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Design of Drip Irrigation with Smart Plug-Based Timer for Urban Agriculture at Surya Makmur Farmer Group, Mantrijeron, Yogyakarta City

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Abstract

Surya Makmur Farmer Group represents a growing community committed to urban agriculture and sustainable food production, such as chili, lettuce, and spinach in Yogyakarta. However, challenges related to manual irrigation practices, inconsistent watering schedules, and resource management have highlighted the need for more sophisticated irrigation methods. This study integrated a drip irrigation system with a smart plug-based timer, leveraging the power of automation to optimize water use, reduce manual labor, and ensure consistent plant hydration. The installation's design was made using Canva editing software. The installation of the drip irrigation systems includes the construction of a water reservoir tank base, assembly of irrigation channels with PVC pipes and 16mm PE hoses, emitters, and dripper sticks, and then installation of mist sprayers in the greenhouse. In this study, the tests carried out were the actual emitter flow rate, evaporation rate, and performance tests, including the coefficient of variance (CV) and emission uniformity (EU). Based on the study's results, the coefficient of variation (CV) value of 0.04% indicates good performance. The emitter with a theoretical flow rate of 8L/hour has an actual flow rate of 8.33L/hour, conforming to the equipment specifications of 94.9%. The average evaporation in the test field was recorded at 8.13 mL/hour. This study concluded that implementing the drip irrigation system has helped KT Surya Makmur reduce labor for manual irrigation practices, maintain a consistent watering schedule, and increase resource utilization efficiency.

Keywords: watering, urban agriculture, automation.

1. Introduction

Designing and constructing efficient irrigation systems tailored for urban agriculture is becoming an essential focus in modern sustainable farming practices. The increasing urbanization and limited availability of water resources have driven the need for innovative solutions supporting agricultural productivity while conserving water. This research presents the conceptualization, design, and implementation of a reliable drip irrigation system enhanced with simple and smart technology. Surya Makmur Farmer Group represents a growing community in Yogyakarta committed to urban agriculture and sustainable horticultural crop production, such as chili. Their cultivation encounters challenges, including water deficit and insufficient human resources to manage the garden. It is well known that water deficit has a negative impact on plant growth [1]. Therefore, implementing a drip irrigation system is recommended to overcome that problem. However, challenges related to manual irrigation practices, inconsistent watering schedules, and resource management have highlighted the need for more sophisticated irrigation methods.

Crops cultivated by the Surya Makmur Farmer Group include horticultural crops, including vegetables, fruits, and ornamental crops, which are grown to fulfill economic, aesthetic, and dietary needs. These crops have several benefits for farmers, such as increasing income and building food security for farmers in urban settings. Red chili (*Capsicum annuum*) is a high-value horticultural crop with significant economic potential due to its widespread use in culinary, medicinal, and industrial applications such as sauces, powders, and oleoresins. They are rich in vitamins A and C and capsaicin, which has health benefits like boosting metabolism and pain relief. However, cultivation poses challenges such as vulnerability to pests like aphids and fruit borers, diseases like leaf curl virus, and sensitivity to weather extremes. Red chili is sensitive to water shortages and excess due to shallow rooting systems, necessitating precise water supply management to enhance productivity and quality. Improper irrigation can lead to failed harvests, emphasizing the importance of regulating water and humidity for optimal growth [2].

This study integrated a drip irrigation system with a smart plug-based timer, leveraging the power of automation to optimize water use, reduce manual labor, and ensure consistent plant hydration. The smart plug timer is a control mechanism that automates watering times based on preset schedules, allowing efficient water distribution without human intervention. This approach aimed to support crops' continuous growth and contributed to the broader sustainability and climate resilience goals. The system's design considerations and selection of suitable irrigation components for the installation process are meticulously detailed in this article. Additionally, the paper explores the potential impact on crop yield (especially red chili), resource savings, and community benefits. This innovative project is a model for similar urban agricultural settings, demonstrating how low-cost technology can bridge the gap between traditional farming practices and modern, resource-efficient solutions.

