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Testing of Twin-Nozzle Agricultural Sprinklers for Field Use

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A B S T R A C T

Testing of agricultural sprinklers is necessary to find the optimum field operating conditions with minimum cost while satisfying design water distribution criteria. In the present study two twin-nozzle agricultural sprinklers were tested in field under ten different operating pressures ranging from 1.6 kg/cm² to 3.5 kg/cm². In each experiment sprinkler discharge rate, nozzle pressure, radius of throw, and water distribution pattern around the sprinkler were observed. The average discharge coefficients of the two sprinkler nozzles were determined. The radius of throw was measured in four orthogonal directions. The distortions in radius of throw were observed to study the effect of wind on water distribution patterns. The depth distribution profiles across the wetted area did not show significant distortions for wind velocities less than 2 m/s. The experimental results obtained for the sprinkler heads showed that the discharge from the sprinkler nozzle increased with the increase in the nozzle pressure. Under identical pressure head the discharge rate of the sprinkler with larger nozzle size was more. Empirical pressure-discharge relationships were developed for the two sprinkler heads. Both the relationships were power functions, which showed good correlation between the nozzle pressure and sprinkler discharge. The observed water distribution patterns for different experiments were analysed to design the ideal operating conditions for the two sprinkler heads. The sprinkler to sprinkler spacing along the lateral was fixed at 12 m and the resulting wetting pattern around the lateral line was estimated by overlapping the wetting patterns of a single sprinkler. This led to the estimation of maximum possible spacing between the laterals by overlapping the wetting patterns of adjacent laterals while maintaining a minimum uniformity coefficient value of 85%. Finally, the best operating pressure and the recommended spacing of the system for the two sprinkler heads were suggested. This study can be used as a simple guideline for the field users to install and operate their sprinkler system efficiently with good uniformity and minimum cost.

Introduction

Efficient application of irrigation water and its management is the prime concern in the modern agricultural practice. Due to climate change the amount of available water for irrigation is reducing day by day in the backdrop of increasing demand for irrigation water (Ahaneku, 2010). Pressurised irrigation systems (drip and sprinkler) are known to be very effective water saving technologies over surface methods of irrigation. Sprinkler irrigation is recommended in water scarce arid and semi-arid regions as an efficient irrigation water application method (Acar *et al.*, 2010; Ahaneku, 2010).

Solid set (Montero *et al.*, 2000; Dechmi *et al.*, 2003), periodic move (McCulloch *et al.*, 1967), and continuous moving centre-pivot

(Thooyamani *et al.,* 1987; Keller and Bliesner, 1990) sprinkler irrigation systems have become popular around the world. In India sprinkler irrigation is also becoming more and more popular in water scarcity regions as an alternative of surface irrigation (Sahoo *et al.,* 2008). However, satisfactory performance of sprinkler irrigation system depends on several installation, operation and design criteria.

Testing of sprinkler nozzles is very important before field use of sprinklers (Merrian and Keller, 1978). The discharge and water distribution pattern of sprinklers depend on the operating pressure at the sprinkler nozzle. In order to have optimum size of water droplets and to ensure uniform distribution of water in the field, the operating pressure is critical (Christiansen, 1942, Schleusener and Kidder, 1960). The optimum spacing of the sprinkler along the length of a lateral and the lateral to lateral spacing are largely influenced by the pressure-discharge relationship of the sprinklers. Proper selection of sprinkler spacing has large influence on the initial cost of the sprinkling systems. Therefore, for selecting the optimum sprinkler spacing, field testing of sprinklers with different combinations of pressure and discharge is necessary.

The operating pressure of most of the agricultural sprinklers is generally in the range of 1.5 kg/cm² to 3.5 kg/cm². Sahoo *et al.,* (2008) suggested that under normal wind condition the optimum uniformity of water distribution was obtained at a nozzle pressure of 2.0 kg/cm² for small and medium size nozzles. Wind speed is another important factor for satisfactory operation of sprinkler system. High wind velocities are known to distort the water distribution pattern and application uniformity of sprinklers. Sahoo *et al.,* (2008) observed that the effect of wind velocity on uniformity of water distribution was less for wind velocities below 4 km/h and moderate for wind velocities below 7 km/h. The distribution pattern was distorted at high wind velocity of 15 km/h. Montero *et al.,* (2000) also showed that higher uniformity of water application could be obtained with twin-nozzle than with a single nozzle sprinkler under low wind speed conditions. It is a standard practice to test a single sprinkler at different pressures and observe the sprinkler performance parameters.

