http://www.pjbs.org

PJBS

ISSN 1028-8880

Pakistan Journal of Biological Sciences

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Pakistan Journal of Biological Sciences 11 (2): 214-219, 2008
ISSN 1028-8880

Determining the Uniformity Coefficient and Water Distribution Characteristics of Some Sprinklers

Tekin Kara, Emine Ekmekci and Mehmet Apan
Department of Agricultural Structures and Irrigation Engineering, Faculty of Agriculture, Ondokuz Mayis University, 55139, Kurupelit, Samsun, Turkey

Abstract: The basic aim of the sprinkler irrigation method, as in other irrigation methods, is to apply irrigation water as uniformly as possible to the root zone. The uniform distribution of the applied water in sprinkler irrigation depends on factors such as sprinkler type, number and size of nozzles, arrangement of sprinklers, working pressure and the speed and direction of the wind. Sprinkler and lateral spacing should be determined by also taking the speed and direction of the wind into consideration. The aim of this study was to determine the application limits and the curves of water distribution under different working pressures, spatial arrangement and nozzle diameters under field conditions of some irrigation sprinklers which are widely used in Turkey. The objective was to determine the most appropriate system arrangement by using a computer program called CATCH3D. Five sprinklers were tested in the experimental area of Ondokuz Mayis University Campus and their water distribution characteristics identified. The most suitable operating parameters for Bereket 3: 12×18 m, Bereket 2: 12×18 m, Egeyildiz 6×18 m, Goktepe 6×12 m and for Atesler sprinkler 12×18 m arrangement type were determined.

Key words: Sprinkler, wind speed, arrangement, water distribution curves

INTRODUCTION

The main objective of irrigation is to apply to the crop root zone the optimum amount of water that the crop needs for development and also that cannot be provided by rains.

The sprinkler irrigation method, one of the pressurized irrigation systems, takes water from a source and sprays it to the atmosphere as droplets by means of an enclosed system and under pressure. The water is transmitted to the surface of the soil in equal distribution with the sprinkler irrigation system to obtain uniform distribution in the crop root zone (Keller and Bliesner, 1990).

Sprinkler irrigation systems, as opposed to furrow irrigation, transmit water to the field independently of topography. Spacing and discharge of sprinkler determine the application rate which should be less than infiltration rate for not producing surface runoff.

The degree of uniformity of water distribution depends on the water distribution styles and features of sprinkler nozzles. The basic function of sprinkler nozzles is to distribute water uniformly, without causing surface flow and excessive drainage from the root zone. For this reason, the sprinkler nozzle is considered to be the most important element of the system. The performance of the sprinkler nozzle determines the productivity and efficiency of the whole system (Keller and Bliesner, 1990; Wilson and Zoldoske, 1997). A successful irrigation regime can be determined by researching all the relevant factors and then effectively using the data produced.

In sprinkler irrigation, water distribution figures for nozzles at different spatial arrangements are determined by considering the soaking field observed for each value of pressure and the size of nozzle. It is necessary that the determined water distribution be at an acceptable level. This is determined by the equal distribution coefficient (Keller and Bliesner, 1990; Allen, 1993). Uniformity coefficient developed by Christiansen in 1942 is stated below (Vories and Von Bernuth, 1986; Losada *et al.*, 1990; Allen, 1993).

$$CU = 100 * \left(1.0 - \frac{\sum x}{n.m}\right)$$

or

$$CU = 100 * \left(1.0 - \frac{\sum |z - m|}{\sum z}\right)$$

Corresponding Author: Tekin Kara, Department of Agricultural Structures and Irrigation Engineering, Faculty of Agriculture, Ondokuz Mayis University, 55139, Kurupelit, Samsun, Turkey
Tel: +90 362 312 1919/1354 Fax: +90 362 457 6034

Where:

CU	=	Equal distribution coefficient developed by Christiansen (%)
Z	=	The amount of water measured in each container while testing uniformity (mm, mL)
x = |z-m|	=	The total absolute value of deviations from average of the amount of water measured in all accumulation containers (mm, mL)
m = (Σz)/n	=	Average amount of water (mm, mL)
n	=	The number of water accumulation containers

A CU coefficient of 84% is desirable. Arrangement styles that have the results less than this value should not be used (Keller and Bliesner, 1990).