2. Material and Methods

Materials

This research was conducted at Surya Makmur Farmer Group, Mantrijeron, Yogyakarta City. Materials used for this research include a water reservoir tank of 600 l, electric water pump 125 watts, filter bag 5 microns, active charcoal, a screen filter for ¾” pipe, a dual smart plug, router, emitter 8L/hour, four-way dripper, PVC pipe ¾”, knee connection ¾“, tee connection ¾”, water valve ¾”, PE hose 16mm, PE hose 5mm, end stopper plug for PE hose 16mm, water valve for PE hose 16mm , 5mm PE hose drip stick, metal hose clamp, pipe connection for ¾" pipe to 16mm PE hose, pipe connection for ¾" pipe to 7mm PE hose, 7mm PE hose, tee connection for 7mm PE hose, mist sprayer nozzle 0.5mm hole size, cable ties, and pipe adhesive. Meanwhile, the tools needed for this research include a metal hacksaw, sandpaper, hand drill machine, measuring cup, 400 ml plastic cup, knife, scissors, soldering iron, stopwatch, calculator, measuring tape, and stationery.

Method

Design and Construction of Installation

a) Hardware Installation

The design was made using Canva editing software. Water reservoir tank installation begins by hardening the soil using cement. The tank used has a volume of 600 liters. The water reservoir is also equipped with a size five filter bag filled with activated charcoal and a screen filter after the output section. A water pump is needed to push water to the 3/4" PVC pipe as an output, which is then made into three branches, namely 1) a branch leading to the chili crop, 2) vegetable growing beds, and 3) a greenhouse (Figure 1). The primary pipe channel is constructed by cutting 3/4" PVC pipe into three pieces, then connecting each piece with a 3/4" tee connector at the middle for the vegetable growing bed and a 3/4" knee connection at each end for the chili crop and greenhouse.

Constructing the secondary channel for the chili crop is done by connecting a 3/4" pipe and a 16mm PE hose using a 3/4"-16mm connector. After that, the 16mm PE hose is branched to each row of chili plants using a tee connector 16mm PE hose and installed with a water valve for 16mm PE hose. Each end of the 16mm PE hose branch is closed with a stopper plug. Then, make a hole for the eight l/hour emitters and install a four-way dripper on the emitter to distribute water to each chili plant. Then, attach a drip stick to the end of the 5mm PE hose and stick it in the chili growing medium. The installation of the vegetable growing bed is done using similar steps. The main 16mm PE hose is circular around the middle of vegetable growing beds. Constructing the secondary channel in the greenhouse begins by connecting a ¾" pipe and 7mm PE hose with a ¾"-7mm connector. After that, the 7mm PE hose is branched with a 7 mm tee connection to distribute the water into a mist using a nozzle emitter. The nozzle used for mist irrigation in greenhouses is a mist sprayer with a hole size of 0.5mm.

Water is stored in a water reservoir tank equipped with a filter substrate, activated charcoal, and a filter bag to filter out dirt, silt, or dissolved minerals. A smart plug-based timer is also installed for the water pump to act as a power switch that can be controlled via mobile phone. The water is channeled through a ¾" pipe to a water pump and a screen filter connected to the primary pipe channel throughout the land. The primary pipe channel is branched into two and three pipes to keep the flow rate consistent throughout the primary and secondary channels.

The secondary channel is placed in three different areas and is equipped with a water valve to regulate the flow. These areas include drip irrigation for chili crops, drip irrigation for growing beds, and mist irrigation in the greenhouse. The main pipe channel is connected to the drip irrigation system using a ¾" connector to a 16mm PE hose. The hose is used to increase the water pressure that is going into the drip irrigation system. The hose is laid flat next to the group of plants for the chili crop. The hose is then branched laterally with a tee connector and installed with a water valve. The branches are placed between two columns of chili plants, and a stop plug is installed at the end of each branch. The branches are then perforated every 20 cm or so that the hole is positioned in the middle of 4 groups of plants. Emitters are installed in each hole, and each emitter is installed with a four-way dripper. Each outlet of the four-way dripper is connected to a 5mm PE hose attached to the dripper stick. The dripper stick is then inserted into the soil of each chili plant. By using dripper sticks, water can be delivered straight into the plant root system. Similar installation procedures are done for the drip irrigation systems in growing beds. The mist irrigation system uses a ¾" connector to a 7mm PE hose. The hose is then cut every 20 cm to install the tee connector and the mist sprayer nozzle with 0,5 mm hole diameter. The hose is then tied to the greenhouse roof using cable ties.

