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EFFECT OF NOZZLE SHAPE AND PRESSURE ON WATER DISTRIBUTION

El-Berry A. M. [1], Ramadan M. Hany[2], El-Adl A. Mohsen[3] and Mahmoud M. Hashem[4]

ABSTRACT

Sprinklers with circular and noncircular nozzles were tested to determine the water application patterns. Circular nozzles usually produced greater wetted radii than noncircular nozzles. Noncircular nozzles have the advantages of providing an acceptable water application pattern over the entire precipitation profile at low operating pressure. Noncircular nozzles (square, rectangular and triangular) were compared to circular nozzle for water application profiles with 100% overlapping. The over irrigation percentage was higher for circular nozzle than all shapes of noncircular nozzles.

Key wards: *sprinkler, distribution, uniformity, noncircular, nozzles, low pressure, water application.*

INTRODUCTION

The distribution of water in a field under sprinkler irrigation is primarily a function of design, operation and climatic factor. Effects of soil characteristics on the distribution are generally considered negligible. Specific effects of these factors on the uniformity of application in sprinkler irrigation are summarized by ***Walker (1980)***.

The well known and most widely used distribution uniformity coefficient is Christiansen's coefficient since six decades ago. ***Christiansen (1942)*** studied distribution patterns of sprinklers and used the following statistical expression as an index of the uniformity.

$$\mathbf{Cu} = \left(1 - \frac{\sum |X_i - X_m|}{X_m \times n}\right) \times 100 \qquad (1)$$

1 Prof of Agric. Eng., Dep. of Agric. Eng. , Faculty of Agriculture, Cairo University, 2 and 3 Assoc. Prof of Agric. Eng. Dep. of Agric. Eng., Faculty of Agriculture, Al-Mansoura University, and 4 Agric. Res. Ins., Alexandria Branch, Alexandria, Egypt

where:

Cu = Christiansen distribution uniformity coefficient

n = Number of collecting cans in the overlapped area

X_i = Water depth in the i^{th} collecting can, mm

X_m = Mean of water depth in the overlapped area, mm

$\Sigma \mid X_i - X_m \mid$ = Sum of the absolute deviations from the mean measurements, mm

A value of Cu = 100% means that the irrigation is completely uniform. This value is unattainable in practice. In general, Cu = 80 % is the minimum acceptable value. Lower values may be acceptable in design area has ample rainfall during the irrigation season ***Soil Conservation Services (SCS)*** (***1984***). A uniformity coefficient of 100% percent obtained with overlapping sprinklers is indicative of absolutely uniform application, whereas the water application is less uniform with a lower percentage. A uniformity coefficient of 85% or more is considered to be satisfactory ***Michale (1978)***. Distribution uniformity coefficients are used to characterize the water distribution evaluated in field test. Several coefficients have been proposed since sprinkler irrigation was first introduced.

Christiansen (1942) studied the effect of wind on single sprinkler pattern, and found that this effect on the distribution was very significant. ***Wiersma (1955)*** studied overlapping application patterns from several small head sprinkler systems operating in winds using different sprinkler spacing and different water pressures. He concluded that: (a) tall risers were superior to short ones, (b) angle of wind with respect to lateral line had little or no effect on the distribution pattern, (c) there was a definite breaking point between 15.2 and 18.3 m moves between lines, (d) high pressure were superior to low ones, and (e) large quantities of water per nozzle resulted in better patterns than small quantities

Uniformity tests have been run by ***Shull and Dylla, (1976)***. These data show considerable scatter, depending on wind velocity, wind direction, quantity of water output, and pressure. The average wind speed for these tests was approximately 16 km/h (4.44 m/s). The average Cu's were 70 and 75 percent for line spacing equal to 70 and 60 percent of the wetted diameters, respectively. When operating within the recommended pressure and lane spacing, the average Cu's were 77 to 83 percent for lane spacing equal to 70 to 50 percent of the wetted diameters. They also found that wind elongated the pattern downwind from the sprinkler, shortened the pattern upwind, and narrowed the pattern at right angles to the wind. The wetted width and wetted distance upwind from the sprinkler decreased at about the same rate as the wind velocity increased. Wind distorts the application pattern. The higher the wind velocity, the greater the distortion, and this factor should be considered when selecting the sprinkler spacing under windy conditions ***(Michale - 1978).***

Vories and Bernuth (1986) studied the effect of wind blowing direction for rectangular spacing patterns. They found that winds blowing perpendicular to the short spacing appear to cause some portions of field to be very wet, while other portions are too dry. Those wet and dry areas result in lower coefficients of uniformity. So they recommended to put the lateral (short spacing) parallel to the wind blow to get more uniformity.

Vories et al. (1987) used physically based equations to model the relationship between the operating conditions of the sprinkler and the Christiansen Coefficient of Uniformity. Sprinkler make, nozzle type, pressure, spacing, and wind speed all affect uniformity ***Solomon, (1979)***. He also stated that Cu can vary between identical tests, mainly due to wind speed variation during a test. In some cases, a given set of conditions can yield a Cu above 90% while another test with the same conditions will have a Cu below 80 %. This problem makes it difficult to predict the uniformity based on operating conditions.

Richards and Weatherhead (1993) studied the effect of wind and reported that wind elongated the pattern at right angles to the wind (crosswind). The wetted distance downwind from the sprinkler increased as wind velocity increased but the increase was proportionately less than the decrease in across wind wetted radius and wetted distance upwind.

The soil damage hazard due to large droplets was further compounded by the high water application rate, near the perimeter (doughnut pattern), for circular orifice nozzles operated at low pressures. Square and triangular orifice nozzles produced doughnut shaped patterns only at the lowest pressure tested, 138 kPa (20 Psi) ***Chen and Wallender (1985)***. They added, the triangular orifice nozzle generates a more uniform pattern than the circular nozzle, especially at low pressures. The circular jet produces a characteristics doughnut pattern with a mound at the outer edge. Unlike the triangular shaped patterns for the square nozzle, the pattern for the triangular nozzle is more rectangular.

Li et al. (1994) reported that circular orifice nozzles usually produced greater wetted radii and larger droplet diameters than noncircular orifice nozzles, however, noncircular orifice nozzles gives higher overlapped uniformity coefficients.

Increasing sprinkler base pressure is increased the effective irrigation diameter and more uniform application may result ***Addink (1981)***.

The objective of this study was to investigate the effect of nozzle shape on water application patterns at different levels of low pressures.

MATERIALS AND METHODS

To study the precipitation depth the following steps were followed. The floor was marked each 1m, and then the collectors were numbered and weighted. Then the collectors were putted at each mark on the floor as shown in Figure (1). The system was started and the sprinkler was left to rotate 10 revolutions. Finally the system was stopped and collectors were weighted again as shown in Figure (2).

Figure (1): The water collector during the precipitation event

Figure (2): weighting the water collector after the precipitation event

To get the water depth during the precipitation event the weight of collectors after precipitation event were subtracted from collectors with precipitated water. Then the water volume was calculated by using the following equation:

$$V = M/\rho \qquad (2)$$

Where:

V = water volume, cm^3.

M = water mass, gm.

ρ = water density, gm/cm^3.

Finally the water depth was calculated by using the following equation.

$$d_w = 10\ (V/A) \qquad (3)$$

Where:

d_w = water depth, mm.

V = water volume, cm^3.

A = area of collector entrance, cm^2.

To describe the relationship between water depth (d_w) as a dependent variable and the sprinkler base pressure (Pr) and the traveling distance from sprinkler (X) as independent variable, the following models were developed using the multiple liner regression technique as follows.

I - For circle : $d_w = 10^{-5}(9.7164 - 4.087 * 10^{-2}\ Pr + 2.5082\ X)$ (4)

II - For square : $d_w = 10^{-5}(112.5171 - 3.733 * 10^{-1}\ Pr + 11.182\ X)$ (5)

III - For rectangular : $d_w = 10^{-5}(129.9412 - 1.437 * 10^{-1}\ Pr + 4.091\ X)$ (6)

VI – For triangular: $d_w = 10^{-5}(32.852 - 2.817 * 10^{-1}\ Pr + 1.470\ X)$ (7)

Where:

d_w = water depth, m.

P = sprinkler base pressure, kPa.

X = distance from sprinkler, m.

Theoretical approach

Calculation of water overlapping on area of 4 sprinklers:

To estimate the water overlapping on each collector (Figure 3); the distance between that collector and the four sprinklers around it were determined firstly. Then the water depths were calculated as a function of sprinkler base pressure and the collector location relative to the surrounded sprinklers according to the nozzle shape, by the regression equation (4) to (7).

