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Hydraulic Performance of the Raingun (PY_1-30) with 6 mm Diameter Nozzle

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The raingun (PY_1-30) with 6 mm diameter nozzle was operated under different pressures ranging from 20 to 80 psi. The discharge of the raingun and the radius of coverage increased with the increase in pressure being 12.59 gpm and 18.5 m at 80 psi pressure. The maximum and minimum theoretical application rates were found to be 2.66 mm h^{-1} at 80 psi and 1.33 mm h^{-1} at 35 psi, respectively. In respect of coverage the high coefficients of uniformity were found in the first quarter and the low coefficients of uniformity in the fourth quarter.

Key words: Hydraulic performance, Raingun, Nozzle.

Introduction

The Indus basin irrigation system is operating at less than 40% efficiency. The annual availability of canal water supplies can meet only less than 40% of the total water requirements (Johnson *et al* 1978; Singh 1981; Anon 1984; Bhatti and Kijne 1990). Based on data from 89 farms during Kharif season and 96 farms during Rabi season Bhatti and Kijne (1990) observed that the majority of the farms received less than 50% of their theoretical share of canal water. The shortage of irrigation water particularly during critical crop growth stages (milking and grain forming) significantly affects the crop yields. The availability of canal water supplies also significantly varies over the year and does not match with the water requirements at various stages of crop development (Anon 1983). Storing of surplus canal water during slack irrigation season or catching excess rainfall in a storage reservoir and subsequently using it with sprinkler irrigation system can help the farmers to irrigate even elevated crop lands.

Rainfed agriculture is solely dependent on the occurrence and distribution of rainfall. The stochastic behaviour of rainfall has serious limitations for sustained and profitable crop production. The yields of major crops are 30 to 50% of the national average crop yields mainly because of drought and lack of available soil moisture at the critical crop growth stages. The planting is often delayed due to uncertain and scanty rains. The plant population and crop stand are poor due to inadequate moisture. If dry spells are prolonged, crop failures become common. The farmers hesitate to apply fertilizers when they are not sure about rainfall (Kemper *et al* 1978). In rainfed areas, water is available through dugwells, mini/small dams, lakes, streams, nullahs, etc. At present there are around 24 small and 94 mini dams in the Punjab rainfed areas, but due to non-availability of appropriate irrigation systems only 20% and 10% of designed command areas, respectively, have been developed for irrigation. Some farmers are practicing lift irrigation but face difficulty in shaping the land for surface irrigation. Therefore, the only option left for rain-fed areas is to use sprinkler irrigation because of high value of water in these areas (NARC 1992). About 6.0 mha rainfed areas of the country lack any regular irrigation facilitiesdue to topography, soil type, shortage of water etc. Hence more efficient use of water becomes necessary, which can be made possible by adopting sprinkler irrigation systems (Elliott *et al* 1980).

In Pakistan different organizations attempted to introduce sprinkler irrigation system, like, Pakistan Council of Appropriate Technology, Pakistan Council of Research in Water Resources, Agricultural Development Bank of Pakistan, Water and Power Development Authority, Provincial Irrigation and Agriculture Departments and OFWM Directorates, etc. but there was very little progress in the adoption and promotion of the systems. Pakistan Agricultural Research Council (PARC), Islamabad was entrusted with the responsibility to initiate research in the area of sprinkler irrigation in 1982-83. PARC critically analysed previous efforts and attributed the causes of failure to discontinued and piecemeal efforts, lack of coordination among research and development agencies, high cost of imported systems, lack of backstop facilities for service, maintenance and spares, lack of scientific knowledge and skills and absence of linkages and advisory services for local industries.

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To overcome these difficulties and ensure continuity, it was realized that the systems must be produced with local skills, technology and materials i.e. the whole process of sprinkler irrigation technology should be indigenized. In recognition of the importance of this thrust area, PARC accorded high priority to it. At present, the electric, diesel and PTO driven portable raingun sprinkler irrigation systems are being produced in the country using locally available materials and technology. Progressive farmers are importing sophisticated systems such as centre pivots and linear move sprinkler machines. Proto type units of semi automatic systems such as reel machines for grassy fields and vegetables and one span centre pivots have also been manufactured in the country using locally available materials and technology. The technical evaluation and hydraulic performance of these systems is required for proper designing and efficient utilization of scarce resource of irrigation water.

