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Water requirement and water productivity for sorghum crop in rainfed areas of Sennar State, Sudan

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ABSTRACT

Sorghum is one of the main crops grown under rainfed conditions in Sennar state, Sudan. However, both within the same season and between the seasons the rainfall amount is quite irregular. It is important to understand how rainfall amount and its distribution during the growing season affect water requirements and grain yield of sorghum in order to improve selection and management of cultural practices. The objective of this study was to determine the water requirement and water productivity of sorghum crop in the areas of Sennar State under three farming systems. A field experiment was conducted in two agroecological zones in Sennar State during two consecutive seasons 2014/2015 and 2015/2016. The first location was a semi-arid zone (Sennar research station farm). The second location was a semi-humid zone (Abu Naama research station farm). The experiment consisted of conventional farming system (CF), conservation agriculture (CA) and water harvesting system (WH). The sorghum variety *Arfa Gadamac*-8 was sown. The collected data included rainfall and weather data in addition to sorghum grain yield. The CROPWAT 8.0 computer software program was used to compute the crop water requirement (ET_c). Reference evapotranspiration (ET_0) and crop coefficient (K_c) were also calculated. The average values of ET_0 during the growing season ranged between 3.29 and 4.4 mm/day in semi-arid zone and between 3.75 and 3.95 mm/day in semi-humid zone, for the seasons 2014/2015 and 2015/2016, respectively. The results showed that the overall average values of K_c during the initial, development, mid-season stage and late-season stage were 0.30, 0.63, 0.91 and 0.64, respectively. The results revealed that the average water requirements for sorghum crop was 2663 and 2390 m^3/ha in semi-arid and semi-humid zones, respectively. The overall average values of water productivity for sorghum crop in semi-arid zone was 0.79 kg/m^3 and it was 0.96 kg/m^3 in semi-humid zone. Conservation agriculture and water harvesting were the best cropping systems compared to the conventional farming for sorghum production in rainfed areas of Sennar State. Investigation on water requirement and water productivity of other sorghum varieties in rainfed is needed.

KEYWORDS:

INTRODUCTION

Throughout Sudan, sorghum is the major cereal crop and considered as main pillar of food security in the country providing about 60% of the quantity of the cereal consumed (Karim, 2002). It is grown in vast areas under rainfed conditions by using conventional systems. Rainfall is a limiting factor for sorghum grain yield. In the rainfed areas of Sudan, the grain yield of sorghum is low and fluctuates from season to season in accordance with the amount and distribution of seasonal rainfall. Geneif (2005) stated that one of the main reasons for lower yield is the low level of technology and its application.

The scarcity of water resources is one of the main challenges in the world, and considered as a limiting factor for economic development especially for agriculture. The demand for water resources is increasing with time for both agriculture and non-agricultural purposes. Wood *et al.,* (2000) mentioned that about 95% of world agricultural land and 83% of world cropland depends on rainfall as the sole source of water.

Crop water requirement (CWR) or crop evapotranspiration (ET_C) is the quantity of water utilized by a crop for obtaining maximum yield in a particular area. Allen *et al*. (1998) and Hess (2005) defined CWR as the total water needed to compensate the evapotranspiration from planting to maturity for a given crop in a specific climatic zone. We believe that determination of crop water requirement is not only necessary for water resources management and planning in irrigated sector; but also for selecting and managing crops in rainfed sector.

The total water requirement for sorghum crop during the growing season may vary considerably as it depends on many factors such as crop variety and days to maturity. It also, varies depending on weather conditions, soil moisture and rainfall received during the growing period. Moreover, crop management practices and the use of external inputs affect the water requirement of sorghum crop. For the same sorghum variety, water requirements varies according to the different growth stages. Many researchers elsewhere, reported different values of water amount required by sorghum crop. Doorenboss and Pruitt (1986) mentioned that the water requirements for sorghum are between 450 and 650 mm. Adam (2005) reported it ranged between 300 and 350 mm and Ibrahim *et al.,* (2005) estimated it as 470 and 560 mm.

