| RESEARCH ARTICLE

Hydraulic Flow in a Smart Watering System

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| ABSTRACT
The agricultural sector continues to rely on efficient and economical water use to meet increasing demand and ensure availability. Irrigation systems, such as smart watering systems, play a crucial role in fulfilling plant water needs. This study focuses on capillary irrigation, a system that delivers water from a main reservoir to plant reservoirs through outlet holes and hose channels, allowing water to be absorbed via capillary axes. On a household scale, this system can be effectively developed and optimized. The research was conducted on spinach plants using a treatment design method with two capillary axes, incorporating a water control system to regulate water flow from the main reservoir. Parameters measured included water use, water loss, and root fresh weight. The results showed daily evaporation under normal conditions from days 1 to 10, with a significant increase observed from day 12 until harvest. The main reservoir, measuring 46 cm in length and 31 cm in width, had an upper water level limit of 13 cm and a lower limit of 9 cm from the bottom. Over the study period, the water level decreased by up to 9.8 cm. The fresh weight of the spinach plants increased from 0 grams on day 1 to 21.23 grams on day 13 and reached 37.12 grams at harvest on day 28. The study highlights the potential of capillary irrigation as an efficient water management solution for small-scale agriculture, emphasizing its ability to optimize water use while supporting plant growth. This research contributes to the development of sustainable irrigation practices, particularly in resource-limited settings, by demonstrating the effectiveness of capillary systems in reducing water loss and improving crop yield.

| KEYWORDS
irrigation; ejection hole; hose line; smart watering system; capillary wick

| ARTICLE DOI:

I. INTRODUCTION
Urban farming often faces challenges such as limited land and water resources, necessitating the adoption of efficient water conservation technologies. One such technology is the smart watering system, which is particularly effective for small-scale irrigation systems like hydroponics. Hydroponic systems are categorized into two types based on the growing medium: water culture and substrate hydroponics. Water culture hydroponics uses water as the primary medium, while substrate hydroponics employs inert materials such as sand, rockwool, or gravel. In substrate hydroponics, an open irrigation system delivers water and nutrient solutions directly to plant roots in controlled amounts, ensuring optimal absorption (Tri Indriyati, 2018). However, traditional open irrigation systems often suffer from water loss due to leaks and inefficiencies, as highlighted by Arbina Satria Afiatan and Cholauna Meilia Sumarantini (2022). To address these issues, the smart watering system utilizing autopot technology offers a more efficient solution. The autopot system, equipped with an automatic valve (smart valve), regulates water flow based on plant needs without requiring electricity. According to Bafdal et al. (2018), the smart valve controls water levels, opening when the water is at a minimum and closing when it reaches the maximum, ensuring consistent water availability for plant roots. This system not only reduces labor but also minimizes water loss through evaporation, making it a sustainable option for urban farming.

The smart watering system operates on a self-draining circulation principle, where maintaining an uninterrupted hydraulic flow is crucial for optimal plant growth. Any blockage in the system can disrupt water and nutrient delivery, hindering plant development. The mechanism relies on a float valve that adjusts water supply based on evapotranspiration rates, ensuring plants receive adequate hydration (Ardiansyah et al., 2023). Compared to traditional irrigation methods, the smart watering system significantly reduces water loss through evaporation, percolation, and surface runoff while maintaining productivity, as emphasized by Kahfiani (2017). This aligns with findings from other studies on similar irrigation systems, such as drip irrigation and wick systems, which also aim to optimize water use efficiency. However, the autopot system stands out due to its self-regulating mechanism and minimal energy requirements. Future research could explore integrating advanced sensors and automation to further enhance the system's efficiency and adaptability to various crop types and urban farming conditions. By addressing these aspects, the smart watering system can contribute to sustainable urban agriculture, ensuring efficient water use and improved crop yields.