In the present study, the raingun (PY_1-30) was selected for evaluation purposes because it is most commonly used. The objectives of the study were to determine discharge, water distribution pattern, radius of coverage and application rate of the raingun under various pressures, to determine relationships of pressure with discharge, radius of coverage and application rate of the raingun and to determine coefficient of uniformity of the raingun under various pressures.

Materials and Methods

The research was undertaken at the Field Station of Water Resources Research Institute (WRRI), National Agricultural Research Centre (NARC), Islamabad. The schematic diagram of the raingun is shown in Fig 1. The diameter of the nozzle of the raingun is 6 mm, however it is replaceable with other nozzles. The water is supplied through 50 mm diameter canvas or polyethylene pipe connected to the raingun with a quickset brass or aluminium coupler. The water is supplied with pressure by a pump.

The raingun was fixed in the middle of a field with the help of stand and pegs and catch cans were placed in four quadrants to collect water. The first catch can was placed at a distance of one half meter from the raingun while the remaining cans were placed with an interval of one meter each. The layout of catch cans is shown in Fig 2. The raingun was tested at pressures ranging from 20 to 80 pounds per square inch (psi) at intervals of 5 psi, for a duration of one hour for each pressure. Every set of data was repeated three times and for each data set, the parameters like discharge, pressure, radius of coverage and volume of water collected in each catch can, were measured.

Measurement of discharge. A water meter of 50 mm diameter was installed on the supply line to measure quantity of water entering into the raingun sprinkler irrigation system in cubic meters. Before starting the system, initial meter reading was recorded. After completion of each set of data, the final meter reading was again recorded. The difference in final and initial meter readings gave quantity of water entering into the raingun sprinkler irrigation system. By dividing quantity of water with time duration gave discharge of the raingun under a given pressure. The discharge of raingun under various pressures is presented in Table 1.

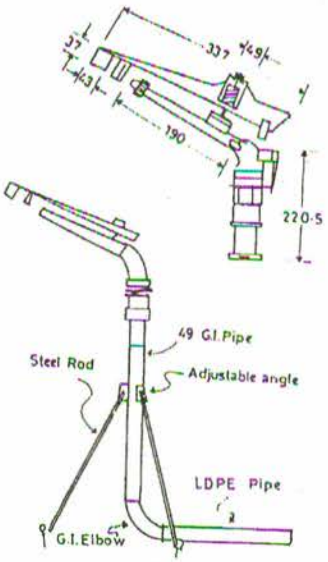

Fig 1. Schematic diagram of the Raingun (PY_1-30). (dimensions in mm).

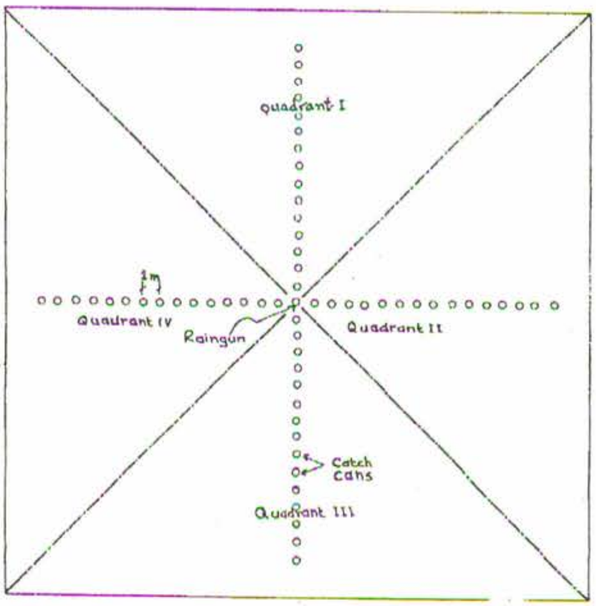

Fig 2. Schematic diagram of the Raingun (PY_1-30). (dimensions in mm).

Table 1
Discharge of the raingun with 6 mm diameter nozzle under various pressures

Serial number	Pressure (psi)*	Discharge (gpm)**
1	20	4.22
2	25	4.91
3	30	5.61
4	35	6.31
5	40	7.01
6	45	7.70
7	50	8.40
8	55	9.10
9	60	9.80
10	65	10.49
11	70	11.19
12	75	11.89
13	80	12.59

* 1 Psi, 6.8951 kpa; ** 1 gpm , 3.785 lpm.

