academicJournals

Vol. 10(53), pp. 4950-4966, 31 December, 2015
DOI: 10.5897/AJAR2015.10422
Article Number: 10639E156601
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Hydraulic performance evaluation of mini sprinkler system

Dhaval Kirankumar Dwivedi*, Narendra Kumar Gontia and Jaypalsinh Mahobatsinh Chavda

Department of Soil And Water Engineering, CAET, Junagadh Agricultural University (JAU), Junagadh, India.

Received 22 September, 2013; Accepted 20 October, 2015

Irrigation system performance assessment is of high priority in irrigation research to solve the problem of irrigation development and management. It is obvious that many irrigation systems are performing below their capacity. This situation may lead to non-uniform and unreliable water distribution. The mini sprinkler systems recently introduced for irrigation needs to be evaluated for their performance. A mini sprinkler system was evaluated for its hydraulic performance. Experiment was conducted to evaluate the hydraulic performance using a mini sprinkler system having double nozzle-full circle sprinkler at various sprinkler spacings (8 m × 8 m, 10 m × 10 m and 12 m × 12 m) at three operating pressures (1.0, 1.5 and 2.0 kg/cm^2). The index of jet break up was obtained in all the three operating pressures in the range of 2.63 to 4.65, however ideal value of index of jet break up was obtained close to 4.0 at 1.5 kg/cm^2. Uniformity coefficient for all the system arrangements was in the range of 79.14 to 87.68%. The uniformity coefficients were obtained at par for 8 m × 8 m spacing at 2.0 kg/cm^2 and 10 m × 10 m spacing at 1.5 kg/cm^2. The spacing of 10 m × 10 m at operating pressure of 1.5 kg/cm^2 showed better hydraulic performance with economical feasibility.

Key words: Mini sprinker, uniformity coefficient, distribution uniformity, index of jet break up, hydraulic performance.

INTRODUCTION

Water is the most vital input in agriculture and has made a significant contribution in providing stability to food grain production and self-sufficiency. Agriculture is by far the biggest user of water, accounting for more than 70% of water utilization worldwide and 90% of water utilization in the developing countries. As compared to the surface water, greater proportion of additional irrigation water comes from the groundwater and this source is increasingly being exploited in an unscientific manner. The adaptation of efficient irrigation methods is important in view of increasing irrigation as well as water uses efficiency. High application efficiencies can only be obtained by pressurised irrigation. Besides this, these methods can be adopted for almost all crops under variable topographic conditions and on different type better choices than surface irrigation methods.

Sprinkler irrigation is the method of applying water above the soil surface in the form of spray or droplets, similar to natural rainfall. The spray is obtained by the flow of water under pressure though small orifices or nozzles. Water is conveyed from the pump and distributed through a network of pipes, called mainline,

*Corresponding author. E-mail: dhavaldwivedi42@gmail.com. Tel: +919904781244.

sub main, laterals and sprinklers. There are different sizes of sprinkler nozzles available in the market depending on the operating pressure and discharge rates. By proper selection of sprinkler spacing and overlapping percentage between the sprinklers, the required quantity of irrigation water for specific soil to refill the crop root zone can be applied at a rate equal to the infiltration rate of soil. Mini sprinkler irrigation is suitable for almost all crops. Water can be spread over row crops and under canopy of tree crops. But sprinklers with large water drops are not suitable for delicate flowering and fruiting plants because larger water drops developed by the sprinkler may damage the crop.

In mini sprinkler irrigation system, water is conveyed along the pipeline under pressure, a part of the pressure developed at the initial end is lost by the friction in the pipes. The sizes and types of laterals and main pipe selected should be such that the pressure loss due to friction for a given rate of flow remains within permissible limits. Mini sprinklers can be operated on a single sub-main, and 2 ha of shift can be operated at a time. 8 ha can be covered in 4 h. Only 50 m sub-main is required per hectare for mini sprinklers.

Irrigation performance assessment is of high priority in irrigation research priorities needed to solve the problem of irrigation development and management. No doubt, irrigation development has contributed immensely to national food security; to economic development and to poverty reduction, yet much more is expected from irrigated agriculture as a result of the increasing population. It is obvious that many irrigation systems are performing below their capacities. This situation may lead to non-uniform and unreliable water distribution. Therefore, a good starting point is to assess the performance of available irrigation systems in order to identify areas of lapses in the system design and make amends.

The hydraulic performance evaluation of a sprinkler system in the present study is evaluated by obtaining nozzle discharge (q), Christiansen's uniformity coefficient (C_U), distribution uniformity (DU), index of jet break up (P_d), application rate (R) and area of coverage (A). Christiansen's coefficient (C_U) of uniformity (Christiansen, 1942) was first used to introduce a uniformity coefficient to the sprinkler system (Karmeli, 1978). This uniformity coefficient is widely used by researches on the global scale and has been applied as a proven criterion to define water distribution uniformity. Distribution uniformity (DU) is a useful term for placing a numerical value on the uniformity of application for irrigation system. It is useful for calculating the average depth to be applied for certain minimum depth. Break-up of jet of water is necessary to obtain the uniformity of coverage and to minimize the droplet size. There is natural tendency of jets to break up because of air resistance. Generally, break up increases with pressure and by having slots in the nozzle. If value of index of jet break up (P_d) is 4, the condition of drop size is considered to be best and if it is greater than 4 then it indicates that pressure is being wasted. Mean application rate (MAR) is the depth of water applied by the sprinkler on the soil surface per unit time.

An ideal irrigation system should apply the correct amount of water, minimize the losses, and apply the water uniformly. A number of tests have been conducted to assess the performance of different sprinkler systems. Singh et al. (2001) conducted a test on performance evaluation of micro jet sprinkler and obtained the emission uniformity (emission uniformity is a relative index of the variability between emitters in an irrigation block). Emission uniformity is defined as the average discharge of 25% of the sampled emitters with the least discharge, divided by the average discharge of all sampled emitters of more than 90% at pressures ranging from 0.5 to 1.7 kg/cm^2 and at stake heights of 0 to 10 cm. Topak (2005) conducted a field test on performance evaluation of sprinkler system in semi arid area in Turkey. The results obtained by Topak indicated the average Christiansen's uniformity (C_U) for 10 m × 10 m spacing (sprinkler and lateral spacing, respectively) and 10 m × 15 m spacing was 86.7 and 80.6%, respectively and for the same spacing the average potential application efficiency (application efficiency is a performance criterion of how well an irrigation system performs when it is operated to deliver a specific amount of water. Application efficiency is defined as the ratio of the average water depth applied and the target water depth during an irrigation event) was 70.6 and 62.4%, respectively. Ahaneku (2010) evaluated the performance of sprinkler system by catch can tests and results indicated the average Christiansen's uniformity (C_U) and delivery performance ratio were 86 and 87% by using American Society of Agricultural and Biological Engineers (ASABE) standard procedures. Siosmarde and Byzedi (2012) found the mean values of Christiansen's uniformity (C_U) and distribution uniformity (DU) to be 62 and 49.4% for five solid set randomly selected sprinkler irrigation systems. The performance evaluation of sprinkler system performed by Frank (2009) yielded the Christiansen's uniformity (C_U) to be 91 and 87% and mean application rates (MAR) to be 10.4 and 4.7 mm/h at 12 m × 12 m and 18 m × 18 m spacing, respectively.

It is important to accurately compute the amount of pressure loss in sprinkle and trickle irrigation system design otherwise it can cause lack of appropriate performance or failure of sprinkle and trickle irrigation. Valipour (2012a) compared the ability of single and tapered pipes in adjusting of pressure loss and concluded that the best diameters for tapered manifolds with single lateral were 69.2 to 36.8 mm, 69.2 - 58.2 - 36.8 mm, and 58.2 - 46.0 - 36.8 mm whereas the best diameters for tapered manifold with tapered lateral were 69.2 - 46.0 - 36.8 mm. Valipour (2012b) used PivNoz software and optimized values of required flow, nozzle diameter and wetter area. It was concluded that optimal values of required flow were obtained by 56% changes in system gross capacity, optimal wetter area was obtained by 49% changes in nozzle length and optimal required flow was obtained by 43% changes in nozzle spacing. Valipour (2012c) examined the scrutiny of pressure loss, friction slope, inflow velocity and Reynolds Number in center picot irrigation. The results showed that pressure loss was more sensitive and amount of inside diameter was in centre pivot irrigation system.

Sprinklers can be a good investment when properly designed, installed, maintained and managed. The basic objective of hydraulic design of mini sprinklers is to obtain uniform distribution of water with desired rate of application, the break-up of jet with small drop size are essential to minimize the structural deterioration of the soil surface.