Montero *et al.,* (2000) conducted more than 300 tests with different sprinkler nozzle pressures to determine the main factors that affect the field water application. The test data of a single sprinkler can be used to simulate various sprinkler spacings along the laterals as well as lateral to lateral spacings (Merrian and Keller, 1978). The water distribution data of a sprinkler irrigation system can be used to compute Christiansen's Uniformity Coefficient, which is a widely adopted and accepted parameter which is used to evaluate the performance of the sprinkling systems (Hart and Reynolds, 1965; McCulloch *et al.,* 1967; Li and Rao, 2001; Dechmi *et al.,* 2003). Wenting and Pute (2011) used software to precisely calculate uniformity of water application from catch can data.

It is well apprehended that proper testing of agricultural sprinklers is necessary before field installation and operation. In India as sprinkler irrigation is getting more and more popular, many of the farmers have a tendency to adopt and install sprinkler systems without proper design and testing. This often leads to higher initial and operating costs of the system. The present study is used to demonstrate a simple methodology for testing the sprinklers under different operating pressures and wind conditions before field use. Two twin-nozzle sprinkler heads with different nozzle sizes were selected for testing. The nozzle pressure was varied in the range of 1.6 to 3.5 kg/cm² and the corresponding discharges and water distribution patterns were measured. Empirical pressure-discharge relationships of both the sprinkler heads were developed within their range of operation. The water distribution patterns obtained at different operating pressures were analysed to estimate the optimum operating pressure and spacing between the laterals. The demonstrated simple method can ensure economic and efficient field operating condition of agricultural sprinklers.

Materials and Methods

Testing of sprinklers is usually done under two conditions: in a well-equipped laboratory or under field conditions. The results obtained from laboratory testing are often limited for field adoption because wind conditions are generally not simulated in laboratory. However, wind velocity is known to distort the sprinkler water distributions significantly. Therefore, field testing of sprinklers is very important prior to its installation in fields. In the present study testing of two twin-nozzle sprinkler heads were conducted under open field condition using a simple experimental setup (Fig. 1). Most of the agricultural sprinkler nozzles are operated in the range of 1.5-3.5 kg/cm^2. To develop the required pressure a 10 HP volute type centrifugal pump (Standard IS: 9079), driven by a close coupled electrical motor, was used. The head and capacity ranges of the pump were 24 m to 52 m and 2.5 to 5 lit/s, respectively. The speed of the impeller was 2900 rpm and overall pump efficiency was 53%. The selected centrifugal pump was able to produce a wide range of system discharge and pressure, which was required for this study. A multi-stage filtration unit was used to filter out the suspended materials from the pumped water. Two different brass made twin-nozzle sprinkler heads were tested. Both the sprinkler heads had compensating nozzle diameter of 3.2 mm and angle of spray of 27 degree with the horizontal. However, one sprinkler had main nozzle diameter of 5.5 mm (Sprinkler 1) and the same for the other one was 5.1 mm (Sprinkler 2).

Before conducting the experiments, catch cans were placed around the sprinkler in a 4 m × 4 m grid spacing (Fig. 1). The catch cans were placed carefully on a horizontal surface and the tall grasses around the cans were removed. For each experiment 49 catch cans were placed around the sprinkler. With this arrangement it was possible to capture a radius of throw of 12 m in each direction from the sprinkler. Tests were conducted with the two selected sprinkler heads under varying operating pressures. The total head loss in the system was computed for a particular discharge. This provided a basis for adjusting the flow control valve so that a desired pressure head is maintained at the sprinkler nozzle. Sprinkler nozzle pressures were always lower than the pressures measured at the pumping unit. The reduction in nozzle pressure was due to the frictional head losses in the pipes, bends, fittings, and head losses in the filters. For each sprinkler head the ten experiments were conducted by varying the nozzle pressure in the range from 1.6 kg/cm² to 3.5 kg/cm² (Table 1). For each experiment the pressure at the sprinkler nozzle was measured by inserting a pitot tube equipped with a pressure gauge into the compensating nozzle. The discharge rate at different nozzle pressures were measured for all the experiments conducted using volumetric method.

Each experiment was conducted at a particular nozzle pressure for a period of 60 minutes. The volume of water collected in each of the catch cans was measured using a measuring cylinder and depths of water collected in the catch cans were then calculated. Wind action is known to distort the sprinkler water distribution patterns. Such distortions affect the percentage overlapping of the sprinkler patterns and thus influence the spacing of the sprinklers significantly (Sahoo *et al.,* 2008). A hand-held anemometer was used to observe wind speed during the experiments. To evaluate the impact of wind action on water distribution around the sprinkler, the radius of throw of water jet was measured in the four perpendicular directions. Radius of throw is a very important parameter which provides information about the wind effect on sprinkler water distribution. If wind action is insignificant, the wetting pattern should be circular with nearly equal radius of throw in all directions. Thus, the effect of wind action can be evaluated by computing the distortions in the wetting patterns.

