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Adaptation and Evaluation of Micro Rain Pipe for Small Scale Irrigation

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ABSTRACT

Micro rain pipe irrigation is a hopeful result for effective water utilization and improved crop yields at a lower cost compared to traditional irrigation systems. Technology adaptation was carried out to evaluate the hydraulic performance of rain pipes with different rain pipe spacing (3 and 4) m and hole spacing of (10, 20 and 30) cm using a 3inch pump having 5 Hp system. Hydraulic performance indicators such as uniformity coefficient, distribution uniformity, mean application rate, discharge per hole, coefficient of variation and width coverage were measured. The highest uniformity coefficient of (91.23%), distribution uniformity (84.93%) and mean application rate (17.17mm/h) were recorded under 3 m and 20 cm rain pipe and hole pipe spacing. The maximum width coverage of 6.25 m by one rain pipe was measured at 30 cm hole space under 3 m spacing of rain pipe but it was at nearest with the values of 20 cm hole space of rain pipe with 5.82 m. The results of evaluation indicated that, the appropriateness of rain pipe irrigation as economical and effective alternative for water management in lower space crops. Therefore, the findings of this study indicates that farmers can enhance water use efficiency and improve crop productivity in water scarce area at 1kg/cm^2 operating pressure under 3 m and 20 cm rain pipe and hole space respectively.

Keywords: Hole space; Hydraulic performance; Rain pipe; Rain pipe space; Small scale irrigation; Uniformity.

1. Introduction

Ethiopian farming is largely dependent on rain-fed smallholder agriculture method as a means of food and income for its population. The low level of performance of rain-fed agriculture could not only be credited to erratic nature of rainfall but also weakening soil fertility and slow acceptance and/or lack of appropriate technologies. On the other hand, private peasant farmers use irrigation at small scale level to enable them increase crop production and as a means of raising income. Small scale irrigation not only increase crop production, but also improves cropping intensity and reduces the effect of erratic rainfall (Hordofa *et al*., 2008).

The exercise of irrigation in Ethiopia has a long way to go to bring about the required change. The farmers who practice irrigation was estimated about 1.2 million but the total irrigated crop area in Ethiopia within the private farmer holdings was estimated around 165,540 hectares (CSA, 2021).

Irrigation planning of micro-irrigation systems is usually based on a water budget method to preserve a promising soil water content status in the root zone, i.e., to minimize periods of water stress and leaching below the root zone. Low-pressure sprinkler that operate at <200 KPa is by changing the internal nozzle structure decrease the operating pressure without bargaining the dispersion uniformity of water droplets and then lowering operating costs (Chauhdary *et al*., 2024).

Sprinkler irrigation is considered the greatest efficient method and is appropriate 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 is a level hose pipe with thin wall to be perforated micro holes continuously under certain distance on one side of the rain pipe; these holes are made with nano punching technology with a zigzag pattern to ensure uniform flow of water. Rain pipe irrigation has begun as a promising solution for efficient water utilization and improved crop yields at a lower cost compared to traditional irrigation systems. Optimizing the working pressure, rain pipe length and spacing, farmers can enhance water use efficiency and improve crop productivity, thereby causal to sustainable agricultural practices in the face of limited water resources (Bhadarka *et al*., 2023).

There is need to increase irrigation efficiency through optimization of irrigation water under conditions of restricted water availability. Under this condition, high application efficiencies can only be obtained by pressurized irrigation. In recent years, the more efficient pressurized irrigation systems such as drip and sprinkler irrigation has become more practical instead of open channel irrigation system to increase the water use efficiency (Cobo *et al*., 2014).

Development in application efficiencies will reduce the problem of waterlogging and salinity. Therefore, it is important to develop techniques to use the available resources of irrigation water more efficiently during field application. Application efficiency can be increased by adopting pressurized irrigation system like (rain-gun sprinkler and rain pipe) irrigation. It was also noticed that nitrate-nitrogen leaching was low with 50 mm depth of irrigation by this method of irrigation as compared to 75 mm depth of irrigation by basin and furrow irrigation method (Rana *et al*., 2006).

Rain pipe irrigation methods offer additional advantages such as the absence of filters and a low risk of clogging. These systems copycat rainfall by spraying water directly onto the soil surface or crops. Compared to conventional sprinklers, it is softer and mistier. Sprinkler irrigation performance is obstructed by variables such Christiansen uniformity coefficient, distribution uniformity and operating pressure (Wenting and Pute; Salmerón *et al*., 2012; Eisa *et al*., 2010; Salmerón1, 2010; Sourell, 2003). It can also accommodate the use of poor-quality water within certain limits.