MATERIALS AND METHODS

A sprinkler set was setup with the following components.

Pump

The existing tube well of 200 mm diameter and submersible pump of 7.5 HP was used to supply water to mini sprinkler. The water was diverted from the existing delivery line of 63 mm diameter to the experimental setup.

Filter

A screen filter of 20 m^3/h capacity of 50 mm was provided to filter out the soil particles and impurities from the water.

Pressure measuring device

A dial pressure gauge of range 0to 7 kg/cm^2 was used to measure the pressure over mini sprinkler. The dial pressure gauge was installed on the main pipe to monitor the pressure in the main line in the unit of kg/cm^2. Sprinklers were operated at different operating pressures of 1.0, 1.5 and 2.5 kg/cm^2 and a by-pass valve was used to regulate the pressure. Pitot pressure gauges of the rage 0 to 7 kg/cm^2 were also used to measure the pressure near the sprinklers.

Main line, lateral line and end plug

Main line: 63 mm ϕ (diameter) Polyvinyl chloride (PVC) × pressure 2.5 kg/cm^2 × 40m length.
Laterals line: 32 mm ϕ (diameter) Linear Low-Density Polyethylene (LLDPE) × pressure 4 kg/cm^2 × 40m length.

Mini sprinkler assembly

In the present study, "double nozzle-full circle" mini sprinkler was used. It was mounted on an installation stake 1.2 m long, 8 mm ϕ (diameter). The mini sprinkler was connected to the lateral using a vinyl tube of 1.2 m and 12 mm ϕ (diameter). The mini sprinkler consisted of two nozzles.
1) Range nozzle (Yellow): 2.4mm ϕ (diameter).
2) Spray nozzle (Green): 1.8 mm ϕ (diameter).

Experimental setup

The experiment was performed using a flexible mini-sprinkler set. A setup with 9 mini-sprinklers was used in the experiment. The sprinklers were arranged in three different row spacing (12 m, 10 m and 8 m) and three sprinkler spacings (12 m, 10 m and 8 m). The middle sprinkler was considered as representative of actual field condition for taking the observations. A matrix of catch can was installed at ground level using 2 m × 2 m grid that cover the experimental area of the four central sprinklers. The system was operated at three different pressures for hydraulic evaluation. Figure 1 shows the layout of the experimental setup. The mini sprinklers are represented by letter 'S' in the figure.

Statistical design

Two factorial completely randomized design with four replication was adopted in the present investigation.

Treatments

The experiment comprises 9 treatment combinations and four replications.

First factor: Pressure (P) with three levels viz.

(1) 1.0 kg/cm^2
(2) 1.5 kg/cm^2
(3) 2.0 kg/cm^2

Second factor: Spacing (S) with three levels viz.

(1) 8 m × 8 m
(2) 10 m × 10 m
(3) 12 m × 12 m

Total treatment combination: 9
Number of replications: 4.

There are in total 9 combinations and each combination was repeated four times.

Hydraulic evaluation of mini sprinkler system

For the determination of index of jet break up (P_d), sprinkler discharge (q), Christiansen's uniformity coefficient (C_U), distribution uniformity (DU), water spread area (A) and mean application rate (MAR), the mini sprinklers were evaluated at three different pressures of 1, 1.5 and 2 kg/cm^2 and three different spacing arrangements of 8 m × 8 m, 10 m × 10 m and 12 m × 12 m. First, the pressure level was maintained at 1.0 kg/cm^2 and the spacing of 8 m × 8 m was arranged. At this combination of spacing and pressure, the measurements of discharge, water depth in the catch cans, pressure head at the nozzles and radius of throw were obtained and consequently the Christiansen's uniformity coefficient (C_U), distribution uniformity (DU), index of jet break up (P_d), wetter area (A) and mean application rate (MAR) were determined. The aforementioned procedure was repeated 4 times and average of the aforementioned parameters was obtained for the same spacing of 8 m × 8 m and pressure of 1.0 kg/cm^2. Then, the pressure level was maintained at 1.5 kg/cm^2 and the spacing was kept at 8 m × 8 m. The aforementioned procedure was repeated 4 times and

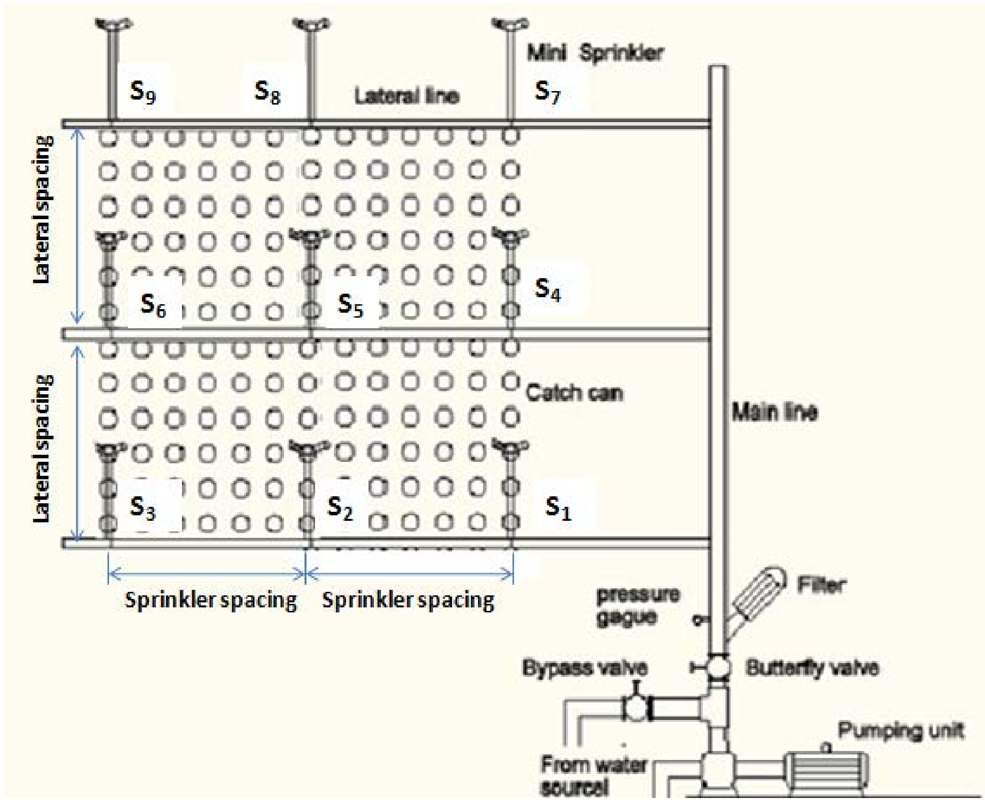

Figure 1. Layout of the experimental setup.

average of the required parameters was obtained. Subsequently, the pressure level was maintained at 2.0 kg/cm^2 and the spacing was kept at 8 m × 8 m. The same procedure was repeated 4 times and the average of required parameters was obtained.

Now, pressure level was maintained at 1.0 kg/cm^2 and the spacing was changed to 10 m × 10 m. As mentioned earlier, the procedure was repeated 4 times. Then the pressure was changed to 1.5 kg/cm^2 and then to 2.0 kg/cm^2 while keeping the spacing constant at 10 m × 10 m. Similarly at operating pressures of 1.0, 1.5 and 2.0 kg/cm^2, the spacing arrangement was kept at 12 m × 12 m and the procedure was repeated 4 times. Meteorological factors cannot be controlled, but the observations were taken at low wind condition (below 1 m/s) for the study. The mini sprinklers were operated for 30 min and the water emitted by the sprinklers was caught in catch cans. This water depth in catch cans was recorded, and then converted into depth of water in accordance with the cross-sectional area of the catch cans. There are in total 9 combinations and four replications for each combination were conducted.

In the present study, index of jet break up (P_d), sprinkler discharge (q), Christiansen's uniformity coefficient (C_U), Distribution uniformity (DU), water spread area (A) and mean application rate (MAR) for the mini sprinklers were determined.

Determination of index of Jet break-up (Pd)

Break-up of jet of water is necessary to obtain the uniformity of coverage and to minimize the droplet size. There is natural tendency of jets to break up because of air resistance. Generally, break up increases with pressure and presence of slots in the nozzle. Slow rotation sprinklers, which makes about 0.67 to 1 revolution per minute (rpm) for small sprinklers and 0.25 to 0.5 rpm for large sprinklers, provides good coverage. The following empirical formula suggested by Tanda (Pillsbury, 1968) is used to calculate an index of jet break up.

$$P_d = \frac{h}{10 \times q^{0.4}} \quad (1)$$

Where, P_d = index for jet break up. h = pressure head at sprinkler nozzle, m (meter). q = sprinkler discharge, lps (litres per second). If value of P_d is greater than 2, the condition of drop size is considered to be good. If the value of P_d is 4, the condition of drop size is considered to be the best and if it is greater than 4 then pressure is being wasted (Pillsbury, 1968).

