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Mini-sprinkler irrigation uniformity and crop water productivity of summer clusterbean in Indian arid zone

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ABSTRACT

Judicious use of water resources has always been a focal point in agriculture sector and it has gained further importance under the changing climatic scenario. So, the use of pressurized irrigation systems has become an inevitable option for enhancing the water use efficiency. The field study was conducted for determination of actual water balance components for summer clusterbean in the Research Farm of ICAR-Central Arid Zone Research Institute, Jodhpur during the summer of 2015-17 through mini-lysimetric approach, where irrigation water was delivered through mini-sprinklers. Under this study, the coefficient of uniformity (C_u) and distribution uniformity (D_u) of the mini-sprinkler system were evaluated. Water was applied to the crop through mini-sprinklers at four irrigation levels of I_{1oo}, I_{80}, I_{60} and I_{40}%, when the cumulative pan evaporation (CPE) attained a value of 50 ± 5 mm. Twin nozzle mini-sprinklers of Model Monsoon S-10 with nozzle size 2.5 × 1.5 mm were used in the field to irrigate the area. For each irrigation level, six sprinklers were used, out of those, 2 sprinklers were fixed at 180° (middle of the plot) and four at 90° (corner of the plot) and the experiment was conducted at operating pressure of 2.0 kg cm^{-2}. Christiansen equation was used for determining the coefficient of uniformity for different irrigation levels and it was found to be 84.22, 84.30, 84.27 and 83.99%, while distribution uniformity was calculated to be 74.12, 74.70, 72.90 and 72.39% at I_{1oo}, I_{80}, I_{60} and I_{40}% irrigation levels. Both C_u and D_u coefficients give complementary information. C_u was consistently found higher than D_u. Water productivity was found the highest (0.35 kg m^{-3}) at the irrigation level of 80% CPE.

Key words: Coefficient of uniformity, irrigation uniformity, mini-sprinkler, water productivity

INTRODUCTION

Improving the productivity of existing irrigation schemes, especially with the limited water and land resources availability has got an increasing attention for global increase in food security (Ahaneku, 2010). This improvement becomes an all-important issue because of the serious constraint faced by irrigators due to water scarcity and the ensuing competition for water by other sectors e.g., industries and urban uses. This becomes much more pertinent for arid condition due to availability of lesser water quantity and erratic nature of rainfall. It is obvious that many irrigation systems are performing below their capacities. This situation may lead to non-uniform and unreliable water distribution. An ideal irrigation system should apply the correct amount of water, minimize the losses, and apply the water uniformly. It necessitates assessing the performance of available irrigation systems in order to identify areas of lapses in the system design and make corrections. Evaluation is an indispensable tool in irrigation project management since it enables irrigation managers to measure and determine actual performance, and the factors that are responsible for low or less performance. The uniformity of water application

in a sprinkler irrigation system is an important aspect of the system performance (Solomon, 1979). The two most common methods of expressing uniformity are the coefficient of uniformity (C_u) and distribution uniformity (D_u).

Several researchers have reported on the evaluation of sprinkler systems with emphasis on irrigation uniformity **(**Dukes et al., 2006; Nasab et al., 2007). Ahaneku (2010) evaluated the performance of sprinkler system by catch can tests and results indicated the average Christiansen's uniformity (C_u) and delivery performance ratio were 86 and 87% by using American Society of Agricultural and Biological Engineers (ASABE) standard procedures. Siosmarde and Byzedi (2012) found the mean values of Christiansen's uniformity (C_u) and distribution uniformity (D_u) to be 62 and 49.4% for five solid set randomly selected sprinkler irrigation systems. The performance evaluation of sprinkler system performed by Frank (2009) yielded the Christiansen's uniformity (C_u) to be 91 and 87% and mean application rates (MAR) to be 10.4 and 4.7 mm h^{-1} at 12 m × 12 m and 18 m × 18 m spacing, respectively.

MATERIALS AND METHODS

The present study was conducted at the Research Farm of ICAR-Central Arid Zone Research Institute, Jodhpur (26.3°N and 73.02°E; 224 m amsl) during the summer season of 2015 to 2017. 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.

