SPRINKLER IRRIGATION SYSTEM DESIGN AND EVALUATION BASED ON UNIFORMITY

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ABSTRACT

A selected rotating sprinkler was tested in radial test within 100 to 300 kPa under nozzle #8 with 25º trajectory angle and #3 with 11º and 25º trajectory angles. K— Rain 75 pop-up sprinklers were selected due to having 12 different nozzle trajectory angles. Sprinkler discharge application rate, and pattern radius were measured at different operating pressures in individual test. For 300kPa high distribution uniformity was obtained for nozzle #8 with 25º trajectory angle in square and rectangular layouts. Square layout achieved distribution uniformity higher than rectangular layout for overlapping 100and 80%. Friction loss for a given pipe length was found in designing optimal main ,sub-main and lateral diameters under optimal nozzle angle, pressure, layout and overlapping.

***Key words*:** **irrigation sprinkler system design, evaluate uniformity distribution coefficient, nozzle discharge, optimal operating pressure.**

1. INTRODUCTION

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. **Hegazi et al. (2007)** found that, optimal layouts were 40% to 60%from diameter of throw in square layout in rang of trajectory angle in between with 15º and 30º. **Amer (2006)** found that, the high degree of water distribution uniformity was obtained from sprinkler layouts as 60% from diameter of throw in square layout and in rang from 50 to 70% from diameter of throw in rectangular.

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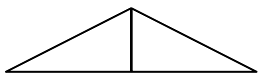
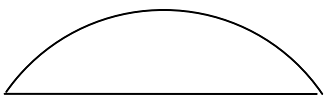
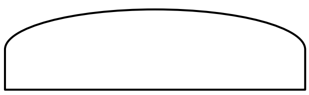
For impact sprinklers, spacing was recommended to be as 50% from diameter of throw in square layout and in rang from 50 to 60% from in rectangular. Triangular layout achieved higher uniformity than square even for the same area.

Ascough and Kiker (2002) studied the application uniformity of different irrigation systems in five sugar-growing regions in South Africa. The average low- quarter uniformity (DU) of center pivot, dragline, micro irrigation, floppy and semi permanent sprinkler systems was 81.40%, 60390%, 72.70%, 67.40% and 56.90% respectively. **Amer (2006)** found that, pressure loss should not exceed 10% of the nozzle operating pressure as used in selecting lateral length based on set a pressure regular at the inlet of each lateral.

Keller and Bliesner (1990) configured that, water distribution pattern in low wind conditions was described in five categories based on sprinkler. They recommended that, spacing among sprinklers should give acceptable application uniformities when a realistic effective diameter of throw is used. Each category has its spacing based on square, triangular and rectangular, layouts ranges from 50 to 80% from diameter of throw. Generally, spacing can be used as 50% of the effective diameter in square layout, 62% in equilateral triangular and 40 to 67% in rectangular based on average wind speed. Profile types A and B are characteristic of sprinklers having two nozzles. Profile types C and D are characteristic of single nozzle sprinklers at recommended pressure. Profile type E is generally produced with gun sprinklers or sprinklers operating at pressures lower than those recommended for the nozzle size, as showed in Table 1.

Table1: Sprinkler application rate profiles and optimum set spacing as a percentage of effective wetted diameters.

Sprinkler profile		Optimum spacing as a percentage of diameter(%)		
Type	Shape	Square	Triangular	Rectangular
A		50	50	50×60 to 65
B		55	66	40×60
C		60	65	40×60 to 65
D		40 -70 (Fair)	70 to 75	40×75 to 75
E		40	80	40×80

Distribution from an individual sprinkler is simulation, in most cases by a precipitation linearly decreasing away from the center **(El-Awady et al., 2003).** Sprinklers are usually spaced at 50% of the wetted diameter around individual heads. Distribution uniformity is usually assessed on overlapped patterns to help determining the critical irrigation water requirement. **Li and Kawano (1998)** described a relationship between discharge and pressure for an orifice nozzle as follows :

$$Q = c \times A(2gH)^{x} \quad ---(1)$$

where: Q is the nozzle discharge rate (m^3/sec), A is the orifice cross sectional area (m^2),g is the gravitational acceleration (9.81 m/sec^2), H is the sprinkler pressure head (m),c is the discharge coefficient and x is the discharge exponent.

Christiansen (1942) indicated of adequate operating pressure, low wind speed, proper speed rotation and proper sprinkler layout. Higher water uniformity may be achieved distribution pattern that define as a measure of low evenly the sprinkler applies water over the irrigated area is an important parameter to plan, design and, manage sprinkler irrigation system. Christiansen's uniformity coefficient (CU) defined as follows:

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

where: ***CU*** is the Christiansen's uniformity coefficient, X is the water depth collected by catch cans in mm, X ⁻ is the mean water depth collected in all catch cans in mm, and N is the total number of catch cans.

Warrick and Yitayew (1988) figured out that, uniformity coefficient (CU)with normal distribution is a function of coefficient of variation as follows:

$$CU = 1 - 0.798CV ---(3)$$

where: ***CU*** is the uniformity coefficient, and CV is the coefficient of variation of water distribution depth.

El-Sherbeni (1994) found that, when riser height increased from 50 to 150cm, the coefficient of uniformity (CU) values decreased from 78.5% to 70.0% for Rain Bird and from 84.60% to 65.0% for developed sprinkler under the same operating pressure of 150kPa and nozzle size 2.4mm.

Aboamera and Sourell(2003) attempted to achieve good water distribution for a new sprinkler nozzle called floppy sprinkler at an acceptable irrigation intensity. They found that, the average Christiansen coefficient of uniformity (CU) and distribution uniformity (DU) were 88.01% and 80.94% respectively for 1.5 m sprinkler height and 200kPa operating pressure.

Keller and Bliesner (1990) defined the ratio of water distribution uniformity as mean depth caught on the one forth of the field receiving the least amount to mean depth caught on the entire area. Distribution uniformity (DU) for sprinkler irrigation system can be formulated as a normal distribution as follows:

$$DU = 1 - 1.27CV ---(4)$$

Irrigation Testing and Research Center, ITRC, (1991) suggested that, the distribution of uniformity (DU) values were excellent (75.0 – 85.0),good (65.0-75.0),and poor (5.0 – 65.0%) for the multi –stream, single –stream rotor and fixed spray –sprinkler , and single –stream rotor respectively.

Duckes and Perry (2006) studied the uniformity along the length of a center pivot and a linear move irrigation system. They found that, the averaged values of the low quarter distribution uniformity were 90.0% and 74.0% for the center pivot and the linear move irrigation system respectively.

