

*Full Length Research Paper*

# Evaluation model development for sprinkler irrigation uniformity based on catch-can data

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**A new evaluation method with accompanying software was developed to precisely calculate uniformity from catch-can test data, assuming sprinkler distribution data to be a continuous variable. Two interpolation steps are required to compute unknown water application depths at grid distribution points from radial distribution of catch-cans' data: using both radial and peripheral interpolations. Interpolation by cubic splines was used to give more accurately interpolated values. This method has higher accuracy theoretically compared with conventional methods to analyze catch-can data. Water application depths were calculated at each grid point and uniformity coefficients were computed from the grid distribution maps of water application depths. This has value in assessing application uniformity of sprinkle irrigation designs.**

**Key words:** Sprinkler irrigation, uniformity evaluation, model development, twice interpolation.

## INTRODUCTION

Water application uniformity is an important performance criterion for the design and evaluation of sprinkler irrigation systems (Derrel and Ronald, 2007). It also affects the profitability of crops (López-Mataa et al., 2010). The most commonly used term for placing a numerical value on uniformity of application for agricultural irrigation systems is Christiansen's coefficient of uniformity expressed as a percent (Christiansen, 1942). It is based on the absolute deviation of individual amounts from the mean amount. Another parameter that is also widely used is the distribution uniformity. The DU is defined as the ratio of the mean depth caught on the quarter of the field receiving the least amount, divided by the mean depth caught on the entire field, and multiplied by 100 to express this as a percent. The magnitude of coefficient of

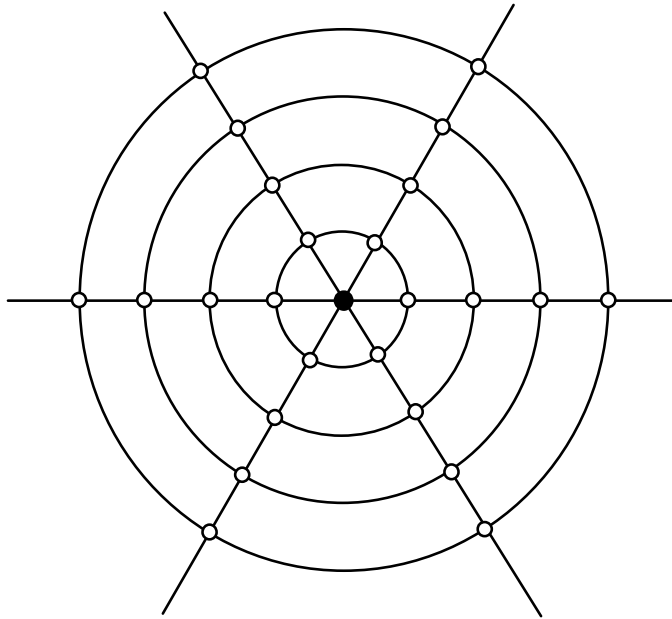
uniformity (CU) is usually greater than that of DU, but this is not the case for all data sets (Lin and Merkley, 2011).

The impact of pressure variation (within the manufacturer-recommended ranges) on application uniformity is less than that of the sprinkler spacing (Lin et al., 2011). A generalized catch weighting factor should be used for calculating the CU and DU for center-pivot catch data from a radial leg of containers with non-uniform container spacing (Marjang et al., 2011).

Most of the effort to evaluate sprinkler irrigation system uniformity and efficiency is done with "can" (catch container) tests and the uniformity and efficiency is calculated from catch-can data (ASAE S398.1 R2007). However, catch-can testing is very time-consuming and in most cases water depth data can only be collected along a limited number of radial lines around a sprinkler head. Therefore, the uniformity under any sprinkler spacing can be determined by overlapping the catch-can test data of a single sprinkler. Data interpolation is required to calculate a certain point's data associated with the overlap. Catch-can data interpolation is also used to build water application depth distribution maps. Maps identify actual field locations receiving given amounts of water, and nutrient input if the irrigation system is also used for chemigation.

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**Abbreviations:** DU, Distribution uniformity; CU, coefficient of uniformity; SOPM, sprinkler overlap program.