In practice, it's not possible to obtain 100% of uniformity on the irrigated area because nozzles distribute water on a circular area, with overlaps between areas of water distribution. It's impossible to have equal water distribution on the areas that are being irrigated (Zoldoske *et al*., 1994; Stryker, 1998).

The main factors affecting water application (water distribution uniformity) are sprinkler nozzle type, operating pressure, nozzle diameters, nozzle elevation, wind speed, heat and damp (Keller and Bliesner, 1990; Allen, 1996; Wilson and Zoldoske, 1997; Tarjuelo *et al*., 1999; Loule and Selker, 2000).

The uniformity in water distribution depends on the distance between the sprinkler nozzles as well (Wilcox and Swailes, 1947). As sprinklers are spaced further apart, uniformities usually decrease (Tarjuelo *et al*., 1999; Joshi *et al*., 1995).

No sprinkler nozzle should be operated without providing the desired over-lateral and inter-lateral overlap. Desired degree of overlap is achieved by the sprinkler pattern of nozzles and wind conditions. Spacing should be closer in windy weather. Lateral and nozzle spacing should be determined according to different speeds and directions of wind and different nozzle pressures (Chawla and Narda, 1995; Faci and Bercero, 1989; Abo-Ghobar and Al-Amoud, 1993). Since windy conditions negatively affect the distribution of water, the spaces between nozzles should be decreased. It is generally suggested that irrigation be carried out when wind speed is lower than 2.5 m sec^{-1} (Ruzicka, 1992). If wind speed increases, the uniformity coefficient decreases (Vories *et al*., 1987; Padmanabhan, 1997; Tarjuelo *et al*., 1999).

Another factor affecting efficiency is sprinkler height which has a great effect on sprinkler uniformity, especially in windy weathers (Abo-Ghobar, 1992). Sprinkler should be at the same height and able to move freely for dispersal of the water droplets. Sprinkler nozzles should also be vertical to the surface of land.

In this research, the single nozzle trial method has been used because, it enables the experiment easily to determine the uniformity coefficient for the different spacing, mostly used in application and it gives sufficient and satisfactory results for the water distribution figures.

The aim of this research was to assess water distribution by using the single nozzle trial method and determine the uniformity distribution coefficient for different arrangement spaces. The objective is to estimate and quantify the effect of main factors influencing the water distribution at the field level in the single nozzle set systems. In addition, a set of recommendation will be given for design and management of these systems for the Middle Black Sea region and for other regions where environmental and agricultural conditions could be similar.

MATERIALS AND METHODS

Material: The experimental field was located on the campus of Ondokuz Mayis University in Samsun, Turkey at 2003. Almost 0.3 ha of experiment field was leveled to 0.0% incline. This incline is important for the water catcher containers.

The water supply was provided from a well that was 150 m distant. The flow rate of the well was 5 L sec^{-1}. A valve that can regulate the pressure and a manometer just under the sprinkler nozzle were used. The flow rate of the sprinkler nozzles was determined with a chronometer and a container, of known volume.

Five different sprinkler nozzles which are widely used in Middle Black Sea region were used. The nozzles used were Bereket 3 and Bereket 2, little plastic sprinkler nozzle produced by Egeyıldız, 15/15 L plastic sprinkler nozzle by Goktepe and the sprinkler nozzle by Atesler.

The height of the nozzle was measured 76 cm from the surface. In order to determine the speed of nozzle rotation, a chronometer was used. For the speed and direction of wind which are important for the distribution figures, an anemometer and a compass were used.

In test, to collect water from the sprinkler nozzles, 576 catch cans (plastic containers) with a 15 cm height and 11.2 cm diameter were used.

The sprinkler head was fixed in the middle of a square field 50×50 m. An approximate 2 m square grid of catch can was located within the space given above. The evaluations were carried out in bare soil.