Measured actual discharge of a sprinkler nozzle is less than its theoretical discharge. Actual discharge is given by the product of theoretical discharge and discharge coefficient (C_d) of the nozzle. Knowing the nozzle size and operating pressure, theoretical discharges for all the experiments were calculated. Then for all the experiments the values of discharge coefficients were calculated for a particular sprinkler head. The average of these values was taken as the discharge coefficient of the sprinkler head.

Sprinkler discharge is related to the operating pressure at the nozzle as:

$$Q = C_d a \sqrt{2gh} \qquad \text{........(1)}$$

where, Q is the sprinkler discharge (m^3/s), a is the cross-sectional area of nozzles (m^2), g is the acceleration due to gravity (m/s^2), and h is pressure head at the sprinkler nozzle (m). Thus, it is apparent that sprinkler discharge is proportional to the square root of operating pressure at the nozzle. The measured data of operating nozzle pressure and discharge of twin-nozzle sprinklers were used to develop an empirical power relationship for a particular sprinkler head. Such a relationship can serve as a quick reference to select a particular pressure-discharge requirement for a sprinkler head. The measured data of pressure and discharge were fitted to the following form of empirical power relationship for the two sprinkler heads under study.

$$Q = bh^x \qquad \text{..........(2)}$$

where, b is a constant that depends on sprinkler nozzle diameter and discharge coefficient and x is an exponent which depends on flow regime.

The Christiansen's uniformity coefficient (C_u) is a statistical measure of degree of uniformity of water distribution around a sprinkler. This uniformity coefficient is affected by the operating pressure, nozzle size, sprinkler spacing, lateral spacing, and wind conditions. The coefficient can be computed from field observations of the depths of water collected in open catch cans placed at regular grid spacing within a sprinkled area. A uniformity coefficient of 100%, which indicates perfectly uniform water application, is possible to attain with overlapping of sprinkler wetting patterns. The lower percentage of uniformity coefficient indicates non-uniform distribution of water in the field. As a standard for designing sprinkler irrigation system the value of uniformity coefficient of 85% or more is considered to be satisfactory. The uniformity coefficient can be calculated from the following equation proposed by Christiansen (1942):

$$C_u = 100\left(1 - \frac{\sum X}{mn}\right) \qquad \text{.......(3)}$$

where, C_u is uniformity coefficient proposed by Christiansen (%), *m* is average depth of water collected in catch cans for all the observations (m), *n* is total number of observation points, and *X* is numerical deviation of individual observations from the average depth (m).

The water distribution pattern of a single sprinkler is non-uniform in nature. Wind also distorts the water distribution pattern of sprinklers to further reduce the uniformity. In order to ensure a uniformity coefficient of 85% or more, overlapping of sprinkler is necessary. A very close spacing of laterals and sprinkler to sprinkler spacing along a lateral ensures high degree of uniformity, but it is often a poor design in terms of economy as such close spacing requires a greater number of laterals, sprinkler heads, and additional fittings and accessories. Therefore, it is important to design a sprinkler system with optimum spacing, which will ensure minimum uniformity coefficient (85% or more) criteria and have minimum cost of system. In this approach depending on crop spacing first a suitable spacing of the sprinklers along a lateral is fixed. This can be done by adopting a suitable percentage overlapping of sprinkler spray. If required the percentage overlapping may be 100% or more. The wetting pattern obtained for a single sprinkler is overlapped with the adopted sprinkler to sprinkler spacing along the lateral to obtain the resulting water distribution profile for one lateral. Then a suitable spacing between the laterals is assumed and the water distribution patterns of the two laterals are again overlapped to obtain the resulting water distribution. This water distribution pattern is then used to calculate the value of uniformity coefficient. The maximum lateral spacing that ensures a uniformity coefficient equal to or slightly higher than 85%, is adopted as the optimum or most economic lateral spacing. For the present study the sprinkler to sprinkler spacing along the lateral was taken as 12 m with 100% overlapping. The lateral to lateral spacing was varied from 8 m to 20 m.

