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Determination of actual evapotranspiration for summer clusterbean (*Cyamopsis tetragonoloba*) using mini-lysimeters in hot arid zone of India

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ABSTRACT

A field experiment was conducted for three consecutive years 2015-17 during the summer season at the experiment farm of ICAR-Central Arid Zone Research Institute, Jodhpur to determine the actual evapotranspiration of clusterbean [*Cyamopsis tetragonoloba* (L.) Taub.] using mini-lysimeter by imposing different levels of irrigation based on cumulative pan evaporation (CPE) 50 mm irrigation at 100, 80, 60 and 40% of CPE. Three year averaged actual crop ET was observed 686, 554, 454 and 340 mm under 100, 80, 60 and 40 % irrigation levels, respectively. The highest crop ET was recorded under 100% followed by 80, 60 and 40 % irrigation levels. However, maximum water productivity (0.35 kg m^{-3}) at 80% irrigation level, while the lowest (0.21 kg m^{-3}) was observed at 40% irrigation level.The results also indicated that to achieve maximum water productivity, crop ET would need to be at least 554 mm and the crop can save 19.2% (132 mm) of water with a compromise in yield reduction by 10.4% (225 kg).

Key words: Actual crop evapotranspiration, Mini-lysimeter, Summer clusterbean, Water productivity.

INTRODUCTION

Under arid and semi-arid conditions, water is the scarcest input which has considerable effects on the efficiency of other natural, applied inputs and individual factor productivity (Cossani *et al.,* 2009). To meet the requirement of ever-increasing population coupled with scarcity and gradual decrease in the share of water for agriculture, the only option available is to produce more food per unit of available water. For this, information on crop water requirements is very vital in the planning and operation of water management strategies. One of the challenges of determining crop water requirement represented by the crop consumptive use, also commonly referred to as evapotranspiration, at field level is the fact that the other output components of the soil water balance (e.g. runoff, deep percolation, and capillary movement) are very volatile and difficult to measure (Igbadun, 2012).

However, this challenge can be overcome with the use of lysimeters. A lysimeter is a device which enables the isolation of a soil column for the purpose of studying water inflow and outflow in the system.The soil column can be isolated from the surrounding using a container of regular shape (referred to as the lysimeter tank) and planted to a crop. The water input to grow the crop can be measured and the crop water use and other output components of the soil water balance (runoff, deep percolation and moisture retained in the soil column) can also be quantified.The literature (e.g. Clark *et al*., 1996; Haman *et al*., 1997; Simon *et al*., 1998; Lie *et al*., 2003) shows that the surface area and depth of standard lysimeter tanks are usually above 1 m^2 and 0.5 m deep. Lysimeter tank with lesser dimensions may therefore be referred to as mini-lysimeters (Igbadun, 2012). Mini-lysimeters have the advantages that permit the measurement of the evaporative flux from smaller areas; create less disturbance to the environment during installation; and are considerably cheaper to construct, install and maintain.

Weighing lysimeter measures crop water use directly by measuring the change in weight of an isolated soil volume. The crop water use is calculated from the changes in weight of the lysimeter tank, and adjusted to account for weight changes caused by factors other than crop water use such as drainage or runoff and water input (Malone *et al*., 2000).

India contributes 80% to the global production of guar seed where it is cultivated on an area of 3.40 m ha, with a very low productivity of 580 kg/ha (NRAA, 2014). Clusterbean (Cyamopsis tetragonoloba) is an important legume cash crop, grown in semi-arid and arid regions of Rajasthan, Haryana and Gujarat during rainy (*kharif*) season. Owing to its demand in the international market, it has been introduced in the non-traditional growing areas like Andhra Pradesh, Tamil Nadu, Karnataka, Maharashtra and Chhattisgarh. Further, its cultivation is also being taken up under irrigated conditions during summer (Bhatt *et al*., 2017; Manjunatha *et al*., 2018). This crop is a source to replenish nutrient, especially nitrogen of the low-fertility soils and can

