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Evaluation of Uniformity Coefficient and Water Distribution Efficiency of Some Impact Sprinklers in Shambat, Sudan

Elsamawal Khalil Makki[1], Osama Osman Ali[2]
and Abdelmoniem Elamin Mohamed

Department of Agricultural Engineering, Faculty of Agriculture, University of Khartoum, Shambat, Sudan

Abstract: This study was carried out during May and June 2010 in the Demonstration Farm of the Faculty of Agriculture, University of Khartoum at Shambat, to evaluate water distribution under different types of sprinkler heads. The study consisted of evaluating Christiansen's coefficient of uniformity (CU %) and uniformity of distribution (DU %) under twin nozzle brass impact sprinkler (JIS2), twin nozzle plastic sprinkler (DAN4455) and single nozzle plastic sprinkler (LEGO55). The twin nozzle brass sprinkler gave significantly better values for all sprinkler configurations, while the difference between twin and single nozzle plastic sprinklers was mostly insignificant. At low wind speeds (<2.0 m/s) and narrow configurations, the single nozzle plastic sprinkler gave better values of CU% and DU%.

Key words: Sprinkler heads; distribution uniformity; CATCH3D; Christiansen's coefficient

INTRODUCTION

Sprinkler irrigation is getting increasingly popular in Sudan. This is expected to continue for decades to come especially with the escalating pressure on water resources in the Nile basin. The dramatic change in water demands for agricultural, urban and industrial uses shall motivate the search for efficient irrigation methods. Sprinkler irrigation is one of these potentially efficient irrigation methods.

[1]Present addresss: School of Rural Extension, Education and Development, Ahfad University for Women, Omdurman, Sudan
[2]Present address: Department of Agricultural Engineering, Faculty of Agricultural Technology and Fish Sciences, Al-Neelain University, Khartoum, Sudan

A sprinkler irrigation system is normally evaluated based on uniformity coefficients determined from field measurements from an array of water collecting devices -catch cans (Topak *et al.* 2005). These coefficients are generally given by the Christiansen coefficient of uniformity (CU %) and the distribution uniformity (DU %). It is well documented that the uniform distribution of irrigation water depends on sprinkler type amongst other factors (Topak *et al.* 2005; Kara *et al.* 2008). Azevedo *et al.* (2000) noted that wind speed is the most influential factor on the uniformity of application, followed by the pressure of the sprinkler, spacing between sprinkler installations in the lateral line, line spacing, wind direction towards lateral line and speed of rotation of the sprinkler. Further, Al-ghobary and Al-rajihy (2001) reported that single nozzle sprinklers gave better CU and DU values than twin nozzle sprinklers at moderate wind speed. Sahoo *et al*. (2008) reported a deviation of uniformity coefficient of plastic sprinklers from that of brass sprinklers between 0% and 2 % for the same nozzle size.

Sprinkler irrigation systems require a minimum value of uniformity to be considered acceptable. Little *et al*. (1993) suggested a classification of uniformity of a sprinkler irrigation system as very good, good, poor and worse if CU value equals 90%, between 80% and 89%, between 70% and 79% and < 69%, respectively. For solid set sprinkler systems, Keller and Bliesner (1990) classified irrigation uniformity as low when CU is below 84%. Merkley and Allen (2003) considered DU>65% and CU>78% to be the minimum acceptable performance level for economic system design. Montero *et al.* (2001) showed that higher CU values were attained with two nozzles than with a single nozzle under low wind speeds. Kara *et al.* (2008) reported that "the main objective in sprinkler irrigation is to choose the sprinkler nozzle that enables wide spacing, low pressure and appropriate water distribution".

