Water distribution characteristics of large cannon irrigation sprinkler under different spacing and layouts

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Abstract: Relevant factors of big gun sprinkler affecting the irrigation performance are the nozzle diameter, operating pressure, layout form, and overlapping distance were studied under no wind conditions. The discharge coefficient ranged from 0.96 to 0.99. A mathematical model of radius of throw was also regressed and the coefficient of determination was 0.9765. The application rate was lower near the sprinkler, and then a peak value occurred under the radius of throw from 4 to 6 m for each water distribution pattern. The average application rate decreased with the increase of operating pressure. The average application rate increased with the increase of nozzle diameter. The increased or decreased magnitude of average application rate under small nozzle diameter was larger than large nozzle diameter within the same range of variation of operating pressure. The maximum CU values increased with the increase of operating pressure under different nozzle diameter or different layout. Equilateral triangle layout achieved higher uniformities compared with square layout. The optimal CU values and spacing coefficients of big gun sprinkler with different conditions of layout [s], operating pressure and nozzle diameter were proposed.

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Key word: sprinkler; hydraulic performance; water distribution; uniformity; layout

Introduction

Sprinkler irrigation system has been widely employed due to the operational simplicity that this irrigation method offers. Furthermore, this kind of irrigation provides good water distribution uniformity, precise controlling of irrigation depth applied, high water application efficiency and potential of use in different types of soil and topography conditions (Bernardo et al., 2006; Frizzone et al., 2011).

One of the key components of a sprinkler irrigation system is the sprinkler. Its purpose is to distribute water over an area so that the appropriate amount of water is applied at all locations. It is important to know and understand that to expect from any sprinkler that designer plan to use. Some general characteristics that should be understood include sprinkler discharge, radius of throw, water distribution pattern and precipitation rate. For combination application, positioning sprinkler is one of the important decisions to design an irrigation system. A poor design will likely result in uneven water distribution with more water in some places than others. There are two basic choices in positioning sprinkler, triangular and square spacing.

Water application uniformity is influenced by many factors, controlled or not by the operator. Among those factors that can be handled by the operator, there are: i) geometric shape of the radial leg, which depends on the kind of sprinkler, nozzle diameter, operating pressure and trajectory angle; ii) sprinkler layout forms (rectangular and triangular); and iii) overlapping distance) (Bernardo et al., 2006; Keller & Bliesner, 1990). However, wind (speed and direction) cannot be controlled by the operator (Seginer et al., 1992; Carrión et al., 2001; Faria et al., 2009; Beskow et al., 2011; Faria et al., 2012).

Furthermore, irrigation uniformity, or uniformity of water distribution is an important performance characteristic and the most relevant parameter of the sprinkler irrigation system. Indeed, this design factor effects on important aspects such as water use efficiency, leaching of fertilizers and crop yield (Seginer et al., 1991b). A non-uniform distribution not only could leave some parts of the crop on a deficiency water situation, also could over-irrigate other parts causing ponding water, plant damage, soil salinization, and leaching of chemical substances to ground water (Solomon, 1983). Non-uniform irrigations might waste energy and chemicals. Increasing water application uniformity can improve irrigation efficiency by preventing deep percolation and surface runoff due to over irrigation (James and Blair 1984).

A great deal of research has been conducted on the effects of operating pressure, nozzle diameter and layout form on hydraulic performance and water uniformity for small or medium size sprinkler (Culver and Sinker 1966; Chen and Wallender 1985; Edling 1985; Fischer and Wallender 1988; Louie and Selker 2000; Faci et al. 2001; Mateos 2006; Zhu et al. 2012; Liu et al. 2013a; Burillo et al. 2013; Fukui et al.1980; Playán et al. 2006; Zhang et al. 2013). Canessa and

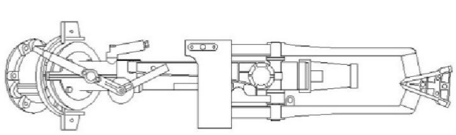
Herman son (1994) described that a correct over-lap is the result of a correct combination of sprinkler spacing, pressure and nozzle diameter. Burt et al. (1997) indicated that the most influential factors of heterogeneity in water distribution are operating pressure variation at the hydrant, sprinkler design, sprinkler layout. Keller and Bliesner (1990) identified that sprinkle irrigation system require a minimum value of water distribution uniformity such as Christiansen's coefficient of uniformity (CU) ≥ 80%. Low values of CU are usually indicators of a faulty combination of nozzle diameter, operating pressure and sprinkler spacing (Tarjuelo et al., 1999a) Low values of CU indicate incorrect combination of nozzle size, operating pressure, and other design factors (Salmerón et al.,2012, Siosemarde et al.,2012, Osman et al., 2014).

Sprinkler irrigation with big gun sprinkler is widely used in the world as it allows for the efficient watering of middle-scale fields at relatively low cost (Pascal et al. 2006, Silva 2006). But, few people studied the hydraulic performance and optimal layout of big gun sprinkler. So, based on the previous studies, the objectives of this paper are: (1) to characterize flow rate and radius of throw on different operating pressures and nozzle diameters on big gun sprinkler and to propose predictive equations to estimate flow rate and radius of throw using multiple regression; (2) to analyze the water distribution pattern and average application rate; (3) to analyze the effect of operating pressure, nozzle diameter, layout form and overlapping distance on water uniformity; (4) to give some optimal values for sprinkler layout to help on design and manage in sprinkle irrigation system with big gun sprinkler.

