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Water Requirement and Water Productivity of Cowpea (*Vigna unguiculata* [L.] Walp.) Crop in Two Agro-ecological Zones of Sennar State, Sudan

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Abstract: A field experiment was conducted in two agro-ecological zones in Sennar State, Sudan during seasons2014/2015 and 2015/2016to estimate crop water requirement and water productivity of cowpea (*Vigna unguiculata L. Walp*) under three farming systems (conventional farming (CF), conservation agriculture (CA) and Water Harvesting (WH).The agro-ecological zones were semi-arid zone (Sennar Research Station Farm) and semi-humid zone (Abu Naama Research Station Farm). The Weather and crop data were collected during the study period. CROPWAT 8.0software was used to compute reference evapotranspiration (ET_O), crop factor (K_c) and the crop water requirement (ET_C). The analysis showed that the average values of ET_O rangedbetween1.2 and5.0 mm/day in semi-arid zone, and between1.56and4.86 mm/day in the semi-humid zone. The average K_c values during the initial, development, mid-season and late-season stages were 0.45, 0.79, 1.08and 0.84, respectively, while the average values of cowpea water requirements during initial, development, mid-season and late-season stages were 37.4, 71.3, 149.5 and 77.0 mm for the semi-arid zone and 34.1, 65.8, 130.6 and 77.3 mm for the semi-humid zone. The

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average water requirement was 3350 m^3/ha and 3050 m^3/ha in the semi-arid and semi-humid zones, respectively. The water productivity for cowpea crop in the semi-arid zone was 0.33 kg/m^3 and 0.35 kg/m^3 in semi-humid zone. The WH and CA farming system gave better results compared to the CF for cowpea production in dryland areas of Sennar state.
Key words: Reference evapotranspiration (ET_O), crop factor (K_c), semi-arid zone, semi-humid zone, cowpea crop

INTRODUCTION

Cowpea (*Vigna unguiculata* [L.] Walp) is a vital crop for millions of poorer people. It is a food and feed crop grown in the semi-arid tropics covering Africa, Asia, Europe, United States and Central and South America (IITA, 2009; Bittenbender *et al.,* 1984; Islam *et al.,* 2006). Moreover, cowpea hay has additional economic value as it is used as fodder especially during the dry season (Singh *et al.,* 2003). It is estimated that the annual world cowpea crop is grown on 12.5 million ha, and the total grain production is 3 million tons. Cowpea is drought-tolerant crop; it can grow under annual rainfall ranging from 400 to 700 mm, well distributed rainfall is important for normal growth and development of cowpea. However, in areas where the frequency of rain is unreliable, moisture conservation remains vitally important for crop production. Cowpea reacts to serious moisture deficit by limiting growth (especially leaf growth) and reducing leaf area by changing leaf orientation and closing the stomata. Smallholder farmers in sub-Saharan Africa produce cowpea under rainfed conditions (Wright *et al.,* 2008) because of its low water requirement and fast-growing with high forage quality (Rao and Shahid, 2011). Cowpea can be grown under dry condition; however, irrigation highly promotes its vegetative growth and results in late maturity of seeds (Peksen, 2007).

The crop growth habit cover the soil surface thus reduces competition with weeds and soil surface evaporation, allowing the crop to save water and have greater growth and yield (Payne, 2000). Some studies showed that the characteristics of the tested cowpea varieties were of medium maturing (75 to 80 days) and high grain yield about 500 to 2000 kg/ha, (Kamara *et al.,* 2007; Ajeigbe *et al.,* 2008). It is an alternative crop to

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more viable and competitive agriculture, with less risk of losses, especially for farmers with low income and small crop areas. Cowpea can be intercropped with other crops such as maize (Dahmardeh *et al.,* 2009), sorghum (Ahmad *et al.,* 2007), millet (Pimentel, 2006; Sprent, 2010) and guar (Rao and Shahid, 2011). In the rainfed areas of the Sudan, cowpea found special research focuses (Dawoud, *et al.,* 2007; Hassan and Elasha, 2008).

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 reference 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 evapotranspiration from planting to harvest for a given crop in a specific climatic zone.

