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DETERMINATION OF ACTUAL EVAPOTRANSPIRATION AND CROP COEFFICIENT OF SESAME (*SESAMUM INDICUM* L. CV. RT-127) FROM LYSIMETRIC STUDIES

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ABSTRACT

A field experiment was conducted to quantify the evapotranspiration rate and crop coefficient of sesame grown under weighing lysimeter in the arid region of India. The crop was grown under three irrigation treatments, viz., (a) irrigation (100% PET), (b) irrigation (50% PET) and (c) rainfed (control). Seasonal evapotranspiration was measured 497 mm, 436 mm and 342mm under irrigated (100% PET), irrigated (50% PET) and rainfed conditions, respectively. Crop coefficient was computed at an early growth stage (0.4 to 0.8), during the peak vegetative stage (0.9 to 1.3), during flowering and capsule formation (1.4 to 2.2) and 0.3 to 1.1 during the crop maturity. The water use efficiency was computed 2.15, 2.35 and 2.75 kg $ha^{-1}mm^{-1}$ under rainfed, 50% ET irrigated and 100% ET irrigated, respectively. Crop water use efficiency increased from 0.89 to 2.56 kg $ha^{-1}mm^{-1}$ in 2009 and 2.93 to 3.16 kg $ha^{-1}mm^{-1}$ in 2010 along with increased soil moisture availability under early and normal sown condition, respectively. The study is beneficial to utilize water under sesame crops in arid regions.

KEY WORDS
sesame
Crop evapotranspiration
lysimeter
Crop coefficient and arid region

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INTRODUCTION

Evapotranspiration is the sum of evaporation and plant transpiration. Evaporation is the process whereby liquid water is converted into water vapour from evaporating surface while in transpiration, vaporization of liquid water contained in plant tissues (Bapuji Rao *et al.*, 2013). The climate is one of the most determining factors to loss of quantum of water through evapotranspiration (Praveen Rao and Raikhelkar, 1993). Evapotranspiration can be estimated with one of the various methods such as water balance, pan evaporation and climatic data etc., but needs to determine an accurate crop water requirement in arid regions to proper utilizing precious natural resources (Jajoria *et al.*, 2015 and Deewan *et al.,* 2015). Weighing lysimeter can determine accurate crop ET directly from the mass balance of the water, as contrasted to a non-weighing lysimeter which indirectly estimate ET from the volume balance (Howell *et al.*, 1991 and Grattan, *et al.*, 1998). According to Allen *et al.* (1998) crop coefficient (ratio of crop ET to reference ET) approach is also one of the most known and used to estimate ET. The class-A pan evaporation method reported (Ucan *et al.*, 2007). Sepaskhah and Andam (2001) determined water requirement for sesame under water balance lysimeter in the semi-arid of I. R. Iran. The crop coefficient is required for estimation of crop water requirement (Pradhan and Dotaniya, 2013). Crop coefficients vary with crop type, the growth stage of the crop, weather and irrigation method, and with some cultural practices (Kang *et al.,* 2003; Amrawat *et al.,* 2013 and Yarami *et al.*, 2011).

India is the largest producer of sesame (*Sesamum indicum* L.) in the world, accounting for 24% of world production. The crop is grown in 19.01 lakh ha area in India with total production and average productivity of 8.1 lakh tonnes and 426 kg ha^{-1}, respectively (DAC, 2012). Sesame is very responsive to environmental conditions and abiotic factors such as temperature, relative humidity and soil moisture, all of which can affect its yield and quality (Ucan *et al.*, 2007). Alizadeh (2002) reported that sesame is sensitive to water deficit at seedling, flowering and seed filling stages which lead to yield loss. Mandal and Roy (2012) observed in pulse crops extremely vulnerable to climate factors viz. temperature, humidity, rainfall and photoperiod at flowering stage. Sesame is commonly grown as dryland crop, but it responds significantly to irrigation. This study was planned to quantify accurate water requirement of sesame crop under lysimeter in arid regions to proper utilise and management of limited resources.

MATERIALS AND METHODS

Site characteristics

A field experiment was conducted in the research farm of Central Arid Zone

Research Institute (CAZRI), Jodhpur (26.3ºN, 73.02ºE and 224 m above MSL). The average rainfall of the region is 368 mm, out of which about 90% received during the SW monsoon (*kharif*) between June to September. Soils of the experimental plots were originated from rhyolite and subsequently modified through alluvial and aeolian processes. These soils belong to a part of Thar Desert. Taxonomically, soils may be defined as coarse loamy mixed hyperthermic of camborthids. Soil organic carbon is very low (0.2 %). The surface soil layer is fine sandy texture with 6.55 % clay and 0.52 % silt and subsurface soil layers may be generalized as non-calcareous loamy sand. Soil moisture content at field capacity (-0.3 bar) and at the permanent wilting point (-15 bar) were 9.5 and 3.0 % (w/w), respectively.