Calculation of the distance between the collector and each sprinkler:

To calculate the distance between the collector and each sprinkler (Figure 3). The distance between sprinklers was assumed as (N) and the distance between laterals as (J). The distance between collector and sprinkler No. 1 was assumed as (n) in X direction and as (j) in Y direction. The distance between collector and sprinkler No. 2 was (N-n) in X direction and (j) in Y direction. By the same way the distance between collector and sprinkler No. 3 was (N-n) in X direction and (J-j) in Y direction. For sprinkler No. 4 the distance was (n) in X direction and (J-j) in Y direction.

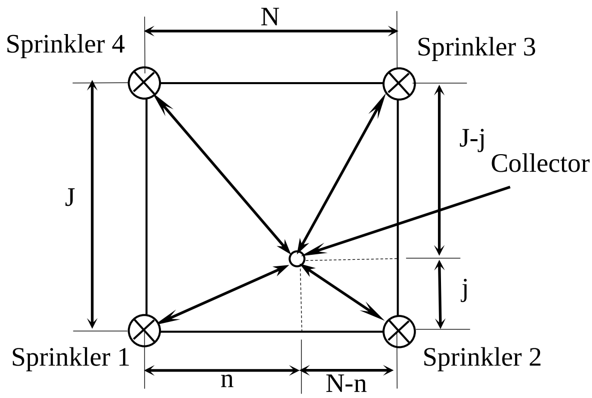

Figure (3): Distance between sprinklers and collectors.

The distance between each collector and the four overlapped sprinklers were calculated using Pythagoras theory as shown in the following equations. The Microsoft Excel spread sheet was used to calculate these distances.

I – The distance between collector and sprinkler 1. $(n^2+j^2)^{0.5}$ (8)
II – The distance between collector and sprinkler 2.$((N\text{-}n)^2+j^2)^{0.5}$ (9)
III – The distance between collector and sprinkler 3.$((N\text{-}n)^2+j^2)^{0.5}$ (10)
IV – The distance between collector and sprinkler 4.$(n^2+(J\text{-}j)^2)^{0.5}$ (11)

Total water depth on the collector:

The total water depth on collectors (d_w) during the precipitation event was calculated using equations (4, 5, 6 and 7) by means of the distance between collector (X) and each sprinkler using equations (8, 9, 10 and 11) and sprinkler base pressure. The Microsoft Excel spread sheet was used to calculate the accumulated water from the four overlapped sprinklers for each collector.

Christiansen distribution uniformity coefficient:

Parameters of Christiansen's coefficient (Cu), equation (1) were substituted to calculate the uniformity. The first step was to calculate the distance between each sprinkler and the collectors (equations 8, 9, 10 and 11). The second step was to calculate the water depth from each sprinkler to the collector in the sprinkler throw range (equations 4, 5, 6 and 7). Some collectors received water from 2 sprinklers and other collectors from 3 sprinklers and the rest of collectors received water from 4 sprinklers depending on the collector position and sprinkler throw range. The Christiansen's coefficient (Cu) was calculated using the accumulated water from the four overlapped sprinklers for each collector (d_w). These calculations were done using the Microsoft Excel spread sheet.

Simulating water application profiles along the throw at 100% overlapping:

To get the water application profile for two sprinklers working together at 100% overlapping, the water depth collected was simulated for accumulation. Assuming the distance between sprinklers X, the accumulation depth of water in the nearest collector to the sprinkler at 1 m is the accumulation of water depth in the collector located at the distance 1 m and (X-1) m. The accumulation depth of water in the second collector to the sprinkler is the accumulation water depth in the distance 2 m and (X-2) m and so on.

Over irrigation percentage calculations:

To achieve the water target for irrigation, the minimum application should be equal to the targeted irrigation depth. Some areas were received over irrigation. The over irrigation was calculated by assuming that the minimum application is the targeted irrigation depth. The over irrigation is the difference between the simulating water application depth in a point and the targeted irrigation depth. The over irrigation percentage is the percentage between the over irrigation and the targeted irrigation depth. Reducing over irrigation realizes two advantages, saving water and energy necessary to pumping this water.

RESULTS AND DISCUSSIONS

Effect of nozzle shape on water distribution:

1- Square orifice shape:

Water application profiles are presented in Figure (4-A) for circular compared with the square orifice. At the low pressure of 138 kPa, a doughnut pattern results for both orifices but the effect is more pronounced with the circular orifice. The doughnut shape changes to a more rectangular profile at 172.5, 207.0 and 241.5 kPa pressures for the square orifice while the circular orifice still produce the doughnut pattern as shown in Figures (4-B), (4-C) and (4-D) respectively. The throw of the circular orifice was approximately 4 m longer than that of the square nozzle for relatively lower pressures (138.0 and 172.5 kPa) and 3 m for higher pressures (207.0 and 241.5 kPa). The results are similar to that of ***Li et al. (1994)***.

2- Rectangular orifice shape:

Water application profiles are presented in Figures (5-A) and (5-B) for circular and rectangular orifice at the low pressure, 138 kPa and 172.5 kPa respectively, a doughnut pattern results for both orifices but the effect is more well seen with the circular orifice. At the same time the doughnut patterns less presented with 172.5 kPa than 138.0 kPa. With rectangular orifice and higher pressures, 207.0 kPa and 241.5 kPa the doughnut shape changes to a more rectangular profile. For the circular orifice the doughnut shape still obvious at 207.0 and 241.5 kPa as shown in Figures (5-C) and (5-D) respectively. The throw of the circular orifice was approximately 3 m longer than that of rectangular orifice for all pressures.

3- Triangular orifice shape:

Triangular orifice shape produced a rectangular water application profiles for all pressures used (138.0, 172.5, 207.0 and 241.5 kPa) as shown in Figure (6-A), (6-B), (6-C) and (6-D) respectively. The circular orifice shape produced a doughnut water application profiles for all pressures especially with lowest pressure 138 kPa. The throw of the circular orifice was approximately 3 m longer than that of the triangular orifice for all pressures. These results agreed with that obtained by ***Chen and Wallender (1985)***.

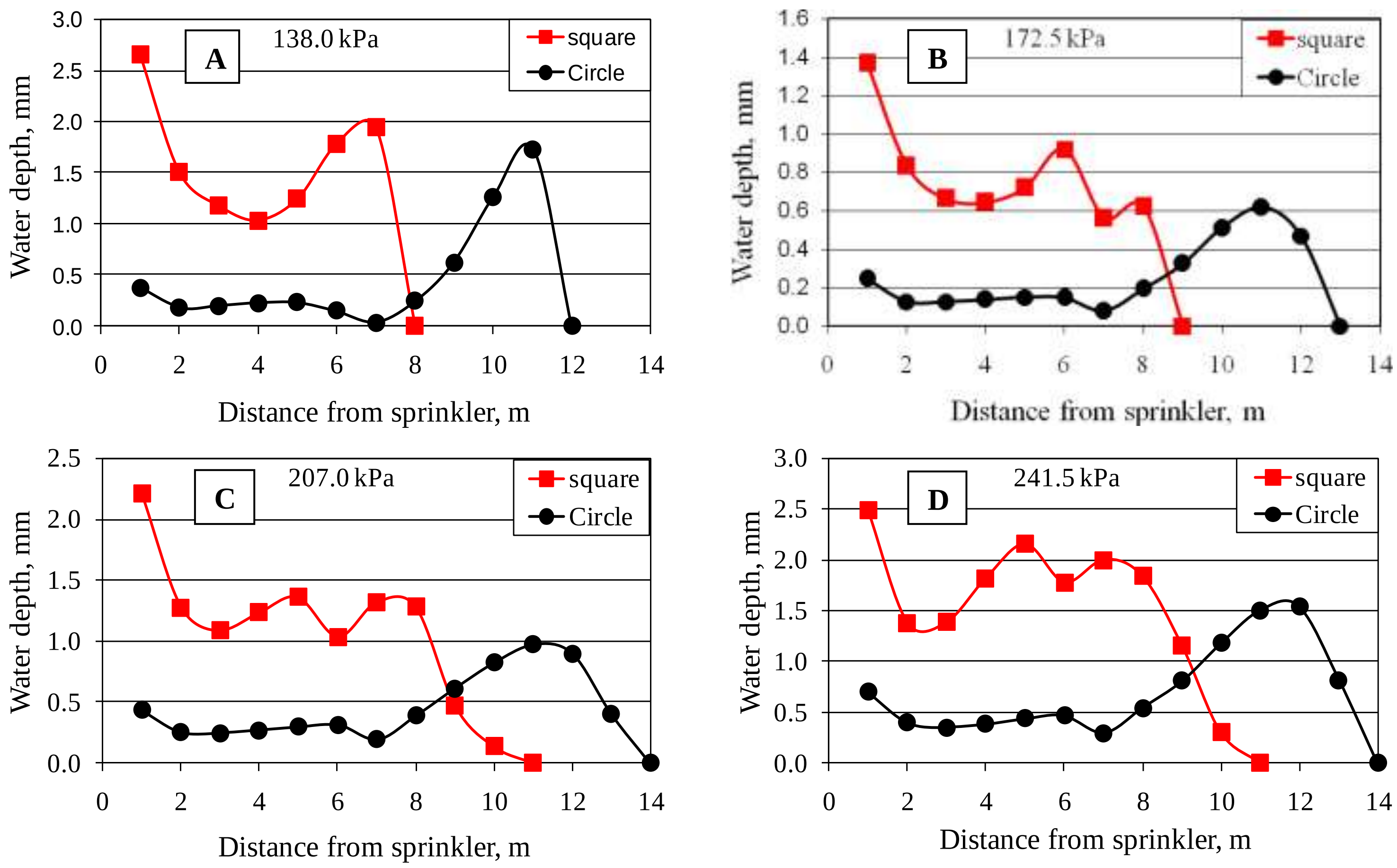

Figure (4): Water application profiles for circle and square orifices at sprinkler base pressure (A) 138.0, (B) 172.5, (C) 207.0 and (D) 241.5 kPa.