From **Watters and Keller (1978)**, the Darcy -Weisbach equation for smooth pipes with turbulent flow in trickle irrigation systems was combined with the Blasius equation for the friction factor which gives accurate prediction for frictional head loss. The friction head loss for a given pipe length with a constant input and output discharge can be estimated **(Amer,2006)**.

$$\Delta H = K_1 \frac{Q^{1.75}}{D^{4.75}} \times L --- (5)$$

where: ΔH is the friction loss in m, Q is the inlet flow rate in m^3/dec at the beginning of each lateral or sub main length L with inside diameter D both are in m, and K_1 is the friction factor which depends on water temperature, viscosity and protrusion. K_1 equals $\mathbf{7.94 \times 10^{-4}}$ with no protrusion at 20º C.

For lateral or sub main line with multiple outlets along the line which flow is non –uniform, an equation is developed based on the change of friction loss due to pipe length considering inconstantly of water flow throughout outlets. Therefore, the friction loss (ΔH_ℓ) at any section of lateral or sub main line can be derived as follows **(Amer,2006):**

$$\Delta H\ell = \frac{K_1}{2.75} \times \frac{\alpha \times Q^{1.75}}{D^{4.75}} \times \left\{ 1 - (1 - \frac{\ell}{L})^{2.75} \right\} --- (6)$$

where: (ΔH_ℓ) is the friction loss head at a length ℓ measured from inlet, α is the equivalent barb coefficient. Considering inlet lateral connector is treated as a barb.

2. MATERIALS AND METHODS

Schematic diagram of k – rain pop – up sprinkler characteristic was shown in Fig.1. The operating pressures which controlled by a pressure regulating valve of 200 and 300 kPa were used to test each nozzle of sprinkler. Bourdon tube gauge 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 each test. Both pressure and flow meters were calibrated prior to the tests. The nozzle height was 10 cm above ground as recommended by most manufacturers and **Zanon et al (2000)**.

Pattern radius for layout test for each individual sprinkler was installed using two diagonal lines north – south and east – west of catch cans at 1m spacing as shown in Fig.2. The test duration was one hour. Tests were accomplished for 3 nozzles for sprinkler which is Pop – up (K–rain Rps75) sprinkler (2 nozzles standard and 1 nozzle low angle nozzles of 25º and 11º trajectory angle). The selecting of this type of sprinkler was based on its ability to have different configurations. It has low nozzle angle and size that help to stream trajectories below fruit foliage for orchard or also in greenhouses. Sprinkler discharge, application rate and pattern radius were recorded at different operating pressures by pattern radius test, as shown in Fig.2. The catch cans were 0.119m entrance diameter and 0.1m height. The collected water was measured and related to its area in mm/h. In fact, the international standards for sprinkler evaluation recommended catch can diameter higher than 85mm **(Anonymous,1995)**.

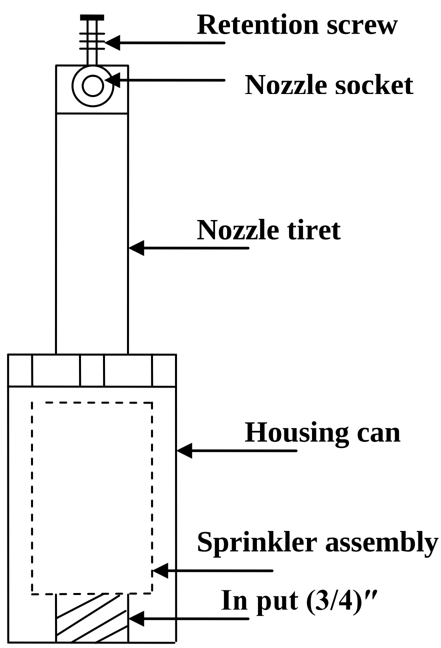


Fig.1: Schematic diagram of K- rain pop – up sprinkler characteristic

Square, triangular and rectangular layouts for uniformity degree for sprinklers water distribution tests were simulated as shown in Fig.3. Catch cans were located at 1m along and across laterals in an overlapping grid pattern Spacing between sprinklers along and across laterals was determined as 40 and 50% of the diameter of throw as spaced. These distances created overlapped percentages as 100% and 80% respectively. To find out the optimum pressure for operating sprinklers, uniformity tests were carried out in square layout at 200 and 300kPa for each nozzle of sprinkler for only 100% overlapped percentage. The optimum operating pressure were 300kPa for all nozzles and 200kPa for nozzle #3 trajectory angle 25º and trajectory angle 11º for K-rain sprinkler.

Uniformity tests that conducted for three layouts of sprinkler under optimum operating pressures were for square, triangular and rectangular layouts as shown in Fig.3. For nozzle #8 trajectory angle 25º of sprinkler with 16 m diameter of throw working under 300kPa, sprinklers were headed for both square and triangular layouts at 8 and 9.6m for 100 and 80% overlapped percentages respectively. Rectangular layout was headed at 9.5×8m and 11.4× 9.6m for 100 and 80% overlapped percentages respectively long (L) =19m and short (X) =16m. For nozzle #3 trajectory angle 25º of sprinkler with 12m diameter of throw working pressure 300kPa, sprinklers were headed for both square and triangular layouts at 7.2m for 100 and 80% overlapped percentages. Headed rectangular layout at 8×6m and 9.6×7.2m for 100 and 80% overlapped percentages respectively long (L) =16m and short (X) =12m. For nozzle #3 trajectory angle 11º of sprinkler with 11m diameter of throw working under 300kPa, sprinklers were headed for both square and triangular layouts at 5.5m and 6.6m for 100 and 80% overlapped percentages respectively. Moreover, headed rectangular layout at 6.5×5.5m and 7.8×6.6m for 100 and 80% overlapped percentages respectively long (L) = 13m and short (X) =11m. The application depth caught in mm/h that collected in uniformity test was categorized based on frequency. The frequency of the application depths was accumulated from maximum to minimum of water caught.