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withstand moisture stress. It is a photosensitive and indeterminate crop (Raj Singh, 2014) and can be raised in summer season also with irrigation facility. Though, Rajanna *et al.* (2016) reported that adoption of bed planting (FIRBS) with application of irrigation at an IW: CPE of 0.80 in clusterbean leads to increase in growth parameters along with yield parameters but no study was taken up to study summer clusterbean when temperatures in this part of the country is high resulting in high evaporative demand. Present investigation aims at the quantification of crop water use or actual evapotranspiration of influenced by different scale of water provided to summer clusterbean through mini-sprinkler under a mini-lysimeter system.

MATERIALS AND METHODS

Experimental site and crop growing environment: The field experiment was conducted at Research Farm of ICAR-Central Arid Zone Research Institute, Jodhpur (26.3°N and 73.02°E; 224 m amsl) during the summer seasons of 2015 to 2017. Soils of the experimental plots were originated from rhyolite and subsequently modified through alluvial and aeolian processes. Taxonomically, soils may be defined as coarse loamy mixed hyperthermic of camborthids. Soil organic carbon is very low (1.6 g kg^{-1}). Soil physical properties of the experimental area are shown in (Table 1).The climate of the region is arid characterized by high diurnal and seasonal temperature variations and annual and inter-annual irregular rainfall with long dry seasons associated with strong winds. During the crop growing season in 2015 four rain events accounted for 38.7 mm rainfall while no rain event occurred in 2016, and in 2017 rainfall occurred 86.5 mm with 5 rainy days (Fig. 1). Relative humidity (RH) varied from 15.5-84, 11-51 and 13-67% in 2015, 2016 and 2017, respectively. Low relative humidity occurred in 2016 due to not a single rainfall event occurrence. Minimum temperature varied from 15-31.7, 15.2-33.2 and 10.5-30.9°C, and maximum temperature varied from 27-44.7, 30.2-49.4 and 27.7-44.5°C in 2015, 2016 and 2017, respectively (Fig 1).

Crop experiment details: Clusterbean cv. RGC 936 was planted after pre-sowing irrigation (60 mm) on 11th March during 2015, 2nd March in 2016 and 4th March in 2017 using seed rate of 10-12 kg ha^{-1}. Plant spacing was 50 cm row to row and plant to plant 10 cm. Fertilizer (Di-ammonium phosphate-D.A.P) was applied at the rate of 20 kg N and 40 kg P_2O_5 ha^{-1}.The other cultural practices followed were kept uniform as per recommendations for all the treatments.The crop was harvested on 1st June, 25th May and 25th May in 2015, 2016 and 2017, respectively.Treatments consisted of 4 irrigation levels, viz. irrigation at 100% ($I_{100\%}$), 80% ($I_{80\%}$), 60% ($I_{60\%}$) and 40% ($I_{40\%}$). The irrigation was given to the crops, when cumulative potential evaporation value reached 50±10 mm because the high rate of open pan evaporation (reached upto 20-25 mm/day) in summer season in hot region.

Soil moisture under different treatments was recorded periodically through FDR soil moisture meter of Micro Gopher.

Design and development of mini-lysimeter: Four mini-lysimeters (ML) were designed and fabricated for quantifying actual measurement of water balance components. Electronic weighing mini-lysimeter comprised three components (i) mini-lysimeter chamber/ pit, (ii) electronic weighing machine based on single load cell and (iii) mini-lysimeter tank. The tanks were designed to quantify actual water balance components from the tanks after irrigation and rainfall event. The tank dimension was 0.50 m × 0.50 m × 0.55 m, including 0.05 m of drainage chamber height, with 10 cm height supporting legs.

