

Application of Capillary Irrigation Systems on Land (Paddy Field Soil, Field Soil and Farm Soil)

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Abstract

Capillary irrigation utilizes water from a water source to a reservoir, where plants absorb it through a wick. Soil porosity is a functional space connecting the soil body with its environment. Water loss is a complex phenomenon in a water distribution system that refers to the volume of water lost between the production source and the point of consumption. Moisture content is the amount of water contained in a material and is expressed as a percentage of the material's wet or dry weight. The capillary irrigation system was designed using a 1.5 L aqua bottle and flannel cloth as a water delivery medium with varying cloth placement depths (2 cm, 4 cm, and 6 cm). This system was applied to paddy fields, farms, and field soil. The parameters observed included soil porosity, moisture content, and water loss. Based on the study's results, farm soil had the highest porosity with an average of 81.3%, followed by field soil at 77.7% and paddy soil at 75.3%. The results of moisture content observations show that farm soil has the highest moisture content with an average of 94.67%, followed by paddy soil at 77.38% and field soil at 68.17%. Based on weekly water volume data, farm soil has the highest average water volume at each axis depth, followed by field soil, and the lowest is paddy soil. Capillary irrigation works effectively. Farm soil has the highest porosity and moisture content and is best for aeration and drainage.

Keywords: Capillary Irrigation; Field Soil; Farm Soil; Kale Plants; Paddy Field Soil.

Introduction

Irrigation is a crucial component of agricultural activities, playing a role in ensuring water supply for plants, especially during the dry season or in areas with uncertain rainfall intensity. One irrigation innovation currently being developed is capillary irrigation, a passive irrigation system that utilizes capillary action to channel water from the source to plant roots through a conductive material. This method is considered efficient in water use, highly suitable for application on narrow plots and small-scale projects, and flexible in various soil types (Al Mayahi et.al, 2020).

The success and efficiency of irrigation systems, including capillary irrigation, are significantly influenced by the physical characteristics of the soil, including porosity, texture, structure, and moisture content (Fadl M.E. et.al, 2024). In this context, soil porosity refers to the proportion of empty space between soil particles that can be filled with water and air. Soils with high porosity tend to have good aeration and drainage, facilitating vertical and horizontal water movement, which is essential in passive irrigation systems such as capillary irrigation. Conversely, soils with low porosity can hinder water absorption and distribution, thus reducing the effectiveness of the

irrigation system (B A A H Al Khateb et. Al, 2025). Furthermore, soil moisture content, which is the amount of water contained in the soil at a given time, is also an important indicator in determining how much water is available to plants. Optimal moisture content supports plant growth, while water deficiency or excess can disrupt plant metabolism. Water loss during the distribution process, whether through evaporation, seepage, or leakage, also poses challenges in irrigation management (Abdullateef et. al, 2022). Therefore, understanding the physical properties of the soil is crucial in designing and implementing efficient irrigation systems, including capillary irrigation technology (Cordero et.al, 2023).

This study aimed to evaluate the performance of a capillary irrigation system under various soil conditions, focusing primarily on porosity, moisture content, and water loss. A simple capillary irrigation system was designed using used 1.5-liter mineral water bottles as water storage containers and flannel cloth as a conducting medium that functions as a capillary wick. One innovative aspect of this study was the variation in the depth of the wick cloth placement into the soil, namely at a depth of 2 cm, 4 cm, and 6 cm, to determine the effect of the wick position on water distribution. Experiments were conducted on three types of soil commonly used in agriculture: paddy soil (which tends to be clayey and saturated with water), farm soil (which has a crumbly structure and good aeration), and field soil (which is generally looser and has a moderate water storage capacity). During the one-week observation period, changes in soil moisture content, porosity level, and the volume of water absorbed from the bottle were recorded and analyzed, which served as an indicator of water loss. This experimental design is expected to provide a comprehensive picture of the relationship between capillary wick depth, soil type, and the effectiveness of water absorption in a capillary irrigation system.

Literature Review

Irrigation is the provision of water to plants to meet their water needs for growth. Irrigation is the activity of regulating and providing water to meet agricultural needs through the use of water from surface water and groundwater. Irrigation is the effort to provide and regulate water to support agriculture, which includes surface water irrigation, groundwater irrigation, pump irrigation, and pond irrigation (Gamal et.al, 2025).

