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Monitoring Water Depth and Seepage Rates in Pitcher Irrigation for Sustainable Crop Water Management

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Pitcher irrigation is an ancient yet effective method for delivering water directly to plant root zones, particularly in regions facing water scarcity. The main objective of this study is to evaluate the efficiency of pitcher irrigation in conserving water and supporting brinjal crop growth. This study investigates the efficiency and dynamics of a pitcher irrigation system in supplying water to brinjal

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crops, utilizing nine porous clay pitchers buried near the plants. Water depth in the pitchers was monitored from March 1 to March 22, 2024, at three intervals daily. Initial water levels of 15 cm were recorded on March 1, followed by gradual declines in water depth over time, with some pots showing rapid depletion, particularly during peak daylight hours. Pot 4 exhibited the most significant water loss, likely due to increased soil absorption or higher crop water demand, while Pots 1 and 3 showed more consistent water retention. The study revealed significant variation in seepage rates, with higher water loss during the day, particularly in the afternoon, compared to slower overnight seepage. These findings emphasize the need for careful irrigation management, including tailored refill schedules, to ensure uniform water availability and prevent moisture deficits. The results demonstrate that pitcher irrigation can effectively sustain crop growth, but its efficiency depends on continuous monitoring and adjustments based on local conditions.

Keywords: Pitcher irrigation; brinjal; seepage.

1. INTRODUCTION

Irrigation is a vital component in agriculture, especially for crops requiring a high water supply. In the pursuit of agricultural innovation, optimizing irrigation techniques is critical for enhancing crop productivity and improving water use efficiency, particularly in regions facing water scarcity. Among various irrigation methods, pitcher irrigation stands out as a promising solution for vegetable crops, offering a low-cost and eco-friendly alternative to conventional systems like drip irrigation (Mahler, 2024).

Pitcher irrigation, a traditional method that dates back centuries, has the potential to revolutionize sustainable agriculture. It is a self-regulating, energy-efficient, and easy-to-install system suitable for small farms (Singh, 2020). The method is particularly useful in areas where water scarcity is a significant challenge, allowing water to be delivered precisely to the roots of plants without waste. This irrigation technique is ideal for small plots (up to 1 acre) and is commonly used for growing vegetables and fruits (Batchelor, 1996). The system consists of porous clay pitchers buried in the soil near crops, with the natural pores allowing water to gradually seep out and moisten the surrounding soil. The number of pitchers used per meter depends on the crop variety, with closer spacing required for crops like tomatoes, brinjals, and chilies, and wider spacing for larger plants like mango or custard apple trees (Siyal, 2009). One key feature of pitcher irrigation is the coating applied to the top portion of the pitcher, which prevents water from seeping out where it’s not needed, directing moisture straight to the plant roots. This efficient design allows water to be replenished as needed, ensuring a continuous supply to the plants and reducing water loss (Faridi, 2023).

Pitcher irrigation has been successfully applied in many arid regions of the world, including parts of Iran, India, Africa, and South America (Tripathi, 2017). Noted its use for watering crops such as watermelons in Pakistan and India, and research from Germany, Indonesia, Brazil, and Zimbabwe has further demonstrated its effectiveness for crops like corn, tomatoes, and okra (Adhikary, 2021). Some studies have also suggested that pitcher irrigation can self-regulate, with water leakage controlled by the soil’s water pressure, which is influenced by the soil's moisture content around the pitcher. Pitcher irrigation is an age-old but highly effective method that offers a sustainable solution for modern agriculture (Meena, 2023). Its simplicity, efficiency, and adaptability make it an ideal choice for smallholder farmers looking to maximize crop yields while conserving water in resource-scarce regions.

2. MATERIALS AND METHODS

Pitcher: The pitcher irrigation system used in this study involves round, porous clay pots buried near the crop to provide slow, consistent water delivery. These pitchers, with a capacity of 3 liters each, allow water to gradually seep through their porous walls, reaching the roots of the plants directly. As plants consume the water, more water seeps out from the pots to maintain soil moisture levels, as illustrated in Fig. 1. This system is designed to enhance water use efficiency by reducing evaporation and delivering water where it is most needed at the root zone.

Vegetable plant: Brinjal was used for determining the efficiency of pitcher irrigation system.

