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Estimation of Water Requirement and Water Productivity of Sesame Crop (*Sesamum indicum* L.*)* in Dryland Areas of Sennar State, Sudan

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Abstract: Sesame is one of the main oil crops grown under dryland areas in Sennar state, Sudan. However, rainfall is quite irregular within the season and between the seasons. Understanding the effect of rainfall variability on water requirement and yield of sesame is essential to help in selecting optimum management practices for crop production. The objective of this study was to determine the water requirement and water productivity of sesame crop grown under two agro-ecological zones and three farming systems. An experiment was conducted in two agro-ecological zones in Sennar State (semi-arid zone and semi-humid zone) during seasons 2014/2015 and 2015/2016.The tested cropping systems were conventional farming (CF), conservation agriculture (CA) and water harvesting techniques (WH). The collected data included weather data and sesame yield data. The results showed that the average values of reference evapotranspiration (ET_O) during the two seasons ranged from 3.29 to 4.4 mm/day in semi-arid site and from 3.75 to 3.95 mm/day in semi-humid site. Regardless of agro-ecological site and season, the average values of crop factor (K_c) during the initial, development, mid-season and late-season stages were 0.30, 0.75, 0.98 and 0.51, respectively. The average values of water requirement for sesame during initial, development, mid-season and late-season stages were 24.1, 87.8, 132.1 and 36.3 mm; and 20.1, 78.2, 114.5 and 37.9 mm, in semi-arid and semi-humid sites, respectively. The average water requirement was 2802 and

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2516 m^3/ha in semi-arid and semi-humid sites, respectively. The overall average values of water productivity for sesame crop in semi-arid site was 0.18 kg/m^3 and it was 0.29 kg/m^3 in semi-humid site. Water harvesting and conservation agriculture systems gave higher performance compared with the conventional farming system for sesame production in dryland areas of Sennar state.

Key words: Reference evapotranspiration (ET_O), crop factor (K_c), semi-arid, semi-humid, water productivity, sesame.

INTRODUCTION

The scarcity of water resources and rainfall variability are of the main challenges in the world, and considered as limiting factors 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 depend on rainfall as the sole source of water.

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. 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. Doorenbos and Pruitt (1977), Allen *et al*. (1998) and Hess (2005) defined CWR as the total water needed to compensate the evapotranspiration, from planting to harvest for a given crop in a specific climatic site.

Water productivity refers to the amount of crop produced per unit of water expressed in kg/m^3. Molden *et al.* (2007) defined crop water productivity (CWP) as amount or the value of product over volume of water depleted or diverted. 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).

There are several practices for enhancement of CWP through the integration of resource management at plant level, field level and agro-

climatic level (Kijne *et al.* 2003), which include implementation of suitable management practices such as selection of suitable variety, optimum sowing date and other management practices. This needs knowledge about the water requirement in each growth stage of the crop. However, there is insufficient information about water requirement and water productivity for sesame crop in rainfed areas.

Sesame world production areas have remained generally stable over the years, but in some countries the crop is being marginalized (Bennet, 2011). Sesame is found growing in most tropical, subtropical and southern temperate areas of the world (Gandhi, 2009).

Sesame plays an essential role in Sudan's economy with regard to both local consumption and export. Sesame seeds are used for oil extraction and for food and feed (El Khier *et al.*, 2008). After the extraction of oil, the cake is used for livestock feed. Sesame in the Sudan is basically grown under rainfed conditions by both mechanized and the traditional farming systems. Sesame has relatively short harvest cycle of 90 to100 days and needs long periods of sunshine. However, good sesame yield can be expected when rainfall of 300-600 mm is optimally distributed throughout the vegetative growth. During each of its growth stages, the plant is highly susceptible to water-logging, and can therefore only thrive during moderate rainfall (Naturland, 2002). The water requirement can be met from available soil moisture at sowing and rainfall during the growing season (Hansen, 2011). Due to its tap root, the plant is highly resistant to drought and can provide good harvest even when only stored soil water is available.

Dryland agriculture in Sennar State extends through two agro-ecological zones, semi-arid and semi-humid zones. Sesame is one of the main oil crops produced in these areas. Although farmers have long experience in practicing sesame production, but its yield is lower than the potential. The low level of technology and its application are the main reasons for the lower yield (Geneif, 2005).

The objective of this study was to determine the water requirement and water productivity of sesame crop in two agro-ecological zones, using three farming systems in Sennar State, Sudan under rainfed farming.

