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Optimum Operating Conditions for Impact Sprinkler

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ABSTRACT

Sprinkler irrigation systems can be managed and designed by only conducting an individual sprinkler test in no wind conditions. The present work was conducted to study the effect of different operating pressures and riser heights to determine optimum operating conditions that achieve high application efficiency and wheat production in impact sprinkler system. The coefficient of uniformity (CU,%) was evaluated within the operating pressure range from 100 to 350 kPa, riser heights 1.0, 1.5 and 2.0 m, overlapped from 100 to 20% under square and triangular layouts sprinkler. It was concluded that the operating conditions that achieved high CU was operating pressure of 250 kPa and 1.5 m riser height for impact sprinkler. Information from individual sprinkler test was established to carry out the corresponding overlapping ranged from 20 to 100% in square and triangular layouts sprinkler. Optimal spacing between sprinklers was found to be as 50 to 70% from diameter of throw in square layout. It was found in range of 50 to 80% from diameter of throw in triangular layout sprinkler. The wheat yield was highly affected by water requirements (100, 80 and 60% ET_c). The results showed that the average values of total grain and straw yield/fed, increased with increasing ET_c from 60 to 100%. The highest yield was achieved with 100% ET_c, while, WUE with 80% ET_c was the highest value. It could be recommended to apply irrigation water to 100% ETc that has the highest yield of wheat under operating pressure of 250 kPa with good CU for impact sprinkler. On the other hand, adding 80% ET_c applied gave the highest values was preferred when the priority to save on the applied water and increase water productivity. Also, layout spacing ≥ 50% from diameter of throw was recommended.

Keywords: Optimum conditions, Wheat, Sprinkler, operating pressure, Water use efficiency and yield.

INTRODUCTION

Wheat is a very important cereal crops in Egypt and all over the world. it is very important to increase wheat production because the local production is not enough to meet the annual demand of local requirements. The crop is more sensitive to the timing of a water deficit period rather than the total reduction of applied irrigation water. Showing wheat plants to high moisture stress depressed seasonal consumptive use and grain yield (Bukhat, 2005). In many agricultural areas of the world, crop production yield depends upon irrigation water efficiently distributed. Water is necessary for plant growth. Furthermore, water available for irrigation is limited. So irrigation system should apply water. If water is not applied uniformly, production yield will be varied based on amount of water located in root zone. A maximum production yield can be obtained under 100% of water uniformity but as a practical matter, no irrigation system can achieve 100% uniformity.

Several irrigation methods are available, and the selection of one depends on factors such as water availability, crop, land topography, soil characteristics, and associated cost. Use of sprinkler irrigation system, where smaller amounts of water can be uniformly applied to fields, further helps to achieve higher water use efficiencies. Also, sprinkler irrigation distributes water more uniformly than any other methods (El-Ansary *et al*., 2003). A sprinkler water distribution pattern depends on many factors, such as sprinkler type, sprinkler spacing, nozzle diameter, angle and operating pressure. In field conditions, it also depends on the temperature, humidity and wind speed (Seginer *et al*., 1991). Amer (2006) found that high degree of water distribution uniformity optimal spacing between spinner sprinklers was found to be as 60% from diameter of throw in square layout and in range from 50 to 70% from diameter of throw in triangular. For impact sprinklers, spacing was recommended to be as 50% from diameter of throw in square layout and in range from 50 to 60% in triangular. Triangular layout achieved higher uniformity than square even for the same served area. Available sprinkler devices have been increased dramatically in recent years, from the conventional single or double nozzle impact sprinkler with many types of nozzles to various types of deflection-plate sprinklers which influence the drop sizes and water distribution patterns over a wide range of flow rates and pressures (Kincaid *et al*., 1996).

The uniformity distribution pattern is a measure of how evenly the sprinkler system applies water over the irrigated area. Many factors that donate non-uniformity are regarded to sprinkler performance and hydraulic variation along lateral. Sprinkler hydraulic performance, which is a study of water application, overlapped uniformity and droplet size distribution, are mainly functions of the sprinkler physical features, nozzle configuration, operating pressure, sprinkler spacing, and environmental conditions (e.g., wind speed and direction). A high degree of sprinkler irrigation system uniformity can be achieved by selecting optimal operating pressure, sprinkler capacity, riser height, trajectory angle and layout as well as overlapped pattern. Keller and Bliesner (1990) stated that there are several factors affect the water application efficiency of sprinkler irrigation system

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such as variation of individual sprinkler discharge throughout the lateral lines, variation in water distribution within the sprinkler spacing area, loss of water by direct evaporation from the spray and evaporation from the soil surface before.

Hegazi *et al.* (2007) found that optimal spacing between sprinklers was found to be as 40 to 60% from diameter of throw in square layout in range of trajectory angles in between 15º to 30º. ITRC (1991) and Schwankl *et al.* (2003) suggested uniformity values as excellent (75 - 85%), good (65 - 75%) and poor (50 - 65%). Tarjuelo *et al.* (1999) investigated two types of sprinkler soiled-set and center pivot system. They showed that when the operating pressure increased from 210 to 480 kPa, the average value of (CU) was 84.59% for soiled-set system and when the operating pressure increased from 55 - 375 kPa, the (CU) values decreased from 87.16 to 84.25% for center pivot system.