Soil is one of the land components that has an important role in plant growth and crop production. It is because, besides functioning as a place/medium for plant growth and holding and providing water for plants, soil also plays a role in providing nutrients needed by plants to support plant growth. Physically, soil functions as a place for the growth and development of roots that support upright plant growth and supply water and air needs. Chemically, it functions as a warehouse and supplier of nutrients (simple organic and inorganic compounds and essential elements such as N, P, K, Ca, Mg, S, Cu, Zn, Fe, Mn, B, and Cl). Biologically, it functions as a habitat for biota (organisms) that actively participate in providing these nutrients and additives (growth promoters, protection) for plants (Gunawan et al., 2019).

Total porosity is the easiest initial indicator of good or poor soil structure. High soil porosity will occur if the soil's organic matter content is also high. Soils with crumbly and granular structures have higher porosity than soils with dense structures. Hanafiah (2005) states that porosity reflects the ease with which water flows through the soil (permeability) or the rate at which water flows through the soil mass (percolation) (Minangkabau, 2022).

Irrigation is an alternative way to provide water to agricultural crops when crop water requirements exceed the available water supply. Providing irrigation water to agricultural land aims to optimally meet crop water needs during their growth period. Irrigation water supply is often uncontrolled, resulting in an imbalance in water supply. The amount of irrigation water used

impacts agribusiness costs (Rinasari et al., 2014).

Capillary irrigation is a micro-irrigation system that boasts a high level of water efficiency. This capillary irrigation system works by utilizing a porous medium, such as flannel, to channel water using the principle of capillarity through a water source. The advantages of capillary irrigation include high water efficiency, ease of application, ease of construction, and relative affordability.

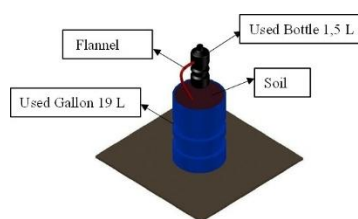
Capillary irrigation is a wick system that utilizes the principle of capillarity, whereby the water and nutrients supplied to plants are absorbed directly by the plants themselves through the wick. The amount of water used can be optimized so that plants use only the necessary amount of water. Furthermore, by avoiding water waste, farmers save time on watering (Harahap 2015).

Research Method

The initial step in this research was designing a capillary irrigation system. This system was constructed using used mineral water bottles as water containers and flannel as a medium for conducting water into the soil. The assembly process began by heating a soldering iron to create a hole in the top of the bottle. Once the hole was formed, the flannel was cut to the required length and inserted through the hole until it reached the bottom of the bottle. This fabric acts as a capillary wick, drawing water from the bottle into the growing medium. Before the system was implemented, a preliminary test was conducted by filling the bottle with water to ensure the flannel could absorb and channel water capillarily into the surrounding environment (Amprin et.al, 2019).

The next stage was installing the capillary irrigation system into the growing medium. First, the assembled capillary irrigation system was prepared for planting in a gallon jug containing soil. A hole was dug 24 cm deep to vertically plant the irrigation bottle (Smagin A. et.al, 2024). The capillary system was then planted and covered with soil for stability. The flannel, which acts as a water wick, was then inserted into the soil at varying depths: 2 cm, 4 cm, and 6 cm. The purpose of this variation was to observe the effect of wick depth on the water absorption and distribution capacity of various soil types: paddy fields, farm soils, and dry fields (Roonjho S. et.al, 2022).

The final step in this study was to observe the effectiveness of capillary irrigation, which was conducted using three main parameters: soil porosity, soil moisture content, and water loss. Porosity was calculated by comparing bulk density (dry weight of soil divided by soil volume) to particle density using the formula $\text{porosity} = 1 - (\text{bulk density} / \text{particle density})$. To obtain this data, soil samples from each soil type were taken and analyzed in the laboratory. Next, soil moisture content was calculated based on the ratio of wet weight to dry weight of the soil, using the formula $\text{KA} = (\text{wet weight} - \text{dry weight}) / \text{dry weight} \times 100\%$. Furthermore, water loss was measured by recording the initial volume of water (1.5 liters) poured into a bottle (Orge R, 2019). After one week of observation, the remaining water was measured again using a measuring cylinder. The difference in water volume indicates how much water has been absorbed or lost during the observation period.

