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Sustainable Farming Practices: A Comprehensive Study on Rain Pipe Irrigation System Performance

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Abstract

Rain pipe irrigation has emerged as a promising solution for efficient water utilization and improved crop yields at a lower cost compared to traditional irrigation systems. An experiment was carried out to evaluate the hydraulic performance of rain pipes with different lengths (30 m and 45 m) and spacing (4 m and 5 m), operated at various pressures (1 kg cm^{-2}, 1.25 kg cm^{-2} and 1.50 kg cm^{-2}) using a 7.5 hp pumping system. Key parameters such as distribution uniformity, uniformity coefficient, mean application rate and coefficient of variation were measured. The results indicated that the rain pipe system achieved optimal performance when operated at an operating pressure of 1.50 kg cm^{-2}, with a rain pipe length of 30 m and a spacing of 4 m. This configuration resulted in the highest uniformity coefficient (87.83%), distribution uniformity (76.29%) and mean application rate (6.81 cm h^{-1}). Additionally, the maximum discharge per meter length of rain pipe and the maximum coverage width of one rain pipe were attained with a 30 m length operated at 1.5 kg cm^{-2}. These findings emphasize the effectiveness of rain pipe irrigation when employing an operating pressure of 1.5 kg cm^{-2}, a rain pipe length of 30 m and a spacing of 4 m. The study highlights the suitability of rain pipe irrigation as a cost-effective and efficient alternative for water management in Indian agriculture. By optimizing the operating pressure, rain pipe length and spacing, farmers can enhance water use efficiency and improve crop productivity, thereby contributing to sustainable agricultural practices in the face of limited water resources.

Keywords: Hydraulic performance, Rain pipe irrigation, Sustainable agriculture, Uniformity coefficient, Water scarcity

Introduction

Agricultural and rural development are closely tied to essential resources like land and water, which play significant roles in addressing global challenges such as hunger, poverty, climate change and the depletion of natural resources. In regions characterized by dry and semi-arid conditions, the availability of water poses a significant challenge to implementing intensive irrigation practices (Pandya and Rank, 2014). The main barrier to raising wheat yield in India is the lack of irrigation water (Vadalia and Prajapati, 2022). Precipitation is India's primary source of water and effective perception is crucial for agriculture (Chavda *et al.*, 2016). The Indian subcontinent is grappling with the challenges of a continuously expanding population and escalating urbanization, resulting in a surge in the need for water for industry, household consumption and agriculture. Over 70% of water use globally and 90% in developing nations is accounted for by agriculture, making it the biggest consumer of water overall. In order to meet irrigation needs, groundwater in particular is increasingly being mined in an unsustainable way (Pandya and Gontia, 2023). A significant limiting factor in coverage of irrigation is the prevalent use

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of flood irrigation, which has a low water use efficiency (Vadalia *et al*., 2022; Prajapati and Subbaiah, 2015). Low crop productivity is caused by a number of negative variables, including insufficient groundwater reserves in terms of quantity and quality, excessive evaporative loss due to inadequate rainfall and increased pest and insect damage as a result of climate change (Prajapati and Subbaiah, 2019).

In India, agriculture is the largest user of water resources and the rising demand for industrial and domestic water threatens to reduce water allocation for agriculture. Under the circumstances of low water availability, it is necessary to increase irrigation efficiency by irrigation water optimisation (Kathiriya *et al*., 2021). Therefore, achieving higher productivity in agriculture is necessary to meet market demands for food production, especially in resource-poor situations. Numerous other factors, including genotypes, pest/disease infestation and limited water availability, may also be contribute to crop production decline (Pandya *et al*., 2022). The gridded information on temperature is generally being used for various applications in agriculture (Parmar *et al*., 2019). To maximise yield per drop of water, it's crucial to control favourable soil moisture at the crop root zone and avoid soil losses (Prajapati and Subbaiah, 2018). In order to raise the standard of life for millions of people, particularly in rural regions, better planning, development and management of India's considerable assets, mainly its water and land resources, is urgently needed (Kumar *et al*., 2005).

Enhancing irrigation efficiency through optimised water management is necessary to address the issue of limited water availability and precise estimation of crop water requirements (ET_c) of any crop is prime requirement for scheduling of irrigation and efficient water management (Parmar and Tiwari, 2020). In order to reduce water use in Indian agriculture, micro-irrigation, including drip and sprinkler systems, has been introduced. Drip irrigation is considered the most efficient method and is suitable for irrigating a wide range of crops, particularly vegetables, orchard crops, flowers and plantation crops (Kunapara *et al*., 2016). Another emerging technique is rain pipe irrigation, which operates at low pressure and is well-suited for closely spaced crops like groundnut, onion and garlic, as well as vegetable crops. It can be utilized in various soil types.

