African Journal of Biotechnology Vol. 10(66), pp. 14796-14802, 26 October, 2011
Available online at http://www.academicjournals.org/AJB
DOI: 10.5897/AJB11.1954

Full Length Research Paper

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

Wenting, Han[1,2,3] and Pute, Wu[1,2,3]*

[1]Institute of Efficient Water Use for Arid Agriculture of China, Northwest A and F University, Yangling, China.
[2]Institute of Soil and Water Conservation, Chinese Academy of Sciences and Ministry of Water Resources, Yangling, China.
[3]National Engineering Laboratory for Crop Water Efficient Use, Yangling, China.

Accepted 5 October, 2011

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.

*Corresponding author. E-mail: wupt2011@vip.sina.com. Tel: +86-29-87082802. Fax: +86-29-87082802.

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

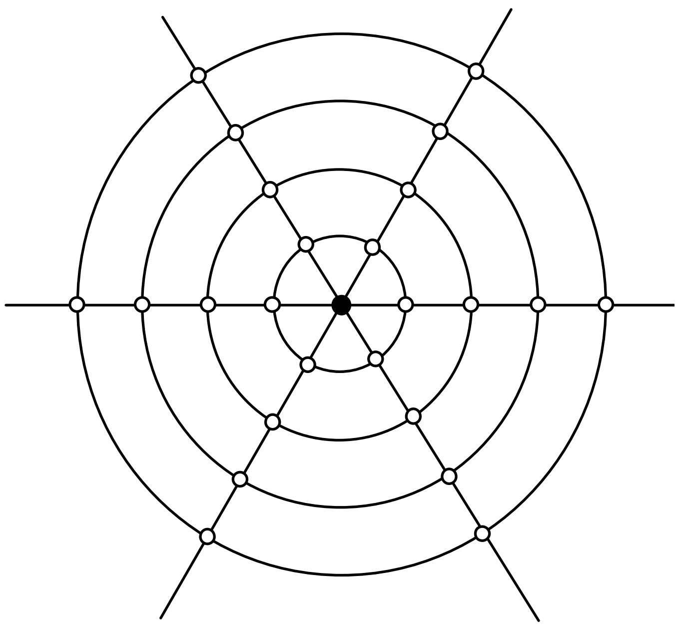


Figure 1. Spider-web distribution of observation points around single sprinkler head.

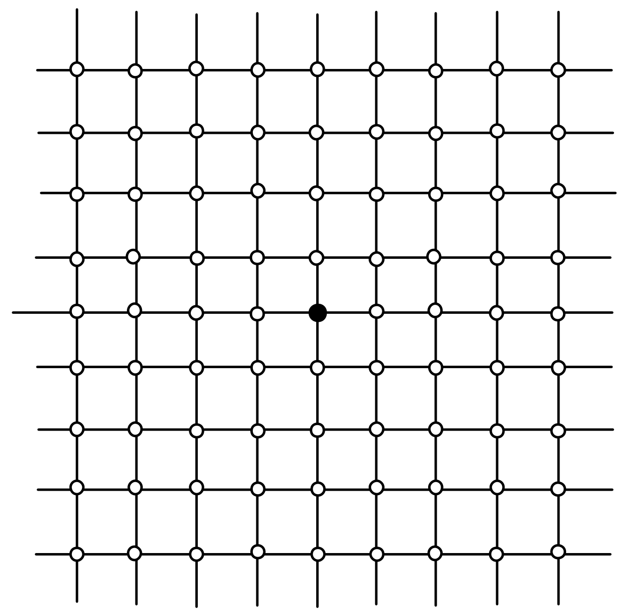


Figure 2. Grid distribution of interpolated points around single sprinkler head.