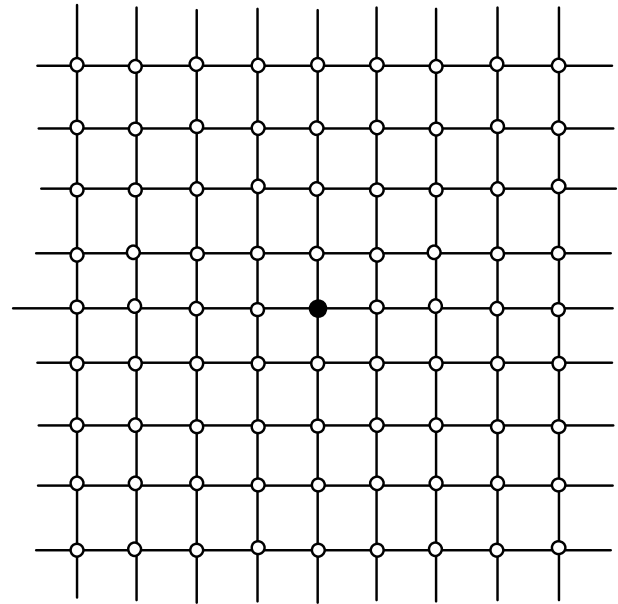
○ Observation Point

**Figure 1.** Spider-web distribution of observation points around single sprinkler head.

The most commonly-used interpolation method is linear interpolation in which unknown data is found from the surrounding three or four known catch-can data points (Evans, 1995). This method assumes that water application depth is a random variable. However, that assumption may not be true if sprinkler distribution patterns have highly predictable shapes. In such a case, application depth may be directly calculated, assuming application depths not to be randomly distributed. This research provides an interpolation algorithm to prepare distribution maps of water depth from catch-can test data for a sprinkler irrigation system. Uniformity parameters (DU and CU) are then calculated from the distribution maps of application depth. This method assumes that water application depth is a continuous variable.

**MODEL DEVELOPMENT**

The water application depth of an irrigation system is not uniform across a field. It depends on the sprinkler design, sprinkler spacing, operating pressure and orientation, wind speed and direction, pressure distribution in the sprinkler lateral and field topography. Developing a theoretical formula for the distribution of application depths is difficult. Practically, catch-can tests and /or computer simulation models are often used to collect and estimate water application depth at a limited number of field locations. If the number of observation points is sufficiently large, a map showing the application depth



○ Interpolated Point

**Figure 2.** Grid distribution of interpolated points around single sprinkler head.

can be built from these data points with an acceptable accuracy.

For a sprinkler in fixed irrigation systems, available data points are typically in spider-web distributions as shown in Figure 1. There are a number of data points along each radial line and the data points usually have the same spacing. A grid of data points is required to prepare distribution maps of water depth as shown in Figure 2. Double interpolation is needed to convert radial data points into grid point data.

In Figure 3, there are six radial lines named  $l_1, l_2, l_3, l_4, l_5$  and  $l_6$ , with catch-cans placed along these six lines and having the same spacing.  $D_{m \times n}$  are estimates of depth of water applied at any grid point  $P_{m \times n}$  in which the subscripts  $m$  and  $n$  are the two dimensional grid coordinates. So, point  $P_{m \times n}$  is the intersection of lines  $m$  and  $n$ . The polar radius  $r_{m \times n}$  of point  $P_{m \times n}$  is the semi-diameter of circle  $\Phi_a$  while  $a_1, a_2, a_3, a_4, a_5$  and  $a_6$  are the intersection points of  $\Phi_a$  and lines  $l_1, l_2, l_3, l_4, l_5$  and  $l_6$ .

The algorithm for double cubic spline interpolation to calculate  $D_{m \times n}$  can be divided into two steps: radial interpolation and peripheral interpolation. Radial interpolation concerns water depths  $D_{a_i}$  of points  $a_i$  ( $i=1,2,3...6$ ) along each line. Smoother interpolated values can be obtained with the cubic spline interpolation method. For example, the water depth  $D_{a_1}$  can be estimated as follows:

