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Impact of Climate Change on Crop Water Requirements for Abu-Sabeen Forage Sorghum (*Sorghum bicolor* L.) and Alfalfa (*Medicagosativa* L.) in Khartoum State, Sudan

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Abstract

This study was carried out to assess the climate change impact on crop water requirement (ETc) of the main fodder crops grown in Khartoum State, Alfalfa and Sorghum (Abu-Sabeen). Daily meteorological data for the period 1988-2017 were collected from Sudan Meteorological Authority (SMA); temperature, humidity, wind speed, sunshine hours and rainfall data. Reference evapotranspiration (ETo) was determined using mean monthly meteorological data with help of CROPWAT 8.0 software package, which uses the FAO Penman-Monteith procedure and then crop water requirement (ETc) was determined. Statistical Analysis System Software (SAS) was used to analyze the data. The results indicated decreasing trends in relative humidity (RH%) and the opposite holds true for temperature and wind speed, with marked fluctuations in rainfall. Accordingly, ETo (mm/day) increased by 23%, ETc increased by 64% for Alfalfa of the second cutting (1734 m^3/ha in 1988 and 2845 m^3/ha in 2017), 26% for Abu-Sabeen forage (4935 m^3/ha in 1988 and 6212 m^3/ha in 2017). It was concluded that ETo values were significuntly ($P \leq 0.05$) different, ETc followed the same trend of ETo and in the rainy seasons irrigation requirements were affected by effective rain. Results showed rising demand of water requirement for fodder crops from 1988 to 2017 due to climate change – decrease in RH%, increase in temperature and wind speed and fluctuations in rainfall. The study recommends taking in consideration the impact of climate change in supplying irrigation water for forage crops and irrigation management according to the growth stage of the crop and season.

Keywords

Climate Change, CROPWAT 8.0, SAS, ETo, ETc, Crop Irrigation Requirement

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1. Introduction

Rising demands for food and uncertainties about climate change call for a paradigm shift in water management with a stronger focus on rainfed agriculture. Water productivity is significantly affected by the climate change especially in arid and semi-arid regions [1]. Climate change is becoming the hottest topic to the entire globe, when it comes to defining climate. When changes in the expected weather occur, these are called climate change. Climate may change in different ways, over different time scales and at different geographical scales. Since climate is changing, scientists have become interested in global warming, due to mankind's impact on the climate system, through the enhancement of the natural greenhouse effect. Since climate change is likely to have impact on the hydrological cycle and consequently on the available water resources and agricultural water demand;

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there are concerns about the impacts of climate change on agricultural productivity. Furthermore, industrialization and the extended use of fossil fuels have lead to a great increase in the atmospheric concentrations of greenhouse gases. With respect to the relations between the hydrological cycle and the climate system, every change on the climate could affect parameters such as precipitation, temperature, runoff, stream flow, groundwater level, and this leads to not only change in the crop water requirement in agriculture but also industrial and domestic water consumption and demand will also change [9]. Climate change has detrimental effects on crop water requirements, by rising of temperature eon earth surface the irrigation demands will be increased while water is becoming a scarce natural resource in the future due to climate variability. Therefore, the main problem of climate change on crops is more water for irrigation will be needed.

Fodder crops such as alfalfa and sorghum (Abu-Sabeen) represent the main forage crops grown in Khartoum State in which the biggest share of the cultivated area is allotted to fodder crops (62% about 78540 ha) as reported by [8]. For most of the cultivated area surface irrigation is used where a lot of troubles are related to this type of irrigation, for example; evaporation, deep percolation and over topping, beside the water scarcity and climate change impacts. Water requirements of alfalfa are relatively high compared to most crops such as sorghum. Despite its high water use, the crop has the ability to withstand short periods of severe soil water deficit of up to 15 atmosphere tensions. Long duration of severe soil water deficit, particularly at water-sensitive growth stages cause significant reduction in yield [2], by limiting evapotranspiration (ET) through stomata closure, reduced assimilation of carbon and decreased biomass production [3]. Producers may reduce water use per hectare by applying less than full crop-consumptive requirements (deficit irrigation), shifting to alternative crops or high yield varieties of the same crop that use less water, or adopting more efficient irrigation technologies [11]. Poor technical skills of farmers to assess the crop water requirements and to monitor the soil moisture conditions in the field are most limiting factors affecting the crop productivity. Therefore, the objective of this study is to estimate the impact ofclimatechangeoncropwaterrequirementsofthetwomajorfoddercropsgrowninKhartoumarea, Alfalfa and Sorghum (Abu-Sabeen).

