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Effect of Different Solid-set Sprinkler Patterns on Water Distribution and Losses under Shambat Conditions, Sudan*

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Abstract: An experiment to compare the performance of different solid-set sprinkler patterns was carried out during March and April 2004 in the Demonstration Farm of the Faculty of Agriculture, University of Khartoum at Shambat. The experiment consisted of testing the effect of square, rectangular and triangular sprinkler patterns on Christiansen's coefficient of uniformity (CU%), uniformity of distribution (DU%) and water loss (%) using the completely randomized design. The triangular pattern recorded the highest uniformity coefficient and uniformity of distribution and the lowest water loss. Water distribution uniformity (CU% and DU%) and water loss (%) were not significantly affected by sprinkler patterns. However, mean CU% and DU% had the following decending order: triangular pattern > square pattern > rectangular pattern, while mean values of water loss (%) was as follows: rectangular pattern > square pattern > triangular pattern.

Key words: Distribution uniformity; sprinkler patterns; Christiansen's coefficient; irrigation efficiency

INTRODUCTION

According to the 1959 Nile water agreement between Egypt and Sudan, Sudan's annual allotted share is 18.5 billions m^3 (as measured at Aswan). The amount would allow the irrigation of about 4.0 to 4.8 million feddans (Al-araki 2002), whereas the area of potentially productive land is about

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200 million feddans (1 fed. = 0.42 ha). Thus, in the near future, water would constitute a limiting factor for agricultural expansion in the country.

The major constraints to produce more food to meet the increasing demand of the world population are land and water scarcity. One possible approach to conserve these scarce resources may be through introducing efficient irrigation systems. Under the conditions of drought and signs of water shortage, studies on efficient use of water and adoption of modern irrigation techniques, such as sprinkler and drip irrigation methods, are gaining more importance worldwide.

Sprinkler irrigation is getting popular in different parts of the Sudan since the mid-1990s. It is mainly adopted in urban and peril-urban farming in Khartoum State for fodder and vegetables production. The method is mainly used for its high efficiency and flexibility in applying small depths of water. Another motive for the spread of sprinkler irrigation is water conservation, particularly for farmers using ground water for irrigation.

An efficient sprinkler system depends on a good design and factors which affect uniformity and distribution of irrigation water. A major factor affecting irrigation water uniformity of distribution is the arrangement and spacing of nozzles on the lateral and spacing between laterals. This refers to the geometrical water application shapes made by nozzle arrangement on any two adjacent laterals. There are commonly three types of patterns; namely, square, triangular and rectangular. The pattern adopted is believed to affect water distribution uniformity under different wind speeds (James 1988). Topak *et al.* (2005) showed that CU% and DU% are higher under square pattern than under rectangular pattern for the same nozzle size and working pressure. Effect of the smaller area is apparent here (10 x 10 m vs. 10 x 15 m). Further, Kara *et al.* (2008) showed that both values of CU% and DU% decrease with increasing area regardless of the sprinklers pattern, but the difference in CU% and DU% is not proportional to the difference in area.

In Sudan, research attempts regarding water distribution efficiency under sprinkler irrigation are either scanty or lacking at least in a published form (Konda 1980; Makki 1996). Therefore, this study was carried out to compare the effect of different sprinkler patterns on water distribution (CU% and DU%) and water loss (%) under Shambat climatic conditions.

MATERIALS AND METHODS

Experimental site and layout

This study was conducted during March and April 2004 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 an area of 0.13 ha. Air temperature, vapour pressure, relative humidity and wind speed during the study period are presented in Table1.

Table 1. Air temperature (°C), relative humidity (%), and vapour pressure (mbar) and wind speed (km/h) during the 26 test runs

Test run	Weather conditions			
	VAP (mbar)	RH (%)	TEMP (ºC)	WS (km/h)
1	8.5	20	30.0	12.95
2	7.9	15	33.0	12.95
3	8.8	19	31.0	9.25
4	8.3	17	33.0	11.10
5	7.8	14	35.0	5.60
6	8.7	15	35.0	12.95
7	12.3	23	34.5	7.40
8	12.3	21	36.0	7.40
9	12.3	19	37.5	7.40

Table 1. Cont.