Increasing the productivity of water in agriculture plays a vital role in easing competition for scarce water resources, prevention of environmental degradation and provision of food security (Molden *et al.,* 2003; Schultz *et al.,* 2009). Increasing water productivity could be achieved through implementation of suitable management practices such as selection of suitable variety, optimum-sowing date and other management practices. This needs knowledge about the water requirements in each growth stage of the crop. Therefore, determination of water requirement and water productivity for rainfed sorghum is necessary to select the suitable management practices.

Rainfed agriculture in Sennar State extends through two agroecological zones, semi-arid and semi-humid zones. Sorghum production in these areas constitutes a major portion of the cultivated land. Although farmers have long experiences in practicing sorghum production under rainfed conditions, the yield is lower than the potential. For example, the average yield of sorghum under research conditions was 1249 kg/ha (Ibrahim *et al.*, 2015) compared to 432 kg/ha under conventional farming system (CF). This yield gab could be attributed to the use of poor agricultural practices. However, farmers could adopt improved agricultural practices such as conservation agriculture (CA) and water harvesting techniques (WH) that suit the environmental condition in each agroecological zone.

The objective of this study was to determine the water requirement and water productivity for the sorghum crop in two agroecological zones of Sennar State under three farming systems.

MATERIALS AND METHODS

Experimental sites

The research work was carried out in rainfed areas of Sennar State, where rainfall is the main source of water for irrigating crops. The State encompasses two agroecological zones; the semi-arid zone in the northern part and semi-humid zone in the southern part (Adam, 2005). The soil is heavy clay with high crack density (Vertisols) with low nitrogen and organic carbon content. The annual rainfall is about 250 to 400 mm and 500 to 700 mm, in these zones, respectively. Rainfall varied in amount and distribution from season to another and within the same season. There is a single rainy season and the effective rainfall occurs in summer during July and October.

A field experiment was conducted in two locations in Sennar State during two consecutive seasons 2014/2015 and 2015/2016. The first location was Sennar research station farm (SRSF), which lies in the northern part of the State at the latitude 13^{o} 33´ N and the longitude 33^{o} 36´ E, representing the semi-arid zone. The second location was Abu Naama research station farm (ANRSF), which lies in the southern part of the State at latitude 12^{o} 44´ N and longitude 34^{o} 7´ E, representing semi- humid zone.

The experiment layout and data collection:

The experiment compromised three farming systems, which were conventional farming system (CF), conservation agriculture (CA) and water harvesting system (WH). In all sites and seasons, the sorghum variety *Arfa Gadamac*-8 was sown at the same seed rate. In seasons 2014/2015, the experiment was sown on 16^{th} of July for both sites; and in season 2015/2016, the experiment was sown on 5^{th} of August in Abu-Naama and on 12^{th} of August in Sennar. All of the experimental plots were kept weed free during the growing period.

Daily rainfall data throughout the growing seasons were collected from rain gauges erected at the experimental sites. Moreover, these data were arranged in 10-days periods and compared with the calculated crop water requirement. On the other hand, data on sorghum grain yield were taken from the tested cropping systems and used to compute the water productivity.

Calculation of crop water requirement (CWR)

The water requirement for sorghum crop was determined by using CROPWAT 8.0 for windows, a software computer program developed by Allen *et al.,* (1998) to determine reference evapotranspiration (ET_0). The crop water requirement for sorghum crop was determined in the two sites for the two seasons. The input data used to run the software program included weather data, soil physical properties and crop characteristics. The weather data used to determine ET_0 were maximum and minimum temperature, relative humidity, wind speed, sunshine hours and rainfall were shown in Tables 1 and 2. These data were established from Sennar and Abu Naama Metrological Stations during the period from first of May to the end of November for 2014/2015 and 2015/2016 seasons. The ET_0 was calculated on a decade base during the growing season.