Water use efficiency (WUE) is defined as the ratio of the total yield to the total water applied. Studies on the effects of irrigation water requirements show that crop yield can be increased and grain quality can be improved while substantially reducing irrigation water volume (Mansour, 2012 & Mansour and Abd El-Hady, 2014). (Mansour *et al.*, 2014) found that WUE decreased with increasing water amount use, while (Musick *et al.*, 1994) found that WUE did not change with seasonal water requirements.

The objectives of this investigation were studying water distribution pattern under individual sprinkler in no wind conditions based on different operating pressure and riser height to determine optimum operating conditions that achieve high application efficiency uniformity, layout and wheat productivity for impact sprinkler system.

MATERIALS AND METHODS

The work was divided into two experiments to achieve the research goals. The first was Hydraulic experiment and the second was field experiment for wheat production.

Hydraulic Experiment

The experimental work of the present study was conducted at the Hydraulic Laboratory and the Farm of Faculty of Agriculture, Suez Canal University, Ismailia. The laboratory hydraulic experiment of subunit was carried out to determine the highest water distribution pattern and the optimum layout from sprinkler as affected by different operating pressure and riser height under no wind conditions. Individual sprinkler was tested in these subunits with consists of a 22 kW electric-centrifugal pump; valves were fitted after the pump to control the flow rate reaching the sprinkler device. The operating pressures which controlled by a pressure-regulating valve of 100, 150, 200, 250, 300 and 350 kPa under three riser heights 1.0, 1.5 and 2.0 m were used to test each sprinkler. Bourdon-tube gage manometer was fixed at the base of sprinklers and used to measure the pressure. Water flow meter was fitted after control valve to measure sprinkler discharge in each test. Main line with outside diameter of PVC 110 mm, submain line having 75 mm outside diameter of PVC, lateral line with outside diameter of PVC 63 mm branched from the submain. Device of impact sprinkler was installed as a permanent system. The unique sprinkler design is suitable for different installation options as required for the crops. Sprinklers as typed impact sprinkler (Topaz 435) had 3.4 mm inner diameter with single-nozzle included full-or part-circle plastic impact sprinkler, half inch male pipe connection as shown in figure 1.

Pattern radius layout test for each individual sprinkler was installed using two diagonal lines of catch cans according to ASAE Standard, (2006). as shown in table 1. The test duration was 15 minutes. The catch cans were 0.15 m diameter and 0.10 m height. Water was collected, measured and related to its area in mm/h.

Figure 1. Individual impact sprinkler pattern test.

Table 1. Spacing of collectors according to ASABE S398.1, 2006.

Sprinkler Radius of Throw, m	Maximum Collector Spacing Center to Center, m
0.3 - 3.0	0.30
3.0 - 6.0	0.60
6.0 - 12.0	0.75
> 12.0	1.50

The uniformity of sprinklers water distribution was simulated from individual sprinkler pattern tests for square and triangular layouts as shown in figures 2 and 3. Catch cans were simulated at 1.0 m along and across laterals in an overlapping grid pattern. Spacing between sprinklers along and across laterals was determined as diameter of throw as spaced. These distances created overlapped percentages as 100, 80, 60, 40 and 20%, respectively. The simulated water depths in catch can were accumulated from water distribution curves in individual sprinkler tests. To find out the optimum pressure for operating sprinklers, water depths were collected in layout at operating presser from 100 to 350 kPa under impact sprinkler for only 100% overlapped percentage.

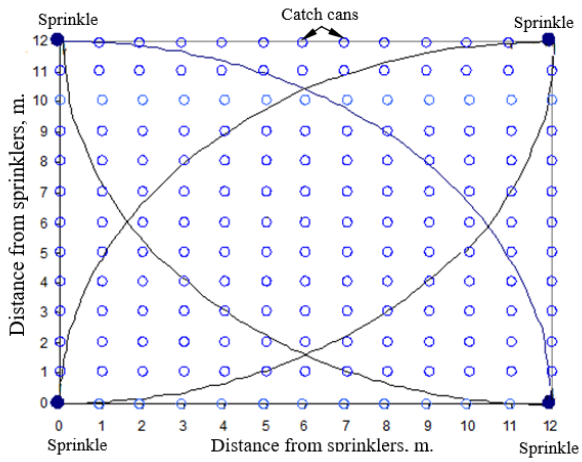


Figure 2. Simulated uniformity test for 100% overlapped square layout at 250 kPa operating pressure and riser height 1.5 m for impact sprinkler.

The water depths caught from square and triangular layouts were cumulated under optimum operating pressure for each 100, 80, 60, 40 and 20% overlapped percentages as layouts simulated in Figures 2 and 3. The two figures showed square and triangular layouts of impact sprinkler with 24 m diameter of throw working under 250 kPa.

The computer software *Catch-3D* Utah State University *Catch-3D* (Allen, 1992) was used to estimate water application uniformity from catch-can testes. Contour maps were constructed to present water depths, water distribution for all treatments using *SURFER* program (Golden Software, 2000). The computer software was used to draw 3-dimentional curves for the water application patterns to determine the sprinkler spacing that achieves optimum performance.

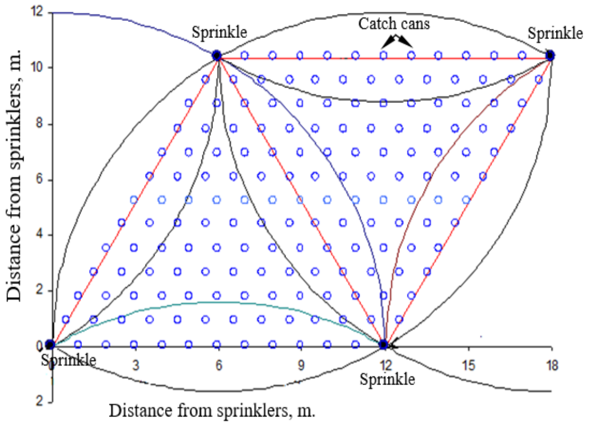


Figure 3. Simulated uniformity test for 100% overlapped triangular layout at pressure 250 kPa and riser height 1.5 m for impact sprinkler.