Results and Discussion

Pressure-discharge relationships of sprinklers

For both the sprinklers the measurements of nozzle pressures and the corresponding discharges were taken (Table 1). These measured data for each sprinkler head were fitted to a power function to obtain the empirical relationship between the nozzle pressure and sprinkler discharge. Fig. 2(a-b) shows the empirical pressure-discharge relationships for the two sprinkler heads. The high values of R^2 indicated good predictability of the power relationships between nozzle pressure and sprinkler discharge.

Effect of wind speed on water distribution

The effect of wind speed on water distribution patterns was studied by analysing the radius of throw in the four perpendicular directions (Table 2). The measured wind velocities are also enumerated in Table 2. The amount of distortions in the radius of throw in the four directions indicated the effect of wind velocity on water distribution patterns of sprinklers. For each experiment the difference between the minimum and maximum radius of throw (x) was estimated (Table 2). The wind distortions were classified as insignificant if x was up to one meter; moderate if $1 \text{ m} < x < 3 \text{ m}$, and significant if $x \geq 3 \text{ m}$ (Table 3). For example, in the experiment E_1-2 the radius of throw measured in east, west, south, and north directions were 9.5 m, 14 m, 13 m, and 11 m, respectively. This indicated that the direction of wind was from north-east to south-west. The difference between the minimum and maximum radius of throw was 4.5 m. Therefore, the wetting pattern was distorted considerably and thus the wind effect was categorized under significant category (Table 3).

Discharge coefficient of sprinkler nozzles

The estimated discharge coefficients for Sprinkler 1 and Sprinkler 2 were in the range of 0.87 to 0.99 and 0.86 to 0.90. The average discharge coefficient for Sprinkler 1 was 0.95 and that for Sprinkler 2 was 0.88. A good sprinkler nozzle should have discharge coefficient of 0.90 or above. The value of discharge coefficient for the Sprinkler 1 was very good and the discharge coefficient of the Sprinkler 2 was roughly acceptable as it is very close to 0.90.

Design of most economic lateral spacing

The most economic lateral spacing for the two sprinkler heads were calculated for each operating pressure following the minimum acceptable design uniformity criteria. The sprinkler to sprinkler spacing along the laterals was fixed at 12 m and the maximum possible lateral spacing was estimated by maintaining the value of uniformity coefficient as 85% or more. For example, the depth distribution patterns obtained from a single sprinkler test (E_1-8) is shown in Fig. 3. After overlapping the sprinklers patterns with 12 m spacing along the lateral, the depth distributions around one lateral was obtained. Then the laterals were overlapped with maximum possible spacing while ensuring a minimum value of uniformity coefficient of 85%. This resulted in maximum lateral spacing of 16 m for the experiment E_1-8.

The results of the experiments conducted with the Sprinkler 1 and Sprinkler 2 are summarized in Table 4 and Table 5, respectively. It was noted that for both the sprinkler heads with increase of nozzle pressure, maximum allowable lateral spacing, for a given sprinkler to sprinkler spacing, increases from a low value to a maximum and then reduces gradually. This provided a basis for selecting an optimum operating pressure which will ensure design uniformity with maximum possible spacing of lateral for a given sprinkler spacing. The percentage overlapping along the sprinkler lateral was calculated from the average radius of throw and sprinkler to sprinkler spacing.

The present study demonstrated that pressure-discharge relationship of sprinkler nozzles can be obtained using simple experimental observations. It was observed that the sprinkler discharge rate increased with the increase in nozzle pressure as a power function. Such empirical relationship can be used to estimate required pressure head for obtaining a desired application rate from a sprinkler. The estimated values of discharge coefficients of the sprinkler heads indicated good quality of nozzles.

Measurements of radius of throw were used to study wind effect on water distribution around a sprinkler. It was observed that with the increase in nozzle pressure the radius of throw also increased. Based on the distortions in the water distribution patterns the wind effects were categorized under insignificant, moderate, and significant. It was observed that under higher wind velocities the wind distortions were more. Wind distortions were insignificant for wind velocities less than 1 m/s. Moderate distortions were observed for wind velocities less than 2 m/s, whereas water distribution patterns were significantly affected with wind velocities 2.95 m/s and above. However, under most of the experimental conditions the wind velocity was less than 2 m/s and consequently wind distortions were either insignificant or moderate. Similar findings were also reported by Sahoo *et al.,* (2008). The water distribution pattern around a single sprinkler is non-uniform in nature. The coefficient of uniformity value of 85% or more is considered satisfactory for the design of sprinkler systems. Therefore, overlapping of sprinklers is necessary. However, excessive overlapping results in closer spacing of laterals and sprinklers. This increases the overall cost of the system.