Very little effort was done to evaluate the performance of the different types of impact sprinklers available in the local market. Elamin (2009) compared the performance of four sizes of twin-nozzle brass and plastic sprinklers under different pressures, his study did not include plastic and single nozzle types of sprinklers. He reported best CU% and DU% values with twin nozzle brass sprinklers. The rest of the studies, carried out to evaluate sprinkler irrigation, considered only one type of sprinklers (Makki 1996; Adam 2006). The present study was undertaken to evaluate water distribution (CU% and DU %) of three types of impact sprinkler heads under five configurations in Shambat, Sudan.

MATERIALS AND METHODS

Experimental site and layout

A study was conducted during May and June 2010 at the Demonstration Farm of the Faculty of Agriculture, University of Khartoum at Shambat (longitude 32°32′ E, latitude 15°40′ N and altitude 380 m asl), on a total area of 0.086 ha. Air temperature, relative humidity and wind speed during the study period are presented in Table1.

Table 1. Air temperature (°C), relative humidity (%) and wind speed (m/s) during the 9 test runs

Test run	TEMP (ºC)	WS (m/s)	RH (%)
1	33.5	1.6	23.0
2	44.0	1.7	11.0
3	33.5	1.5	17.0
4	44.0	2.1	16.0
5	34.5	2.4	23.0
6	31.0	2.4	49.0
7	32.0	1.5	30.0
8	33.0	2.0	40.0
9	40.5	2.4	15.0

RH= relative humidity; TEMP= Air temperature and WS= wind speed.

The study consisted of testing the performance of three types of sprinkler heads: a single nozzle plastic head (LEGO 55), a twin-nozzle plastic head (DAN 4455) and a twin-nozzle brass head (JIS2). The performance of these heads was compared in terms of water distribution (CU% and DU %).

Plastic cups were used as catch containers and were placed at the centre of grids of 3 x 3 m to collect water under each sprinkler head as described by Merriam and Keller (1978). Thirty-six containers were used for each sprinkler head covering an area of 24 x 24 m. The volume of water for each container was measured using a measuring cylinder and converted to depth by dividing the water volume by the container top catching area.

A completely randomized design with two replicates for each type of sprinkler heads was adopted to layout the study in 9 test runs. The single point test was adopted and field data were analyzed using the CATCH3D software developed by Allen (1996) to test water distribution under different spacing. The software determines CU% and DU % using input data of the duration of the test, the direction and speed of wind, the flow rate and water volume in the catch cans. It produces results for different sprinkler spacing. The software is rapid and reduces the complexity and calculation mistakes of the traditional methods.
Data was analyzed for each single test and average values were compared across the test runs for the three sprinkler heads and all configurations.

Description of the sprinkler system

The sprinkler system consisted of the following components:

(i) A centrifugal pump (50 mm in diameter); it gives a maximum discharge of 600 ℓ/min at a maximum head of 41 m

(ii) A 48 m PVC pipeline (5 cm internal diameter) as a main line

(iii) Three PVC pipelines (48 m long, 5 cm internal diameter) as lateral lines, set at 24 m distance

(iv) Galvanized steel pipes (1.9 cm internal diameter and 1.75 m high) risers. Risers were set on the lateral lines at 24 m distance forming a square pattern of sprinklers layout. A buffer distance of 12 m was set between each two adjacent sprinkler heads to avoid overlap in water application

(v) The sprinkler heads were
 - Lego 55 part/full circle (single nozzle plastic head, Ø = 4 mm)
 - DAN 4455 (twin-nozzle plastic head, 4.6 x 3.0 mm)
 - JIS2 (twin-nozzle brass head, 5.1 x 3.1mm)

In all test runs, the sprinkler system was operated at 3.0 bar head. The manufacturer's performance table of the three sprinkler heads is shown in Table 2.

Sprinkler system performance

Before starting the experiment, the sprinkler system was tested to verify its proper operation within the acceptable performance parameters following the procedures adopted by Makki (1996). These parameters were sprinkler discharge and pressure at the sprinkler head, sprinkler water application rate (cm/h) and system discharge (m^3/h). Pressure and discharge at the sprinkler head, distance of throw and water application rates were within the range specified by the manufacturer.