Crop water productivity (CWP) is defined as amount or the value of product over volume of water depleted or diverted (Kijne *et al.,* 2003; Molden *et al.,* 2007). It is usually expressed in amount of crop produced per unit of water (Kg/m^3). Increasing the productivity of water in agriculture plays a vital role in easing competition for scarce water resources, prevention of environmental degradation and achieving of food security (Molden *et al.,* 2003; Schultz *et al.,* 2009).Kijne *et al.* (2003) suggested several strategies for enhancement of agricultural CWP by integrating varietal improvement and better resource management at plant level, field level and agro-climatic level. Increasing CWP 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 requirement in each growth stage of the crop. However, there is insufficient information about water requirement and water productivity of cowpea crop in rainfed areas of Sudan. Rainfed agriculture in Sennar State, Sudan extends through two agro-ecological zones, semi-arid and semi-humid zones. Cowpea is one of the crops produced in these areas.

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

MATERIALS AND METHODS

Study sites

The research work was carried out in the rainfed areas of Sennar State, where rainfall is the main source of watering crops. The State encompasses two agro-ecological 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 in the semi-arid zone and 500 to 700 mm, in the semi-humid zone. Rainfall varies 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 from July to 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, which lies in the northern part of the State altitude 13° 33′ N and longitude 33° 36′ E, representing the semi-arid zone. The second location 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 semi- humid zone.

Data collection and analysis

Three farming systems; conventional farming system (CF), conservation agriculture (CA) and water harvesting system (WH); were used in this study. The cowpea crop was sown at a seed rate of 19.04 kg/ha in the two sites. In seasons 2014/2015, the experiment started on the 16th of July for both sites; and in season 2015/2016, the experiment started on the 5th of August in Abu-Naama and on 12th 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 were arranged in 10-days interval. On the other hand, cowpea yield data were

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taken from the tested farming systems and used to compute water productivity.

Crop water requirement (CWR)

The water requirement for cowpea crop was determined by using CROPWAT 8.0 program (Allen *et al.*, 1998) for the two sites. The input data used to run the 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 which obtained 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_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 cowpea were taken from FAO paper No. 56. The values of K_c were 0.40, 1.05 and 0.35 for early, mid and late seasons, respectively. However, the CROPWAT 8.0 software adjusted these K_c values to local conditions according to the equation described by (Allen *et al.* 1998) as follows:

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

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 cowpea was 90 to 100 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.

Crop water requirement

The crop water requirement was calculated according to the procedure described by Allen *et al.* (1998) using equation 2 as follows:

$ET_C = ET_o \times K_C$………………………………………..…………………. (2)

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Where:
ET_c = Crop evapotranspiration (mm/day).
ET_o = Reference evapotranspiration (mm/day)
K_c = Crop coefficient (dimensionless).

The crop water requirement for cowpea was calculated on decadal 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 cycle 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

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

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

RESULT AND DISCUSSION

The computed reference evapotranspiration (ET_O) according to the local conditions in Sennar and Abu Naama Research Stations in both seasons is shown in Table 1. The average ET_O during the growing season ranged between 1.2 and 5.0 mm/day in Sennar Research Station and between 1.56 and 4.86 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 sites during both seasons was the highest among the values of ET_O in other decades during both growing seasons. These higher values of ET_O were due to the higher values of relative humidity (RH %) during August for two sites and seasons. Allen *et al.* (1998) mentioned that weather

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parameters affecting evapotranspiration are radiation, air temperature, humidity and wind speed.

Table 1.The calculated ET_O for cowpea (mm/decade) in Sennar and Abu Naama Research Stations for two 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	-	17.6	-
Jul-III	48.3	-	48.6	-
Aug-I	43.4	-	43.7	35.3
Aug-II	43.7	40.2	44.1	38.8
Aug-III	48.3	50.0	46.7	42.4
Sep-I	44.5	45.4	40.9	37.9
Sep-II	45.1	46.0	39.4	37.4
Sep-III	43.2	45.4	39.3	38.7
Oct-I	41.8	44.8	39.2	40.4
Oct-II	12.1	44.1	15.6	41.9
Oct-III	-	45.7	-	45.6
Nov-I	-	34.8	-	-
Average	39.2	43.7	37.5	39.8

The crop coefficient (K_c) was calculated on decadal base 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. Mohammed *et al.* (2016) found similar trend of K_c values during the growing stages of maize crop under Gezira conditions, Sudan. The values of crop coefficient (K_c) of cowpea in the two sites during the initial stage ranged between 0.40 and 0.53. In the development stage, the K_c increased from 0.50 to 1.05. The maximum value of K_c during mid-stage was between 1.05 and 1.11 and it declined gradually from 1.10 to 0.38 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 0.46 - 0.45, 0.80 – 0.79, 1.10 – 1.07 and 0.80 – 0.89 for semi-arid and semi-humid zones, respectively.