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 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 co-ordinates. 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 Φ_a while a_1, a_2, a_3, a_4, a_5 and a_6 are the intersection points of Φ_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_{ai} 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_{a1} can be estimated as follows:

$$D_{a1} = f\,(d_1, d_2, \ldots, d_j) \quad (1)$$

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

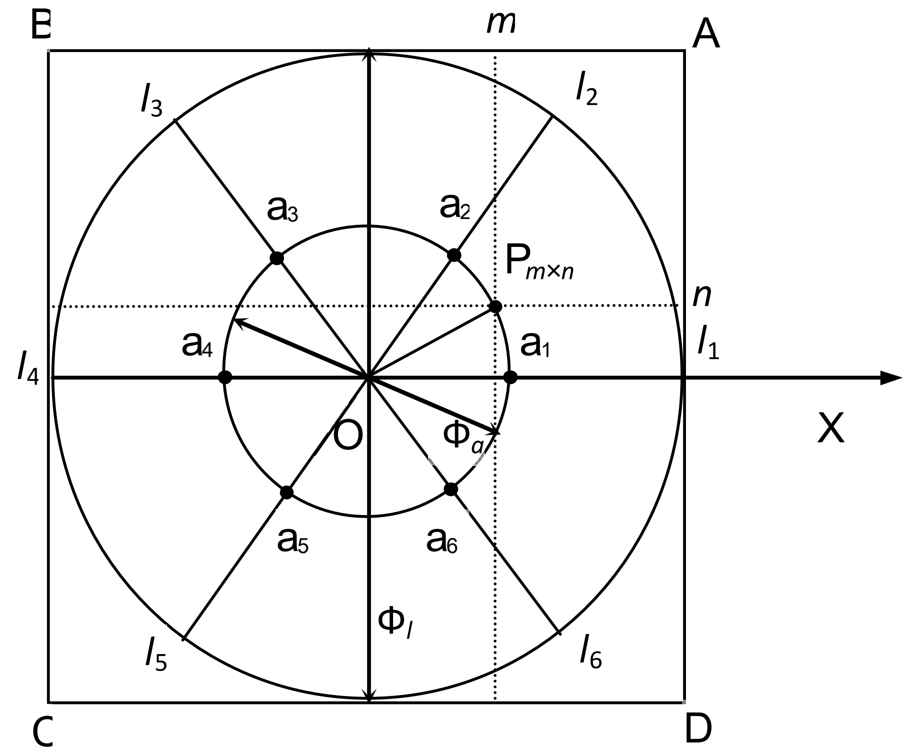


Figure 3. Two-dimensional interpolation.

radial line l_1; f is the cubic spline interpolating function; d_i (i=1,2,3,…j) is the depth at observation points along line l_1. 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:

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

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

The interpolated distribution uniformity is:

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

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 × 12 m, 6 m × 14 m and 15 m ×15 m irrigation spacings:

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

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)	0º	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
	60º	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
	120º	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
	180º	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
	240º	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
	300º	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