Table 2. Manufacturer's performance tables of the three sprinkler heads

Nozzle size Ø (mm)	Pressure (atm)	Discharge (m^3/h)	Wetted diameter (m)
		DAN4455	
4.6 x 3.0			
	1.00	-	-
	1.50	-	-
	2.00	1.38	29.00
	2.50	1.53	30.00
	3.00	1.68	31.00
	3.50	1.82	32.00
	4.00	1.95	32.00
		JIS2	
5.1 x 3.1			
	2.00	1.80	23.00
	2.50	2.04	24.00
	3.00	2.22	24.50
	3.50	2.28	26.00
	4.00	2.40	28.00
		LEGO 55	
4.0			
	1.00	0.57	21.00
	1.50	0.69	22.00
	2.00	0.81	23.00
	2.50	0.91	24.00
	3.00	0.99	26.00
	3.50	1.07	26.50
	4.00	1.14	27.00

RESULTS AND DISCUSSION

Christiansen's coefficient of uniformity (CU %)

Under the 12x12 m configuration, CU% values were in the following descending order: JIS2> DAN4455> LEGO55 in all the test runs except for the 1st and 7th runs where CU% values for LEGO55 exceeded that of DAN4455 (Table 3). This relates directly to the comparatively low wind speed and high relative humidity during these test runs (Table 1). Values under the JIS2 sprinkler head were higher than the threshold suggested by Keller and Bliesner (1990). Nearly 77% of CU % values with LEGO55 were on the moderately low range of the scale suggested by Keller and Bliesner (1990). LEGO55 and JIS2 sprinkler heads gave significantly higher CU% values when compared with DAN4455 ($P \leq 0.05$), while JIS2 gave significant values compared with both LEGO 55 and DAN4455.

Similar values were obtained under the 12x9 m configuration, except for the 1st, 4th and 8th test runs where CU% values under LEGO55 exceeded that of DAN4455. Further, during the 7th test run LEGO55 recorded the highest value. In these test runs (except for the 7th), JIS2 gave greater CU% values than the threshold suggested by Keller and Bliesner (1990).

All CU% values under the 12x6 m configuration were superior compared with the 12x9 m configuration (Table 3). This is normal under sprinkler irrigation as CU% increases with reducing spacing. Further, in all test runs, JIS2 recorded values greater than 80%, while those of DAN4455 and LEGO55 heads were fluctuating. This suggests that wind velocity and air temperature affect CU% values in different ways under different sprinkler configurations. Under low wind speeds and high relative humidity, LEGO55 recorded higher results, while at moderate and high wind speeds and low relative humidity DAN4455 sprinkler head recorded comparatively higher results. This is conforming to Al-ghobary and Al-rajihy (2001) who reported higher CU% values with single nozzle sprinklers at low wind speed.

Table 3. CU% for three sprinkler heads and different configurations

Test run	Sprinkler head	Sprinkler spacing (m)				
		12x12	12x9	12x6	9x9	9x6
1	LEGO 55	88.9	77.8	92.8	78.9	87.8
	DAN 4455	74.2	69.7	79.2	77.8	83.0
	JIS 2	87.8	88.1	90.5	87.1	89.2
2	LEGO 55	63.4	58.1	69.8	71.6	82.2
	DAN 4455	72.4	67.8	76.8	70.6	78.9
	JIS 2	75.7	73.9	84.2	86.8	89.4
3	LEGO 55	69.7	67.0	69.7	67.0	72.8
	DAN 4455	76.0	77.0	86.0	71.3	78.6
	JIS 2	88.9	90.9	90.5	89.9	90.5
4	LEGO 55	65.7	70.2	74.9	68.0	68.2
	DAN 4455	68.0	68.9	72.8	66.2	68.1
	JIS 2	81.0	85.2	88.9	82.8	90.4
5	LEGO 55	34.7	49.3	50.6	70.2	69.9
	DAN 4455	43.2	54.6	82.0	75.0	79.8
	JIS 2	77.4	75.1	89.1	79.5	88.6
6	LEGO 55	72.8	76.6	82.8	71.5	75.7
	DAN 4455	73.7	78.4	79.5	87.4	86.9
	JIS 2	87.5	85.8	91.0	87.0	95.1

Table 3. Cont.