Water application uniformity is a significant performance principle for the design and evaluation of pressurized irrigation systems (Hoffman *et al*., 2007). Uniformity of a system is a measure of its ability to apply the same depth of water to every unit area. Without good uniformity, it is impossible to irrigate adequately and efficiently; parts of the field will be either over-irrigated or under-irrigated. The magnitude of coefficient of uniformity (CU) is usually greater than that of DU, but this is not the case for all data sets (Zhang and Merkley 2017).

Micro rain pipe irrigation systems are best in their ability to function efficiently even under un-stable and low-pressure conditions. Therefore, this study was conducted with the objective of adapting and evaluating the performance of rain pipe under different pipe and hole spacing.

2. Materials and Methods

2.1. Description of the study area

The technology was evaluated in the Research Center of Asella Agricultural Engineering located in Asella town at 2430 m above sea level, 7°55’59.3N latitude and 39°07’52.52’’E longitude.

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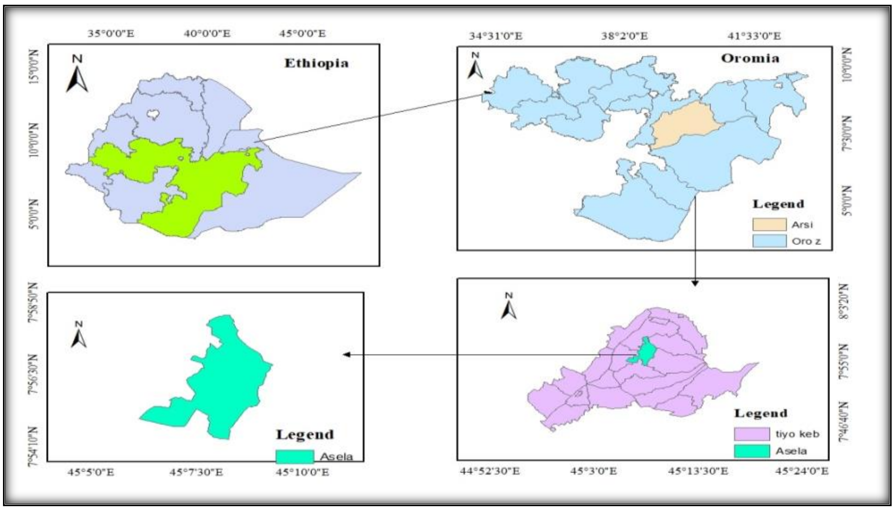

Figure 1. Study area map

2.2. Evaluation procedure of rain pipe

The test place was laid with 63 mm-diameter pvc pipes that were spaced 3 m and 4 m apart and had length of 12 m as shown in figure 2 below. The space between holes on the PVC pipe was (10, 20 and 30) cm that were punched by 2 mm drill bit. A 5 Hp water pump was used as a power source to evaluate the micro rain pipe. A grid of 2 m × 2 m test 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 to estimate the hydraulic performance of rain pipe. In catch cans positioned between two rain pipes, the water released by the rain pipe was collected. The amount of water in catch cans were measured and the depth of water was converted based on the catch can's cross-sectional area.

Figure 2. Micro rain pipe on test

2.3. Estimation of discharge

Discharge of rain pipe was estimated by collecting the water released by the rain pipe per meter length into a bucket in a given time. By dividing the collected volume by the filling time, the discharge was computed (Ali, 2011).

$$q = \frac{v}{\Delta t} \quad \ldots(1)$$

Where, q – Rain pipe discharge (liter/hour); v – Volume of water collected from single hole of rain pipe (liters); and Δt – Time duration (hour).

2.4. Estimation of distribution uniformity

The distribution uniformity (Du) was measured by the depth of water falling into a series arranged catch cans during an irrigation event and analyzing the variation of water depths in the catch cans. It shows how evenly water was applied throughout the area (Howell and Hiler 1975).

$$\text{Du} = \frac{\text{Minimum depth}}{\text{Average depth}} \quad \ldots(2)$$

The minimum depth was calculated by taking the average of the lowest 1/4th of the can used in a particular test.

2.5. 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 (1942) presented the following formula for calculating the homogeneity coefficient.

$$\text{UC} = 100\left(1 - \frac{\sum x}{mn}\right) \quad \ldots(3)$$

Where, Uc – Uniformity coefficient developed by Christiansen, %; x – Absolute deviation of the individual observations from the mean, mm; m – Average value of all observations, mm; and n – Number of observations.

