African Stud. Rev. Vol. (42) (2017) : 1 - 32

Performance study of sprinkler irrigation system in Sudan

By

Hosham S. Yousif(*); El-Syed I. Gaber(**); Goma A. Bakeer(***); Abbas E. Rahma(****) Fathi G. EL-Ebabi(*****)

Abstract :

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 due to the high efficiency and flexibility in applying small depths of water. Another motive for the spread of sprinkler irrigation is the water conservation, particularly for farmers using groundwater for irrigation.

Field experiments were carried out during the agricultural season of 2015/2016, in order to study three riser heights, three discharges and three operation pressures for a lateral sprinkler system performed at the demonstration farm of Shambat area at

(*) Ministry of agriculture mechanized farming Corporation, elgadarif state, Sudan.

(**) Institute of African Researches & studies, Cairo University, Egypt.

(***) Agricultural Engineering Department, Faculty of Agriculture, Cairo University, Egypt.

(****) Sudan University of Science and Technology, College of Agricultural Studies. Department of Agricultural Engineering, Shambat Khartoum. Sudan.

(*****) Agricultural Engineering Department. Faculty of Agriculture, Cairo University, Egypt

University of Khartoum, Sudan. The aim of this paper was to study the effect of weather conditions, pressure, riser height and discharge on the performance of sprinkler irrigation system in Sudan. To achieve the work goal, two types of impact sprinkler (single and dual nozzles), three riser heights of 50, 75 and 100 cm, three pressures 1.5, 2 and 2.5 bar and three discharges 264, 324 and 354 L/h for single nozzle sprinkler and 510, 576 and 631 L/h for dual nozzles sprinkler were tested to study the effect of these types on Christiansen's coefficient of uniformity (CU%), distribution uniformity (DU%), moisture distribution patterns, precipitation rate, wind drift and evaporation loses WDEL. The results obtained from this study revealed that, impact sprinkler single nozzle under 50 cm riser height produced the best uniformity coefficient and uniformity of distribution, precipitation rate and the lowest wind drift and evaporation losses WDEL. Precipitation rate and WDEL were significantly affected by pressure and riser height. The sequence of the different sprinkler types according to moisture distribution was found to be in a descending order, so that overlapping with 4 sprinkler overlapping with 2 sprinkler solid set sprinkler. The sequence of the different types according to the volume of water stored in the soil profile was found to be in a descending order so the impact sprinkler dual nozzles impact sprinkler single nozzle.

Key words: Sprinkler, Distribution Uniformity, Wind drift, Irrigation in Sudan.

INTRODUCTION

The growing demand and the increasing freshwater scarcity urgently require effective and sustainable management of water for irrigation to assure future satisfaction of food. The sustainable management uses advanced technologies to improve water use efficiency.

Increasing crop production to meet food requirements of the world's population is placing a pressure on global water resources. Total volume of water on the Earth is 1.4 billion km3; however, a proportion of this, which is fresh and reasonably accessible, is 11 million km3 (Maidment, 1992). Though, there is no shortage of water on this planet but just there is a lack of accessibility to the freshwater in some places at sometimes (Wallace and Batchelor, 1997). With Earth's available potential of freshwater, land, and human resources, it is quite possible to produce enough food for the future (IWMI, 2007). The vast freshwater resources available worldwide are still far away from fully exploited. However, there are large areas where low water supply and high demand may lead to regional shortages of water for future food production. Irrigation is the major consumer of freshwater amongst various consumers. In arid and semi-arid areas, water is a major constraint for crop production, therefore improving irrigation water management is a crucial to meet food and fiber demands.

Moutasim et al. (2010) mentioned that according to the 1959 Nile water agreement between Egypt and Sudan, Sudan's annual allotted share is 18.5 billion m3 (as measured at Aswan). This amount would allow the irrigation of about 4.0 to 4.8

million feddan (Al-araki, 2002), whereas the area of potentially productive land is about 200 million feddan (1 feddan = 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.

Wind speed was not the only variable affecting the radial distribution of a sprinkler's irrigation water. Results showed that the wind direction was also considered as a variable that affected the radial water distribution. Sa´nchezet et al. (2011) found that prevailing winds, even at very low speeds, a significant volume of water drifted. For this reason, it has been necessary to evaluate the predominant wind direction before selecting a suitable radial water distribution.

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 distribution uniformity is the arrangement and spacing of nozzles on the lateral and spacing between laterals. This refers to the geometrical water application shapes made by nozzles arrangement on any two adjacent laterals (Moutasim et al., 2010). The study was intended to examine the impact of two types of sprinkler nozzles (the single and the dual ones) in order to estimate the water distribution, uniformity, evaporation and drift losses in a set of sprinkler irrigation under Sudan conditions for high water use efficiency purposes.

MATERIALS AND METHODS

The field experiment was carried out at Shambat the demonstration farm of the Faculty of Agriculture, University of Khartoum during 2015 and 2016. The experimental Field is located on latitude of 15°40’ N and longitude of 32°32’ E altitude of 380 m height above the mean sea level (MSL). To achieve the goal of the work, two types of impact sprinkler (single and dual nozzles), three riser heights 50, 75 and 100 cm, three pressures of 1.5, 2 and 2.5 bar and three discharges of 337.5, 450 and 562.5 L/h for single nozzle sprinkler and 414, 552 and 690 L/h for dual nozzles sprinkler, were tested to study the effect of these types on Christiansen’s coefficient of uniformity CU, distribution uniformity DU, moisture distribution patterns, precipitation rate and wind drift and evaporation losses WDEL.

Two sets of experiments were performed. The first set was carried out using a single sprinkler installed on bare soils. The second set of experiments was performed using a solid set of sprinklers mounted on a square spacing of 18 m * 18 m. The experiments were performed based on recommendation of Merriam and Keller (1978) findings, and the relevant international standards ASAE S330.1 (Anonymous 1, 1987), ISO 7749/1 (Anonymous 2, 1995) and ISO 7749/2 (Anonymous 3, 1990). The sprinkler used in all experiments was the impact sprinkler model WEtta 8427 single nozzle and 8022 dual nozzles. The arrangement and sequence of different implement actions are shown in Fig. (1).