Materials And Methods

Sprinkler

The big gun sprinkler was selected for this study and it was from the Nelson Irrigation Co., Walla Walla, Washington, USA. Figure 1 presents the photograph of big gun sprinkler. The inlet diameter of sprinkler was 38 mm, and the sprinkler jet forms a 24° angle with respect to the horizontal. Circular nozzle with four different nozzle diameters (12.5, 15.1, 19 and 22.5 mm) was selected in this study.



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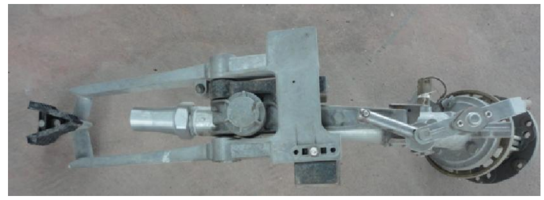

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Figure 1. Photographs of big gun sprinkler. (a) Schematic diagram of big gun sprinkler, (b) Picture of real product

Experiment set-up

Performing experiments in an indoor facility ensures water distribution and avoids water drift and loss (Sourell et al., 2003; Dukes, 2006; Liu et al, 2013(a)). A schematic of the sprinkler set-up is shown in Figure 2. A centrifugal pump supplied water to the irrigation system from a constant level reservoir. Discharge was measured by an electromagnetic flow meter with an accuracy tolerance of 0.5 %. Pressure was measured at the base of the sprinkler head using a pressure gauge with an accuracy tolerance of 0.4 %. The catch cans used in the study for testing radial water application were cylindrical in shape with a height of 0.6 m and an inside diameter of 0.2 m. Catch cans, which were used to collect water, were spaced at 1m intervals from the sprinkler in two single collector lines in opposite directions. The water collected in each can was measured using a graduated cylinder. The application rate was calculated based on the diameter of the catch cans and the duration of each test. The radial application rate distributions for the sprinklers were then determined in the laboratory.

The sprinkler heads were installed on a 1.5 m riser at a 90° angle to the horizontal and were placed approximately 0.9 m above the top of the catch cans. The following six operating pressures were tested for the big gun sprinkler: 300, 400, 500, 600, 700 and 800 kPa, respectively. The sprinkler was run for a few minutes before performing the experiments in order to standardize environmental conditions. The following standards were adopted in the design of the experimental set-up and in the experiment itself: ASAE S.330.1 (1985a), ASAE S.398.1 (1985b), and ISO 7749-2 (1990), MOD GB/T 19795.2 (2005). Three repetitions were made for every operating pressure. The volume of water in each catch cans was determined as the average of catch cans and for three repetitions.

Sprinkler water distribution pattern

Water distribution pattern is useful for designers when choosing the nozzle diameter, operating pressure, layout form and overlapping distance in order to achieve high water distribution uniformity (Tarjuelo et al., 1999c).

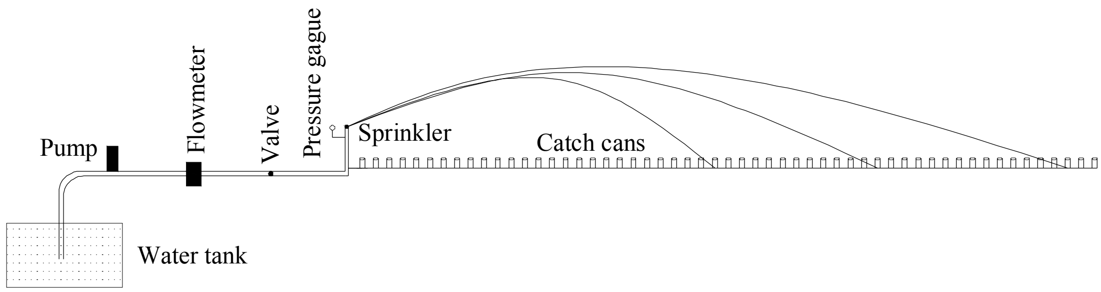


Figure 2. Schematic diagram of the experimental conditions in the laboratory

Sprinkler flow rate

A relationship which is necessary for designing sprinkler irrigation system have been described between discharge and pressure for an orifice nozzle by Li and Kawano (1998) as follows:

$$Q = c \cdot A\left(2g \cdot H\right)^x \quad (1)$$

Where: Q is nozzle discharge rate in $m^3 \cdot s^{-1}$; A is orifice cross-sectional area in m^2; g is gravitational acceleration in $m \cdot s^{-2}$ ($9.8 m \cdot s^{-2}$); H is sprinkler pressure head in m; c is discharge coefficient and x is the discharge exponent.

Radius of throw

The big gun sprinkler was operated at different operating pressures and the radius of throw was measured using a measuring tape.