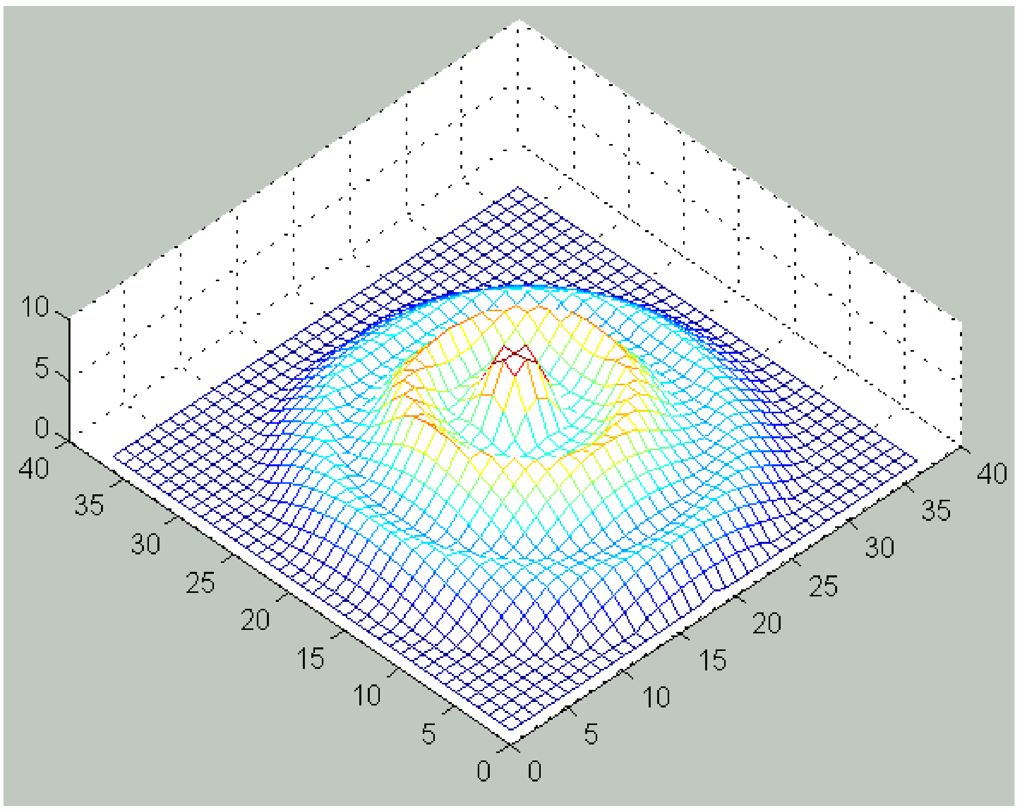


Figure 4. Distribution map of water depth for single 30 PSH sprinkler head

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 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 × 22 m spacing are shown in Figures 6 and 7.

From maps of water depth on a grid distribution, the four uniformity parameters (*C*U, 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,

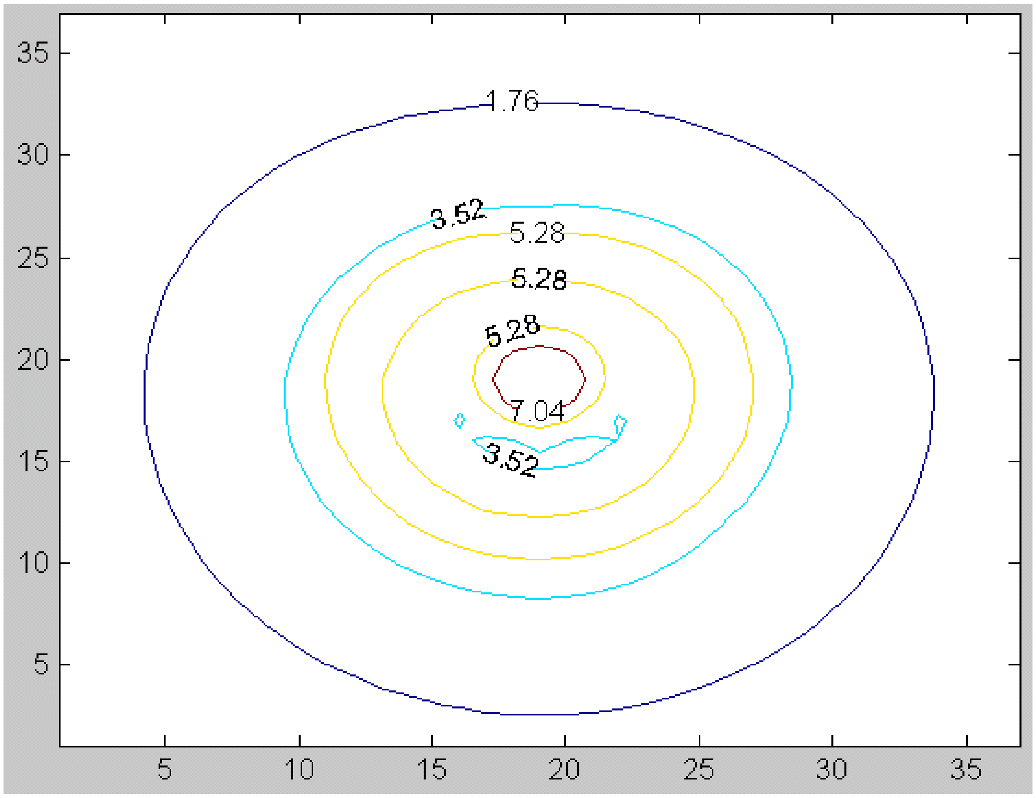


Figure 5. Distribution contour map of water depth for single 30 PSH sprinkler head