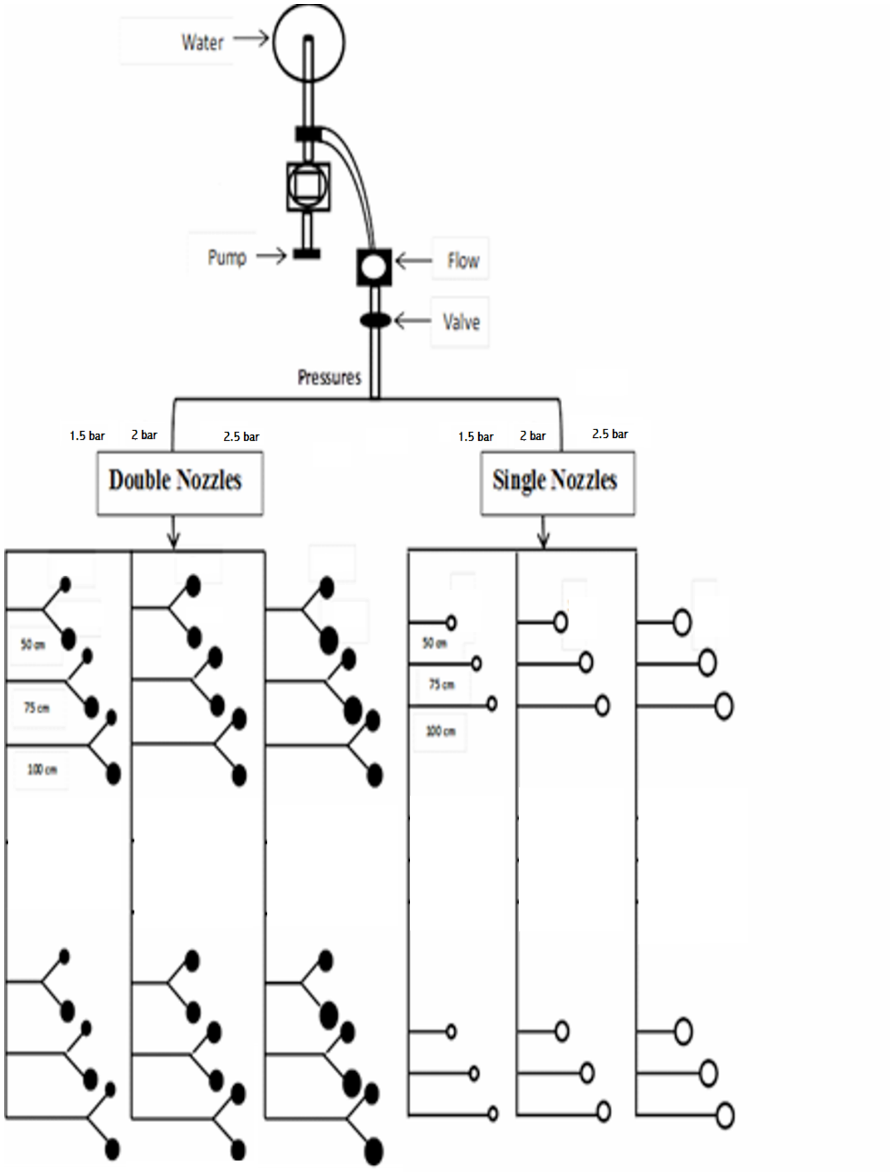

Fig. 1. Schematic diagram showing the treatments and variables of laboratory experiment

A single sprinkler, model 8427B wetta, was installed in a riser pipe at 50, 75 and 100 cm above ground level. The irrigation depth (ID) emitted by the sprinkler was collected in catch cans located along four perpendicular radii at distances from the sprinkler ranging from 1 to 13 m and separated at 1.5 m. Additional pluviometers were installed at 0.5 m from the sprinkler in each radius to determine precisely the ID in the area adjacent to the sprinkler. A total number of 10 catch cans were installed in each radius at 0.1m above the ground level . The radii of pluviometers faced north (N), west (W), south (S) and east (E) directions. Each catch cans was 0.1m high and conical with a circular opening of 14.5 cm. The experimental plot was examine in open area to test the effect of the wind as shown in Fig. (2) described by Talel et al. (2014).

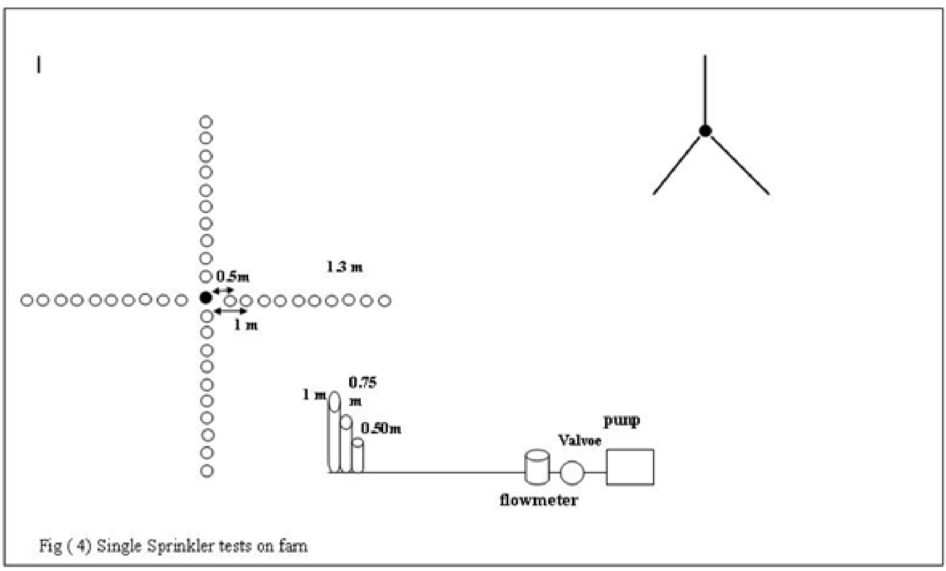

Fig . 2. Single sprinkler tests under difference variable.

The WDEL during each test was estimated as the percentage of the water depth emitted by the sprinklers (ID) that were not collected in the pluviometers (Dechmi et al., 2003; Playa´n et al., 2005; Sa´nchez et al., 2010) as expressed in equation 1 below.

(1) $$WDEL = \frac{ID - IDcc}{ID} \times 100$$ $$WDEL = \frac{ID - IDcc}{ID} \times 100$$

Where: IDCC is the mean water depth collected in the pluviometers and ID the mean water depth emitted by the sprinkler. Solid-set evaluations were performed under a wide range of Meteorological conditions in an attempt to characterize the WDEL resulting from different impact sprinkler.

A pilot area of 18 * 18 m was used as tested area. The experiments were applied by using two type of impact sprinkler (single and dual nozzles).

The operating pressure was maintained at required level by using sustaining and reducing valve. The rainfall catch-cans were used to collect water, they have conical shape with side walls 45° from the horizontal. The catch-cans have sharp-edged, round openings, 10 cm diameter and free from deformities. The openings of all the collectors were installed in the same horizontal plane. The collectors were spaced by 2 m apart except the first collector, that it was spaced by 1 m from the sprinkler as shown in Fig. (3), to be sufficient to cover the entire spray coverage area.