Average precipitation rate

There are great differences between natural precipitation and big gun sprinkler precipitation. One is the application rate change with the radius of throw, and it can cause the water distribution non-uniform. The other is the spraying is intermittent for the field due to the big gun sprinkler is rotary when it works. So, average application rate was selected as one hydraulic performance index to evaluate big gun sprinkler.

The rate that water falls to the ground is called average precipitation rate. It is usually reported in units of millimeter per hour. Precipitation rate is important to designer for at least two reasons: (1) designer want to avoid applying water at a faster rate than the soil can absorb it, and (2) designer need precipitation rate to compute the time required to apply a desired depth of water. Precipitation rate is simply the flow into an area divided by the area:

$$I = \frac{Q}{S} \quad (2)$$

Where: I is average precipitation rate in $mm \cdot h^{-1}$; Q is sprinkler discharge in $m^3 \cdot h^{-1}$; and S is surface area irrigated by sprinkler in m^2.

Christiansen's uniformity coefficient

Sprinkler irrigation uniformity coefficient mainly reflect the distribution of the water volume in the irrigation area of homogeneous degree, it has a decisive influence on the growth of crops, is one of the important indexes to measure quality of sprinkler irrigation. Christiansen's uniformity coefficient (Christiansen 1942) was defined to evaluate sprinkler irrigation systems and has the strongest historical precedent in the sprinkler irrigation industry. It is defined as:

$$\mathrm{CU} = 100\left[1.0 - \frac{\sum\left|x_i - x_m\right|}{\sum x_i}\right] \quad (3)$$

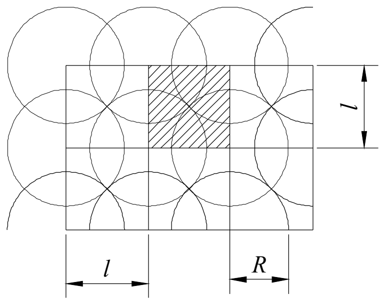
Where: CUis Christiansen's uniformity coefficient, %. $x_i$is measured depth (volume or mass) of water in equally spaced catch cans on a grid; x_m is mean depth (volume or mass) of water of the catch in all cans.

Matrix laboratory (MATLAB) was used as the computational program to calculate the combined CU values according to the radial application rate of water distribution. In this work, two common different layout forms were adopt to analysis the effects of different layout form and overlapping distance on CU values. Figure 3 presents the two different layout forms, one is square layout and the other is equilateral triangle layout. Spacing coefficient was defined as a parameter to describe the overlapping distance of two sprinklers for two different layout forms, and spacing coefficient was equal to the times of radius of throw. As can be seen from Fig. 3a, the relationship between overlapping distance and radius of throw can be presented as follow:

$$l = S_d \cdot R \quad (4)$$

Where: l is overlapping distance of two sprinklers in m, S_d is spacing coefficient, R is radius of throw in m. The maximum S_d can be achieved for square layout from Fig. 3a and the value was 1.41. In the same way, the maximum S_d can be achieved for equilateral triangle layout from Fig. 3b and the value was 1.73. When the spacing coefficient exceeded 1.41 or 1.73 with square or equilateral triangle layout respectively, some area cannot be irrigated with the sprinkler. Therefore, five different spacing coefficients were selected for square layout, 1.0, 1.1, 1.2, 1.3 and

1.4. And eight different spacing coefficients were selected for equilateral triangle layout,.



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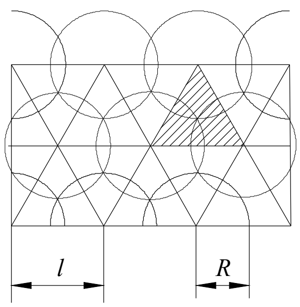

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Figure 3. Two different layout forms of big gun sprinkler. (a) Square layout, (b) Equilateral triangle layout

Results And Discussion

Sprinkler flow rate

Figure 4 shows the results of flow rate under different operating pressures and nozzle diameters. The flow rate of the evaluated big gun sprinkler increased with operating pressure and nozzle diameter.

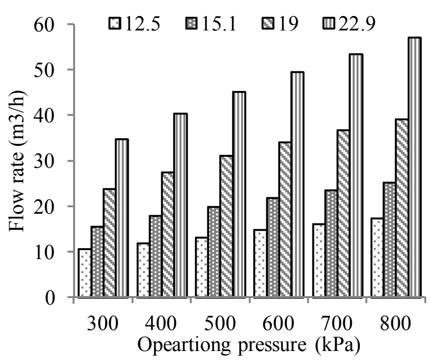


Figure 4. Flow rate of big gun sprinkler under different operating pressure and nozzle diameter

With regard to the discharge equation (Eq. (1)), several studies applied to agricultural sprinklers interpreted that discharge exponent is essentially independent of operating pressure for a given nozzle diameter and that discharge exponent is constant and equal to 0.5 (Li, 1996; Li and Kawano, 1998; Tarjuelo et al., 1999a). We also assumed discharge exponent to be equal to 0.5.