Clusterbean cv. RGC 936 was sown after pre-sowing irrigation of 60 mm on 11th March in 2015, 2nd March in 2016 and 4th March in 2017 using seed rate of 10-12 kg ha^{-1}. Distance between two rows was 50 cm, whereas spacing between plants in a row was 10 cm. All agronomic and cultural practices followed were kept uniform 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 four irrigation levels, *viz.* irrigation at 100% ($I_{100\%}$), 80% ($I_{80\%}$), 60% ($I_{60\%}$) and 40% ($I_{40\%}$) of cumulative pan evaporation. The irrigation was applied, when cumulative potential evaporation value reached to 50 ± 5 mm.

The performance evaluation of a sprinkler system in the present study was evaluated by obtaining nozzle discharge (q), Christiansen's uniformity coefficient (Cu), distribution uniformity (Du), and application rate (MAR). Christiansen's coefficient (C_u) of uniformity (Christiansen, 1942) was first used to introduce a uniformity coefficient to the sprinkler system. C_u calculates the average deviation of the catch compared to the depth of the catch, while D_u compares the driest quarter of the field to the rest. The mini-sprinkler system was setup with the following components.

Pump

The existing tube well of 200 mm diameter and submersible pump of 15 HP was used to lift the water from submersible pump to the ground surface with 61 m static head (suction head + discharge head), where it was stored in a tank of 1000 L capacity, from where water was supplied to mini sprinklers by one HP pump. The water was diverted from the existing delivery line of 63 mm diameter to the experimental setup field. There was an existing submersible pump used for miscellaneous purposes for farm and other operations. The irrigation water for this research study was provided by the farm section by this pump only. Although the mini-sprinkler does not require such a heavy pump for its operation, it is has been used only as a water source.

Filter

A screen filter of 25 m^3 h^{-1} capacity was provided to filter out the soil particles and impurities from the water.

Pressure measuring device

A dial pressure gauge of range 0 to 7 kg cm^{-2} was used to measure the pressure over mini sprinkler. The dial pressure gauge was installed on the main pipe to monitor the pressure in the main line in the unit of psi and kg cm^{-2}. Sprinklers were operated at the operating pressure of 2 kg cm^{-2} and a by-pass valve was used to regulate the pressure. Pitot pressure gauges of the rage 0 to 7 kg cm^{-2}

were also used to measure the pressure near the sprinklers.

Main line and lateral line

Main line: 63 mm ϕ (diameter) High-density polyethylene (HDPE) × pressure 2.5 kg cm^{-2}; Laterals line: 32 mm ϕ (diameter) Linear Low-Density Polyethylene (LLDPE) × pressure 2.5 kg cm^{-2}.

Mini sprinkler assembly

In the present study, twin nozzle mini-sprinklers of Model Monsoon S-10 with nozzle size 2.5 × 1.5 mm were used in the field to irrigate the area. It was mounted on an installation stake 1.2 m long, 8 mm ϕ (diameter). The mini sprinkler was connected to the lateral using a vinyl tube of 1.2 m and 12 mm ϕ (diameter).

Hydraulic evaluation of mini sprinkler system

For the determination of sprinkler discharge (q), Christiansen's uniformity coefficient (CU), distribution uniformity (DU), and precipitation rate (MAR), the mini sprinklers were evaluated at the pressure of 2 kg cm^{-2} at the spacing arrangement of 10 m (along the main line) × 10.5 m (along the lateral). The net area under one irrigation level was kept as 21 m × 11 m. One meter gap was left between the rows of two irrigation levels plots. The mini-sprinklers were used in a part circle. The sprinkler fixed at the middle of the individual plot was fixed at 180° (half circle), while sprinklers at the corner of the plot were fixed at 90° angle (quarter circle). For each irrigation level six sprinklers were used, out of that, 2 sprinklers were fixed at 180° and four at 90°. Discharge of a single nozzle was found to be 480 L per hour. Precipitation rate of the sprinkler system was calculated to be 4.6 mm h^{-1} with the use of following equation.

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

Determination of sprinkler discharge (q)

Sprinkler discharge was assessed by collecting the water emitted by the sprinkler into a bucket in a time interval of 2 minute. The discharge was calculated by dividing the collected volume by the time of filling. The observations of discharge were recorded thrice for operating pressure.