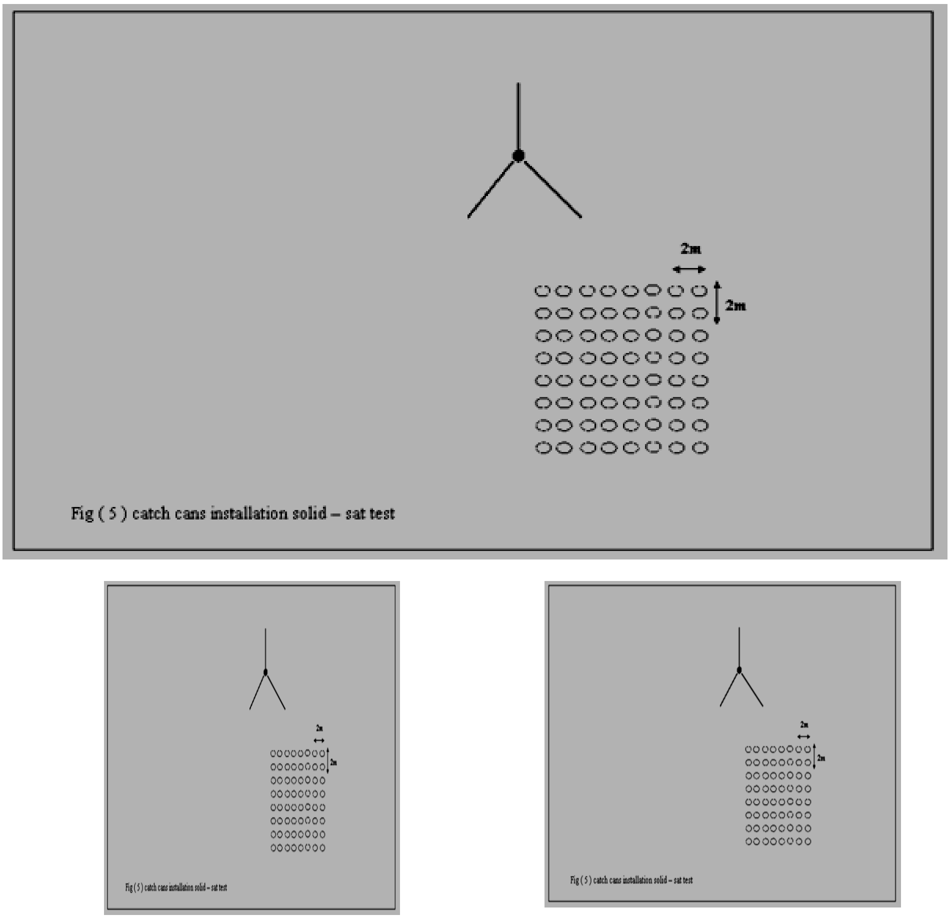

Fig .3. Solid- set experiment tests (single and dual nozzle) under difference variable

For specifying the best shape of water distribution over the soil surface, the application uniformity was applied to determine how evenly the water for different discharges is distributed, beside the operating pressure and nozzle heights. The application uniformity was estimated using Christiansen uniformity coefficient (CU) and distribution uniformity (DU) which are coefficients that are widely used to evaluate application uniformity and the distribution uniformity developed by Christiansen (1942). Equation 2 expresses the calculation of the application uniformity.

Where: $$CU = 100\left(1.0 - \frac{\sum_{i=1}^{n}\left|z - m\right|}{\sum_{i=1}^{n} z}\right) \qquad (2)$$

CU = Christiansen uniformity coefficient.

z = Individual depth of catch observations from uniformity test (mm).

m = Mean depth of observations (mm) (Keller and Bliesner, 1990).

n = Number of observations.

The distribution uniformity is a ratio expressed in a percent of the average low-quarter amount caught or infiltrated to the average amount caught or infiltrated as express in equation 3 (James, 1988).

Where: $$DU = 100 \frac{\overline{X}_{LQ}}{\overline{X}} \qquad (3)$$

$\overline{X}_{LQ}$: The average low-quarter amount caught or infiltrated (mm)

$\overline{X}$: The average amount caught or infiltrated (mm).

Moisture Content (MC)

The soil moisture content was determined using the standard oven method. the Samples were collected from the field before and after irrigation at different depths (0 – 30, 30 – 60 and 60 - 90 cm), weighed and dried to constant weight at 105, then the moisture was determined a dry-base, the soil moisture content measurement was adopted at different distance from sprinkler according to the wetted radius of each sprinkler with 300 cm apart between each point.

Surfer software was used to draw the soil moisture distribution as contour lines and the soil water movement within the whole soil profile. It is a software package transforms XYZ data to create contour maps, 3D surfer maps, 3D wireframe maps, shaded relief maps, rainbow color " amage" maps, post maps, classed post maps, vector maps and base maps.

The data was inserted to the model in XYZ coordinates format, where X represents the distances from sprinkler and distances between two sprinklers, Y represents the investigation soil depth (0, 30, 60, 90 cm), and Z is the soil moisture content values.

RESULTS AND DISCUSSION

The field experiments were conducted on clay soil. That has structure and depth information is shown Table 1.

Table (1) Particle size distribution and soil texture classes.

Depth (cm)	Clay %	Silt %	Sand %	Soil texture class
0 – 30	53.58	41.02	5.4	Clay
30 – 60	57.24	32.5	10.26	Clay
60 – 90	62.24	32.36	5.4	Clay

The daily weather data necessary to calculate the water distribution and moisture water distribution was obtained from Shambat Station in Sudan. Air temperature, vapour pressure, relative humidity and wind speed during the study period are show in Table (2).

Table (2) sprinkler type, riser, air temperature (T), relative humidity (RH) , vapor pressure (VAP) and wind speed (V).

Sprinkler type	Riser (cm)	Weather conditions				
		Pressure (bar)	VAP (m bar)	RH (%)	T (C^0)	V (Km/h)
Single nozzle	50	1.5	7.8	18	31	11.80
		2	8.3	17	35	12.20
		2.5	8.5	19	33	12.90
	75	1.5	7.8	15	36	6.20
		2	8.4	20	35.10	12.93
		2.5	9.4	22	31	9.35
	100	1.5	10.5	14	41	7.51
		2	10.4	16	32	5.61
		2.5	11.6	18	39.5	6.50
Dual nozzles	50	1.5	13.4	15	40	9.25
		2	12.5	14	41	9.10
		2.5	11.8	17	38.5	8.30
	75	1.5	5.7	11	37	9.23
		2	6.5	10	38.5	5.73
		2.5	9.2	20	31	9.25
	100	1.5	8	23	35.5	8.30
		2	14.5	21	38	7.41
		2.5	12	15	41.5	6.40

Field evaluation: Uniformity of the variable-rate systems

1. Single sprinkler tests

Water distribution patterns

The operational conditions of different impact sprinkler in the isolated-sprinkler experiment to assess the water precipitation for different impact sprinkler single nozzle and dual nozzles, radius (m), pressure (bar), discharge and riser are presented in table (3).