Computation of crop coefficient (K_c)

The standard values of crop coefficient (K_c) for growth stages of sorghum were taken from FAO irrigation and drainage paper No. 56. The values of K_c were 0.3, 1.0 and 0.55 for early, mid and late season, respectively.

However, the software adjusted these K_c values to local conditions according to the equation described by Allen *et al*. (1998) as shown in equation 1.

$$K_{ci} = K_{c\,prev} + \left[\frac{i-\sum(L_{prev}}{L_{stage}}\right](K_{c\,next} - K_{c\,prev}) \quad \ldots\ldots (1)$$

Where:

i = day number within the growing season

K_{ci} = crop coefficient for day i.

L_{stage} = length of the stage under consideration (day)

$\sum(L_{prev})$ = sum of the lengths of all previous stages (day)

The total growing period for sorghum variety *Arfa Gadamac-8* was 100 days from sowing to maturity. This period was divided into four growing stages; initial, development, mid-season and late-season stages. The length of these stages was 20, 25, 30 and 25 days, respectively.

The crop water requirement

The crop water requirement was calculated according to the procedure described by Allen *et al*. (1998) as follows:

$$ET_C = ET_0 \text{ X } K_C \quad \ldots\ldots (2)$$

Where:

ET_c = Crop evapotranspiration (mm/day).

ET_0 = Reference evapotranspiration (mm/day)

K_c = Crop coefficient (dimensionless).

The crop water requirement for sorghum crop was calculated on decade base throughout the growing period and summed up to the end of the season. The growing period was 10 and 9 decades for the first and the second seasons, respectively. As the second season has lower rainfall, the crop completed its life cycle in 9 decades. Moreover, rainfall data (rainfall amount and rainy days), were compared to the crop water requirement for each decade during the growing seasons.

Water productivity (WP)

The water productivity (WP) was calculated by dividing the sorghum grain yield (kg/ha) of each cropping system by the total crop water requirement for sorghum (m^3). Equation 3 describes the calculation procedure for the WP (Loomis, 1983). The sorghum grain yield was obtained from each cropping system.

$$WP = \frac{yield\ (\frac{kg}{m2})}{water\ used(\frac{m3}{m2})}\left(\frac{kg}{m3}\right) \quad \ldots\ldots (3)$$

RESULTS AND DISCUSSION

Table 3 summarizes the computed reference evapotranspiration (ET_0) in millimeter per decade according to local conditions in Sennar and Abu Naama research stations in both seasons. The average ET_0 during the growing season was ranged between 3.92 and 4.4 mm/day in Sennar and between 3.75 and 3.95 mm/day in Abu Naama for the seasons 2014/2015 and 2015/2016, respectively. In both sites, the highest average values of ET_0 coincided with the year of lower rainfall. The results showed that the value of the ET_0 for the third decade of August in the two sites and both seasons was the highest among the values of ET_0 in other decades during

the growing seasons. These higher values of ET_0 may be due to higher values of relative humidity (R H %) during August for all sites and in both seasons (Tables 1 and 2). Allen *et al*. (1998) mentioned that weather parameters affecting evapotranspiration are radiation, air temperature, humidity and wind speed.

The crop coefficient (K_c) was calculated on decade base from sowing date to maturity for both sites and for the two seasons (Table 4). The values of K_c increased steadily with advancement of crop age until it reached its peak value at the mid stage and then started to decline. Mohammed *et al.,* (2016) found similar trend of K_C values during the growing stages of maize crop. The computed values of crop coefficient (K_c) for rainfed sorghum in Sennar areas (Sennar and Abu Naama sites) during the initial stage was 0.30. In the development stage, the K_c increased from 0.36 to 0.89. The maximum value of K_c during mid stage was between 0.87 and 0.94 and it declined gradually from 0.78 to 0.49 in the late-season stage. The results revealed that the overall average values of K_c during the initial, development, mid-season stage and late-season stage were (0.3, 0.3), (0.64, 0.61), (0.92, 0.90) and 0.64, 0.63 for semi-arid and semi-humid zones, respectively. The calculated K_c values for the sorghum crop in this study were low compared to that obtained in Ethiopia by Shenkut *et al.*, (2013), especially during development, mid-season, and late-season stages. They found that the K_c values for sorghum crop were 0.45, 0.83, 1.18 and 0.78 during the initial, development, mid-season, and late-season stages, respectively.