Measurement of pressure. A pressure gauge, calibrated in psi, was installed on the supply line of the raingun to measure pressure. Another pressure gauge was installed in the pump control room near the well to regulate pressure. The required pressure was obtained by using bypass. When the required pressure was obtained, the raingun system was started. The pressure was again checked with the help of the pressure gauge installed on the supply line of the raingun (Fig 3). The required pressure was maintained throughout the operation of raingun for each set of data.

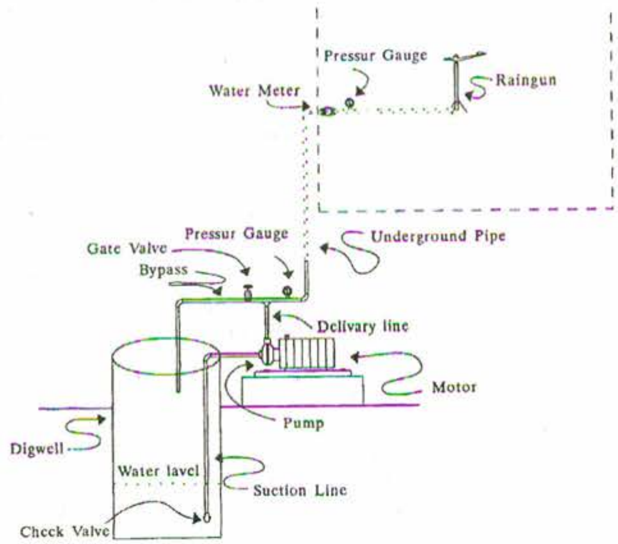

Fig 3. Schematic diagram of raingun PY_1-30 operating under different pressures.

Measurement of distribution of water. Before initiation of operation of the raingun, the catch cans were properly cleaned and placed in the field in four quadrants. At the end of the operation, the water collected in each catch can was measured using a graduated cylinder and recorded. The distribution of water of the raingun under various pressures was measured and recorded.

Measurement of radius of coverage. The catch cans were placed at measured distances from the raingun in four quadrants. The water collected in each catch can was measured and recorded. The distance from raingun to the last catch can where water reached is the radius of coverage of the raingun under a specific pressure. The radii of coverage of the raingun were measured under various pressures, are presented in Table 2.

Determination of application rate. The quantity of water collected in each catch can divided by area of mouth of the catch can gave depth of water applied to the field. The depth of water divided by time duration of the raingun gave application rate. The average application rate was obtained by dividing the sum of the depths of water collected in each catch can by total number of catch cans. In this method, the wetted areas were not considered so the theoretical application rate was obtained the following relationship (James 1988):

$$A = K\frac{Q}{a} \qquad \text{.................................} (1)$$

where;

A = application rate of the raingun, mm hr^{-1},
K = constant, 60.00,

Table 2
Radii of coverage of the raingun with 6 mm diameter nozzle under various pressures

Serial number	Pressure (psi)*	Radius of coverage (m)**
1	20	14.5
2	25	15.5
3	30	16.5
4	35	18.5
5	40	18.5
6	45	18.5
7	50	19.5
8	55	19.5
9	60	20.5
10	65	20.5
11	70	18.5
12	75	18.5
13	80	18.5

*1 Psi , 6.8951 kPa; **1 m , 3.2808 ft.

Q = discharge of the raingun, $l\,min^{-1}$ and
a = wetted area, m^2.

The wetted area of the raingun was calculated using the following relationship:

$$a = \pi \tau^2 \qquad \text{.................. (2)}$$

where;
a = wetted area of the raingun, m^2 and
τ = radius of coverage of the raingun.

The theoretical application rates under various pressures were calculated using already determined discharge and radius of coverage data of the raingun (Table 3).

Determination of coefficient of uniformity. The coefficient of uniformity of the raingun was determined using the following relationship (Christiansen 1942):

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

where
C_u = coefficient of uniformity, %,
X = absolute numerical deviation of individual observations from the average application, mm,
m = average of all the observations, mm and
n = total number of observations.

The layout of the quarters for determination of coefficient of uniformity is shown in Fig 4. The coefficients of uniformity for each quarter are presented in Table 4.