Test run	Sprinkler head	Sprinkler spacing (m)				
		12x12	12x9	12x6	9x9	9x6
7	LEGO 55	81.3	85.4	90.6	85.0	88.2
	DAN 4455	76.8	78.1	82.6	83.6	88.3
	JIS 2	84.2	81.9	86.8	89.8	88.6
8	LEGO 55	80.0	80.1	87.0	79.4	83.9
	DAN 4455	59.4	61.2	62.4	72.5	78.8
	JIS 2	80.7	82.2	89.4	84.4	91.3
9	LEGO 55	36.0	37.2	40.7	61.6	72.7
	DAN 4455	71.0	69.6	80.7	69.2	73.5
	JIS 2	76.4	82.3	86.4	70.8	80.3

CU% values recorded by the JIS2 sprinkler were significantly different from those of LEGO55, and they were statistically similar to DAN4455. The sprinkler head that can be used most appropriately and economically with 12 x 9 m spacing under the existing pressure is JIS2. These results were obtained under wind speeds <2.4 m/s. If the wind speed exceeds the stated limit, wider spacing than the recommended should be avoided.

Under the 9x9 m configuration, JIS2 sprinkler head recorded the highest CU% values in all test runs. All of these values except for the 9th run were 80% or more. The low CU% in the 9th run is attributed to the effect of both high wind speed and temperature (2.4 m/s and 40.5°C, respectively). LEGO55 ranked second in 4 test runs where wind speed was relatively low. In all test runs, CU% values of LEGO55 sprinkler head were below the threshold suggested by Keller and Bliesner (1990). Once again, the sprinkler head that can be used most appropriately and economically with this configuration and under the existing pressure is JIS2. These results were obtained under wind speeds <2.4 m/s. DAN4455 sprinkler head ranked second in 4 test runs with all CU values (except for the 6th and 7th runs) below 80% suggesting careful consideration of the selection of this head under a 9x9 m configuration.

Better results were recorded by JIS2 sprinkler head in all test runs under the 9x6 m configuration (Table 3). All values were greater than the minimum threshold (80%); however, the narrower spacing increases the installation cost as a result of increasing both the number of sprinklers and laterals. Although DAN4455 sprinkler head ranked second, yet it recorded CU values in the range of 70% -79% in 44% of the test runs. Wind effect was marginal as it was subsided by narrower spacing. In all the test runs, JIS2 gave significantly higher CU% values compared with NAD4455 and LEGO55 which gave statistically similar results.

The lowest average CU% values in all sprinkler configurations were recorded by LEGO55 sprinkler head (Table 4). Average CU% values under this sprinkler were within the poor range under the wider configurations (12x12 m and 12x9 m), while it was within the moderate range under the narrower configurations of 12x6 m, 9x9 m and 9x6 m. DAN4455 recorded comparatively higher CU% values. Nevertheless, these values were on the poor range in the 12x12 m and 12x9 m configurations. This head recorded a good CU (>80%) only in the 9x6 m configuration. JIS2 sprinkler head recorded the highest CU% values. Under all sprinkler configurations, the values obtained were on the good range established by Little *et al*. (1993). This suggests that this sprinkler head is feasible for both wide and narrow configurations. In all configurations, average CU% values under JIS2 were significantly higher than those of DAN4455 and LEGO55 which were not statistically different from each other.