Table 3. Operational conditions of different impact sprinklers (single and dual nozzle)

Sprinkler type	Riser (cm)	Pressure (bar)	Discharge (l/h)	Radius (m)	Precipitation (mm/h) Cans Distance (m)							
					1.5	3	4.5	6	7.5	9	10.5	**12**
Single nozzle	50	1.5	337.5	9	9	8	8	7	7	6	6	**5**
		2	450	10	13	12	13	12	12	12	10	**9**
		2.5	562.5	11	16	19	18	19	17	13	12	**11**
	mean			10								
	75	1.5	337.5	10	12	11	9	10	10	9	7	**6**
		2	450	10	13	14	12	10	9	8	7	**8**
		2.5	562.5	11	15	12	15	12	13	11	9	**9**
	mean			10.3								
	100	1.5	337.5	10	9	9	9	7	8	6	5	**4**
		2	450	11	10	9	11	9	9	7	6	**5**
		2.5	562.5	11	16	15	13	11	12	10	9	**8**
	mean			10.6								
Dual nozzle	50	1.5	414	9	10	9	8	8	9	8	8	**6**
		2	552	10	12	10	9	8	9	7	9	**7**
		2.5	690	11	13	12	12	10	11	9	7	**8**
	mean			10								
	75	1.5	414	10	10	8	9	9	8	8	7	**5**
		2	552	11	11	9	9	8	7	9	7	**8**
		2.5	690	10.5	12	10	9	9	8	9	7	**8**
	mean			10.5								
	100	1.5	414	10.5	12	12	11	9	10	9	8	**7**
		2	552	11	13	13	11	12	11	10	9	**8**
		2.5	690	11	14	14	12	13	12	11	10	**9**
	mean			10.8								

Dealing with the effect of different riser heights and different pressures on the precipitation rate presented in table (3), it was found that the highest precipitation rates were at the 50, 75 and 100 cm under working pressures of 2.5, 2 and 1.5 bar for the single impact sprinkler, respectively. However, the dual nozzles showed irregular behavior with riser heights. From the data in table, it was clear that according to the previous change in riser the radius shows regular behavior of increase with the increase of riser height and pressures. It was found that average radiuses were 10, 10.3 and 10.6 m for riser heights of 50, 75 and 100 cm, respectively for single nozzle and 10, 10.5 and 10.8 m for riser heights of 50, 75 and 100 cm, respectively for dual nozzles impact sprinkler.

The relevant factors that affected the water distribution patterns under sprinkler irrigation systems were the type of sprinkler, operating pressure, nozzle height. All these factors were studied in the present work to develop guidelines for adequate design of laterals equipped with sprinklers. The water distribution pattern is the main factor in the evaluation process for irrigation performance.

The radial patterns obtained from radial water distribution curve for impact sprinkler (single and dual nozzle) are show in figs. (4 and 5). It has been noticed that although there are some differences between the riser heights and operating pressures for the same type, the water distribution patterns for different sprinkler types, riser heights, operating pressures, discharges and the precipitation rate curves maintain one shape under the two types of impact sprinkler. It has been remarked also that there was a triangular shape which showed a plateau of a maximum precipitation rate and gradually decreasing towards the minimum precipitation rate for single and dual nozzles, respectively, as previously reported in other studies for difference micro sprinkler types (Abu arab 2008). The radial water distribution patterns curve for single impact sprinkler single nozzle are show in Fig. (4), the distribution curve due to use any riser height with difference operating pressure showed irregular behavior,

The radial water distribution of impact sprinkler with plastic nozzle in single sprinkler tests in open air conditions requires several precaution because the wind significantly distorted the water distribution patterns, as previously showed by Sanchez et al (2011), while wetted radius was increased with increasing the riser height and operating pressure . Causes of maximum plateau and wetted radius in accordance to the increase of operating pressure and discharge could be attributed to the energy increment of each drop, which increases the traveling distance and also the wetted radius. The discharge had an effect on the water distribution patterns for each impact-sprinkler under the two types. Hence, the water distribution pattern differs from one sprinkler to another under the same type. The higher discharges need high operating pressure to give the optimal distribution pattern

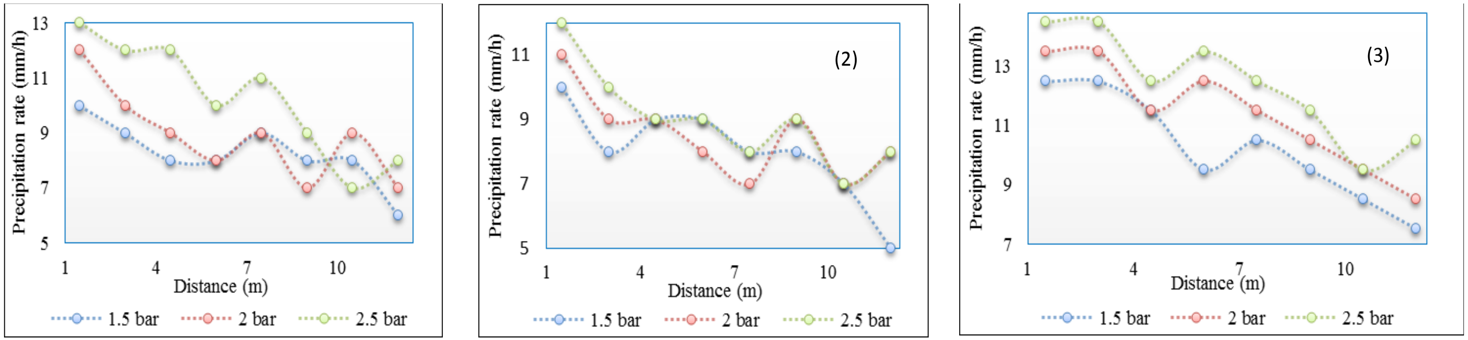

Fig. 4. The average irrigation depth (mm/ h) collected along the wetted radius of the single nozzles sprinkler at riser heights (1) 50 cm, (2) 75 cm and (3) 100 cm

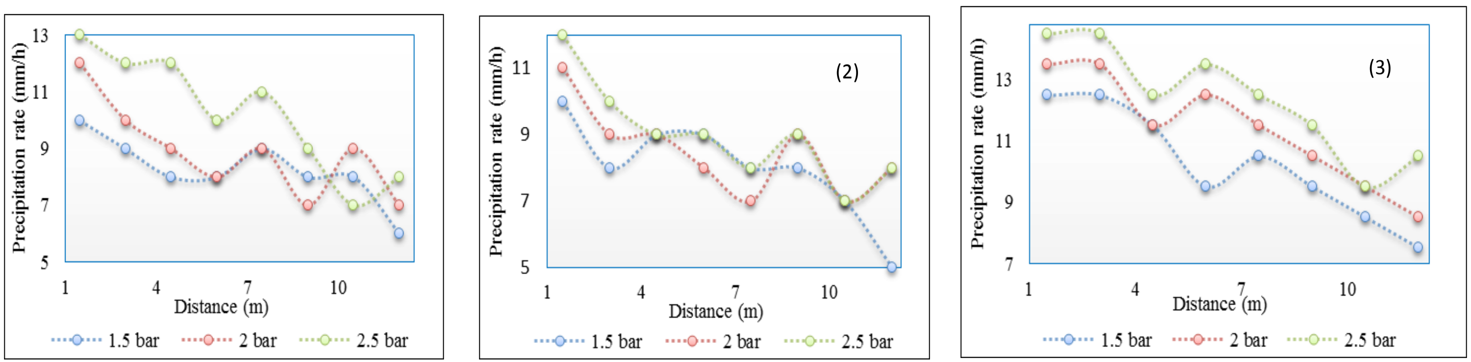

Fig. 5. The average irrigation depth (mm/ h) collected along the wetted radius of the dual nozzles sprinkler at riser heights (1) 50 cm, (2) 75 cm and (3) 100 cm.

There was an inverse relationship between the wetted radius and the precipitation rate, so the maximum precipitation rate was observed under 50 cm riser height, and the minimum precipitation rate was under 100 cm riser height, this is related to the wetted area so the low riser height the high wetted area.