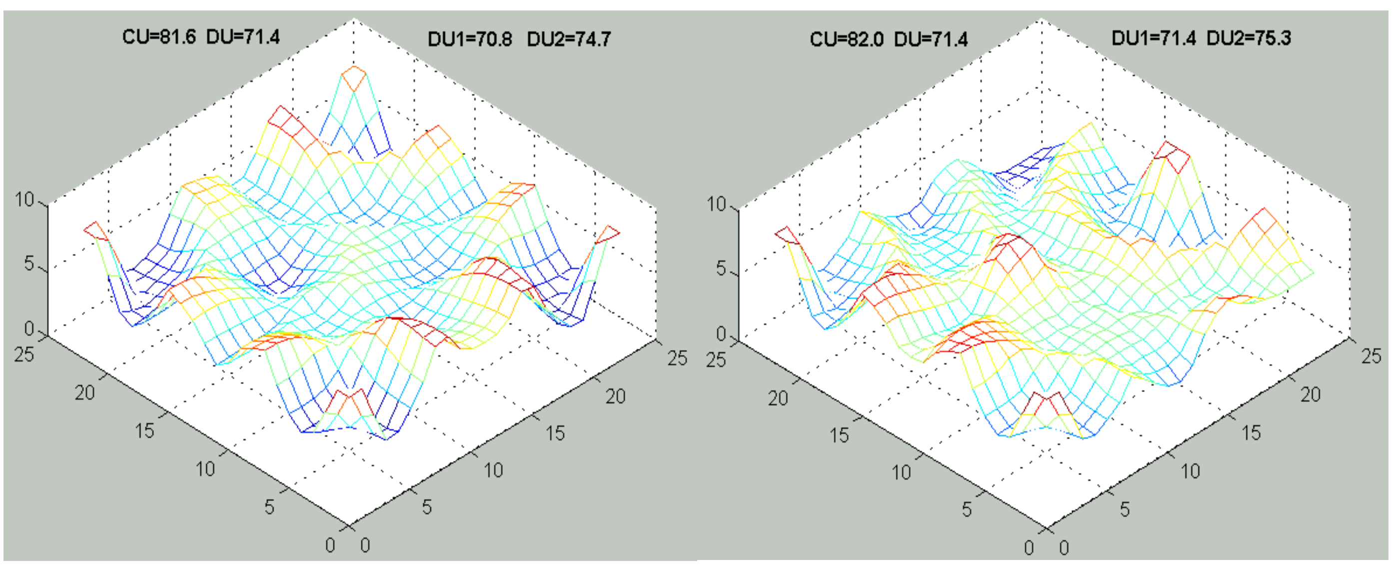
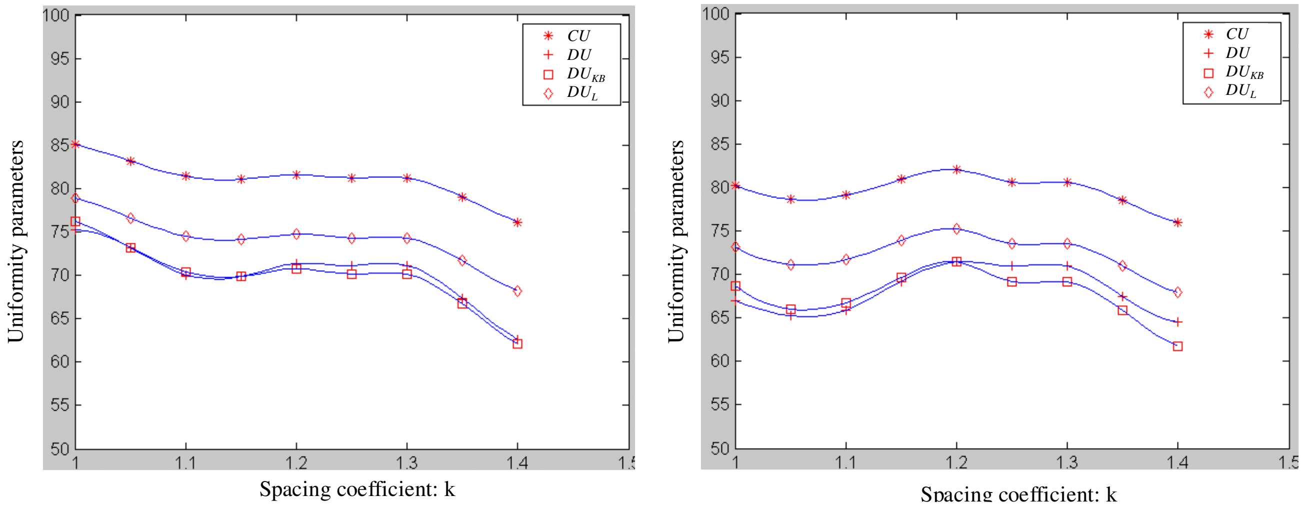


Figure 6. Distribution map of water depth overlap for four 30 PSH sprinklers in 22×22m spacings.