The sprinklers were operated under different operation pressure in atmosphere (atm). Operation pressures were constant throughout procedure. The sprinkler heads operated pressure were suggested in the brochures of the firms; the Bereket 3 sprinkler nozzle was operated at 1.5, 2.0, 2.5, 3.0, 3.5, 4.0 and 4.5 atm. Bereket 2 at 2.0, 2.5, 3.0, 3.5 and 4.0 atm Egeyıldız at 2.0, 2.5 and 3.0 atm Goktepe at 2.0, 2.5 and 3.0 atm and Atesler at 2.0, 2.5, 3.0, 3.5, 4.0, 4.5 and 4.8 atm. Each test operated 3 h.

Water throwing distances, flow rates and rotation speeds were obtained. Collected data taken from field experiments. Each experimental data entered a computer program called CATCH3D. CU coefficients and 3D water distribution graphs were determined by using the values obtained.

Method: During the trial, the operation pressure and the flow rate was controlled. The rotation speed of the nozzle as cycles/minute was measured. The speed and direction of the wind was measured every 15 min at a height of 2 m with an anemometer. At the end of the trial, the amount of water accumulated in each catch can was measured with cylinders (mL). These experiment procedures were repeated for each sprinkler nozzle at their respective pressure intervals.

Data obtained was entered into the Catch3D computer program developed by Allen (1996). First, the water distribution figure of in the single nozzle was determined and the results have been assessed by determining the Christiansen Uniformity Coefficients on nozzle spacing.

The CU coefficient can be determined with CATCH3D by using input the duration of the experiment, the direction and speed of the wind, the flow rate and water volume in the catch can. The water distribution graphs had drawn by program in three dimensionally (3D). The program can be uses only for field data. It does not produce new data. The most important feature of the program is that it can determine the spacing and CU coefficient. This program is used because it provides rapid and correct calculations and it produces graphics and results directly and rapidly by disregarding complexity and the calculations errors in traditional methods (Allen, 1996).

The figure for water distribution for spacing is generally obtained by applying the overlap method while being used the nozzle in sprinkler systems. This is a time-consuming but cheapest method. In addition, water distribution graphs at different lateral and nozzle spacing can be obtained and plotted without entering the data again. In order to determine whether distribution in the figures is acceptable or not, the CU values are integrated with all these graphics. Thus, it is possible to find suitable spacing by trying more alternative lateral and nozzle spacing in a short time. It also prevents the complexity and manual calculation errors of traditional methods.

RESULTS AND DISCUSSION

During the field experiments data were entered program as given above. The results for the Bereket 3 are given in the Table 1. The 3D water distribution graph for the Bereket 3 at 1.5 atm, is given in Fig. 1 and the water distribution graphs for different spacings and CU coefficients in Fig. 2.

For the Bereket 3 sprinkler nozzle at 1.5 atm pressure, the wind speed was 1.0 m sec^{-1}. At this pressure, a flow rate was 0.30 L sec^{-1} and a wind speed of 1.0 m sec^{-1} there was no accumulation of water distribution in the direction the wind. Water distribution graphics and CU coefficients for different spacing for Bereket 3 were examined, Keller and Bliesner (1990), Allen (1993) and Tarjuelo *et al.* (1999) have reported that CU coefficient should be more than 84%. If this is taken into consideration, the spacing that give a value of CU>84% for Bereket 3 are 6×6 and 6×12 m. It is therefore not appropriate to have the sprinkle nozzle operating at other spacings.

Christiansen Uniformity coefficients of the nozzles at different spacing and pressure are described in Table 1. The spacings giving the value of CU>84.4 for the Bereket 3 are 6×6 and 6×12 m at 1.5 atm; 6×6 and 6×12 m at 2.0 atm; 6×6, 6×12 and 6×18 m at 2.5 atm; 6×6, 6×12, 6×18, 12×12 and 12×18 m at 3.0 atm. At 3.5 and 4.0 atm, the CU

Table 1: Christiansen Uniformity Coefficients of Bereket 3 sprinkler nozzle in the square and rectangle arrangement styles (nozzle diameter, 5 mm)