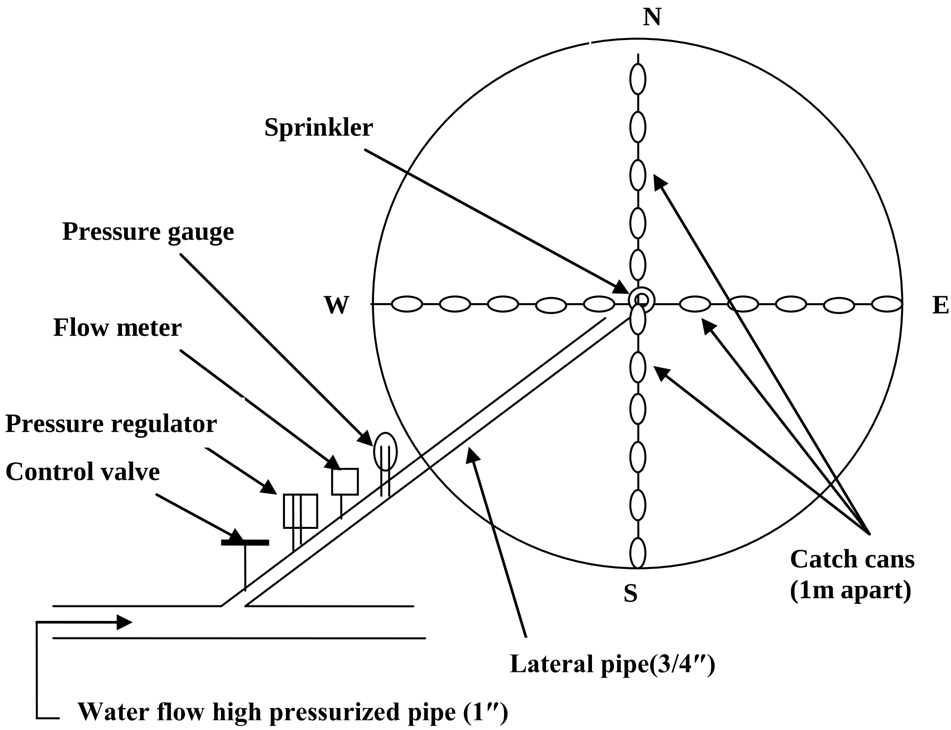


Fig.2: Pattern test layout

Application rate was determined by the following equation:

$$AR = \frac{1000q}{A} --- (7)$$

where, AR is the theoretical application rate in mm/h,q is the sprinkler discharge in m^3/sec and A is the served area in.

Actual irrigation application rate (I_p) was determined based on average of collected water depths in layout area in catch cans per unit time as follows :

$$I_p = \frac{\overline{X}}{t} --- (8)$$

where, (I_p) is the actual application rate in mm/h, X^- is the collected irrigation depth using catch cans during operating sprinkler in mm, and t is the collected time in h.

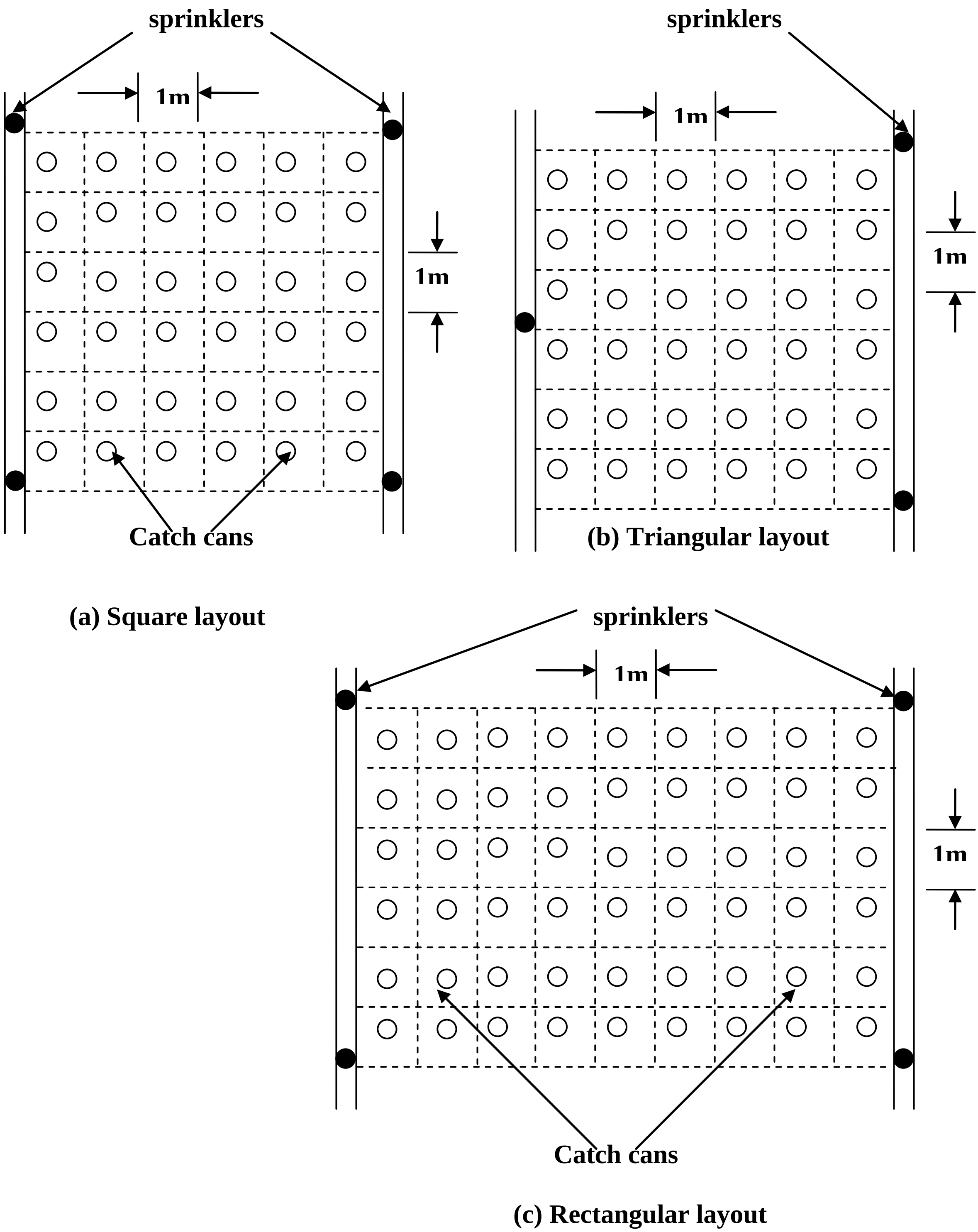


Fig.3: Schematic diagram of uniformity distribution tests for sprinklers layouts

The design was conducted in Menoufia university Stadium at Sibin El-kom which dimensioned at 121×55m using Pop-up sprinklers, 72 sprinklers were used and 121 lateral and 4 sub main lines and single main line. Nozzles #3 trajectory angle 25º was used with wetted diameter 22m and square layout under optimal pressure 300kPa and 100% overlapping.

Field dimension was 55m wide ×121m length, 72 sprinklers were used and 121 lateral with (20 and 25mm) inner diameter and 4 sub main lines (50mm) and single inlet main line with 62mm inner diameter.