2. Materials and Methods

2.1. Study Area

Khartoum State is located in the semi-arid savanna belt of the Sudan, with an average annual rainfall of 100-200 mm; crops grown in Khartoum State comprise a long list of vegetables, fruit trees, medicinal and aromatic plants and field crops [4]. This study was carried out in Khartoum State, in an area located at Latitude $15^0.36$ N and Longitude $32^0.33$ E with altitude of 380 m.

2.2. Meteorological Data

Meteorological data (temperature, wind speed, sunshine hours, relative humidity (RH%) and rainfall) were collected from Sudan Meteorological Authority (SMA) for the period 1988-2017. Thesedatawereusedasinput in CROPWAT.8 Program, which uses the FAO Penman-Monteith procedure for the calculation of reference evapotranspiration (ET_o).

2.3. Determination of Reference Evapotranspiration (ETo)

Reference evapotranspiration (ETo) was calculated by using CROPWAT.8 Program and climate data, ETo was determined in mm/day using the formula below, as given by [5]:

$$ETo = \frac{0.408\Delta(Rn-G)+\gamma\frac{900}{T+273}u2(es-ea)}{\Delta+\gamma(1+0.34u2)}$$

Where:

ETo= reference evapotranspiration (mm/day).

Rn= net radiation at the crop surface ($Mj/m^2/day$).

G = soil heat flux density ($Mj/\ m^2/day$).

900 =coefficient for reference crop (Kj/day)

T = mean daily air temperature at 2 m height (°C).

u2 = wind speed at 2 m height (m/s).

es = saturation vapour pressure (kPa).

ea = actual vapour pressure (kPa).

es-ea = saturation vapour pressure deficit (kPa).

Δ = slope vapour pressure curve (kPa/°C).

γ = psychrometric (kPa/°C).

2.4. CROPWAT

CROPWAT is a computer program which uses the FAO Penman-Monteith procedure for the estimation of reference crop evapotranspiration (ETo), crop evapotranspiration (ETo) and irrigation scheduling. Major input parameters of the program are agricultural meteorological data, crop growth data, and soil data, which include meteorological data: highest temperature, lowest temperature, sunshine, relative humidity, wind speed and rainfall; crop growth data: growing days, crop factor, and depth of root system, and soil data: extreme infiltration rate, extreme rooting depth, gross available water and primary soil moisture depletion [7].

2.5. Crop Water Requirements (ETc)

Crop water requirement (ETc) was calculated in mm/month for Alfalfa crop and in mm/period for Sorghum. The period was taken as 70 days, three months were chosen (April, May and June) for the selected years for sorghum growth. Crop coefficient values (initial 0.4, mid-season 1.2 and Kc end is 1.15 for Alfalfa and initial 0.5, mid-season 1.15, and end stage is 1.10 for Sorghum), growth stages length in days (initial stage 5, development 10, mid-season 10 and late stage is 5 days for Alfalfa and init 23, dev 23, mid 14 and late season 10 days for Sorghum) as reported by [5].

The following equation was used to calculate ETc for both Alfalfa and Sorghum:

ETc = Kc * ETo mm/day

Where:

Etc = Crop water requirements mm/day

Kc = Crop coefficient.

ETo = Reference evapotranspiration mm/day.

2.6. Quantity of Crop Water Requirements ETc (m^3/ha)

Crop water requirements in m^3/ha can be calculated as follow:

$$\text{ETc}\ (m^3/\text{ha}) = \frac{\text{ETc (mm)}}{1000} \times 10000$$

2.7. Effective Precipitation (PE)

Effective precipitation over the growth period for Alfalfa was calculated as follows, as given by [13]:

$$\text{PE} = \frac{\text{P}(4.17 - 0.02\text{P})}{4.17}\text{P} < 83$$

$$= 41.7 + 0.1\text{PP} \geq 83$$

Where:

P = is the precipitation during crop growing period (mm).

2.8. Crop Irrigation Requirement (CIR)

Crop irrigation requirement is the amount of water other than precipitation that crops needto meet water demand, and can be calculated as follows:

$$\text{CIR} = \text{ETc} - \text{PE}$$

Where:

CIR = is the crop irrigation requirement.

ETc = the crop evapotranspiration.

PE = theeffectiveprecipitation over the crop growth period.

2.9. Data Analysis

The computer program (SAS statistical package) was used to analyze the data. The variations among means werechecked by the least significant difference (LSD).