$$D_{a_1} = f(d_1, d_2, \dots, d_j) \tag{1}$$

Where,  $j$  is the total number of observation points along a

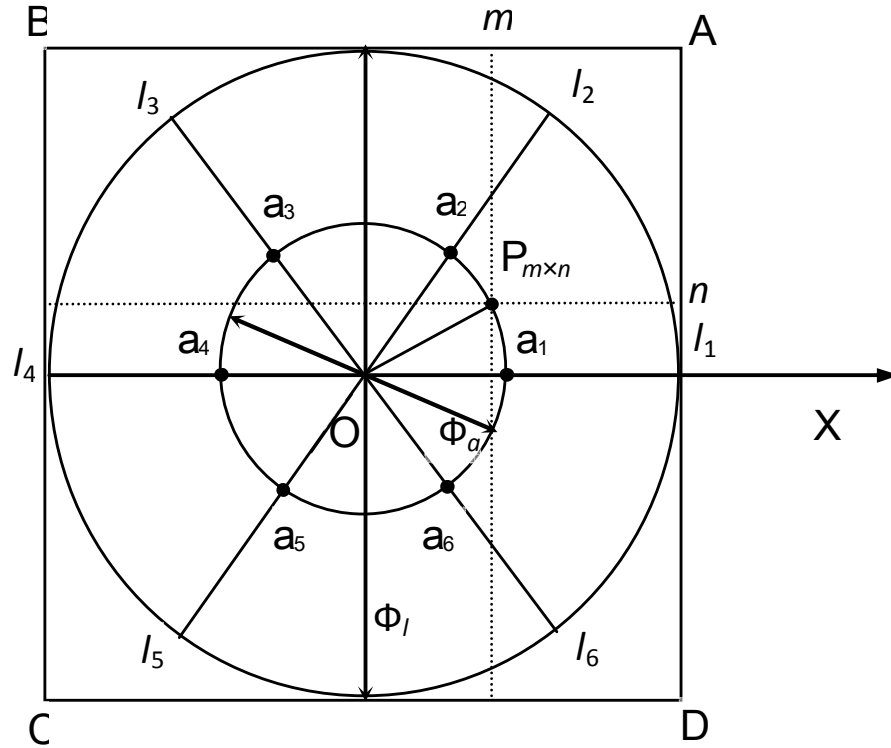


Figure 3. Two-dimensional interpolation.

radial line  $l_i$ ;  $f$  is the cubic spline interpolating function;  $d_i$  ( $i=1,2,3,\dots,j$ ) is the depth at observation points along line  $l_i$ . Other estimates of water depth, namely  $D_{a2}$ ,  $D_{a3}$ ,  $D_{a4}$ ,  $D_{a5}$ , and  $D_{a6}$  can be obtained in a similar way.

The second step, peripheral interpolation, estimates the value of a water depth  $D_{m \times n}$  at grid point  $P_{m \times n}$  from  $D_{a1}$ ,  $D_{a2}$ ,  $D_{a3}$ ,  $D_{a4}$ ,  $D_{a5}$ , and  $D_{a6}$  using:

$$D_{m \times n} = f(D_{a1}, D_{a2}, D_{a3}, D_{a4}, D_{a5}, D_{a6}) \tag{2}$$

In this way, the unknown water depths in a grid distribution can be interpolated from known observation points obtained by tests. Therefore, radial point data from catch-can tests can be converted into grid point data and distribution maps of water depth can be obtained under any sprinkler spacings. Then application uniformity can be calculated based on the interpolated water depth distribution. The interpolated coefficient of uniformity (CU) is:

$$CU = 100 * \left\{ 1.0 - \frac{\sum |D_{m \times n} - \bar{D}|}{\bar{D}} \right\} \tag{3}$$

Where,  $\bar{D}$  = average application depth over the whole field.

The interpolated distribution uniformity is:

$$DU = \frac{\text{Meandepth on a quarter of interpolated grid points receiving least amounts}}{\text{Meandepth on all interpolated grid points}} \times 100\% \tag{4}$$

