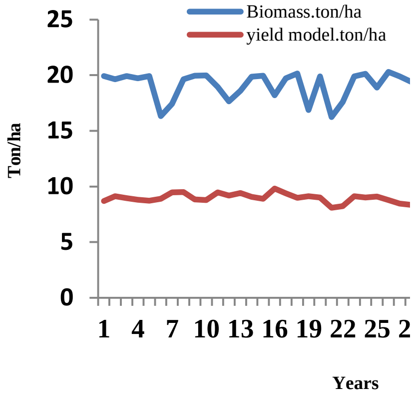
Al-Damazin



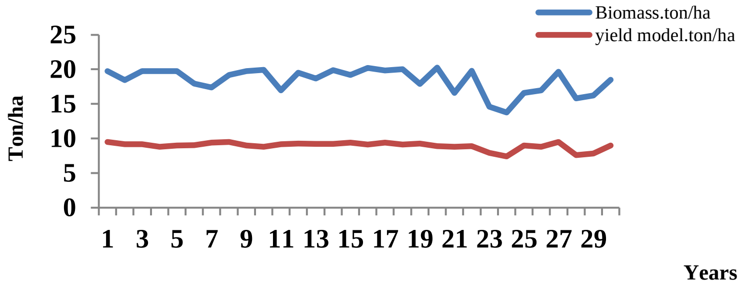
El-Obeied



El-Fasher



Al-Dalang



Al-Gadaref

Figure 3. Inter-annual variability, of biomass yield in the five stations (ton/ha)

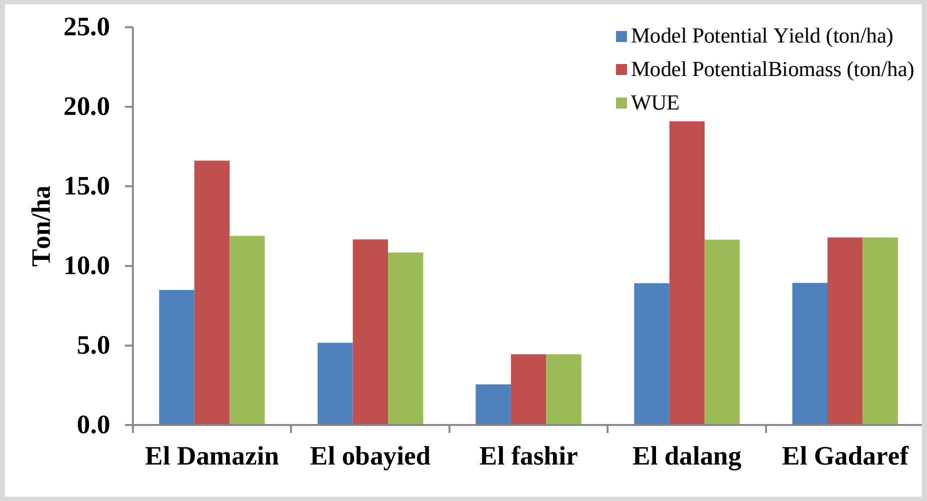


Figure 4. Variability of Water use efficiency for different climatic regions

4. CONCLUSION

AQUACROP model can be used to determine yield gap between potential yield Identify regions and crops whereby substantial improvements in production and productivity may be possible.

From the study of prediction of rain fed Sorghum crop grain and biomass yield at five regions representing different climate zones in Sudan under the prevailing climate conditions shows that:

- The annual variability of both grain yield and biomass follows the same trend.
- The farmers 'choice of sowing date can be an important adaptation strategy to climate change and this management options should be considered in climate change impact studies on agriculture.
- The study on Rain fall water Use Efficiency (WUE) for regions of different climate element shows that WUE is lower in the driest regions and higher for those of high rain fall.

- There is potential to increase farm productivity by better exploitation of the scarce water in the dry season and it may be possible to increase farm incomes significantly by growing high value short-duration crop cultivars through improving water utilization efficiency by early crop planting to better use of early season soil water.

- All the possibilities of Aqua Crop model have not yet been explored in this paper it remains necessary to:
  - Evaluate and quantify the errors involved in Aqua Crop simulations.
  - Using Aqua Crop for water allocation decisions at basin or regional levels
  - Determining the seasonal water requirements and its components for various crops on a farm
  - Developing deficit and supplemental irrigation programmers' at a field scale influence of field management on rain fed agriculture.

REFERENCES

Allen RG, Pereira LS, RAES D and Smith M (1998) Crop evapotranspiration – Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper No. 56. FAO, Rome. 300 pp.

AQUACROP -The FAO crop model to simulate yield response to water: III. Parameterization and testing for maize (2009). Agronomy Journal 101: 448-459.

Asseng, S., Foster, I. & Turner, N.C. (2011). The impact of temperature variability on wheat yields. Global Change Biology 17, 997-1012.

Doorenbos, J., Kassam, A.H. 1979. Yield Response to Water. Irrigation & Drainage Paper No 33, FAO, Rome.

Hadjichristodoulou A, Della A, Photiades J (1977). Effect of sowing depth on plant establishment, tillering capacity and other agronomic characters of cereals. J. Agric. Sci. 89: 161-167.