Flow rate of sprinkler was measured by connecting the impact sprinkler nozzle and collecting known volume of water in a container over a specified period (5 min). Water application of individual sprinkler was collected by catch cans installed across the full circle of sprinkler under different treatments. The application rate of sprinkler was calculated as:

$$Ar = k\frac{Q}{a} \quad (1)$$

Where, ***Ar*** **is the application rate in mm h^{-1},** ***Q*** **is the flow rate of sprinkler in *ℓ* min^{-1},** ***a*** **is the wetted area of sprinkler in m^2 and** ***k*****: unit constant (*k* = 60.0 for *A* in mm h^{-1}, *Q* in *ℓ* min^{-1} and *a* in m^2).**

The uniformity plays an important role in water distribution, yield and water use efficiency. The irrigation unit was tested under different operating pressure, riser height under square and triangular layout ts to determine the application uniformity. Uniformity tests were conducted by placing several identical collectors in an equally spaced grid in the field around sprinkler. The amount of water caught in each can was measured and recorded, the coefficient of uniformity (*CU,%*) calculated using the following equation (Christiansen, 1942):

$$CU = 100\left(1 - \frac{\sum_{i=1}^{i=n}\left|X_i - \bar{X}\right|}{n\,\bar{X}}\right) \quad (2)$$

Where, $\sum_{i=1}^{i=n}\left|X_i - \bar{X}\right|$ **is the summation of absolute values of deviation from the means catch can depth,** ***X$_i$*** **is the individual catch can measurement in mm,** $\bar{X}$ **is the mean of catch can measurements in mm and** ***n*** **is the number of measuring collectors.**

The performance of the simulation model was determined by calculating the relative error (*RE*,%) and mean relative deviation (*MRD*,%) between the measured and predicted coefficient of uniformity (*CU*) at different layout and overlapped percentages for impact sprinkler using equations 3 and 4, respectively (ElGamal *et al*., 2015):

$$RE = \frac{\left|CU_{meas} - CU_{predic}\right|}{CU_{meas}} \times 100 \quad (3)$$

$$MRD = \left[\frac{1}{N}\sum_{j=1}^{N}\left(\frac{CU_{meas,j} - CU_{predic,j}}{CU_{meas,j}}\right)^2\right]^{0.5} \times 100 \quad (4)$$

Where ***CU$_{meas}$*** **and** ***CU$_{predic}$*** **are the measured and predicted values of coefficient of uniformity (*CU*), respectively, and *N* is the number of measurements in each test.**

Field Experiment

A field experiment was conducted during the winter season 2019/2020 at the experimental farm of the El-Salhia, El-Sharkia Governorate, Egypt, representing the sandy soil (latitude angle of 30° 36′ N, Longitude angle of 31° 47′ E). Wheat variety "Misr 1" was planted on 24th November 2019 in rows 15 cm apart and harvested was done on 13th April 2020, the growing season lasted 142 days. The constructed impact sprinkler irrigation system was used under operating pressure of 250 kPa, riser height 1.5 m, square and triangular layouts and water requirements was applied at three treatments (100, 80 and 60% of crop evapotranspiration; ET_c) which calculated using CROPWAT software version 8.0 based on Penman-Monteith equation which recommended by FAO (Allen *et al.*, 2011). ET_c and fertilizer recommendation of Egyptian Agriculture Ministry are applied.

This experiment was achieved to study how application uniformity, wheat yield production and water use efficiency (*WUE*) could be affected by a changing overlapped percentages, square and triangular layouts. The filed has a homogeneous sandy soil in the tested depth layers as shown in table 2.

Table 2. Physical characteristics of the experimental.

Soil depth (cm)	Particle size distribution % Sand	Silt	Clay	Texture Class	*DBD* (g/cm^3)	*FC* (%)	*PWP* (%)	*AW* (%)
0-20	91.27	5.42	3.31	Sand	1.60	9.1	2.0	7.1
20-40	92.52	4.31	3.17	Sand	1.63	8.9	2.1	6.8
40-60	90.64	4.70	4.66	Sand	1.62	8.8	1.9	6.9

DBD**: Dry bulk density,** ***FC*****: Field capacity (- 0.1 atm),** ***PWP*****: Permanent wilting point (- 15 atm), and** ***AW*****: Available water.**

Irrigation water requirements (*IWR*) of wheat through the growing season were calculated based on the determination of crop evapotranspiration (ET_c, mm/day) by the Penman-Monteith equation which recommended by FAO (Allen *et al.*, 2011) using CROPWAT software (v. 8.0):

$$ET_c = ET_o\ k_c \quad (5)$$

$$IWR = ET_c\ A\ F \quad (6)$$

Where, ET_o **is the reference evapotranspiration (mm/day),** k_c **is the crop coefficients,** ***IWR*** **is amount of applied irrigation water (*ℓ/Irri.*),** ***A*** **is the plant area (m^2) and** ***F*** **is the irrigation frequency.**

Three irrigation water percentages from requirements as 100, 80 and 60% of evapotranspiration (ET_C) were applied. The water application time for each ET_C% was calculated from the following equation:

$$I_t = \frac{ET_c \ A \ F}{q} \qquad (7)$$

Where, I_t **is water application time (*h*) and** q **is the sprinkler discharge (*ℓ/h*).**

To understand how Water use efficiency (*WUE*) could be affected by different treatments, it will be necessary to determine how these changes will impact plant growth and water use of the plant. *WUE* (*kg/m*^{3}) is defined as the relation between grain wheat yield (*kg/fed*) and water applied (*m*^{3}*/fed*) during the growing season.