Working pressure (atm)	CU coefficient (%)					
	6×6 m	6×12 m	6×18 m	12×12 m	12×18 m	18×18 m
1.5	92.7	85.6	72.0	70.9	66.2	49.5
2.0	94.7	85.3	69.6	77.8	68.2	62.5
2.5	95.1	91.6	86.7	80.7	82.3	72.5
3.0	96.2	93.4	91.2	88.6	88.3	80.4
3.5	78.9	72.0	65.6	67.8	58.7	49.5
4.0	81.8	78.5	42.9	64.7	38.2	30.0
4.5	93.9	88.2	91.4	80.0	79.6	71.8

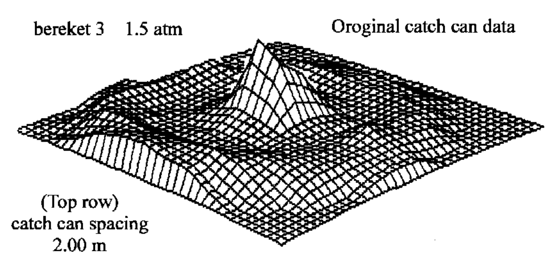

Fig. 1: Three dimensional water distribution, the data observed from Bereket 3 sprinkler nozzle, drawn with the Catch3D. (The flow rate, 0.30 L sec^{-1}, working pressure, 1.5 atm, the wind speed, 1.0 m sec^{-1})

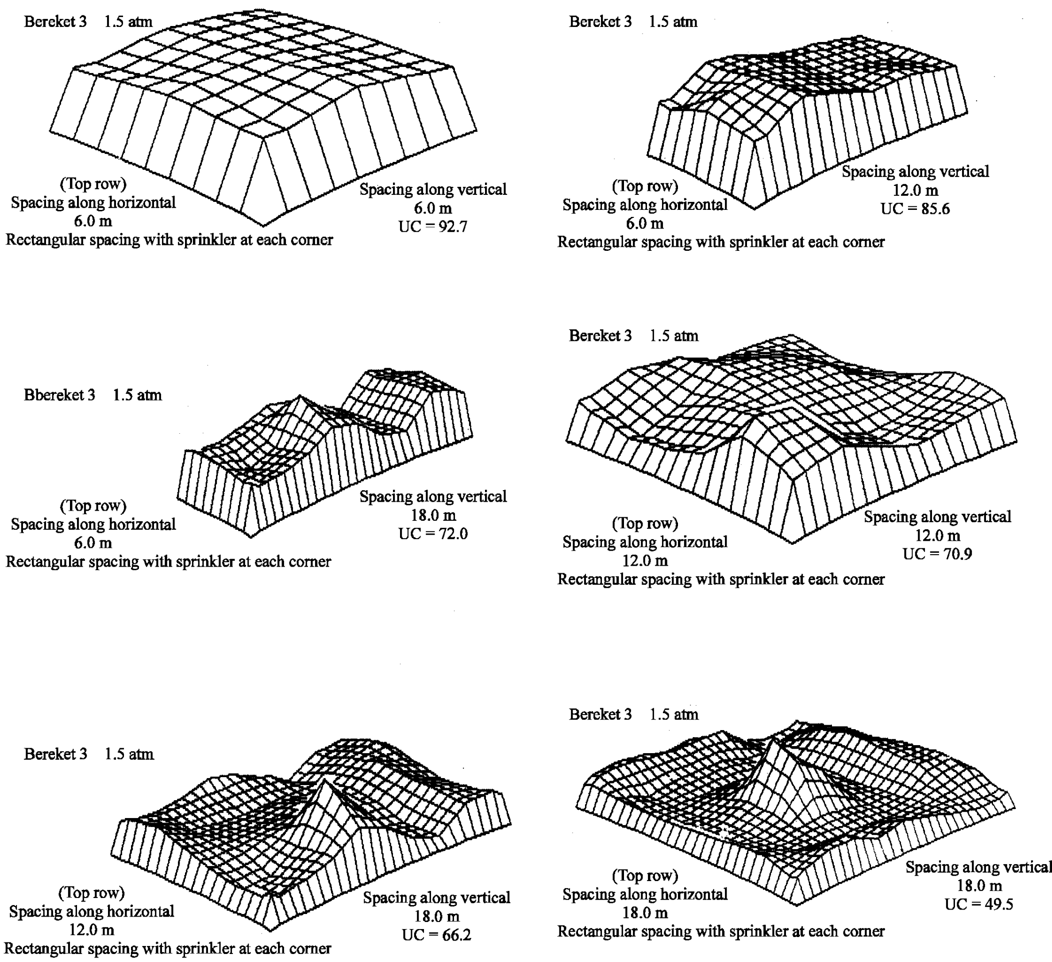

Fig. 2: The three dimensional appearance of water distribution for different spacing in 1.5 atm pressure of Bereket 3 sprinkler nozzle and its uniformity coefficient