Tables 5 and 6 show the water requirement for sorghum crop during the two growing seasons on decade base in Sennar and Abu Naama, respectively. The results showed that for both seasons and the two sites, the crop water requirement increased form early stage of crop growth up to the mid stage and then decreased at late stage. Several studies showed similar trend of water requirements during the different growing stages of other crops (Alla Jabow *et al*., 2013; Mohamed *et al.,* 2016; Mohammed *et al.*, 2016). The total water requirement in semi-arid zone was 261.7 mm in the first season and 270.9 mm in the second season. The average values of water requirements during the initial, development, mid-season and late-season stages, were 24.1, 57.8, 125.0 and 59.5 mm, respectively. These values of water requirements for these stages represented 9%, 21.6%, 47% and 22.4%, respectively from the total water requirements. On the other hand, the total water requirement in semi-humid zone was 237.4 mm in the first season and 240.6 mm in the second season. The average values of water requirements during the initial, development, mid-season and late-season stages, were 21.1, 50.6, 108.3 and 59.1 mm, respectively. These values of water requirements for these stages represented 8.8%, 21.1%, 45.3% and 24.7%, respectively from the total water requirements. The obtained values of water requirement were lower compared to that mentioned by Shenkut *et al.,* (2013) in Ethiopia. They found that the values of water requirements for sorghum crop were 53.8, 138.5, 214.4, and 94.0 mm during the initial, development, mid-season and late-season stages, respectively, and the seasonal total value was 500.7 mm. The results revealed that the average water requirements for sorghum crop was 2663 m^3/ha in semi-arid zone and it was 2390 m^3/ha in semi-humid zone. This indicated that Northern areas of Sennar State requires more water that Southern areas. The variation in total water requirement for sorghum between sites and seasons may be due to the differences in locations and variations in climate conditions as well as the variations in sowing date in both seasons. Many studies showed that crop water requirement for the same crop varied from season to another (Alla Jabow *et al.*, 2013; Mohamed *et al.,* 2016; Mohammed *et al.*, 2016).

Moreover, Tables 5 and 6 compare the water requirements with the received amount of rain water during the crop growth period. The results showed that the received rainwater during the early stages of crop growth in both locations was higher than the water required by the crop. While during the late critical stages of the

crop growth, the received rainwater was less than the required water in both seasons. The rain distribution during the growing season may affect crop performance and final yield. Manyathi (2014) mentioned that water stress during reproductive and yield formation stages results in yield losses and poor seed quality. Therefore, planting dates of sorghum should be adjusted so that growth stages with high water demand can occur in months with higher rainfall also other management practices such the use of water-harvesting techniques should be considered (Assefa *et al.,* 2010). In both experimental sites, the total rainfall received during the first growing season was greater than that received in the second season. In Sennar research station the total rainfall was 371.2 mm and 261.4 mm occurred in 30 days and 18 days for the first and the second seasons respectively. In Abu Naama research station, the total rainfall was 507 mm and 307 mm occurred in 30 days and 21 days for the first and the second seasons respectively. Although, Sennar research station had lower rainfall compared to Abu Naama research station, but it had better rain distribution. In both research sites, the season of lower rainfall coincided with higher water requirements. However, the success in production systems in rainfed areas is not only due to the total amount of rainfall, but rather the spatial and temporal distribution as well as the occurrence of dry spells (Feitosa *et al.,* 2017).