Table 3
Application rates of the raingun with 6 mm diameter nozzle under various pressures

Serial number	Pressure (psi)	Wetted area (m^2)	Application rate (mmh^{-1})	
			Average	Theoretical
1	20	660.52	2.44	1.45
2	25	754.77	2.56	1.48
3	30	855.30	2.86	1.49
4	35	1075.21	3.13	1.33
5	40	1075.21	3.12	1.48
6	45	1075.21	2.68	1.63
7	50	1194.60	3.33	1.60
8	55	1194.60	3.30	1.73
9	60	1320.30	3.66	1.69
10	65	1320.30	·2.59	1.80
11	70	1075.20	3.22	2.36
12	75	1075.20	3.24	2.51
13	80	1075.20	3.36	2.66

Table 4
Coefficients of uniformity of the raingun with 6 mm diameter nozzle in different quarters under various pressures

Pressure (psi)	Coefficient of Uniformity (%) Quarters			
	I	I+II	I+II+III*	I+II+III+IV**
20	87	76	71	57
25	82	64	56	42
30	81	62	50	35
35	88	80	74	52
40	90	83	81	59
45	85	80	81	64
50	92	88	80	52
55	87	80	81	61
60	88	86	67	40
65	83	82	81	67
70	90	88	83	67
75	87	86	83	67
80	89	83	81	63

* Effective diameter of coverage; ** Potential diameter of coverage.

Results and Discussion

The discharge, pressure, water distribution pattern and radius of coverage of the raingun (Py_1-30) with 6 mm diameter nozzle were measured under various pressures and the application rate and coefficient of uniformity were determined.

The relationship between pressure and discharge was determined in pounds per square inch (psi) and gallons per minute (gpm) respectively (Keller and Bliesner 1990) using techniques of linear regression, logarithmic function, exponential function and power function using pressure as independent and discharge as dependent variables. The relationship between pressure and discharge can be described mathematically as:

$$Q = a P^b \qquad \text{.................. (4)}$$
with $R^2 = 0.998$

where;
Q = Discharge of the raingun, gpm;
a = Coefficient, 0.377;
P = Pressure, psi; and
b = Exponent, 0.796.

It was observed that the discharge increased with the increase in pressure and ranged from 4.22 to 12.59 gpm for a pressure range of 20 to 80 psi, respectively (Fig 5).

Relationship between pressure and radius of coverage. The radius of coverage of the raingun increased with the increase in pressure but was not uniform and regular (Fig 6). The radius of coverage increased from 14.5 m at 20 psi to a maximum value of 20.5 m at 60 psi pressure. There was no increase at 65 psi pressure, then it decreased to 18.5 m at 70 psi and remained the same upto 80 psi pressure. The relationship can be described mathematically as:

$$R = a P^b \quad \text{.................................} (5)$$
with $R^2 = 0.658$

where;

R = Radius of coverage of the raingun, m;
a = Coefficient, 8.766;
P = Pressure, psi; and
b = Exponent, 0.190.

Relationship between pressure and application rate. The minimum and maximum average application rate without considering wetted area of the raingun were 2.44 mm h^{-1} at 20 psi and 3.36 mm h^{-1} at 80 psi pressure. There was no relationship between pressure and average application rate. However, the optimum average application rate of 3.33 mm h^{-1} was obtained at 50 psi pressure.

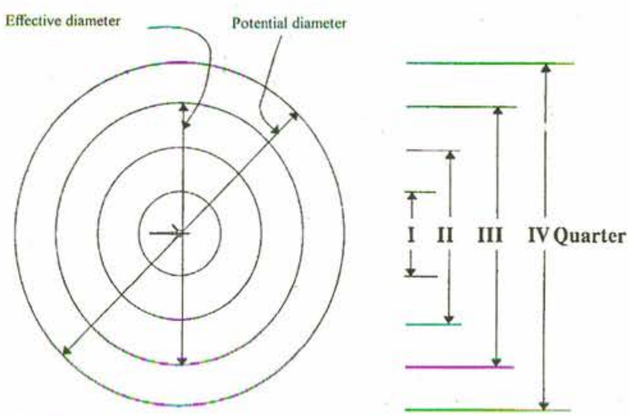

Fig 4. Layout of quarters for determination of coefficient of uniformity.

