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Impact of Crop Water Requirements and Effective Rainfall on Yield and Water Productivity of Sorghum (*Sorghum bicolor* (L.) Moench) - Gedaref State, Sudan

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Abstract

The high variability of rainfall has serious impacts on food security in the world. Knowledge of crop water requirement is vital in agriculture for designing and managing irrigation and drainage systems. This research was, therefore, conducted to compare between sorghum (*Sorghum bicolor* (L.) Moench) crop water requirements and effective rainfall and their effect on yield and water productivity. Arfaa Gadamk variety (2009/10, 2010/11 and 2011/12) under the dry-land farming of Gedaref State during three consecutive seasons was used. Mean annual rainfall (mm), measured within the three rainy seasons, and collected crop data were plant population, plant height at flowering, dry matter, 1000- seeds weight, grain yield and water productivity (kg/m^3). Mean rainfall was 483.7, 568.3 and 284.5 mm while the crop water requirement was 443, 462.5 and 462.4 for season one, two and three, respectively. Result showed that the effective rainfall was below the crop water requirements for the third season. The highest grain yield (1864.7 kg/ha) for sorghum was produced in season two and lowest (1619 kg/ha) was produced in season three. The highest value of water productivity 0.5 kg/m^3 for sorghum was produced in season one and the lowest 0.45 kg/ m^3 in season three. The main recommendation was the possibility for early sowing date by using of climate forecasts instead of historical data in selecting planting dates. Also, the government and development partners should consider increasing investments in construct and maintain rain-water harvesting (RWH) structures to ensure supplemental irrigation during critical stages.

Keywords: crop water requirement, rainfall, sorghum, water productivity

Introduction

In Sudan, sorghum (*Sorghum bicolor* (L.) Moench) is the staple food crop utilized in various forms for human and animal feed. The area under irrigated sorghum is about 8% while 92% is under rain-fed (Fadlelmula, 2009). Gedarif State is the most important rain-fed sector. It is the largest rain-fed area for sorghum production. Gedarif rain-fed area extends from North to South through three climate zones. The soil is heavy clay soils, (Lotfie and Babikir, 2015). Climate is characterized by high summer temperatures and warm winters. Rainfall is usually within the summer, and most of the rain falls within the period of May to October. Seasonal rainfall ranges from 200 mm in the arid area at the far northern areas to 800 mm in the savannah zone at the far southern areas (Mohamed *et al.*, 2015). Elramlawi et. al., (2020) sorghum crop experiences frequent water stress periods during its life cycle due to unreliable water source (rainfall) and deteriorated reservoir (soil). According to Ibrahim (2015) sorghum productivity in traditional rain-fed agriculture in Sudan can hardly exceeds 1-2 sacks approximately 215-430 Kg/ha. This low productivity is attributed to number of factors among which are the use of inappropriate machinery such as wide level disc that accelerates soil erosion by constituting hardpans and causing poor soil water retention. Rainfall is most vital climatic index of productivity. At the same time it is the most variable climatic element both in time and space. Abubaker *et. al.*, (2017) reported that tied-ridging and riding tillage could enhance the yield and water use efficiency. He found that both the conservation tillage techniques showed positive effect on the WUEs. Also, Hakeem, (2018) stated that N increased grain yield by 35–64% at the Bayero University Kano and 23–78% at Minjibir in Nigeria.

For many years, scientists tried to correlate yield of crops with total rainfall, without success. The total rainfall may be more than adequate, but not enough is received when most needed, and too much comes when least desired (Adam, 2005). Effective rainfall may be defined as the fraction of rainfall that is effectively intercepted by the vegetation or stored in the root zone and used by the plant-soil system for evapotranspiration. A number of empirical formulas have been developed for the estimation of effective rainfall (Adam, 2014). Also, Babu *et al.*, (2014) defined effective rainfall as that a part of the rainfall which is effectively used by the crop after rainfall losses due to surface run off and deep percolation have been accounted for. The effective rainfall is that the rainfall ultimately wont to determine the crop irrigation requirements.

Crop water requirement (CWR) is the quantity of water utilized by a crop, irrespective of its source, for obtaining maximum yield in a particular area without adverse effects on soil properties. The evapotranspiration (ET_o) data for agricultural crops has become increasingly important in irrigation as well as in water resources management. It is dependent not only on the meteorological elements, but also on factors related to crop, soil environment, and management (Abu-Zeid and Hamdy, 2002). Karrar *et al.*, (2014) reported that yield values clearly show that sorghum is being produced under conditions of water stress, with a pronounced effect on yields. This means that different crop varieties and soil water management practices need to be adopted. The main objective of this study were to compare the amounts of sorghum (*Sorghum bicolor* L.) water requirements and effective rainfall amounts during growing season and their consequent effects on yield and water productivity.