Figures 1 and 2 compare the average water productivity (kg/m^3) of sorghum crop under three cropping systems of two seasons for the in Sennar and Abu Naama research sites respectively. The overall average water productivity of sorghum crop in rainfed areas of Sennar and Abu Naama research stations were 0.79 kg/m^3 and 0.96 kg/m^3, respectively. The experimental site of higher rainfall (Abu Naama) transcended the water productivity of the experimental site of lower rainfall (Sennar) by about 22%. Different sources reported similar ranges of water productivity values for sorghum 0.60 to 1.00 kg/m^3 by FAO, (1979); 0.70 kg/m^3 by Wahaj *et al.,* (2007); 0.56 and 1.43 kg/m^3 by Singh *et al.,* (2010) and 0.207 and 0.885 kg/m^3 by Feitosa *et al.,* (2017).

Improving water productivity is a key factor for the success of agricultural production in the arid and semi-arid regions (Xiao *et al.,* 2016). The results of water productivity for the three cropping systems showed some variations. Irrespective of the experimental site, the conservation agriculture (CA) obtained the highest water productivity followed by water harvesting (WH) and the least water productivity was obtained by the conventional farming system (CF) (Fig. 1 and 2). This result indicates the superiority of conservation agriculture and water harvesting over the conventional farming for sorghum production in rainfed areas of Sennar State.

CONCLUSION

Based on the obtained results of water requirement and water productivity for sorghum crop in two agroecological zones of Sennar state during two seasons, the flowing conclusion could be obtained:

1. The average water requirements for sorghum crop in semi-arid zone was higher ($2663 m^3/ha$) compared to that in semi-humid zone ($2390 m^3/ha$). The zone of higher rainfall consumed lower water amount.
2. The water requirements of sorghum crop increased from the initial stage to development stage, and reach its maximum value in mid-season stage and declined again in late-season stage. The respective values of these stages were 24.1, 57.8, 125.0 and 59.5 mm; and 21.1, 50.6, 108.3 and 59.1 mm, semi-arid zone and semi-humid zone, respectively.

3. The over average values of water productivity for sorghum crop was 0.79 kg/m^3 in semi-arid zone and 0.96 kg/m^3 in semi-humid zone. The water productivity of sorghum in semi-humid zone is better than that of semi-arid zone.
4. Conservation agriculture and water harvesting were the best compared to the conventional farming for sorghum production in rainfed areas of Sennar State.
5. Investigation on water requirement and water productivity of other sorghum varieties in rainfed is needed.

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Table 1. Monthly climatic data for Sennar research station during seasons 2014/2015 and 2015/2016

	Max temperature. ° C	Min temperature. ° C	R. H. (%)	W.S. (km/day)	Sunshine (hrs)
	Season 2014				
May	40.5	25.3	47	7	9.5
June	39.6	25.1	60	9	9
July	35.1	23.5	80	6	7
August	32.2	22.1	86	4	7.5
September	33.9	22.4	81	4	8.5
October	36.6	22.4	67	4	9.2
November	36.4	17.5	42	4	10
	Season 2015				
May	41.4	27.3	45	9	9.5
June	39	24.9	62	10	9
July	38.7	24.7	63	11	7
August	35.1	22.6	78	8	7.5
September	36.1	23.1	76	6	8.5
October	38	23.5	61	5	9.2
November	36.8	18.2	40	5	10

Source: Sennar Metrological Station Office

Table 2. Monthly climatic data for Abu-Naama research station during seasons 2014/2015 and 2015/2016

	Max temperature ° C	Min temperature ° C	R. H. (%)	W.S. (km/day)	Sunshine (hrs)
	Season 2014				
May	43.8	39.9	51	4	7.7
June	42.5	38.0	34	5	6
July	39.8	33.7	78	5	5
August	35.4	31.8	84	3	5.2
September	31.3	21.8	80	2	6.4
October	35.0	21.1	71	2	7.8
November	0	0	0	3	9.9
	Season 2015				
May	40.0	26.3	47	6	7.5
June	38.6	24.4	57	5	6.8
July	37.4	23.2	64	4	6.1
August	33.4	21.8	80	3	5.8
September	34.2	22.1	79	3	5.8
October	0	0	0	2	8.3
November	0	0	0	4	22.1