Test run	Weather conditions			
	VAP (mbar)	RH (%)	TEMP (ºC)	WS(km/h)
10	11.2	16	39.0	7.40
11	5.7	10	35.0	9.25
12	4.2	7	37.0	7.40
13	6.2	10	37.0	5.60
14	8.0	22	26.0	7.40
15	4.5	14	36.5	9.25
16	9.1	21	30.5	9.25
17	9.8	14	37.5	7.40
18	10.5	13	41.7	7.40
19	10.4	15	39.5	5.60
20	14.7	23	37.5	7.40
21	13.4	18	40.0	7.40
22	11.6	17	38.5	5.60
23	12.7	33	28.5	7.40
24	12.5	15	42.0	9.25
25	12.5	15	42.0	5.60
26	12.7	15	41.0	8.32

VAP = vapour pressure; RH = relative humidity; TEMP = Air temperature; and WS = wind speed

The experiment consisted of testing the effect of square, rectangular and triangular sprinkler patterns on water distribution (CU% and DU%) and water losses (%). The square pattern layout spacing was 7.8 x 7.8 m, an equilateral triangle of 9 m for the triangular pattern and 9 x 7.8 m for the rectangular pattern. Sprinklers spacing for the square and rectangular patterns was chosen from the performance tables provided by the manufacturer with reference to the prevailing wind speed (Makki 1996). Spacing of the triangular pattern was dictated by the fact that all the three patterns were arranged on the same laterals in which lateral spacing was 7.8 m. This is slightly different from the lateral spacing (0.86 of the distance between sprinklers) recommended by James (1988). But, this difference is marginal (7.8 vs. 7.74 m). The parameters studied were sprinkler discharge (m^3/h) and pressure (bar), distance of throw (m), water loss (%) and water distribution uniformity (CU% and DU%).

Catch cans (14.5 cm high and 10 cm inside diameter) were placed at the centre of grids of 2 x 2 m to collect water depths under each pattern as described by Michael (1978). Cans were coated on their inner walls with motor oil (SAE 20 W/40) to reduce water evaporation and water adhesion to the can walls.

A completely randomized design with 26 replicates (test runs) was adopted to lay out the experiment (Fig. 1). The relative positioning of the three sprinkler patterns was randomly altered between the test runs to minimize the effect of wind direction and fixed position on water distribution on an area of 0.034 ha. Lateral lines were set in a prependicular direction to wind.