The water source position with 10 m3/h at half for main line and distance from the source to last sprinkler (critical length) 115.5m. The area were blocked to four blocks had one valve and one sub main and three lateral lines and 15 sprinklers and all lines were made from (PVC). The system used nozzle #3 trajectory angle 25º,0.5 m3/h discharge with wetted diameter 22m, 300kPa operating pressure, square layout and 100% overlapping percentage as shown in Fig.4. Friction factor which gives accurate prediction for head, friction head loss for a given pipe length with a constant input and output discharge sprinkler was estimated for design to reach the optimal inner diameter for main, sub main and lateral lines under optimal nozzle, trajectory angle, pressure, layout and overlapping. Sprinklers in design to irrigate full cycle, but at corner it irrigate a quarter cycle and at the edges of it irrigate half cycle. During irrigation 3 sub main's valves were closed and one was opened to irrigate one block after one. Sub main line (40mm) inner diameter 22m long (PVC) pipe and 3 lateral lines and 15 sprinklers with distance between laterals (L) 11m and with distance between sprinklers (s) 11m as shown in Fig.4. Lateral lines with 5 sprinklers and 55m total length (20and 25mm) inner diameter for (33 and 22mm) length respectively. The average discharge in lateral line was 2 and 1 m^3/h for inner diameter 25 and 20mm respectively.

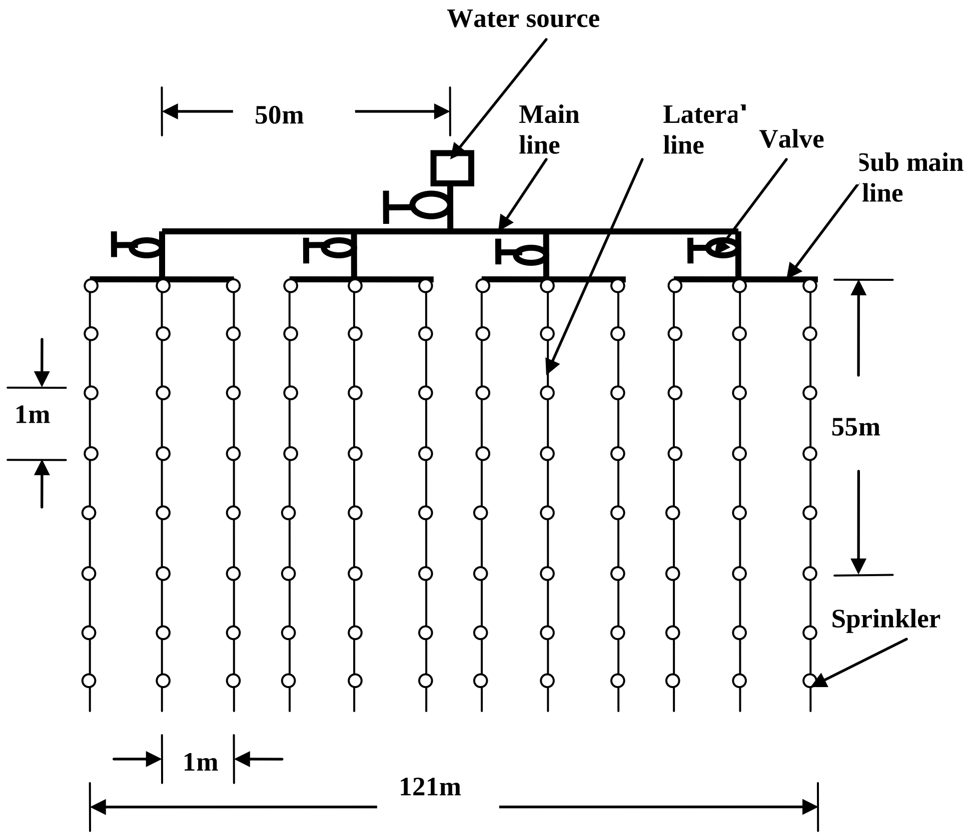


Fig.4: Sprinkler system diagram with nozzle #3 and trajectory angle 25º

3.RESULTS AND DISCUSSION

3.1. Water application rate

Water application rate in (mm/h) by individual sprinkler under 200kPa and 300kPa operating pressure was found as related to distance from sprinkler in (m). For a given operating pressure, sprinkler pattern was also plotted for different sprinkler nozzle sizes and throw angles. Different nozzle sizes were numbered as #8 and #3 which tested under the foregoing pressures as shown in Table 2. For a given trajectory angle, discharge rates were recorded and plotted against heads under pressures 200kPa and 300kPa for each nozzle. All trajectory heights started from the beginning point as 0.11m which was the height of sprinkler nozzle. It seemed that trajectory was not significantly changed for the same set under any operating pressure. Water throw angle from sprinkler nozzle was almost averaged (25º and 11º) for high pressure of 200kPa and 300kPa. The throw was increased by exceeding pressure regarding to creating high jet velocity by pressure. Furthermore, wetted diameter was also increased by increased trajectory angle. Reasonably, the higher the trajectory height the bigger the throw. Inversely, throw was decreased under both low operating pressure and trajectory angle.

Table2: Configuration of sprinklers with nozzle under different pressure

Pressure (kPa)	Parameters	Nozzle #8	Nozzle #3	
			Trajectory angle	
			25º	11º
200	Discharge (m^3/h)	1.14	0.41	0.48
	Throw (m)	12.00	12.00	8.00
	Application rate,AR,(mm/h)	2.51	0.90	2.39
300	Discharge (m^3/h)	1.47	0.49	0.51
	Throw (m)	16.00	12.00	10.00
	Application rate,AR,(mm/h)	1.82	1.09	1.61

At operating pressure 200kPa nozzle #8 trajectory angle 25º application rate increase in which faraway in wetted cycle of sprinkler and application rate decrease in area near sprinkler in wetted cycle in individual sprinkler test. This distribution not accepted as shown in Fig.5 and 6, while nozzle #3 trajectory