Rain pipe irrigation serves as an alternative system to mini-sprinkler and drip irrigation, allowing efficient utilization of irrigation water. It entails using a low-pressure delivery method to apply water at a high pace over a brief period of time. The mistiest irrigation system will be created by the tiny water spray that the rain pipe produces. Compared to conventional sprinklers, it is softer and mistier. Sprinkler irrigation performance is impacted by variables such Christiansen uniformity coefficient, distribution uniformity and operating pressure (Sourell *et al*., 2003; Maroufpoor *et al*., 2010; Wenting and Pute, 2011; Salmeron *et al*., 2012). It can also accommodate the use of poor-quality water within certain limits. Rain pipe irrigation systems offer additional advantages such as the absence of filters and a low risk of clogging. These systems mimic rainfall by spraying water directly onto the soil surface or crops. Rain pipe irrigation systems excel in their ability to function efficiently even under fluctuating and low-pressure conditions. Therefore, it becomes imperative to assess the hydraulic performance of rain pipe systems when utilized in conjunction with submersible pumps under variable pressure, length and spacing.

Materials and Methods

The experiment was carried out at farm of office of Research Scientist (Agril. Engg.), JAU, Junagadh. It is 82.92 m above mean sea level and is situated at 21.5° N latitude and 70.44° E longitude.

A 7.5 hp AC submersible pump was used in the experiment. The field was covered with 32 mm-diameter rain pipes that were spaced 4 and 5 m apart and had lengths of 30 and 45 m, respectively. A grid of 2 m × 2 m measuring the experimental area between two rain pipes was used to place a matrix of catch cans at ground level. Christiansen's uniformity coefficient (CU), coefficient of variation (CV), distribution uniformity (DU) and mean application rate (MAR) were measured after the rain pipe was operated for 30 and 45 m, respectively, at three different pressures of 1.0, 1.25 and 1.50 kg cm^{-2}. The rain pipe was spaced at 4 and 5 m apart. A by-pass valve was utilised to control the pressure after a digital manometer was used to measure the operating pressure. In catch cans positioned between two rain pipes, the water released by the rain pipe was collected. The amount of water in catch cans was measured and the depth of the water was converted based on the catch can's cross-sectional area.

Estimation of Uniformity Coefficient

The uniformity coefficient is a quantifiable indicator of uniformity acquired from any size of sprinkler operating under a certain circumstance. Christiansen (Christiansen, 1942) presented the following formula for calculating the homogeneity coefficient. It is expressed by,

$$U_c = 100\left(1.0 - \frac{\sum x}{mn}\right) \qquad \text{.......................... (1)}$$

Where,

U_c = Uniformity coefficient developed by Christiansen, %

x = Absolute deviation of the individual observations from the mean, mm

m = Average value of all observations, mm

n = Number of observations

Estimation of Distribution Uniformity

The distribution uniformity (Du) is a useful concept for giving the uniformity of application for irrigation systems a numerical value. The term "pattern efficiency" (Pe) also refers to the homogeneity of the distribution. It is calculated by and it shows how evenly water is applied throughout the area.

$$D_u = \frac{\text{minimum depth}}{\text{average depth}} \qquad \text{.......................... (2)}$$

The lowest $1/4^{th}$ of the can utilised in a certain test is averaged to determine the minimum depth.

Estimation of coefficient of variation

According to ASAE (1991), the coefficient of variation (CV) is the product of the standard deviation of the applied water depths () and the average of the collected water depth.

$$CV = \frac{\sigma}{\mu} \quad \text{......................... (3)}$$

Where,

σ = Standard deviation of the water depth of catch-cans

μ = Mean of all water depth of catch-cans

Estimation of Mean Application Rate

The depth of water that a rain pipe applies to the soil surface in one unit of time is known as the mean application rate. To ascertain the volume of application during the rain pipe's operation at various locations throughout the field, an experiment using catch cans was carried out. The depth of application of the rain pipe can be calculated by dividing the volume by the cross-sectional area of the catch. The mean application rate of the rain pipe irrigation system is calculated using this depth. Application rate was calculated using formula,

$$I = \frac{\sum X}{n \times t} \quad \text{......................... (4)}$$

Where,

I = Application rate, mm h^{-1}

Σ X = total depth of water collected in the catch cans (volume/area of can), mm

n = number of catch cans

t = time of operation, h

Estimation of Discharge

Rain pipe discharge was measured by filling a bucket with the water released by each metre of pipe over the course of one minute. The water has been collected in a 0.45 m by 0.45 m bucket. By dividing the collected volume by the filling time, the discharge was computed. For each working pressure and length, the discharge observation was recorded twice.

Estimation of Width Coverage and Percentage of Overlap Area

It was manually measured using measuring tape to determine the largest breadth that could be wet by a single rain pipe at various lengths and operating pressures. And a percentage of the overlapped region was calculated using the data.