coefficient is below 84.4% for all configurations. The suitable arrangements for 4.5 atm, which was the highest pressure of the Bereket 3 sprinkler nozzle, were 6×6, 6×12 and 6×18 m. The results with other sprinkler nozzles are given in Table 2-5.

Technical features of sprinkler nozzles and the suitable arrangements are shown in Table 6. The main objective in sprinkler irrigation is to choose the sprinkler nozzle that enables wide spacing, low pressure and appropriate water distribution. More than one solution that is suitable for the conditions can be found. For this reason, an irrigation project is planned using the appropriate sprinkler nozzle and the water emitting speed nozzle into consideration.

Table 6 shows that the CU coefficient of the sprinkler nozzles tried is rarely over 84.4% at a working pressure. Considering the necessity of choosing the wide spacing for economic reasons, the most suitable spacing

Table 2: Christiansen Uniformity Coefficients of Bereket 2 sprinkler nozzle in the square and rectangle arrangement styles (nozzle diameter, 10 mm)

Working pressure (atm)	CU coefficient (%)					
	6×6 m	6×12 m	6×18 m	12×12 m	12×18 m	18×18 m
2.0	96.2	90.2	86.4	83.9	80.7	74.7
2.5	93.9	86.4	75.0	77.1	66.6	63.3
3.0	93.2	85.1	76.0	77.2	68.7	66.6
3.5	96.6	95.7	87.7	91.8	84.5	77.3
4.0	98.1	89.9	91.2	85.9	86.3	78.0

Table 3: Christiansen Uniformity Coefficients of Egeyildiz sprinkler nozzle in the square and rectangle arrangement styles (nozzle diameter, 4.5×5.0 mm)

Working pressure (atm)	CU coefficient (%)					
	6×6 m	6×12 m	6×18 m	12×12 m	12×18 m	18×18 m
2.0	94.5	64.7	82.3	64.7	70.9	60.6
2.5	95.4	78.6	90.2	73.5	78.2	68.8
3.0	94.1	91.3	61.1	80.2	59.1	46.8

of the Bereket 3 sprinkler nozzle at different working pressures were determined as 6×12 m at 1.5 atm, 6×12 m at 2 atm, 6×18 m at 2.5 atm, 12×18 m at 3.0 atm and 6×18 m in 4.5 atm. No arrangement is suitable for 3.5 and 4.0 atm.

For the Bereket 2 Sprinkler nozzle, which is similar to the Bereket 3, the most suitable spacing was determined as 12×12 m at 2.0 atm, 6×12 m at 2.5 atm, 6×12 m at 3.0 atm, 12×18 m in 3.5 atm and 6×18 m at 4.0 atm.

Table 4: Christiansen Uniformity Coefficients of Goktepe sprinkler nozzle in the square and rectangle arrangement styles (nozzle diameter, 5.5×4.5 mm)

Working pressure (atm)	CU coefficient (%)					
	6×6 m	6×12 m	6×18 m	12×12 m	12×18 m	18×18 m
2.0	91.4	80.6	83.7	74.8	63.2	63.8
2.5	93.3	84.1	64.0	70.8	55.0	47.5
3.0	90.0	81.3	63.9	71.5	55.4	51.4

Table 5: Christiansen Uniformity Coefficients of Bereket 3 sprinkler nozzle in the square and rectangle arrangement styles (nozzle diameter, 8 mm)

Working pressure (atm)	CU coefficient (%)					
	6×6 m	6×12 m	6×18 m	12×12 m	12×18 m	18×18 m
2.0	93.6	79.9	72.6	70.7	66.8	61.7
2.5	93.1	69.5	59.7	65.3	56.5	46.9
3.0	93.9	85.3	87.2	79.1	79.1	71.0
3.5	94.0	81.1	82.2	76.0	73.8	69.7
4.0	95.6	85.9	87.8	83.7	85.2	72.3
4.5	95.4	81.4	90.1	78.7	81.7	71.2
4.8	96.7	83.9	92.1	81.3	81.3	75.6

For the Egeyıldız, the most suitable spacing was determined as 6×6 m at 2.0 atm, 6×18 m at 2.5 atm and 6×12 m at 3.0 atm.