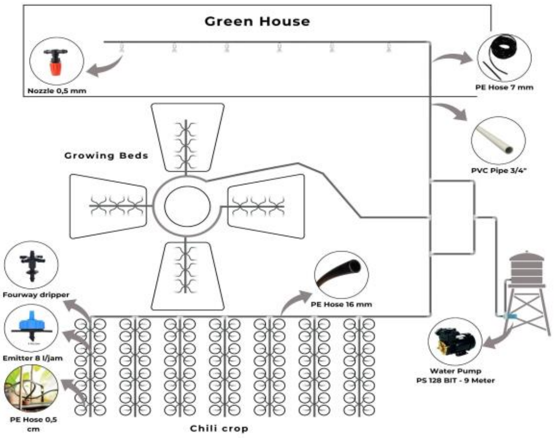

Figure 1.
Design of Drip Irrigation with Smart Plug-Based Timer

b) Smart plug's setting

Smart plug installation begins with setting up the router. The smart plug was a tool from BARDI whose operation can be done via the BARDI mobile application. Settings are done by connecting the smart plug device to a WiFi router, then pairing the smart plug with a mobile phone with the BARDI mobile application via WiFi connection. After the smart plug and phone are paired, the application could be used to turn on or off, set a schedule, or regulate the power for the water pump via mobile phone anywhere and anytime.

Test installation

Testing the smart plug function is carried out by setting the schedule and duration of irrigation. The flow rate measurement trial was carried out after all hardware and software installations had been completed. The tests include measuring the actual emitter flow and evaporation rates, and the performance test includes coefficient of variance (CV) and emission uniformity (EU). The sample used for measuring the water flow rate was chosen randomly from five plants in the chili plantations. Data collection was carried out in two repetitions to obtain more accurate results. The actual flow rate of each emitter is measured by collecting water droplets using a measuring cup and then calculated according to the predetermined time. The volume of water collected is then compared with the amount of time needed to obtain the flow rate in units of time (liters/second). Evaporation rate is measured by calculating the water volume loss after evaporation in 9 hours at the field. Coefficient of variance (CV) is calculated with formula according to [2] as follows:

$$CV = \frac{Sd}{\underline{Q}} \times 100\% \quad (1)$$

CV : Coefficient of variance (%)

Sd : Standard deviation

$\underline{Q}$: average of actual flow rate (liters/hours)

Coefficient of variance (CV) is calculated with formula according to [3] as follows:

$$EU = \frac{\underline{Q1q}}{\underline{Q}} \times 100\% \quad (2)$$

EU : Emission uniformity (%)

$\underline{Q1q}$: Average actual flow rate of lower quartile (liters/hours)

$\underline{Q}$: average of actual flow rate (liters/hours)

3. Results and Discussion

3.1. Design and construction

Irrigation construction begins with measuring the land using a measuring tape. The size of the land owned by Surya Makmur Farmer Group was 12x10 m or an area of 120 m^2. The reservoir or water storage tank is installed after strengthening the soil foundation by casting a concrete base so that it is strong enough to withstand the weight of the reservoir. (Figure 2). Furthermore, the sandy texture of the soil will increase the risk of the base collapsing. The water is filtered twice before entering the reservoir by a filtering substrate of activated charcoal in a filter bag, then after the reservoir output section by a screen filter before going to the pump. The function of the filter is to filter dirt, dust, or sediment carried by the water that could prevent the drip stick from clogging and maintain optimal water flow rate.

Dripper clogging in drip irrigation systems can be attributed to biological, physical, and chemical factors. Differentiating between surface water and groundwater is essential, as each source carries unique clogging risks [4]. Physical clogging often results from sand particles commonly found in surface water, which can obstruct emitters. Additionally, larger suspended solids may fail to pass through the emitter openings, causing blockages [5],[6]. In some cases, silt-sized particles may clump together, leading to clogging. While turbidity is used as an indicator of suspended solids, it does not reliably reflect the potential for clogging. A well-designed filtration system, based on the water's quality, effectively prevents physical blockages [7],[8].

Figure 2
a) concrete base b) secondary pipe

Biological clogging occurs as drip irrigation systems create an ideal environment for bacteria, fungi, and algae, which can form slimy residues [9]. Bacterial slime may directly clog emitters and cause mineral particles to bind, creating aggregates large enough to block emitter openings. This issue is particularly notable in water with manganese, sulfide, and iron content. The slime color can vary—appearing reddish, yellowish, or grayish—depending on the bacterial type. Biological clogging is prevalent with water containing high biological activity, elevated iron or manganese levels, or hydrogen sulfide. Proper chlorination and disinfection are crucial to controlling biological clogging in drip systems [10].