Table 1 shows a summary of the calculated results of the discharge coefficient under different operating pressures and nozzle diameters. The discharge coefficient ranged from 0.96 to 0.99, and it remained basically unchanged for the entire range of operating pressures with each nozzle diameter. Small differences were due to experimental error themselves. This indicated that the discharge coefficient was independent of the operating pressure. The discharge coefficients that were showed in table 1 and Eq. (3) allowed us to calculate flow rate for every operating pressure and nozzle diameter.

Table 1. Discharge coefficient under different operating pressures and nozzle diameters

Operating pressure (kPa)	Nozzle diameter (mm)			
	12.5	15.1	19	22.9
300	0.99	0.99	0.97	0.97
400	0.96	0.99	0.96	0.97
500	0.95	0.99	0.98	0.97
600	0.97	0.99	0.98	0.97
700	0.98	0.99	0.98	0.97
800	0.99	0.99	0.97	0.97

Radius of throw

The relationship between radius of throw and operating pressures under different nozzle diameters was shown in figure 5. The results showed that there is a linear relationship between the radius of throw and operating pressures under the same nozzle diameter and the radius of throw increased with the increase of operating pressure. Under the same operating pressure, the radius of throw increased with the increase of nozzle diameter. When the nozzle diameter was 12.5 mm, the radius of throw was 27 m and 38 m at 300 kPa and 800 kPa, respectively, and the growth range was 11 mm. When the nozzle diameter was 22.9 mm, the radius of throw was 38 m and 52 m at 300 kPa and 800 kPa, respectively, and the growth range was 14 mm. This indicated that the growth range of radius of throw with larger nozzle diameter was bigger than smaller nozzle diameter when the same operating pressure was increased. A regress equation about the radius of throw and operating pressure and nozzle diameter was built by using the regression analysis, and the model was proposed as follow:

$$R=0.0164\cdot p\cdot e^{0.0242d}+15.534\cdot \ln(d)-18.861 \quad (6)$$

Where: R is radius of throw in m, p is operating pressure in kPa, d is nozzle diameter in mm, and the coefficient of determination is 0.9765.

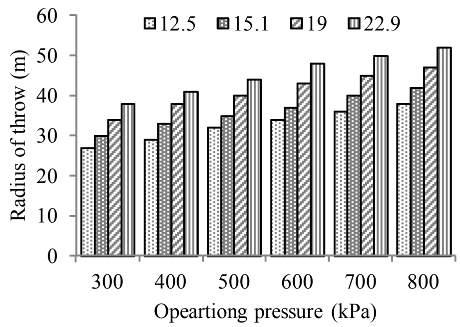


Figure 5. Radius of throw of big gun sprinkler under different operating pressures and nozzle diameters

Sprinkler water distribution pattern

Due to the shape of water distribution under different nozzle diameters versus the distance from sprinkler had the similar rule, therefore, the water distribution patterns under the nozzle diameter was 12.5 mm were selected to analyze the effect of different operating pressure on water distribution pattern. A graphic representation of single-radius sprinkler water distribution patterns with the nozzle diameter was 12.5 mm obtained in tests was shown in figure 6. Comparing the six water distribution patterns, curves with triangular shape can be observed at the end of radius of throw. Also, it can be observed that the application rate was lower near the sprinkler (1–3 m) because of the secondary nozzle was not used, and then a peak value of application rate was occurred under the radius of throw from 4 to 6 m for each water distribution pattern. When the operating pressures (300, 400 and 500 kPa) were relatively lower, the application rates at the end of radius of throw declined dramatically. When the operation pressures (600, 700 and 800 kPa) were relatively higher, the application rates at the end of radius of throw declined slowly. When the operating pressure exceed 500 kPa, the application rate at the middle radius of throw had a good consistency and water distribution uniformity.

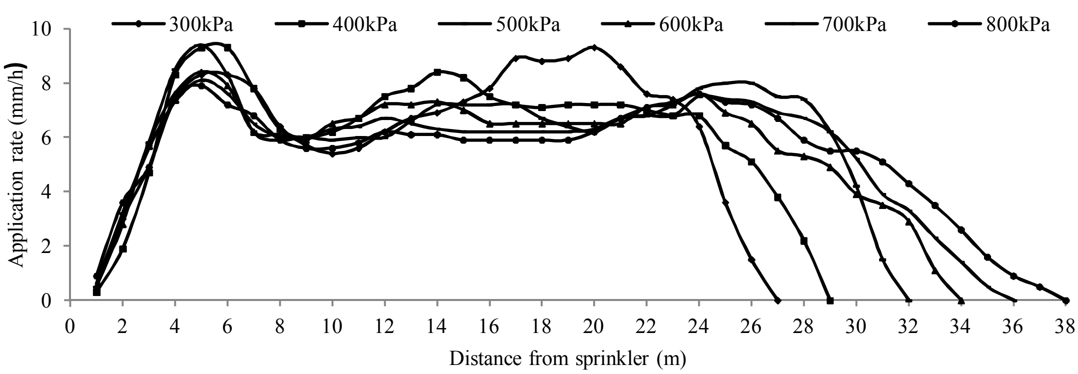


Figure 6. Water distribution patterns of the big gun sprinkler with the nozzle diameter is 12.5 mm under different operation pressures (300, 400, 500, 600, 700 and 800 kPa)