Uniformity evaluation for sprinkler system

Uniformity evaluation tests are of fixed duration (generally half an hour to one hour duration) for each treatment. Once the test is over, the water collected in each catch-can is measured volumetrically with a calibrated test tube. For each treatment, coefficient of uniformity (CU), distribution uniformity (DU) and coefficient of variation (CV) are determined as the follows:

Determination of Christiansen's uniformity coefficient (C_U)

Christiansen's uniformity coefficient (C_u) is the most commonly used statistical method for evaluating sprinkler system uniformity (Warrick, 1983). Christiansen's uniformity is defined as

$$Cu = [1 - \frac{\Sigma(X - \bar{X})}{n \times \bar{X}}] \times 100$$

Where, C_u = Christiansen's uniformity coefficient (%)

$\bar{X}$ = mean water depth collected in the catch can.

$\Sigma X - \bar{X}$= cumulative of numerical deviation of individual observation from the mean water depth. n = total no. of catch cans (observation points)

20 catch-cans for each irrigation level were placed at a grid of 2 m × 2m for one hour. It was repeated four times and then the average was taken for each irrigation level.

Distribution uniformity

The distribution uniformity (DU) was calculated using the eq. (2) (Merriam and Keller, 1978):

$$DU = \frac{ADC_{25}}{\bar{X}} \times 100$$

Where,

ADC_{25} = the lowest quarter of the average water depth of catch cans

$\bar{X}$ = mean water depth collected in all catch cans (mm)

Coefficient of variation

The coefficient of variation (CV) is the quotient between the standard deviation of the applied water depths (σ) and the average of water depth collected according to ASAE (1991):

$$CV = \frac{\sigma}{\bar{X}}$$

Where,

σ = Standard deviation of the water depth of catch cans.

RESULTS AND DISCUSSION

Christiansen's uniformity coefficient (C_u)

The results obtained are presented in Fig. 1, showing uniformity coefficient at operating pressure at 2 kg cm^{-2} for different irrigation levels. For all the irrigation levels, C_u was recorded ≥84%, which is satisfactory. According to Keller and Bliesner (1990), the coefficient of uniformity of irrigation below the specified value 84%, following Christiansen, represents a low work quality of irrigators. Absolute uniformity is not required because it is almost impossible to achieve it with spray irrigation technology due to the effect of wind.

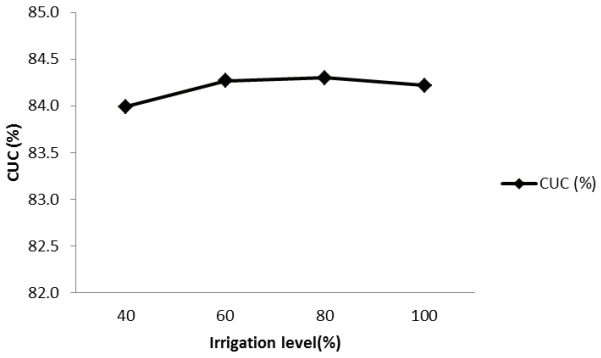

Fig. 1. Uniformity coefficient (C_u) in different irrigation levels

Distribution uniformity (D_u)

As shown in Fig. 2, the value of distribution uniformity ranged between 72.39 and 74.12%. The lowest value of distribution uniformity coefficient was obtained at irrigation level I_{40}%. All these values were greater than the minimum acceptable D_u of 60% specified by Keller and Bliesner (1990). As reported by (Keller and Bliesner, 2000), the distribution uniformity and application efficiency of sprinkler irrigation systems are potentially high, but these parameters are highly dependent on the weather conditions, especially on wind. Further, Al-ghobary and Al-rajihy (2001) reported that single nozzle sprinklers gave better C_u and D_u values than twin nozzle sprinklers at moderate wind speed.