Chemical clogging in drip irrigation systems is primarily caused by mineral precipitation, which occurs when the solubility of certain minerals decreases. Factors influencing mineral solubility include water temperature, pH, redox potential, and the concentration of mineral elements [11]. Common clogging agents precipitating and accumulating in drip emitters include calcium, magnesium, iron, and manganese, with calcium carbonate being the most prevalent. Water with high levels of these minerals and a pH above 7.0 poses a higher risk for emitter clogging. Additionally, fertigation-adding fertilizers to irrigation water—can lead to emitter clogging when mineral concentrations exceed solubility limits, causing precipitates to form. A jar test or specialized software can help assess whether specific fertilizer combinations will precipitate [12]. The acid injection can lower irrigation water's pH, reducing precipitation's likelihood. Surface water carries more biological and physical clogging risks, while groundwater, with its higher mineral content, tends to present a greater chemical clogging hazard [13].

Meanwhile, in the greenhouse, the irrigation system used a mist nozzle for garlic chives, lettuce, and strawberry plants. This type of nozzle was chosen considering the number of plants that would not be economically efficient using a drip nozzle.

Drip irrigation systems offer a range of significant benefits when applied to urban agriculture, making them an ideal choice for efficient and sustainable farming in cities [14]. One of the primary advantages of drip irrigation is its ability to deliver water and essential nutrients directly to the root zone of plants, ensuring precise and uniform distribution. This targeted watering method minimizes water loss by ensuring that only the plant roots receive the moisture they need rather than saturating the entire soil surface. As a result, the plants receive consistent hydration without the excess water that typically runs off in traditional irrigation methods [15].

Another key benefit of drip irrigation is its role in preventing runoff. Runoff is when water is applied too quickly or in excess, which can wash away valuable topsoil and lead to erosion. In urban environments, runoff can also carry pollutants, chemicals, and debris into other bodies of water, contributing to waterborne contamination [16]. Drip irrigation systems are designed to apply water slowly and directly into the soil, eliminating the risk of surface runoff and protecting soil integrity and water quality. It also reduces the need for expensive soil amendments, as the topsoil remains intact and fertile [17].

In addition to precise watering, drip irrigation is highly effective in increasing water efficiency. By delivering water directly to the root zone and minimizing transpiration losses, drip systems use significantly less water compared to sprinkler or flood irrigation systems. It is especially important in urban agriculture, where water conservation is crucial due to limited water resources and the growing demand for water in densely populated areas [18]. Furthermore, the system's efficiency helps prevent excess moisture from accumulating on the soil surface, which could otherwise promote weed germination. With less free water available in the soil, weed seeds have a reduced opportunity to sprout and compete with crops [19].

The reduced overall water usage associated with drip irrigation provides an additional benefit for weed control. With less free water available to saturate the soil, the conditions for weed seed germination are greatly diminished [20]. Weeds typically require ample moisture to sprout, and by limiting water availability to the areas between crops, drip irrigation reduces the likelihood of weed growth. It creates a more favorable environment for crops to grow without the competition of unwanted plants, reducing the need for herbicides and manual weeding efforts [21].

Drip irrigation systems offer a significant advantage in pest and disease control by minimizing the moisture on plant foliage, which can create an inhospitable environment for many pests and pathogens; unlike traditional irrigation methods such as overhead sprinklers, which water the entire plant, drip irrigation delivers water directly to the soil at the root zone [22]. This targeted watering system ensures that the foliage remains dry, which helps prevent the proliferation of CMV prevalent in chili crops from the previous planting season in the experimental plot. Excess moisture on plant leaves, especially in humid or warm environments, creates the perfect breeding ground for various plant diseases such as powdery mildew, downy mildew, and rust. These fungal pathogens spread rapidly in moist conditions and can cause significant damage to crops [23].

Moreover, by minimizing water contact with foliage, drip irrigation reduces the likelihood of water droplets splashing from infected soil or decaying plant matter into healthy plants [24]. This splash effect can carry soil-borne pathogens from one plant to another, spreading secondary infection across the crop. Drip irrigation avoids this issue by delivering water gently and precisely to the root zone without disturbing the soil surface or spreading pathogens [25].

In addition to disease prevention, the lower humidity around the plants also plays a role in pest management. Many pests, including aphids, whiteflies, and certain insects, are attracted to the moisture and damp conditions on the leaf undersides [26]. Before the implementation of this irrigation system, the chili crops were damaged by pests such as whiteflies. It caused yield loss and crop failure in the previous planting season. The drip irrigation system reduced the pest population during the planting season. By preventing excess water from wetting the plant surfaces, drip irrigation makes the environment less favorable for pest activity. This dry condition reduced pest populations and prevented them from establishing themselves on the crops [27].