MATERIALS AND METHODS

Experimental sites

The experiment was carried out in rainfed areas of Sennar State. The State encompasses two agro-ecological zones; the semi-arid site in the northern part and semi-humid site in the southern part (Adam, 2005). The soil is heavy clay with high crack density (Vertisols) and with low nitrogen and organic carbon content. The annual rainfall is about 250 to 400 mm and 500 to 700 mm, in these sites, respectively. There is inter-annual and intra-annual rainfall variability in the area. There is a single rainy season and the effective rainfall occurs in summer between July and October.

A field experiment was conducted in two sites in Sennar State during two consecutive seasons 2014/2015 and 2015/2016. The first site was Sennar Research Station Farm, which lies in the northern part of the State at latitude 13° $33'$ N and longitude 33° $36'$ E, representing the semi-arid site. The second site was Abu Naama Research Station Farm, which lies in the southern part of the State at latitude 12° $44'$ N and longitude 34° $7'$ E, representing the semi-humid site.

Data collection and analysis:

Three farming systems, which were conventional farming system (CF), conservation agriculture (CA) and water harvesting system (WH) were used in this study. In the two sites and seasons, the sesame variety Promo was sown at a seed rate of 4.76 kg/ha. In seasons 2014/2015, the experiment was started on the 16^{th} of July for both sites; and in season 2015/2016, the experiment was started on the 5^{th} of August in Abu-Naama and on the 12^{th} of August in Sennar. The experimental plots were kept weed free during the growing period.

Daily rainfall data throughout the growing seasons were collected from rain gauges located at the experimental sites. Moreover, the data was arranged in 10-days interval. On the other hand, data on sesame yield was taken from the tested cropping systems and used to compute the water productivity.

Crop water requirement (CWR)

The CWR for sesame crop was determined by using CROPWAT 8.0 for windows, a software computer program developed by Allen *et al.* (1998) to determined reference evapotranspiration (ET_0). The CWR for sesame 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_O were maximum and minimum temperature, relative humidity, wind speed, sunshine hours and rainfall. The weather data were obtained from Sennar and Abu Naama Meteorological Stations during the period from first of May to the end of November for 2014/2015 and 2015/2016 seasons. The ET_O was calculated in decadal base during the growing season.

Computation of crop coefficient (K_c)

The standard values of crop coefficient (K_c) for growth stages of sesame were taken from FAO paper No. 56. The values of K_c were 0.35, 1.1 and 0.25 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.

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

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 sesame cultivar Promo was100 days from sowing to harvest. This period was divided into four growing stages; initial, development, mid-season and late-season stages, the length of theses 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) by using equation 2:

$ET_C = ET_o \text{ X } K_C$……..…….
(2)

Where:

ET_c = Crop evapotranspiration (mm/day).

ET_o = Reference evapotranspiration (mm/day)

K_c = Crop coefficient (dimensionless).

The crop water requirement for sesame crop was calculated on decadal base throughout the growing season and summed up at the end of the season. The growing season was 10 and 9 decades for the first and the second seasons, respectively. As the second season had lower rainfall, the crop completed the growing season in 9 decades. Moreover, rainfall data (rainfall amount (mm) 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 sesame grain yield (kg/ha) of the cropping system by the total crop water requirement for sesame (m^3). Equation 3 describes the calculation procedure for the WP (Loomis, 1983). The sesame grain yield was obtained from each cropping system.

$$WP = \frac{yield\ (\frac{kg}{m2})}{water\ used(\frac{m3}{m2})}(\frac{kg}{m3}) \text{…….. ……. (3)}$$

RESULTS AND DISCUSSION

Table 1. summarizes the computed reference evapotranspiration (ET_O) in millimeter per 10 days according to local conditions in Sennar and Abu Naama Research Stations in both seasons. The average ET_O during the growing season ranged between 3.92 and 4.41 mm/day in Sennar Research Station and between 3.75 and 3.97 mm/day in Abu Naama Research Station, for the seasons 2014/2015 and 2015/2016, respectively. In both sites, the highest average values of ET_O coincided with the year of lower rainfall. The results showed that the value of the ET_O for the third decade of August in the Sennar site during both seasons was the highest among the values of ET_O in other decades during the growing seasons. These higher values of ET_O may have been due to higher values of relative humidity (86 – 81%) during August for the two sites and seasons.

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 decadal base from sowing to harvest for both sites and the two seasons as shown in Table 2. The values of K_c increased steadily with advancement of crop stage until it reached its peak value at the mid stage and then, started to decline. The computed values of crop coefficient (K_c) of sesame in Sennar and Abu Naama sites during the initial stage were 0.30, increased from 0.37 to 0.99 in the development stage. The maximum value of K_c during mid-stage was between 1.02 and 1.03 and declined gradually from 0.73 to 0.33 in the late-season stage. The results revealed that the average values of K_c during the initial, development, mid-season stage and late-season stage were 0.30, 0.77, and 0.99, and0.50 for semi-arid and 0.3, 0.73, 0.97, and 0.51for semi-humid sites, respectively. The calculated average values of K_C for the sesame crop were comparable to those obtained by Allen *et al.* (1998) who found that the K_C values for sesame crop were 0.35, 1.10 and 0.25 during the initial, mid-season, and end-season stages, respectively.