Several empirical studies of sprinkler irrigation uniformity found essentially linear relationships between CU and DU. Numerous studies concluded that distributions of sprinkler application depths in field conditions are often properly described by a normal distribution function (Bliesner and Keller, 2001). A commonly accepted equation is:

$$DU_{KB} = 0.63CU + 37.0 \tag{5}$$

Li and Rao, (1999) obtained a similar equation from permanent set sprinkler irrigation tests under 12 m x 12 m, 6 m x 14 m and 15 m x 15 m irrigation spacings:

$$DU_L = 1.21CU + 24 \quad (r^2 = 0.94, n = 25) \tag{6}$$

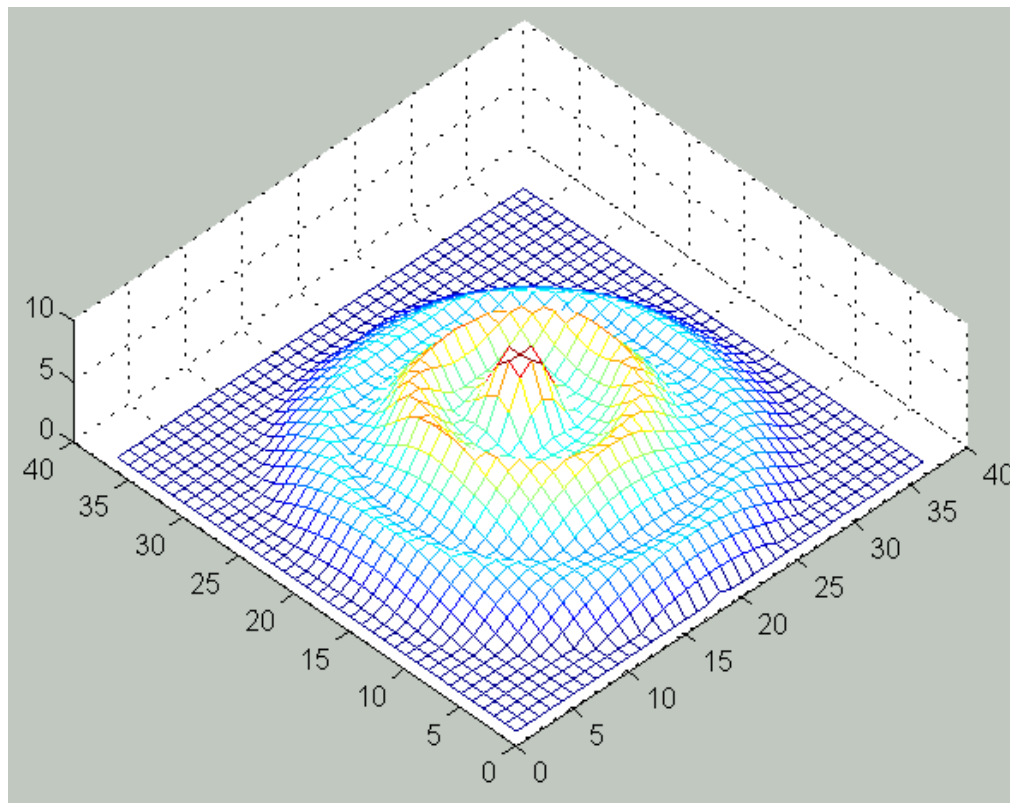
Where,  $r$  is correlation coefficient;  $n$  is sample number. The CU varied from 44 to 98% in tests.

### RESULTS AND DISCUSSION

From interpolated water depths, a set of uniformity parameters were calculated for several spacings between

**Table 1.** Water depth data under catch-can testing for a 30 PSH sprinkler.

Radial distance (m)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
Water depths along different radial lines (mm)	0°	8.7	8.6	6.2	3.3	3.5	3.8	5.1	6.9	5.2	3.6	2.9	2.6	3.5	2.5	1.0	0.3	0.0	0.0	0.0
	60°	8.7	8.7	6.5	3.2	3.4	3.9	4.1	6.4	4.9	4.0	3.7	3.2	3.1	2.0	2.5	1.2	0.7	0.3	0.0
	120°	8.7	8.7	6.6	3.5	3.8	4.2	4.7	5.8	4.9	4.6	3.9	3.3	3.4	2.9	2.9	1.9	1.5	0.9	0.3
	180°	8.7	8.8	6.7	3.9	4.3	4.8	5.2	5.6	4.6	4.2	3.0	2.0	3.1	2.2	2.6	2.0	1.7	1.3	0.6
	240°	8.7	8.7	6.5	3.7	3.6	4.4	4.5	5.4	4.8	4.3	3.6	3.3	3.2	2.5	2.7	1.4	1.4	0.8	0.3
	300°	8.7	8.7	6.4	3.9	3.5	4.6	4.7	6.3	4.5	4.9	3.8	3.9	3.7	2.8	2.2	1.2	0.9	0.3	0.0



**Figure 4.** Distribution map of water depth for single 30 PSH sprinkler head

sprinklers. To do this, a sprinkler overlap program “SOPM” (sprinkler overlap program using MATLAB) was developed. In this program, cubic spline interpolation can be done quickly after inputting the original data for observation points of the catch-can tests. The catch-can tests were conducted with six radial lines for a Rain Bird 30 PSH sprinkler (Throw distance:  $r = 18\text{ m}$ ) and the water depths along these lines are shown in Table 1.