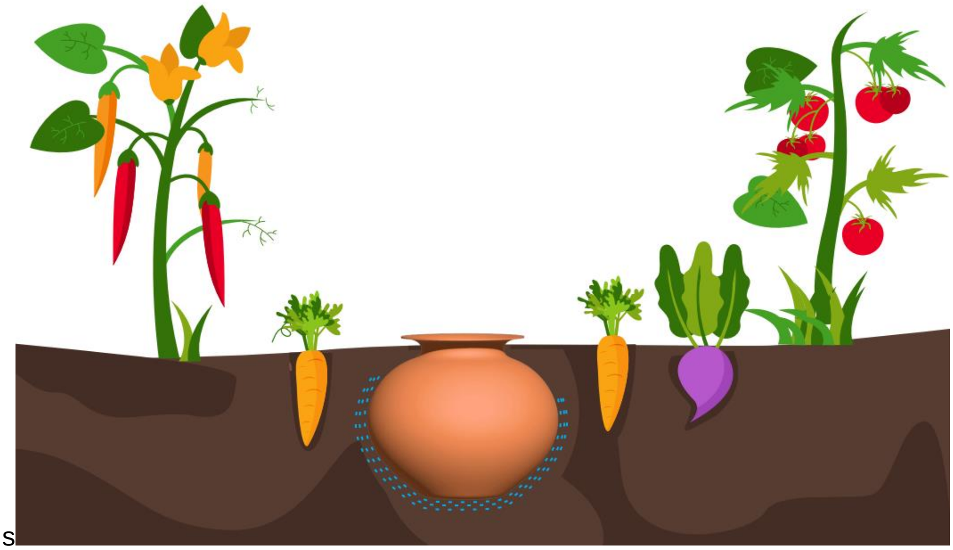

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Fig. 1. Schematic diagram of pitcher irrigation system

Installation of pitchers:

Marking locations: The locations for pitchers were marked based on crop type, with wider spacing for creeping crops and closer spacing for erect crops.

Digging pits: At each marked location, a circular pit measuring at least 60 cm deep and 90 cm in diameter was dug. The soil from the pit was set aside.

Placing the pitcher: An unglazed pitcher was placed in the center of each pit, and the dug-out soil, often mixed with a thin layer of sand for heavy soils, was used to fill the remaining space around the pitcher. Proper compaction of the soil was ensured to facilitate good contact between the soil and the pitcher, as areas with poor contact may lead to irregular water flow.

Filling the pitcher: Each pitcher was filled with clear water, ensuring a consistent water supply for the crops.

Planting: Vegetables were planted around the pitchers, allowing them to receive water through the gradual seepage from the pitcher.

3. RESULTS AND DISCUSSION

The water depth in the nine pots buried close to the crop, used for pitcher irrigation, was monitored from March 1 to March 22, 2024, at three different times each day: 8:00 AM, 1:00 PM, and 6:00 PM. This continuous monitoring provides insight into how water levels varied throughout the irrigation period. On March 1, 2024, the pots were uniformly filled with water at a depth of 15 cm across all pots. This initial condition reflects the full capacity of the pitcher irrigation system. March 1 to March 3: The water levels showed a gradual decrease, particularly in the afternoon and evening readings. For instance, Pot 4, which had 15 cm of water on March 1 at 8:00 AM, reduced to 12.3 cm by 1:00 PM and further dropped to 10.5 cm by 6:00 PM. By March 3, Pot 4 exhibited the lowest water levels of 0 cm by 6:00 PM, indicating complete water depletion within the pot, signaling high water consumption by the crop or significant soil absorption. After replenishing water on March 6, where water depth was reset to 15 cm, a similar pattern of water reduction was observed. Pot 4, for example, started at 15 cm at 8:00 AM on March 6, but by March 13, its water depth had significantly decreased, and some pots, such as Pot 4, remained at 0 cm for multiple time points. This suggests uneven water usage or varying rates of absorption by the surrounding soil. Across the monitoring period, it was observed that pots like Pot 4 consistently displayed more rapid water depletion compared to others. Pots such as Pot 1 and Pot 3, however, maintained slightly higher water levels throughout, suggesting differences in soil moisture retention or crop water demand in proximity to each pot. Water depth declined significantly as time progressed in all pots, with multiple pots showing close-to-zero water levels by the end of March 12. This depletion indicates that the irrigation system's refilling schedule needs to be adjusted to avoid dry periods that could affect crop health. Refill events on March 6 and March 14 re-established uniform water levels of 15 cm in all pots. However, the data shows that within a few days after refilling, significant variations in water depth were observed again, suggesting that crops closer to certain pots were consuming more water or the soil properties varied in different parts of the field.By March 22, water levels had stabilized at a lower depth across all pots, with depths ranging from 7.5 to 11.9 cm. This final state indicates that while water replenishment events temporarily restored full capacity, the system still faces challenges in maintaining consistent water availability. The observed variation in water depth between pots highlights the complexity of managing pitcher irrigation. Factors such as soil type, crop water demand, and proximity to each pot influence how quickly water is depleted. Pots like Pot 4 consistently exhibited rapid water loss, which could be attributed to higher absorption rates by the surrounding soil or greater water uptake by nearby crops. In contrast, other pots, such as Pot 1 and Pot 3, showed more moderate water depletion rates, suggesting that either the crop water demand was lower in those areas or the soil retained moisture better.