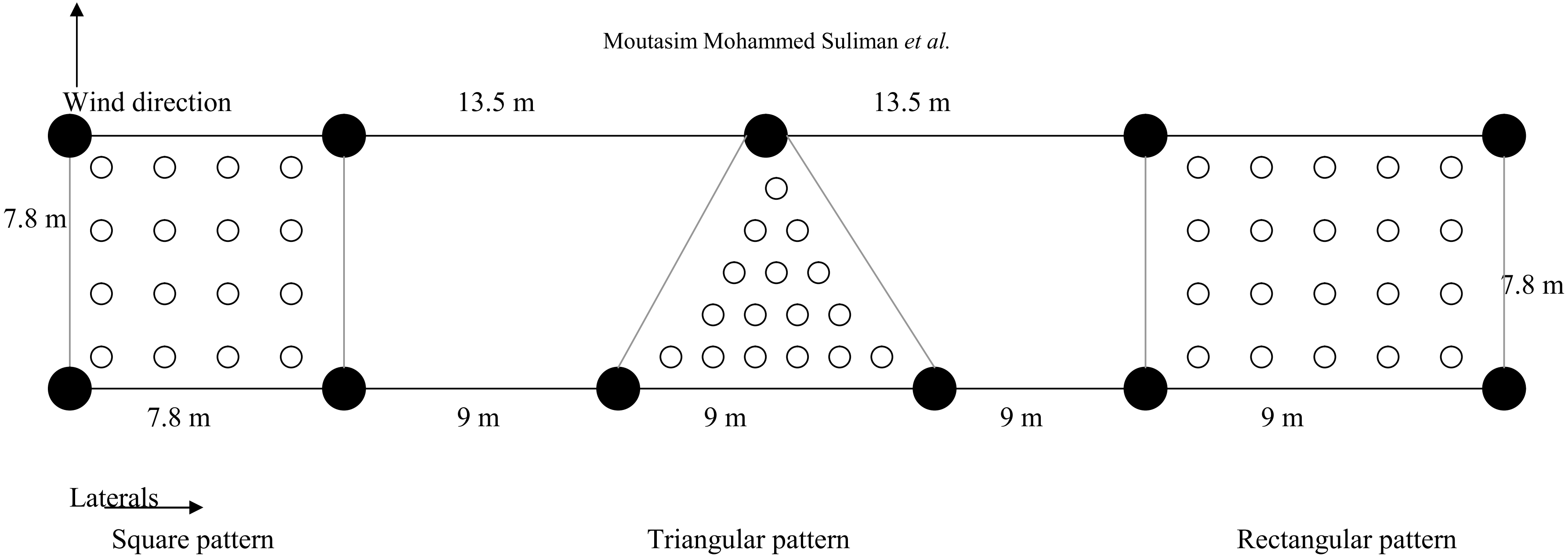

Fig. 1. The experimental layout and catch cans grids (not to scale)

Description of the sprinkler system

The sprinkler system consisted of the following components:

(i) A centrifugal pump (50 mm in diameter) to provide the sprinkler system with the required pressure. The pump gives a maximum discharge of 600 ℓ/min at a maximium head of 26 m.

(ii) A rubber hose (5 cm internal diameter and 9 m long) as a main pipeline. One end of the line was connected to the pump outlet and the other end to a junction which branched to form a sub-main line with two sides of the same material to the left and right.

(iii) Two quick coupler aluminum pipelines (5 cm internal diameter with 9 m sections) as lateral lines. Each lateral line was 43.8 m long.

(iv) Galvanized steel pipes (1.9 cm internal diameter and 1 m high) as risers. Risers were set on the lateral lines according to the tested pattern in three arrangements, i.e. square, rectangular and triangular. A buffer plot of 9.0 x 7.8 m was set between each two adjacent patterns to avoid water addition by any pattern to the other as shown in Fig. 1.

(v) Lego 55 part/full circle (single nozzle, Ø = 4 mm) sprinkler heads working at 2 bar head. The manufacturer's performance table of the sprinkler head is shown in Table 2.

Table 2. Manufacturer's performance table of Lego 55 sprinkler head (4 mm nozzle)

Pressure (bar)	Discharge (m^3/h)	Wetted diameter (m)
1.0	0.57	21.0
1.5	0.69	22.0
2.0	0.81	23.0
2.5	0.91	24.0
3.0	0.99	26.0
3.5	1.07	26.5
4.0	1.14	27.0

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 varaition along the lateral (%), distance of throw (m), sprinkler water application rate (cm/h) and total system discharge (m^3/h). Pressure and discharge variation along the lateral were within the allowable range and distance of throw and water application rates were within the range specified by the manufacturer.

Water distribution uniformity

A. Christiansen's coefficient of uniformity (CU%): The pattern uniformity coefficient (CU%) was tested using the following formula as stated by Christiansen (1942):

$$CU\% = 100 \left(1 - \frac{\Sigma x}{mn} \right)$$

where:

CU% = Christiansen coefficient of uniformity (%)

x = absolute deviation of individual observations from the mean value

n = number of observations

m = mean value of observations

B. Distribution uniformity (DU%): Water distribution uniformity for each sprinkler pattern was determined from the collected depths in the catch cans using the following equation (Keller and Blienser 1990):

$$DU(\%) = \frac{\text{Average low quarter of depths collected in the cans (mm)}}{\text{Average water depth collected in all cans (mm)}} \times 100$$

Water loss during sprinkling process

Water loss was determined for all sprinkling patterns at all test runs. It was taken to equal the difference between application depth of each pattern determined from the manufacturer's tables at the operation pressure and the average water depth received in the catch cans. This procedure, however, does not reflect the source of water loss whether it is evaporation or drift. It reflects the total loss during the sprinkling process.