3. Results and Discussion

3.1. Reference Evapotranspiration (ETo)

As presented in Table 1 and Figure 1, reference evapotranspiration (ETo) values were significantly ($P \leq 0.05$) different for the different selected years. The values of ETo gradually increased from 1988 (8.07 mm/day) to 1997 (9.22 mm/day) while in 2002 the results showed decreasing ETo values (8.57 mm/day). In 2007 it started to rise again with maximum value occurring in 2017 (9.92 mm/day). This fluctuation in ETo values was due to the variation in climate (slight increase of minimum and maximum temperatures, marked increase of wind speed and decrease in relative humidity. The results were in conformity with the results obtained by Ruo and others [10], who in their findings implied that the reduction in temperature and high relative humidity also reduces the reference evapotranspiration and crop water requirements.

Table 1. Average of climate factors, total rainfall and reference evapotranspiration (ETo) values

Year	Min-Temp C°.	Max-Temp C°.	Relative Humidity RH%	Wind Speed (km/day)	Sunshine Hours	Rainfall (mm)	ET_o (mm/day)
1988	23.3	37	31.6	295.9	9	415.5	8.07[c]
1992	22.4	35.2	31.1	377.5	8.9	149.3	8.94[b]
1997	22.8	37	30.8	392.1	9	141	9.22[b]
2002	23.1	36.9	28.4	303.3	9.5	107.5	8.57[c]
2007	23.3	37.4	27.9	403.3	9.3	178	9.01[b]
2012	24.3	37.3	26.3	395.8	8.4	87.1	9.64[a]
2017	23.9	37.4	25.3	407	8.4	112.4	9.92[a]
LSD							0.32

Means followed by the same letter(s) in the same column are not significantly different at $P \leq 0.05$.

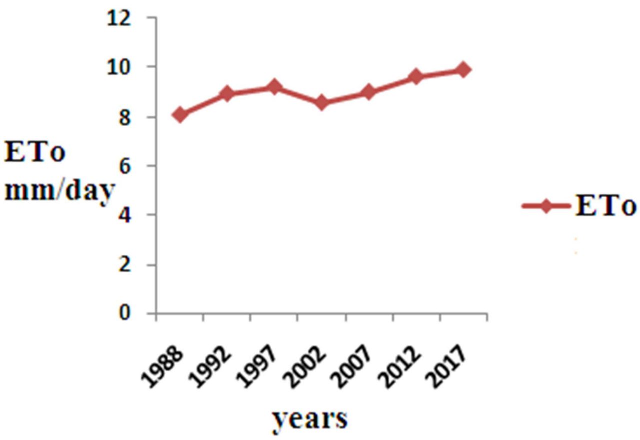

Figure 1. Reference evapotranspiration (ETo) values.

3.2. Crop Water Requirements (ETc)

Crop water requirement (ETc) is closely correlated with ETo, and indicates the amount of water that a type of plant needs during its growth season. According to the results presented in Table 2, Table 3, Figures 2 and 3, ETo values for the different years were significantly ($P \leq 0.05$) different and crop water requirements followed the same trend of ETo. The crop water requirement (ETc) for both Alfalfa and Sorghum demonstrated that the highest need of water occurred in 2017 while the lowest requirement was recorded in 1988, and considerable differences in ETc values between the other years. The change of meteorological parameters will cause a change in ETo, therefore, the crop water requirement will be changed [13].

Table 2. Evapotranspiration (ETo), crop water requirement (ETc), effective rain and crop irrigation recuirement (CIR) for October months of selected years (Alfalfa)

Year	October			
	ETo mm/day	ETc mm/month	Effective Rain mm	CIR mm/month
1988	6.25^{d}	173.4	3.5	171.5^{c}
1992	8.33^{b}	231.2	0	231.2^{b}
1997	7.73^{c}	214.5	34	180.5^{c}
2002	8.32^{b}	231	3.4	227.6^{b}
2007	9.74^{a}	270.3	5.6	264.7^{a}
2012	8.20^{b}	227.5	7.7	219.8^{b}
2017	10.25^{a}	284.5	0	284.5^{a}
LSD	0.53			22.1

Means followed by the same letter(s) in the same column are not significantly difference at $P \leq 0.05$.

3.3. Effective Rain in October Month of Selected Years for Alfala

Effective precipitation refers to portion of rainfall that can effectively be used by plants. As shown in Table 2, the effective rain values in October months for the experiment years were little in the years 1988, 2002, 2007 and 2012, and it was zero in 1992 and 2017, the highest value occurred in 1997. The influence of effective rain on crop irrigation requirements was slight becauze October represents the end period of the rainy season. The rainy season in north Sudan onsets in June and extends to July, August and September, ending eventually in October [12].