Results and Discussion

Testing at various operating pressures under rain pipes with a length of 30 m and a spacing of 4 m produced representations for the uniformity coefficient, distribution uniformity, coefficient of variation and mean application rate (Table 1).

Response of Operating Pressure on Uniformity Coefficient (CU) of Rain Pipe Irrigation

Figure 1 shows the impact of different operating pressures on the uniformity coefficient of the rain pipe. The value of the uniformity coefficient increased, according to the results, as operating pressure increased. The highest uniformity coefficient was measured at a 4 m spacing between rain pipes operating at 1.50 kg cm^{-2} pressure under a 30 m length of rain pipe, while the lowest value was measured at a 5 m spacing between rain pipes operating at 1.00 kg cm^{-2} pressure under a 45 m length of rain pipe.

Response of Operating Pressure on Distribution Uniformity (DU) of Rain Pipe Irrigation

As shown in Figure 2, the results showed that the distribution uniformity reached its highest value of 76.29% at a rain pipe spacing of 4 and operating pressure of 1.50 kg cm^{-2} under a rain pipe length of 30 m and its lowest value of 61.55% at a rain pipe spacing of 5 and operating pressure of 1.00 kg cm^{-2} under a rain pipe length of 45 m. It was shown that

Table 1: Uniformity coefficient, Distribution uniformity, Coefficient of variation and mean application rate for various combinations of length and spacing

Length (m)	Spacing (m)	Operating Pressure (kg cm^{-2})	Uniformity Coefficient (%)	Distribution uniformity (%)	Mean application rate (cm h^{-1})	CV (%)
30	4	1.00	82.16	65.16	5.06	17.83
		1.25	83.89	69.71	5.31	16.10
		1.50	87.83	76.29	6.81	12.16
	5	1.00	80.58	66.34	4.52	19.41
		1.25	82.23	68.72	5.06	17.76
		1.50	85.77	75.86	5.40	14.22
45	4	1.00	78.23	64.09	5.21	21.76
		1.25	81.78	64.87	5.30	18.21
		1.50	84.69	69.72	6.77	15.30
	5	1.00	77.18	61.55	4.50	22.81
		1.25	79.53	62.03	5.05	20.46
		1.50	80.60	64.87	5.39	19.39

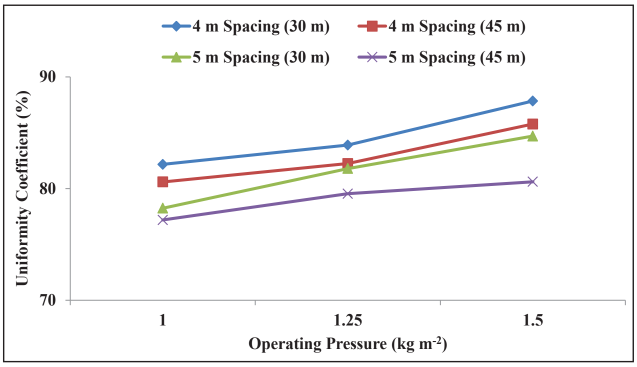

Figure 1: Response of operating pressure on uniformity coefficient of rain pipe

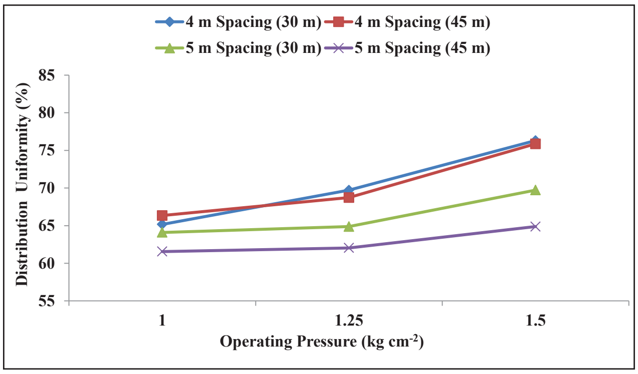

Figure 2: Response of operating pressure on distribution uniformity of rain pipe

as operating pressure increased, the value of distribution uniformity increased as well.