Therefore, for a feasible sprinkler to sprinkler spacing the maximum lateral spacing was calculated by overlapping the water distribution patterns while maintaining the design uniformity coefficient equal to or marginally higher than 85%. Thus, economical spacing of sprinkler laterals were calculated based on the field tests conducted. It was also observed that for Sprinkler 1 the suitable operating pressure range was 2.4 to 2.9 kg/cm^2, which allowed maximum lateral spacing of 20 m with 12 m spacing of sprinklers along the lateral. Within this range at 2.6 kg/cm^2 pressure the uniformity coefficient was maximum. Therefore, for the Sprinkler 1 the best operating conditions were: nozzle pressure of 2.6 kg/cm^2 and sprinkler spacing of 12 m × 20 m.

Similarly, for Sprinkler 2 the most suitable operating conditions were: 3.1 kg/cm^2 nozzle pressure and 12 m × 20 m of sprinkler spacing which provided uniformity coefficient of 85.04%. In both the cases the wind distortions were moderate. In case the wind distortions were significant, a more conservative spacing could be adopted to ensure that the minimum uniformity value was satisfied.

The experimental results showed that operating pressures at the sprinkler nozzle and sprinkler discharge rates were closely related. The pressure-discharge relationships of the sprinkler nozzles could be defined empirically using a power function. The estimated average discharge coefficients of both the sprinklers indicated good quality of the spraying nozzles. The radius of throw measurements in the four orthogonal directions did show some distortions due to wind effect.

Table.1 Pressures at the pump and sprinkler nozzle for different experiments

Sprinkler 1				**Sprinkler 2**			
Exp. No.	Pressure at pump (kg/cm²)	Pressure at nozzle (kg/cm²)	Discharge (lit/s)	Exp. No.	Pressure at pump (kg/cm²)	Pressure at nozzle (kg/cm²)	Discharge (lit/s)
E_1-1	1.70	1.60	0.549	E_2-1	1.70	1.60	0.483
E_1-2	1.90	1.80	0.574	E_2-2	1.90	1.80	0.527
E_1-3	2.00	1.90	0.588	E_2-3	2.00	1.90	0.519
E_1-4	2.30	2.20	0.568	E_2-4	2.30	2.20	0.587
E_1-5	2.50	2.40	0.660	E_2-5	2.50	2.40	0.599
E_1-6	2.80	2.60	0.668	E_2-6	2.80	2.70	0.620
E_1-7	3.10	2.90	0.731	E_2-7	3.10	3.00	0.653
E_1-8	3.20	3.00	0.705	E_2-8	3.20	3.10	0.675
E_1-9	3.50	3.30	0.758	E_2-9	3.50	3.30	0.684
E_1-10	3.70	3.50	0.779	E_2-10	3.65	3.50	0.728

Table.2 Measured radius of throw at different nozzle pressures and wind conditions

Exp. No.	Radius of throw (m)				Maximum difference, *x* (m)	Exp. No.	Radius of throw (m)				Maximum difference, *x* (m)
	East	South	West	North			East	South	West	North	
E_1-1	12.5	12	12.5	12	0.5	E_2-1	12	10	12	12	2
E_1-2	9.5	13	14	11	4.5	E_2-2	13	11.8	13	12	1.2
E_1-3	12	13	13	12	1	E_2-3	12	10	11.5	13	3
E_1-4	11	12	15	13	4	E_2-4	12	12	13.5	13.5	1.5
E_1-5	13	14	14	13.7	1	E_2-5	12.5	14	13.5	12	2
E_1-6	13	14.5	14	13.5	1.5	E_2-6	12.5	12.5	14	12	2
E_1-7	14	13	14	13.5	1	E_2-7	13.5	12.5	13	13	1
E_1-8	13.5	14.3	14	13.5	0.8	E_2-8	14	13	11.8	13.8	2
E_1-9	14	14	14	14	0	E_2-9	12	13.5	14.5	12	2.5
E_1-10	14	11.6	13	15	3.4	E_2-10	13	14.5	12	13.5	2.5

Table.3 Classification of distortions in sprinkler wetting patterns by wind action

Exp. No.	Wind speed (m/s)	Wind distortion	Exp. No.	Wind speed (m/s)	Wind distortion
E_1-1	0.25	Insignificant	E_2-1	1.62	Moderate
E_1-2	4.20	Significant	E_2-2	1.04	Moderate
E_1-3	0.68	Insignificant	E_2-3	2.95	Significant
E_1-4	3.96	Significant	E_2-4	1.50	Moderate
E_1-5	0.60	Insignificant	E_2-5	1.70	Moderate
E_1-6	1.42	Moderate	E_2-6	1.57	Moderate
E_1-7	0.72	Insignificant	E_2-7	0.75	Insignificant
E_1-8	0.57	Insignificant	E_2-8	1.54	Moderate
E_1-9	0	Insignificant	E_2-9	1.95	Moderate
E_1-10	3.48	Significant	E_2-10	1.88	Moderate

