Journal of Agricultural Extension and Rural Development Vol. 2(4), pp. 59-63, May 2010
Available online http:// academicjournals.org/jaerd
ISSN-2141-2170 © 2010 Academic Journals

Full Length Research Paper

Effect of irrigation on consumptive use, water use efficiency and crop coefficient of sesame (*Sesamum indicum L.*)

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Accepted 5 March, 2010

Sesame was grown for two successive seasons (2001/2002 - 2002/2003) at Shambat, Sudan. The aim of the study was to investigate five irrigation water quantities on actual evapotranspiration as compared with estimated evapotranspiration using Penman-Monteith method, modified Penman formula and pan evaporation. Water use efficiency and crop factors were calculated and the best water use efficiency was obtained under irrigation water 650 mm. Under all irrigation treatments, there was a large deviation of pan evaporation, modified Penman and Penman-monteith estimate from actually measured evapotranspiration. Crop coefficients were decreased with decreased water quantities in all treatments. Crop coefficients computed by pan evaporation were under all circumstances, lower than these obtained by modified Penman and Penman- Monteiths methods.

Key words: Water quantities, consumptive use, water use efficiency, crop coefficient, sesame.

INTRODUCTION

Sesame is probably one of the most ancient oilseed crop known and used by man (Weis, 1983). Sesame is grown as a rain fed crop in Sudan. The total area of production varies from one year to another, mainly due to fluctuation of rainfall (Khidir, 1997). About 77% of the cultivated area lies in the three states, North Kordofan state, Blue Nile state and Gedarif state. The total cultivated area of sesame in Sudan is about 1.5 million ha (FAO, 2000).

Literature on the influence of soil moisture on the growth of sesame seem to be ambiguous, it is agreed that water logging is harmful. Sesame is very sensitive to excess moisture (Van Rheenen, 1973, Khidir, 1997). Hence, lack of proper drainage system caused major reduction in sesame yield in areas where rain water stands for long periods of time (Osman, 1985). The crop grown generally in areas that are too dry to ground nuts with a rainfall ranging 300 - 600 mm.

Excellent crops are produced with 500 mm (Weiss, 1971). Meager research has been carried out on sesame water requirements under Sudan condition.

The main objectives of this study were to determine the crop coefficients (factor) of sesame by relating the actual evapotranspiraiton, measured in the field, estimation of evaporation from pan, modified Penman and Penman-Monteith formula, as well as studying the water use efficiency of sesame crop under Shambat conditions.

MATERIALS AND METHODS

The experiment was conducted in a clay soil, with 48 - 54% clay at the Demonstration Farm of the Faculty of Agriculture, Shambat, Sudan (Latitude 15° 40' N and longitude 32° 32' E) during the 2001/2002 and 2002/2003 seasons. The area of the experiment is classified as a semi-arid region, changing gradually to an arid area.

The experiment plots were 4 x 4 m. The four borders of each plot were raised to about 60 cm above soil surface. The layout of the experiment was split plot design with four replicates. The main plots were assigned for water quantities and the subplot for the varieties. The water quantities treatments consisted of five levels (750, 650, 550, 450 and 350 mm) designated as Q_1, Q_2, Q_3, Q_4 and Q_5, respectively. Two varieties of sesame, Khidir and Promo were used, (V_1 and V_2). The crop was sown at spacing of 15 cm apart on ridges of 70 cm spacing on 2nd of July 2001 and 2002. Manual weeding was carried out three times during each growing season. Watering was controlled by an electric pump of a calibrated discharge. The

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Table 1. Number of irrigations, amount of water per irrigation and total water applied for each treatment during the season.