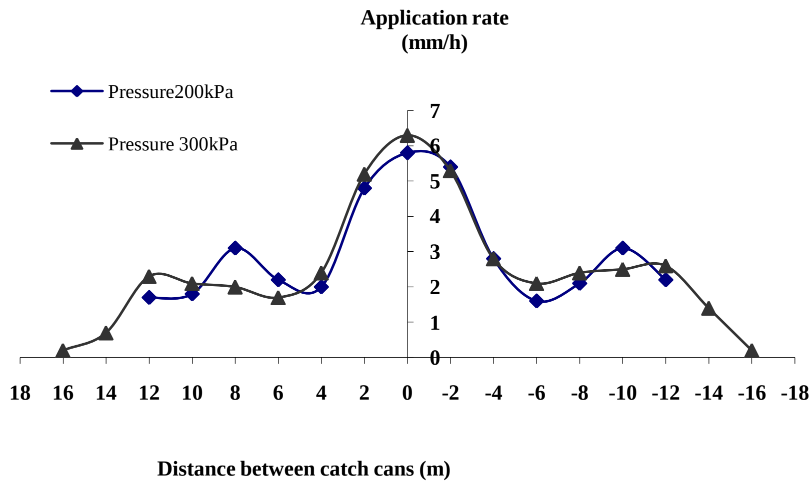


Fig.5: Individual distribution pattern for nozzle #8H,North & south

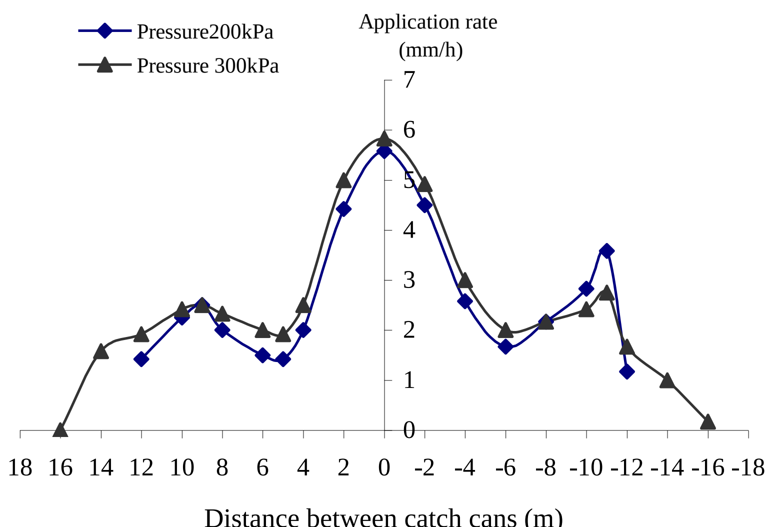


Fig.6: Individual distribution pattern,nozzle #8H.East& West

angle 25° the distribution is nearly accepted and trajectory angle 11° the distribution is accepted as shown in Fig.7,8,9 and 10 respectively.

At operating pressure 300kPa for all nozzle application rate distributed as bell shape in wetted cycle of sprinkler in individual sprinkler test distributions for nozzle #8 at trajectory angle 25º of sprinkler with 16 m throw gave good acceptable distribution as shown in Fig.5 and 6. For nozzle #3 trajectory angle 11º of sprinkler with 12m and 11m throw gave a very good acceptable distribution as shown in Fig.7 and 8. Selecting the optimal range of operating pressure was not depended on analysis from radial test, but also analysis from uniformity test as in the approaching text. But that will achieve the desirable uniformity.

3.2. Water distribution pattern

(a) Nozzle #8 trajectory angle 25º

Different water distribution patterns from nozzle #8 at trajectory angle 25º under 200kPa and 300kPa operating pressure were found and presented in Fig.5. At 200kPa operating pressure, the application rate was 5.5mm/h at the center and was 0.15 mm/h at north and 0.54mm/h at south. For 300 kPa, it was 6mm/h at the center and was 0.30 mm/h at north and 0.57 mm/h at south.

The results also showed that, the higher the operating pressure the higher the wetted area because sprinkler discharge was increased. Reversely, application rate was decreased by increasing the operating pressure due to increasing wetted area, relative to increasing sprinkler discharge. Figure 6 showed different water distribution for application rate in wetted area for sprinkler as follows: (1)Pressure 200kPa gave 5.5mm/h at the center and 0.76 mm/h at east and 0.91mm/h at west.(2)For 300 kPa, it was 6mm/h at the center and 0.08 mm/h at east and 0.53 mm/h at west.

Water distribution pattern curve under 100 kPa showed that water concentrated around and a distance away from sprinklers due to insignificant pressure. The curve produced under medium pressure of 200kPa showed water from nozzle settled around sprinkler and smoothly dropped from start to end of water trajectory. Curves in Figure 6 turned to be semi-trapezoid with slight peak at the middle of the throw radius. For high pressures of 300 kPa, water patterns semi-trapezoid shape.

(b) Nozzle #3 trajectory angle 25º

Figure7showed the water application rate in wetted cercal for sprinkler as follows (1) Pressure 200kPa gave 4.0 mm/h at the center and 0.15

mm/h at north and 0.18 mm/h at south. (2)For 300 kPa, it was 4.6 mm/h at the center and 0.18 mm/h at north and 0.15 mm/h at south.

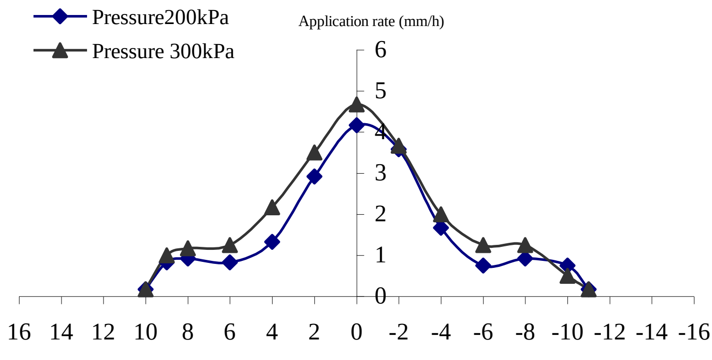


Fig.7: Individual distribution pattern ,nozzle #3.HNorth &South

Figure 8 showed the water application rate in wetted cercal for sprinkler as follows: (1)Pressure 200kPa gave 4.0 mm/h at the center and 0.08 mm/h at east and 0.6 mm/h at west. (2)For 300 kPa, it was 4.6 mm/h at the center and 0.36 mm/h at east and 0.44 mm/h at west.

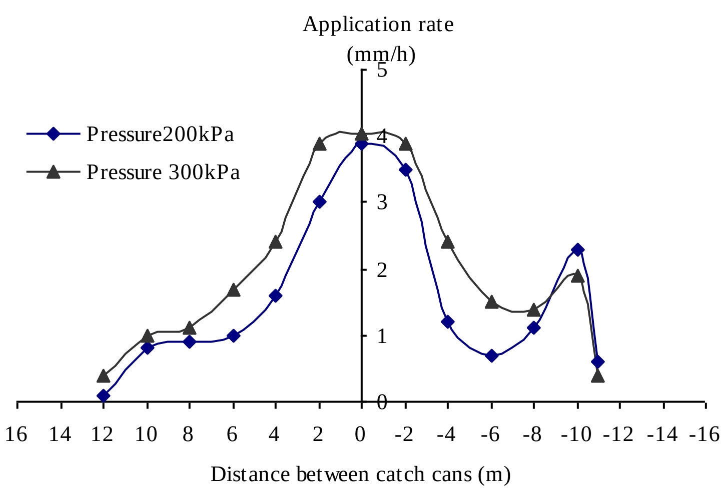


Fig.8: Individual distribution pattern,nozzle#3H,East& West

<u>(c) Nozzle #3 trajectory angle 11º</u>

Figure 9 showed the water application rate in wetted cercal for sprinkler as follows: (1)Pressure 200kPa gave 5.2 mm/h at the center and 1.7

mm/h at north and 1.76 mm/h at south.(2)For 300 kPa, it was 5.6 mm/h at the center and 0.05 mm/h at north and 0.29 mm/h at south.