Materials and Method

Study area

The experimental work was conducted for three consecutive seasons (2009/10, 2010/11 and 2011/12) at the pilot farm of the Faculty of Agricultural and Environmental Sciences, University of Gedaref at Twawa area (longitude 35º24′E latitude 14 º 02′N and 602 masl, the soil of the study area is predominantly vertisoils, deep dark coloured clays of montmorillonitic mineralogical origin (clay content is 40-65%). The land was sloping from east to west with a general slope of 0.04 %.

Cultural practices

The total numbers of plots were 20 and each plot size was 10×10m. A local sorghum variety, Arfaa Gadamak was sown on 20th of July and harvested on 1st of November in the three seasons. Seeding was carried manually in the bottom of the ridge. The spacing between furrow of ridging were 80 cm. Spacing between holes was sown as 30 cm. 5 seeds per hole was sown and thinned to two plants per hole three weeks later.

Data collection

Crop Data

The collected crop data were plant population, plant height, 1000 seeds weight (g), dry matter and grain yield (kg/ha).

Meteorological data

Daily meteorological data including rainfall (mm) maximum and minimum temperatures (C°), relative humidity (%), wind speed (m/s) and sunshine hours (hr/day) were collected for the period of 2009 to 2012 from the Gedarif Meteolorgical Station.

Effective rainfall

The effective rainfall was taken as 75% from the total rainfall according to Mohamed *et al.*, (2015).

ER= P*75 ………………………………………... (1)

Reference evapotranspiration (ET_o)

The mathematical expression of the reference evapotranspiration (ET_o) is follows:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

Where:

ET_o = Reference evapotranspiration (mm/day)

Rn = Net radiation at the crop surface ($MJm^{-2}day^{-1}$)

G = Soil heat flux density (MJm^{-2} day^{-1})

T = Mean daily air temperature at 2 m height (^0C)

u_2 = Wind speed at 2 m height (m/sec)

es = Saturation vapour pressure (k Pa)

ea = Actual vapour pressure curve (k Pa /^0C)

Δ = Psychrometric constant (k Pa /^0C).

Crop water requirement

Crop water requirement was determined from reference evapotranspiration from available climatic data for different months. CROPWAT 8.0 software program was used to calculate ET_o. Using the model suggested by Penman- Monteith's formula multiplied by the crop coefficient as follows:

CWR = ET_o x K_c…………………………………… (2)

Where:

CWR = Crop water requirement (mm/day)

ET_o= Reference crop evapotranspiration (mm/day)

K_c= Crop coefficien

Water productivity (kg/m^3)

Rain water productivity (WP) was calculated as the ratio of the crop yield to seasonal rain water applied according to Al- jamal *et. al.*, (2001) using the following formula:

WP (kg/m^3) = Yield (kg) / applied water (m^3) ..……………………………… (3)

Results and Discussion

Reference evapotranspiration (ET_o)

Estimated monthly reference evapotranspiration (ET_o) for the study area is presented in Table 1. Results showed that the average peak monthly ET_O was observed to be 6.8, 5.4, 5.6 and 8.2 mm/day for the months of July, August, September and October for the three seasons, respectively. The highest reference evapotranspiration recorded on October due to the high temperatures during the month. Whereas, average minimum reference evapotranspiration observed as 5.4 mm/day in the month of August.

Effective rainfall (ER)

The amount of monthly effective rainfall (mm) measured in the three rainy seasons is shown in Table 1. The total annual rainfall for the growing period was 483.7, 568.3 and 284.5 mm for first, second and third seasons, respectively. Rainfall records showed that the seasons began in

May and lasted during October the remaining months of the year were dry. The lowest annual rainfall (284.5mm) was received during the third season (2011/12). July, August and September were the rainiest months.

Crop water requirement (CWR)

Result of crop water requirement (mm) for different seasons are shown in Table (2). Result showed that the highest value of sorghum crop water requirement was obtained in September for all three seasons. The lowest value of crop water requirement for sorghum was obtained in July for all three seasons.