Table.4 Maximum lateral spacing and percent overlap for Sprinkler 1

Exp. No.	Nozzle pressure (kg/cm^2)	Sprinkler to sprinkler spacing (m)	Maximum lateral to lateral spacing (m)	Percentage overlapping along the lateral (%)	Uniformity coefficient (%)
E_1-1	1.6	12	8	102	86.05
E_1-2	1.8	12	16	99	87.07
E_1-3	1.9	12	16	104	85.00
E_1-4	2.2	12	16	106	87.97
E_1-5	2.4	12	20	114	85.00
E_1-6	2.6	12	20	115	87.79
E_1-7	2.9	12	20	114	86.28
E_1-8	3.0	12	16	115	89.33
E_1-9	3.3	12	16	117	86.18
E_1-10	3.5	12	12	112	90.00

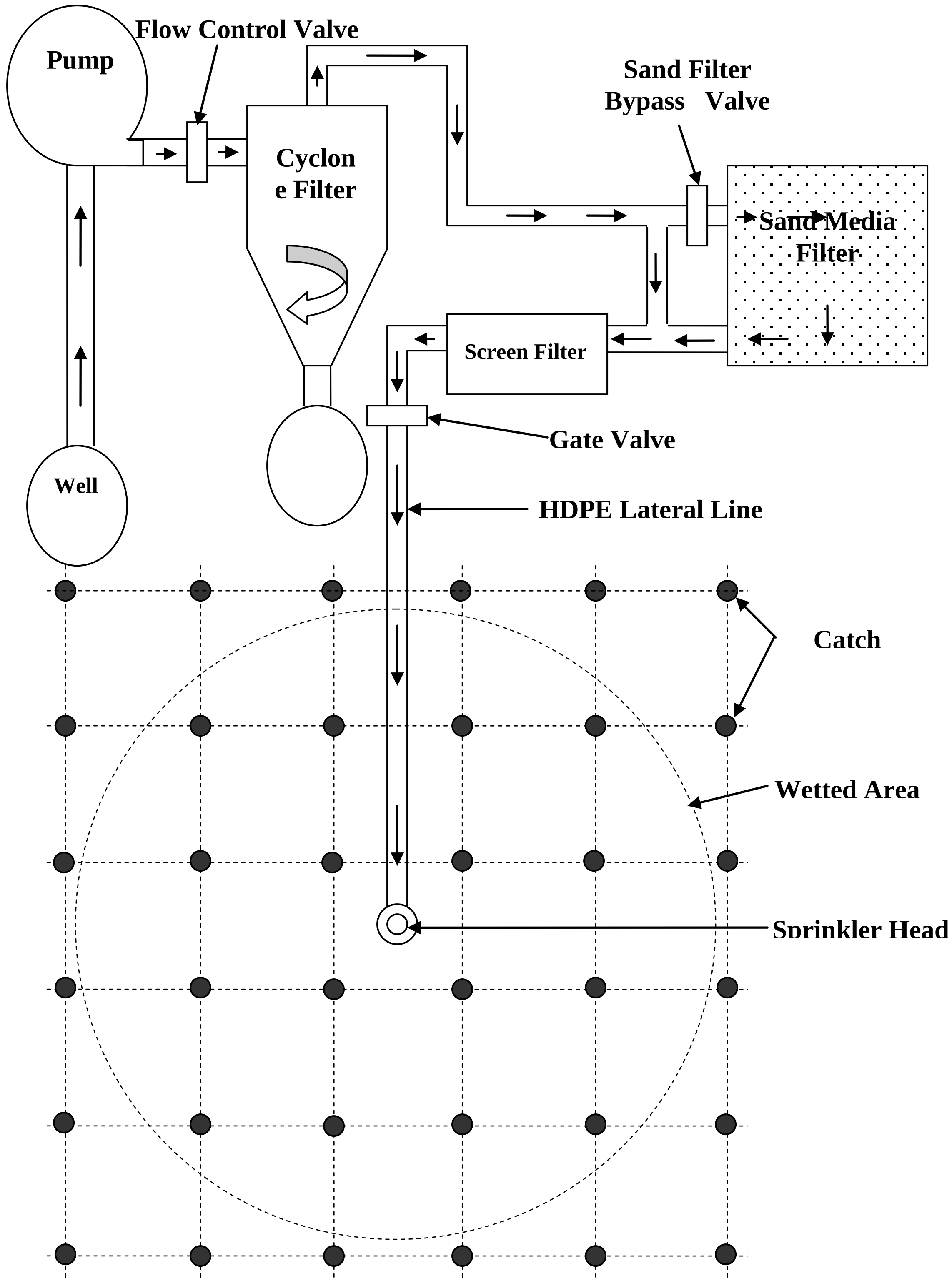


Fig.1 Schematic diagram of the experimental setup