Determination of sprinkler discharge (q)

Sprinkler discharge is assessed by collecting the water emitted by the sprinkler into a bucket in a time interval of 2 minute. The discharge was calculated by dividing the collected volume by the time of filling. The observations of discharge were recorded thrice for each operating pressure. The theoretical discharge of sprinkler nozzle may be computed from the orifice flow equation.

$$q = C_d \times a \times \sqrt{2gh} \quad (2)$$

Where, q = Nozzle discharge, m^3/s (cubic metre per second). a = Cross sectional area of sprinkler nozzle, m^2 (meter square). h = Pressure head at the nozzle, m (meter). C_d = Coefficient of discharge which is a function of friction and contraction losses. g = Acceleration due to gravity, m/s^2 (metre per second square).

Operating pressure and discharge (q) relationship of mini sprinkler system

The relationship between discharge and pressure can be established for double nozzle full circle mini sprinkler from the discharge equation by plotting the data of the discharge (q) and pressure and then relating it to the power series curve.

$$q = C_d \times a \times (2 \times g \times h)^N \quad (3)$$

Where, q = Nozzle discharge, m^3/s (cubic metre per second). a = Cross sectional area of sprinkler nozzle, m^2 (meter square). h = Pressure head at the nozzle, m (meter). C_d = Coefficient of discharge which is a function of friction and contraction losses. g = Acceleration due to gravity, m/s^2 (metre per second square). N = Slope of the power series curve

Determination of Christiansen's uniformity coefficient (C_U)

The average precipitation rate of three replications in each case was used to determine the uniformity coefficient by applying the Christiansen's formula (Christiansen, 1942).

$$C_U = \left[1 - \frac{\Sigma|X - \bar{X}|}{n \times \bar{X}}\right] \times 100 \quad (4)$$

Where C_U = Christiansen's uniformity coefficient (%). $\bar{X}$ is the mean water depth collected in the catch can. $\Sigma|X-\bar{X}|$ = cumulative of numerical deviation of individual observation from the mean water depth. n = total no. of catch cans.

Distribution uniformity (DU)

A useful term for placing a numerical value on the uniformity of application for irrigation system is the distribution uniformity (DU). The distribution uniformity is also known as pattern efficiency (Pe). It indicates the uniformity of water application throughout the field and is computed by:

$$DU = \frac{Minimum\ depth}{Average\ depth} \quad (5)$$

Where minimum depth is calculated by taking the average of the lowest 1/4th of the can used in a particular test. The DU is useful for calculating the average depth to be applied for certain minimum depth; for example if minimum depth of 4 cm is to be applied and the distribution efficiency is 80%, then average depth of 5 cm should be applied.

Determination of mean application rate (MAR)

Mean application rate is the depth of water applied by the sprinkler on the soil surface per unit time. The experiments were conducted with the catch cans to determine the volume of application during the time of operation of the sprinkler, at different places in the field. This volume is divided by the cross-sectional area of the catch can to determine the depth of application of the mini sprinkler. This depth was used to estimate the mean application rate of the mini sprinkler. It was estimated according to the following formula (Hansen, 1980).

$$MAR = \frac{\Sigma X}{n \times t} \quad (6)$$

Where MAR = mean application rate in mm/h (millimetre per hour). ΣX = total depth of water collected in the catch cans, mm (millimeter). n = total number of catch cans. t = time of operation h (hour).

Determination of effective radius and area (A)

Effective Radius of the mini sprinkler was calculated using the boundary sprinklers of the experimental setup. The mini sprinklers were operated at different pressures and the throw radius was measured using a measuring tape. By this way throw radius of all sprinklers were measured, and an average of this was calculated to give effective radius. The irrigation area covered by rotating head sprinkler was estimated by using the following formula suggested by Cavazza (Pillsbury, 1968).

$$A = \pi R^2 \quad (7)$$

$$in\ which\ R = 1.35\sqrt{dh}$$

Where A = Area covered by the sprinkler, m^2 (meter square). R = Radius of wetted area covered by the sprinkler, m (meter). d = Diameter of sprinkler nozzle, mm (millimetre). h = Pressure head at the nozzle, m (meter)

Cost of mini sprinkler system

The cost of the design system for one hectare of land with zero slope condition for various spacings was evaluated. The cost is estimated considering 10 years life of the system and 2 seasons in a year at an interest rate of 10% per annum. Fixed cost = subtotal of head unit + subtotal of field unit. The annual cost of instalment is determined by the following equation:

$$A_i = \frac{P_{i*} * (1+i)^n}{(1+i)^n - 1} \quad (8)$$

Where i = interest rate (%). n = expected life of system (years). P = present cost of the system (Rupees). A_i = annual instalment cost (Rupees). Annual cost = annual instalment + variable cost (10% of the annual instalment). Seasonal cost = Annual cost /2 (considering 2 season crops per year).

RESULTS AND DISCUSSION

Index of jet break up (P_d)

If the droplet size is not satisfactory it will also affect the uniformity and yield. It is because certain soils are subject to compaction under sprinkler application. This tends to seal the surface soil layer, reducing the infiltration rate and thus may affect the yield. For a given soil and application rate, the extent of the infiltration rate reduction

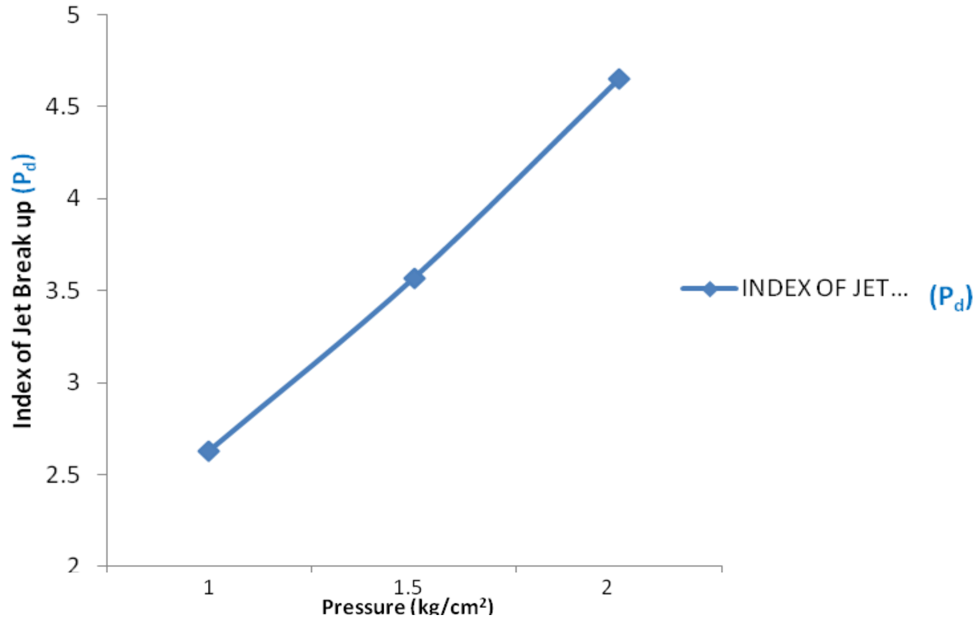

Figure 2. Index of Jet Break Up (P_d) at various operating pressures of mini sprinkler.

depends on the impact energy of the spray (Stillmunkes and James, 1980; King and James, 1984). A drop's impact energy is determined by its mass and impact velocity. Large drops strike the soil with greater kinetic energy than small drops. Also, the amount of water that evaporates from a drop depends on the surface area of the drop, and on how long the drop is in the air. Both of these factors are related to drop size. For small enough drops, it can be shown that even a slight wind can keep the drop suspended long enough that it will evaporate before it hits the ground (Inoue, 1963). Christiansen (1942) showed that wind distorts the application pattern of a sprinkler. This distortion may affect the uniformity of water application and irrigation efficiency. The extent of the wind effect depends on wind speed and direction, and on the sizes of drop in the spray.