Source: Abu-Naama Metrological Station Office

Tale 3. The calculated ET_0 for sorghum (mm/decade) in Sennar and Abu Naama research stations for seasons 2014/2015 and 2015/2016

Month-decade	Sennar research station		Abu Naama research station	
	Season 2014	Season 2015	Season 2014	Season 2015
Jul-II	22.0	-	17.7	-
Jul-III	48.3	-	48.7	-
Aug-I	43.1	-	43.6	35.3
Aug-II	43.7	40.3	43.7	38.7
Aug-III	48.5	49.7	46.4	42.0
Sep-I	44.5	45.8	40.7	38.0
Sep-II	44.8	46.3	39.2	37.2
Sep-III	43.5	45.2	39.5	38.6
Oct-I	41.5	44.6	39.3	40.2
Oct-II	11.8	44.2	15.7	41.3
Oct-III	-	45.2	-	45.4
Nov-I	-	34.9	-	-
Average	32.9	44.0	37.5	39.6

Table 4. The calculated K_c for sorghum in Sennar and Abu Naama Research Stations on decade base for two seasons 2014/2015 and 2015/2016

	Sennar Research Station		Abu Naama Research Station	
Month-decade	Seasons 2014	Seasons 2015	Seasons 2014	Seasons 2015
Jul-II	0.30	-	-	-
Jul-III	0.30	-	0.30	-
Aug-I	0.39	-	0.30	0.30
Aug-II	0.76	0.30	0.36	0.30
Aug-III	0.91	0.30	0.70	0.51
Sep-I	0.91	0.53	0.87	0.88
Sep-II	0.91	0.89	0.87	0.93
Sep-III	0.78	0.94	0.87	0.93
Oct-I	0.61	0.94	0.76	0.90
Oct-II	0.50	0.91	0.60	0.75
Oct-III	-	0.75	0.49	0.57
Nov-I	-	0.57	-	-
Average	0.64	0.68	0.61	0.67

Table 5. Water requirement for sorghum crop at Sennar research station during seasons 2014/2015 and 2015/2016

Month-decade	Rain (mm)	Rain days	ET_c (mm)	Rain (mm)	Rain days	ET_c (mm)
	Season 2014			Season 2015		
Jul-II	9.9	4	6.6	-	-	-
Jul-III	113.0	6	14.5	-	-	-
Aug-I	6.3	3	16.8	-	-	-
Aug-II	85.5	4	33.2	134.5	5	12.1
Aug-III	81.7	6	44.1	42.1	6	14.9
Sep-I	41.4	3	40.5	19.9	3	24.3
Sep-II	33.4	4	40.8	61.9	3	41.2
Sep-III	-	-	33.9	3.0	1	42.5
Oct-I	-	-	25.3	-	-	41.9
Oct-II	-	-	5.9	-	-	40.2
Oct-III	-	-	-	-	-	33.9
Nov-I	-	-	-	-	-	19.9
Total CWR	371.2	30	261.6	261.4	18	270.9

Table 6. Water requirement for sorghum crop at Abu Naama research station during seasons 2014/2015 and 2015/2016

Month-decade	Season 2014			Season 2015		
	Rain (mm/decade)	Rainy days	ET_c (mm/decade)	Rain (mm/decade)	Rainy days	ET_c (mm/decade)
Jul-II	24.2	3	5.3	-	-	-
Jul-III	98.8	7	14.6	-	-	-
Aug-I	58.6	2	15.7	105.5	7	10.6
Aug-II	71.7	4	30.6	119.4	3	11.6
Aug-III	175.9	5	40.4	38.8	4	21.4
Sep-I	38.9	3	35.4	25.2	3	33.4
Sep-II	13.4	2	34.1	17.0	3	34.6
Sep-III	15.0	1	30	1.6	1	35.9
Oct-I	4.8	1	23.6	-	-	36.2
Oct-II	5.5	2	7.7	-	-	31
Oct-III	-	-	-	-	-	25.9
Total CWR	506.8	30	237.4	307.5	21	240.6