Experimental details

The field experiments on sesame (cv. RT 127) were conducted for three consecutive *kharif* season (July to October) of 2009-2011. The crop was sown on 4th July, 2009, 26th July, 2010 and 18th July, 2011 in the three gravimetric lysimeters consisting of a sensitive type of weighing machines of 2 tonnes capacity (Anonymous, 1979), after receiving 41.1 mm, 54.4 mm and 45.4 mm rainfall, respectively. The sesame crop was grown under three irrigation treatments, namely (a) Irrigation daily with an amount equal to 100% of potential evapotranspiration (PET) of previous day, (b) irrigated every fourth day with an amount equal to 50% of PET of previous 4 days and (c) rainfed (control). Rao (2011) studied by using methodology for clusterbean and chillies crops under lysimetric studies and also for mothbean used by (Singh *et al.*, 2000). These lysimeters were surrounded by 5x5 meter with cropped plot of with similar irrigation treatment. These plots act as buffer to change of micro-climatic condition surrounding the lysimeter. The seed rate during sowing was maintained @ 2.5 kg ha^{-1}. Fertilizer was applied as per standard recommendation.

Observations

Weather data were recorded at agrometeorology observatory located close to experiment field. The plant growth and yield parameters were observed from a fixed sample of marked plants at alternated days. Evapotranspiration (ET_c) of sesame was measured by using three gravimetric lysimeters. Reference evapotranspiration (ET_o) computed by PET Calculator v3.0 (Bapuji Rao *et al.*, 2013) and the calculator computed PET based on the various methods and used FAO Penman-Monteith method (Allen and Pruitt, 1991) equation (i). Crop coefficient (Kc), the ratio of crop evapotranspiration (ET_c) to reference evapotranspiration (ET_o) is an important parameter in irrigation planning and management. The water use efficiency (WUE) calculated using equation (ii) (Howell *et al.*, 1990).

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} U_2 (e_a - e_d)}{\Delta + \gamma(1 + 0.34U_2)} \quad \text{Equ...........(i)}$$

Where, ET_o = potential evapotranspiration [mm d^{-1}]

R_n = net radiation at crop surface (MJ m^{-2} d^{-1}]

G = soil heat flux (MJ m^{-2} d^{-1}]

T = average temperature at 2 m height (ºC)

U_2 = wind speed measured at 2 m height [m s^{-1}]

(e_a-e_d) = vapour pressure deficit for measurement at 2 m height (k Pa)

Δ = slope vapour pressure curve [k PaºC^{-1}]

ã = psychometric constant [k PaºC^{-1}]

900 = coefficient for the reference crop [l J^{-1} kg K d^{-1}]

0.34 = wind coefficient for the reference crop [s m^{-1}]

$$WUE = \frac{Y}{ET} \quad \text{Equ...........(ii)}$$

Whereas, WUE is water use efficiency (kg $ha^{-1}mm^{-1}$), Y is economic yield of crop (kg ha^{-1}) and ET is evapotranspiration (mm) during the crop cycle.

RESULTS AND DISCUSSION

Prevailing weather conditions during growing periods

The normal as well as actual weather conditions during the crop growth seasons (2009, 2010 and 2011) are given in (Table.1). The study revealed that the mean monthly maximum temperature during the growing periods ranged from 38.2 °C in September (2009) to 32.9 °C September (2011). It was observed highly variable only in September as compared to other months during the whole crop growth periods. On the other hand, mean minimum temperatures varied between 28.1°C in July (2010) to 19.3 °C in October (2011) during growing periods. The pan evaporation was observed more in whole growing period 2009 except July month as compared to other growing periods. The pan evaporation varied from 8.8 mm in September (2009) to 4.4 mm in September (2010). Overall, the potential evapotranspiration is excess than normal rainfall in arid regions of Rajasthan. Rao and Roy (2012) estimated potential evapotranspiration more than 2000 mm $year^{-1}$ which is too far excess of rainfall in arid regions and one of the scarcity zones of Maharashtra, where also potential evapotranspiration is far excess of average rainfall (Pawar *et al.*, 2015). Relative humidity varied from 34 % to 74% during crop periods. The rainfall during the crop growth period was highly variable and it was observed late season drought in 2009 and excess rainfall in the month of September (202 mm and 94 mm as against to normal rainfall 47 mm) in 2010 and 2011, respectively.