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The calculated average values of K_c for the cowpea crop were higher than that obtained by Allen *et al.* (1998) who found that the K_C values for cowpea crop were 0.40, 1.05 and 0.35 during the initial, mid-season, and end-season stages, respectively.

Table 2.The calculated K_c for cowpea in Sennar and Abu Naama Research Stations on decadal base for two 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	0.40	-	0.50	-
Jul-III	0.40	-	0.50	-
Aug-I	0.50	-	0.63	0.40
Aug-II	0.92	0.50	0.85	0.40
Aug-III	1.09	0.53	1.05	0.63
Sep-I	1.09	0.76	1.07	1.05
Sep-II	1.08	1.00	1.07	1.10
Sep-III	0.87	1.11	1.07	1.10
Oct-I	0.57	1.11	1.06	1.05
Oct-II	0.38	1.11	1.06	0.78
Oct-III	-	1.10	-	0.48
Nov-I	-	1.08	-	-
Average	0.73	0.92	0.89	0.78

Tables 3 and 4 illustrate the water requirement for cowpea crop during the two growing seasons on decadal base in Sennar and Abu Naama sites, respectively. The results showed that, for the two sites and seasons, the crop water requirement increased from early stage 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 for cowpea crop in semi-arid zone was305.9 mm in the first season and364.1 mm in the second season. The overall average values of water requirements during the initial, development, mid-season and late-season stages, weres37.4,71.3, 149.5and 77.0 mm,

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respectively. These values of water requirements for these stages represented 11.1%, 21.3%, 44.6% and 23.0%, respectively of the total water requirements. On the other hand, the total water requirement in semi-humid zone was 333.2 mm in the first season and 276.8 mm in the second season. In the semi-humid zone, the average values of water requirements during the initial, development, mid-season and late-season stages, were 31.4, 65.8, 130.6 and 77.3 mm, respectively. These values of water requirements for these stages represented 10.3%, 21.6%, 42.8% and 25.3%, respectively of the total water requirements. The average water requirement for cowpea crop was 3350m^3/ha in semi-arid zone and it was 3050 m^3/ha in semi-humid zone. This indicated that semi-arid areas of Sennar State require more water than semi-humid areas. The variation in total water requirement for cowpea crop between sites and seasons may be due to the differences in the 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).

The analysis showed the two sites received rainfall higher than the water required by crop during the early stages of crop growth in both seasons (Tables 3 and 4). However, during the late critical stages of the crop growth, the received rainfall was less than the required water in both seasons. The rain distribution during the growing season affects crop performance and final yield. Manyathi (2014) mentioned that the water stress during reproductive and yield formation stages lead to losses in yield and poor seed quality. Therefore, planting dates of cowpea 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 sites, the total rainfall received during the first growing season was higher than that 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 both 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 both seasons, respectively. Although, Sennar had lower rainfall compared to Abu Naama, it had better rainfall distribution. In the semi-arid zone (Sennar site) the season of lower rainfall coincided with higher water requirement.

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Hence, the success of production systems in rainfed areas is not only due to the total amount of rainfall, but distribution as well (Feitosa *et al.*, 2017).