RESULTS AND DISCUSSION

Hydraulic Experimental:

1- Flow rate at different operating pressure

The effect of operating pressure on the performance of impact sprinkler has been investigated. The flow rate increased with the increased operating pressure for individual sprinkler as shown in table 3 and figure 4. When increasing operating pressure from 100 to 350 kPa, the flow rate for impact sprinkler increased from 0.43 to 0.88 m^{3}h^{-1}. The results indicated that the flow rate from impact sprinkler was highly affected by operating pressure.

Table 3. Average of flow rate, wetted area (*A*), application rate (*Ar*) under different levels of operating pressure and riser height for impact sprinkler.

Pressure (kPa)	Flow rate (m^3/h)	Riser height (m) 1.0		1.5		2.0	
		A (m^2)	*Ar* (mm/h)	*A* (m^2)	*Ar* (mm/h)	*A* (m^2)	*Ar* (mm/h)
100	0.43	283.4	1.52	314.0	1.37	333.1	1.29
150	0.48	314.0	1.53	346.2	1.39	366.2	1.31
200	0.60	346.2	1.73	400.9	1.50	415.3	1.44
250	0.67	379.9	1.76	437.2	1.53	452.2	1.48
300	0.80	400.9	2.00	475.1	1.68	490.6	1.63
350	0.88	415.3	2.12	490.6	1.79	530.7	1.66

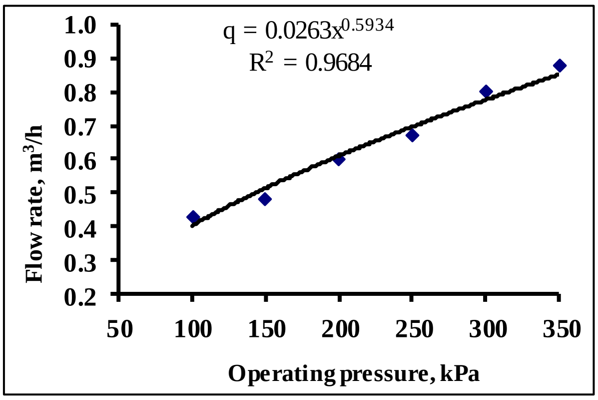


Figure 4. Relationship between operating pressure and flow rate for impact sprinkler, under the tested conditions.

2- Wetted area at different operating pressure and different riser height

The effect of operating pressure and riser height on wetted diameter as show in table 3. In general, the wetted area was affected by operating pressure for impact sprinkler. When the operating pressure increased from 100 to 350 kPa the wetted area increased by 46.5, 56.3 and 59.3% for riser height from 1.0 to 2.0 m, respectively. Also. the riser height increased from 1.0 to 2.0 m the wetted area increased at the different operating pressure.

The application rate increased with increasing operating pressure under the same riser height. Meanwhile, the application rate decreased with increasing of riser height as shown in table 3 and figure 5. The application rate increased by 39.66% when the operating pressure increased from 100 to 350 kPa at riser height of 1.0 m for impact sprinkler. Similar trend was observed for riser heights of 1.5 and 2.0 m. The application rate decreased by 14.93 % by increasing riser heights from 1.0 to 2.0 m at operating pressure 100 kPa for impact sprinkler. Based on the obtained results, it can be concluded that the high application rate could be achieved by combination of high operating pressure with low riser height for impact sprinkler. This may be due to increase of water discharge. Also, application rate decreased by increasing riser heights from 1.0 to 2.0 m this may be due to increase of wetted area.

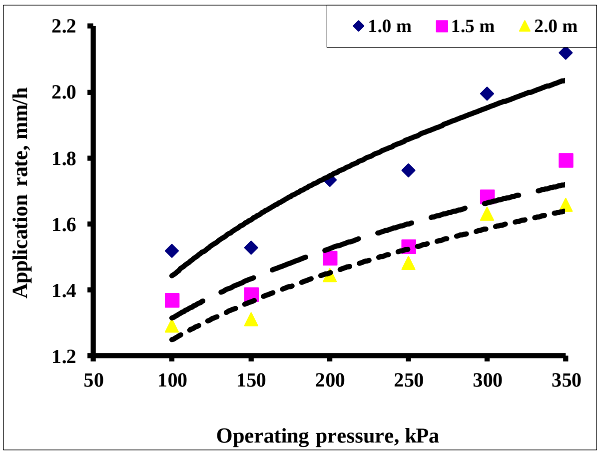


Figure 5. Relationship between operating pressure and application rate for impact sprinkler, under the tested conditions.