Table 1. The calculated ET_O for sesame (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 2014/2015	Season 2015/2016	Season 2014/2015	Season 2015/2016
Jul-II	22.0	-	17.7	-
Jul-III	48.3	-	48.7	-
Aug-I	43.8	-	43.8	35.3
Aug-II	43.3	40.3	43.8	38.7
Aug-III	48.4	49.7	46.7	42.4
Sep-I	44.5	45.8	41.0	37.7
Sep-II	45.1	46.3	39.4	37.5
Sep-III	43.6	45.6	39.5	38.9
Oct-I	41.3	44.9	39.2	40.2
Oct-II	11.8	44.1	15.6	41.4
Oct-III	-	45.3	-	45.3
Nov-I	-	34.8	-	-
Average	39.2	44.1	37.5	39.7

Tables3 and 4 illustrate that the CWR for the two sites and seasons increased form early crop stage up to the mid stage and then decreased at late stage. Several studies showed similar trend of CWR 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 site was 276.1 mm in the first season and 284.3 mm in the second season. The average values of CWR during the initial, development, mid-season and late-season stages, were 24.1, 87.8, 132.1 and 36.3 mm, respectively. These values of water requirements for these stages represented 8.6%, 31.3%, 47.1% and 13.0%, respectively of the total water requirements for sesame crop during the growing season. On the other hand, the total water requirement in semi-humid site was 252.6 mm in the first season and 250.6 mm in the second season.

Table 2. The calculated K_c for sesame in Sennar and Abu Naama Research Stations on decadal base for two consecutive seasons (2014/2015 and 2015/2016)

Month-decade	**Sennar Research Station**		**Abu Naama Research Station**	
	Seasons 2014/2015	Seasons 2015/2016	Seasons 2014/2015	Seasons 2015/2016
Jul-II	0.30	-	0.30	-
Jul-III	0.30	-	0.30	-
Aug-I	0.40	-	0.37	0.30
Aug-II	0.85	0.30	0.78	0.30
Aug-III	1.02	0.30	0.98	0.54
Sep-I	1.02	0.57	0.98	0.99
Sep-II	1.01	0.99	0.98	1.03
Sep-III	0.80	1.04	0.80	1.03
Oct-I	0.52	1.04	0.53	0.99
Oct-II	0.33	1.00	0.34	0.73
Oct-III	-	0.72	-	0.43
Nov-I	-	0.42	-	-
Average	0.66	0.71	0.64	0.70

In the semi-humid site, the average values of water requirements during the initial, development, mid-season and late-season stages, were 21.0, 78.2, 114.5 and 37.9 mm, respectively. These values of water

requirements for these stages represented 8.3%, 31.1%, 45.5% and 15.1%, respectively of the total water requirement. The average water requirement for sesame crop was 2802m^3/ha in the semi-arid site and it was 2516 m^3/ha in the semi-humid site. This indicated that the Northern areas of Sennar State require more water than the Southern areas. The variation in total water requirement for sesame between sites and seasons may be due to variations in climate conditions as well as the variations in sowing date in both seasons. Many studies showed that CWR for the same crop varied from season to another (Alla Jabow *et al*, 2013; Mohamed *et al.,* 2016; Mohammed *et al.,* 2016).

Tables 3 and 4 compare the water requirements with the received amount of rainwater 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. However, 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 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 sesame should be adjusted so that growth stages with high water demand can occur in months with higher rainfall also; other management practices such as 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 site, the total rainfall was 371.2 mm and 261.4 mm and it occurred in 30 days and 18 days for the first and the second seasons, respectively. In Abu Naama site, the total rainfall was 507 mm and 307 mm and it 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 sites, the season of lower rainfall coincided with higher water requirement. However, the success of 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 (of two seasons) water productivity (kg/m^3) of sesame for the three farming systems in Sennar and Abu Naama Research sites, respectively. The overall average water productivity of sesame crop in Sennar and Abu Naama Research Stations were 0.18 kg/m^3 and 0.29 kg/m^3, respectively.