RESULTS AND DISCUSSION

Sprinkler water distribution efficiency

Christiansen coefficient of uniformity (CU%): The minimum and maximum CU values under the triangular pattern were 45.2% and 94.4% at the 10th and 19th test runs, respectively (Table 3). The minimum CU occurred at 39ºC air temperature, 16% relative humidity and 7.4 km/h wind speed. In contrast, the maximum one occurred at 39.5ºC air temperature, 15% relative humidity and 5.6 km/h wind speed. This shows that the effect of wind speed on CU is quite evident as compared with the effect of temperature and relative humidity.

Table 3. Christiansen coefficient of uniformity (CU%) under three sprinkler patterns

Test run	Christiansen's coefficient of uniformity (%)		
	Square pattern	Rectangular pattern	Triangular pattern
1	84.07	86.51	88.90
2	81.36	88.94	82.59
3	70.47	71.06	77.17
4	70.76	72.13	80.04
5	78.19	62.10	75.56
6	81.26	54.15	69.63
7	81.38	67.70	55.84
8	84.70	77.64	66.22
9	73.53	65.46	75.21
10	78.15	66.90	45.19
11	71.88	65.21	60.09
12	82.42	83.59	89.96

Table 3. Cont.

Test run	Christiansen's coefficient of uniformity (%)		
	Square pattern	Rectangular pattern	Triangular pattern
13	92.24	87.50	94.21
14	76.44	75.45	87.66
15	58.12	68.31	85.79
16	73.41	76.70	85.38
17	82.69	83.49	90.72
18	83.29	84.51	86.35
19	87.48	86.78	94.39
20	74.55	78.80	78.00
21	86.63	89.39	89.65
22	85.43	85.06	90.11
23	79.36	74.95	84.95
24	83.24	81.51	80.34
25	88.34	87.83	89.36
26	79.90	86.33	83.08

The minimum and maximum CU values under the square pattern were 58.1% and 92.2% at the 15^{th} and 13^{th} runs, respectively. The minimum CU was recorded at 36.5ºC air temperature, 17% relative humidity and 9.3 km/h wind speed. On the other hand, the maximum CU occurred at 37ºC air temperature, 10% relative humidity and 5.6 wind speed. In this regard, the combined effect of wind speed and relative humidity on CU is evident.

With the rectangular pattern, the minimum and maximum CU values were 54.2% (at the 5^{th} test run) and 89.4% (at the 25^{th} test run). The minimum CU occurred at 35ºC air temperature, 15% relative humidity and 9.3 km/h wind speed, whereas the maximum CU occurred at 42ºC air temperature, 15% relative humidity and 5.6 km/h wind speed.

The mean values of CU% are arranged in the following manner: triangular pattern> square pattern> rectangular pattern (Fig. 2). There were no significant differences between the three sprinkler patterns in their effect on the mean CU%. This result is in agreement with that reported by Al-araki (2002). The mean CU% under the rectangular pattern (77.2%) is higher than the 65% reported by Makki (1996). This relatively high value can possibly be attributed to the narrower sprinkler spacing used in this study. Apparantly, differences in the area irrigated by each pattern influenced the average CU% values, but the difference in CU% is not proportional to the difference in area. The results suggest that sprinklers' spacing is another determinal factor in CU% as it influences the geometrical water application resulting from different forms of overlap. For the same area, widely spaced sprinklers along the lateral results in reduced overlap and consequently reduced CU%. Variation in CU% can not be solely attributed to differences in the area as a 100% increase in the area of the rectrangular pattern over the triangular pattern was reflected only in 1% decrease in CU%. Similarly a 66% increase in the area of the square pattern over the triangular pattern was reflected only in a 4% decrease in CU%, and the same trend can be presented with square vs. rectangular patterns. This suggests that sprinklers' spacing in relation to distance of throw masked the effect of area on CU%.

Distribution uniformity (DU%): The minimum and maximum DU% under the triangular pattern were 35.3% (at the 10^{th} test run) and 90.4% (at the 19^{th} test run) as shown in Table 4. The minimum DU% occurred at 10% relative humidity, 39ºC air temperature and 7.4 km/h wind speed, whereas the maximum occurred at 15% relative humidity, 39.5ºC air temperature and 5.6 km/h wind speed. This shows that the maximum and minimum DU% under this pattern followed the same trend of CU%.