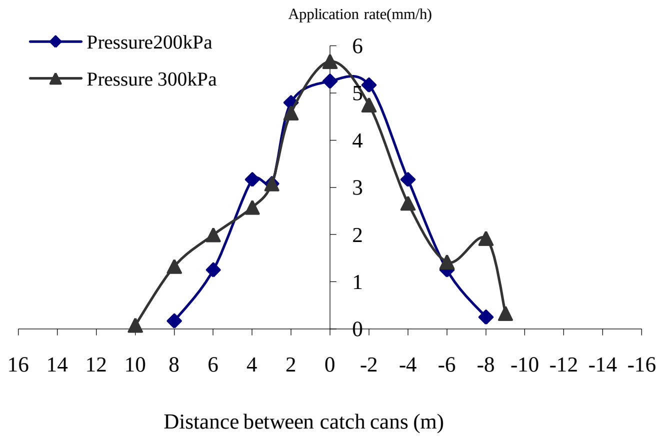


Fig.9: Individual distribuyion pattern,nozzle3L,North &South

Figure 10 showed the water application rate in wetted cercal for sprinkler as follows: (1)Pressure 200kPa gave 5.2 mm/h at the center and 0.74 mm/h at east and 0.08 mm/h at west. (2)For 300 kPa, it was 5.6 mm/h at the center and 0.17 mm/h at east and 0.02 mm/h at west.

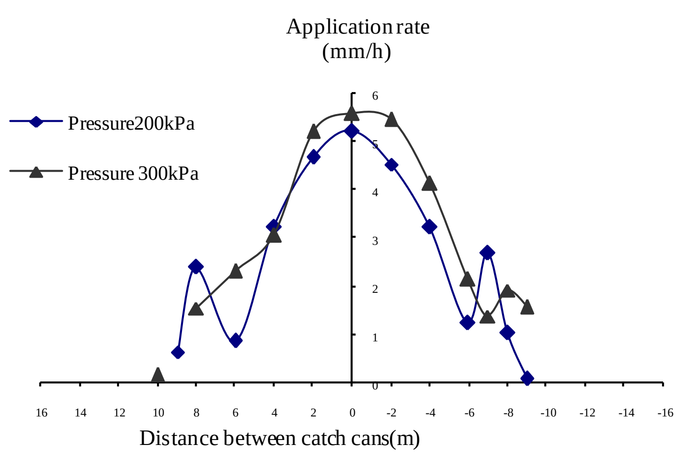


Fig.10: Individual distribution pattern ,nozzle # 3L,East & West

For each nozzle, sprinkler discharge (q in m^3/h) was measured within the pressure range of 200 and 300kPa and represented as pressure head (h in m) and both formulated in a power relationship as :

$$\mathbf{q = 0.128\sqrt{h}}$$

Discharge in m^3/h and diameter of throw in meters were measured at 200 and 300kPa operating pressure. Coefficient of discharge was found 0.952. Sprinkler discharge was increased by increasing pressure. The mean of the application rate (AR in mm/h) was recorded for individual sprinkler and increased by increasing water pressure due to increasing discharge and decreased by increasing sprinkler pattern diameter. The discharge was unchanged by trajectory angle (changed 25º and 11º) . But mean of application rate was increased by decreasing trajectory angle due to decreasing of sprinkler pattern diameter.

Sprinkler application rate as found by sprinkler radial test as related to distance from individual sprinkler for each nozzle was presented in all figures. For sets of range 11º and 25º, the curves produced under medium pressure of 200kPa showed that, water from nozzle settled around sprinkler and smoothly dropped from start to end of water trajectory. Curves under 200kPa were profiled as type C. For high pressure of 300kPa, water patterns showed semi-trapezoid shape and a mixed type in between curves C and D as presented in table (1) in nozzle #8 and #3. Under high pressure, the shape of the curves was typed as E profile. Selecting the optimal operating pressure based on the shape of the curve, 300kPa for most sets could be the required value.

3.3. Performance parameters for sprinkler with different layouts

Table 3 represents a group of sprinklers performance simulated in square layout under different pressures and trajectory angles 25º and 11º, for each nozzle spaced as 50% from throw diameter and 100% overlapping. Data in Table 3 were collected for all nozzles from sprinkler layout at different operating pressures headed in square corners based on 100% overlapped percentage (50% from diameter or head to head). Mean application rate (AR in mm/h) was determined based on collected depths as cumulated from water distribution pattern. Mean (AR) was increased by operating pressure and decreased by increasing layout area. Coefficient of variation (CV) was calculated in each set and achieved a low value of 6.14% at optimal operating pressure of 300kPa for 25º trajectory angle. (CV) values at 300kPa in nozzles ranging from 4.35 to 29.24% ere insignificant at 8% level. However, it was significantly different in some nozzles. The values of (CV) at 200kPa and 300kPa were highly significant at 8% level. The optimal operating pressure was recommended as 300kPa. Uniformity coefficient (CU) as a function of coefficient of variation achieved high value at 300kPa for sprinkler in nozzle ranging from #3 to #8.

For all nozzles of sprinkler and trajectory angle, ranging from 11º to 25º under 300kPa of optimal operating pressure, the effective diameter of throw was chosen to create different spacing between sprinklers and overlapped percentages as shown in Table 3 for square layout and Table 4 for rectangular layout and Table 5 for triangular layout. Area saved by four sprinklers and operated at less than 300kPa of operating pressure was related only to wetted diameter. Wetted diameter was constant for each test. The discharge of each sprinkler was not changed under300kPa, application rate (AR) was only decreased by increasing the served area and vice versa. Application rate (mm/h) could be used for purpose of schedule and management of sprinkler system with the tested head as described before in material and methods. For a nozzle in square layout Table 3, a high degree of uniformity was achieved for 11º trajectory angle in nozzle #3. But such close spacing raised both application rate runoff and system cost. For purpose of changing trajectory angle range 11º and 25º achieved acceptable uniformity as 96.57 and 96.53% in square layout for 80 and100 overlapped percentages. For purpose of increasing sprinklers spacing and trajectory angle, acceptance uniformity was achieved as more than 80% using spacing as 60% of wetted diameter (80% of overlapping). For hydraulic variation 10%, more than 80% of uniformity was accepted for general crops and greater than 90% for high value crops. System cost could be lowered by using sprinklers spacing as 70% from diameter of throw for general crops as in (50%of overlapping) . As most of water distribution patterns were profiled as C and D typed (Table 1), therefore, results of recommended spacing in this work were harmonized with those reported by **Keller and R.D.Bliesner(1990)**.