Average application rate

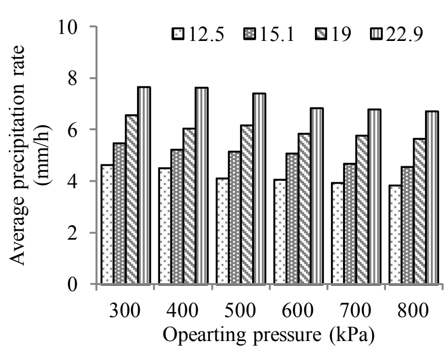


Figure7. Average application rate of big gun sprinkler under different operating pressures and nozzle diameters

Figure 7 shows the average application rate of big gun sprinkler under different operating pressures and nozzle diameters. The average application rate was decreased with the increase of operating pressure. This was due to the flow rate and surface area irrigated by big gun sprinkler were increased with the increase of operation pressure, but the growth rang of surface area was bigger than flow rate so that the average application rate was decreased. The average application rate increased with the increase of nozzle diameter. Conversely, this was due to the growth range of flow rate was bigger than surface area. When the operating pressure was 300 kPa, the average application rate were 4.62, 5.47, 6.57 and 7.66 mm/h with the nozzle diameter were 12.5, 15.1, 19 and 22.9 mm, respectively. When the operating pressure was 800 kPa, the average application rate were 3.83, 4.56, 5.64and 6.72 mm/h. Therefore, the decreased in magnitudes were 0.79, 0.91, 0.93 and 0.94 mm/h respectively, which indicates that the increase or decrease in magnitude of average application rate under small nozzle diameter was larger than the large nozzle diameter within the same range of variation of operating pressure.

Uniformity coefficient analysis for square layout

The CU values under different operating pressures (300, 400, 500, 600, 700 and 800kPa), nozzle diameters (12.5, 15.1, 19 and 22.9 mm) and spacing coefficients (1.0, 1.1, 1.2, 1.3 and 1.4) for square layout in no wind conditions were shown in figure 8.

Figure 8(a) presents the CU values with the nozzle diameter is 12.5 mm. As it can be seen in Fig. 9a, at 300 kPa, the maximum CU was 68.5% with spacing coefficient was 1.4, the minimum CU was 59.2% with spacing coefficient was 1.3. At 400 kPa, the maximum CU was 69.1% with spacing coefficient was 1.4, and the minimum CU was 60.5% with spacing coefficient was 1.1. At 500 kPa, CU changed slightly with the increase of spacing coefficient, and CU values were around 73%. At 600 kPa, CU values decreased with the increase of spacing coefficient, and the maximum CU was 76.2% with spacing coefficient was 1.0. The maximum CU was 80.1% with spacing coefficient of 1.0 at 700 kPa. When the operating pressure was 500 kPa, the CU value changed slightly to 82% with the increase of spacing coefficient.

Figure 8(b) presents the CU values with nozzle diameter of 15.1 mm. For 300 kPa, the maximum CU was 67.5% with spacing coefficient was 1.4, the minimum CU was 57.5% with spacing coefficient of 1.2. At 400 kPa, the maximum CU was 69.1% with spacing coefficient was 1.4, the minimum CU was 60.2% with spacing coefficient was 1.3. However, at 500 kPa a maximum CU of 73.6% with spacing coefficient of 1.0, and the minimum CU was 69.1% with spacing coefficient of 1.2. Additionally, at 600 kPa, the maximum CU was 72.5% with spacing coefficient of 1.0, the minimum CU was 64.5% with spacing coefficient was 1.4. The CU values decreased initially and finally remained stable at 700 kPa, with the increase of spacing coefficient, and the maximum CU was 78.8% with spacing coefficient of 1.0. At 800 kPa, CU values decreased with the increase of spacing coefficient, and the maximum CU was 83.5% with spacing coefficient of 1.0.

Figure 8(c) shows the CU values for the nozzle diameter 19 mm. At 300 kPa, the maximum CU was 61.3% with spacing coefficient was 1.0, the minimum CU was 55.6% with spacing coefficient was 1.2. At 400 kPa, the maximum CU was 65.1% with spacing coefficient was 1.0, the minimum CU was 57.2% with spacing coefficient of 1.4. The 500 kPa recorded a maximum CU of 67.8% with spacing coefficient of 1.0, and the minimum CU recorded was 62.1% with spacing coefficient of 1.2. For 600 kPa, the maximum CU was 71.6% with spacing coefficient of 1.2, and the minimum CU was 64.2% with spacing coefficient of 1.4. Further, at 700 kPa, the maximum CU was 77.2% with spacing coefficient was 1.4, the minimum CU was 71.6% with spacing coefficient of 1.1. Similarly, the 800 kPa had a maximum CU was 81.7% with spacing coefficient of 1.2, however the CU values decreased rapidly with the increase of spacing coefficient.