The wetted radius has increased directly proportional to the riser height, related to the trajectory angle which equal to 260 and the shape of trajectory which takes a convex shape. So it can be observed that the maximum and the minimum wetted radiuses were found under 100 cm and 50 cm riser heights, respectively for both types of impact sprinklers. While the 75 riser height showed medial behavior between riser 50 cm and 100 cm. Otherwise, the wetted diameter is controlled by the velocity of the water leaving a particular nozzle and the distance between the water stream and the soil surface. Thus, as the distance between the nozzle and the soil surface decreases, the wetted diameter decreases

Results summary of isolated sprinkler's performance test

Air temperature and wind speed effects on the impact-sprinkler radial water distribution

Information in Table (4) shows the weather variables that have been gained in order to assess the radial water distribution of the two types. The average air temperatures of the single sprinkler tests were 33, 34 and 37.5 Co for riser heights of 50, 75 and 100 cm for single nozzle, respectively; and 39.8, 35.5 and 38.3 Co for riser heights of 50, 75 and 100 cm for dual nozzles, respectively.

The average of wind velocities during tests were 12.3, 9.4 and 6.54 km/h for riser heights of 50 ,75 and 100 cm, respectively for single nozzle and 8.8, 8 and 7.37 km/h for riser heights of 50 ,75 and 100 cm, respectively for dual nozzles. The tests were started under field condition and difference discharges of 264, 324 and 354 l/h with working pressures of 1.5, 2 and 2.5 bar, respectively for single nozzle and 510, 576 and 631 l/h with working pressures of 1.5, 2 and 2.5 bar, respectively for dual nozzles.

The effect of different treatment of performance of impact sprinkler on (SD ID, IDcc, ID and WDEL)

The mean depth (IDcc) collected in cans and mean water depth (ID) emitted by the sprinkler are presented in the Table (4). The average of IDcc was found to be equal to 2, 9 and 9 l/h and the average ID was 14.9, 13.30 and 12.54 l/h with the riser high 50, 75 and 100 cm, respectively for single nozzle and the average of IDcc, ID for dual nozzles was 8.9, 7.3 and 10.4 L/h, 11.15, 9.35 and 14 L/h with the riser high 50, 75 and 100 cm for dual nozzles, respectively.

The standard deviation values for irrigation depth (Sd ID) presented in Table (4) was 3.7, 3.6 and 2.9 for single nozzle with different riser heights where regular behavior was noticed. It was ranging in a descending order when riser heights were increasing and were found to be 3.24, 2.29 and 3.8 for dual nozzles, where different riser heights showed irregular behavior which could be attributed to the operation pressures and the weather effects.

From the wind drift and evaporation losses (WDEL) which are presented in Table (4), the average percentages were 18.66, 25.3 and 21.96 % and 20.16, 21 and 24.3 % with riser heights of 50, 75 and 100 cm for single and dual nozzles, respectively. The mean depth collected in cans, mean water depth emitted by the sprinkler, wind drift and evaporation losses, irregular behavior was shown in different riser heights, which must be according to the previous change in air temperature and wind speed. Table (4), shows a summary of the test performed at different impact sprinkler experiments. A group of parameter is listed in the table namely: riser (cm), pressure (bar), discharge (l/h), irrigation deeps (ID), mean water deeps collected in cans (IDcc), weather condition and wind drift and evaporation losses (WDEL %).

Table 4: A summary of the tests performed at the different impact sprinkler experiments.

Sprinkler Type	Riser (cm)	Pressure (bar)	Discharge (L/h)	Weather data			SD ID mm/h	ID_{cc}	*ID*	WDEL %
				T(c)	V (km/h)	RH %				
Single nozzle	50	1.5	337.5	31	11.80	7.8	3.78	14.45	18	19.72
		2	450	35	12.20	8.3	4.01	12.60	15.55	18.97
		2.5	562.5	33	12.90	8.5	3.54	9.23	11.39	18.96
	mean			33	12.3		3.7	12	14.9	19.21
	75	1.5	337.5	36	6.20	15	3.03	6.80	9.94	31
		2	450	35.1	12.93	20	4.46	11.89	15.64	23
		2.5	562.5	31	9.35	22	3.33	11.04	14.33	22
	mean			34	9.4		3.6	9	13.30	25.3
	100	1.5	337.5	41	7.51	14	3.71	10.57	13.21	19.98
		2	450	32	5.61	16	2.06	6.42	8.12	21
		2.5	562.5	39.5	6.50	18	3.01	12.23	16.30	24.9
	mean			37.5	6.54		2.9	9	12.54	21.96
Dual nozzle	50	1.5	414	40	9.25	15	4.11	8.89	11.25	21
		2	552	41	9.10	14	3.33	9.15	11.43	20
		2.5	690	38.5	8.30	17	2.30	8.68	10.78	19.48
	mean			39.8	8.8		3.24	8.9	11.15	20.16
	75	1.5	414	37	9.23	11	2.58	7.35	9.38	21.74
		2	552	38.5	5.73	10	2.26	7.23	9.21	21.5
		2.5	690	31	9.23	20	2.04	7.57	9.46	20
	mean			35.5	8		2.29	7.3	9.35	21
	100	1.5	414	35.5	8.30	23	7.20	10.4	12.3	18
		2	552	38	7.41	21	2.25	7.73	9.91	22
		2.5	690	41.5	6.40	15	2.14	8.01	10.68	25
	mean			38.3	7.37		3.8	8.7	10.9	21.6

2. **Solid- set experiment tests (single and dual nozzle)**

Effect of impact-sprinkler performance on (CU and DU) with different treatments

A total of 64 water collection tests were done for the lateral irrigation system. 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 %).

The mean values of CU % obtained from three sprinkler patterns for two types of impact sprinkler (single and dual nozzles) are show in figs. (6 and 7) it has been noticed that although there are some difference between the riser height and sprinkler patterns for the same type the maximum and minimum average CU% vales under triangular , square and rectangular were 76, 75.3 and 75% at the 50 cm riser height and 75, 75.3 and 74% at 100 cm riser height for (single nozzle) and 76.6, 74.6 and 74.3% at the 50cm riser height and 74.6, 73.3 and 70% at 100 cm riser height for (dual nozzles), respectively. While the average CU % at 75 cm riser height showed medial behavior between riser 50 cm and 100 cm under three sprinkler patterns.

The mean values of CU% are arranged in the following manner: triangular pattern> square pattern> rectangular pattern Figs. (6 and 7). The riser height was difference effect on the mean of CU% under same pattern. While 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).