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

Month-decadal	**Rain (mm)**	**Rainy days**	**ETc (mm)**	**Rain (mm)**	**Rainy days**	**ETc (mm)**
	Season 2014/2015			Season 2015/2016		
Jul-II	9.9	4	8.8	0	0	-
Jul-III	113.0	6	19.3	0	0	-
Aug-I	6.3	3	21.7	0	0	-
Aug-II	85.5	4	40.2	134.5	5	20.1
Aug-III	81.7	6	52.7	42.1	6	26.5
Sep-I	41.4	3	48.5	19.9	3	34.5
Sep-II	33.4	4	48.7	61.9	3	46.1
Sep-III	0	0	37.6	3.0	1	50.4
Oct-I	0	0	23.8	0	0	49.7
Oct-II	0	0	4.6	0	0	48.9
Oct-III	0	0	-	0	0	50.3
Nov-I	0	0	-	0	0	37.6
Total CWR	371.2	30	305.9	261.4	18	364.1

Figures 1 and 2 compare the average (of two seasons) water productivity (kg/m^3) of cowpea for the three farming systems in Sennar and Abu Naama Research sites, respectively. The overall average water productivity of cowpea crop in rainfed areas of Sennar and Abu Naama Research Stations were 0.33 kg/m^3 and 0.35 kg/m^3, respectively. Abu Naama site being of higher rainfall exceeded the water productivity of the Sennar site which characterized by lower rainfall by about 6.1%.

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 farming systems showed some variations. Irrespective of the experimental site, the water harvesting (WH) gave the highest water productivity followed by conservation

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agriculture (CA) and the least water productivity was given from the conventional farming system (CF) (Figs. 1 and 2).

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

Month-decadal	Rain (mm)	Rainy days	ETc (mm)	Rain (mm)	Rainy days	ETc (mm)
	Season 2014/2015			Season 2015/2016		
Jul-II	24.2	3	8.8	0	0	-
Jul-III	98.8	7	24.3	0	0	-
Aug-I	58.6	2	27.5	105.5	7	14.1
Aug-II	71.7	4	37.5	119.4	3	15.5
Aug-III	175.9	5	49.0	38.8	4	26.7
Sep-I	38.9	3	43.8	25.2	3	39.8
Sep-II	13.4	2	42.2	17.0	3	41.1
Sep-III	15.0	1	42.0	1.6	1	42.6
Oct-I	4.8	1	41.6	0	0	42.4
Oct-II	5.5	2	16.5	0	0	32.7
Oct-III	18.7	1	-	0	0	21.9
Total CWR	506.8	30	333.2	307.5	21	276.8

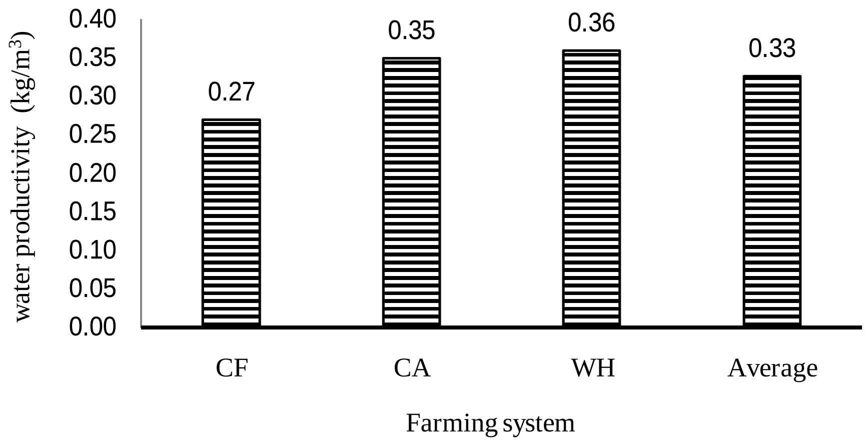

Fig. 1. Water productivity of cowpea crop under different farming systems at Sennar site for seasons 2014/2015 and 2015/2016

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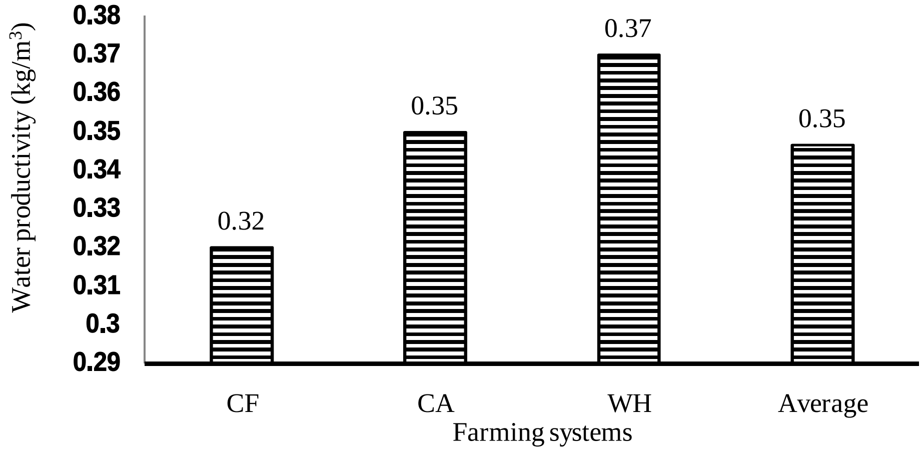