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



A. Square spacing B. Regular triangular spacing

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

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

Spacing / Uniformity	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_{KB}	76.2	73.2	70.4	69.9	70.8	70.1	70.1	66.7	62.1
DU_L	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 / Uniformity	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_{KB}	68.6	66.0	66.7	69.6	71.4	69.1	69.1	65.8	61.8
DU_L	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

This paper founded by National Nature Science Project " Dynamic simulation on water distribution of irrigation sprinkler under wind condition and various water pressure" from National Nature Science Foundation of China (Project number: 51079140), National Science and Technology Supporting Plan (2011BAD29B08), '111' Project of Chinese Education Ministry (B12007) and the Basic Research Supporting Plan of Northwest A and F University.

REFERENCES

ASAE (1985). Procedure for sprinkler distribution testing for sprinkler distribution testing for research purposes (32nd Edition). ASAE Standards S 330.1, Michigan.

Akima H (1978). A method of bivariate interpolation and smooth surface fitting for irregularly distributed data points. ACM Trans. Math. Softw. 4: 148-149.

Christiansen JE (1942). Irrigation by sprinkling. California agricultural experiment station bulletin, vol 670. University of California, Berkeley.

Derrel LM, Ronald LE (2007). Design and Operation of Farm Irrigation Systems (2 Edition). American Society of Agricultural and Biological Engineers, Michigan.

Evans RG, Han S, Kroeger MW (1995). Spatial distribution and uniformity evaluations for chemigation with center pivots. Trans. ASAE. 38(1): 85-89.

Han WT (2003). Variable rate application and contour controlled precision sprinkler and sprinkler irrigation. Northwest A & F Univ. Yangling, Shaanxi, China.

Hart WE, Renolds WN (1965). Analytical design of sprinkler system. Trans. ASAE. 8(1): 83-85,89.

Heermann DF, Duke HR, Serafim AM, Dawson LJ (1992). Distribution functions to represent center-pivot water distribution. Trans. ASAE. 35(5): 1465-1472.

Keller J, Bliesner RD (2001). Sprinkle and trickle irrigation. The Blackburn Press, New Jersey, USA.

Li JS, Rao MJ (1999). Evaluation method of sprinkler irrigation nonuniformity. Trans. CSAE. 15(4): 78-82.

Lin Z, Merkley GP (2011). Relationships between common irrigation application uniformity indicators. Irrig Sci. Online First™, 27 January 2011

Lin Z, Merkley, GP, Pinthong K (2011). Assessing whole-field sprinkler irrigation application uniformity. Irrig Sci. Online First™, 7 July 2011

López-Mata E, Tarjuelo JM, de Juan JA (2010). Effect of irrigation uniformity on the profitability of crops. Agric. Water Manage. 98(1): 190-198.

Marjang N., Merkley GP, Shaban M (2011). Center-pivot uniformity analysis with variable container spacing. Irrig Sci. Online First™, 3 March 2011.

Merlo C (1999). Water distribution and operating parameters of the sprinklers at the Moncrivello-Maglione Irriguous Union. Rivista-di-Ingegneria-Agraria (Italy). 30(1): 19-24.

Pietras F (1988). Discharge profile equations of multiple overlapping sprinklers as a base of analysis of the irrigation non-uniformity degree in view of using it to optimization of irrigation uniformity. Polish Agricultural Annual. Series F-Land Reclamation, 81(3): 121-133.

The Irrigation Association. (2007). Procedure for Sprinkler Testing and Performance Reporting. ASAE S398.1 MAR1985 (R2007).

Warrick AW (1983). Interrelationships of irrigation uniformity terms. J. Irrig. Drain. Eng. 115(4):129-136.