The water depth distribution map and contour map for this single 30 PSH sprinkler head are shown in Figures 4 and 5. A distribution map of water depth overlap and contour map for 30 PSH sprinklers in  $22 \times 22\text{ m}$  spacing are shown in Figures 6 and 7.

From maps of water depth on a grid distribution, the

four uniformity parameters ( $CU$ ,  $DU$ ,  $DU_{KB}$ , and  $DU_L$ ) were calculated for several spacings (Tables 2 and 3 and Figure 7).

From Tables 2 and 3 and Figure 7, the distribution uniformity  $DU_{KB}$ , (Equation 5) closely followed the value of distribution uniformity  $DU$  (Equation 4).  $DU_{KB}$ , was slightly greater than  $DU$  with the spacing coefficient being less than 1.20 while the spacing coefficient was greater than 1.20. The  $DU_L$ , (Equation 6) closely followed the variation of distribution uniformity  $DU$ , but had higher values than  $DU$  and  $DU_{KB}$ . The uniformities fall generally when spacing distance increased for a square spacing (Table 2 and Figure 7), while the uniformities reached their highest values ( $CU = 82.0$ ,  $DU = 71.4$ ,  $DU_{KB} = 71.4$ ,

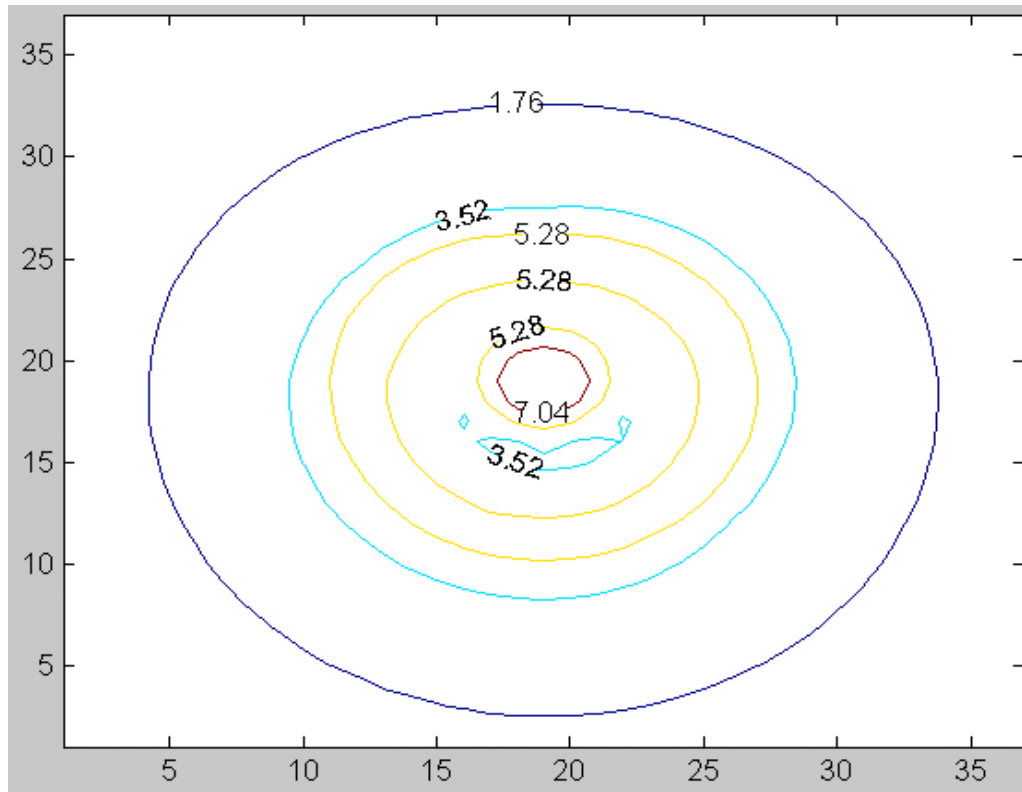


Figure 5. Distribution contour map of water depth for single 30 PSH sprinkler head