The study demonstrates that pitcher irrigation is effective in delivering water directly to the crop's root zone, but it requires careful monitoring and management to ensure all areas receive sufficient water. Adjustments in refill frequency, possibly informed by monitoring data, may help prevent periods of water scarcity that could negatively impact crop growth.

Calculation of seepage rate: The average seepage rate of water from the nine pots was calculated by assessing the change in water depth at specific time intervals. Seepage rates were determined between 8:00 AM and 1:00 PM (5 hours), between 1:00 PM and 6:00 PM (5 hours), and from 6:00 PM to 8:00 AM of the following day (14 hours). For example, on March 1, 2024, the seepage rate for Pot 1 between 8:00 AM and 1:00 PM was calculated as 0.3 cm/hour, based on a 1.5 cm reduction in water depth over 5 hours. Between 1:00 PM and 6:00 PM, Pot 1 exhibited a slightly higher seepage rate of 0.46 cm/hour, with a 2.3 cm reduction in water depth. However, overnight (from 6:00 PM to 8:00 AM), the seepage rate was lower at 0.0214 cm/hour, reflecting a smaller 0.3 cm reduction over a longer 14-hour period (Figs. 2 to 4).

Across the dataset, the seepage rates showed consistent trends of higher water loss during the daytime, particularly in the early afternoon when evaporation and crop water uptake are likely to be at their peak. The evening and overnight periods, in contrast, displayed slower water loss, likely due to cooler temperatures and reduced stomatal conductance and transpiration from the crops (McAusland, 2021). Pots closer to rapidly drying areas, such as Pot 4, consistently exhibited higher seepage rates compared to others like Pot 1 and Pot 3, which showed more moderate declines. This suggests that water uptake by the crops and soil absorption varied spatially across the field, influenced by factors such as plant density, root zone activity, and soil composition (Zhang, 2023).