Table 4. Average CU% for three sprinkler heads and different configurations

Sprinkler configuration (m)	Sprinkler head								
	LEGO55			DAN4455			JIS2		
	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
12x12	34.7	88.9	65.8	43.2	76.8	68.3	75.7	88.9	82.2
12x9	37.2	85.4	66.9	54.6	78.4	69.5	73.9	90.9	82.8
12x6	40.7	92.8	73.2	62.4	86.0	78.0	84.2	91.0	88.5
9x9	61.6	85.0	72.6	66.2	87.4	74.8	70.8	89.9	84.2
9x6	68.2	88.2	77.9	68.1	88.3	79.5	80.3	95.1	89.3

Distribution Uniformity (DU %)

Distribution uniformity under all sprinkler configurations and test runs is presented in Table 5, and average values under the three sprinkler heads and configurations are presented in Table 6. Generally, DU% values followed the same trend of CU% values with slight variations between the test runs. Under the 12x12 m configuration JIS2, consistently gave the highest values in all test runs. All these values were greater than the minimum acceptable DU of (60%) specified by Keller and Bliesner (1990). Lower DU% values were associated with high wind speed.

Table 5. CU% for three sprinkler heads and different configurations

Test run	Sprinkler head	Sprinkler spacing (m)				
		12x12	12x9	12x6	9x9	9x6
1	LEGO 55	86.7	75.6	91.1	68.8	85.0
	DAN 4455	59.4	63.0	72.7	65.5	72.7
	JIS 2	83.5	81.4	87.3	84.9	83.5
2	LEGO 55	51.2	41.9	51.2	57.6	62.8
	DAN 4455	56.3	62.0	73.2	63.4	67.6
	JIS 2	62.0	56.3	56.3	77.6	86.6
3	LEGO 55	52.1	53.6	61.3	46.6	57.5
	DAN 4455	56.6	59.1	76.7	62.3	67.9
	JIS 2	83.5	88.0	85.7	87.6	79.0
4	LEGO 55	49.4	53.9	59.9	45.5	44.9
	DAN 4455	48.2	58.3	58.3	59.2	57.1
	JIS 2	67.3	80.8	82.7	77.9	82.2
5	LEGO 55	14.6	25.6	32.9	49.3	43.8
	DAN 4455	26.2	32.8	74.3	27.0	68.9
	JIS 2	64.7	59.1	79.0	58.8	84.9
6	LEGO 55	47.9	54.3	65.6	51.1	49.2
	DAN 4455	66.1	68.3	75.7	81.6	80.0
	JIS 2	78.8	76.1	85.6	79.5	

Table 5. Cont.

Test run	Sprinkler head	Sprinkler spacing (m)				
		12x12	12x9	12x6	9x9	9x6
7	LEGO 55	70.3	75.6	84.0	72.0	78.7
	DAN 4455	66.4	74.9	79.6	80.0	79.6
	JIS 2	75.4	72.9	81.1	72.4	77.6
8	LEGO 55	65.9	69.6	83.2	57.3	72.7
	DAN 4455	42.4	41.2	43.6	69.5	58.2
	JIS 2	72.0	79.8	82.2	67.6	77.9
9	LEGO 55	41.6	41.0	48.2	50.2	39.7
	DAN 4455	59.3	66.8	72.2	57.0	72.8
	JIS 2	63.8	79.2	81.5	62.2	69.2

Table 6. Average CU% for three sprinkler heads and different configurations

Sprinkler configur-ation (m)	Sprinkler head								
	LEGO55			DAN4455			JIS2		
	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
12x12	14.6	86.7	53.3	26.2	66.4	53.4	62.0	83.5	73.2
12x9	25.6	75.6	54.6	32.8	74.9	58.5	56.3	88.0	74.8
12x6	32.9	91.1	64.2	43.6	79.6	69.6	56.3	87.3	80.2
9x9	45.5	72.0	55.4	27.0	81.6	62.8	58.8	87.6	74.3
9x6	39.7	85.0	59.4	57.1	80.0	69.4	69.2	91.7	81.4

Under the 12x9 m configuration, JIS2 gave significantly the highest DU% values except for the 2nd and 7th test runs. All DU% values were greater than the 60% minimum acceptable value except for the 2nd test. High temperature and consequently evaporation loss could be the main reasons for this low value. DU% values with LEGO55 were lower than the minimum acceptable value in 55% of the test runs and were lower than those of DAN4455 except for the 1st, 7th and 8th test runs in which wind speed was less than 2 m/s. Under this condition, single nozzle sprinklers perform better than twin nozzle ones.