3- Uniformity at different operating pressure and riser height

The water application uniformity is considered as a primary concern in the individual sprinkler irrigation design procedure. The uniformity of application was evaluated by investigating the effect of different operating pressures and riser heights on coefficient of uniformity (*CU*). figure 6 show the relationship between water application uniformity and operating pressure at different riser height. The *CU* increased with increased operating pressure until its maximum at 250 kPa, but at operating pressures higher than 250 kPa, the *CU* decreased again. It can be seen that increasing of operating pressure from 100 to 250 kPa at height 1.0 m, the *CU* value increased from 51.34 to 65.30%. In contract, when the operating pressure increased from 250 to 350 kPa, the *CU* value decreased from 65.30 to 55.23% for impact sprinkler. The same trend was found for riser heights of 1.5 and 2.0 m, but with different values.

Also, the values of *CU* at the same operating pressure increased when the riser height increases from 1.0 to 1.5 m and decreased at the riser height of 2.0 m. In addition, it is clear that the *CU* was affected by riser height of sprinkler too. At the operating pressure 250 kPa, it was found that when riser height increased from 1.0 to 1.5 m, the *CU* increased from 65.30% to 70.12 % for sprinkler. On the other hand, when the riser height increases from 1.5 to 2.0 m, the values of *CU* decreased from 70.12 % to 67.22% for impact sprinkler. The decreased of the coefficient of uniformity with increase of riser height could be due to evaporative effect and drift of water drops.

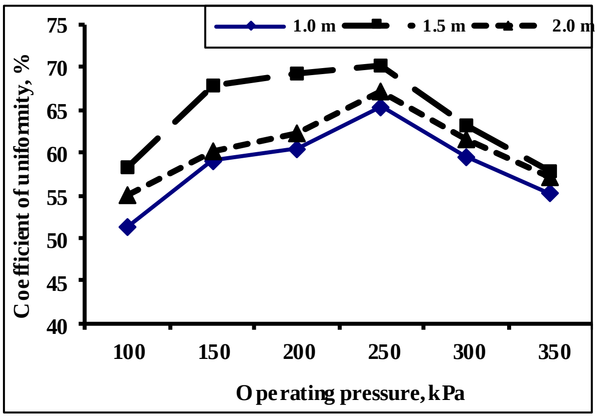


Figure 6. Relationship between operating pressure and coefficient of uniformity under different riser height for impact sprinkler.

The results indicated that, there is a parallel trend of *CU*, the highest value of *CU* was achieved with operating pressure of 250 kPa and 1.5 m riser height. This means that the more improved water application uniformity could be achieved under previously mentioned operating pressure and riser height at wind speed ranged from 0.34 to 0.89 m s^{-1}.

4- Uniformity at different operating pressure and layout

The effect of operating pressure and layout on *CU* at 1.5 m riser height for impact sprinkler. figure 7 and table 4 show the relationship between *CU* and operating pressure at square and triangular layout under riser height 1.5 m. It can be seen that the *CU* increased by increasing of operating pressure from 100 to 250 kPa and decreased by increasing of operating pressure from 250 to 350 kPa with different layouts. The *CU* value increased from 60.5 to 88.3%, from 63.5 to 90.1% and from 68.9 to 90.7%, from 70.1 to 91.5%, respectively, when operating pressure increased from 100 to 250 kPa at different square of measured (*SM*) and square of predicted (*SP*) layout and triangular of measured (*TM*) and triangular of predicted (*TP*) layout. Meanwhile, the operating pressure increased from 250 to 350 kPa, the *CU* value decreased from 88.3 to 66.4%, from 90.1 to 69.6% and from 90.7 to 70.7%, from 91.5 to 73.2%, respectively at the same layout. The results indicated that the highest values of *CU* were achieved at operating pressure of 250 kPa and *TM, TP* layout. The corresponds values were 90.7 % and 91.5 %, respectively. Also, the lowest value of *CU* was 66.4 %, respectively at operating pressure of 100 kPa and *SM* layout.

The decrease of coefficient of uniformity at low and high operating pressures with all tested layout sprinkler could be due to non-uniform water distribution. Thus, at low operating pressure level, long water drops were formed and fall close to the sprinkler and sprinkler throw is reduced. Also, at high operating pressure level, small water drops were produced which was be easily to be blown and thrown away from the sprinkler. Therefore, it can be concluded that to achieve high coefficient of uniformity operating pressure of 250 kPa and triangular layout are recommended under riser height 1.5 m. Based on the obtained results we concluded that, the high performance of impact sprinkler can be achieved at operating pressure of 250 kPa and triangular layout.

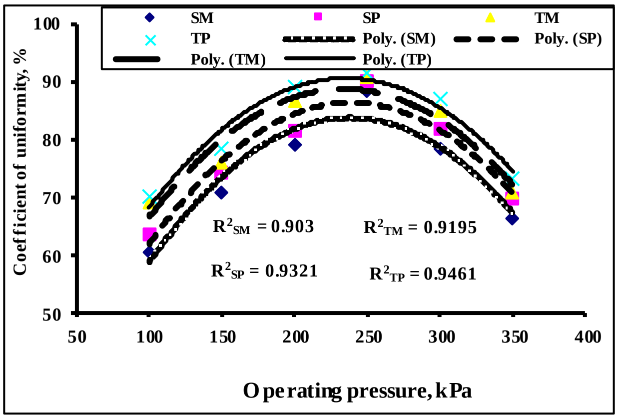


Figure 7. Relationship between operating pressure and coefficient of uniformity for impact sprinkler, under riser height 1.5 m.

Table 4. The relative error (*RE*, %) and mean relative deviation (*MRD*, %) between the measured and predicted coefficients of uniformity (*CU*) in square and triangular layout at different operating pressure for impact sprinkler.