Table3: A group of sprinklers performance simulated in square layout under different pressures				
Pressure (kPa)	Parameters	Nozzle #8	Nozzle #3	
			Trajectory angle	
			25º	11º
200	Served area (m^2)	144.00	144.00	64.00
	Application rate,AR,(mm/h)	7.90	2.83	7.50
	Coefficient of variation,CV, (%)	26.00	23.10	22.00
	Coefficient of uniformity,CU, (%)	74.00	76.90	78.00
	Distribution uniformity, DU,(%)	58.62	63.24	64.99
300	Served area (m^2)	256.00	144.00	100.0
	Application rate,AR,(mm/h)	5.72	3.42	5.06
	Coefficient of variation,CV, (%)	23.33	14.25	8.39
	Coefficient of uniformity,CU, (%)	76.67	85.75	91.61
	Distribution uniformity, DU,(%)	62.87	77.32	86.65

Table 4 represents a group of sprinklers performance simulated in square layout at 300kPa of operating pressure under different overlapped percentages and trajectory angle 25º for all nozzles and trajectory angle 11º, for nozzle #8and #3.

Table 4: A group of sprinklers performance simulated in square layout at 300kPa of pressure under different overlapped percentages.				
Overlapping (%)	Parameters	Nozzle #8	Nozzle #3	
			Trajectory angle	
			25º	11º
100	Served area (m^2)	256.00	144.00	100.00
	Application rate,AR,(mm/h)	5.72	3.42	5.06
	Coefficient of variation,CV, (%)	23.33	14.25	8.39
	Coefficient of uniformity,CU, (%)	76.67	85.75	91.61
	Distribution uniformity, DU,(%)	62.87	77.32	86.65
80	Served area (m^2)	368.60	207.40	144.00
	Application rate,AR,(mm/h)	3.97	2.37	3.51
	Coefficient of variation,CV, (%)	19.86	10.00	11.82
	Coefficient of uniformity,CU, (%)	80.14	90.00	88.18
	Distribution uniformity, DU,(%)	68.39	84.09	81.19

Served area (m^2), application rate (mm/h), coefficient of variation (CV),uniformity coefficient (CU) and distribution uniformity (DU) were calculated and listed in Table 4.

Table 5 represents a group of sprinklers performance simulated in triangular layout at 300kPa of operating pressure under different overlapped percentages and trajectory angle 25° for all nozzles and trajectory angle 11°, for nozzle #8and #3. Served area (m^2), application rate (mm/h), coefficient of variation (CV),uniformity coefficient (CU) and distribution uniformity (DU) were calculated and listed in Table 5.

Table 5: A group of sprinklers performance simulated in triangular layout at 300kPa of pressure under different overlapped percentages.

Overlapping (%)	Parameters	Nozzle #8	Nozzle #3	
			Trajectory angle	
			25°	11°
100	Served area (m^2)	174.10	97.90	68.00
	Application rate,AR,(mm/h)	8.42	5.02	7.44
	Coefficient of variation,CV, (%)	18.03	9.75	8.11
	Coefficient of uniformity,CU, (%)	81.97	90.25	91.89
	Distribution uniformity, DU,(%)	71.31	84.48	87.09
80	Served area (m^2)	250.70	141.00	97.90
	Application rate,AR,(mm/h)	5.84	3.49	5.17
	Coefficient of variation,CV, (%)	24.48	15.43	8.00
	Coefficient of uniformity,CU, (%)	75.52	84.57	92.00
	Distribution uniformity, DU,(%)	61.04	75.44	87.27

For 100% overlapping, ≥ 90% of uniformity coefficient (CU) was achieved for trajectory angle ranged from11° to 25° for all nozzles and trajectory angle and ≥71% of (CU) for nozzles #8, #6 and #4 which achieved <71%. For 80% overlapping, all nozzles achieved more than

72% at trajectory angle 11º and 25º. For low angle and low overlapping percentages in triangular layout, a high uniformity degree was obtained compared to square layout. Results of recommended spacing in this work were harmonized with those reported by **Keller and R.D.Bliesner(1990)**.

Table 6 showed a group of sprinklers performance simulated in rectangular layout at 300kPa of operating pressure under different overlapped percentages and trajectory angle 25º for all nozzles and trajectory angle 11º, for nozzle #8and #3. Served area (m^2), application rate (mm/h), coefficient of variation (CV), uniformity coefficient (CU) and distribution uniformity (DU) were calculated and listed in Table 6.

Table 6: A group of sprinklers performance simulated in rectangular layout at 300kPa of pressure under different overlapped percentages.

Overlapping (%)	Parameters	Nozzle #8	Nozzle #3	
			Trajectory angle	
			25º	11º
100	Served area (m^2)	307.00	173.00	120.00
	Application rate,AR,(mm/h)	4.77	2.85	4.22
	Coefficient of variation,CV, (%)	34.07	23.60	27.16
	Coefficient of uniformity,CU, (%)	65.93	76.40	72.84
	Distribution uniformity, DU,(%)	45.78	62.44	56.78
80	Served area (m^2)	372.50	210.20	146.40
	Application rate,AR,(mm/h)	3.93	2.34	3.46
	Coefficient of variation,CV, (%)	42.56	32.26	34.12
	Coefficient of uniformity,CU, (%)	57.44	67.74	65.88
	Distribution uniformity, DU,(%)	32.27	48.66	45.70

In rectangular layout, the overlap of 100% achieved low coefficient of variation and high uniformity. For a given overlapped percentages, the higher degree of uniformity was achieved for 11º trajectory angle in nozzle #3. For 100% overlapping, ≥ 80% of uniformity coefficient (CU) was achieved for trajectory angle ranged from 11º to 25º, nozzle #3 at 11º trajectory angle and <78% of (CU) for nozzles #8. For 80% overlapping, all nozzles achieved more than 57% at trajectory angle 11º and 25º which was not recommended.

Friction factor which gives accurate prediction for friction head loss for a given pipe length with a constant input and output discharge sprinkler has been estimated for the design to reach the optimal inner diameter for main, sub main and lateral lines under optimal nozzle, trajectory angle, pressure, layout and overlapping. Area (6655m^2) (55m wide × 121m length) , 72 sprinklers were used and 12 lateral lines with (20 and 25mm) inner diameter and 4 sub main lines (50mm) inner diameter and single inlet main line (62mm) inner diameter. The water source position with 10m^3/h at half for main line and distance from the source to the last sprinkler (critical length) 115.5m. The area were blocked to four blokes, each had one valve and one sub main and three lateral lines and 15 sprinklers and all lines were made from (PVC). The system used nozzle #3 trajectory angle 25º, 0.5m^3/h discharge with wetted diameter 22m ,300kPa operating pressure, square layout and 100% overlapping percentage.