Electronic weighing machine of the mini-lysimeter was based on load cell (Make-ADI Company India; regular 410), having the weighing capacity up to 750 kg with a resolution of 50 g. It was fabricated according to our requirement within platform size 0.50 m × 0.50 m × 0.27 m. The platform was made of 4 mm mild steel (MS) iron and MS angle for supporting legs. The single load cell was bolted in an upright orientation in the centre of platform. The load cell gives output in millivolts with a connected EG Tech display indicator and is converted in kg, which is displayed by the system indicator. All the components were assembled to operate electronic weighing mini-lysimeter based on the single load cell. Soil up to 50 cm profile from the ground level from the experimental plot was excavated to fill the ML. Tank filled-in soil layer was alternatively saturated and drained until the bulk density inside the ML was close to the field soil condition. The mini-lysimeter was calibrated in field with conversion factor of 1 kg = 4 mm with resolution of 0.2 mm (Meena *et al*., 2015).

Established mini-sprinkler irrigation system: Mini sprinkler irrigation system setup was made in the experimental field, which consisted of pump (1 HP), main pipe (HDPE pipe 63 mm diameter; 2.5 kg/cm^2 pressure), screen filter (25 m^3/hr), low linear density polyethylene (LLDPE) plain lateral (32 mm; 2.5Kg/cm^2), risers, sprinkler head and pressure gauge. Twin nozzle mini-sprinklers of model Monsoon S-10 with nozzle size 2.5 x 1.5 mm were

Table 1: Characteristics of soil physical properties.

Depth	Clay (%)	Silt (%)	Sand (%)	Field capacity (%)	Permanent wilting point (%)
0-10 cm	7.5	10.8	81.7	8.98	3.44
10-20 cm	8.3	6.7	85.0	8.59	3.48
20-30 cm	9.6	7.5	82.9	9.76	3.87

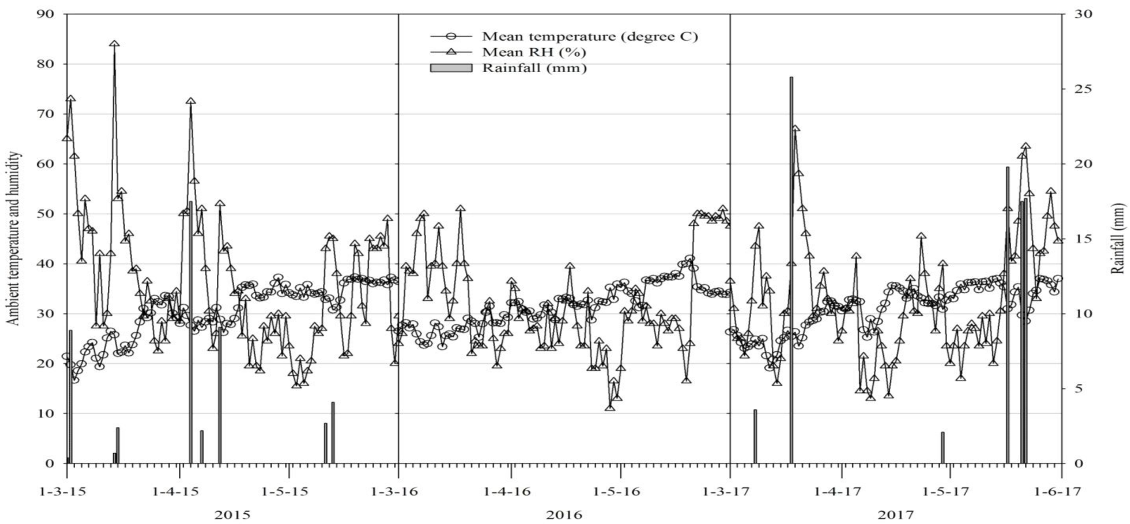

Fig 1: Weather occurrence during summer cluster bean growing seasons.

used in the field to irrigate the area. The mini-sprinklers were used in a part circle. The sprinkler fixed at the middle of the individual plot was fixed at 180°, while sprinklers at the corner of the plot were fixed at 90° angle. For each irrigation level six sprinklers were used, out of that, 2 sprinklers were fixed at 180° and four at 90°. The net area under one irrigation level was kept as 21 m x 11 m. The spacing of sprinklers along the lateral was kept as 10.5 m and spacing of laterals along the main line was kept at 10 m. One meter gap was left between the rows of two irrigation levels plots.The experiment was conducted at operating pressures of 2.0 kg/cm^2 at the nozzle. Discharge of a single nozzle was found to be 480 lph. Precipitation rate of the sprinkler system was calculated to be 4.6 mm/hr with the use of following equation.