Pressure (kPa)	Layout treatment					
	Square layout			Triangular layout		
	SM	*SP*	*RE*	*TM*	*TP*	*RE*
100	60.5	63.5	3.25	68.9	70.1	1.74
150	70.9	74.3	4.80	75.8	78.2	3.17
200	79.0	81.6	3.29	86.8	89.1	2.65
250	88.3	90.1	2.05	90.7	91.5	0.83
300	78.3	81.9	4.60	84.9	87.1	2.59
350	66.4	69.6	4.82	70.7	73.2	3.54
MRD			4.22			2.58

The statistical coefficient of determination for the pressure-*CU* relationship was recorded high value ($R^2 \geq 0.93$) with *SP* and *TP* predicted of layout as shown in figure 8. Meanwhile, *SM* square of layout impact sprinkler had a relatively lower correlation coefficient ($R^2 \leq 0.91$). The high values of R^2 with *TP* triangular layout for impact sprinkler is an appropriate model to describe the relationship between the water discharge and the operating pressure of triangular layout more than the square layout for impact sprinkler. Triangular layout achieved higher uniformity than square even for the same served area.

The evaluation between the measured and the predicted values is very important in order to check out how far the simulated results from the measured ones to evaluate the capability of the programmed model in analyzing new designed of layout sprinkler. Coefficient of determination (R^2) were approximately constant values about 0.945 and 0.975 between measured and predicted *CU* for different square and triangular layout of impact sprinkler, respectively as shown in figure 8. The simulated model and the validation experiment were compared indicating that there was a strong relationship between the measured and predicted *CU* at different treatments. Results will be aimed to figure out procedures and available information that help to carry out design and management of impact sprinkler irrigation systems.

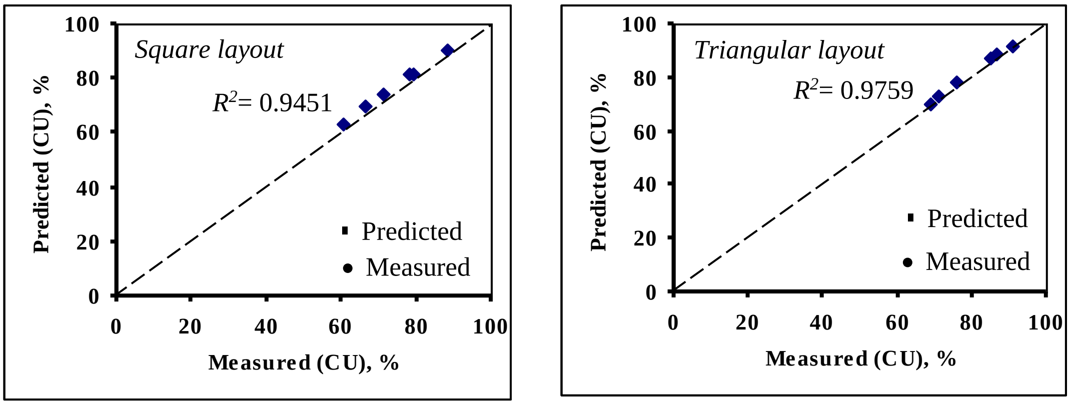


Figure 8. Validation of the measured and predicted coefficient of uniformity at square and triangular layout under different operating pressure for impact sprinkler as 50% from throw diameter.

5- Optimization of water uniformity for impact sprinkler

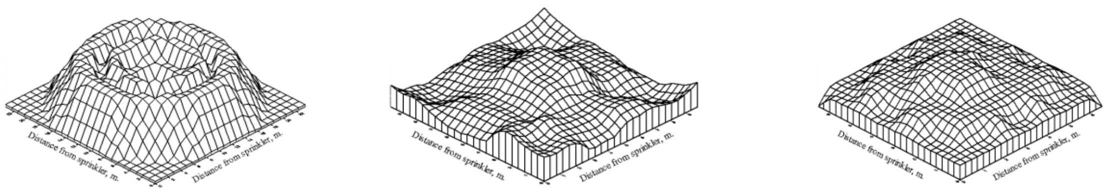
Water uniformity is considered as limited factor to choose spacing between sprinklers. Therefore, it is relevant to predict sprinkler spacing that achieves optimum water distribution. Coefficient of uniformity (*CU*) is considered as a basic indicator for water application uniformity for each sprinkler and it is affected by overlapping between sprinklers. The experimental data were simulated using computer software *Catch-3D* and *SURFER* program at operating pressure 250 kPa and 1.5 m riser height under overlap percentage ranged from 20 to 100%.

The results showed that the water distribution profiles of impact sprinkler were affected by overlapping between sprinklers. It is clear that the increasing of overlapping improved water application uniformity. The *CU* for individual sprinkler at operating pressure of 250 kPa and 1.5 m riser height was 70.12%, with improved in measured and predicted square and triangular layout values were 72.1, 75.2% and 77.9, 80.1%, respectively at overlap percentage 60% for impact sprinkler as shown in table 5 and figure 9. These results are in agreement with those reported by Keller and Bliesner, (1990). This means that the overlapping percentage improved water uniformity by 3.28, 7.24% and 11.10, 14.23% for measured and predicted square and triangular layout sprinkler. In addition, the *CU* values decreased with decreased overlap percentage. The highest value of *CU* was 77.9% that achieved in triangular layout sprinkler at overlap percentage 60%. Consequently, the C*U* was in excellent according to ITRC (1991) and Schwankl *et al.* (2003) at overlap percentage of 60%.