Christiansen developed uniformity coefficient to measure the uniformity of sprinkler systems, and it is most often applied in sprinkler irrigation situation. It was rarely used in other types of irrigation. Values of UC typically range from 0.6 to 0.9 (Christiansen, 1942).

2.6. Estimation of coefficient of variation

According to Lamm *et al*. (1997), the coefficient of variation (CV) compares the standard deviation of the applied water depths (σ) and the average of the collected water depth.

$$\text{Cv} = \frac{\sigma}{\mu} \quad \ldots(4)$$

Where, σ – Standard deviation of the water depth of catch-cans, ml; μ – Mean of all water depth of catch-cans, ml.

2.7. Estimation of mean application rate

Application rate should be correlated to infiltration rate of the soil, and should not be greater than the infiltration rate in order to prevent surface runoff and/or ponding. It is the depth of water that a rain pipe applies to the soil surface in one unit of time.

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 can. The mean application rate of the rain pipe irrigation system was calculated by using this formula;

$$I = \frac{\Sigma X}{n \times t} \quad \ldots(5)$$

Where, I – application rate, mm/h; 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.

2.8. Estimation of width coverage

It was manually measured using measuring tape to determine the largest extent that could be wet by a single rain pipe at various lengths and optimum water pump discharge.

3. Results and Discussions

Testing at different hole space under rain pipes with a length of 12 m and a spacing of 3 and 4 m produced representations for the discharge, uniformity coefficient, distribution uniformity, coefficient of variation and mean application rate (Table 1).

3.1. Effect of rain pipe and hole space on uniformity coefficient

The highest uniformity coefficient 91.23% was measured at 20 cm hole spacing at 3 m rain pipe spacing and the lowest 86.08% was recorded at 10 cm hole spacing for 4 m rain pipe spacing (Table 1). An operating pressure gauge was 1kg/cm^2 at maximum water pump discharge.

Table 1. Uniformity parameter for various hole and rain pipe space

Rain pipe spacing (m)	Hole spacing (cm)	Uniformity coefficient (%)	Distribution uniformity (%)	Coefficient of variation (%)	Mean application rate (mm/hr)
3	10	87.55	80.14	17.20	10.44
	20	91.23	84.93	10.71	17.17
	30	89.94	83.12	11.32	30.31
4	10	86.08	79.10	18.40	10.40
	20	89.88	84.53	11.79	16.93
	30	88.74	82.11	12.64	29.94

3.2. Effect of rain pipe and hole space on distribution uniformity

As shown in (Table 1), the highest distribution uniformity obtained was 84.93 and 84.53% for 3 and 4m rain pipe spacing respectively. The lowest value of distribution uniformity (79.10 and 80.14) % was obtained at a rain pipe spacing of 3 and 4 m respectively 10 m hole spacing.

Kathiriya *et al*. (2021) and Bhadarka *et al*. (2023) also evaluated for (4 and 5) m rain pipe spacing and obtained that at maximum operating pressure, the value of distribution uniformity and uniformity coefficient increased for the shortest rain pipe spacing.

3.3. Effect of rain pipe and hole space mean application rate

The highest value of mean application rate 30.31 mm/hr was obtained when spacing of rain pipe kept 3 m and 30 cm hole spacing. While, the lowest value 10.4 mm/hr was obtained when spacing of rain pipe is 4 m and 10 cm hole spacing (Table 1). This result was similar with the finding of Bhadarka *et al*. (2023), as operating pressure increase the value of mean application rate increase.

3.4. Correlation coefficient

A regress equation about the uniformity coefficient and distribution uniformity analysis for 3 m rain pipe spacing and different hole spacing of rain pipe presented in (Figure 3). It was observed that uniformity coefficient was consistently higher than distribution uniformity and both are inversely related to coefficient of variation. This result is found to be in line with the finding obtained by (Bliesner, 1990). The maximum magnitude of CV (10.71%) was attained at hole spacing of 20 cm and 3 m rain pipe spacing (Table 1).