$$\text{Precipitation rate} = \text{Discharge of the sprinkler nozzle} \times \frac{1000}{\text{Wetted area}}$$

Where, precipitation rate (mm/hr); Discharge (m^3/hr) and wetted area (m^2).

Based on the flow discharge of sprinkler nozzle, the flow rate of 6 sprinkles for the individual plot was calculated as 2880 lph. Total water to be applied on the individual plot was calculated to be 10500 litres at 50 mm depth of irrigation, hence, time of operation of sprinkler system for irrigation levels of I_{100}, I_{80}, I_{60} and I_{40}% was calculated to be 3.6, 2.9, 2.2 and 1.5 hrs, respectively. Assessment of water productivity was done as defined by Araya *et al.* (2011) and Payero *et al.* (2009).

$$WP = \frac{Ya}{ET}$$

Where, Ya is the actual yield achieved (kg ha^{-1}) and ET is water used in evapotranspiration (mm).

Plant water potential (PWP) and Relative leaf water content (RLWC): Sampling for assessment of plant water status was done in triplicate prior to subsequent irrigation. Observations on plant water status were done at flowering and pod maturation stage as they have been reported to be critical for yield (Garg and Burman, 2002).

Plants were uprooted and water potential was measured using a pressure chamber (PMS Instrument Co., USA). Relative leaf water content (RLWC) was also determined at these two stages from fully expanded leaves (third from top) following the procedure of Barrs (1968), wherein 200 mg of fresh samples of leaf disc (FW) were floated on equal amount of distilled water for 3 h to obtain turgid weight (TW). After oven drying for 24h at 80^{0}C the dry weight (DW) was recorded. Thereafter LRWC was calculated as –

$$LRWC\ (\%) = \left[\frac{(FW - DW)}{(TW - DW)}\right] \times 100$$

RESULTS AND DISCUSSION

Daily actual crop evapotranspiration: Daily crop ET was measured with installed mini-lysimeter under irrigation levels. The variation of daily average ET_c under irrigation levels was 8.0, 6.9, 5.3 and 3.8 mm/day in 2015, respectively. In summer 2016 was 8.5, 6.8, 5.6 and 4.0 mm/day while in 2017, it was 8.0. 6.3, 6.1 and 5.0 mm/day, respectively. It was observed over the three summer seasons that highest average ET_c (mm/day) under irrigation levels in 2016 as compared to 2015 and 2017. Also observed maximum ET_c reached 20 (mm/ day) was in 2016 followed by 2017 (19.6 mm/day) and 2015 (19.2 mm/day) (Fig.2). The highest ET_c in 2016 occurred due to low relative humidity and high air maximum temperature and these were influenced due to no rain events particularly in the summer season (Fig 1). Crop growth and yield was also higher in summer 2016 because it is a photosensitive and indeterminate crop.

Clusterbean yield: Perusal of Table 2 shows that water consumed for actual evapotranspiration (ET) was maximum with treatment T_1, where 100% water was applied to the plant on volumetric basis, and the lowest was for T_4, where 40% of water was applied in all the years. Mean ET value across the years was maximum (686 mm) for T_1 and the lowest (340 mm) for the treatment T_4. As can be observed from the table, grain yields decreased as the amount of irrigation water applied decreased. The highest yield, averaging 2149 kg ha^{-1}, was measured in the fully irrigated treatment, T_1, while water deficit treatment T_4 produced the lowest yield of 680 kg ha^{-1}. Clusterbean yield for treatment T_2 (I_{80}%) was very close to that of T_1, but yield in other treatments T_3 (I_{60}%) and T_4 (I_{40}%) were very less in comparison to T_1.