Per-experimental period	Amount/ Irrigation (mm)	Treatment	Number of irrigations	Amount/ irrigation (mm)	Total amount of water applied during the season (mm)
1st irrigation	70	Q_1	5	95	750
2nd irrigation	70	Q_2	5	75	650
3rd irrigation	70	Q_3	5	55	550
4th irrigation	65	Q_4	5	35	450
Total	275	Q_5	5	15	350

Table 2. Average soil moisture content (% w/w) for the different treatments at different soil depths during 2001/2002 and 2002/2003 seasons

Treatments	2001/2002			2002/2003		
	Soil depth (cm)			Soil depth (cm)		
	20	40	60	20	40	60
Q_1 V_1	20.2	25.0	21.61	19.40	23.20	20.20
V_2	20.3	24.13	22.60	19.91	22.66	21.70
Q_2 V_1	18.9	22.05	19.14	18.41	21.25	19.80
V_2	19.1	24.11	20.0	19.23	22.00	20.00
Q_3 V_1	16.4	20.01	21.11	17.10	20.10	21.14
V_2	17.1	20.30	25.51	17.72	20.40	21.23
Q_4 V_1	15.5	18.30	17.33	16.51	18.73	18.94
V_2	15.4	19.02	17.40	16.90	19.91	18.47
Q_5 V_1	14.1	18.80	16.54	15.40	18.02	17.89
V_2	14.3	18.71	16.35	15.62	18.07	17.00

N.B: One sample was taken from each experimental unit just before irrigation. Therefore, the number of samples corresponded to the number of irrigations applied during the experimental period.

irrigation system used was designed by El Nadi (1969). Five irrigations with amount of 95, 75, 55, 35, 15 mm per irrigation were applied at ten days intervals for treatments Q_1, Q_2, Q_3, Q_4 and Q_5, respectively. In addition four irrigations (275 mm) were equally applied to all experimental units for establishment of plants till they were 30 days old. Table 1 shows the number of irrigations, amount of water per irrigation and total water applied during the season.

Soil moisture was determined a day before each irrigation for the depth 20, 40 and 60 cm on weight basis, and then was converted to volumetric water content by multiplication with the soil bulk density, using the following formula:

$$S = [(M2 - M_1)/ 100] \times G \times D$$

S = soil moisture storage.
M_1 = initial moisture content.
M_2 = final moisture content (after irrigation).
G = bulk density.
D = soil depth (cm).

The relative turgidity of leaves was determined (at morning) before each watering using the techniques developed by Weatherly (1950).

The actual crop evapotranspiration was calculated using the water balance equation:

$$ET_c = P - (o + d + s)$$

ET_c = Evapotranspiration (mm).
P = irrigation and /or precipitation (mm).
O = Surface run off (mm).
D = deep drainage (mm).
S = change in soil water storage (mm).

Both surface run off and deep drainage were neglected because the area was flat and the heavy clay soils restrict the movement of the water to deeper layers. Hence the change in soil water storage between two successive samples was taken as the amount of water used by the crop during that period. The estimated evapotranspiration (ET) was calculated using the Penman - Moneith method (Allen et al., 1998) and modified Penman formula (Doorenbos and Pruit, 1977). Pan (class A) evaporation data were obtained from Shambat Meteorological Station, 250 meters away from the experiments. Crop coefficients (factors) were calculated as a ratio of the actual ET_c to pan evaporation, Penman and Penman-Monteith estimate.

The water use efficiency was calculated as kg of seed yield Produced Per cubic meters of water consumed.

RESULTS AND DISCUSSION

Soil water content

Table 2 shows the soil water content. The soil moisture content decreased with 20 and 60 cm depth under Q_1, Q_2, Q_4 and Q_5. However, Q_3 showed more or less consistent

Table 3. The effect of water quantities and cultivars on the mean relative turgidity of leaves (%).

Treatments	2001/2002			2002/2003		
	V_1	V_2	Mean	V_1	V_2	Mean
Q_1	82.3	81.5	81.9	81.0	79.5	80.3[a]
Q_2	80.0	78.3	79.1[b]	69.0	69.5	69.3[b]
Q_3	72.0	70.8	71.4[c]	67.0	67.5	67.3[c]
Q_4	60.8	60.3	60.5[d]	60.0	60.0	60.0[d]
Q_5	51.8	50.5	51.1[e]	47.8	48.8	48.3[e]
Mean	69.4[a]	68.3[b]		65.0[a]	65.0[a]	
C.V. % a	1.46			1.72		
C.V. % b	0.84			1.46		
SE ± (Q)	0.36			0.37		
SE ± (V)	0.13			0.20		
SE ± (Q × V)	0.29			0.44		

Means in similar letters are not significantly different at the 0.05% level of probability according to DMRT.