II. METHODOLOGY

This research was conducted over three months, from June to August 2024, in Cirebon City, West Java Province, located at an altitude of 32 meters above sea level. The study focused on designing a smart watering system for spinach cultivation, consisting of 60 planting holes. Each hole was equipped with two capillary axes to regulate water flow from a main reservoir. The reservoir was filled, allowing water to flow through hoses into flannel cloths, which served as capillary wicks. Water supply was monitored and controlled to ensure optimal capillary action, as described by Fujimaki and Mamedov (2018). The planting medium used was rockwool with a thickness of 1.5 cm, and spinach seeds were cultivated over a 28-day period from sowing to harvest. Initially, water flow was restricted until liquid fertilizer was added to the reservoir as a nutrient solution.

III. RESULTS AND DISCUSSION

Table 1 illustrates the condition of the hydraulic flow before it is distributed through the hose lines and system network. When the reservoir is filled with water, the flow begins once the regulator hole is opened. The outlet hole, positioned 5 cm above the reservoir's base, allows water to flow at a velocity of 0.0016 m/s over a flow length of 0.22 m. As water is discharged, the level in the reservoir gradually decreases, causing the flow to stabilize and the flow length to shorten. The flow ceases when the water level drops to 3 cm below the outlet hole, effectively stopping the discharge. This process ensures controlled water distribution within the system.

FIGURE 1. RESERVOIR WITH OUTLET HOLE

TABLE 1.
HYDRAULICS FLOW IN RESERVOIR BEFORE DISTRIBUTION

No	Discharge Length (m)	Flow Velocity (ms^{-1})
1	0.22	0.00160
2	0.20	0.00155
3	0.15	0.00058
4	0.10	0.00050
5	0.07	0.00009