Water productivity: The seasonal ET varied in all the years for the different irrigation treatments. Crop water use for treatments T_1, T_2, T_3, and T_4 was 673, 574, 442, and 313 mm, respectively, in 2015. In 2016 season, the respective values for these treatments were 723, 577, 425, and 299 mm, while for 2017 season these values were measured to be 663, 512, 494, and 407 mm. The mean value of crop water use (ET) for the treatments was 686, 554, 454 and 340 mm. The marked differences observed among the treatments, can be attributed to the large difference in irrigation water applied. The mean water productivity ranged from 0.21 (T_4) to 0.35 kg m^{-3} (T_2). In a study done by Kumar *et al.* (2016) water productivity of *kharif* clusterbean in hot arid region was found to be 0.38 kg m^{-3}, which is similar to our results in this study.

The values estimated for water productivity have some very important implications. Under a limited water supply situation where the goal may be to achieve the highest possible water productivity, utilizing a water application depth of 40 mm (T_2) at each irrigation event offers opportunities for water savings. In other words, utilizing this water application depth offers water savings of 19.24% (Table 2) compared to the fully irrigated treatment with only 10.46 yield reductions. In other words, if yield is to be maximized, crop ET would need to be about 686 mm (3

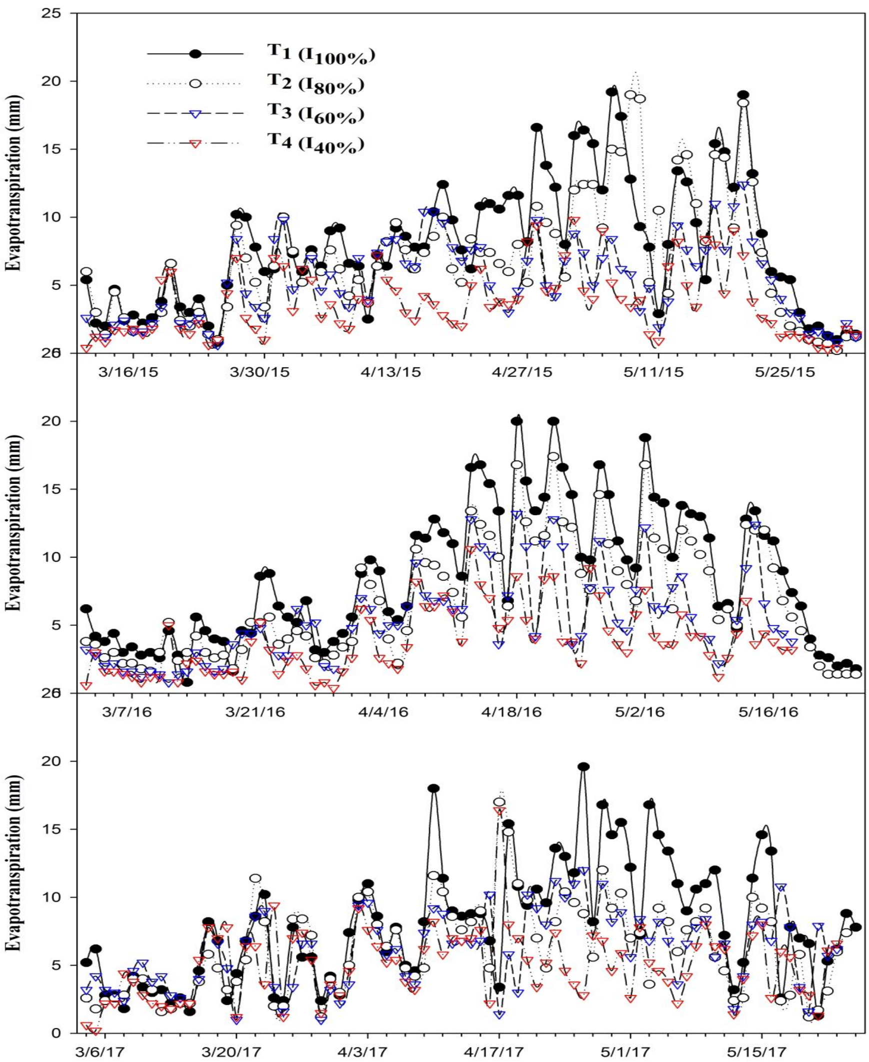

Fig 2: Actual crop evapotranspiration under various irrigation levels in different years.