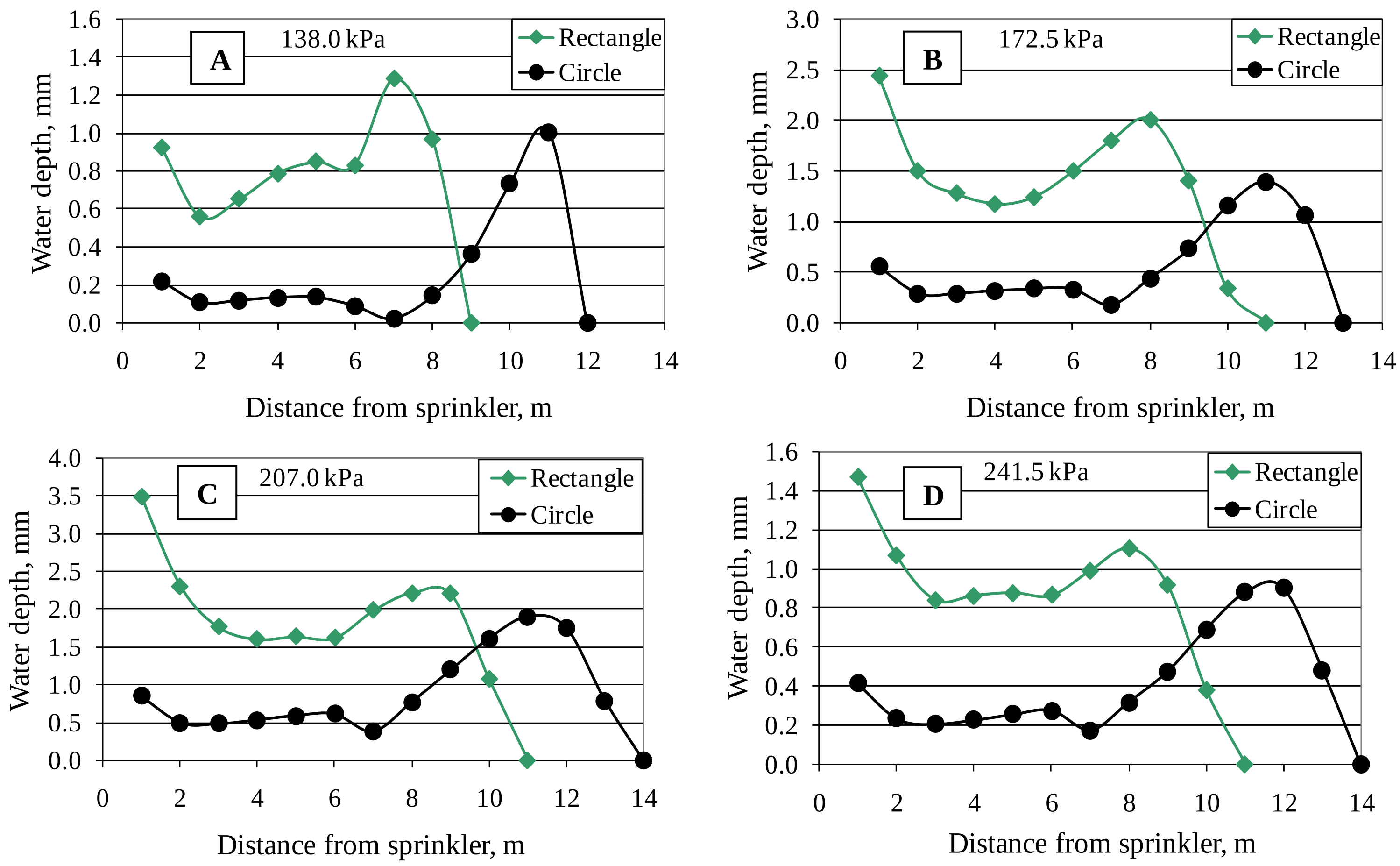

Figure (5): Water application profiles for circle and rectangle orifices at sprinkler base pressure (A) 138.0, (B) 172.5, (C) 207.0 and (D) 241.5 kPa.

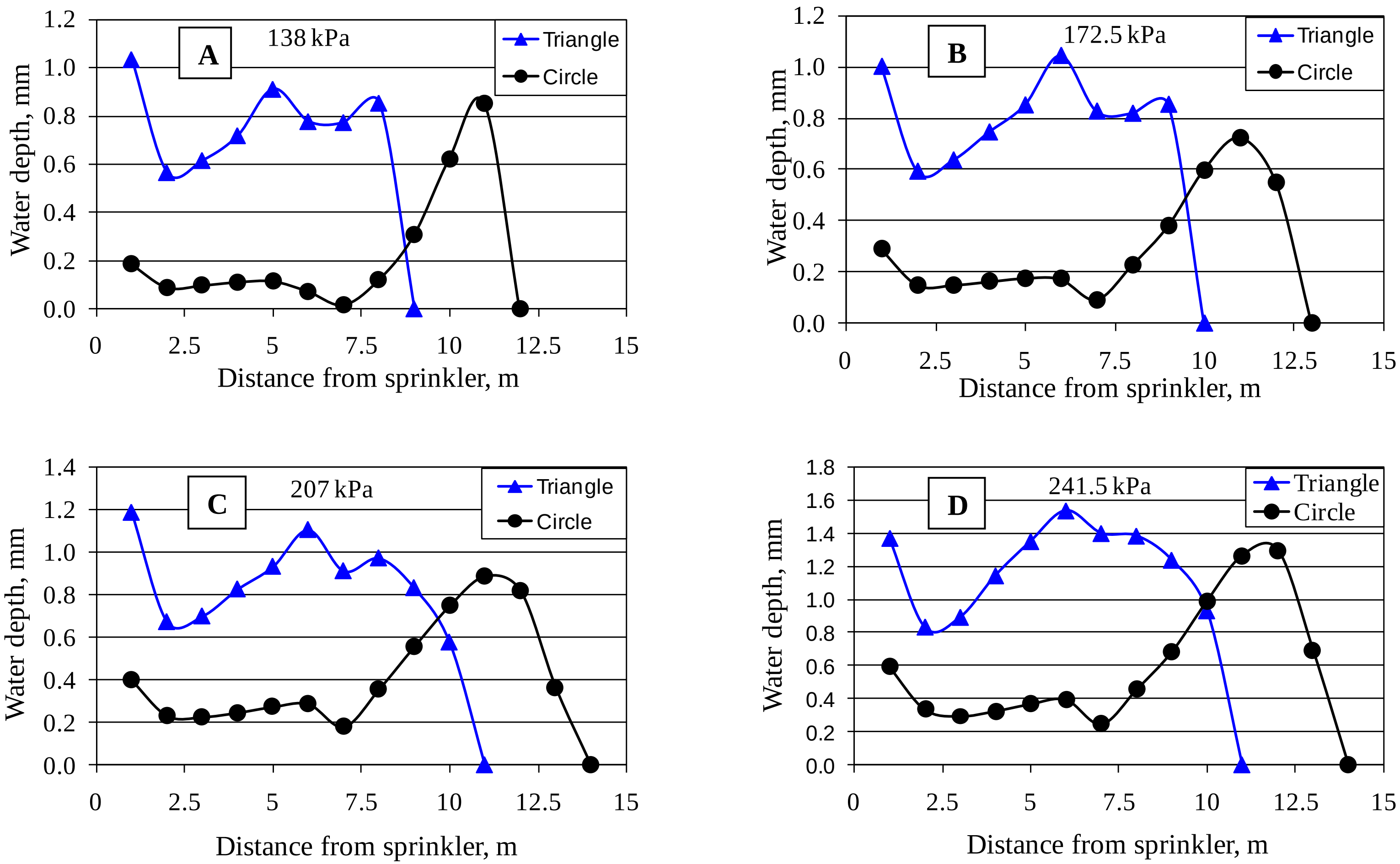

Figure (6): Water application profiles for circle and triangle orifices at sprinkler base pressure (A) 138.0, (B) 172.5, (C) 207.0 and (D) 241.5 kPa.