For the Göktepe nozzle, the most suitable spacing was 6×18 m at 2.0 atm, 6×12 m at 2.5 atm and 6×6 m at 3.0 atm.

For the Ateşler nozzle, the most suitable spacing was 6×6 m in 2.0 atm, 6×6 m at 2.5 atm, 6×18 m at 3.0 atm, 6×6 m at 3.5 atm, 12×18 m at 4.0 atm, 6×18 m at 4.5 atm and 6×18 m at 4.8 atm.

According to the results, the most suitable pressure of the Bereket 3 nozzle is 3.0 atm and the spacing is 12×18 m. Similarly, the most suitable operating parameters for the other sprinkler nozzles are 3.5 atm and 12×18 m spacing for the Bereket 2; for Egeyıldız, 2.5 atm and 6×18 m spacing; for Göktepe, 2.0 atm and 6×18 m spacing; and for Ateþler, 4.0 atm and 12×18 m spacing. The sprinkler nozzle that can be used most appropriately and economically with wide spacing and under low pressure is the Bereket 3 nozzle. These results were obtained when there was low wind speed (0-2.5 m sec^{-1}). For this reason, if the wind speed exceeds the suggested limit, wider spacing than that suggested should be avoided.

The aim of this research was to determine the technical features of the nozzles under the field conditions. Speed and direction of wind in irrigation by the sprinkler method have significant effects on water

Table 6: Technical features of the sprinkler, which can be used in application, sprinklers that were tried and applicable spacing

Sprinkler name	Nozzle diameter (mm)	Operating (Atm)	Flow rate ($m^3 h^{-1}$)	Water throw distance (m)	Uniformity coefficient (%) Spacing (m×m)					
					6×6	6×12	6×18	12×12	12×18	18×18
Bereket 3	5	1.5	1.08	10	92.7	85.6	-	-	-	-
		2.0	1.22	11	94.7	85.3	-	-	-	
		2.5	1.44	11	95.1	91.6	86.7	-	-	-
		3.0	1.58	12	96.7	93.4	91.2	88.6	88.3	-
		3.5	1.65	11	-	-	-	-	-	-
		4.0	1.73	12	-	-	-	-	-	-
		4.5	1.80	12	93.9	88.2	91.4	-	-	-
Bereket 2	10	2.0	4.54	12	96.2	90.2	86.4	83.9	-	-
		2.5	5.65	12	93.9	86.4	-	-	-	-
		3.0	6.19	12	93.2	85.1	-	-	-	-
		3.5	6.84	17	96.6	95.7	87.7	91.8	84.5	
		4.0	7.20	18	98.1	89.9	91.2	85.9	86.3	-
Egeyıldız	4.5×5.0	2.0	4.32	10	94.5	-	-	-	-	-
		2.5	4.86	11	95.4	-	90.2	-	-	-
		3.0	5.14	11	94.1	91.3	-	-	-	-
Göktepe	5.5×4.5	2.0	2.45	9	91.4	-	83.7	-	-	-
		2.5	2.59	9	93.3	84.1	-	-	-	-
		3.0	2.88	10	90.0	-	-	-	-	-
Ateşler	8	2.0	3.45	11	93.6	-	-	-	-	-
		2.5	3.88	11	93.1	-	-	-	-	-
		3.0	4.25	13	93.9	85.3	87.2	-	-	-
		3.5	4.78	12	94.0	-	-	-	-	-
		4.0	5.07	12	95.6	85.9	87.8	83.7	85.2	-
		4.5	5.33	13	95.4	-	90.1	-	-	-
		4.8	5.69	14	96.7	83.9*	92.1	-	-	-

distribution uniformity and the performance of the system. For this reason, irrigation applications should be made when the wind speed is low and laterals should be fixed parallel to the dominant wind direction.