Growth and yield attributes

Sesame crop sown on the early date after the occurrence of rainfall in 2009 performed better under the unstressed condition as compared to delayed and normal sown crop in 2010 and 2011, respectively, as evidenced from the number of branches, leaves, capsules and seed yield (Table 2). The variations of 38, 21 and 56 % of the main stem contribution to capsule production might be explained by the temperature profile, relative humidity and PAR, respectively. The height of plants varied from 128-157 cm in 2011 that was highest as compared to other growing year 115-135 cm, 121-141 cm in 2009 and 2010, respectively. Earlier, Tahir *et al.* (2012) and Nath *et al.* (2000) also reported that all the yield attributing parameters were significantly affected by different sowing dates

Table1: Normal as well as actual weather data during crop growth period

Parameters	Month			
Rainfall (mm)	July	August	September	October
2009	115.2	44.1	6.5	0.0
2010	133.9	120.7	202.9	0.0
2011	92.3	118.8	93.8	0.3
Normal	128.1	117.4	47.8	6.3
Mean maximum air temperature (°C)				
2009	36.8	36.1	38.2	36.8
2010	37.2	33.6	33.7	36.5
2011	37.1	34.0	32.8	35.9
Normal	36.0	34.0	35.5	36.2
Mean minimum air temperature (°C)				
2009	27.8	27.1	25.9	20.8
2010	28.1	26.5	23.7	21.3
2011	27.6	26.4	24.0	19.3
Normal	26.8	25.5	24.2	20.1
Mean relative humidity (%)				
2009	63.3	60.9	49.4	34.0
2010	64.9	74.0	67.9	43.9.
2011	61.7	73.3	73.5	42.2
Normal	64.0	70.0	59.0	39.0
Mean open pan evaporation (mm day^{-1})				
2009	7.7	8.2	8.8	7.2
2010	7.9	4.5	4.4	5.8
2011	8.2	4.8	4.4	5.9
Normal	8.5	6.3	6.9	6.6

Table 2: Growth and yield attributes of sesame

Parameters	2009				2010				2011			
	Rainfed	50% ET	100 % ET	SEm	Rainfed	50% ET	100 % ET	SEm	Rainfed	50% ET	100 % ET	SEm
Plant height (cm)	115	156	135	6.2	121	127	141	3.6	128	158	157	5.22
Number of branches/plant	13	14	11	0.6	8	9	8	0.3	8	14	12	1.09
Number of leaves/plant												
Main branch	32	44	39	2.1	29	39	33	1.6	27	35	37	1.72
Sub branches	84	98	85	5.6	55	43	59	3.8	61	45	85	9.49
Total	116	142	124	6.6	84	82	91	3.6	87	79	123	9.63
Number of capsules/plant												
Main branch	22	39	29	2.6	22	18	21	3.1	13	19	25	2.03
Sub branches	36	37	59	17.4	27	32	36	4.0	33	18	35	6.35
Total	59	76	88	18.8	49	50	57	5.7	46	37	60	6.10
Seed yield (kg/ha)	323	1018	1953	472.2	947	1006	976	17.0	885	923	1041	47.0

Table 3: Actual evapotranspiration and water use efficiency of sesame

Variables	2009	2010	2011	Mean
Seasonal ET (mm)				
Rainfed	364	360	302	342
Irrigated (50% ET)	609	380	318	436
Irrigated (100% ET)	763	398	329	497
Water use efficiency (kg/ha/mm)				
Rainfed	0.89	2.63	2.93	2.15
Irrigated (50% ET)	1.67	2.49	2.90	2.35
Irrigated (100% ET)	2.56	2.53	3.16	2.75
SEm	0.39	0.03	0.07	

with different row spacing. The maximum plant height (158.9 cm) and number of capsules per plant (24.90) recorded where sesame was sown on 15th June with row spacing of 15 cm. The average seed yield of the crop growth period enhanced 39 % and 84 % as against of rainfed by 50 % evapotranspiration irrigated and 100 % evapotranspiration irrigated, respectively.

Actual evapotranspiration and water use efficiency

The mean of three seasonal evapotranspiration of sesame was 342 mm, 436 mm and 497 mm under rainfed, 50%