Effect of Sprinkler base pressure on water distribution:

1- Circular orifice shape:

Figure (7-A) shows very sharp doughnut pattern results from low pressure (138 kPa). The doughnut pattern was less pronounced for the higher pressures (172.5, 207.0 and 241.5 kPa) respectively. The water application mound at the outer limit of the circular orifice pattern corresponds to large mean droplet diameters, compounding the potential soil damage due to droplet impact. These results are corresponding with the ones obtained by ***Addink (1981)***. The effect of pressure on water application among the lower sprinkler base pressure (138.0, 172.5 and 204.0 kPa) is prominent than its effect between the higher sprinkler base pressure (204.0 and 241.5 kPa).

2- Square orifice shape:

Figure (7-B) shows the effect of pressure on water distribution along the sprinkler radius. By increasing pressure the doughnut pattern transfer gradually to rectangular shape having longer throw. This would achieve more water distribution uniformity.

3- Rectangular orifice shape:

Figure (7-C) shows the effect of pressure on water distribution along the sprinkler radius. By increasing pressure the doughnut pattern transfer gradually to rectangular shape for 207.0 and 241.5 kPa with extend the radial distance from the sprinkler which gives more water uniformity.

4- Triangular orifice shape:

Water distribution along the throw Figure (7-D) improved with the sprinkler base pressure increase. Increasing pressure transfer the doughnut pattern gradually to rectangular shape with pull out in the water throw from the sprinkler which gives more water uniformity. The improvement on water distribution pattern is palpable between 138.0, 172.5 and 207.0 kPa sprinkler base pressure respectively. In the meantime, the effect is not sensible between 207.0 and 241.5 kPa.

Simulating water application profiles along the throw at 100% Overlapping:

To get the water application profile for two sprinklers working together at 100% overlapping, the water depth collected was simulated for accumulation. The simulated results were compared among the circular and noncircular orifice nozzle shapes.

1- Water application profiles for square bore nozzle shape:

The water application profiles for circular and square orifice nozzle sprinklers working on 138.0 kPa had the same concave shape (i.e. low irrigation density in the middle and high near to sprinkler) as shown in Figure (8-A). By increasing pressure to 172.5 kPa the application profile took the same shape but the difference between minimum and maximum application between sprinklers decreased as shown in Figure (8-B). The higher pressures 207.0 and 241.5 kPa for square orifice nozzle changed the application profile to produce lower application near the sprinklers and higher ones in the middle (i.e. convex) between the sprinklers. Meanwhile the application profile for the circular orifice nozzle shape still higher near sprinklers than in the middle in between as shown in Figures (8-C) and (8-D) respectively.

2- Water application profiles for rectangular bore nozzle shape:

The water application profiles for circular orifice nozzle was high near the sprinklers for all pressures range. Water application profiles took the same trend for the rectangular orifice nozzles shape but with less difference between the minimum application near the middle of throw and the maximum near the sprinkles. The difference between minimum and maximum applications decreases by increasing pressure as shown in the Figures (9-A) to (9-D).

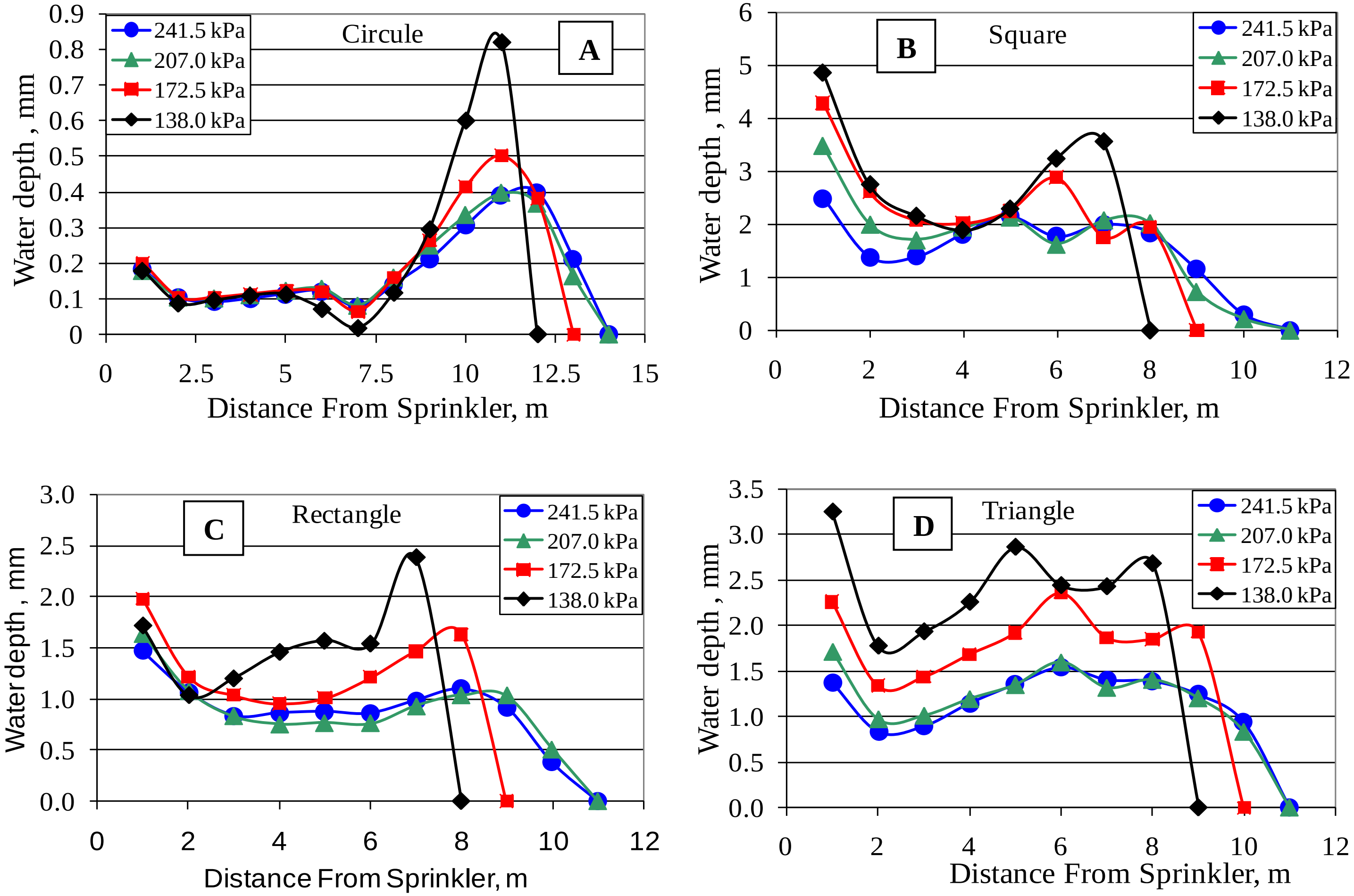

Figure (7): Water application profiles for (A) circle, (B) square, (C) rectangle and (D) triangle orifices at different sprinkler base pressure.

3- Water application profiles for triangular bore nozzle shape:

The water application profiles for circular orifice nozzles were high near the sprinklers for all pressures range. The water application profiles for triangular bore nozzle shape near the sprinklers at 138.0 kPa was higher than the application at the middle distance between sprinklers as shown in Figures (10-A). With increasing pressure to 172.5 kPa the difference between the minimum application near the sprinkler and maximum application in the middle distance between sprinklers decreased as shown in Figure (10-B). More increasing of pressure to 207.0 kPa and 241.5 kPa the application is further increased gradually in the middle distance between sprinklers than near the sprinkler as shown in Figures (10-C) and (10-D).

Over irrigation percentage:

1- Square bore nozzle sprinkler:

The percentage of over irrigation for circular bore nozzle near the sprinkler reached 775% which mean to get the targeted irrigation depth at low application areas from 5 to 7 m from sprinkler (at the middle distance between sprinklers) the areas near sprinkler were received 675% more than the targeted water application. Meanwhile with square bore nozzle these areas were received 123.5% more than the targeted water application as shown in Figure (11-A).

With increasing pressure the over irrigation for circular bore nozzles was still higher than the square bore nozzle but by lower percentage. The over irrigation at the high pressure 241.5 kPa for circular bore nozzles was 230.26 % meanwhile for square nozzles was 55.43 % as shown in Figures (11-B) to (11-D).