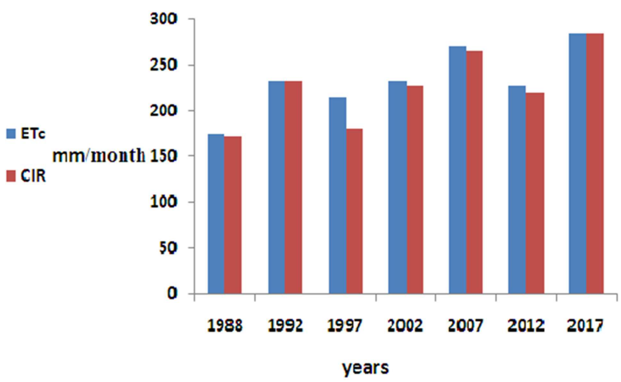

Figure 2. Crop water requirements (ETc) and irrigationrequirements for Alfalfa.

3.4. Crop Irrigation Riquirements (CIR) for Alfafa

Crop irrigation requirement (CIR) is the quantity of additional water needed by crops via irrigation, beyond precipitation, to satisfy the crop's growing period water requirements and guarantee their yield. As presented in Table 2 and Figure 2, CIR was found to be significantly ($P \leq 0.05$) different in the different selected years. The results demonstrated that the highest need of water occurred in 2017 and the lawest demand for irrigation water in 1988. There wasa considerable increase in water requirement in the first two years 1988 and 1992. Water requirement in 1997 decreased due to the amount of effictive rain and CIR started to increase gradualy in 2002 and 2007, in 2012 decreased again. The highest demand of water occurred in 2017. These variations in crop irrigation requirementdue to the change of climatic factors. The requirement for irrigation water would be affected by the variation of meteorological effects under the conditions of climate change [6].

Table 3. Crop water requirements (ETc mm/period) for sorghum (Abu-Sabeen) at selected years

Year	ETc (mm/period)
1988	493.5^{c}
1992	597.44^{a}
1997	575.2^{b}

Year	ETc (mm/period)
2002	516.7[c]
2007	606[a]
2012	606.2[a]
2017	621.16[a]
LSD	23.3

Means followed by the same letter(s) in the same column are not significantly different at $P \leq 0.05$.

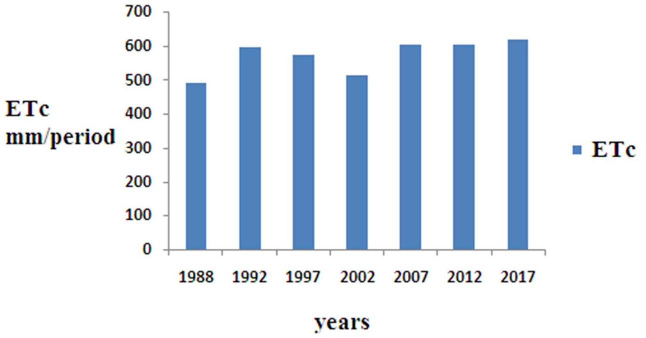

Figure 3. Crop water requirements (ETc mm/period) for Sorghum (Abu-Sabeen).

3.5. Quantity of Crop Water Requirements m^3/ha

According to the results presented in Table 4, ETc (m^3/ha) increased by 64% for Alfalfa of the second cutting (1734 m^3/ha in 1988 and 2845 m^3/ha in 2017), 26% for Abu-Sabeen (4935 m^3/ha in 1988 and 6212 m^3/ha in 2017), the difference in amounts of water needed by Alfalfa and Sorghum (Abu-Sabeen) in years 1988 and 2017 were 1111 and 1277 m^3/ha respectively, this huge variance of crop water use was due to variations of climate factors in these years. It is clear that crop water requirements in future will increase, the reason for this may be due to increase in Maximum and Minimum temperatures and decrease in relative humidity [9].

Table 4. Quantity of crop water requirements (m^3/ha) for selected years

Year	ETc m^3/ha	
	Alfalfa	Sorghum (Abu-Sabeen)
1988	1734	4935
1992	2312	5974
1997	2145	5752
2002	2310	5167
2007	2703	6060
2012	2275	6062
2017	2845	6212

4. Conclusions

Evapotranspiration (ETo) values in this study were found to be significantly different for the different selected years. The results of crop water requirements (ETc) for Alfalfa and Sorghum (Abu-Sabeen) showed marked variations, the highest values occurred in 2017 while the minimum requirements in 1988. Increase in crop water requirement due to rise in temperature, rise in wind speed and decrease in relative humidity which signifies the impact of climate change on crop water requirement.

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