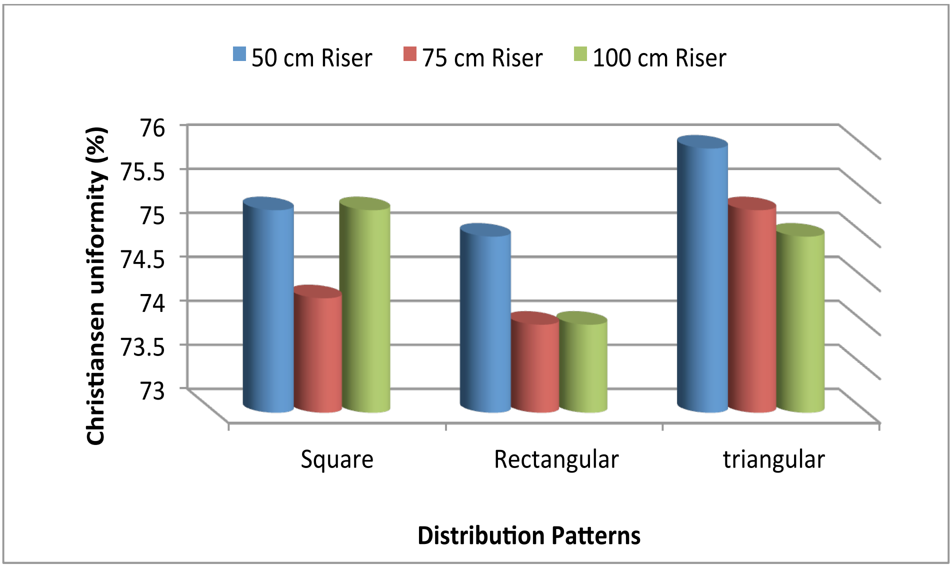

Fig. 6: Average uniformity coefficient CU (%) under square, rectangular and triangular patterns sprinkler for single nozzle sprinkler

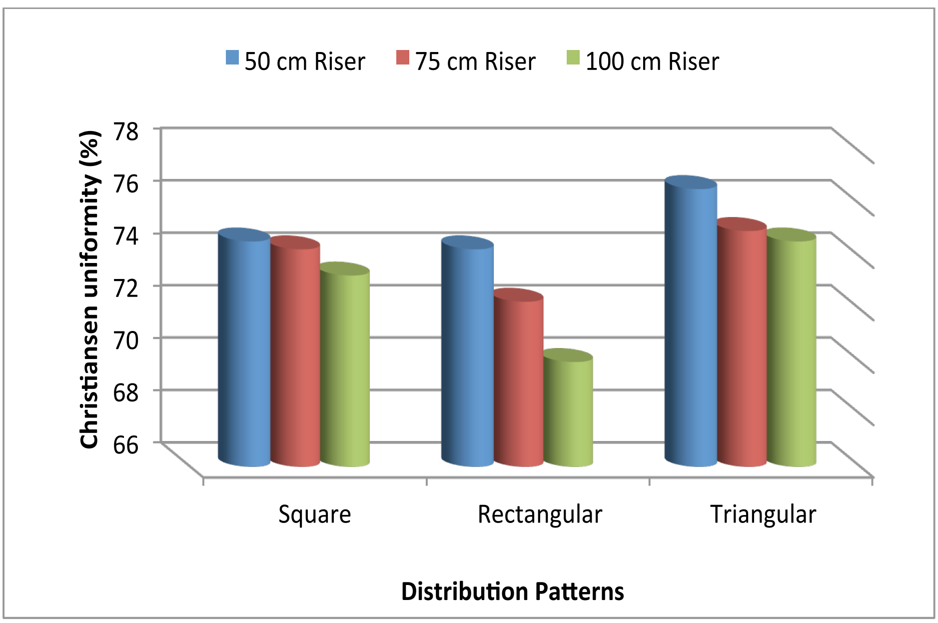

Fig. 7. Average uniformity coefficient CU (%) under square, rectangular and triangular patterns sprinkler for dual nozzles sprinkler

The mean DU% values followed the same order as CU%, the maximum and minimum average DU% vales under triangular , square and rectangular were 64.3, 63.6 and 61 % at the 50 cm riser height and 62.6, 62.3 and 50.3 % at 100 cm riser height for (single nozzle) and 66, 64.3 and 59 % at the 50 cm riser height and 60, 58.6 and 58.3 % at 100 cm riser height for (dual nozzles), respectively. While the average DU % at 75 cm riser height showed medial behavior between riser 50 cm and 100 cm under three sprinkler patterns.

The mean values of DU% are arranged in the following manner: triangular pattern> square pattern> rectangular pattern Figs. (8 and 9).

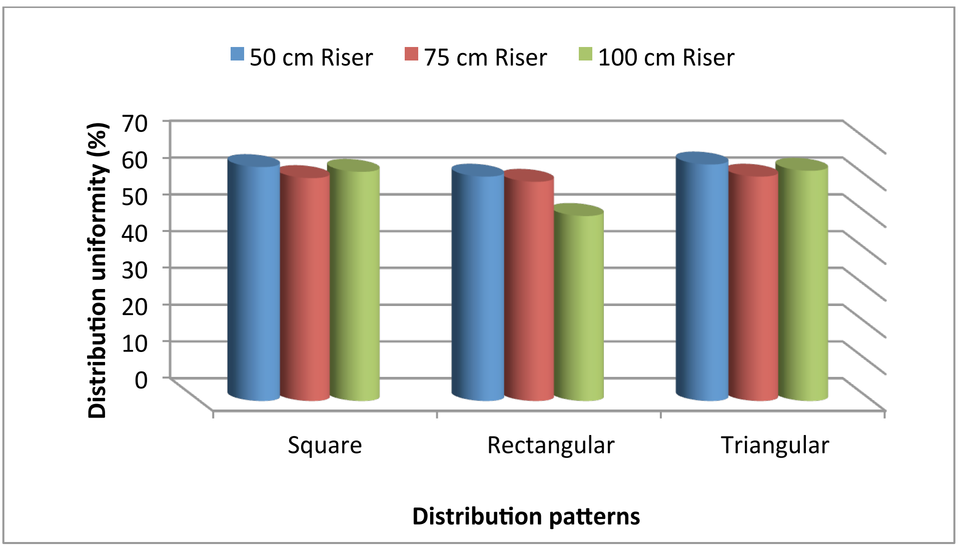

Fig.8. Average distribution uniformity DU (%) under square, rectangular and triangular sprinkler patterns for single nozzle sprinkler

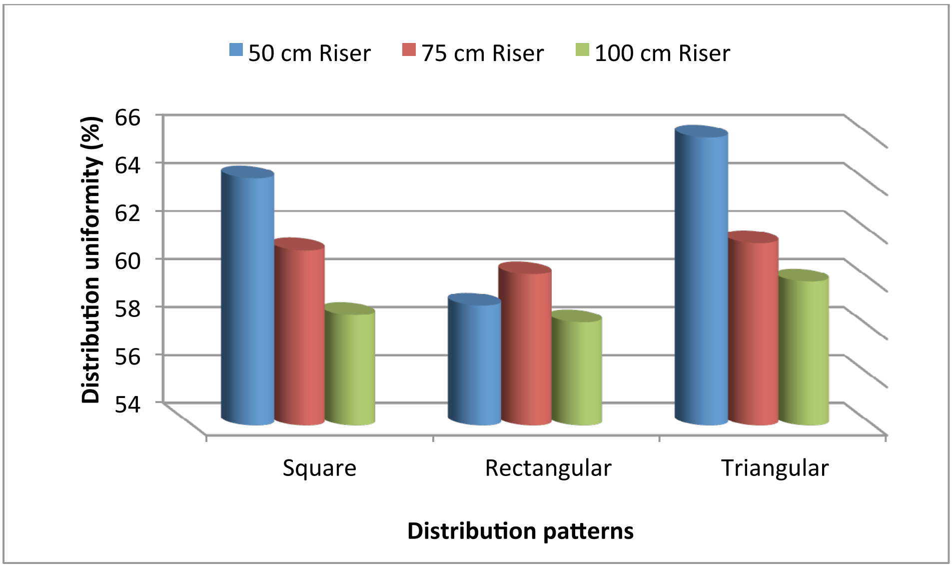

Fig9. Average distribution uniformity DU (%) under square, rectangular and Triangular sprinkler patterns for dual nozzles sprinkler