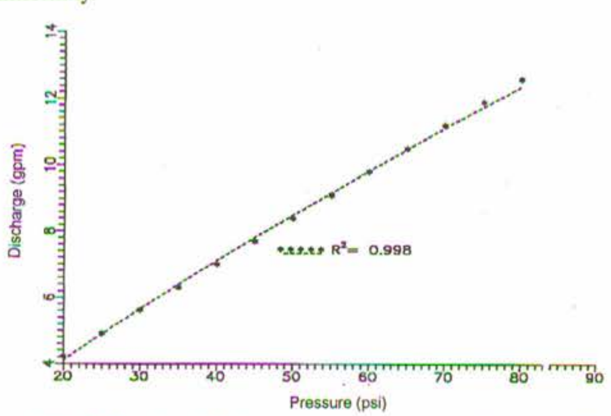

Fig 5. Relationship between pressure and discharge of the raingun with 6 mm diameter nozzle.

The maximum and minimum theoretical application rate with wetted area parameters were 2.66 mm h^{-1} at 80 psi pressure and 1.33 mm h^{-1} at 35 psi pressure.

The relationship between pressure and theoretical application rates of the raingun (Fig 7) were determined by using different statistical techniques using pressure as independent and application rate as dependent variable and the linear regression was used to describe the relationship. It can be described mathematically as:

$$A = c + bP \quad (6)$$
with $R^2 = 0.764$

where;

A = Application rate of the raingun, mm h^{-1};
c = Constant, 0.806;
b = Coefficient, 1.958; and
P = Pressure, psi.

Coefficient of uniformity of the raingun. The highest and the lowest coefficient of uniformity of the raingun was 92% in first quarter at 50 psi and 35% in fourth quarter at 30 psi respectively.

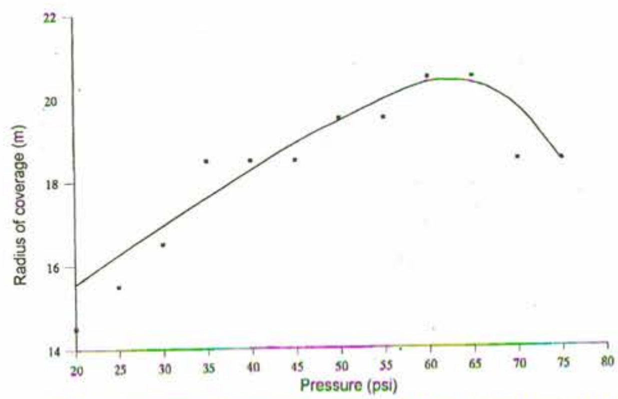

Fig 6. Relationship between pressure and radius of coverage of the raingun with 6 mm diameter nozzle.

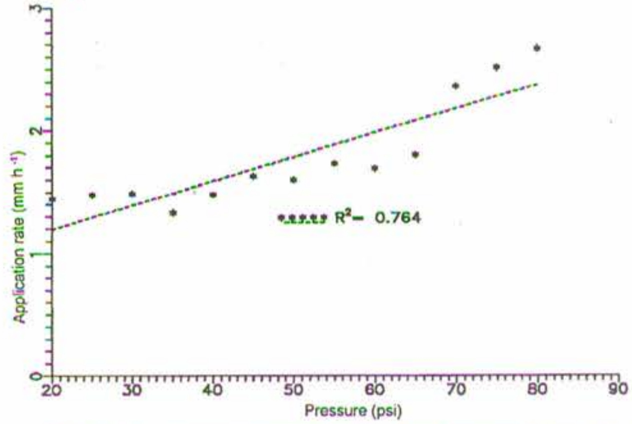

Fig 7. Relationship between pressure and theoretical application rate of the raingun with 6 mm diameter nozzle.

At potential diameter of coverage of 41 m , the highest coefficient of uniformity was recorded being 67% at 40 psi. The lowest coefficient of uniformity was 35% at 30 psi at the potential diameter of coverage of 33 m. At effective diameter of coverage, the highest coefficient of uniformity was 83% at 70 psi. The lowest coefficient of uniformity was 56% at 25 psi at the effective diameter of coverage of 23 m.

Conclusion

Based on the results of the present study, it is felt that further research studies are required to be undertaken to study the adequacy and suitability of raingun sprinkler irrigation system for different crops under various conditions with other models of rainguns as well.

The results of this study could be used for designing sprinkler irrigation systems for different farms.

The controlled laboratory facility should be established to undertake such studies for documenting the effect of wind speed on distribution pattern of irrigation water, radius of coverage and coefficient of uniformity of the raingun with different sizes of nozzles under various pressures.

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