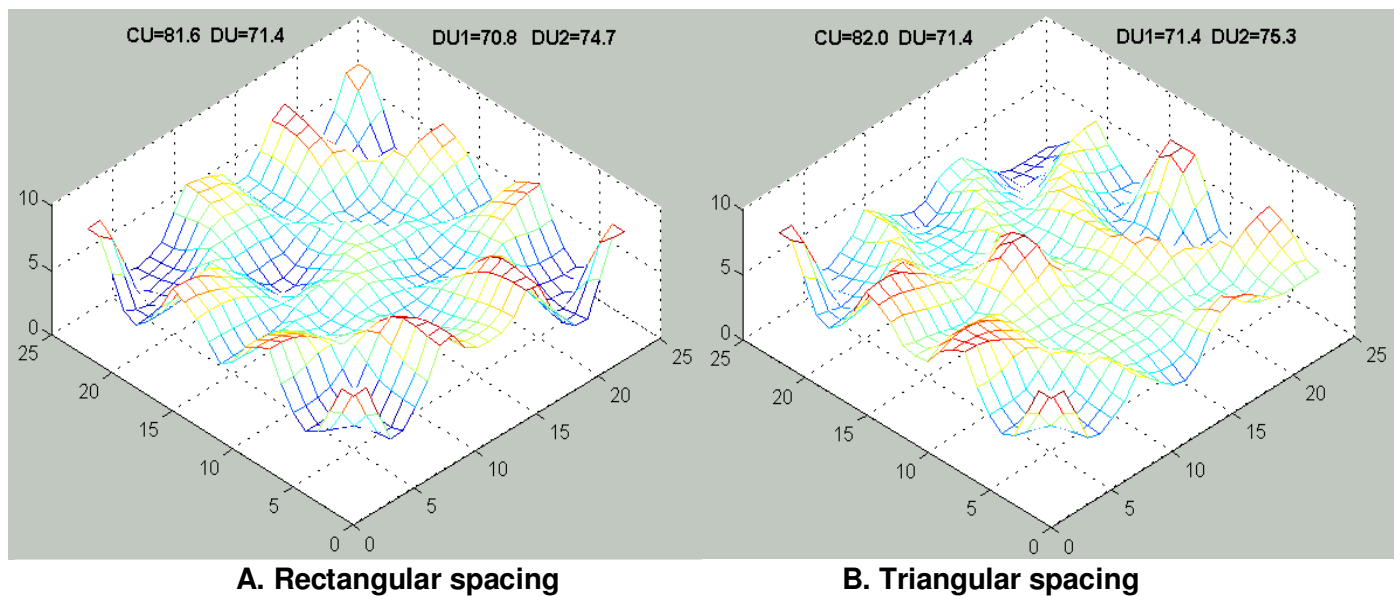


Figure 6. Distribution map of water depth overlap for four 30 PSH sprinklers in 22x22m spacings.

and  $DU_L = 75.3$ ) when spacing coefficient was equal to 1.20 under the regular triangle spacing (Table 3 and Figure 7).