CONCLUSIONS

The experiments data and model simulation output tables and figures have permitted to identify the conditions best suited for each sprinkler. As a consequence, technical criteria can be used for the selection of the adequate sprinkler and nozzle diameter for the prevailing operation and environmental conditions at the given location. CU tables and figures can also be used in given sprinkler layout to optimize irrigation management in response to the operating pressure and wind speed. These results could be implemented by advanced irrigation programmers.

In the context of growing concerns about water availability, it is very important that this is made available to farmers and irrigation specialists.

ACKNOWLEDGMENT

The authors thank Gregory T. Sullivan of Ondokuz Mayis University for his comments.

REFERENCES

Abo-Ghobar, H.M., 1992. Losses from low-pressure center-pivot irrigation systems in a desert climate as affected by nozzle height. Agric. Water Manage., 21: 23-32.

Abo-Ghobar, H.M. and A.I. Al-Amoud, 1993. Center pivot water application uniformity relative to travel speed and direction. Alex. J. Agric. Res., 38: 1-18.

Allen, R.G., 1993. Irrigation engineering principles. Department of Biological and Irrigation Engineering, Utah State University, Logan, Utah.

Allen, R.G., 1996. CATCH3D, Sprinkler pattern overlap program, version 4.60. Utah State University, Logan, Utah.

Chawla, J.K. and N.K. Narda, 1995. Sprinkler pattern parameters as influenced by climatic and operating conditions. J. Res. Punjab Agric. Univ., 32: 426-438.

Faci, J. and A. Bercero, 1989. Measurement of sprinkler irrigation uniformity under different working pressure, wind conditions and by different systems. Invest. Agr. Prod. Prot. Veg. Vol. 4(1), Zaragoza.

Joshi, D.S., D.T. Shete and P.M. Modi, 1995. Sprinkler performance evaluation with respect to nozzle size, pressure, riser height and grid spacing. Proceedings of ICID Special Technical Session on the Role of Advanced Technologies in Making Effective Use of Scarce Water Resources, Rome, Italy, 2; 2 ref, Cab Abst.

Keller, J. and R.D. Bliesner, 1990. Sprinkle and Trickle Irrigation, Van Nostrand Reinhold. New York.

Losada, A., L. Juana and J. Roldan, 1990. Operation diagrams for irrigation management. Agric. Water Manage., 18: 289-300.

Loule, M.J. and S. Selker, 2000. Sprinkler head maintenance effects on water application uniformity. J. Irrig. Drainage Eng., /May/June, 2000.

Padmanabhan, R.M., 1997. Influence of climatic factors on uniformity in sprinkler irrigation. Madras Agric. J., 84: 158-160.

Ruzicka, M., 1992. The uniformity of application rate of the irrigation sprinkler. Pedol. A Melior., 28: 145-151.

Stryker, J., 1998. Sprinkler Spacing. http://www.JessStryker.com/spklr.htm.

Tarjuelo, J.M., J. Montero, F.T. Honrubia, J.J. Ortiz and J.F. Ortega, 1999. Analysis of uniformity of sprinkle irrigation in semi-arid area. Agric. Water Manage., 40: 315-331.

Vories, E.D. and R.D. von Bernuth, 1986. Single nozzle sprinkler performance in wind. Trans. Am. Soc. Agric. Eng., 29: 1325-1330.

Vories, E.D., R.D. von Bernuth and R.H. Mickelson, 1987. Simulating sprinkler performance in wind. J. Irrig. and Drain. Engrg., ASCE, 113: 119-130.

Wilcox, J.C. and G.E. Swailes, 1947. Uniformity of water distribution by some under tree orchard sprinklers. Sci. Agric. Can., 27: 565-583.

Wilson, T.P. and D.F. Zoldoske, 1997. Evaluating Sprinkler Irrigation Uniformity. http://www.Wateright.org/site/publications/970703. html.

Zoldoske, D.F., K.H. Solomon and E.M. Norum, 1994. Uniformity Measurement for Turfgrass. http://www.atinet.org/cati/cit/rese/94/941102/index.html.