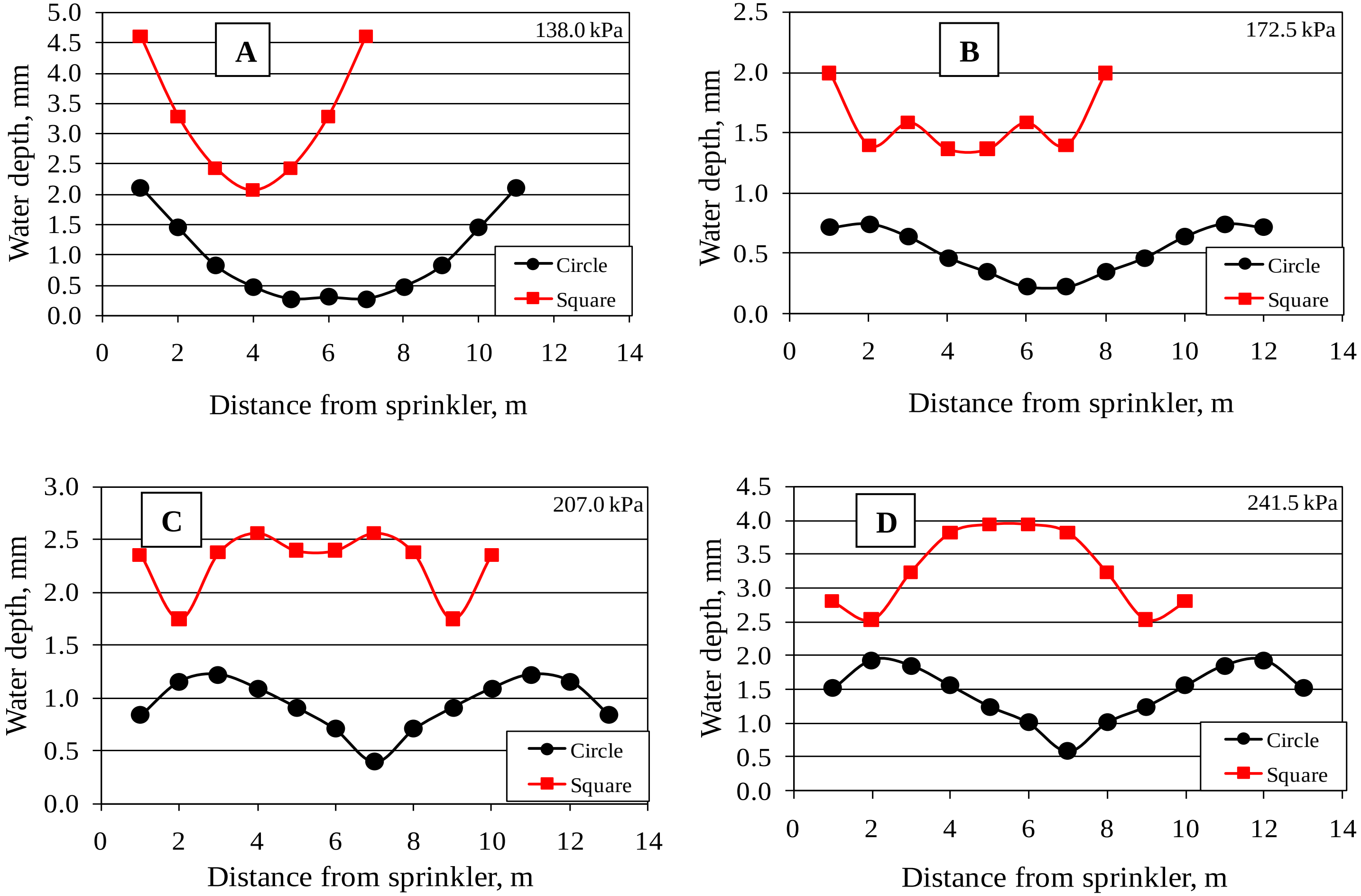

Figure (8): Water application profiles for circular and square orifices with 100% overlapping at sprinkler base pressure (A) 138.0, (B) 172.5, (C) 207.0 and (D) 241.5 kPa.

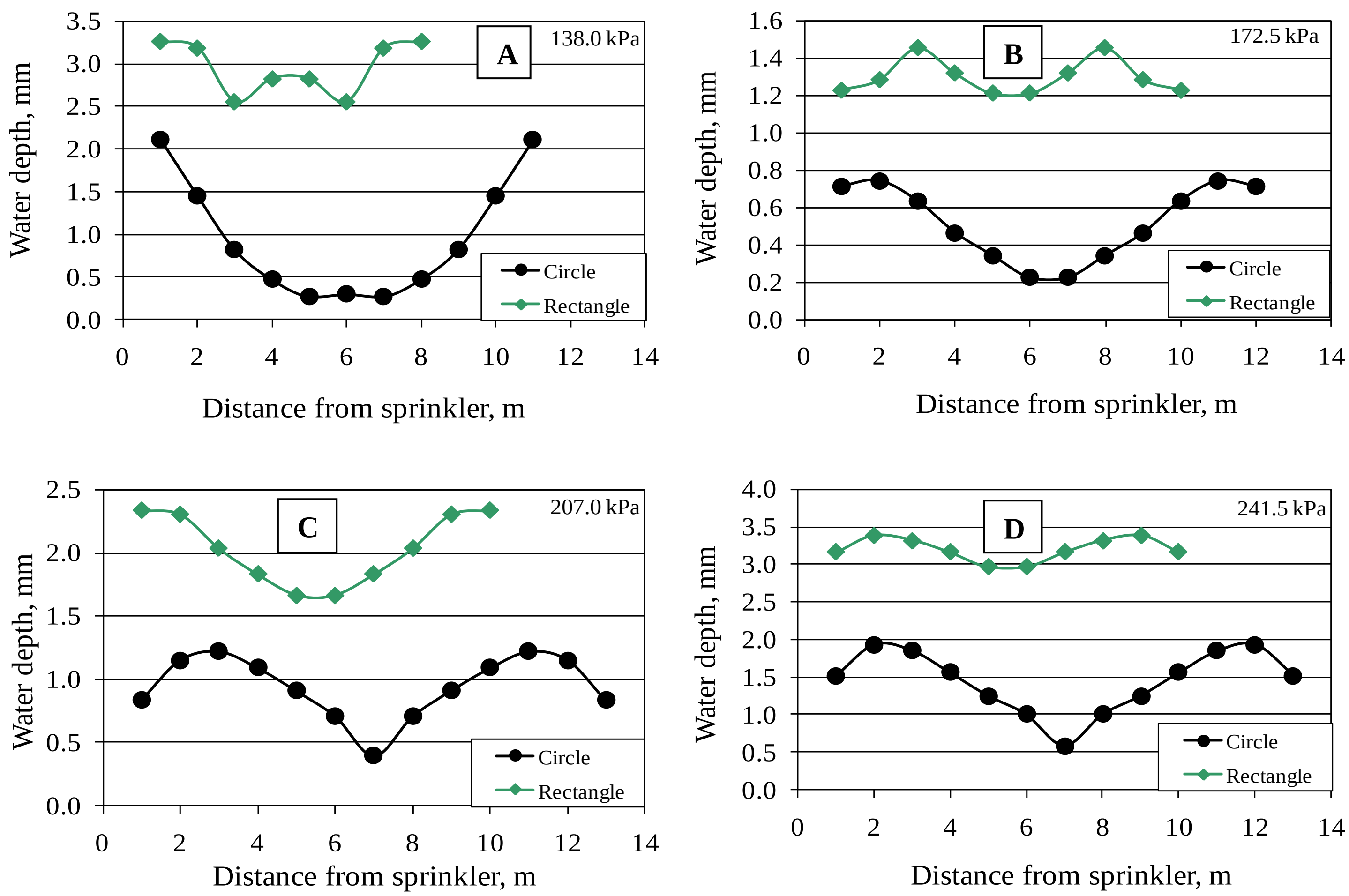

Figure (9): Water application profiles for circular and rectangle orifices with 100% overlapping at sprinkler base pressure (A) 138.0, (B) 172.5, (C) 207.0 and (D) 241.5 kPa.