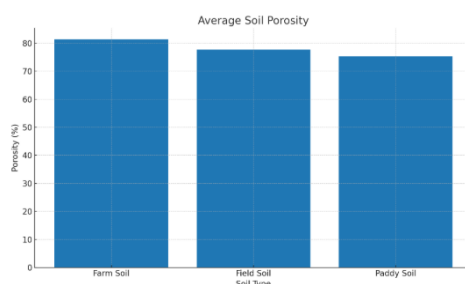


Design of capillary irrigation system

Results and Discussion

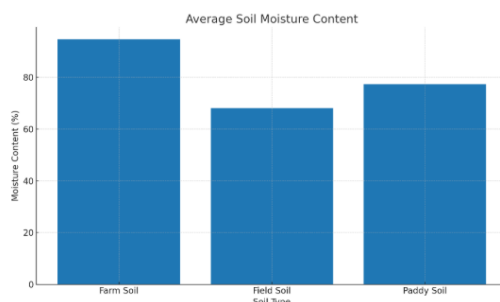
This study aimed to evaluate the effectiveness of a capillary irrigation system on three different soil types: farm soil, field soil, and paddy soil. The evaluation was conducted by measuring three main parameters: soil porosity, soil moisture content, and water loss during one week of capillary irrigation. The capillary irrigation system used was designed using used mineral water bottles as reservoirs and flannel cloth as a medium for delivering water into the soil. Variations in the depth of the flannel cloth (2 cm, 4 cm, and 6 cm) were applied to determine their effect on the system's performance in delivering water to the plant root zone.

The results of soil porosity measurements showed that farm soil had the highest porosity, with an average of 81.3%, followed by field soil at 77.7%, and paddy soil at 75.3%. High porosity in farm soil indicates a looser soil structure with larger pore spaces, thus better able to store and distribute water and air. Conversely, lower porosity in paddy and field soil indicates a denser soil structure, which can restrict the movement of water and air within the soil and impact irrigation effectiveness.



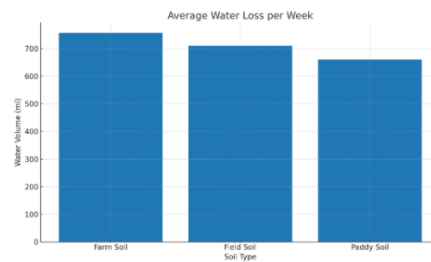
Average Soil Porosity

Furthermore, observations of soil moisture content confirmed the previous results. Farm soil had the highest moisture content, at 94.67%, while paddy and field soils had moisture contents of 77.38% and 68.17%, respectively. These results indicate that farm soil is not only able to absorb more water but also retains soil moisture for longer periods. This is supported by the soil's porous structure and high water-holding capacity, making it the most suitable growing medium for capillary irrigation systems.



Average Soil Moisture Content

In terms of water loss, or the volume of water used by the system over a week, a similar pattern was observed. Farm soil showed the highest average water loss of 756.67 ml, followed by field soil at 710.00 ml and paddy soil at 660.00 ml. This water loss indicates the amount of water absorbed and used by the soil through capillary action. Farm soil, with its high absorption capacity, demonstrates more optimal water use, while paddy soil, despite its relatively good water retention, exhibits lower water absorption through the capillary system.



Average Water Loss per Week

Overall, the results of this study indicate that the capillary irrigation system works effectively, especially on farm soils with the most favorable physical characteristics, namely high porosity and high-water retention capacity. This system has been proven to be able to passively channel water without requiring additional energy and is efficient for use in small, heterogeneous areas. These findings contribute to the development of water-efficient irrigation methods that are adaptive to soil conditions and can be a sustainable solution to support agricultural practices in areas with limited water resources.

This result aligns with the current research of Semananda, 2018, where capillary irrigation can function effectively, passively channel water, and suit small-scale or water-limited contexts—especially in favorable soil conditions. The -0.2 m porous membrane method and wick systems offer concrete evidence of its promising application, while organic capillary barriers underline innovative ways to maximize soil retention and crop uptake.

According to Gbadegesin, L., et al, 2022, soil characteristics significantly influence capillary irrigation performance. Systems are most effective in soils with higher clay content, porosity, and water retention capacity, which promote optimal wetting fronts and water distribution.

Conclusion

This research successfully designed and installed a capillary irrigation system using simple materials such as 1.5-liter mineral water bottles and flannel as wicks and used 19-liter gallon jugs filled with soil. Observations showed that this system worked well, distributing water capillary into the growing medium effectively and sustainably.

In terms of soil physical properties, farm soil demonstrated superior characteristics with the highest porosity of 81.3% and an average moisture content of 94.67%. This was followed by paddy and field soil, which had lower porosity and moisture content. The relatively uniform soil bulk density (± 2.66 g/cm³) reinforced the finding that farm soil has better aeration and water retention capacity.

The volume of water absorbed through the capillary irrigation wick was also highest in farm soil at all depths (2 cm, 4 cm, and 6 cm), followed by field and paddy soil. Overall, these results indicate that the capillary irrigation system is most effective when applied to farm soil with a structure and water retention capacity that optimally supports plant needs.

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