Table 4a. Comparison of monthly evapotranspiration (mm) estimated by different methods for sesame during 2001/2002.

Month (2001)	E_o mm/day	ET_o mm/day	ET_o* mm/day	ET_c				
				Q_1 mm/day	Q_2 mm/day	Q_3 mm/day	Q_4 mm/day	Q_5 mm/day
July	9.3	8.9	7.1	7.0	7.0	7.0	7.0	7.0
August	8.6	7.6	6.5	8.1	7.2	5.8	4.5	3.2
September	8.8	7.6	6.4	9.1	7.5	5.5	3.5	1.5
October	10.6	8.4	7.2	7.0	6.1	4.8	3.1	1.4
Mean	9.33	8.13	6.8	7.8	7.0	5.8	4.5	3.3

E_o = Pan evaporation.
ET_o = Modified Penman's estimate.
ET_o*= Penman - Monteith's estimate.
ET_c = Actually measured evapotranspiration.
Q_1, Q_2, Q_3, Q_4 and Q_5 = Water quantities 750, 650, 550, 450 and 350 mm respectively.

soil water content at different depth of sampling. The decreased in soil moisture with 60 cm depth in these soils recorded by Ahmed and El naim (1993). The decrease in soil moisture with 20 cm depth may be due to the fact that most of the actively absorbing roots of sesame were near this layer. This is in tandem with results obtained by Weiss (1983) and Lazim (1973).

The relative turgidity

Highest water quantity treatments maintained a relative high leaf turgidity, which decreased as water quantity was decreased (Table 3). This decrease in relative turgidity is due to decreased photosynthesis as a consequence of stomata closure (Kramer, 1983); this caused reduced translocation and hence reduced turgor pressure.

Actual and estimated evapotranspiration

Only the overall effect of the irrigation treatments will be considered for evaluation of crop coefficients and water use efficiency (WUE). Table 4a,b shows the monthly ET values. It is to be noted that ET_c during the early growth stage (July) were very similar, mainly because all treatments had received the same quantity of irrigation water during these times. The ET_c values reached this maximum during September with Q_1 attaining the height values. This was followed by a gradual decrease of ET_c for all treatments during the maturation period.

Regarding evaporation values those estimated with pan were higher than those with Penman and Penman-Monteith formula between and within the two seasons. There is a significant relation-ship between irrigation water quantity and ETc, increase the amount of irrigation water increased ETc, but at a decreasing rate, as was reported by Stewart et al. (1983) and Ahmed and El Naim (1993).

Crop coefficients (factors)

Tables 5a and b shows the crop coefficients as the ratios of actual ET to estimated ET. It is shown that except

Table 4b. Comparison of monthly evapotranspiration (mm) estimated by different methods for sesame during 2002/2003.

Month (2002)	E_o Mm/day	ET_o Mm/day	ET_o* mm/day	ET_c				
				Q_1 mm/day	Q_2 mm/day	Q_3 mm/day	Q_4 mm/day	Q_5 mm/day
July	10.5	10.8	8.9	7.02	7.02	7.02	7.02	7.02
August	8.7	8.0	6.7	8.4	7.24	5.90	4.51	3.20
September	8.8	7.4	6.0	9.0	7.39	5.45	3.50	1.50
October	11.6	8.7	7.2	7.1	6.14	4.82	3.13	1.4
Mean	9.4	8.7	7.2	7.9	6.95	5.8	4.54	3.28

Eo = pan evaporation.
ETo = Modified Penman's estimate.
ETo*= Penman – Monteith's estimate.
ETc = Actually measured evapotranspiration.
Q1, Q2, Q3, Q4 and Q5 = Water quantities 750, 650, 550, 450 and 350 mm, respectively.

Table 5a. Monthly crop factors (coefficients) calculated for pan evaporation modified Penman and Penman- Monteith formula for sesame.