**Conclusion**

Interpolation of catch-can test data is required to prepare

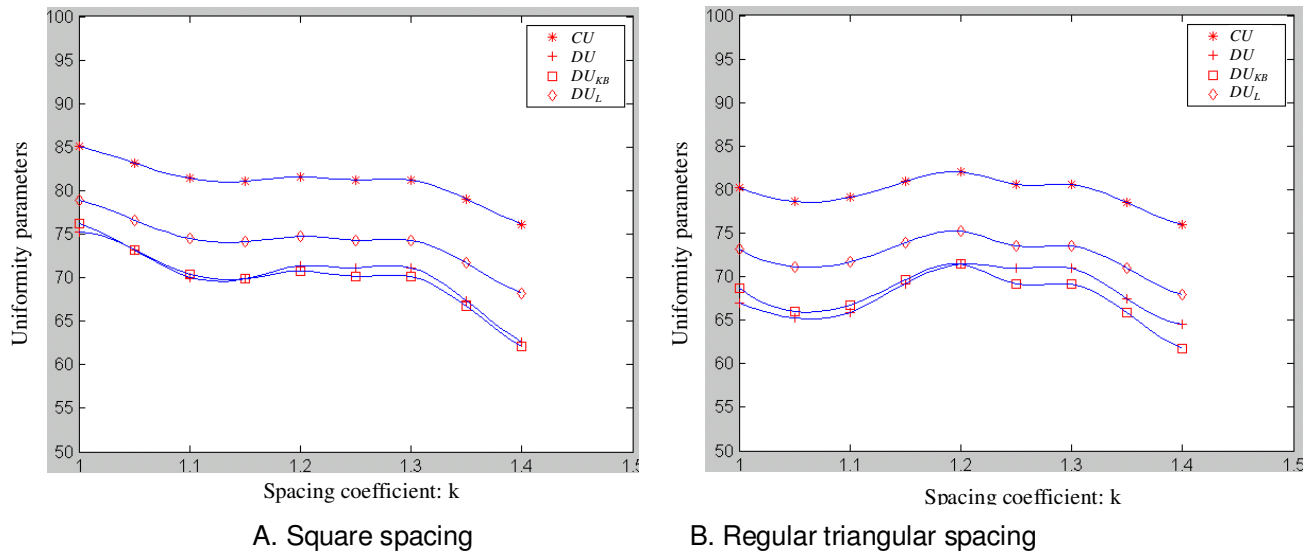


Figure 7. Distribution map of water depth overlap for four 30 PSH sprinklers in 22x22m spacings

Table 2. Water application uniformity for 30 PSH sprinklers under square spacing with different spacings.

Spacing	k=1.00 (l=18m)	k=1.05 (l=19m)	k=1.10 (l=20m)	k=1.15 (l=21m)	k=1.20 (l=22m)	k=1.25 (l=23m)	k=1.30 (l=23m)	k=1.35 (l=24m)	k=1.40 (l=25m)
CU	85.1	83.2	81.4	81.1	81.6	81.2	81.2	79.1	76.2
DU	75.2	73.2	70.1	69.9	71.4	71.1	71.1	67.3	62.6
DU <sub>KB</sub>	76.2	73.2	70.4	69.9	70.8	70.1	70.1	66.7	62.1
DU <sub>L</sub>	78.9	76.6	74.5	74.1	74.7	74.3	74.3	71.7	68.1

k-spacing coefficient; l-distance of spacing, l=kr, where r is throw distance of sprinkler, r=18m.

Table 3. Water application uniformity for 30 PSH sprinklers under regular triangle spacing with different spacings.

Spacing	k=1.00 (l=18m)	k=1.05 (l=19m)	k=1.10 (l=20m)	k=1.15 (l=21m)	k=1.20 (l=22m)	k=1.25 (l=23m)	k=1.30 (l=23m)	k=1.35 (l=24m)	k=1.40 (l=25m)
CU	80.3	78.6	79.1	80.9	82.0	80.6	80.6	78.5	76.0
DU	67.0	65.2	65.9	69.2	71.4	70.9	70.9	67.5	64.5
DU <sub>KB</sub>	68.6	66.0	66.7	69.6	71.4	69.1	69.1	65.8	61.8
DU <sub>L</sub>	73.1	71.1	71.7	73.9	75.3	73.5	73.5	71.0	68.0

maps of water application depth and to calculate irrigation uniformity parameters. When sprinkler distribution patterns have highly predictable shapes, the water distribution will be a continuous variable. Based on this, a new evaluation method and accompanying software “SOPM” were developed to precisely calculate uniformity from catch-can test data. This interpolation includes radial and peripheral interpolations. Cubic splines interpolation was used to give more accurately interpolated values.

This method had higher accuracy in estimating irrigation uniformity parameters compared with conventional methods, as it considered all catch-cans’ data and their positional information in estimating water depths on a two dimensional grid. Distribution maps of water depth could also be generated from a limited number of observation data points by interpolation. Spatial water and/or nutrient application distribution maps are often required in management and evaluation of sprinkler irrigation systems.

## ACKNOWLEDGMENTS

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