6	0.00	0.00000

Source: Results of Research 2024

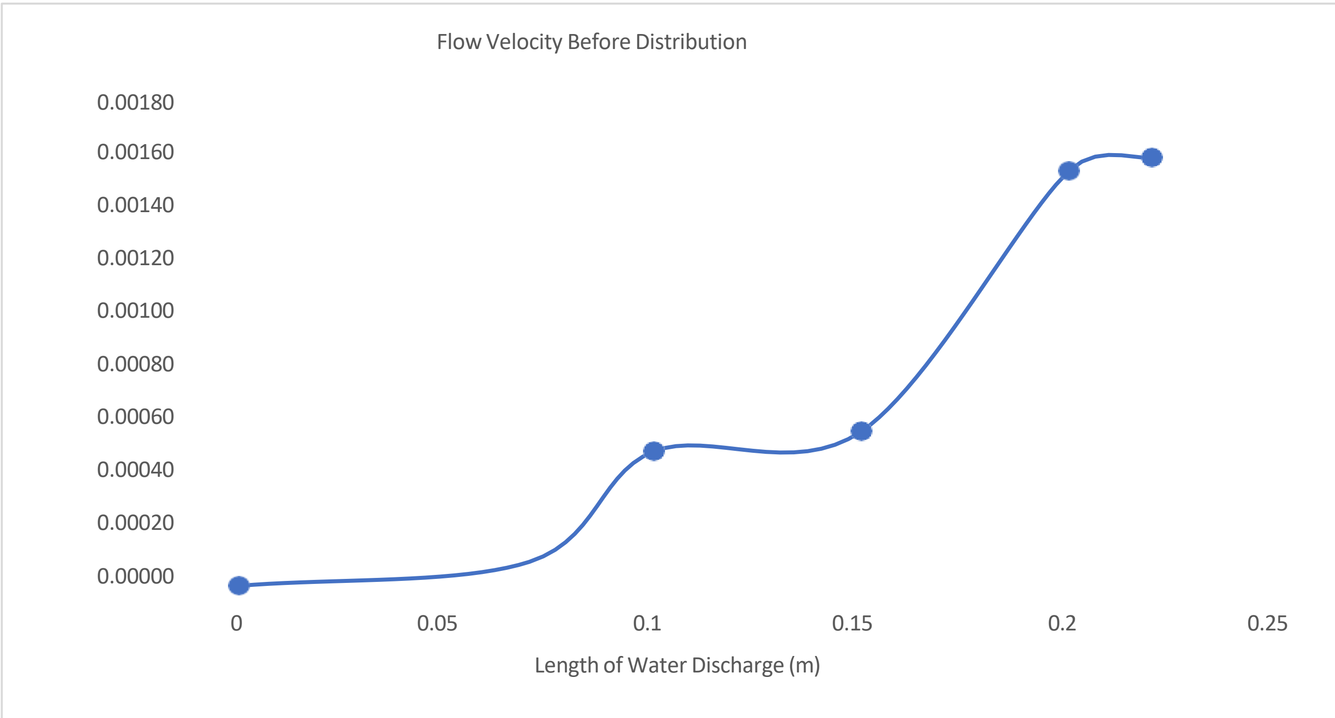


FIGURE 2. GRAPHIC HYDRAULICS FLOW IN RESERVOIR BEFORE DISTRIBUTION

For capillary flow, Table 2 provides detailed insights. The capillary flow initiates when the reservoir's regulator hole is opened, allowing water to pass through a hose with a diameter of 0.008 m. Spinach plants, previously sown, are placed in netpots within the smart watering system. The storage tank is filled with a water volume of 0.0185 m^3. The water balance between the reservoir and the volume beneath the netpot is maintained by the capillary action of the flannel fabric and the capillary valve. The flannel fabric, consisting of two axes, facilitates this process. After a 14-day interval, plant growth is evaluated to assess performance metrics such as height, stem development, and leaf growth, following the methodology outlined by Semananda et al. (2016). This evaluation helps determine the effectiveness of the capillary system in supporting plant growth and water efficiency.

TABLE 2.
CAPILLARY FLOW

No	Day	Volume (m^3)
1	1	0.0185
2	10	0.0171
3	13	0.0143
4	20	0.0128
5	25	0.0071
6	28	0.0043