In the present study as shown in Table 1 and Figure 2, when the pressure was maintained at 1.0 kg/cm^2, the value of index of jet break up was found to be 2.63. This value of index of jet break up near to 2.0 indicates that the droplet size is not good at the pressure of 1.0 kg/cm^2. The pressure was then raised to 1.5 kg/cm^2 and maintained at that level to obtain further observations. The value of index of jet break up when the pressure was maintained at 1.5 kg/cm^2 was found to be 3.57 which is very well in between 2.00 and 4.00 values and so it is an indication of good droplet size. The droplet size is considered best if the value of index of jet break up is 4. Therefore, in order to obtain best droplet size the pressure was further increased to 2.0 kg/cm^2 and maintained at that level. However, it was found that the value of index of jet break up (4.65) at 2.0 kg/cm^2 pressure was found to be exceeding the value of 4 which clearly indicated that the pressure was being wasted. Graphically, by interpolation the optimum value was found to be 1.7 kg/cm^2 at which the best droplet size can be obtained, as the value of index of jet break up will be nearer to 4.

Discharge (q) from mini sprinkler

From Figure 3, it can be seen that the mini sprinkler's discharge increases as the operating pressure increases. The discharge equation under study that is, $q = C_d*A*(2*g*h)^N$ is equated with the power series equation obtained in Figure 3 and the value of N was obtained. The sum of area of nozzle orifices was obtained as 7.07 mm^2 measuring the diameters of twin nozzles as 2.4 and 1.8 mm, respectively. The value N was determined as 0.274 as presented in Table 2. As shown in Figure 3, the minimum and maximum discharges of 332 and 445 lph were obtained at pressures 1.0 and 2.0 kg/cm^2, respectively. The relationship between pressure and discharge is shown in Table 3 with R^2 value of 0.9716. The coefficient of discharge is a function of friction losses and contraction losses. The value of the coefficient of discharge (C_d) can be obtained by evaluating C_d in the equation of discharge from a sprinkler nozzle if the discharge is already known. The value of N is obtained from the power series curve and thus we get an equation showing relationship between discharge and pressure as shown in the Table 3. As the pressure increases from 1.0 to 1.5 kg/cm^2, there is a significant rise in the discharge.

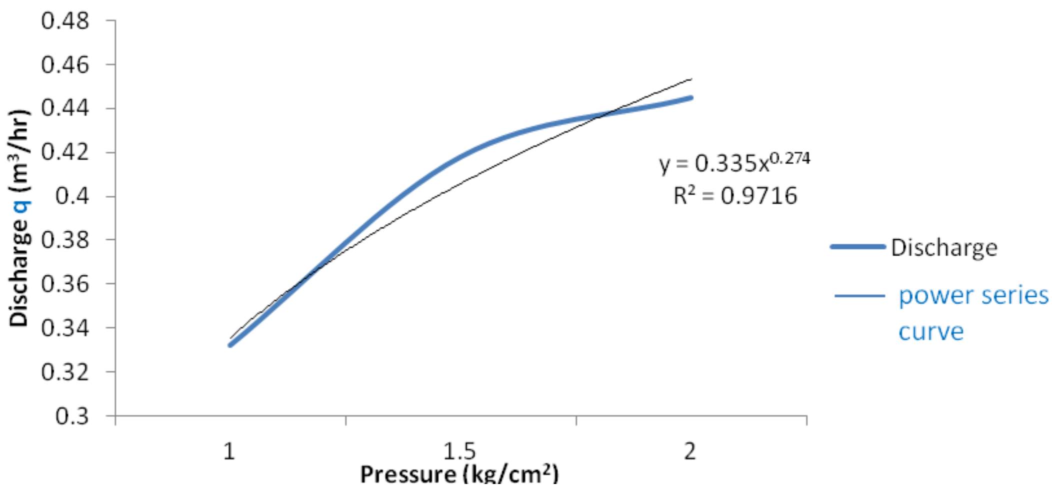

Figure 3. Discharge (q) of mini sprinkler at various operating pressures.

Table 1. Index of Jet break up at various operating pressures.

S/N	Operating pressure (kg/cm^2)	Average discharge (q) (lps)	Index of jet break up (P_d)
1	1.0	0.092	2.63
2	1.5	0.116	3.57
3	2.0	0.123	4.65

Table 2. Discharge rates at various operating pressures for mini sprinkler.

S/N	Operating pressure (kg/cm^2)	Average discharge (m^3/h)
1	1.0	0.332
2	1.5	0.418
3	2.0	0.445

Table 3. Operating pressure and discharge relationship of mini sprinkler system.

Type of sprinkler	Coefficient of discharge C_d	Slope of power series curve N	Relationship
Double nozzle-full circle mini sprinkler	0.94	0.274	$q = 0.94 * A * (2 * g * h)^{0.274}$

where, q = mini sprinkler discharge (lph), A = 7.07 (mm^2), h = operating pressure (m) (pressure head).

However, it can be noted from the figure that the rate of increase in discharge is reduced as the pressure increased from 1.5 to 2.0 kg/cm^2.

Christiansen's uniformity coefficient (C_U)

The results obtained are presented in Figure 4, showing uniformity coefficient at various operating pressures. As shown in Table 4 and Figure 4, the highest value of uniformity coefficient was obtained when the spacing of mini sprinklers was kept at 8 m × 8 m and the pressure was 2.0 kg/cm^2. The lowest value of uniformity coefficient was obtained at the spacing of 12 m × 12 m and the pressure was 1.0 kg/cm^2.

Statistically significant difference was found between the treatments. The results are also presented for uniformity coefficient at various spacings in Figure 5. The 8 m × 8 m spacing at operating pressure of 2.0 kg/cm^2 is giving highest uniformity coefficient, but in that case

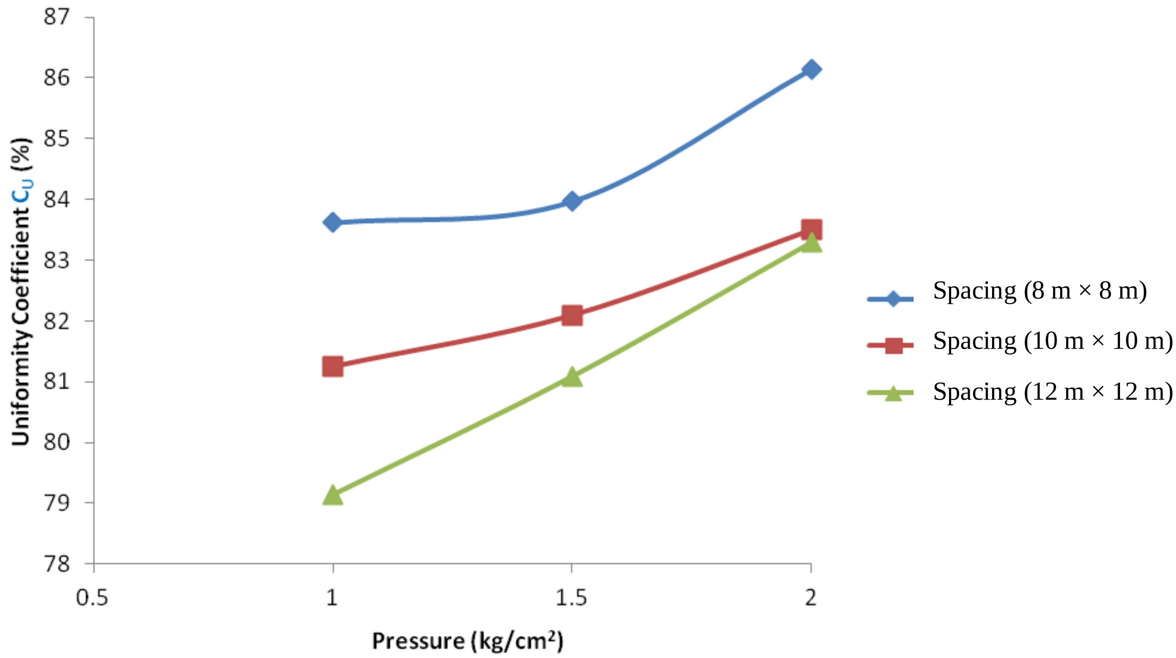

Figure 4. Uniformity Coefficient (C_U) at various operating pressures.