Figure 8(d) presents the CU values with the nozzle diameter is 22.5 mm. The 300 kPa had a maximum CU of 62.5% with spacing coefficient of 1.0, and the minimum CU was 55.6% with spacing coefficient of 1.1. In addition, the 400 kPa recorded a maximum CU of 62.6% with spacing coefficient of 1.4, and the minimum CU was 56.4% with spacing coefficient of 1.1. However, the 500 kPa, CU changed slightly with the increase of spacing coefficient, and CU values was about 63%. At 600 kPa, the maximum CU was 68.6% with spacing coefficient was 1.4, the minimum CU was 59.4% with spacing coefficient was 1.2. For the 700 kPa, the maximum CU was 72.6% with spacing coefficient of 1.2, and the minimum CU was 65.5% with spacing coefficient of 1.4. At 800 kPa, CU values increased initially and finally decreased with the increase of spacing coefficient, and the maximum CU was 78.4% with spacing coefficient of 1.1.

From the above analysis, it can be concluded that CU values increased with the increase in operation pressure and decreased with the nozzle diameter. Also, the optimum spacing coefficients under different operating pressure were not same.

Uniformity coefficient analysis for equilateral triangle layout

The CU values under different operating pressures (300, 400, 500, 600, 700 and 800kPa), nozzle diameters (12.5, 15.1, 19 and 22.9 mm) and spacing coefficients (1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6 and 1.7) for equilateral triangle layout in no wind conditions were shown in figure 9.

Figure 9(a) presents the CU values with the nozzle diameter is 12.5 mm. At 300 kPa, CU values increased firstly and then decreased with the increase of spacing coefficient, and the maximum CU was 65.7% with spacing coefficient was 1.3. At 400 kPa, CU values changed small, and the maximum CU was 72.7% with spacing coefficient was 1.7. At 500 kPa, CU values decreased firstly and then increased with the increase of spacing coefficient, and the maximum CU was 78% with spacing coefficient was 1.6. At 600 kPa, CU values decreased slowly with the increase of spacing coefficient, and the maximum CU was 79.6% with spacing coefficient was1.0. At 700 kPa, the maximum CU was 86.1% with spacing coefficient was 1.6. At 800 kPa, CU values changed small and were around 84%.

Figure 9(b) presents the CU values with the nozzle diameter is 15.1 mm. At 300 kPa, CU values presented normal distribution along spacing coefficient, and the maximum CU was 66.9 with spacing coefficient was 1.4. At 400 kPa, CU values increased firstly and then decreased, the maximum CU was 73.1% with spacing coefficient was 1.5. At 500 kPa, CU values decreased with the increase of spacing coefficient, and the maximum CU was 74.1 with spacing coefficient was 1.0. At 600 kPa, the maximum CU was 76.4 with spacing coefficient was 1.1. At 700 kPa, the maximum CU was 83.5% with spacing coefficient was 1.5. At 700 kPa, CU values kept stable firstly and then decreased, the maximum CU was 83.5% with spacing coefficient was 1.3.

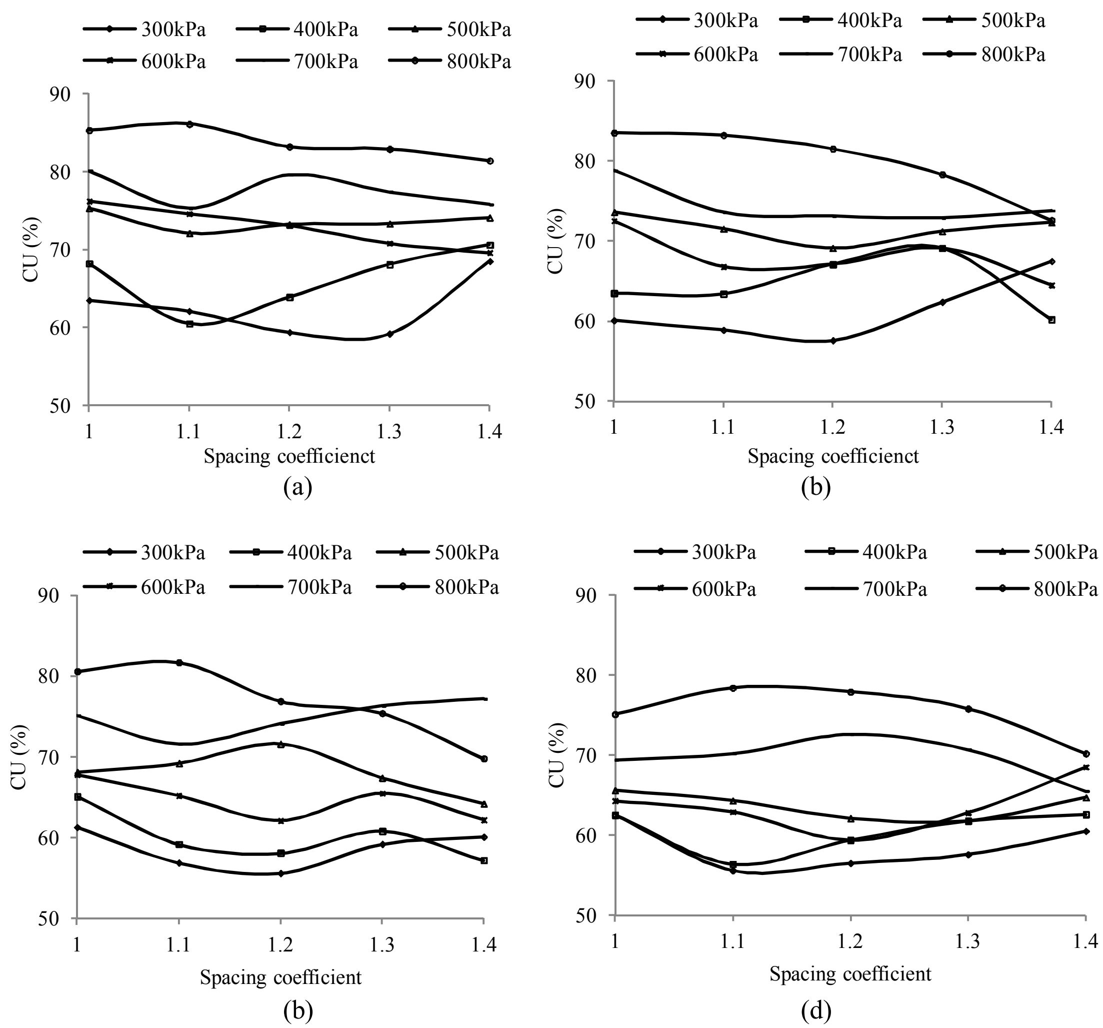
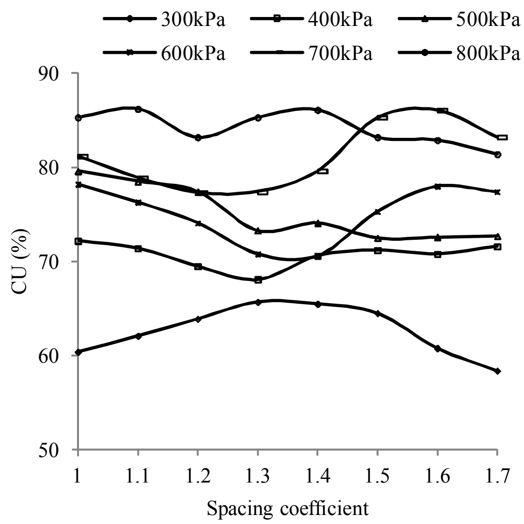