4. CONCLUSSION

Performance of sprinkler pattern radius and uniformity tests were carried out and evaluated at Shibin El-Kom, faculty of Agriculture, Menoufiya University, Egypt. K-rain Rps 75 pop up sprinklers were selected due to having 12 nozzles with different configurations where, trajectory angle of eight nozzles is 25º and four nozzles is 11º. Water distribution pattern was determined at 200 and 300kPa of operating pressure for nozzle #8 and nozzle #3 of sprinkler. Proper operating pressure was 300kPa for nozzles trajectory angle 25º. At operating pressure 300kPa, the application rate in (mm/h) distributed as bell shape in wetted cycle of the individual test for nozzle #8 and trajectory angle 25º of sprinkler with 32m diameter and considered as good distribution. The spacing between sprinklers was considered, to be based on the results, as 50% from wetted diameter. Coefficient of variation,(CV) was calculated in each test and its low value of 6.14% was occurred at optimal operating pressure of 300kPa for 25º trajectory angle. The values of (CV) at 200kPa were found highly significant at 8% level. Uniformity coefficient (CU) as a function of coefficient of variation achieved high value at 300kPa. Triangular layout test achieved higher distribution of uniformity more than both square and rectangular layouts. Square layout test achieved higher distribution of uniformity than rectangular layout for 100 and 80% overlapping. Friction factor which gives accurate prediction for head, friction head for a given pipe length with a constant input and output sprinkler discharge has been estimated for design to reach the optimal inner diameter for main, sub main and lateral lines under optimal nozzle, trajectory angle, operating pressure, layout and overlapping. Area of ($6655m^2$) (55m wide × 121m length),and 72 sprinklers were used.

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الملخص العربي

تصميم وتقييم نظام ري بالرش بنـاء على الانتظامية

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أجريت هذه التجربة بمزرعة كلية الزراعة جامعة المنوفية بمدينة شبين الكوم واستهدفت دراسة انتظامية توزيع مياه الري بأداء الرشاش بناء على :

ضغط التشغيل ، خواص الرشاش مثل قطر فتحة الرشاش وزاوية قذف المياه ، وكذلك وضع الرشاش داخل قطعة الري بالرش كالمسافة بين الرشاشات ، ونوع التخطيط واستخدام النتائج المتحصل عليها في تصميم وتقييم نظام للري بالرش ، واستخدم لذلك رشاش القفاز (K-rain Rps 75)يحتوى على ثلاثة فوهات يعطى كل منها تصرف مختلف ودائرة ابتلال مختلفة٠

وهذا النوع من الرشاشات يمتاز بإمكانية تغيير فوهة الرش فالثلاث فوهات المستخدمة اثنتان منهم تعملان بزاوية قذف 25^{o} وتعمل الفوهة الثالثة على زاوية قذف 11^{o} ٠

ولتحقيق الهدف من الدراسة تم إجراء تجربة لتحديد شكل ومدى قذف المياه من الرشاش على ارتفاع 11سم (الارتفاع الذي يصل إلية الرشاش أثناء فتح المياه) تحت ضغوط مختلفة هي 300 & 200 كيلوباسكال ٠ وتم قياس كمية المياه بأواني التجميع بالملي متر مكعب الموضوعة على مسافات واحد متر بطول خطين قطريين احدهما شمالي جنوبي والأخر شرقي غربي أسفل الرشاش وتم وضع أنائين ممتلئين بالمياه في نفش منطقة التجربة واخذ متوسط الفاقد منهما وخصم المتوسط من كمية المياه المتجمعة بأواني التجميع وتم التعبير عن كمية المياه المتجمعة بمعدلات رش (مم/ساعة) لضغوط تشغيل 200 &300 كيلوباسكال لرشاشات موضوعة على رؤوس مربع طول ضلعة يساوى 50% من قطر القذف (100%تداخل) لتحديد ضغط التشغيل الأمثل حيث كان 300 كيلوباسكال للرشاش عند استخدام كل فوهة & 200 كيلوباسكال للرشاش عند استخدام الفوهة # 3 ٠ وتم إعادة تجربة انتظامية التوزيع بضغط التشغيل الأمثل 300 كيلوباسكال لنسب تداخل هي 100% & 80% لثلاثة أنواع من التخطيط هي المربع والمثلث والمستطيل٠واستخدمت الفوهة 3# بقطر ابتلال 11متر وبتصرف 0.5 متر مكعب/ساعة للرشاش واستخدم التخطيط المربع وضغط تشغيل 300 كيلوباسكال ونسبة تداخل 100% في عمل تصميم لنظام ري بالرش لري قطعة أرض مساحتها $6655m^2$ بأبعاد $121m \times 55m$ باستاد جامعة المنوفية وتكون نظام الري من خط رئيسي بطول 100 متر وبقطر داخلي 62 مم

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ومصدر المياه يتوسط الخط وبتصرف كلى 9 متر مكعب/ساعة ويغذى أربعة خطوط ري تحت رئيسية بطول 22 متر وقطر داخلي 50 مم وكل خط ري تحت رئيسي يخرج منة ثلاثة خطوط ري فرعية بطول كلى 55 متر (33 متر بقطر داخلي 25مم وبتصرف متوسط 2 متر مكعب/ساعة & 22 متر بقطر داخلي 20مم وبتصرف متوسط 1 متر مكعب/ساعة) وعد ستة رشاشات قفاز لكل خط ري فرعى وتم حساب الطول الحرج وحساب قيمة معامل الاحتكاك داخل الأنابيب للوصول إلى أنسب قطر داخلي لكل من خط الري الرئيسي وخطوط الري التحت رئيسية وخطوط الري الفرعية ٠

وتوصلت الدراسة إلى النتائج الآتية:

-1- أعلى انتظامية توزيع تم الحصول عليها عند ضغط 300 كيلوباسكال للرشاش ذو الفوهة #8 وبزاوية قذف 25° وذلك لكل من التخطيط المربع والمستطيل٠

-2- التخطيط المربع حقق أعلى انتظامية توزيع مقارنة بالتخطيط المستطيل وذلك عند قيمتي نسبة التداخل المستخدمتان وهما 100% & 80% ٠

-3- فاقد الاحتكاك لطول معين من خط الري استخدم في تصميم أقطار خط الري الرئيسي والخط تحت الرئيسي والخط الفرعي عند زاوية القذف المثلي والضغط والتخطيط الأمثل والقيمة المثلي لنسبة التداخل ٠