Month	Q_1			Q_2			Q_3			Q_4			Q_5		
	ETc/ E_o	ETc/ ET_o	ETc/ ET_o*	ETc/ E_o	ETc/ ET_o	ETc/ ET_o*	ETc/ E_o	ETc/ ET_o	Etc/ ET_o*	ETc/ E_o	ETc/ ET_o	ETc/ ET_o*	ETc/ E_o	ETc/ ET_o	ETc/ E_o*
July	0.75	0.79	0.99	0.75	0.79	0.99	0.75	0.79	0.99	0.75	0.79	0.99	0.75	0.79	0.99
August	0.94	1.07	1.25	0.84	0.95	1.11	0.67	0.76	0.89	0.52	0.59	0.69	0.37	0.42	0.48
September	1.03	1.2	1.4	0.85	0.99	1.17	0.63	0.72	0.86	0.40	0.46	0.55	0.17	0.20	0.23
October	0.66	0.83	0.97	0.58	0.73	0.85	0.45	0.57	0.67	0.29	0.40	0.43	0.13	0.17	0.19
Mean	0.85	0.97	1.15	0.76	0.87	1.03	0.63	0.71	0.85	0.49	0.56	0.67	0.36	0.40	0.47

ETc = Actual measured evapotranspiration.
E_o = Pan evaporation .
ET_o = Modified Penman's estimate.
ET_o*= Penman-Monteith estimate.

for July and October the wettest treatment (Q_1) had attained coefficients greater than one, when based on Penman-Monteith and modified Penman formula. Coefficients based on pan evaporation, on other hand, attained values greater than one only during August in first season and during August and September in second season.

There was a tendency of decreasing values of crop coefficients with decreased water quantities treatments and with pan evaporation more than with Penman formula and Penman-Manteith (lesser values) in all treatments.

Water use efficiency

Data presented in Table 6 reveal that Q_2 (650 mm) treatment had the highest water use efficiency (the lowest numerical value). It was observed that the second season (2002/2003) showed higher water use efficiency as a result of relatively higher yields. This is attributed to weather conditions, which slightly varied during the two seasons.

Conclusion

Second water quantity (650 mm) resulted in

Table 5b. Monthly crop factors (coefficient) calculated for pan evaporation Modified Penman and Penman- Monteith formula for sesame.

Month (2002)	Q_1			Q_2			Q_3			Q_4			Q_5		
	ET/E_o	ETc/ET_o	ETc/ET_o^*	ETc/E_o	ETc/ET_o	ETc/ET_o^*	ETc/E_o	ETc/ET_o	ETc/ET_o^*	ETc/E_o	ETc/ET_o	ETc/ET_o^*	Etc/E_o	ETc/ET_o	ETc/ET_o^*
July	0.67	0.65	0.79	0.67	0.65	0.79	0.67	0.65	0.79	0.67	0.65	0.79	0.67	0.65	0.79
August	1.25	1.05	1.25	0.08	0.91	1.08	0.88	0.74	0.88	0.67	0.56	0.67	0.48	0.40	0.48
September	1.02	1.22	1.50	0.84	1.00	1.23	0.26	0.74	0.91	0.40	0.47	0.58	0.17	0.20	0.25
October	0.61	0.82	0.99	0.53	0.71	0.85	0.42	0.55	0.67	0.27	0.36	0.43	0.12	0.16	0.19
Mean	0.89	0.94	1.13	0.78	0.82	0.99	0.65	0.67	0.81	0.50	0.51	0.62	0.36	0.35	0.43

ETc = Actual measured evapotranspiration.
E_o = Pan evaporation.
ET_o = Modified Penman's estimate.
ET_o^*= Penman-Monteith estimate.

Table 6. Water use efficiency of different water quantities treatments during 2001/2002 and 2002/2003 seasons.

Treatments	Total crop water use (M^3/ha)	Total seed yield (kg/ha)		Water use efficiency (M^3/kg)	
		2001/02	2002/03	2001/02	2002/03
Q_1	7500	3450	4188	2.2	1.8
Q_2	6500	3180	3963	2.0	1.6
Q_3	5500	1700	1850	3.2	2.9
Q_4	4500	1060	1113	4.2	4.0
Q_5	3500	890	975	3.9	3.6
SE ±		0.03	0.18	0.1	0.3

increased water use efficiency due to increased seed yield. Modified Penman's and Penman - Monteith estimates showed a greater deviation from actual evapotranspiration under all irrigation treatments, consequently, crop coefficients computed by pan evaporation were, under all circumstances, lower than these obtained by modified Penman and Penman-Monteiths formula.

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