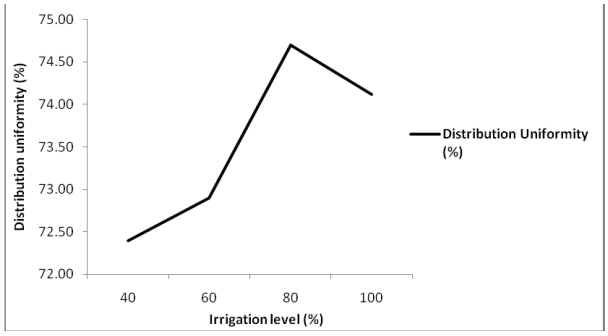

Fig. 2. Distribution uniformity (%) at different irrigation levels

Coefficient of variation (Cv)

The coefficient of variation varied from 19.25% at 40% irrigation level to 21.08 at 60% irrigation level. It was 20.42 and 19.73 for irrigation levels at 100 and 80%. It can be seen from the graph that Cu was consistently higher than Du. This result is found to be on line with the finding obtained by Keller and Bliesner (2000). They reported that, according to the mathematical relationship between Cu and Du, Cu will always be larger since positive and negative deviations from the mean application volume are used in calculating Cu. But, only negative deviations are used in the calculation of D_u. Similar results were reported by Tarjuelo et al. (1999).

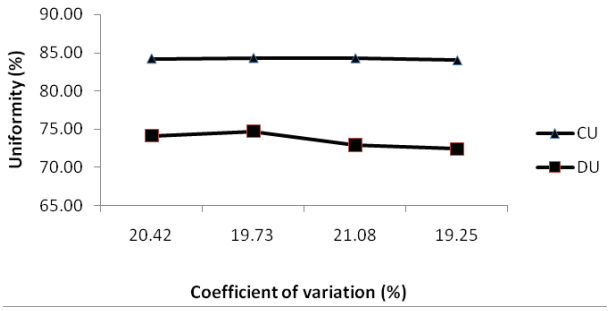

Fig. 3. Relationship of C_u and D_u with respect to C_v

Crop water productivity of summer clusterbean

Crop water productivity of clusterbean is presented in Table 1. Average value of water productivity for three seasons of 2015, 2016 and 2017 are presented in the table. Crop yield was recorded as 2149, 1924, 1119 and 708 kg ha^{-1} under 100, 80, 60 and 40% irrigation levels, respectively. During the growing seasons, average crop water productivity observed from 0.21 ($I_{40\%}$) to 0.35 kg m^{-3} ($I_{80\%}$). Water productivity was found maximum, 0.35 kg m^{-3}, at irrigation level equivalent to 80% CPE compared to control (100% of CPE) for which the water productivity was 0.30 kg m^{-3}. Applied water consumed by crop as crop evapotranspiration was maximum (686 mm) for 100 % irrigation level while lowest (340 mm) for 40% irrigation level (Table 1). 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 has been found similar to our results. It can also be seen from Table 1 that uniformity coefficient and distribution uniformity are on higher side for irrigation level at 100 and 80% which might have resulted in more uniform application and distribution of water under these two treatments for better crop water productivity.

Table 1. Water productivity of summer clusterbean

*Treatment	Actual crop ET (mm) (mean of three seasons)	Yield (kg ha^{-1})	Water productivity (kg m^{-3})	Uniformity coefficient (%)	Distribution uniformity (%)
T_1 (I_{100}%)	686	2149	0.31	84.22	74.12
T_2 (I_{80}%)	554	1924	0.35	84.30	74.70
T_3 (I_{60}%)	454	1119	0.25	84.27	72.90
T_4 (I_{40}%)	340	708	0.21	83.99	72.39

CONCLUSION

Based on the results obtained under this study, Christiansen's uniformity coefficient (C_u) for all the irrigation levels was found in the range of 84-85%. Distribution uniformity (D_u) was found in the range of 72.39 and 74.12%, which can be put under satisfactory category. Under 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 30 mm ($I_{60\%}$) and 20 mm ($I_{40\%}$) 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}. Better uniformity coefficient and distribution uniformity at 100 and 80% of irrigation level resulted in more uniform application and distribution of water for better crop water productivity. As was indicated in previous studies researchers use various methods to evaluate work quality of irrigation machinery, e.g. coefficient of uniformity, coefficient of non-uniformity, degree of uniformity and coefficient of variation. It means that the expressed individual equations may achieve different results in irrigation water distribution uniformity on the same elementary areas.

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