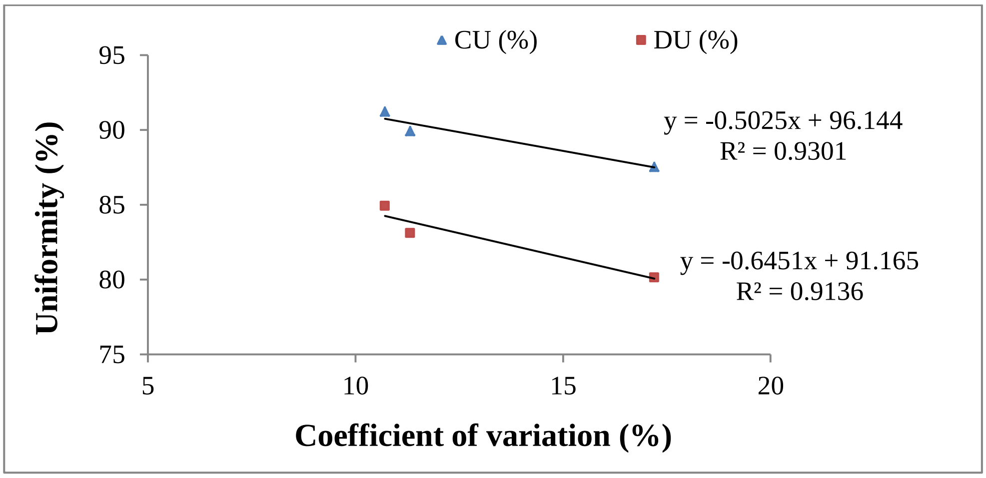

Figure 3. Relationship between UC and DU with CV of rain pipe

3.5. Rain pipe discharge per hole

Rain pipe hole discharge was affected by the number tested at a time using the catch can test method. An average rain pipe discharge obtained was 18.42, 37.27 and 61.77 liter/hr for 3 m rain pipe spacing and 18.05, 36.73 and 60.97 liter/hr for 4 m rain pipe spacing under 10, 20 and 30 cm hole spacing respectively (Table 2). It reveals that as the space between holes on the rain pipe increase its discharge also increase. Kathiriya and Kelaiya (2021) and Bhadarka *et al*. (2023) also observed that the value of discharge per hole of rain pipe was increased as pressure increased for 4 m spacing of rain pipe.

3.6. Rain pipe width coverage

The maximum width coverage of 6.25 m by one rain pipe was measured at 30 cm hole spacing under 3 m space of rain pipe but it was at nearest with the values of 20 cm hole space of rain pipe (Table 2). The minimum width coverage by one rain pipe 3.20 m was measured at 10 cm hole space under 4 m length of rain pipe. Increasing the hole space of rain pipe increase the width coverage. Additionally, Kathiriya and Kelaiya (2021) and Bhadarka *et al*. (2023) found that when rain pipe pressure increased, the width covered by one rain pipe increased.

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Table 2. Mean discharge and width coverage of rain pipe

Rain pipe spacing (m)	Hole spacing (cm)	No of hole per pipe	Discharge per hole (liter/hr)	Width coverage by one rain pipe (m)
3	10	120	18.42	3.34
	20	60	37.27	5.82
	30	40	61.77	6.25
4	10	120	18.05	3.20
	20	60	36.73	5.65
	30	40	60.97	6.10

3.7. Rain pipe actual discharge

Actual rain pipe discharge more than pump discharge 60 m^3/hr doesn't give the required irrigation uniformity.

Table 3. Actual rain pipe discharge

Rain pipe spacing (m)	Hole spacing (cm)	Total length of pipe (m)	No of hole per pipe	No of lateral pipe	Total No of hole	Discharge per hole (l/hr)	Actual discharge (l/hr)
3	10	240	480	6	2,880	18.42	53,050
	20	240	240	6	1,440	37.27	53,669
	30	240	160	6	960	61.77	59,299
4	10	240	480	6	2,880	18.05	51,984
	20	240	240	6	1,440	36.73	52,891
	30	240	160	6	960	60.97	58,531

4. Conclusions

The rain pipe irrigation system achieved its highest values for uniformity coefficient, distribution uniformity and mean application rate when operated at a hole space of 20 cm and 3 m between two rain pipes. The results indicated that as the hole space increased from 10 to 20 cm, the uniformity coefficient, distribution uniformity and mean application rate also increased and decreased for 30 cm spacing. Conversely, at 20 cm hole space of rain pipe there is an increase in the coefficient of variation.

5. Recommendations

Micro rain pipe perform better if the water pipe is operated/ installed with less than 2.5 inch PVC pipe and further evaluated on-farm level with low spaced crops or vegetables and different soil types. Therefore, for optimal uniformity in the rain pipe irrigation system, it is recommended to operate at a hole space of 20 cm and 3 m between rain pipe.

Declarations

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Competing Interests Statement

The authors declare no competing financial, professional, or personal interests.

Consent for publication

The authors declare that they consented to the publication of this study.

Authors' contributions

All the authors took part in literature review, analysis and manuscript writing equally.

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