The comparison between the measured and predicted *CU* at different of overlapped percentages and square & triangular layout for impact sprinkler indicates a very good agreement between the experimentally obtained results and the results calculated from the use of computer software. The differences in optimum layout between the experimental and calculated values obtained from the computer software range between 1.0 and 5.0%, calculated by equations 3 and 4, respectively (ElGamal *et al*., 2015). The results of the validation test were recorded it Table 5. It can be seen that the computer software predicts the coefficient of uniformity with high accuracy for 100 and 60% overlapped percentages, and with low accuracy for 40% overlapped percentages of impact sprinkler. Meanwhile, the model results were unacceptable for *SM* layout at 20%. In other words, the highest value of the relative error (*RE*, %) and mean relative deviation (*MRD*, %) between the measured and predicted of *CU* at different overlapped percentages were for square layout, while the lowest value was obtained with triangular layout. It is believed that the computer software in this study will help manufacturers and engineers in finding the optimum layout sprinkler in a short time with reasonable accuracy.

Table 5. The relative error (*RE*, %) and mean relative deviation (*MRD*, %) between the measured and predicted coefficients of uniformity (*CU*) in square and triangular layout at 250 kPa of operating pressure under different overlapped percentages for impact sprinkler.

Overlapping (%)	Layout treatment					
	Square layout			Triangular layout		
	SM	*SP*	*RE*	*TM*	*TP*	*RE*
100	88.3	90.1	2.05	90.7	91.5	0.83
80	85.6	88.7	3.60	89.2	90.7	1.65
60	72.4	75.2	3.84	77.9	80.1	2.82
40	61.5	64.8	5.33	68.2	70.4	3.26
20	58.9	62.8	6.61	61.3	64.5	5.28
MRD			3.50			2.72



***CU* = 70.12% single sprinkler** ***CU* = 75.2% square layout.** ***CU* = 80.1% triangularlayout (predicted)**

Figure 9. Water distribution profiles at operating pressures 250 kPa and overlap pattern for 60%.

Figure 10 show the result indicate that the highest value of *CU* was obtained in triangular layout of impact sprinkler for all tested ranges of overlapped percentages. The *CU* values excellent classifications was achieved at overlapped percentages from 100 to 60%, good of 40% and poor of 20% overlapped for triangular layout sprinkler. Meanwhile, The *CU* values excellent classifications was achieved at overlapped percentages from 100 to 80%, good of 60% and poor from 40 to 20% for square layout sprinkler according to Schwankl *et al.* (2003). However, it was above 40% overlapped of triangular layout sprinkler and 60% of square layout sprinkler. Therefore, it can be concluded that the good design coefficient of uniformity could be achieved at 40% for triangular layout and using 60% at the same classifications for square layout sprinkler. Optimal spacing between sprinklers was found to be as 50 to 70% from diameter of throw in square layout. They were found in range of 50 to 80% from diameter of throw in triangular layout. The obtained recommendations agree with those obtained by Hegazi *et al.* (2007).

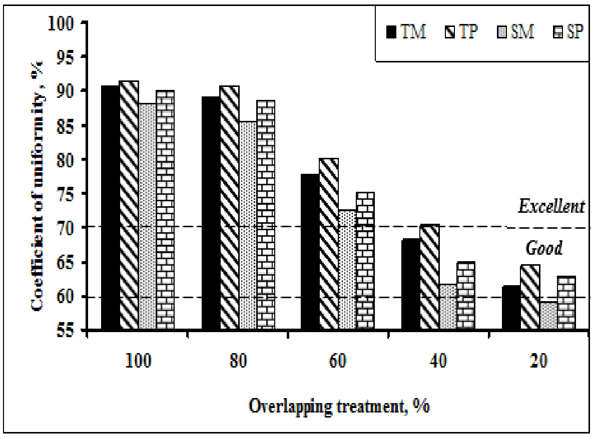


Figure 10. Effect of different overlapped percentages, square and triangular layout at operating pressure of 250 kPa in coefficient uniformity for impact sprinkler.

Field Experiment:

Wheat yield and water use efficiency

At the end of the growing season, 1.0 m^2 from each replicate were taken to determine yield and water use efficiency (*WUE*). The data were presented in figures 11 and 12. For all the investigated parameters, water requirements of 60% treatment recorded the lowest values in square and triangular layout sprinkler. However, 100% treatment recorded the highest values for all other parameters. In regard to the grain yield in $Mgha^{-1}$, all the investigated treatments gave higher yield than the 60% treatment, the percentage grain yield and straw yield increases were 47.37, 36.84% and 64.71, 35.29% for square layout and 55.13, 45.05% and 72.22, 38.89% for triangular layout sprinkler grain and straw yield, respectively. While, the highest value of *WUE* 1.49 and 1.66 kg m^{-3} was achieved at 80% treatment for square and triangular layout sprinkler, respectively, which could be recommended for sprinkler irrigated wheat in sandy soil.

It was detected that, the highest crop yield obtained under 100% treatment of impact sprinkler. On the other hand, the highest crop yield obtained under triangular layout sprinkler conditions was responded to the relative increasing in available moisture for plants. The current study recommended the use of 80% treatment was saving water 20% anther treatments for different layout sprinkler.