Effective rainfall (ER) and crop water requirement (CWR)

The total amount of the crop water requirement (mm) and amount of rainfall (mm) for different studied months were presented in (Fig. 1, 2 and 3). This comparison showed clearly the periods of water shortage, periods of water excess and periods when the rainfall matched the crop water requirement. During the first and second seasons the rainfall was more than the total crop water requirement during the growing seasons except in October. In the third season the rainfall was less than the crop water requirement during the months of August and September. During the critical period of end of August, to mid of September when all crops reach their peak requirements the crop water requirement was more than the available water. In other words the rainfall is less than the requirements. Adam, (2014) reported that sorghum needs 7140 m^3/ha for the whole growing season in Gezira scheme.

Plant parameters

Results of plant parameters for three seasons were shown in Table (3). The effects of rainfall were significant ($P \leq 0.05$) on plant parameters except on plant population (plant/m^2). Sorghum plant population (plant/m^2), plant height (cm), 1000 seed weight (g), dry matter (kg/ha) and grain yield (kg/ha) were higher in the second season, the wettest season, compared to the two other seasons while highest values of the water productivity (kg/m^3) were obtained in first season. This finding supports the hypothesis of higher sorghum performance with higher rainfall.

Grain yield (kg/ha) and water productivity (kg/m^3)

Result of grain yield **(**kg/ha**)** for the three seasons were shown in Table (3). Results showed that the highest grain yield **(**1846.7 kg/ha**)** for sorghum was produced in season (2010/11), and the lowest (1619 kg/ha**)** in season (2011/12). This was probably due to insufficient rains which led to water stress during the third season. Also, may be attributed to the other environmental conditions such as temperature and to the distribution of rainfall within the growing period. These results were in line with Kambal (2015) and Dhawelbait, (2015) who reported that sorghum production in Gedarif area amounted to 706, 547, 535 and 321 kg/ha for decade 1970/80, 81/90, 91/2000 and 2001/09, respectively. Abdelhadi *et al.*, (2002) reported that simple water harvesting techniques such as sowing on the bottom of the ridges or on tied ridges will significantly increase the yield of grain sorghum. Ali, (2008) found that there was a positive association between yield and rainfall during May and from the beginning of July to the first half of September, but a negative association at other times of the year. Farah, (1983) reported that high yields of rain-grown sorghum can be obtained if water deficits were avoided by supplementary irrigation during one or more of its growth periods. Elkhatim (2016) reported that the dry rainfall years affected the productivity of sorghum reducing it by 11.8 kg/ha/year which floody rainfall years led to the decrease within the productivity by 27 kg/ha/year, while it was decreasing by 8 kg/ha/year in normal rainfall years.

Alshikh *et. al.,* (2017) indicated that increase in sorghum yields under historical climate conditions is possible when early sowing is used and initial rain showers are utilized.

Concolussion

Effective rainfall is below the crop water requirements in the third season so this resulted in low yields in the third season. Also, effective rainfall was not well distributed during the three months July, August and September. The comparison of water requirement of sorghum and the amount of rainfall indicated that the rainfall was quite enough in the first two seasons while it was insufficient in the final stage during the growing period (August and September) in the third season. This period is very sensitive because important phonological events like flowering, spikelet's formation, grain filling and ripening occur during this period. If these events are affected due to water shortage, sorghum production declines significantly.

Recommendation

The main recommendation was the possibility for early sowing date to avoid water shortage. Early onset of rainfall and high variability in rainfall during the growing seasons suggest that use of climate forecasts instead of historical data should be recommended for use in selecting planting dates. Also, the government and development partners should consider increasing investments in constructing and maintaining rain-water harvesting (RWH) structures to ensure supplemental irrigation during critical stages.

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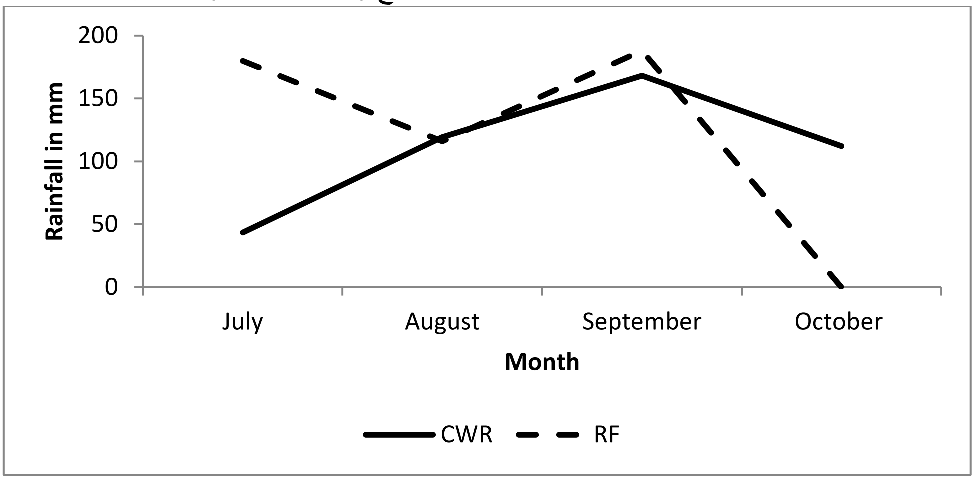