Figure 8. The CU values under different nozzle diameters (12.5, 15.1, 19 and 22.5 mm), operating pressure (300, 400, 500, 600, 700 and 800 kPa) and spacing coefficient (1.0, 1.1, 1.2, 1.3 and 1.4) for square layout. (a) Nozzle diameter is 12.5 mm, (b) Nozzle diameter is 15.1 mm, (c) Nozzle diameter is 19 mm, (d) Nozzle diameter is 22.5 mm.

Figure 9(c) presents the CU values with the nozzle diameter is 19 mm. At 300 kPa, CU values decreased firstly and then increased with the increase of spacing coefficient, and the maximum CU was 68.2% with spacing coefficient was 1.7. At 400 kPa, CU values changed small and the maximum CU was 68.2 with spacing coefficient was 1.0. At 500 kPa, CU values decreased with the increase of spacing coefficient, and the maximum CU was 74.1% with spacing coefficient was 1.0. At 600 kPa, CU values decreased firstly and then increased, the maximum CU was 75.6% with spacing coefficient was 1.0. At 700 kPa, the maximum CU was 81.7% with spacing coefficient was 1.6. At 800 kPa, CU values increased firstly and then decreased, the maximum CU was 82.7% with spacing coefficient was 1.4.

Figure 9(d) presents the CU values with the nozzle diameter is 22.5 mm. At 300 kPa, CU values decreased firstly and then increased, the maximum CU was 63.7% with spacing coefficient was 1.4. At 400 kPa, the maximum CU was 67.3% with spacing coefficient was 1.2. At 500 kPa, CU values decreased firstly and then increased, the maximum CU was 70.6 with spacing coefficient was 1.0. At 600 kPa, the maximum CU was 70.6 with spacing coefficient was 1.0. At 700 kPa, the maximum CU was 78.2 with spacing coefficient was 1.7. At 800 kPa, the maximum CU was 79.5 with spacing coefficient was 1.3.



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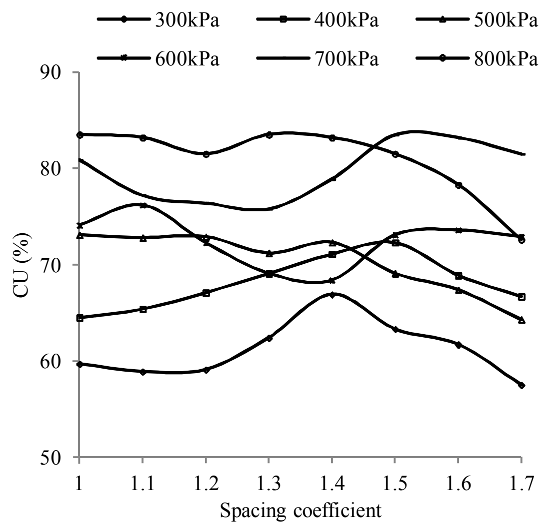