Source: Results of Research 2024

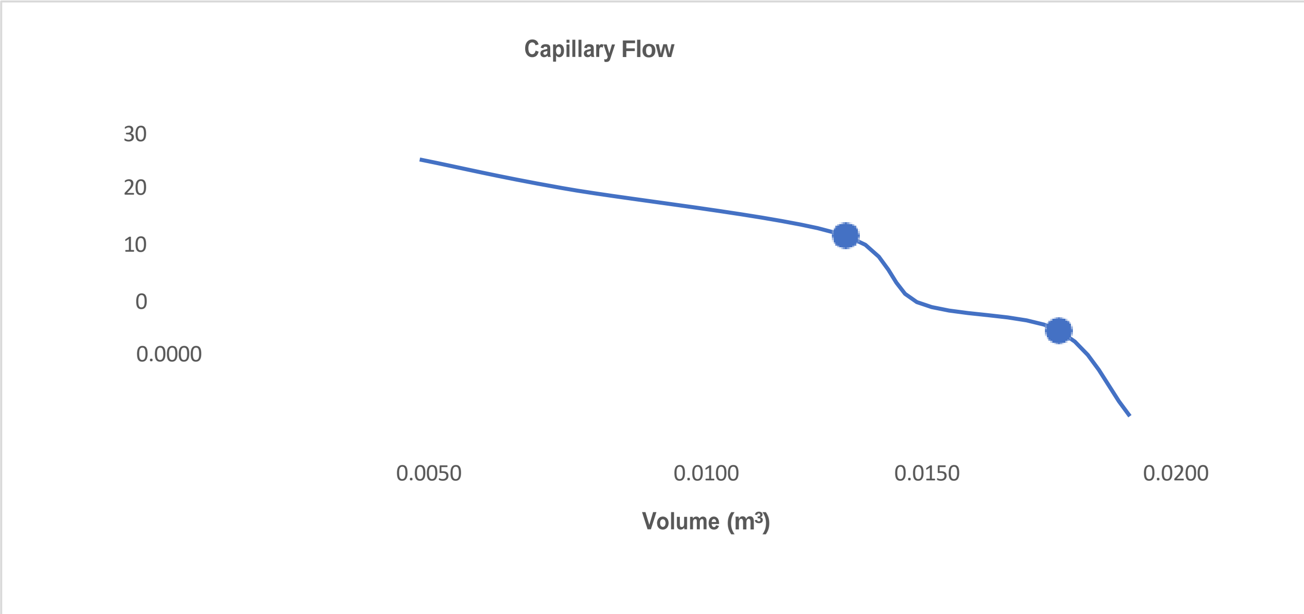


FIGURE 3. GRAPHIC CAPILLARY FLOW

From the graph above, it can be seen that capillary flow with high water requirements occurs on days 20 to 25. In these conditions the growth of spinach plants is very significant. Capillary flow has garnered significant attention due to its unique dynamic characteristics that require no external force (Wang et al., 2024).

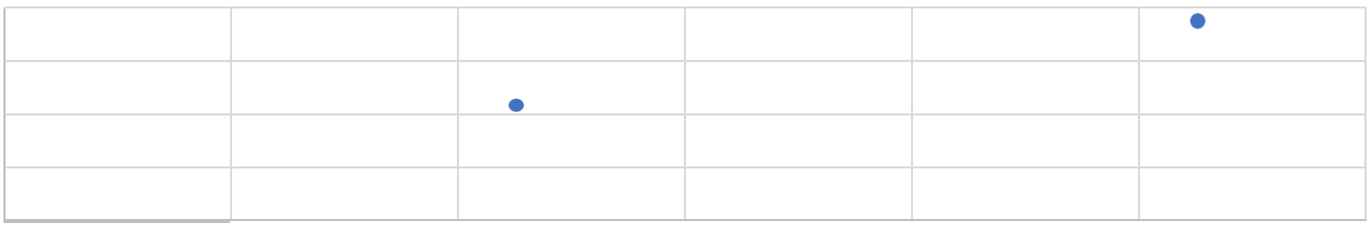
FIGURE 4. CAPILLARY FLOW IN NETPOT

The fresh root weight of spinach plants, as shown in Table 3, reflects the wet weight of the roots after harvest. In the smart watering system, the roots grow within rockwool media and adhere to the capillary flannel fabric. Root development is significantly influenced by the planting medium, with rockwool used at a thickness of 1.5 cm, aligned with the depth of the flannel capillary and the water level limits of the submerged netpot. Adequate water and nutrient absorption by the spinach plants directly impact their growth. A higher density of roots within the planting medium enhances the plant's ability to access water and nutrients, leading to improved growth and overall plant performance. This relationship underscores the importance of optimizing the planting medium and capillary system for effective root development and nutrient uptake.

TABLE 3.
FRESH ROOT WEIGHT

No	Day	Weight (grams)
1	1	0.00
2	10	0.00
3	13	21.23
4	20	25.42
5	25	30.12
6	28	37.12