Table 2: Actual crop ET and water productivity of summer clusterbean.

Treatment	ET (mm)				ET decrement (%)	Yield(Kg ha^{-1})				Yield decrement (%)	Water productivity (Kg m^{-3})
	2015	**2016**	**2017**	**Mean**		**2015**	**2016**	**2017**	**Mean**		
T_1 ($I_{100\%}$)	662	723	663	686		2101	2651	1694	2149		0.31
T_2 ($I_{80\%}$)	574	577	512	554	19	2082	2184	1507	1924	10	0.35
T_3 ($I_{60\%}$)	442	425	494	454	34	1076	1516	764	1119	48	0.25
T_4 ($I_{40\%}$)	313	299	407	340	50	359	1086	680	708	67	0.21

year average), or 23.8% greater than the water use at maximum water productivity (Table 2).

Soil moisture: Yearly variation in the pattern of soil moisture across different treatments (T_1 through T_4) was observed at both the critical stages (flowering and pod maturation stage) of crop growth (Table 3). In 2015, soil moisture progressively decreased with increasing deficit of irrigation at flowering stage. Similar trend was broadly observed at pod maturation stage too. Slightly high value in T_2 and T_3 could be due to less plant population resulting in more residual soil moisture.

Table 3: Soil moisture (%, m3/m3 volumetric basis) at flowering (FS) and pod maturation (PMS) stages under different irrigation levels in 2015, 2016 and 2017.

	T_1 ($I_{100\%}$)	T_2 ($I_{80\%}$)	T_3 ($I_{60\%}$)	T_4 ($I_{40\%}$)
2015				
FS	13.8	12.6	12.6	10.8
PMS	10.9	12.5	12.5	8.6
2016				
FS	13.1	11.9	11.9	12.6
PMS	13.0	13.4	13.4	12.1
2017				
FS	12.9	13.3	13.3	12.0
PMS	12.5	10.9	10.9	14.2

In T_4, however, deficit irrigation was so severe that soil moisture declined further probably in spite of less plant population. More soil moisture in T_1 and less in T_4 were also observed in 2016 at both the growth stages. Intermediate levels of irrigation (T_2 and T_3) reflected inconsistent trend probably because of variation in plant population in these treatments. In 2017, the interplay between rain fall events and plant population strongly influenced the soil moisture as at pod maturation stage probably due to last 2-3 rainfall events prior to harvest (Fig 1).

Plant water potential and relative leaf water content: As the intensity of deficit irrigation increased from 0.0% to 60% (*i.e.* at 100 and 40% CPE irrigation level, respectively) the plant generally experienced increase in water deficit which was maximum at 40% level (Table 4). However, variability with respect to plant water deficit on different sampling days could be explained due to variation in rainfall event, plant population in different treatments and consequent soil moisture level. High plant water potential at pod maturation compared to that at flowering stage in 2017 is a clear-cut example wherein rainfall events and the associated increase in relative humidity and mean temperature (Fig 1) resulted in less plant water deficit.

Table 4: Effect of different irrigation levels on plant water potential (-bars) at flowering (FS) and pod maturation (PMS) stages of clusterbean grown in the summer for three consecutive years (All values are average of three replicates).