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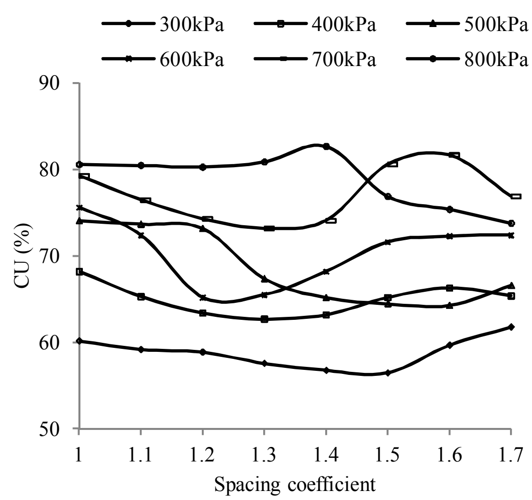

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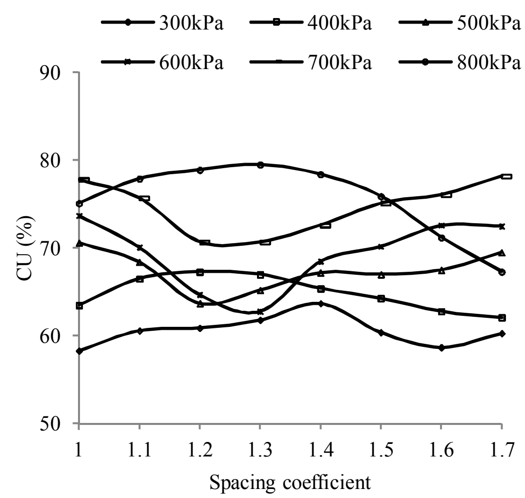

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Figure 9. The CU values under different nozzle diameters (12.5, 15.1, 19 and 22.5 mm), operating pressure (300, 400, 500, 600, 700 and 800 kPa) and spacing coefficient (1.0, 1.1, 1.2, 1.3 and 1.4) for equilateral triangle layout. (a) Nozzle diameter is 12.5 mm, (b) Nozzle diameter is 15.1 mm, (c) Nozzle diameter is 19 mm, (d) Nozzle diameter is 22.5 mm.

Recommendation

Table 2 presents the optimal CU values and spacing coefficients of big gun sprinkler with different conditions of layout, operating pressure and nozzle diameter. This table can be readily applied to the design of irrigation system equipped with this type of big gun sprinkler. As seen from the table, the maximum CU values increased with the increase of operating pressure under different nozzle diameter or different layout. Equilateral triangle layout achieved higher uniformities compared with square layout.

Table 2. The Optimal CU values and spacing coefficients of big gun sprinkler with different conditions of layout, operating pressure and nozzle diameter

Operating pressure	Square								Equilateral triangle							
	12.5		15.1		19		22.9		12.5		15.1		19		22.9	
	S_d	CU	S_d	CU	S_d	CU	S_d	CU	S_d	CU	S_d	CU	S_d	CU	S_d	CU
300	1.4	68.5	1.4	67.5	1.0	61.3	1.0	62.5	1.3	65.7	1.3	62.4	1.7	61.8	1.4	63.7
400	1.4	70.6	1.3	69.1	1.0	65.1	1.4	62.6	1.0	72.2	1.5	72.3	1.0	68.2	1.2	67.3
500	1.0	75.3	1.0	73.6	1.3	71.6	1.0	65.6	1.0	79.6	1.0	73.1	1.0	74.1	1.0	70.6
600	1.0	76.2	1.0	72.5	1.0	67.8	1.4	68.5	1.0	78.2	1.2	76.2	1.0	75.6	1.0	73.7
700	1.0	80.1	1.0	78.8	1.4	77.2	1.3	72.6	1.6	86.1	1.5	83.5	1.6	81.7	1.7	78.2
800	1.1	86.1	1.0	83.5	1.2	81.7	1.2	78.4	1.2	86.2	1.3	83.7	1.4	82.7	1.3	79.5

Conclusions

Selection of the sprinkler plays an important role in the performance of modern irrigation system. Relevant factors of big gun sprinkler affecting the irrigation performance are the nozzle diameter, operating pressure, layout form, and overlapping distance. All these factors were studied in the present work to develop guidelines for adequate design of irrigation system with the Nelson big gun sprinkler SR100-24°, and the following conclusions can be drawn:

1. For sprinkler discharge, the discharge coefficient ranged from 0.96 to 0.99. A mathematical model of radius of throw was also regressed and the coefficient of determination was 0.9765.

2. The application rate was lower near the sprinkler, and then a peak value was occurred under the radius of throw from 4 to 6 m for each water distribution pattern. The average application rate was decreased with the increase of operating pressure. The average application rate increased with the increase of nozzle diameter. The increased or decreased magnitude of average application rate under small nozzle diameter was larger than large nozzle diameter within the same range of variation of operating pressure.

3. The maximum CU values increased with the increase of operating pressure under different nozzle diameter or different layout forms. Equilateral triangle layout achieved higher uniformities compared with square layout. The optimal CU values and spacing coefficients of the big gun sprinkler with different conditions of layout, operating pressure and nozzle diameter were proposed.

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