Heng, L.K., T.C. Hsiao, S.R. Evett, T.A. Howell, and P. Steduto. (2009). Testing of FAO Aquacrop model for rainfed and irrigated maize. Agron. J. 101: 488–498 (this issue)

Hsiao, T.C., Heng, L.K., Steduto, P., Rojas-Lara, B., Raes, D. and Fereres, E. 2009.

Mac Carthy, D.S. & Vlek, P.L.G. (2012). Impact of climate change on sorghum production under different nutrient and crop residue management in semi-arid region of Ghana: A modeling perspective. African Crop Science Journal 20, 243-259.

Mhizha, T. (2010). Increase of yield stability by staggering the sowing dates of different varieties of rainfed maize in Zimbabwe. PhD Thesis, Katholieke Universiteit Leuven, Belgium, 166 pp.

Phillips JG, Cane MA and Rosenzweig, C (1998) ENSO, seasonal rainfall patterns and simulated maize yield variability in Zimbabwe. Agric. For. Meteorol. 90 39–50.

Steduto, P., T .C.Hsiao,D. Raes and E. Fereres. (2009). AQUACROP the FAO crop model to simulate yield response to water: I. concepts and underlying principles. Agron. J., 101: 426-437

Raes, D. (2009). Reference Manual - ETo calculator (Version 3.1) (Accessed 13/05/2009).http://www.fao.org/nr/water/docs/referencemanualeto.pdf.

Raes, D., Steduto, P., Hsiao, T.C. and Fereres, E. (2009). AquaCrop-The FAO crop model to simulate yield response to water: II. Main algorithms and soft ware description. In Validating the FAO AquaCrop Model. For Irrigated and Water Deficient Field Maize.

Ramirez-Villegas, J., Challinor, A. J., Thornton. K. P. & Rinaldy M, Losavio N, Flagella Z. (2013). Evaluation of OILCROP-SUN model for sunflower in southern Italy. Agricultural Systems. 78: 17-30.

Rinaldi, M., Casagli, N., Dapporto, S., Gargini, A., (2004). Monitoring and modeling of pore water pressure changes and riverbank stability during flow events. Earth Surf. Process. Landf. 29 (2), 237–254.

Rockström, J. and Barron, J. (2007) Water productivity in rainfed systems: overview of challenges and analysis of opportunities in water scarcity prone savannahs. Irrig. Sci. 25 299–311.

Rockström J, Barron, J. and FOX P (2003) Water productivity in rain-fed agriculture: challenges and opportunities for smallholder farmers in drought-prone tropical agro ecosystems. In: Kijne JW, Barker R and Molden D (eds.) Water Productivity in Agriculture: Limits and Opportunities for Improvement. International Water Management Institute (IWMI), Colombo.

Steduto, P., Hsiao, T.C., Raes, D. and Fereres, E. (2009). AquaCrop - The FAO crop model to simulate yield response to water: I. Concepts and underlying principles. Agronomy Journal 101: 426-437.

Todorovic, M., Albrizio, R., Zivotic, L., Saab, M.T.A., Stockle, C., Steduto, P. (2009). Assessment of Aqua Crop, Crop System, and WOFOST Models in the Simulation of Sunflower Growth under Different Water Regimes, Agron. J. 101(3), 509-521.

White JW, Hoogenboom G, Kimball BA, Wall GW (2011) Methodologies for simulating impacts of climate change on crop production. Field Crops Research 124: 357-368.

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المستخلص

يهدف هذا البحث إلى تحديد موعد الزراعة الأمثل للذرة الرفيعة، والتنوع الموسمي لإنتاج الكتلة الحيوية، وكفاءة استخدام المياه في مناطق الزراعية المطرية في السودان باستخدام نموذج AQUACROP. اختيرت للدراسة خمس محطات أرصاد جوية تمثل خمس مناطق زراعية مختلفة البيئة تقع في شمال ووسط وجنوب السودان وهي الدلنج، الدمازين، القضارف، الأبيض والفاشر للفترة 1979-2014م. توصلت الدراسة إلى أن زيادة محصول الذرة الرفيعة في ظل هذه الظروف المناخية التاريخية في المحطات المدروسة المختلفة ممكنة مع

الزراعة المبكرة. أظهرت المحطات ذات الأمطار الغزيرة (الدمازين، القضارف والدلنج) اختلافات طفيفة في الإنتاج السنوي وعائد الكتلة الحيوية بين السنوات. كانت هناك فجوة كبيرة بين إنتاجية المياه الفعلية والنموذجية مما يدل على أنه من الممكن إدخال وسائل مختلفة (حصاد المياه والممارسات الثقافية المحسنة) لتقليل هذه الفجوة WUE .التي تم الحصول عليها أقل في المناطق الأكثر جفافاً (الفاشر والأبيض) وأعلى في المناطق التي تسقط فيها الأمطار بغزارة. لمساعدة صانعي القرار ومزارعي المحاصيل في المناطق المطرية، تم تحديد مجموعة من التوصيات لصنع السياسات والبحوث المستقبلية.

الكلمات المفتاحية: *AQUACROP؛ المقارنة المعيارية؛ إنتاجية المياه؛ كفاءة استخدام المياه (WUE) ؛ الذرة الرفيعة؛ المطرية.*