Under the square pattern, the minimum and maximum DU were 54.9% and 87.9% at the 12^{th} and 13^{th} test runs, respectively. The minimum DU% occurred at 10% relative humidity, 35ºC air temperature and 9.25 km/h wind speed. On the other hand, the maximum DU% occurred at 10% relative humidity, 37ºC air temperature and 5.6 km/h wind speed.

Under the rectangular pattern, the minimum and maximum DU% values were 41.5% and 83.9% at the 11th and 2nd test runs, respectively. The minimum DU% occurred at 10% relative humidity, 35ºC air temperature and 9.25 km/h wind speed, while the maximum value occurred at 15% relative humidity, 33.5ºC air temperature and 5.6 km/h wind speed.

The mean DU% values followed the same order as CU%, i.e. triangular pattern> square pattern> rectangular pattern (Fig. 3). It is evident that the dimensions of the irrigated area caused to this arrangement (smaller area under the trianglar pattern and larger area under the rectagular one). The analysis of variance did not indicate any significant differences between the three patterns. These results are in agreement with those reported by Al-araki (2002). This supports the argument that for the same sprinkler size and working pressure, variation in DU% is not proportional to the difference in area under each pattern.

Sprinkler water loss (%)

Sprinkler water losses under the triangular, square and rectangular patterns during the 26 test runs are shown in Table 5, and the average water losses values are shown in Fig. 4. The sprinkler total water losses referred to in this study include evaporation and wind drift losses and represents the difference between the applied depth and that caught in the catch-cans. The highest value of water losses under the square pattern was 62.2% at the 15th test run, with 9.25 km/h wind speed, 4.5 mbar vapour pressure, 14% relative humidity and 35.6ºC air temperature. The lowest water loss value under this pattern was 0.3% and occurred with 7.4 km/h wind speed, 8.8 mbar vapour pressure, 15% relative humidity and 31ºC air temperature. Most of the losses ranged between 26.4% and 49.5 %. Rise in the mean air vapour pressure will reduce water evaporation. The general trend of this result agreed with the results reported by Yazar (1984).

For the rectangular pattern, the highest water loss was 51.6% and occurred at the 21st test run with 7.4 km/h wind speed, 8 mbar vapour pressure, 22% relative humidity and 26ºC air temperature. while, the lowest value was 2.5% and occurred at the 5th test run with 5.60 km/h wind speed, 7.8 mbar vapour pressure, 14% relative humidity and 35ºC air temperature. These losses ranged between 27% and 48.4%, and follow a similar trend to that reported by Yazar (1984).

For the triangular pattern, the highest water loss was 42.8% at the 15th test run with 9.25 km/h wind speed, 4.5 mbar vapour pressure, 14% relative humidity and 36.5ºC air temperature. The lowest loss was 2.5% and occurred at the 5th test run with 5.60 km/h wind speed, 7.8 mbar vapour pressure, 14% relative humidity and 35ºC air temperature. These losses ranged between 20.5% and 42.8%. This result is in conformity with that reported by Yazar (1984).

The mean water loss values could be ranked in the following decending manner: rectangular pattern (29.4%)> square pattern (28.5%) > triangular pattern (26.7%) (Fig. 4). There were no significant (P≤0.05) differences between the three sprinkler patterns. Once again, the mean loss increased with incease in the irrigated area.