Treatment	Level of irrigation	2015		2016		2017		Mean over years and growth stages
		FS	**PMS**	**FS**	**PMS**	**FS**	**PMS**	
T_1 ($I_{100\%}$)	100%	11.0	18.0	16.0	17.3	27.3	17.6	17.86
T_2 ($I_{80\%}$)	80%	13.6	18.7	17.6	16.0	26.5	17.3	18.28
T_3 ($I_{60\%}$)	60%	11.0	19.7	18.0	16.7	30.3	18.0	18.95
T_4 ($I_{40\%}$)	40%	15.0	20.7	20.6	16.7	29.6	18.0	20.10

Table 5: Effect of different irrigation levels on relative water content (%) of leaves at flowering (FS) and pod maturation (PMS) stages of clusterbean grown in the summer for three consecutive years (All values are average of three replicates).

Treatment	Level of irrigation	2015		2016		2017		Mean over years and growth stages
		FS	**PMS**	**FS**	**PMS**	**FS**	**PMS**	
T_1 ($I_{100\%}$)	100%	75.8	69.1	66.2	61.2	49.2	63.9	64.2
T_2 ($I_{80\%}$)	80%	73.1	68.7	63.5	67.3	51.2	67.5	65.3
T_3 ($I_{60\%}$)	60%	74.6	69.1	68.4	66.7	57.4	73.3	68.2
T_4 ($I_{40\%}$)	40%	68.9	66.6	69.0	66.2	59.4	65.5	65.5

With progressive decrease in irrigation level the clusterbean plants experienced more plant water deficit. On an average of plant water potential dropped from -17.8 to -20.1 bars (Table 4). Further, clusterbean plants also reflected their potential to adapt as evident from themaintenance of comparable relative water content in its leaves even at lower levels of irrigation (Table 5). But maintenance of comparable level of plant water status could not check decline in yield. It is pertinent to add here that yield reduction was less at 80% level probably because deficit irrigation reduced leaf area (consequently checking transpiration) besides improvement in root growth (data not presented).It is well known that a specific level of soil moisture deficit will not necessarily be accompanied by same degree of water stress and this in turn does not influence all aspects of growth equally (Turner and Begg, 1981). Literature reveals that shoot growth invariably decreases, whereas root growth increases till an acceptable level of water deficit (Krida, 2002; Nangare *et al*., 2016) followed by yield reduction.

CONCLUSION

Soil water availability is a major limiting factor in arid agricultural production systems. Knowledge of crop response to water supply, full and limited, in localized environments can aid in the development of effective irrigation strategies for improving water management and crop productivity. Based on a mini-lysimetric approach for direct measurement of crop water use or actual evapotranspiration, a water application depth of 40 mm (I_{80}%) showed highest water productivity, while a 30 (I_{60}%) and 20 (I_{40}%) mm water application depth was insufficient to maintain a wet soil profile, resulting in lower crop water productivity value with 0.25 and 0.21 kg m^{-3}. The results also indicate that to achieve maximum water productivity, crop ET would need to be at least 554 mm. High water productivity is attainable without significant yield reduction at water application depth of 40 mm, offering opportunities for improving farm level water use and saving of water resources.From the present study, it may be inferred that that the crop can save 19.2% (132 mm) of water with a compromise in yield reduction by 10.4% (225 kg). Therefore, clusterbean crop can be grown profitably during summer season with 80% of irrigation level in the arid zone of India.

REFERENCES

Araya, A., Stroosnijder, L., Girmay, G., and Keesstra, SD. (2011).Crop coefficient, yield response to water stress and water productivity of teff (*Eragrostis tef* (Zucc.)). *Agricultural Water Management*, **98**: 775–783.

Barrs, H.D. (1968). Determination of water deficit in plant tissue. *In*: Water Deficit and Plant Growth Vol1 [(ed) T.T Kozlowski], Academic Press (New York), pp235-268.

Bhatt, R.K., Jukanti, A.K. and Roy, M.M. (2017). Cluster bean (*Cyamopsis tetragonoloba* (L.) Taub.), an important industrial arid legume: A review. *Legume Research*, **40**(2): 207-214.

Clark, G.A., Albergts, E.E., Stanley, C.D., Smajstrala, A.G. and Zazueta. F.S. (1996). Water requirements and crop coefficients of drip-irrigated strawberry plants. *Transactions of ASAE*. **39**(3): 905-913.