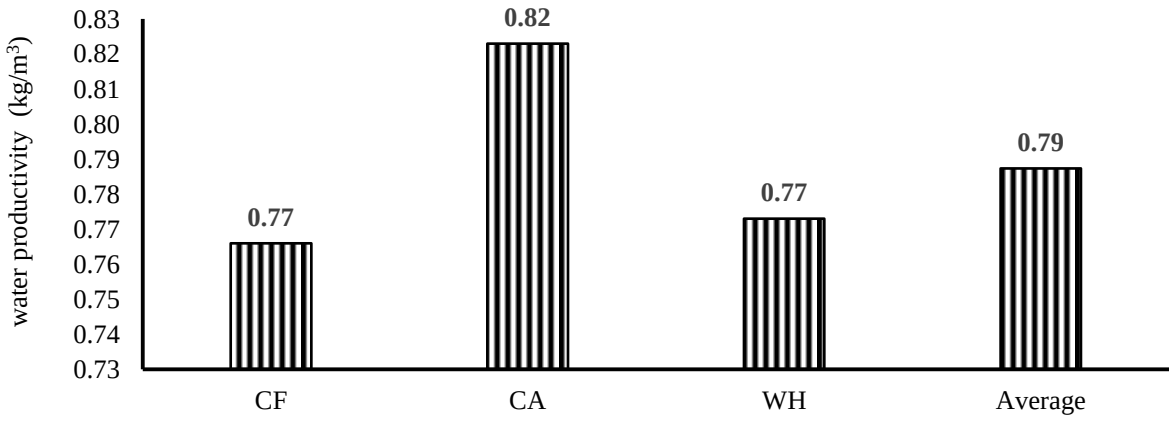

Fig. 1. Water productivity of sorghum crop under different farming systems at Sennar site, during the two seasons (2014/2015 and 2015/2016).

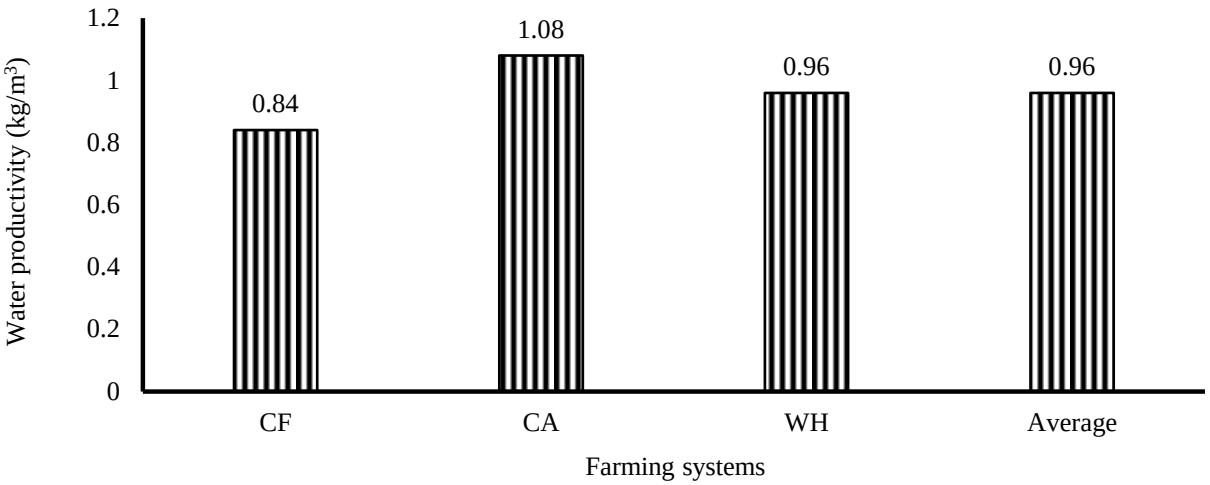

Fig. 2. Water productivity of sorghum crop under different farming systems at Abu Naama site, during the two seasons (2014/2015 and 2015/2016).