Statistical analysis

Randomized complete block

The statistical analysis, were applied by using dependent variable (CU % and WDEL %) and independent variable sprinkler type, riser height, pressure, discharge and other meteorological variables

Effect of the independent variable on WDEL %

The effects of sprinkler type, riser height and discharge on the wind drift and evaporation losses only riser height were significant. While the effect of wind speeds, air temperature and humidity on WDEL % were assessed using backward stepwise analysis to select the best suited model for the prediction of this parameters. The best model found for the predication of the WDEL (%) was a linear function of wind speed V (km/h) the following equation was obtained:

Resulting Stepwise Model

Variable	Coefficient	Std Error	T	P
Constant	26.8853	2.61278	10.29	0.0000
V	-0.61624	0.28786	-2.14	0.0480

WDEL % = 26.88 – 0.61 * V

The linear regression shows that there is a negative relationship between the WDEL and the independent variable V (km/h).

Effect of independent variables on CU % .

The effect of sprinkler patterns (square patterns, rectangular patterns and triangular pattern), riser height, operating pressure and discharge on CU % only operating pressure and discharge were significant

Soil moisture distribution patterns under single sprinkler tests (single nozzle and dual nozzles*)*

The soil moisture distribution pattern was investigated by applying water under 50 cm nozzles height for impact sprinkler of both single nozzle and dual nozzles as well, where 2.5 bar operating pressure was adopted for both types. The selected nozzle heights and operating pressures were according to the maximum CU and DU which were obtained from the irrigation performance characteristics. Soil moisture distribution pattern are illustrated in Fig (10 and 11) over clayey soils, the color key at figure legend illustrates the precipitation rate (mm/h) for the single and the dual types. The (y) axis represents the soil profile with a maximum depth of 90 cm. The maximum width varied from 10 m to 11 m according to the maximum wetted radius of the surface water distribution pattern for each impact sprinkler.

The effect of WDEL on the precipitation rate was taken into consideration, according to experiments. Calculations of wind drift and evaporation loses of minimum losses under 50 cm riser height was found to be equal to 19 %. According to the surface water distribution patterns (which takes a triangular shape for all discharges), the field experiments revealed that the soil moisture distribution patterns take an inverse triangular shape under all discharge conditions, therefore, it can be noticed that the soil moisture distribution patterns are indicators of surface water distribution patterns, and also the soil moisture distribution was significantly affected by the uniformity on the soil surface within that distance.

The soil moisture distribution patterns increase in depth and width when the volume of water applied increases for all discharges, while the moisture content decreases when the distance from sprinkler increases, so the soil moisture distribution depth and width were adopted under 600 liter applied water for both types. The soil moisture distribution patterns depth and width under single nozzle impact sprinkler were higher than the dual nozzles impact sprinkler.

The soil moisture distribution patterns depth and width under single nozzle impact sprinkler showed regular shape patterns than dual nozzles sprinkler. This is related to the higher application time which makes the soil to get the best use of application water.The distribution of water through soil profile for clay soil under sprinkler irrigation system is considered one of the most important factors for soil water management.

Single sprinkler (single nozzle) shows uniformity in soil, the maximum soil moisture content values after irrigation were measured at depth ranged from 10 to 60 cm and it was 29 and 21 % respectively and gradually decreased up and down along wetted radius till the minimum values measured at depth ranged from 10 to 30 cm and 10 m distance from sprinkler it was 21 and 24 %. Fig. (10), represents the field capacity for the impact sprinkler single nozzle which is represented by contour lines 0.60, with discharge of 562.5 l/h. The field capacity was adopted under 600 liters applied water, the minimum and maximum width and depth for contour line, where the minimum width and depth were 6 m and 0.25 m and the maximum width and depth were 9 m and 0.35 m, respectively. The figure shows that the contour lines decreasing as the distance increases at the sprinkler; this could be due to the moisture content.

Single sprinkler test (dual nozzles) achieved the heights moisture content after irrigation 33 % and it was measured at depth 10 to 60 cm and it gradually decreased up and down along wetted radius till the minimum values measured at depth ranged from 10 to 30 cm and 10 m distance from sprinkler, it was 21 and 25 %. Fig. (11)

Fig (11) on the other hand, represents the field capacity for the impact sprinkler dual nozzles with the contour lines 0.60, with discharge of 690 L/h. The field capacity was adopted under 600 liters applied water, the minimum and maximum width and depth for contour line, where the minimum width and depth were 4 m and 0.35 m and the maximum width and depth were 11 and 0.60 m.

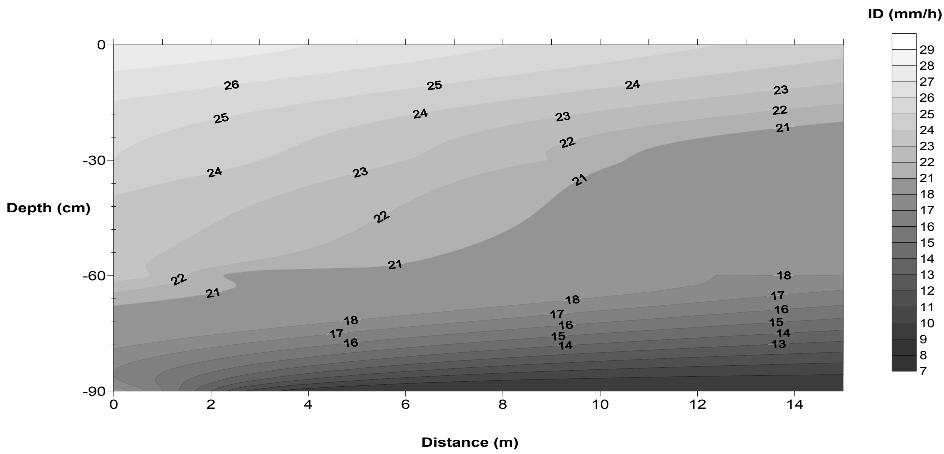

Fig. 10. Contour maps of the water distribution pattern (ID, mm hL1) for the single nozzle sprinkler