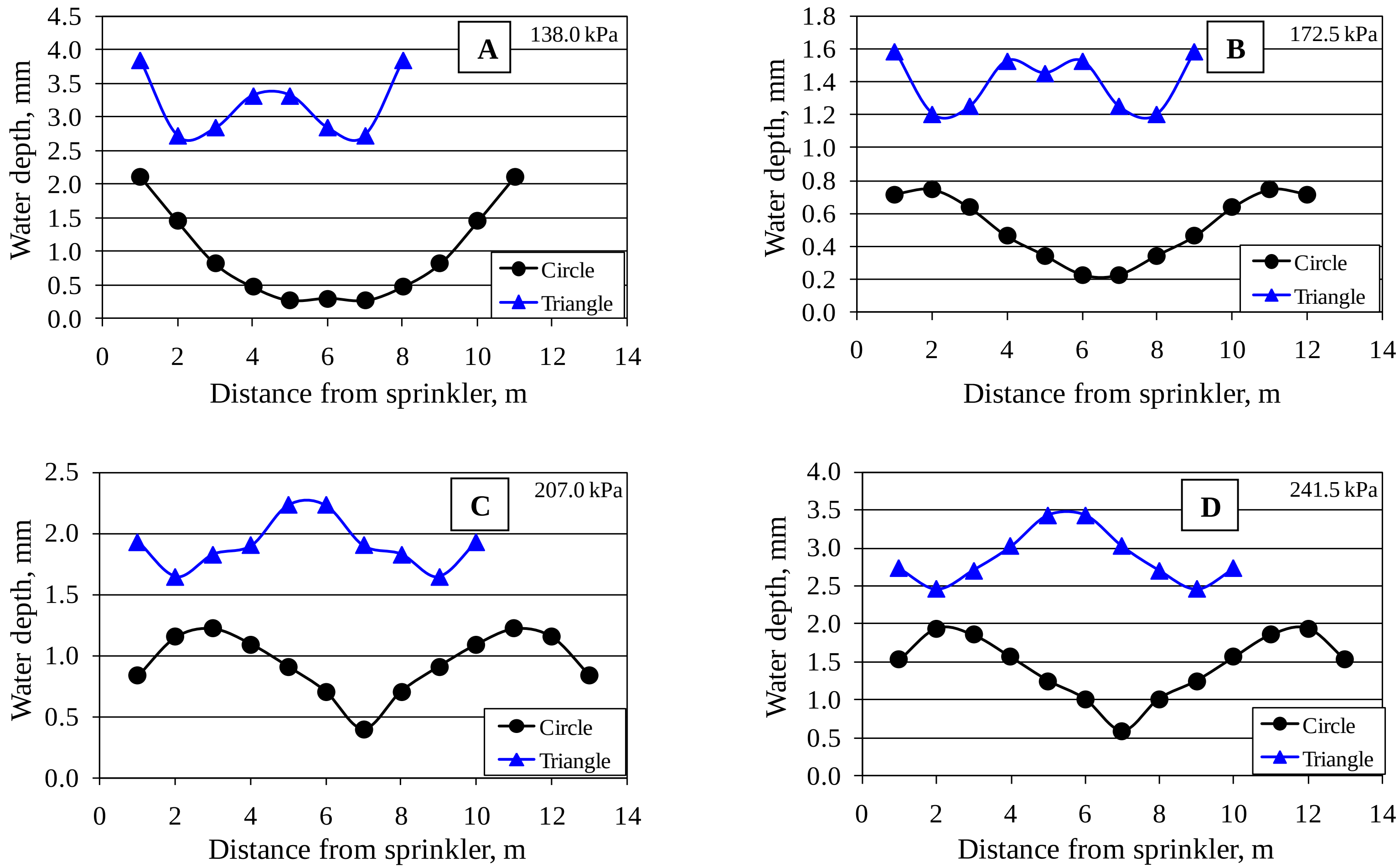

Figure (10): Water application profiles for circle and triangle orifices with 100% overlapping at sprinkler base pressure (A) 138.0, (B) 172.5, (C) 207.0 and (D) 241.5 kPa.

2- Rectangular bore nozzle sprinkler:

The rectangular bore nozzle were received 27.54% more than the required water application near the sprinkler at 138.0 kPa sprinkler base pressure as shown in Figure (12-A).The percentage of over irrigation for circular bore nozzle near the sprinkler reaches to 775 %. The over irrigation for circular bore nozzles were still higher than the rectangular bore nozzle for all pressure levels. Increasing pressure from 138.0 to 172.5 kPa decreasing the over irrigation percentage from 675% to 230.8%. The over irrigation at the high pressure 241.5 kPa for circular bore nozzles was 230.26 % for the meantime the rectangular nozzles was 14.04 % as shown in Figures (12-B) to (12-D). The over irrigation percentage is totally satisfaction for rectangular bore nozzle shape throw the all tested pressure levels.

3- Triangular bore nozzle sprinkler:

Figure (13-A) show the over irrigation percentage for circular and triangular bore nozzle. The maximum percentage of over irrigation for circular bore nozzle near the sprinkler reaches to 775 %. For the time being with triangular bore nozzle these areas were received 41.04% more than the targeted irrigation depth near the sprinkler. The over irrigation for circular bore nozzles were still higher than the triangular bore nozzle with increasing pressure. The over irrigation at the high pressure 241.5 kPa for circular bore nozzles was 230.26 % near the sprinklers meanwhile, for rectangular nozzles was 39.37 % at the middle distance between sprinklers as shown in Figures (13-B) to (13-D). Generally the over irrigation percentage for triangular bore nozzle for all tested sprinkler base pressure is under 40%.

Coefficient of uniformity among 4 sprinklers at 100% overlapping:

To calculate the coefficient of uniformity using equation (1); four sprinklers were virtually assumed to have square pattern. Four levels of pressure (i.e. 138.0, 172.5, 207.0 and 241.5 kPa) were examined. Four orifice shapes (i.e. circle, square, rectangle and triangle) were tested.

The results indicated that the noncircular nozzles produce higher coefficient of uniformity especially ones working at lower pressure (138.0 kPa). The noncircular nozzles exhibited higher coefficient of uniformity (over 75%) while the circular nozzle was 62%. By increasing pressure the coefficient of uniformity increased for all nozzle shapes. The difference between circular and non circle nozzle decreased. For example the difference of Cu between circular and triangular nozzle was 16.53% at 138 kPa. While, this difference was 1.22% at 241.5 kPa as shown in Figure (14).

Effect of nozzle shape on saving energy:

Figure (14) was used to estimate the energy saving when different types of nozzles were used. Assuming 80 % Cu, the equivalent pressure needed for different nozzle shapes were determined on the graph (i.e. Arrows shown on Fig.14). The rectangular and triangle orifice nozzles need 150 kPa. For the same Cu figure, the square nozzle traditional circular nozzle requires 142 and 188 kPa. Pressure is function of the energy per unit volume. The percentage of energy saving is equal to the percentage of pressure saving between traditional (circular) nozzle and non circular. Table (1) reports the percentage of energy saving of different operating pressure compared with 300 kPa (the optimum average pressure for traditional nozzle).

The energy saving per 1 m^3 water volume is 58.5, 93, 127.5 and 162 kJ/m^3 at 241.5, 207, 172.5 and 138 kPa respectively (Table 1). Considering wheat crop irrigated by sprinkle system needs about 6 irrigations per season and 30 cm total irrigation depth per season per Faddan at working pressure of 241.5, 207, 172.5 and 138 kPa respectively. If the total cultivated area is 10^6 Faddan per year, the total energy saving will multiplied by one million.