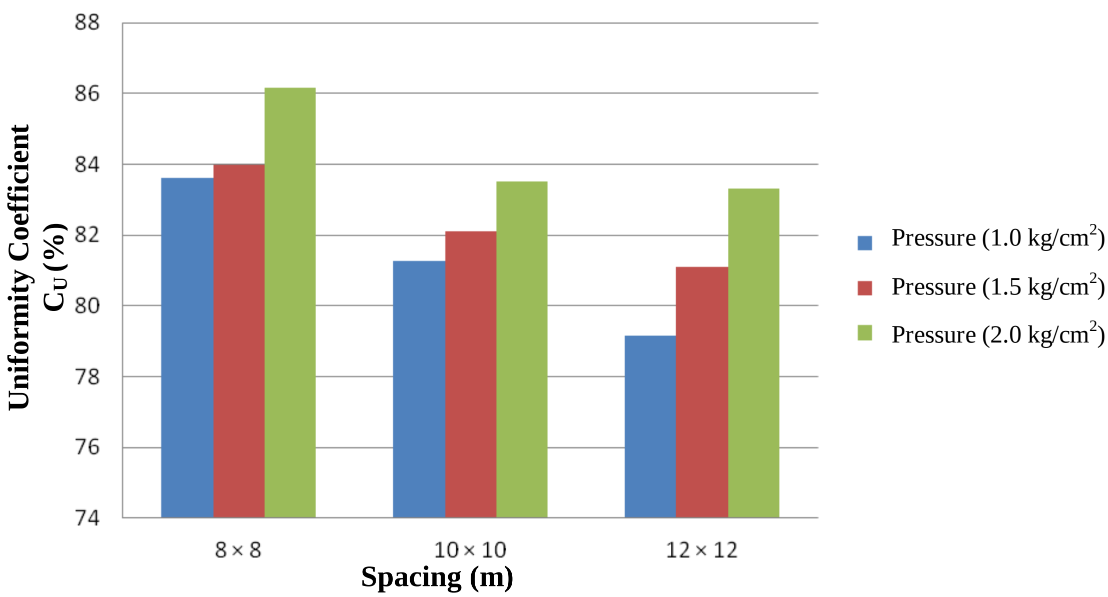

Figure 5. Uniformity Coefficient (C_U) at various spacings (%).

higher number of mini sprinklers will be required if the sprinkler arrangement is to be set up in an area of one hectare or more which will not be beneficial from economic point of view as shown in Table 8. The uniformity coefficient of more than 80% was obtained at the spacing of 10 m × 10m and it would be less costly to install it than in 8 m × 8 m spacing.

Distribution uniformity (DU)

As shown in Table 5 and Figure 6, the highest value of distribution uniformity was obtained when the spacing mini sprinkler was kept at 8 m × 8 m and the pressure was 2.0 kg/cm^2. The lowest value of distribution uniformity coefficient was obtained at the spacing of 12 m

Table 4. Christiansen's Uniformity Coefficient (C_U) at various pressures and spacing of mini sprinklers.

Pressure (kg/cm^2)	Spacing (m)	Uniformity coefficient (%)
1.0	12 × 12	79.14
	10 × 10	82.35
	8 × 8	83.62
1.5	12 × 12	81.74
	10 × 10	82.49
	8 × 8	84.16
2.0	12 × 12	82.68
	10 × 10	86.23
	8 × 8	87.68

Table 5. Distribution Uniformity (DU) at various operating pressures and various sprinkler spacings.

Pressure (kg/cm^2)	Spacing (m)	Distribution uniformity (%)
1.0	12 × 12	66.60
	10 × 10	73.26
	8 × 8	78.84
1.5	12 × 12	69.95
	10 × 10	79.69
	8 × 8	81.66
2.0	12 × 12	78.79
	10 × 10	82.61
	8 × 8	83.98

Table 6. Mean application rate (MAR) of mini sprinkler at various operating pressures and spacings.

S/N	Pressure (kg/cm^2)	Spacing (m)	Application rate (mm/h)
1	1.0	12 × 12	2.31
2		10 × 10	3.32
3		8 × 8	5.18
4	1.5	12 × 12	2.90
5		10 × 10	4.18
6		8 × 8	6.53
7	2.0	12 × 12	3.09
8		10 × 10	4.45
9		8 × 8	6.95

× 12 m and the pressure was 1.0 kg/cm^2. Statistically significant difference wasfound between the treatments. Figure 7 clearly indicates that as the spacing between the mini sprinklers increased there was reduction in the value of distribution uniformity coefficient and vice versa.

Mean application rate of mini sprinkler (MAR)

As shown in Table 6, Figures 8 and 9, the maximum application rate is obtained at the spacing of 8 m × 8 m and operating pressure of 2.0 kg/cm^2 and least application

Table 7. Radius (R) and Area of Coverage (A) of mini sprinkler at various operating pressures.

S/N	Pressure (kg/cm^2)	Radius of coverage [R (m)]	Area of coverage [A (m^2)]
1	1.0	5.93	110.69
2	1.5	7.12	159.25
3	2.0	8.08	205.45

Table 8. Summary of fixed and annual cost of mini sprinkler systems per hectare.

Sprinkler spacing (m)	Fixed cost	Annual cost
8 × 8	110760.20	20729.56
10 × 10	90399.73	16918.96
12 × 12	73004.32	13663.27

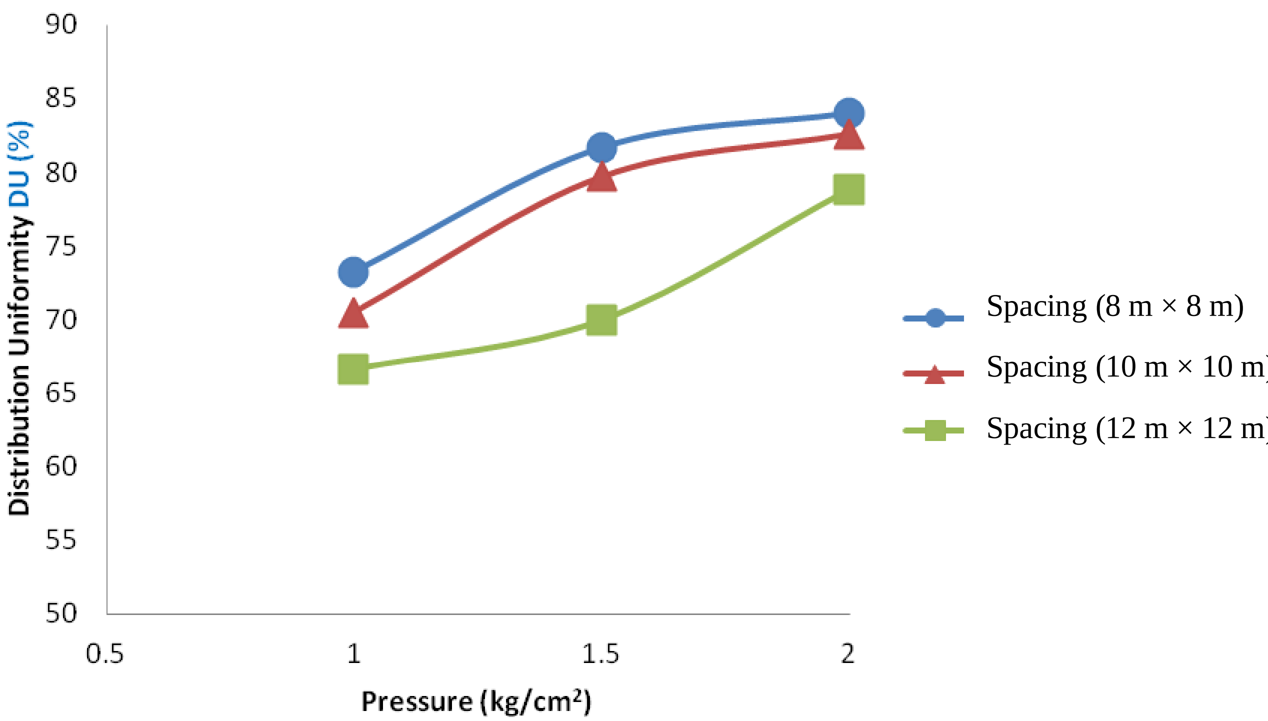

Figure 6. Distribution uniformity (DU) at various operating pressures.

rate is obtained at 12 m × 12 m spacing and operating pressure of 1.0 kg/cm^2. Therefore, it is not advisable to operate the mini sprinkler at such low pressure as the application rate obtained is very low. As the spacing between the mini sprinklers is increased, the application rate decreases and vice versa. To obtain better application rates at higher spacings, the operating pressure will have to be increased. There is a considerable difference in application rate if the pressure is lowered. If low operating pressure is available it is advisable to keep the spacing as low as possible in order to obtain higher application rates. For example, the application rate at spacing of 8 m × 8 m even at low operating pressure of 1 kg/cm^2 is 5.18 mm/h. The application rate of 4.45 mm/h was obtained even at 10 m× 10 m spacing when the operating pressure was maintained at 2.0 kg/cm^2. The application rates were much lower at the spacing of 12 m × 12 m. This spacing can be used in the field for certain kind of soils that are suitable for low application rates. There was an increase in the application rate when the spacing was reduced to 10 m × 10 m. Highest mean application rates were