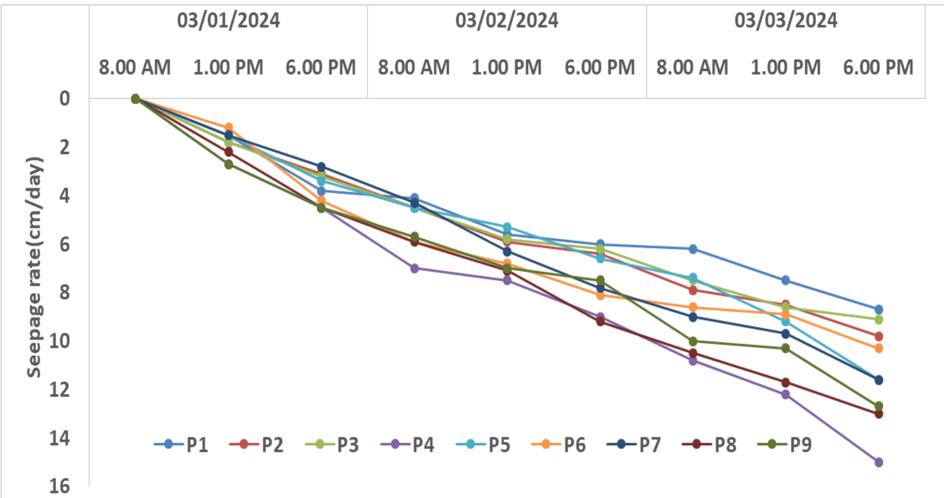

Fig. 2. The seepage rate of water from pot during 03/01/2024-03/03/2024

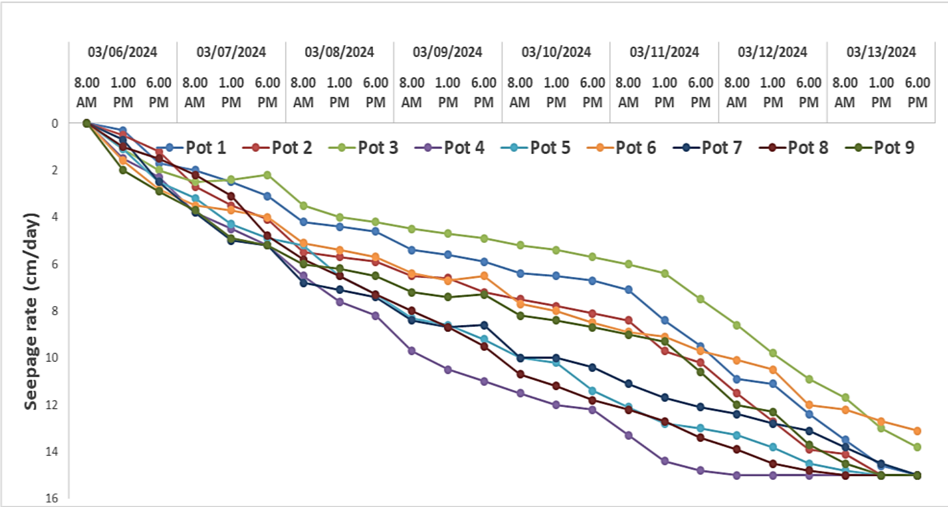

Fig. 3. The seepage rate of water from pot during 03/6/2024-03/13/2024

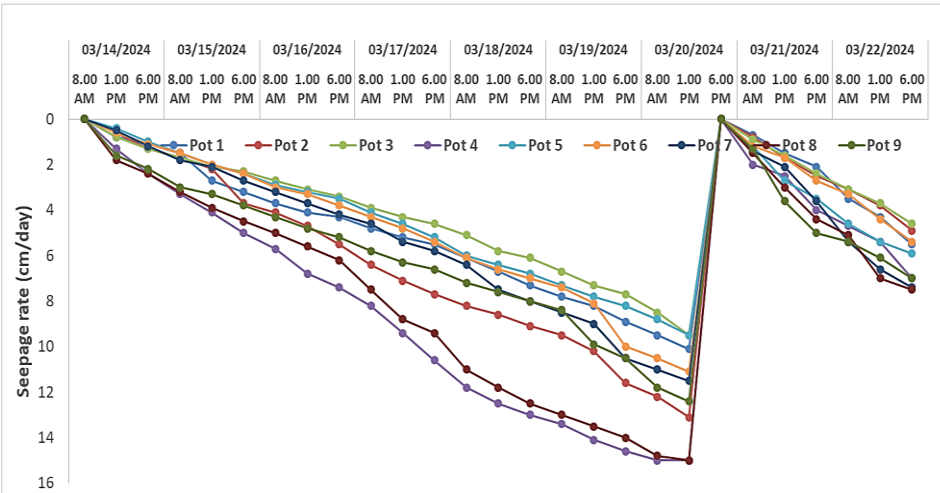

Fig. 4. The seepage rate of water from pot during 03/14/2024-03/22/2024

The seepage rate analysis provides critical insights into the efficiency of the pitcher irrigation system (Amankwah-Yeboah, 2023). While water loss through seepage is expected, the variation in seepage rates between pots indicates that certain areas of the field may require more frequent water replenishment to prevent moisture deficits. The calculated seepage rates can inform irrigation management decisions, such as optimizing refill schedules to maintain adequate water levels for crop growth while minimizing water waste.

4. CONCLUSION

The analysis of water depth fluctuations in the pitcher irrigation system from March 1 to March 22, 2024, reveals several key insights into its efficiency and challenges. The variation in water depletion rates across different pots highlights the spatial heterogeneity in soil properties and crop water demand. Pots like Pot 4, which experienced rapid water loss, likely require more frequent refills or adjustments to maintain adequate soil moisture, while other pots like Pot 1 and Pot 3 demonstrated more stable water retention. The seepage rate analysis further underscores the need for careful irrigation management, as daytime periods, particularly early afternoon, experienced the highest water loss due to evaporation and increased crop water uptake. In contrast, nighttime water loss rates were lower, suggesting that cooler temperatures and reduced plant activity play a role in retaining moisture. This study demonstrates that while pitcher irrigation can be effective in supplying water to crops, it must be optimized with a tailored refilling schedule that considers local conditions. Continuous monitoring of water depth is essential to prevent moisture deficits, ensuring uniform water availability across the field and supporting healthy crop growth.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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