Source: Results of Research 2024



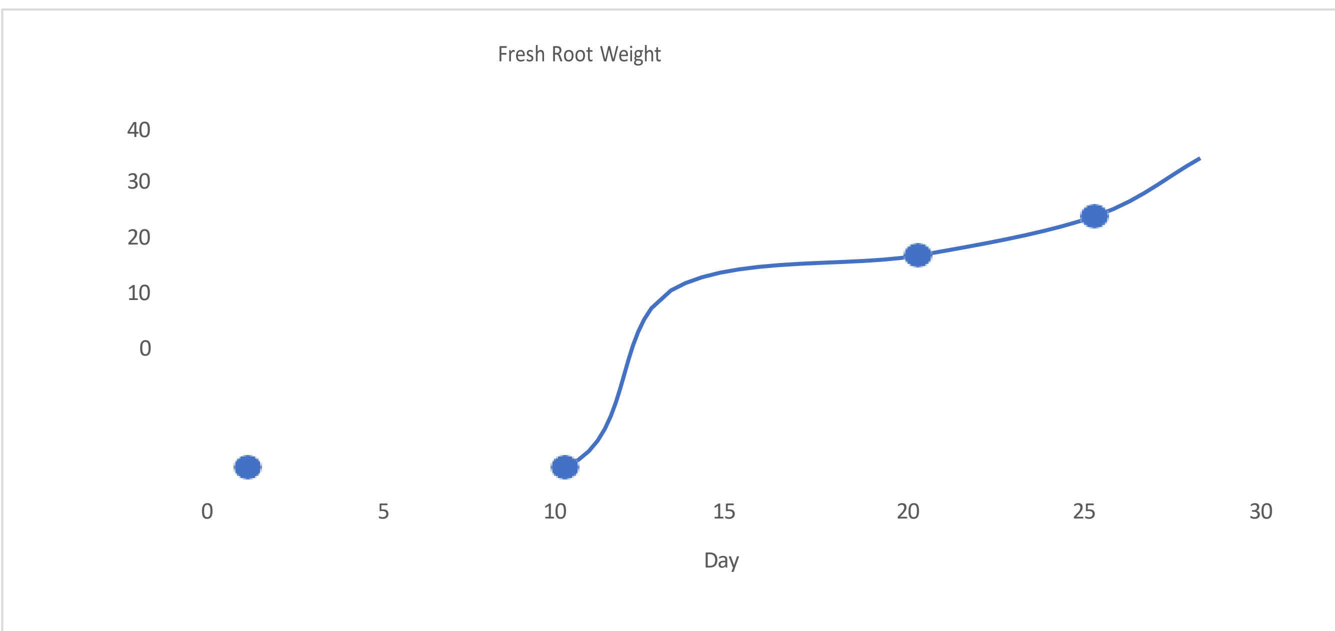


FIGURE 5. GRAPHIC FRESH ROOT WEIGHT

From the graph in Figure 3 above, it can be seen that the fresh weight of the roots on days 1 to 10 is 0 grams. This happens because on that day there was no significant root growth. The roots of spinach plants do not need much water and nutrients at this time. On the 13th day the root weight was 21.23 grams and on the 28th day (harvest) it was 37.12 grams. In this period, spinach plants need more water and nutrients so they grow and develop quickly.

FIGURE 6. FRESH ROOT WEIGHT

IV. CONCLUSION

This research demonstrates the potential of smart watering systems to address agricultural challenges in urban areas with limited land availability. The study highlights the effectiveness of capillary-based irrigation in optimizing water use and supporting spinach growth, as evidenced by the fresh root weight and plant performance metrics. The hydraulic flow in the system is constrained by water volume and crop harvest periods, emphasizing the need for precise water management. Notably, the use of rockwool as a planting medium and the capillary action of flannel fabric significantly enhanced root development and nutrient uptake, aligning with findings from Semananda et al. (2016) on the importance of planting media in root growth.

The study was conducted during the dry season, and future research could explore the system's performance during the rainy season to assess its adaptability under varying climatic conditions. This would provide a more comprehensive understanding of its scalability and resilience. The support from the Research Institute of Swadaya Gunung Jati University, Cirebon, West Java, Indonesia, was instrumental in facilitating this research. Special thanks are extended to the university's chancellor, dean, academic community, and the committee of the 2024 CAIIC International Seminar for their invaluable support, guidance, and opportunities.

The findings of this study contribute to the growing body of research on sustainable urban agriculture, offering a practical solution for efficient water use and crop cultivation in resource-constrained environments. By integrating smart watering systems with capillary technology, urban farming can achieve higher productivity and environmental sustainability, paving the way for future innovations in agricultural practices.

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