Fig. (1): Rainfall versus crop water requirement for season (2009/10)

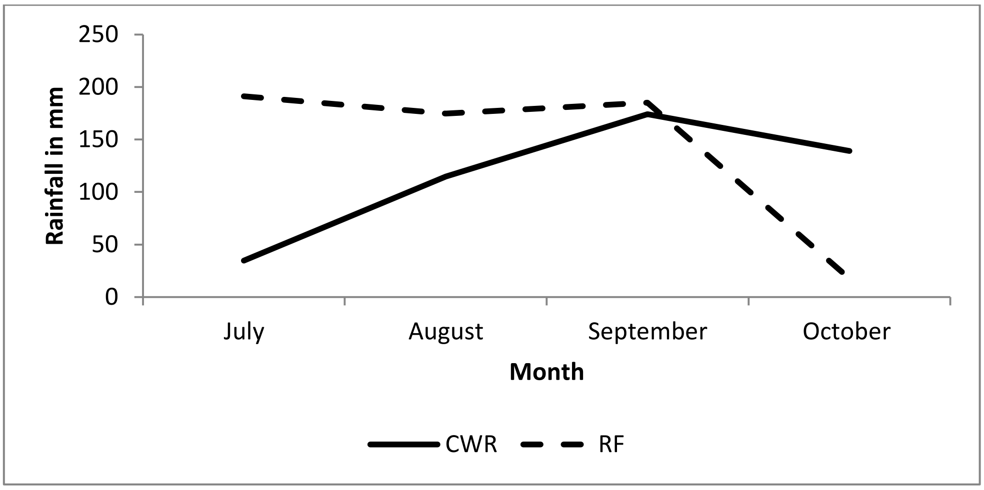

Fig. (2): Rainfall versus crop water requirement for season (2010/11)

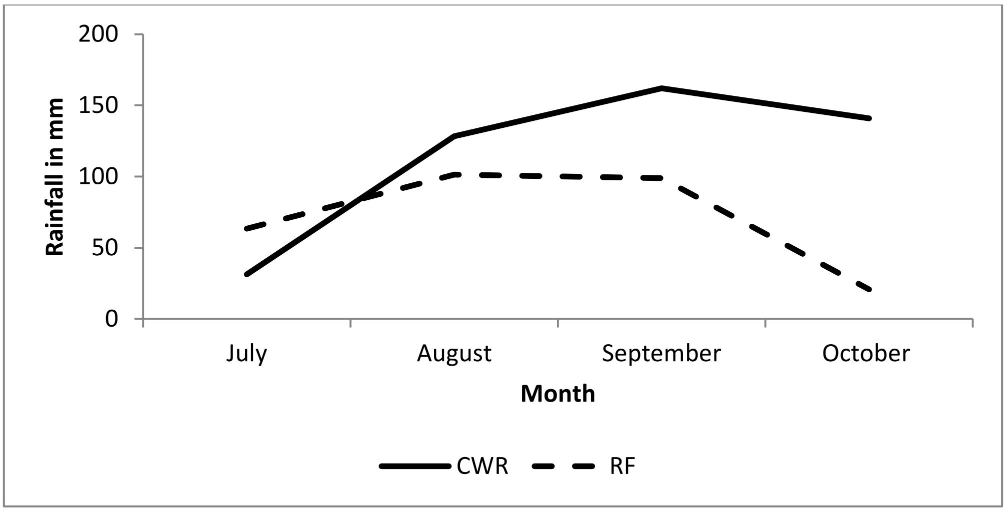

Fig. (3): Rainfall versus crop water requirement for season 2011/12

Table (1): Reference evapotranspiration (ET_o) mm/day for the three seasons (2009/10, 2010/11 and 2011/12)