Table 3. Crop Water requirement for sesame crop at Sennar site for two seasons

Month-decade	Rain (mm)	Rainy days	ETc (mm)	Rain (mm)	Rainy days	ETc (mm)
	Season 2014/2015			Season 2015/2016		
Jul-II	9.9	4	6.6	-	-	-
Jul-III	113.0	6	14.5	-	-	-
Aug-I	6.3	3	17.5	-	-	-
Aug-II	85.5	4	36.8	134.5	5	12.1
Aug-III	81.7	6	49.4	42.1	6	14.9
Sep-I	41.4	3	45.4	19.9	3	26.1
Sep-II	33.4	4	45.6	61.9	3	45.8
Sep-III	-	-	34.9	3.0	1	47.4
Oct-I	-	-	21.5	-	-	46.7
Oct-II	-	-	3.9	-	-	44.1
Oct-III	-	-	-	-	-	32.6
Nov-I	-	-	-	-	-	14.6
Total CWR	371.2	30	276.1	261.4	18	284.3

Water Productivity and Farming systems

The semi-humid site with higher rainfall (Abu Naama) exceeded the water productivity of the semi-arid site with lower rainfall (Sennar) by about 61%. Singh, *et al.* (2010) reported that the water productivity for sesamewas0.36 kg/m^3.

The results of water productivity for the three cropping systems showed some variations. Irrespective of the experimental site, the water harvesting (WH) gave the highest water productivity followed by conservation agriculture (CA) and the least water productivity was given by the conventional farming system (CF) (Figs. 1 and 2). This result

indicated the superiority of water harvesting and conservation agriculture over the conventional farming for sesame production in rainfed areas of Sennar State.

Table 4. Crop Water requirement for sesame crop at Abu-Naama site for two seasons

Month-decade	Rain (mm)	Rainy days	ETc (mm)	Rain (mm)	Rainy days	ETc (mm)
	Season 2014/2015			Season 2015/2016		
Jul-II	24.2	3	5.3	-	-	-
Jul-III	98.8	7	14.6	-	-	-
Aug-I	58.6	2	16.2	105.5	7	10.6
Aug-II	71.7	4	34.2	119.4	3	11.6
Aug-III	175.9	5	45.8	38.8	4	22.9
Sep-I	38.9	3	40.2	25.2	3	37.3
Sep-II	13.4	2	38.6	17.0	3	38.6
Sep-III	15.0	1	31.6	1.6	1	40.1
Oct-I	4.8	1	20.8	-	-	39.8
Oct-II	5.5	2	5.3	-	-	30.2
Oct-III	18.7	1	-	-	-	19.5
Total CWR	506.8	30	252.6	307.5	21	250.6

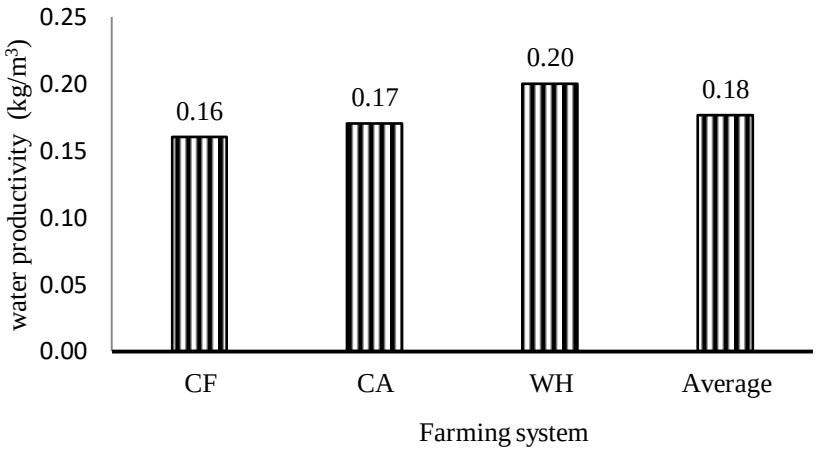

Fig. 1. Water productivity of sesame crop under different farming systems at Sennar site, for two seasons (2014/2015 and 2015/2016)