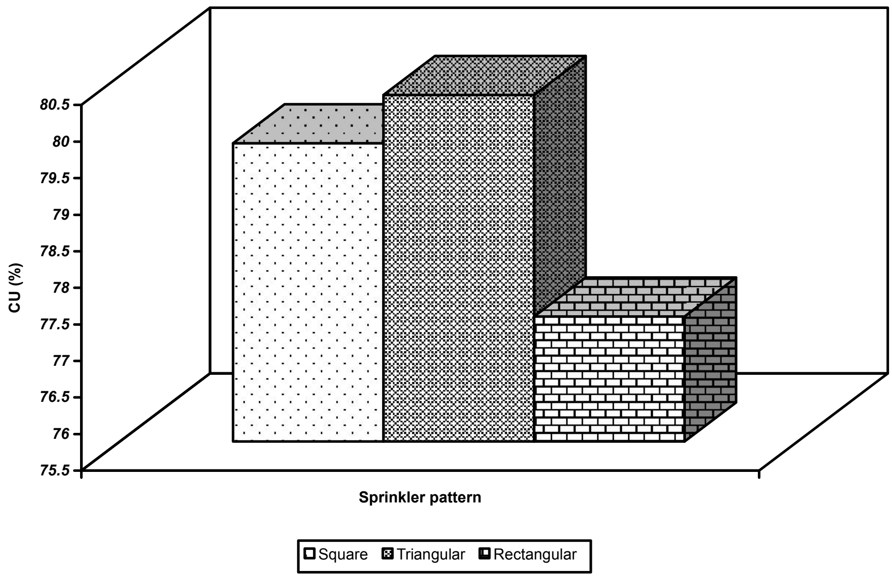

Fig. 2. Average uniformity coefficients (%) under square, rectangular and triangular sprinkler patterns

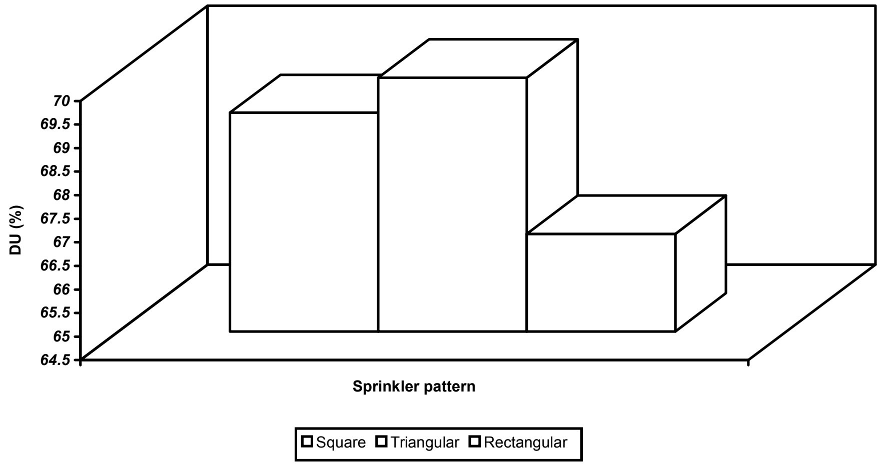

Fig. 3. Average distribution uniformity (DU%) under square, rectangular and triangular sprinkler patterns

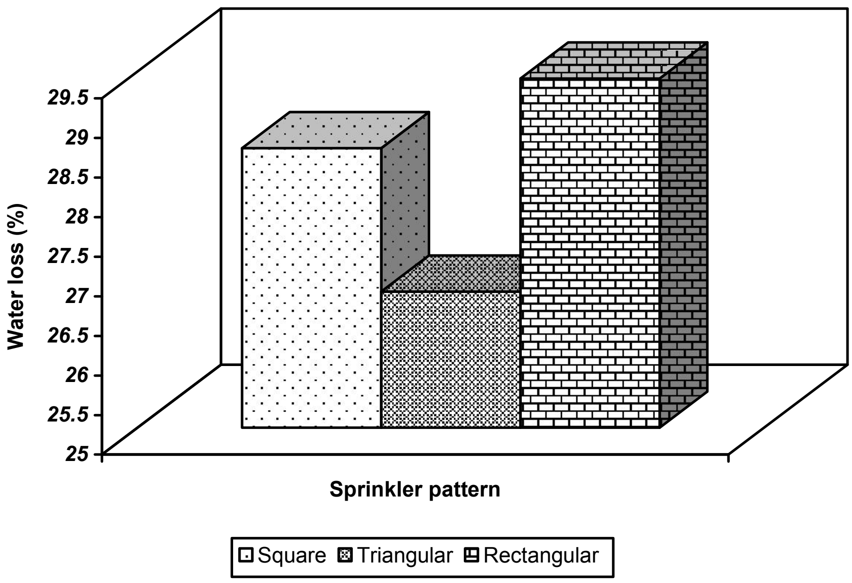

Fig. 4. Average water loss (%) under square, rectangular and triangular sprinkler patterns