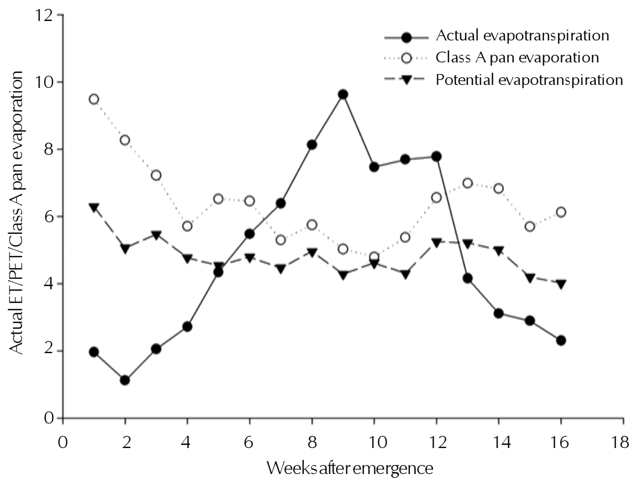

Figure 1: Actual and potential ET, Pan Evaporation rates at Jodhpur

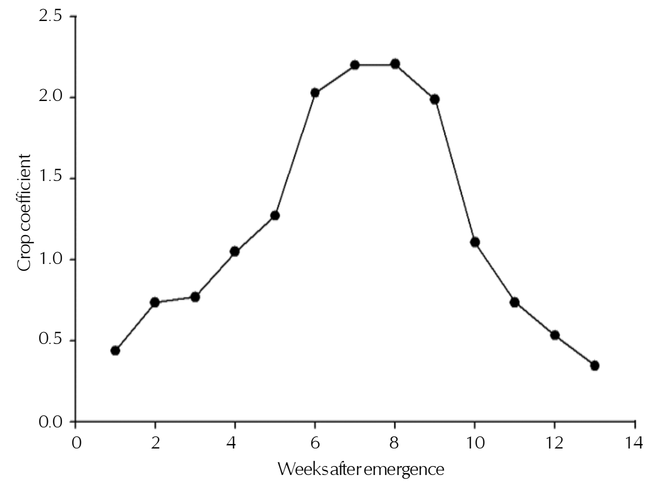

Figure 2: Crop coefficient for sesame at Jodhpur

evapotranspiration irrigated and 100% evapotranspiration irrigated (Table 3). Under rainfed condition lowest seasonal ET was observed as compared to irrigated condition; which was due to variation in micro-climate among the rainfed and irrigated condition. Igbadun (2012) said that the micro-climate during the wet season differs from that of the dry season, it is most expected that crop water requirements for irrigation should differ from that under rainfed condition. The highest evapotranspiration was 763 mm under 100% evapotranspiration irrigated in 2009 due to low rainfall and relative humidity during the growing period. The quantum of water loss as evapotranspiaration also depends on weather conditions, if relative humidity low means atmosphere water demand is more. Rao and Roy (2012) estimated more than 2000 mm year^{-1} in arid Rajasthan and generally occurrence of high solar radiation throughout the year with a mean of 22 MJ m^2 day^{-1}. In the study, evapotranspiration ranged from 1.2 to 2.7 mm day^{-1} at initial stage, 4.3 to 9.6 mm day^{-1} at the vegetative stage and 7.4 to 7.9 mm day^{-1} during flowering and capsule formation stage and 2.2 to 4.2 mm day^{-1} at maturity stage (Fig.1).

Crop water use efficiency increased from 0.89 to 2.56 kg ha^{-1}mm^{-1} in 2009 and 2.93 to 3.16 kg ha^{-1}mm^{-1} in 2010 along with increased soil moisture availability under early and normal sown condition, respectively. In case of delayed sown condition, water use efficiency decreased from 2.63 to 2.53 kg ha^{-1}mm^{-1}. Ucan *et al.* (2007) reported that the water use efficiency of sesame decreased when irrigation water increased. Arid zone crops like clusterbean (Rao *et al.*, 2000) and mustard (Ramakrishna *et al.*, 1990) responded linearly upto 50% PET and thereafter the water use efficiency decreased as a result of a lower efficiency of crop to utilise the excess available water for increasing grain production linearly.

Crop coefficient

The crop coefficient is required for estimation of crop water requirement. The mean of crop coefficient during growing seasons for sesame were 0.4 to 0.8 at an early growth stage, 0.9-1.3 during the peak vegetative stage, 1.4 to 2.2 during flowering and capsule formation and 0.3 to 1.1 during the crop matures (Fig.2). Pereira *et al.* (2014) estimated 0.63 (planting/establishment), 0.83 (Growth), 0.97 (development/ flowering) and 0.56 (maturation) at Brazil. Praveen Rao and Raikhelkar (1994) were estimated crop coefficient of sesame in clayey soil at Parbani, Maharashtra and they found 0.430 at initial stage, 0.680 at vegetative, 0.841 at flowering and capsule initiation, and 0.437 at ripening stage. Sepaskhah and Andam (2001) reported the crop coefficient of sesame varied between 0.49-1.0 from beginning to middle of the growing season in semi-arid region of I.R. It was low as compared to loamy sand soil under the arid zone of Rajasthan, because Kc for a crop may vary from one place to another, depending on factors such as climate, soil, crop type, crop variety, irrigation methods (Kang, *et al.*, 2003 and Yarami *et al.*, 2011). The sesame crop yield responds with availability of soil moisture under early and normal sown in arid regions.

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