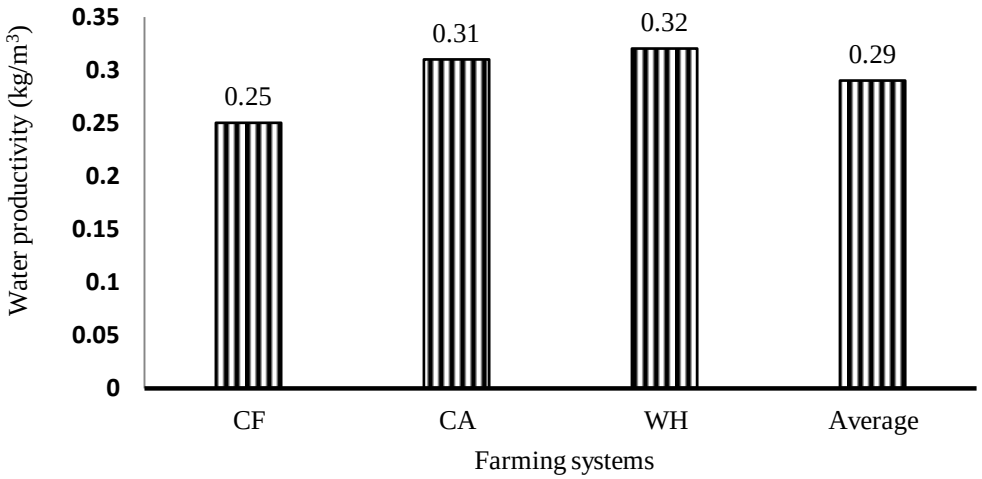

Fig.2. Water productivity of sesame crop under different farming systems at Abu Naama site, for two seasons (2014/2015 and 2015/2016)

CONCLUSIONS

1. The average water requirement for sesame crop in semi-arid site was higher (2802 m^3/ha) compared to that in semi-humid site (2516 m^3/ha).Sesame crop in the site of higher rainfall consumed lower water amount.
2. The overall average value of water productivity for sesame crop was 0.18 kg/m^3in semi-arid site and 0.29 kg/m^3in semi-humid site. The water productivity of sesame in semi-humid site was better than that of semi-arid site.
3. Water harvesting technique improved the water productivity of production in rainfed areas of Sennar State compared to the conservation agriculture and the conventional farming system.

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تقدير الاحتياج المائي وإنتاجية المياه لمحصول السمسم (*Sesamum indicum* L.) في الأراضي الجافة لولاية سنار، السودان

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مستخلص البحث: السمسم أحد محاصيل الحبوب الزيتية الرئيسية التي تزرع في المناطق المطرية في ولاية سنار، السودان. الأمطار في ولاية سنار متذبذبة خلال الموسم الواحد وبين المواسم. فهم تأثير كمية وتوزيع الأمطار خلال موسم النمو على الاحتياج المائي وإنتاجية المياه لمحصول السمسم ضروري وذلك للمساعدة في إختيار العمليات الفلاحية المناسبة لإنتاج المحصول. الهدف من هذه الدراسة هو تقديرالاحتياج المائي وإنتاجية المياه لمحصول السمسم في بئتين مختلفتين في ولاية سنار تحت ثلاثة نظم زراعية. نفذت تجربة حقلية في موقعين مختلفين في ولاية سنار (المنطقة شبه الجافة والمنطقة شبه الرطبة) خلال موسمي2015/2014 و 2016/2015.النظم الزراعية المختبرة في هذه التجربة هي نظام الزراعة التقليدية (CF)، ونظام الزراعة الحافظة (CA) ونظام حصاد المياه (WH). شملت البيانات التي تم جمعها الأمطار والبيانات المناخية بالإضافة إلى إنتاجية محصول السمسم. أوضحت النتائج أن القيم المتوسطة للبخرنتح المرجعي (ET_O) خلال الموسمين تراوحت بين 3.29 و 4.4 مم/اليوم في المناطق شبه الجافة وبين 3.75 و3.95 مم/اليوم في المنطقة شبه الرطبة. بغض النظر عن الموقع والموسم كانت متوسط قيم معامل المحصول (K_c) خلال المرحلة الأولية، والنمو، ومنتصف الموسم، ومرحلة ونهاية الموسم كانت 0.30 ، 0.75 ، 0.98 و0.51 على التوالي. كان متوسط قيم الإحياج المائي خلال المرحلة الأولية، والنمو، ومنتصف الموسم، والمرحلة والنهاية لنموء المحصول هي 24.1 ، 87.8، 132.1 و 36.3مم وكانت 20.1، 78.2، 114.5 و 37.9 مم في المناطق شبه الجافة وشبه الرطبة على التوالي. متوسط الاحتياج المائي لمحصول السمسم بلغ 2802 و 2516 متر^3/ هكتار في المناطق شبه الجافة وشبه الرطبة على التوالي. كانت القيم المتوسطة لإنتاجية المياه لمحصول السمسم في المنطقة شبه الجافة 0.18 كجم/متر^{3}وكانت 0.29 كجم/مت^3 في المنطقة شبه الرطبة. إن نظامي حصاد المياه والزراعة الحافظة كانت الأفضل مقارنة بالزراعة التقليدية لإنتاج محصول السمسم في المناطق الجافة لولاية سنار.

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