Table.5 Maximum lateral spacing and percent overlap for Sprinkler 2

Exp. No.	Nozzle pressure (kg/cm²)	Sprinkler to sprinkler spacing (m)	Maximum lateral to lateral spacing (m)	Percentage overlapping along the lateral (%)	Uniformity coefficient (%)
E_2-1	1.6	12	8	96	85.00
E_2-2	1.8	12	16	104	85.59
E_2-3	1.9	12	16	97	88.40
E_2-4	2.2	12	16	106	87.19
E_2-5	2.4	12	16	108	90.97
E_2-6	2.7	12	16	106	87.06
E_2-7	3.0	12	16	108	89.57
E_2-8	3.1	12	20	110	85.04
E_2-9	3.3	12	16	108	90.43
E_2-10	3.5	12	16	110	89.35

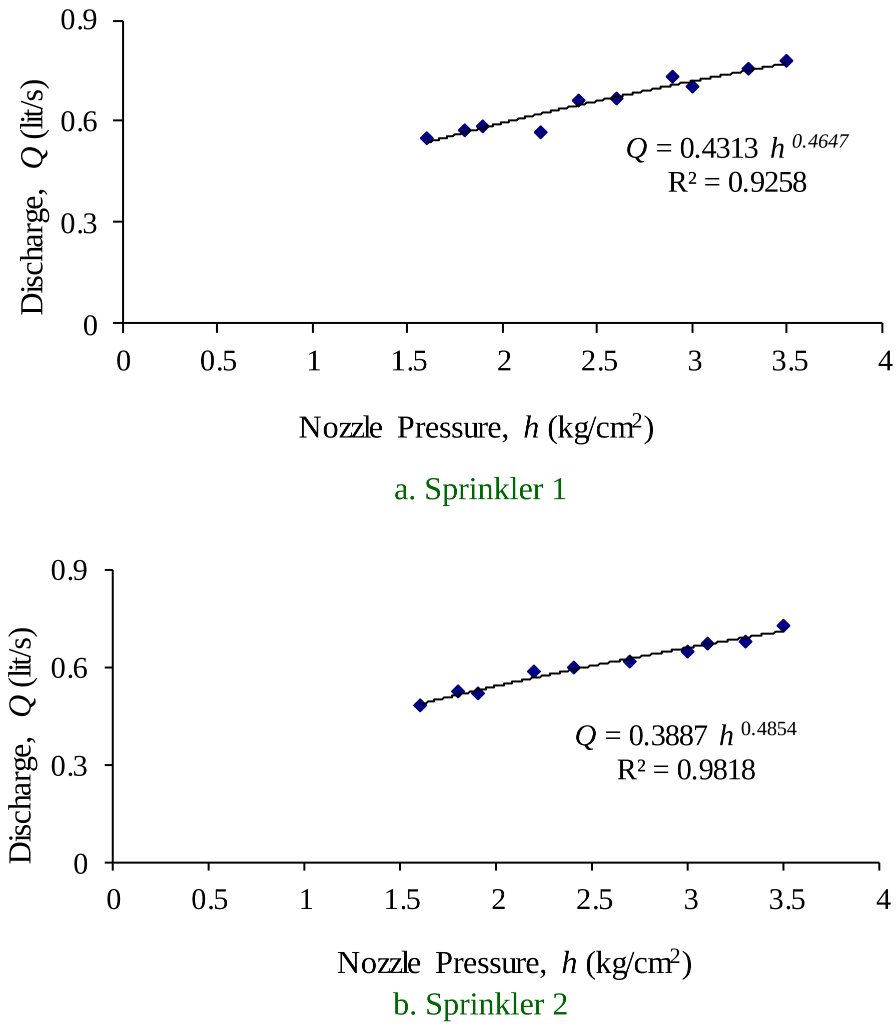
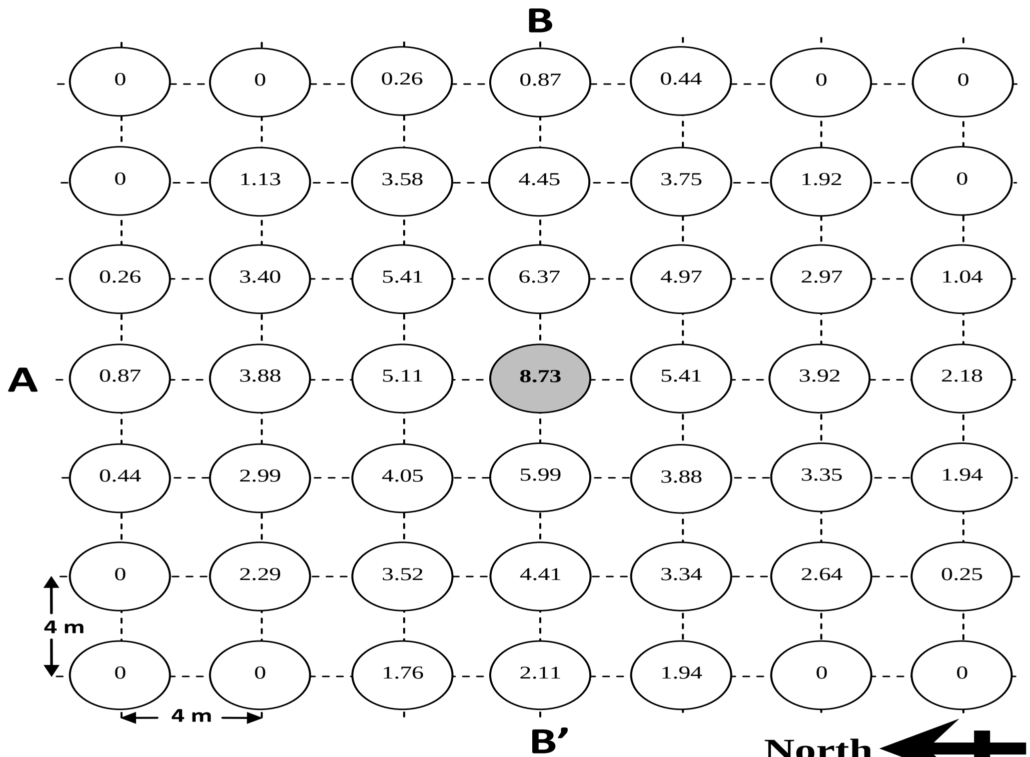
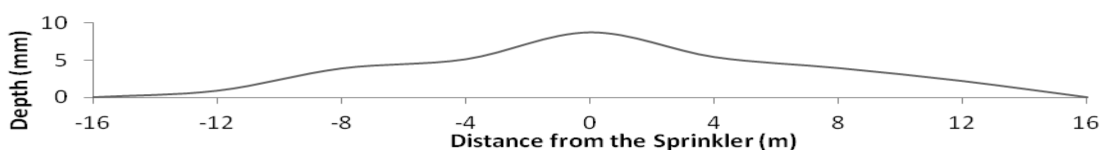