Variable results were obtained under the 12x6 m configuration. LEGO55 gave the highest values in the 1st, 7th and 8th test runs. However, no significant differences were found between the three sprinkler heads in these runs. In the rest of test runs, JIS2 consistently gave significantly higher values than LEGO55 and DAN4455. All DU% values with JIS2 sprinkler head were higher than the minimum acceptable value (60%). The same trend was observed under the 9x9 m and 9x6 m sprinkler configurations.

Significantly higher average DU% values were recorded by JIS2 in all sprinkler configurations compared with both LEGO55 and DAN4455, while the latter two were statistically similar. This is conforming to Elamin (2009) and Sahoo *et al.* (2008). All DU% values with JIS2 were greater than the minimum acceptable value (60%) specified by Keller and Bliesner (1990) which makes it a suitable choice with all configurations. DU% values with DAN4455 and LEGO55 sprinkler heads were greater than the minimum acceptable value only under the 12x9, 9x9 and 9x6 m sprinkler configurations under which only DAN4455 recorded acceptable CU% values. Hence, system designers should be very careful when selecting those sprinkler heads and should compromise between sacrificing water distribution uniformity and efficiency for wider configurations, and targeting higher efficiency values under narrower spacing and jeopardize the economic feasibility of the system.

CONCLUSIONS

Under the same system pressure and spacing, twin nozzle brass sprinklers give better water distribution efficiency than plastic ones. Single nozzle plastic sprinklers better suit narrower spacing, especially at low wind speed.

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تقويم انتظام وكفاءة توزيع مياه الرى بواسطة مختلف أنواع الرشاشات فى شمبات (السودان)

السموأل خليل مكى[1] وأسامة عثمان على[2] وعبدالمنعم الأمين محمد

قسم الهندسة الزراعية، كلية الزراعة - جامعة الخرطوم ، شمبات - السودان

المستخلص: تم إجراء هذه الدراسة خلال شهري مايو ويونيو 2010م في المزرعة التجريبية بكلية الزراعة ، جامعة الخرطوم بشمبات بغرض تقويم توزيع المياه تحت مختلف أنواع الرشاشات. اشتملت التجربة على عامل كريستيانسن للتوزيع (CU%) وانتظام توزيع مياه الرى (DU%) باستخدام رشاش نحاسى ذو فوهتين (JIS2) ورشاش بلاستيكى ذو فوهتين (DAN4455) ورشاش بلاستيكى ذو فوهة واحدة (LEGO55) . أعطى الرشاش النحاسى ذو الفوهتين قيما أعلى وذات فرق معنوى لمعامل كريستيانسن للتوزيع (CU%) وانتظام توزيع مياه الرى (DU%) فى كل المسافات ، بينما لم يكن الفرق معنوياً بين الرشاش البلاستيكى ذو الفوهة الواحدة والرشاش البلاستيكى ذو الفوهتين . اضافة و أعطى الرشاش البلاستيكى ذو الفوهة الواحدة قيما أكبر لمعامل كريستيانسن للتوزيع وانتظام توزيع مياه الرى عند سرعات الرياح المنخفضة (<2.0 م/ث) والمسافات المتقاربة .

[1]العنوان الحالى: مدرسة التنمية والتدريب والأرشاد الريفى، جامعة الأحفاد للبنات ، أمدرمان - السودان
[2]العنوان الحالى: قسم الهندسة الزراعية ، كلية التقانة الزراعية وعلوم الأسماك ، جامعة النيلين، الخرطوم السودان