Cossani, M., Slafer, G. and Savin, R. (2009). Yield and biomass inwheat and barley under a range of conditions in a Mediterraneansite. *Field Crops Research,* **112**: 205–213.

Garg, B.K. and Burman, U (2002). Physiology. In: Guar in India (Eds. D. Kumar and N.B. Singh) Scientific.Pub. Jodhpur pp. 63-83.

Haman, D.Z., Pritchard R.T., Smajstrla A.G., Zazueta F.S., and Lyrene P. M. (1997). Evapotranspiration and crop coefficients for young blueberries in Florida. *Applied Engineering in Agriculture*, **13**(2): 209-216.

Igbadun, Henry E. (2012). Estimation of crop water use of rain-fed maize and groundnut using mini-lysimeters. *The Pacific Journal of Science and Technology*, **13** (1): 527-535.

Kirda, C., (2002). Deficit irrigation scheduling based on plant growth stages showing water stress tolerance. Deficit irrigation practices. In: FAO Corp. Doc. Rep. 22, Rome, pp. 3–10.

Kumar, Ramesh., Yadav, R.S., Yadava, N.D., Kumawat, A., Nangia, V., Glazirina, M., Rathore, V.S., *et al*. (2016) Evaluation of CropSyst model for clusterbean under hot arid condition. *Legume Research*, **39** (5): 774-779.

Lie, T., Xiao, J., Li, G., Yu, Y., Liu, Z. and Wang, J. (2003). Estimating crop coefficients of drip irrigated watermelons and honeydew melons from pan evaporation. ASAE Paper No.032247. ASAE: St. Joseph, MI.

Malone, R.W., Bonta, J.V., Stewardson, D.J. and Nelsen, T. (2000). Error analysis and quality improvement of the cosheton weighing lysimeters. *Trans ASAE*. **31**:477-484.

Manjunatha, N., Lokesha, H. and Deshmanya, Jagrathi. B. (2018). Structural changes in the performance of gum guar in India. *Indian Journal of Agricultural Research*, **52** (3): 336-338.

Meena, H.M., Singh, R.K. and Santra, P. (2015). Design and development of a load-cell based cost effective mini-lysimeter. *Journal of Agricultural Physics*, **15**(1): 1-6.

Nangare, Singh, D.D., Kumar, Y. and Minhas, P.S. (2016). Growth, fruit yield and quality of tomato (*Lycopersicon esculentum* Mill.) as affected by deficit irrigation regulated on phenological basis. *Agricultural Water Management*, **171**: 73–79.

NRAA. (2014). Potential of rainfed guar (Clusterbeans) cultivation, processing and export in India. *Policy paper no. 3 NationalRainfed Area Authority*, NASC Complex, DPS Marg, New Delhi, India, pp.109.

Payero, J. O., Tarkalson, D. D., Irmak, S., Davison, D., and Petersen, J. L. (2009). Effect of timing of a deficit-irrigation allocation oncorn evapotranspiration, yield, water use efficiency and drymass. *Agricultural Water Management*, **96**: 1387–1397.

Rajanna, G.A., Dhindwal, A.S. and Sriharsha, V.P. (2016). Performance of clusterbean (*Cyamopsis tetragonoloba*) under variable irrigation schedules and crop-establishment techniques. *Indian Journal of Agronomy,* **61** (2): 223- 230.

Simon, C.M., Ekwue, E.I., Gumbs, F.A. and Narayan. C.V. (1998). Evapotranspiration and crop coefficients of irrigated maize (*Zea mays* L.) in Trinidad. *Tropical Agriculture*, **75**(3):342-346.

Singh, R. (2014). Improved cultivation practices for clusterbean in *Kharif* and summer season. Bulletins on: http://www.cazri.res.in.

Turner, N.C and Begg, J.C. (1981). Plant water relations and adaptations to stress. *Plant soil*, **58**: 97-131.