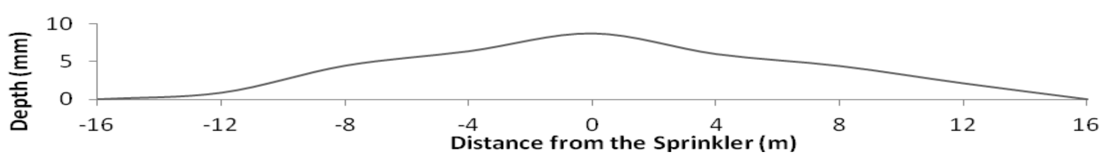
Fig.2(a-b) Pressure-discharge relationship of the sprinkler heads



(a)



(b)



(c)

Fig.3 (a) Depth distribution of water collected in the catch cans in mm with nozzle pressure of 3.0 kg/cm^2 with insignificant wind effect (E_1-8) (b) Depth distribution of water along the axis AA', and (c) Depth distribution of water along the axis BB'

However, the depth distribution profiles across the wetted area did not show significant distortions for wind velocities less than 2 m/s. Wind distortions were significant for wind velocities 2.95 m/s and above. The test results could be used to identify ideal operating condition of the sprinkler head i.e. nozzle pressure, sprinkler to sprinkler spacing, and lateral to lateral spacing. In most of the experiments the required percentage overlapping of sprinklers along the length of laterals was more than 100%. This simple field-based testing approach can be used for standardizing sprinkler operating and installation conditions.

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