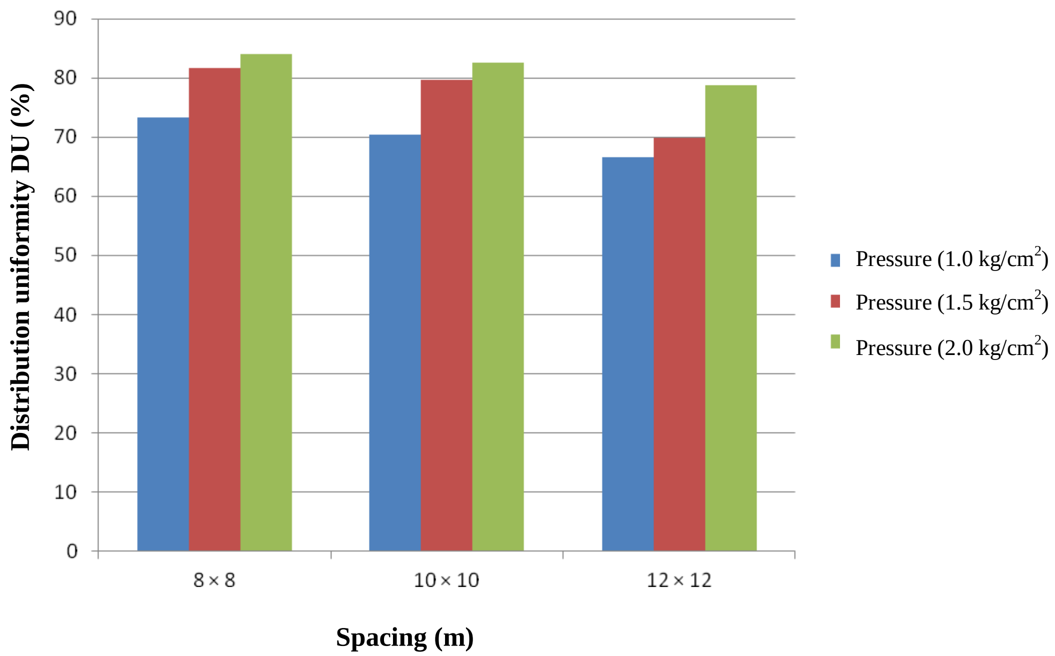

Figure 7. Distribution uniformity (DU) at various spacings.

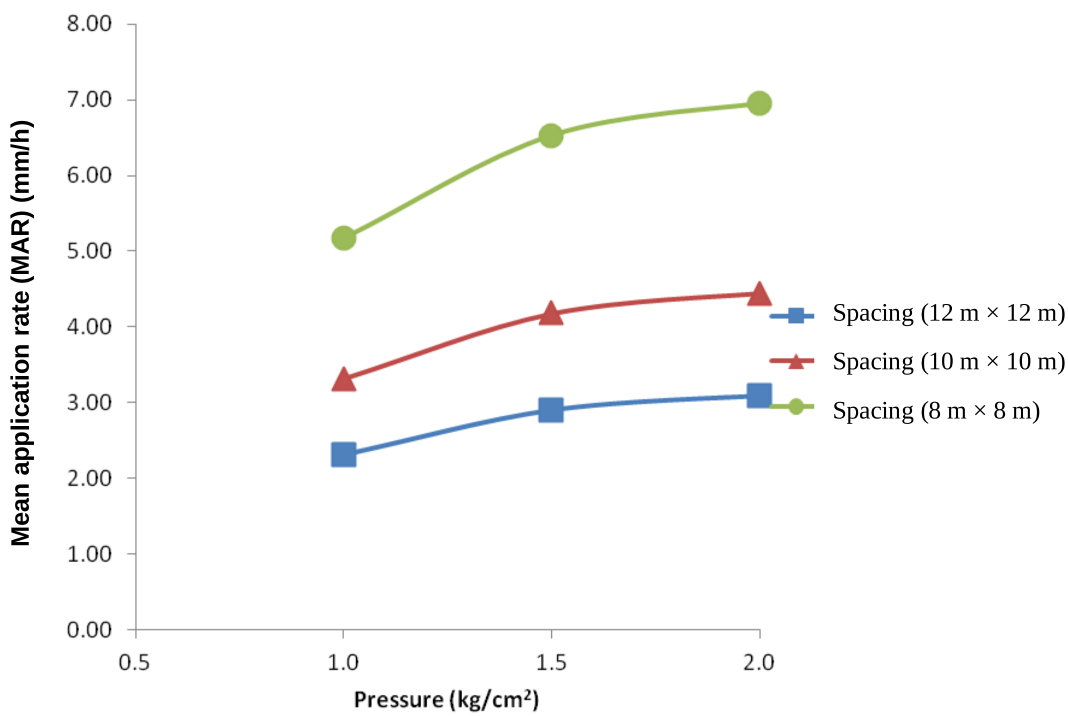

Figure 8. Mean application rate (MAR) at various operating pressures.

obtained at the spacing of 8 m × 8 m. However, this spacing arrangement is costly if it is to be installed in a large field as the number of mini sprinklers required will be more. The spacing of 8 m × 8 m can be used on the soil that can tolerate the application rate.

Radius (R) and area of coverage (A)

As shown in Table 7 and Figure 10, the least radius of coverage was obtained when the mini sprinkler was operated at the pressure of 1.0 kg/cm^2 and maximum

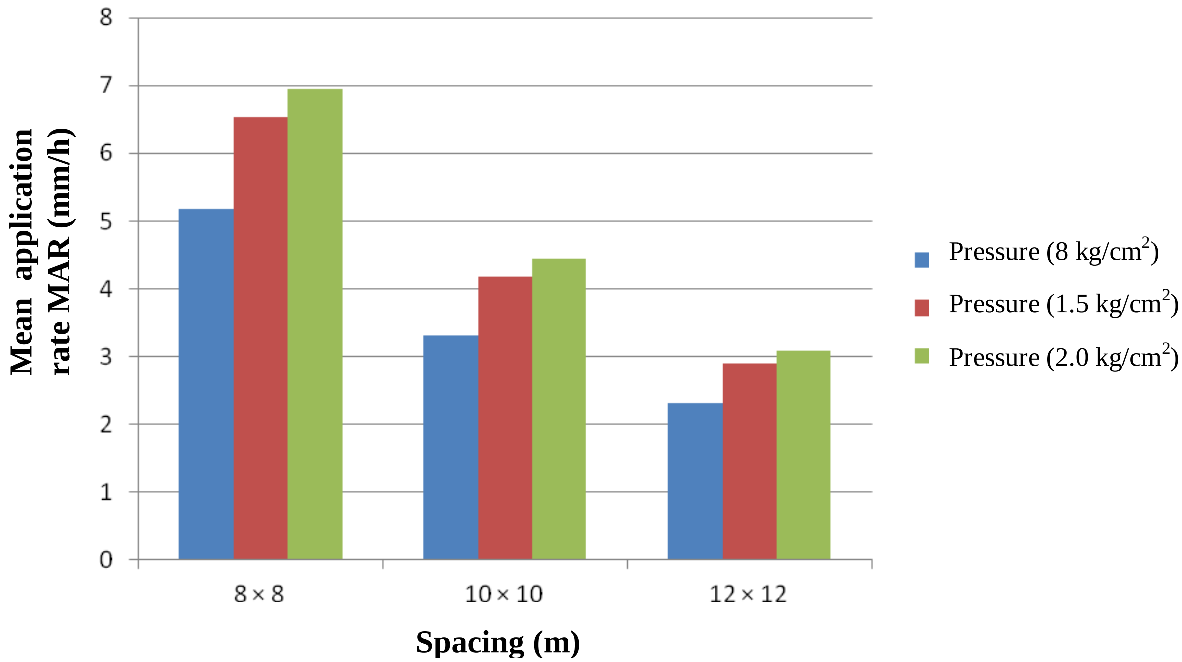

Figure 9. Mean application rate (MAR) at various sprinkler spacings.

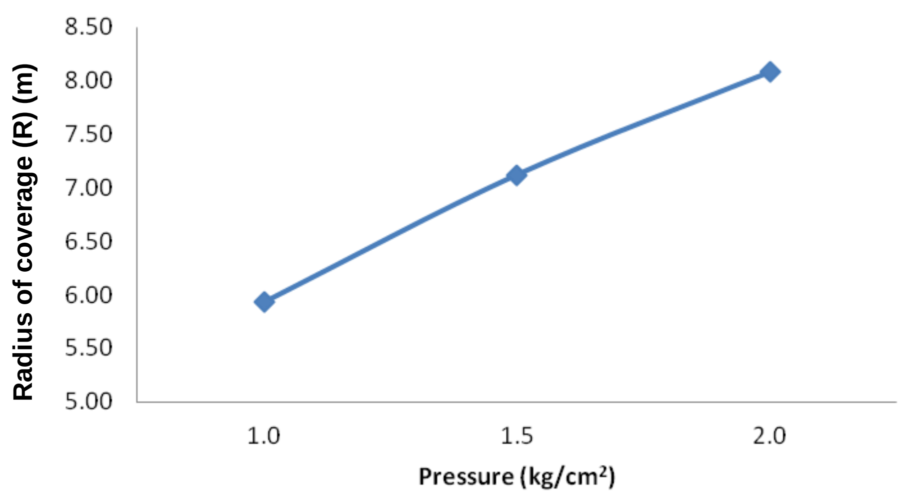

Figure 10. Radius of coverage (R) of mini sprinkler at various operating pressures

radius of coverage is obtained when the mini sprinkler is operated at the pressure of 2.0 kg/cm^2.