Table 4.\ Distribution uniformity (DU%) under the three sprinkler patterns

Test run	DU (%)		
	Square pattern	Rectangular pattern	Triangular pattern
1	74.29	80.94	82.31
2	69.80	83.90	72.25
3	66.71	52.77	60.61
4	60.32	53.39	66.36
5	69.05	53.39	61.72
6	74.87	44.13	64.99
7	72.25	53.80	43.52
8	74.51	73.35	60.02
9	56.73	47.61	55.57
10	63.09	45.24	35.33
11	54.89	41.52	38.59
12	67.42	74.16	80.79
13	87.53	76.26	88.52
14	63.13	66.43	80.31
15	55.16	56.50	77.69
16	59.25	61.31	75.94
17	68.51	72.68	82.26
18	71.85	74.75	75.03
19	77.25	75.98	90.38
20	60.90	70.60	60.08
21	79.20	80.45	82.57
22	75.01	77.15	82.84
23	65.66	67.19	74.68
24	75.57	77.73	62.19
25	80.88	80.69	85.69
26	73.83	79.69	76.92

Table 5. Water loss (%) uder three spinkler ptterns

Test run	Sprinkler pattern		
	Square pattern	Rectangular pattern	Triangular pattern
1	5.55	3.50	5.76
2	10.32	8.91	20.52
3	0.28	8.68	5.16
4	17.41	26.98	36.50
5	3.14	2.50	2.50
6	3.09	4.90	40.15
7	30.07	33.07	38.82
8	12.04	14.71	28.63
9	1.79	5.32	3.98
10	11.02	10.11	3.65
11	12.04	31.68	3.45
12	41.30	51.62	38.53
13	29.93	33.59	20.55
14	24.63	37.02	21.73
15	62.60	48.42	42.78
16	49.54	48.03	37.57
17	44.28	45.47	35.40
18	44.53	47.15	31.49
19	38.77	40.00	26.41
20	46.07	40.74	34.97

Table 5. Cont.

Test run	Sprinkler pattern		
	Square pattern	Rectangular pattern	Triangular pattern
21	40.46	36.40	33.75
22	36.95	33.68	35.23
23	49.12	42.36	41.87
24	36.67	36.01	34.10
25	45.69	40.13	39.00
26	44.49	33.68	32.27

CONCLUSIONS

- Water distribution uniformity (CU% and DU %) under sprinkler patterns could be arranged in the following manner: triangular> square> rectangular patterns; despite the insignificant differences between the three patterns. However, decrease in both values of CU% and DU% is not proportional to increase in the area between the different patterns.
- The average water losses during the sprinkling process are in the following manner: rectangular> square> triangular; despite the insignificant differences between the patterns.

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تأثير أنماط نظام الرى بالرش الثابت على انتظام توزيع المياه و فواقدها تحت ظروف شمبات (السودان)*

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موجز البحث: أجريت هذه الدراسة لمقارنة أداء أنماط مختلفة لنظام الرى بالرش الثابت في المزرعة التجريبية بكلية الزراعة، جامعة الخرطوم بشمبات خلال شهري مارس وابريل 2004م. اختبرت التجربة تأثير أنماط الرش المربع والمستطيل والمثلث على كفاءة توزيع مياه الري بالرش (معامل كريتسيانسن للتوزيع CU%) وانتظام التوزيع (DU%) وفواقد المياه (%) باستخدام التصميم كامل العشوائية. سجل النمط المثلث أعلى معدلات للتوزيع وأقل فواقد للمياه. أوضح التحليل الاحصائى أن نمط الرشاشات غير مؤثر معنوياً على كفاءة التوزيع (CU% و DU%) وفواقد المياه. كان ترتيب متوسط DU% و CU% للأنماط الثلاثة كالتالي: المثلث> المربع> المستطيل. بينما كان ترتيب متوسط فاقد المياه للأنماط الثلاثة كالتالى المستطيل> المربع> المثلث.

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