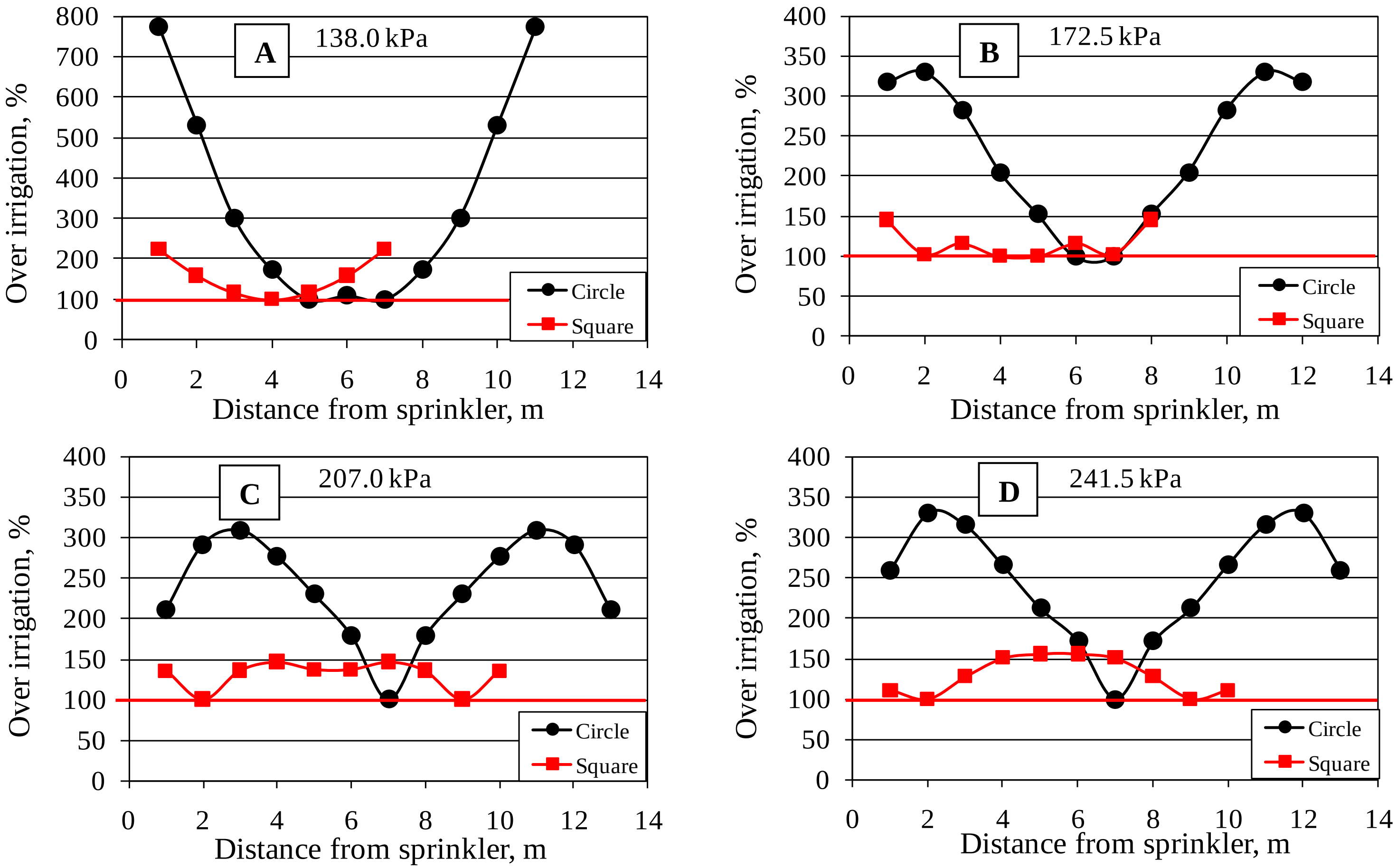

Figure (11): Over irrigation application profiles % for circular and square orifices with 100% overlapping at sprinkler base pressure (A) 138.0, (B) 172.5, (C) 207.0 and (D) 241.5 kPa.

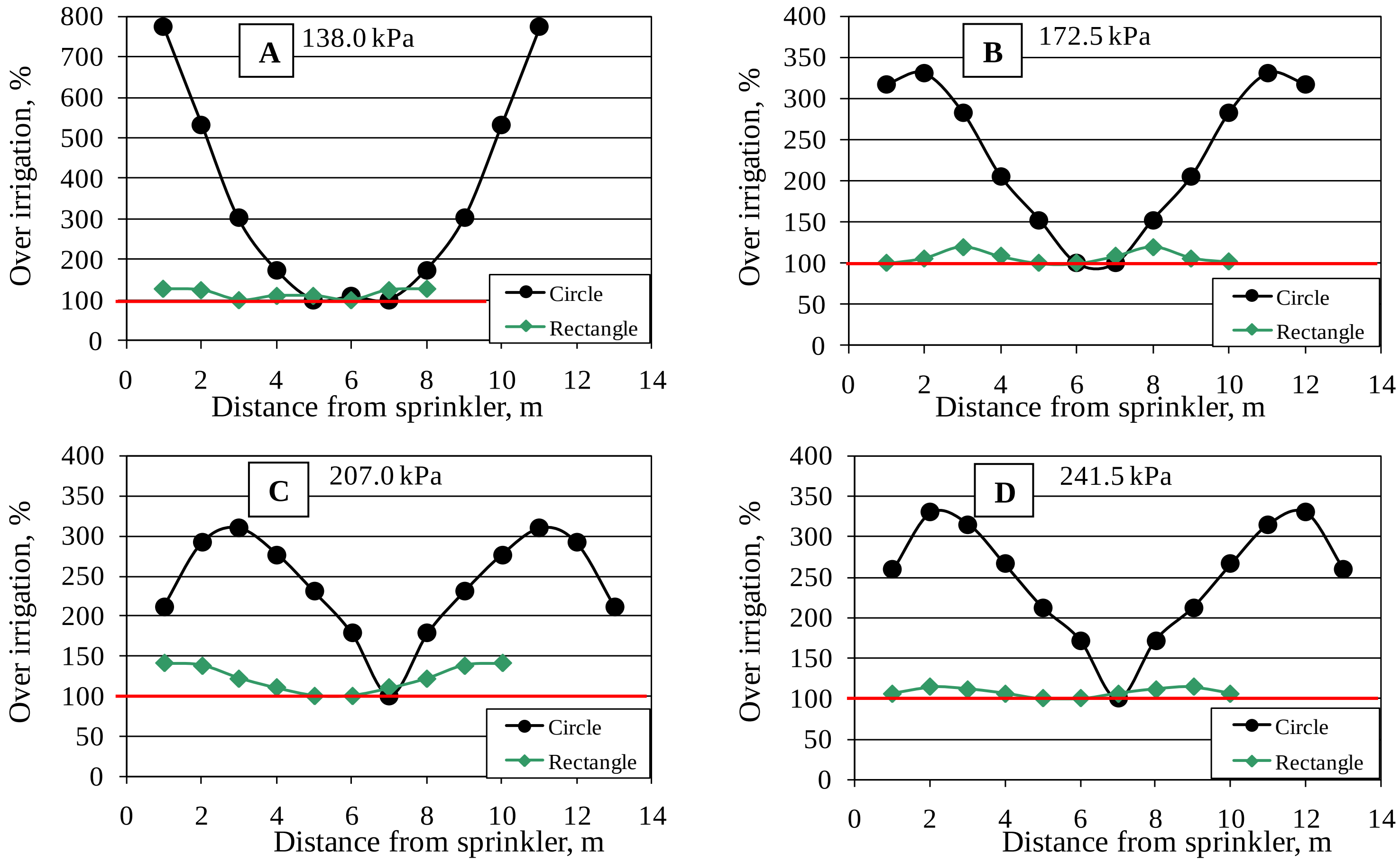

Figure (12): Over irrigation application profiles % for circular and rectangular orifices with 100% overlapping at sprinkler base pressure (A) 138.0, (B) 172.5, (C) 207.0 and (D) 241.5 kPa.