The difference between the maximum and minimum radius of coverage is 2.15 m. At the pressure of 1.5 kg/cm^2, the radius of coverage obtained is 7.12 m which is just 0.96 m less than the value obtained at maximum operating pressure of 2.0 kg/cm^2. Similarly as shown in the figure, the least area of coverage was obtained when the mini sprinkler is operated at the pressure of 1.0 kg/cm^2 and maximum area of coverage is obtained when the mini sprinkler is operated at the pressure of 2.0 kg/cm^2. The difference between the maximum and minimum area of coverage is 94.76 m^2. At the pressure of 1.5 kg/cm^2, the area of coverage obtained is 159.25 m^2.The statistical analyses indicated that significant difference was found between the treatments at 5% level.

The systems were designed for one hectare land of zero slopes considering 10 years life of the system and two seasons in a year at interest rate of 10% per annum. The costs of all these systems are shown in the Table 8.

There is a reduction in fixed as well as annual cost when the sprinkler spacing is increased from 8 m × 8 m to 12 m × 12 m. The details of the cost analysis are given in supplementary Tables A, B and C.

Conclusions

Based on the study, the following conclusions may be drawn from the present investigation:

1) The index of jet break up (P_d) varied from 2.63 to 4.65 as the operating pressure increased from 1 to 2 kg/cm^2, respectively. The optimal index of jet break up (P_d) was obtained as 3.57 at 1.5 kg/cm^2.
2) The discharge rates (q) was obtained as 332, 412 and 445 lph at operating pressures of 1, 1.5 and 2 kg/cm^2, respectively.
2) Effective radius of throw (R) of the mini sprinklers was obtained as 5.93, 7.12 and 8.08 m at operating pressures of 1, 1.5 and 2 kg/cm^2, respectively.
4) Water spread area (A) was obtained as 110.69, 159.25 and 205.45 m^2 at operating pressures of 1, 1.5 and 2 kg/cm^2, respectively.
5) Mean application rate (MAR) was in the range of 6.95 to 2.31 mm/h.
7) Distribution uniformity (DU) was found in the range of 66.7 to 78.8%. The sprinkler arrangements 12 m × 12 m at operating pressure of 1 and 1.5 kg/cm^2 and 10 m × 10 m at 1 kg/cm^2 have distribution uniformity less than 70% and were considered inefficient.
8) Christiansen's uniformity coefficient (C_U) for all the systems was in the range of 79.14 to 87.68%. Uniformity coefficient (C_U) was higher than 80% in all the cases except for 12 m × 12 m arrangement operating at a pressure of 1 kg/cm^2.
9) Cost analysis showed that the annual costs were obtained as 13663.27, 16918.96 and 20729.56 rupees and the fixed costs were obtained as 110760.20, 90399.73 and 73004.32 rupees for spacings of 8 m × 8 m, 10 m × 10 m and 12 m × 12 m, respectively.

From the economic point of view the spacing of 12 m × 12 m can be considered as good as it also gives a uniformity of more than 80%. However, if this arrangement is operated at a lower operating pressure then the application rate would be lower and a higher operating pressure will be required to increase the application rate.
Although better application rates and uniformity are obtained at 8 m × 8 m spacing, its cost is much higher. Also, a higher application rate may not be suitable for certain soils that have a lower infiltration rate. The type of crops grown should also be taken into consideration as only certain range of application rates would be suitable for them and based on that the spacing of the sprinkler system should be arranged. The spacing of 12 m × 12 m gives slightly less uniformity coefficient compared to 8 m × 8 m spacing but from economic point of view it is advisable to install 12 m × 12 m on large fields. The sprinkler spacing should be selected on the basis of the type of soil, water requirement of crop and leaching fraction. If low pressure is available such sprinkler spacing should be selected that gives better uniformity and application rate at that pressure. If high pressure from the water source is available then it is economically feasible to have a wider spacing as that would also give better uniformity at high pressure. From the hydraulic evaluation of the mini sprinkler system the best acknowledged system was 10 m × 10 m at an operating pressure of 2 kg/cm^2. On the basis of performance the systems the 8 m × 8 m working at an operating pressure of 1.5 and 2 kg/cm^2 may also be preferred. The spacing of 10 m × 10 m at operating pressure of 1.5 kg/cm^2 showed better hydraulic performance with economical feasibility.

Conflict of Interests

The authors have not declared any conflict of interests.

REFERENCES

Ahaneku E (2010). Performance evaluation of portable sprinkler irrigation system in Ilorin. Nigeria. Indian J. Sci. Technol. 3:11-14.

Christiansen JE (1942). Irrigation by Sprinkling. University of california, College of Agriculture, Agricultural Experiment Station, Berkeley, California. Bulletin 670, October, 1942.

Inoue H (1963). Experimental Studies on Losses Due to Wind Drift in Sprinkler Irrigation. Technical Bulletin of the Faculty of Agriculture, Kagawa University, Japan 15(1):50-71.

Frank KBO (2009). Evaluation of sprinkler irrigation system for improved maize seed production for farmers in Ghana. A Thesis submitted to the Department of Agricultural Engineering, Kwame, Nkrumah University of Science and Technology, Kumasi, Ghana.

King B, James L (1984). Determining Specific Power and Impact Energy of Sprinkler Droplets. ASAE Paper No. 84-2081, ASAE, St. Joseph, Michigan.

Pillsbury AF (1968). Sprinkler irrigation. Food and Agriculture Organization of the United Nations, Rome. P 179.

Singh R, Kale M, Chandra A (2001). Performance evaluation of micro jets in micro irrigation design. Central Board of Irrigation and Power, New Delhi, India.

Stillmunkes RT, James LG (1980). Impact Energy of Water Droplets Beneath Sprinkler Irrigation Systems. Transactions of the ASAE 25(1):0130-0133.

Siosmarde M, Byzedi M (2012). Studding of Sprinkler Irrigation Uniformity. World Acad. Sci. Eng. Technol. 61(2012).

Topak R, Suheri S, Ciftci N, Acar B (2005). Performance evaluation of sprinkler irrigation in semi-arid area. Pakistan J. Biol. Sci. 8(1):97-103.

Valipour M (2012a). Sprinkle and Trickle Irrigation System Design Using Tapered Pipes for Pressure Loss Adjusting. J. Agric. Sci. 4(2).

Valipour M (2012c). Scrutiny of Pressure Loss, Friction Slope, Inflow Velocity, Velocity Head, and Reynolds Number in Center Pivot. Int. J. Adv. Sci. Technol. Res. 2(5):703-711.

Valipour M (2012b). Determining possible optimal values of required flow, nozzle diameter, and wetted area for linear traveling laterals. Int. J. Eng. Sci. 1(1):37-43.

Supplementary

The sprinkler systems were designed for one hectare land of zero slopes considering 10 years life of the system and two seasons in a year at interest rate of 10% per annum. The cost of all these systems were determined and presented in the Table A, B and C.

Table A. Cost analysis of mini sprinkler with spacing 8mx8m installed in 1 hectare.