Season	Month	Temperature (°C) Max.	Min.	R.H (%)	W.S (km/hr)	E.Rainfall (mm)	ET_o (mm)
2010	July	35.6	23.4	61.5	8.0	179.7	6.8
	August	33.6	22	71.8	5.7	116.0	5.3
	September	34.5	23	67.7	6.0	188.0	5.6
	October	37.3	30.2	51.9	3.9	0	8.6
2011	July	37.0	23.6	53.6	8.5	191.2	7.2
	August	36.7	23.5	56.0	6.5	174.6	5.1
	September	35.7	23.1	63.6	4.6	184.9	5.8
	October	38.1	23.6	50.9	6.0	17.60	8.0
2012	July	34.9	21.3	72.6	8.7	63.5	6.5
	August	27.9	21.3	86.5	7.8	101.4	5.7
	September	34.2	22.7	68.5	7.8	98.8	5.4
	October	37.4	24.4	47.3	7.1	20.8	8.1

Table (2): Monthly Sorghum crop water requirement (mm) and effective rainfall (mm) for seasons 2009/10, 2010/11 and 2011/12

Season		20 July	August	September	15th October
2009/10	RF	179.7	116.0	188.0	0
	CWR	046.4	112.5	171.0	66.55
2010/11	RF	191.2	174.6	184.9	17.60
	CWR	028.3	119.2	180.0	93.96
2011/12	RF	063.5	101.4	098.8	20.80
	CWR	028.8	126.0	174.0	95.70

Table (3): Yield components and grain yield of sorghum for three seasons (2009/10, 2010/11 and 2011/12)

Parameters	Seasons			
	2009/10	2010/l1	2011/l2	LSD
Plant population (plant/m^2)	13a	14a	13a	1.99
Plant height (cm)	76.7b	84.8a	67.6c	1.92
1000 S.W (gm)	23.1b	26.1a	20.6c	0.89
Dry matter (kg/ha)	994.4b	1124.8a	872.3c	8.21
Grain yield (kg/ha)	1747b	1846.7a	1619c	8.51
Effective rainfall (mm)	483.7	568.3	284.5	*
Water productivity (kg/m^3)	0.50a	0.48a	0.45b	0.018

Means followed by the same letters horizontally were not significantly different at 0.05 levels.

تأثير الاحتياج المائي والامطار الفعالة على انتاجية وكفاءة انتاجية المياه لمحصول الذرة الرفيعة – ولاية القضارف ، السودان

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المستخلص:

التباين العالي في الامطار لديه تأثير خطير في الامن الغذائي العالمي. معرفة الاحتياجات المائية مهمة جدا في الزراعة من اجل تصميم وادارة نظم الري والصرف. أجريت هذه الدراسة لمقارنة الاحتياج المائي للذرة الرفيعة و المطر الفعال على الانتاجية وكفاءة انتاج المياه تحت ظروف الزراعة الجافة بولاية القضارف لثلاثة مواسم (09/10 و 2010/ 2011 و/11 2012), تم اخذ المعلومات المناخية من محطة القضارف وتم حساب كمية الأمطار الفعالة (مم) كما تم حساب البخر نتح المرجعي(ET_o) بواسطة برنامج (CROPWAT.8) و حساب الاحتياج المائي (CWR) للثلاثة مواسم ومن ثم تم اخذ قياسات النبات وهي الكثافة النباتية و طول النبات عند الإزهار و وزن ال 1000 حبة بالجرام و الوزن الجاف (كجم/ هكتار) و الإنتاجية (كجم/ هكتار) وكفاءة انتاجية الماء (كجم/متر مكعب). أوضحت النتائج أن متوسط الامطار هي 483.7 و 568.3 و 284.5 ملم و الاحتياج المائي للنبات 443 و 462.51 و 462.39 ملم للمواسم الثلاثة على التوالي. اوضحت نتائج المقارنة ان المطر الفعال اقل من الاحتياج المائي للموسم الثالث. اعلى كفاءة انتاجية للماء تم الحصول عليها في الموسم الاول 0.50 كجم/م^3 وأدناها 0.45 كجم/م^3 في الموسم الثالث. تقترح البيانات أنه يمكن التبكير في بداية الموسم الزراعي وذلك باستخدام المعلومات المناخية لفترة زمنية طويلة. ايضا على الحكومة وشركاءها زيادة الاستثمارات فى بناء وصيانة منشآت حصاد المياه لتوفير ري تكميلي اثناء المراحل الحساسة للمحصول.