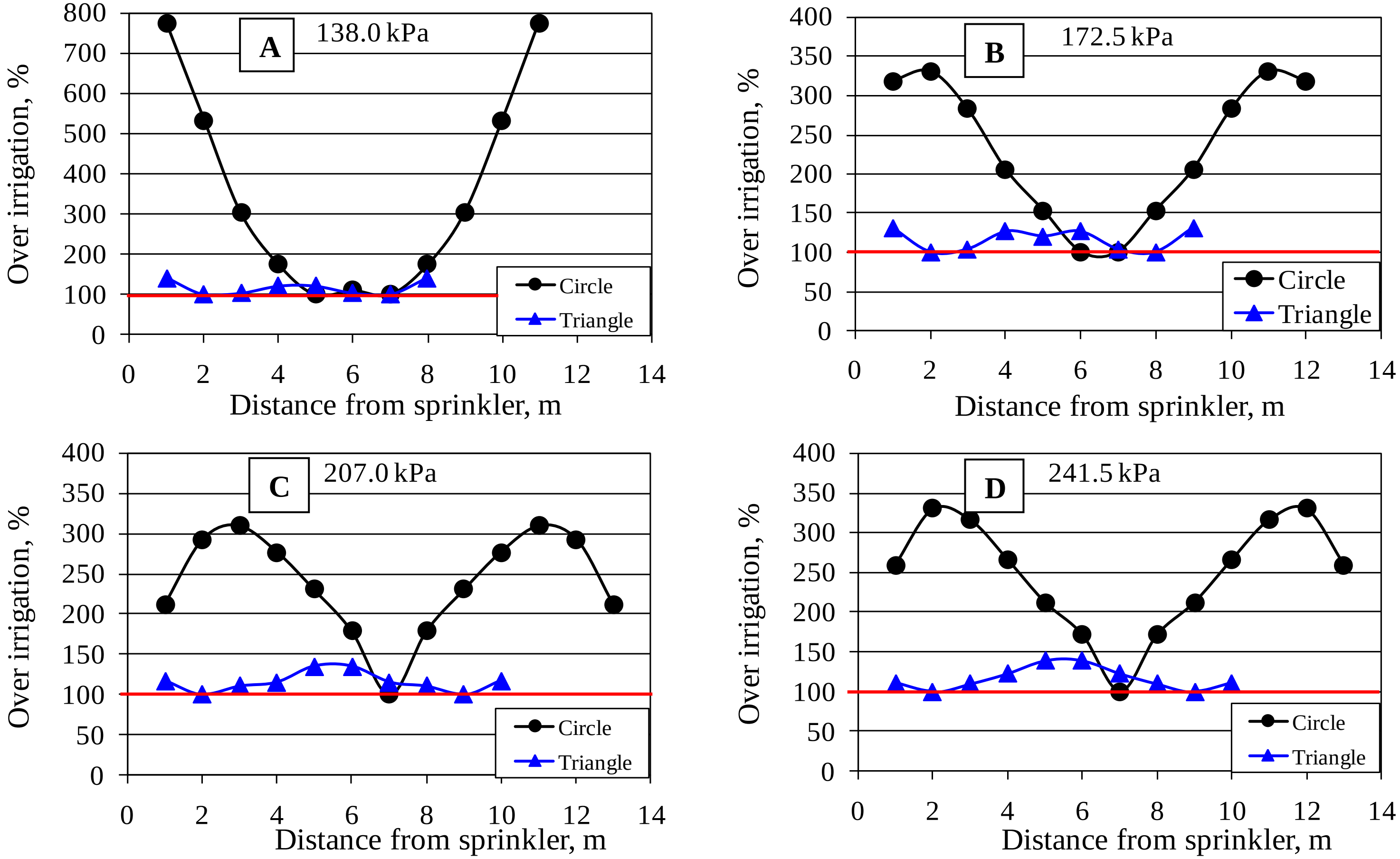

Figure (13): Over irrigation application profiles % for circular and triangular orifices with 100% overlapping at sprinkler base pressure (A) 138.0, (B) 172.5, (C) 207.0 and (D) 241.5 kPa.

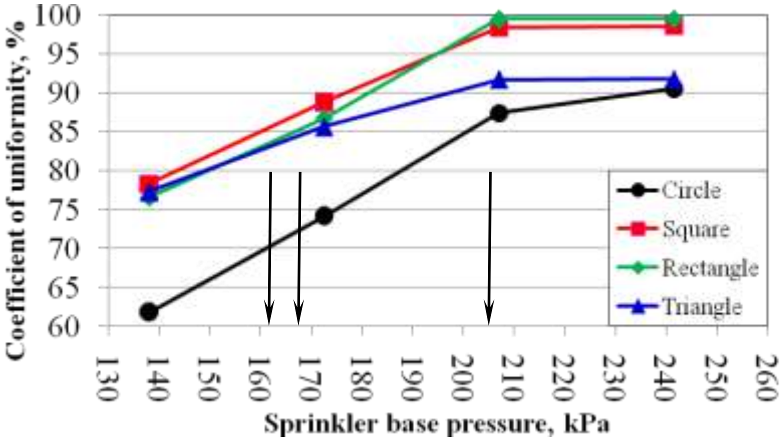

Figure (14): effect of Sprinkler base pressure on coefficient of uniformity for different nozzle shapes.

Table (1): The percentage of energy saving for wheat crop as a result of reducing pressure from 300 kPa to low pressure levels.

	Sprinkler base pressure, kPa			
	241.5	207	172.5	138
Pressure difference from 300, kPa	58.5	93	127.5	162
Energy Saving per unit volume, kJ/m^3	58.5	93	127.5	162
Energy Saving, kJ/Faddan	7371	11718	16065	20412
Energy Saving, kw.hr/Faddan	20.475	32.55	44.625	56.7

CONCLUSIONS

Water distributions for square, rectangular and triangular nozzle shapes were compared with the performances of circular nozzle. Generally the noncircular nozzles were getting more efficient water application profiles with 100% overlapping. Noncircular nozzles gives lower over irrigation percentage comparing with circular nozzles especially in lower pressures. The noncircular nozzles have acceptable coefficient of uniformity for all pressures meanwhile the circular nozzles have unacceptable coefficient of uniformity at 138.0, 172.5 kPa and gives acceptable at 207.0 kPa and higher. Finally, at low pressures using triangular or rectangular nozzles gives less percentage of over irrigation with acceptable coefficient of uniformity. Using noncircular orifice nozzles at 172.5 kPa was reducing energy than using traditional nozzle 127.5 kJ for each $1m^3$ of irrigation water.

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الملخص العربي

تأثير شكل فتحة الرشاش والضغط على توزيع المياه

عزمي البري[١]، محمود هانئ رمضان[٢]، محسن عبدالسلام العدل[٣]، هاشم محمد عبدالمجيد[٤]

انتظام توزيع المياه هو الهدف الرئيسي لعملية الري بالرش. للوصول لذلك الانتظام باستخدام الفتحات الدائرية تحتاج إلى ضغوط عالية نسبياً. في هذا البحث تم اختبار مجموعة من الفتحات الغير دائرية (المربعة والمستطيلة والمثلثة بمواصفات معينة) ومقارنة أدائهم بالفتحة الدائرية عند ضغوط التشغيل المنخفضة. استخدمت ٤ مستويات من الضغوط المنخفضة (١٣٨,٠، ١٧٢,٥، ٢٠٧,٠، ٢٤١,٥ كيلوبسكال). بينت النتائج أن زيادة ضغط التشغيل يحسن من شكل توزيع المياه لجميع أشكال الفتحات (الدائرية والغير دائرية). وكان مقدار التحسن في شكل توزيع المياه بين التشغيل على ضغط ١٣٨ و ١٧٢,٥ كيلوبسكال وكذلك بين ١٧٢,٥، ٢٠٧,٠ كيلوبسكال أكبر من التحسن عند التشغيل بين الضغوط ٢٠٧,٠، ٢٤١,٥ كيلوبسكال وذلك لجميع الأشكال الدائرية والغير دائرية. الشكل الدائري يعطي شكل توزيع غير منتظم عند كل الضغوط مقارنة بالأشكال الغير دائرية. الشكل المربع والمستطيل يحسن من شكل توزيع المياه بشكل واضح ابتداءً من ضغط ١٧٢,٥ كيلوبسكال أما المثلث فقد أعطى شكل توزيع جيد عند كل الضغوط المستخدمة. بدراسة التداخل بنسبة ١٠٠٪ بين رشاشين تبين أن الأشكال الغير دائرية تعطي توزيع أفضل من الشكل الدائري. كما أهتم البحث بحساب نسبة كمية مياه الري الزائدة عن عمق الري المستهدف. أوضحت النتائج تفوق الأشكال الغير دائرية على الشكل الدائري. وصلت نسبة الماء الزائد عن المستهدف للشكل الدائري إلى ٦٧٥٪ عند ضغط ١٣٨ كيلوبسكال بينما كانت للشكل المثلث ٤١,٥٪ فقط عند نفس الضغط. ونتيجة لذلك تقل كمية المياه الزائدة عن المستهدف مما يوفر في كمية الماء وكذلك في تكاليف الطاقة اللازمة للضخ.

أستاذ الهندسة الزراعية - كلية الزراعة - جامعة القاهرة.٢و٣ أستاذ مساعد الهندسة الزراعية - كلية الزراعة- جامعة المنصورة. ٤ باحث مساعد محطة بحوث واختبار الجرارات - معهد بحوث الهندسة الزراعية – وزارة الزراعة

باستخدام برنامج الأكسل تم عمل محاكاة لتشغيل ٤ رشاشات وحساب كميات تساقط المياه على رؤوس مربعات ١ × ١م وحساب معامل الانتظامية للأشكال المختلفة ومستويات الضغوط المستخدمة في البحث أوضحت النتائج ارتفاع واضح لقيم معامل الانتظام للأشكال الغير دائرية مقارنة بالشكل الدائري ولاسيما عند الضغوط الأقل. للوصول إلى معامل انتظامية ٨٠٪ كان يلزم للأشكال الغير دائرية أن تعمل على ضغط لا يقل عن ١٤٩ كيلوبسكال أما الشكل الدائري فكان يحتاج إلى ضغط فوق ١٨٨كيلوبسكال. تم استنتاج أن استخدام الفتحات الغير دائرية على ضغط ٢٠٧ لري محصول القمح خلال موسم زراعته توفر ٣٢,٥٥ كيلووات ساعة لكل فدان أي ٣٢,٥٥ مليون كيلووات ساعة لإجمالي المساحة المنزرعة قمح بمصر على فرض أنها مليون فدان سنوياً. ويوصي البحث بضرورة التحول إلى الفتحات الغير دائرية ولاسيما الشكل المستطيل والمثلث للعمل على ضغوط تشغيل منخفضة (توفيراً للطاقة) بأداء جيد.