S/N	Description of product	Size	Unit	Qty.	Rate	Amount
a	**Head unit**					
1	Header assembiy-1 filter	76.2 mm × 25.4 mm	No	1	3047.03	3047.03
2	Hydro-cyclone filter-2"	20 m^3	No	1	3265.88	3265.88
3	Screen filter-2"-plastic	20 m^3	No	1	2123.43	2123.43
4	Fertilizer tank with assembly	30 ltr.	No	1	2582.3	2582.3
5	Butterfly valve	76.2 mm	No	2	1183.42	2366.84
6	Air release valve	25.4 mm	No	1	384.55	384.55
7	By pass assembly	76.2 mm × 38.2 mm	No	1	805.65	805.65
8	Pressure gauge	50.8 mm	No	2	172.01	344.02
9	Gi fittings l. S.	L. S.	Hact.	1	665.82	665.82
			Sub total			15585.52
			Hact.	1	-	15585.52
			Vat @ 5 % on head unit cost			779.28
			Total of head unit cost a			16364.8
b	**Field unit including secondary transportation**					
1	Pvc pipe/4 kg/cm^2	75 mm	Mtr	175	53.8	9415
2	Pvc pipe/4 kg/cm^2	63 mm	Mtr	200	37.28	7456
3	Pp ball valve	63mm	No	4	566.48	2265.92
4	End plug quick action	63 mm	No	4	63.19	252.76
5	Double nozzle	0	No	157	223.23	35047.11
6	M/f adaptor	12.8 mm	No	157	14.71	2309.47
7	Extension tube - pvc	13 mm × 1.2 mtr	No	157	17.19	2698.83
8	Male connector	9 / 12 mm	No	157	9.8	1538.6
9	Female connector	9 / 12 mm	No	157	9.8	1538.6
10	Installation stake	8 mm × 1.2 mtr	No	157	23.66	3714.62
11	Plain lateral	25 mm	Mtr	1250	14.98	18725
13	Coupler/joiner	25 mm	No	50	42.9	2145
14	End plug	25 mm	No	50	32.9	1645
15	Pvc/hdpe fittings l.s.	LS	Hact.	1	713.01	713.01
c	**Field unit cost without secondary transportation**					89464.92
16	Secondary transportation	0	Hact	1	435.45	435.45
			Sub total			89900.37
			Vat @ 5 % on b cost			4495.02
			total field unit cost b			94395.39
			Sub total (a+b)			110760.2

Considering 10 years life of the system and 2 seasons in a year at interest rate of 10% per annum.

Fixed cost = sub- total of head units + sub- total of field unit
= 16364.8 + 94395.39
= Rs.110760.2

$$\text{Annual installment } (A_i) = \frac{P_{i*} * (1+i)^n}{(1+i)^n - 1}$$

$=110760.2[0.1(1+0.1)^{10}] / [(1+0.1)^{10}-1]$
= Rs.18025.71

Annual cost = annual installment + variable cost (operating cost 10% of the annual installment + repair and maintenance cost 5% of the annual installment).
=18025.71+ 1802.57 + 901.28
= Rs.20729.56 per ha.

Seasonal cost = annual cost/2
= Rs.10364.78

Table B. Cost analysis of mini sprinkler with spacing 10 m × 10 m installed in 1 ha.

S/N	Description of product	Size	Unit	Qty.	Rate	Amount
a	**Head unit**					
1	Header assembiy-1 filter	76.2 mm × 25.4 mm	No	1	3047.03	3047.03
2	Hydro-cyclone filter-2"	20 m^3	No	1	3265.88	3265.88
3	Screen filter-2"-plastic	20m^3	No	1	2123.43	2123.43
4	Fertilizer tank with assembly	30 ltr	No	1	2582.3	2582.3
5	Butterfly valve	76.2 mm	No	2	1183.42	2366.84
6	Air release valve	25.4 mm	No	1	384.55	384.55
7	By pass assembly	76.2 mm × 38.1 mm	No	1	805.65	805.65
8	Pressure gauge	50.8 mm	No	2	172.01	344.02
9	Gi fittings l.S	LS	Hact.	1	665.82	665.82
			Sub total			15585.52
			Hact.	1		15585.52
			Vat @ 5 % on head unit cost			779.28
			Total of head unit cost a			16364.8
b	**Field unit including secondary transportation**					
1	Pvc pipe/4 kg/cm^2	75 mm	Mtr	100	74.94	7494
2	Pvc pipe/4 kg/cm^2	63 mm	Mtr	100	53.8	5380
3	Pp ball valve	63mm	No	2	725.88	1451.76
4	End plug quick action	63 mm	No	2	77.22	154.44
5	Double nozzle	0	No	100	223.23	22323
6	M / f adaptor	12.7mm	No	100	14.71	1471
7	Extension tube - pvc	13 mm × 1.2 mtr	No	100	17.19	1719
8	Male connector	9 / 12 mm	No	100	9.8	980
9	Female connector	9 / 12 mm	No	100	9.8	980
10	Installation stake	8 mm × 1.2 mtr.	No	100	23.66	2366
11	Plain lateral	32 mm	Mtr	1000	23.35	23350
12	Coupler/joiner	32 mm	No	20	51.69	1033.8
13	End plug	32 mm	No	20	32.9	658
14	Pvc / hdpe fittings l.s.	LS	Hact.	1	713.01	713.01
c	**Field unit cost without secondary transportation**					70074.01
15	Secondary transportation	0	Hact	1	435.45	435.45
			Sub total			70509.46
			Vat @ 5 % on b cost			3525.47
			Total field unit cost b			74034.93
			Sub total (a+b)			90399.73

Considering 10 years life of the system and 2 seasons in a year at interest rate of 10% per annum.

Fixed cost = sub- total of head units + sub- total of field unit
=16364.8+ 74034.93
= Rs. 90399.73

$$\text{Annual installment } (A_i) = \frac{P_{i*} * (1+i)^n}{(1+i)^n - 1}$$

$=90399.73*[0.1(1+0.1)^{10}] / [(1+0.1)^{10}-1]$
= Rs. 14712.14

Annual cost = annual installment + variable cost (operating cost 10% of the annual installment + repair and maintenance cost 5% of the annual installment).
= Rs. 14712.14 + 1471.21 + 735.61
= Rs.16918.96 per ha.

Seasonal cost = annual cost/2
= Rs.8459.48

Table C. Cost analysis of mini sprinkler with spacing 12 m ×12 m in 1 ha.

S/N	Description of product	Size	Unit	Qty.	Rate	Amount
a	**Head unit**					
1	Header assembiy-1 filter	76.2 mm × 25.4 mm	No	1	3047.03	3047.03
2	Hydro-cyclone filter-2"	20 m^3	No	1	3265.88	3265.88
3	Screen filter-2"-plastic	20 m^3	No	1	2123.43	2123.43
4	Fertilizer tank with assembly	30 ltr.	No	1	2582.3	2582.3
5	Butterfly valve	76.2 mm	No	2	1183.42	2366.84
6	Air release valve	25.4 mm	No	1	384.55	384.55
7	By pass assembly	76.2 mm × 38.2 mm	No	1	805.65	805.65
8	Pressure gauge	50.8 mm	No	2	172.01	344.02
9	Gi fittings l. S.	LS	Hact.	1	665.82	665.82
			Sub total			15585.5
			Hact.	1		15585.5
			Vat @ 5% on head unit cost			779.28
			Total of head unit cost a			16364.8
b	**Field unit including secondary transportation**					
1	Pvc pipe/4 kg/cm^2	75 mm	Mtr	100	53.8	5380
2	Pvc pipe/4 kg/cm^2	63 mm	Mtr	100	37.28	3728
3	Pp ball valve	63mm	No	2	566.48	1132.96
4	End plug quick action	63 mm	No	2	63.19	126.38
5	Double nozzle	0	No	70	223.23	15626.1
6	M/f adaptor	12.7mm	No	70	14.71	1029.7
7	Extension tube - pvc	13 mm × 1.2 mtr	No	70	17.19	1203.3
8	Male connector	9 / 12 mm	No	70	9.8	686
9	Female connector	9 / 12 mm	No	70	9.8	686
10	Installation stake	8 mm × 1.2 mtr.	No	70	23.66	1656.2
11	Plain lateral	32 mm	Mtr	850	23.35	19847.5
12	Coupler/joiner	32 mm	No	20	51.69	1033.8
13	End plug	32 mm	No	20	32.9	658
14	Pvc/hdpe fittings l.s.	LS	Hact.	1	713.01	713.01
c	**Field unit cost without secondary transportation**					53507
15	Secondary transportation	0	Hact	1	435.45	435.45
			Sub total			53942.4
			Vat @ 5 % on b cost			2697.12
			Total field unit cost b			56639.5
			Sub total (a+b)			73004.3

Considering 10 years life of the system and 2 seasons in a year at interest rate of10% per annum.

Fixed cost = sub- total of head units + sub- total of field unit
=16364.8 + 56639.52
= Rs. 73004.32

$$\text{Annual installment } (A_i) = \frac{P_{i*} * (1+i)^n}{(1+i)^n - 1}$$

= 73004.32*[0.1(1+0.1)^{10}] / [(1+0.1)^{10}-1]
= Rs. 11881.11

Annual cost = annual installment + variable cost (operating cost 10% of the annual installment + repair and maintenance cost 5% of the annual installment)
= Rs. 11881.11 + 1188.11+ 594.05
= Rs.13663.27 per ha.

Seasonal cost = annual cost/2
= Rs.6831.63