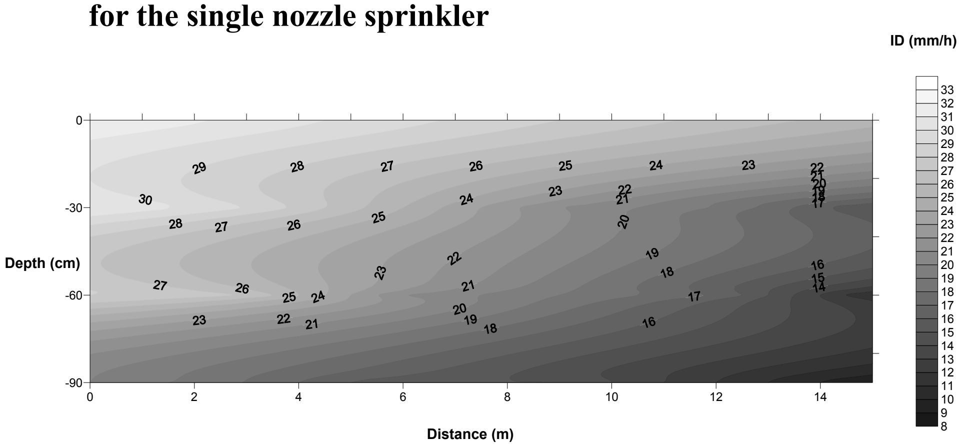

Fig. 11. Contour maps of the water distribution pattern (ID, mm hL1) for the dual nozzles sprinkler

CONCLUSION

The aim of this work was to study the effect of weather condition, pressure, riser height and discharge on performance of sprinkler irrigation system in Sudan. The following conclusions can be made from the study:

- Dealing with the effect of different riser heights, discharges and different pressures with single nozzle, the minimum riser heights produced the highest precipitation rate, while the maximum riser heights with dual nozzle produced the highest precipitation rate.
- The maximum *(CUand DU)* were measured at the highest pressure, highest discharge and minimum riser height for the measured two types of impact sprinkler.
- The biggest radius was observed at the highest riser, while the smallest radius was observed when using minimum riser height with two types of impact sprinkler.
- The minimum WDEL % was observed at the lowest riser height, while the maximum WDEL % was observed when using the highest riser height.
- The maximum moisture content was observed when using overlap of 4 sprinklers, while the minimum moisture content was observed when using overlap of 2 sprinklers for the two types of impact sprinkler.

It is recommend that the overlap of 4 sprinklers is a perfect, because it takes into consideration the density effect of the 4 sprinklers. The impact sprinkler single nozzle was found to be better to irrigate, because it has the highest distribution uniformity under the low pressure. The results presented showed that the selection of the sprinkler models is complicated because it depends on many factors, and most of those factors are out of the farmer’s control. However, the differences in the performance observed between sprinkler with single nozzle or dual nozzles could assist in the selection of a particular type of sprinkler. Other economic and technical factors should be taken into account as well.

REFERENCE

- Al-araki, G.Y. (2002). Design and Evaluation of Sprinkler Irrigation System. Unpublished Ph. D. thesis. Department of Agricultural Engineering, Faculty of Agriculture,' University of Khartoum, Sudan.
- Abu arab, E. M. (2008). Water and soil moisture distribution patterns under micro sprinkler irrigation system. phD. Thesis . department of agriculture engineering, faculty of agriculture, university of Cairo, Egypt..
- Anonymous 3. (1995). Agricultural irrigation equipment. Rotating sprinklers. Part 1. Design and operational requirements. ISO standard 7749/1. Geneva, Switzerland: ISO.
- Christiansen, J. E. (1942). Irrigation by sprinkling. California Ag. Expt. Sta. Bulletin 670. Berkeley: University of California. Dechmi, F., Playa´ n, E., Cavero, J., Faci, J. M., & Martinez-Cob, A. (2003). Wind effects on solid set sprinkler irrigation depth and yield of maize (Zea mays). Irrigation Science, 22, 67 - 77.
- Dechmi, F., Playa´ n, E., Cavero, J., Faci, J. M., & Martinez-Cob, A. (2003). Wind effects on solid set sprinkler irrigation depth and yield of maize (Zea mays). Irrigation Science, 22, 67 - 77.
- IWMI, (2007), "Water Management Urgent Need for More Food with Less Water", Spearheaded by International Water Management Institute (IWMI), Science Daily (Press Release)-USA, March 27, 2007.
- James, L. G. (1988). "Principles of farm irrigation system design". Chapter 9. New York. John Wiley and Sons
- Keller, J., and Bliesner, R. D. (1990). Sprinkler and trickle irrigation. New York, NY: Van Nostrand Reinhold.
- Maidment, D.R. (Ed.). (1992), "Handbook of Hydrology", McGraw Hill, New York.

- Majumdar, D.K. (2002), “Irrigation Water Management, Principles and Practices”, Published by Prentice ⁄ Hall of India (Pvt. Limited), New Delhi – 110001.
- Merriam, J. L., and Keller, J. (1978). Farm irrigation system evaluation: A guide for management. Logan, Utah: Utah State University.
- Michael, A.M. (1978).Irrigation: Theory and Practice. First edition. Viskas Publishing House, PVT. Ltd., New Delhi, Bombay, Bagalore, Calcutta, Knapur
- Montero, J. (1999). Ana´ lisis de la distribucio´n de agua en system as driego por aspersio´n estacionario. Desarrollo del modelo de simulacio´n de riego por aspersio´n (SIRIAS) (Doctoral thesis). Albacete, Spain: Universidad de Castilla La Mancha.
- Moutasim, M. S., Mohamed, A. E.,. Makki, E. K. (2010). Effect of different solid-set sprinkler pattern on water distribution and losses under shambat condition Sudan.
- Playa´ n, E., Salvador, R., Faci, J. M., Zapata, N., Martı´nez-Cob, A., & Sanchez, I. (2005). Day and night wind drift and evaporation losses in sprinkler solid-sets and moving laterals. Agricultural Water Management, 76(3), 139 - 159.
- Plusquellec, H. (2002), “How Design, Management and Policy affect the Performance of Irrigation Projects: Emerging Modernization Procedures and Design Standards”, FAO, Bangkok, Thailand.
- Sa´nchez, I., Faci, J. M., & Zapata, N. (2011). The effects of pressure, nozzle diameter and meteorological conditions on the performance of agricultural impact sprinklers. Agricultural Water Management, 102(1), 13 - 24.
- Sa´nchez, I., Zapata, N., & Faci, J. M. (2010). Combined effect of technical, meteorological and agronomical factors on solid-set sprinkler irrigation: I. Irrigation performance and soil water recharge in alfalfa and maize. Agricultural Water Management, 97(10), 1571e1581.

- St. Joseph, MI, USA: ASAE. Anonymous 2. (1990). Agricultural irrigation equipment. Rotating sprinklers. Part 2. Uniformity of distribution and test methods. ISOstandard 7749/2. Geneva, Switzerland: ISO.
- Tarjuelo, J. M., Montero, J., Honrubia, F. T., Ortiz, J. J., & Ortega, J. F. (1999). Analysis of
- uniformity of sprinkler irrigation in a semiarid area. Agricultural Water Management, 40, 315 - 331.
- Wallace, J.S. and Batchelor, C.H. [1997], "Managing Water Resources for Crop Production". The Royal Society Journal B, V. 352, pp. 937-947, UK.