Effect of Operating Pressure on Mean Application Rate of Rain Pipe Irrigation

The highest value of mean application rate 6.8 cm h^{-1} was obtained when spacing of rain pipe kept 4 m and operated at pressure 1.50 kg cm^{-2} under 30 m length of the rain pipe and it was at par with same spacing and operating pressure under 45 m length. While, lowest value of 4.50 cm h^{-1} was obtained when spacing of rain pipe kept 5 m and operated at pressure 1.00 kg cm^{-2} under 45 m length of rain pipe (Figure 3). For rain pipes with a 30 m length and a 4 m spacing, it was found that the value of the mean application rate rose

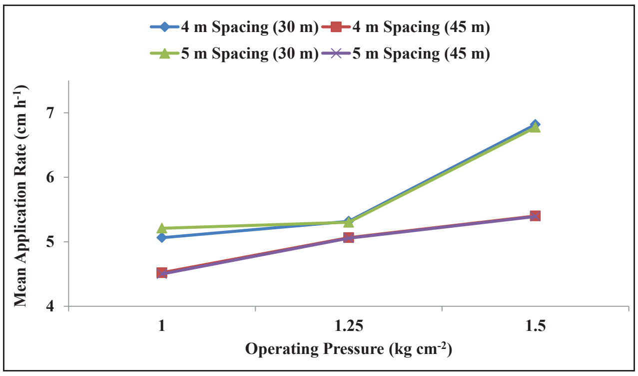

Figure 3: Mean application rate of rain pipe for different operating pressure

as operating pressure increased.

Discharge per Meter of Rain Pipe

Table 2 represents the discharge of a rain pipe per metre of length at various operating pressures. The rain pipe with a pressure of 1.50 kg cm^{-2} under 30 m of length produced the maximum value of 272 LPH discharge per metre, which was comparable to the rain pipe with a pressure of 1.50 kg cm^{-2} under 45 m of length shown in figure 4. While the lowest measurement of 181 LPH discharge per metre of rain pipe was made under 45 m of rain pipe at a pressure of 1.00 kg cm^{-2}. Additionally, it was observed that as rain pipe pressure grew, the value of discharge per metre of rain pipe increased.

Table 2: Discharge and width coverage by one pipe at different operating pressures

Length (m)	Operating pressure (kg cm^{-2})	Discharge (L h^{-1})	Width coverage by one rain pipe (m)
30	1.00	195	7.6
	1.25	213	8.8
	1.50	272	10.2
45	1.00	181	6.6
	1.25	202	7.4
	1.50	245	8.4

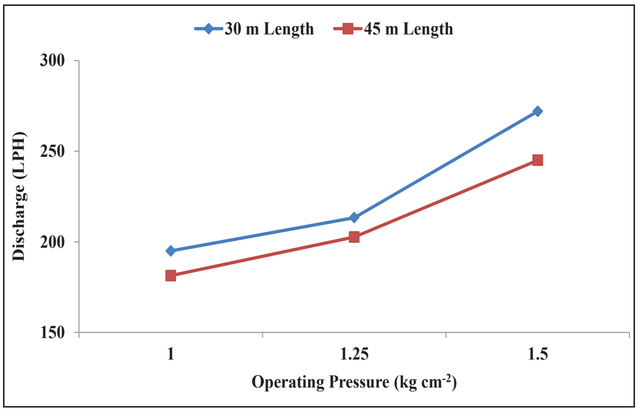

Figure 4: Discharge rain pipe at various operating pressure

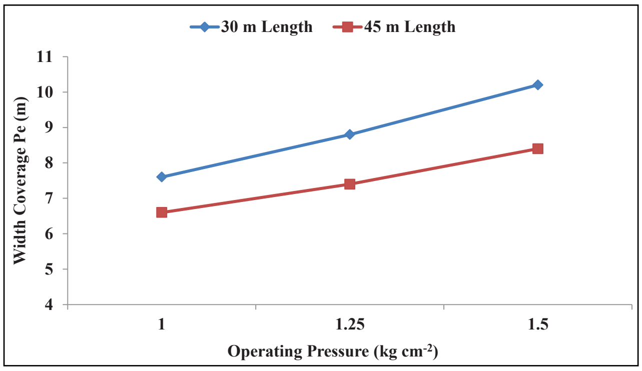

Figure 5: Width coverage by one rain pipe at various operating pressure

Width of Coverage

The result revealed that maximum width of coverage of 10.2 m by one rain pipe was measured at 1.50 kg cm^{-2} pressure under 30 m length of rain pipe but it was at par with the values of 45 m length of rain pipe at same pressure. The minimum width coverage by one rain pipe 6.6 m was measured at 1.00 kg cm^{-2} pressure under 45 m length of rain pipe as depicted in figure 5. Additionally, it was observed that when rain pipe pressure increased, the width covered by one pipe increased.

Conclusion

The rain pipe irrigation system achieved its highest values for uniformity coefficient, distribution uniformity and mean application rate when operated at a pressure of 1.5 kg cm^{-2}. The results indicated that as the operating pressure increased, the uniformity coefficient, distribution uniformity and mean application rate also increased. Conversely, decreasing the pressure resulted in an increase in the coefficient of variation. Therefore, for optimal uniformity in the rain pipe irrigation system, it is recommended to operate it at a pressure of 1.5 kg cm^{-2}.

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