Fig.2. Water productivity of cowpea crop under different farming systems at Abu Naama site for seasons 2014/2015 and 2015/2016

CONCLUSIONS

1. The average water requirements of cowpea crop in the semi-arid zone and in the semi-humid zone were3350 m^3/ha and 3050 m^3/ha, respectively. Cowpea crop in the zone of higher rainfall demands lower water amount.
2. The water requirements of cowpea crop in the initial, development, mid-season and late-season stages were 37.4, 71.3, 149.5 and 77.0 mm; and34.1, 65.8, 130.6 and 77.3 mm, for semi-arid zone and semi-humid zone, respectively.
3. The overall average values of water productivity for cowpea crop were 0.33 kg/m^3in semi-arid zone and 0.35 kg/m^3in semi-humid zone. The water productivity of cowpea in semi-humid zone was better than that of semi-arid zone.
4. Both water harvesting techniques and conservation agriculture farming system performed better than the conventional farming for cowpea production in the rainfed areas of Sennar State.

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الاحتياج المائي وإنتاجية المياه لمحصول اللوبيا (*Vigna unguiculata* [L.] Walp.) في بيئتين زراعيتين في ولاية سنار، السودان

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مستخلص البحث: نفذت تجربة حقلية في بيئتين زراعيتين في ولاية سنار، السودان خلال موسمي 2015/2014 و 2016/2015، لتقديرالاحتياج المائي وإنتاجية المياه لمحصول اللوبيا (*Vigna unguiculata L. Walp*) تحت ثلاثة نظم زراعية، هي نظام الزراعة التقليدية (CF) ، ونظام الزراعة الحافظة (CA) ونظام حصاد المياه (WH) .البيئات الزراعية هي المنطقة شبه الجافة (مزرعة محطة بحوث سنار) والمنطقة شبه الرطبة (مزرعة محطة بحوث أبو نعامة).تم جمع البيانات المناخية بالإضافة إلى إنتاجية المحصول خلال فترة الدراسة. استخدم برنامج CROPWAT 8.0 لحساب كل من البخرنتح (ET_o)، معامل المحصول (K_c) والاحتياج المائي للمحصول (ET_c).أوضح الحليل أن القيم المتوسطة للبخرنتح المرجعي (ET_O) خلال الموسمين تراوحت بين 1.2 و 5.0 مم/اليوم في المناطق شبه الجافة وبين 1.56 و4.86 مم/اليوم في المنطقة شبه الرطبة. القيم المتوسطة لمعامل المحصول (K_c) خلال المرحلة الأولية، والنموء، ومنتصف الموسم، ونهاية الموسم كانت 0.45 ، 0.79 ، 1.08 و0.84 على التوالي. كان متوسط قيم الإحياجات المائية خلال المرحلة الأولية، والنموء، ومنتصف الموسم، ونهاية الموسم هي 37.4 ، 71.3، 149.5 و 77.0مم وكانت 34.1، 65.8، 130.6 و 77.3 مم في المناطق شبه الجافة وشبه الرطبة على التوالي. بلغ متوسط الاحتياج المائي لمحصول اللوبيا3350 و 3050 متر^3/ هكتار في المناطق شبه الجافة وشبه الرطبة على التوالي. كانت القيم المتوسطة لإنتاجية المياه لمحصول اللوبيا في المنطقة شبه الجافة 0.33 كجم/متر^3 و0.35 كجم/متر^3 في المنطقة شبه الرطبة. إن نظامي حصاد المياه والزراعة الحافظة أعطيتا أفضل النتائج مقارنة بالزراعة التقليدية لإنتاج محصول اللوبيا في المناطق المطرية لولاية سنار.

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