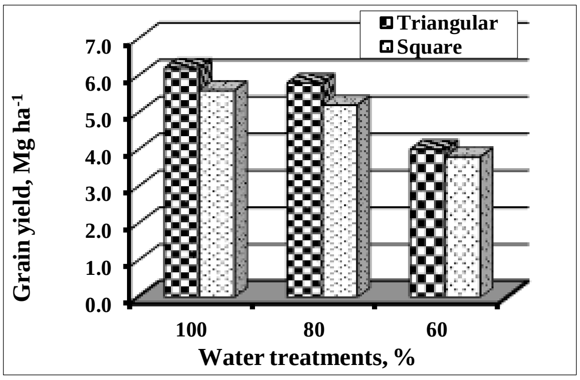


Figure 11. Yield of wheat plants under different treatments.

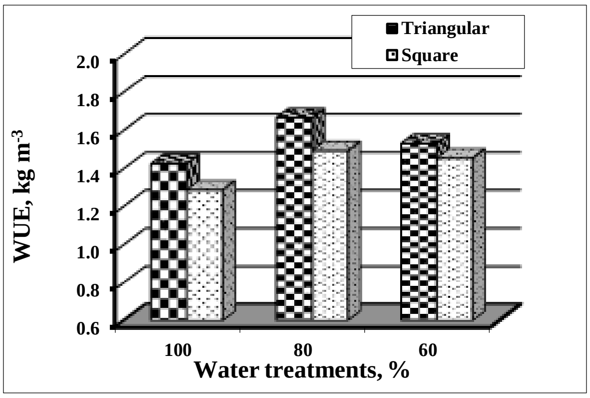


Figure 12. Water use efficiency (*WUE*) of wheat plants under different treatments.

CONCLUSION

The main results could be summarized as the following:

1- Flow rate and application rate were increased by increasing operating pressure for impact sprinklers, is it need more energy.

2- High water application uniformity was achieved at operating pressure of 250 kPa and 1.5 m riser height for individual sprinkler under triangular layout.

3- Optimal spacing between sprinklers was found to be as 50 to 70% from diameter of throw in square layout.

4- Optimal spacing between sprinklers was found in range of 50 to 80% from diameter of throw in triangular layout.

5- The comparison between measured and predicted *CU*, indicates a strong correlation with coefficient of determination (R^2) more than 0.94 at different layouts under different operating pressures.

6- The highest yield of wheat was obtained by using 100%, while the highest *WUE* was obtained by using 80%.

7- For reduction of system cost and precluding water runoff due to increase of precipitation rate in layout, spacing ≥ 50% for square and triangular layouts from diameter of throw was recommended.

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أفضل ظروف تشغيل للرشاش التصادمى

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تخطيط وإدارة نظام الرى بالرش يتوقف على شكل توزيع دائرة مياه الرشاش والتى بدورها دالة فى الخواص الهندسية الأساسية للرشاش. حيث إهتمت الدراسة بتأثر ضغط التشغيل وإرتفاع الرشاش، لإيجاد شكل توزيع الرش عند تشغيله فى ظروف عدم تأثير الرياح وكيفية محاكاتها لتحديد أفضل إرتفاع الرشاش، ضغط التشغيل والمسافة بين الرشاشات لنوع التخطيط المناسب وكذلك معدل الرش. حيث تم إختيار نوع من الرشاشات ذى فوهة واحدة قطرها 3.4 مم وإجراء تجربة لتحديد شكل توزيع أثر الرش بقياس كمية المياه فى علب التجميع أسفل الرشاش تحت ضغوط تشغيل (100، 150، 200، 250، 300، 350 ك باسكال)، وإرتفاع الرشاش (1، 1.5، 2 متر)، تم محاكاة تجربة انتظامية توزيع معدل الرش بتراكم كمية المياه فى موضع علب التجميع على مسافات متر واحد من كل رشاش مستخدماً معدل التجميع من تجربة تحديد شكل توزيع الرش لضغوط تشغيل المختلفة، لرشاشات موضوعة على رؤوس مربع ومثلث ضلعه يساوى 50٪ من قطر القذف (100٪ تداخل) لتحديد أفضل ضغط تشغيل مناسب، حيث كان 250 ك باسكال وارتفاع 1.5 متر. تم أيضاً المحاكاة لانتظامية توزيع المياه بضغط التشغيل المناسب وهو 250 ك باسكال وارتفاع 1.5 متر لنسب مختلفة من التداخل هى 100 , 80 , 60 , 40 , 20٪ لكل من التخطيط المربع والمثلث , أظهرت النتائج الأتى: 1- تزايد تصرف ومعدل الرش مع زيادة ضغط التشغيل. 2- أعلى قيمة لمعامل انتظامية توزيع المياه تحت ضغط التشغيل المناسب 250 ك باسكال و1.5 متر إرتفاع الرشاش. 3- لتحديد البعد المناسب بين الرشاشات عند ضغط التشغيل وإرتفاع الرش كان على مسافة تتراوح من50٪ الى70٪ من قطر الرش للتخطيط المربع. 4- أفضل مسافة بين الرشاشات عند ضغط التشغيل وإرتفاع رش مناسب كان على مسافة تتراوح من50٪ الى80٪ من قطر الرش للتخطيط المثلث. 5- معامل الارتباط (R^2) أعلى من 0.94 بين القيم المحسوبة والقيمة المتنبأ بها لمعامل انتظامية توزيع المياه. 6- أعلى إنتاجية لمحصول القمح عند 100% من الإحتياجات المائيه وأعلى كفاءه استخدام مياه 80% 7- أوصت الدراسة بأخذ البعد المناسب بين الرشاشات ≤50٪ من قطر الرش على التخطيط المربع أو المثلث وذلك لتفادى زيادة معدل الرش عن معدل تسرب التربة وتقليل تكاليف الإنشاء.