3.2. Performance of drip irrigation

3.2.1. Emitter testing

Ensuring a uniform water flow rate from emitters is critical for optimizing resource utilization and enhancing crop yield. Variations in emitter performance can lead to inefficient water use and reduced agricultural productivity [28]. In this study, the actual emitter flow rate was measured. The measurement results are shown in Table 1. The results showed that the emitter with a theoretical flow rate of 8L/hour used has an actual flow rate of 8.33L/hour and conformity with the equipment specifications of 94.9%.

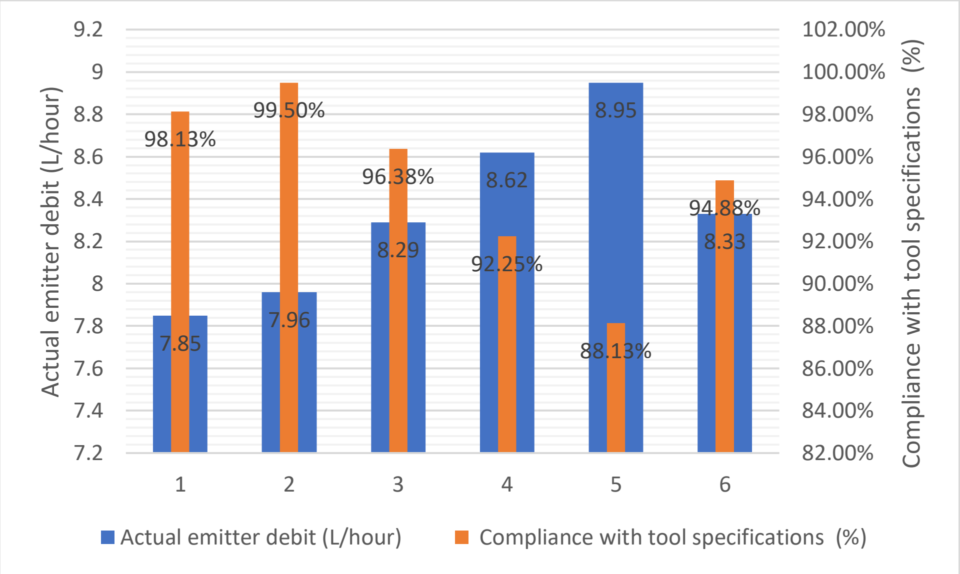

Figure 3.
Actual emitter flow rate

3.2.2. Performance of irrigation system

The performance test for drip irrigation systems can be evaluated using the coefficient of variance (CV) and emission uniformity (EU) values. The emitter's coefficient of variance (CV) shows the relative size of the standard deviation compared to the mean. Higher CV can be defined as greater dispersion around the mean. Meanwhile, lower CV can be defined as lower dispersion around the mean. A lower CV is desired in evaluating emitter performance as it shows lower variability and increasing predictability. The CV was 0,04% and was categorized as good performance according to [2].

Emission uniformity (EU) is a relative index of the variability between emitters in an irrigation block. Emission uniformity is defined as the average discharge of 25% of the sampled emitters with the least discharge, divided by the average discharge of all sampled emitters. The higher value of EU shows that every dripper in the irrigation block has a similar flow rate. The EU was 95,55% and was categorized as very good performance according to [3]. CV and EU values showed that this irrigation system performed well, which is important for productivity in the field. This result indicated that the system was optimally working, which increased water efficiency, easier irrigation scheduling, and soil and plant health. The uniform flow rate also showed an increase in plant yield. The parameter used to test the performance of this irrigation system is emission uniformity (EU) [29].

3.2.3. Evaporation rate

The evaporation rate is defined as water volume loss for some time in the area of the field. The calculation was carried out by measuring a volume of water in a measuring cup and then placing it on an area without any shade from 08.00 am until 5.00 pm or a total of 9 hours. After a while, the volume of water was measured again to determine the volume of water lost. The results showed that the average evaporation in the experimental field was 8.13 mL/hour. This measurement was considered when considering the volume of water needed to irrigate chili plants. The evaporation rate is crucial in drip irrigation as it influences water management.

Understanding the daily average helps optimize water use, reducing losses and improving efficiency in irrigation practices for crops like chili [30].

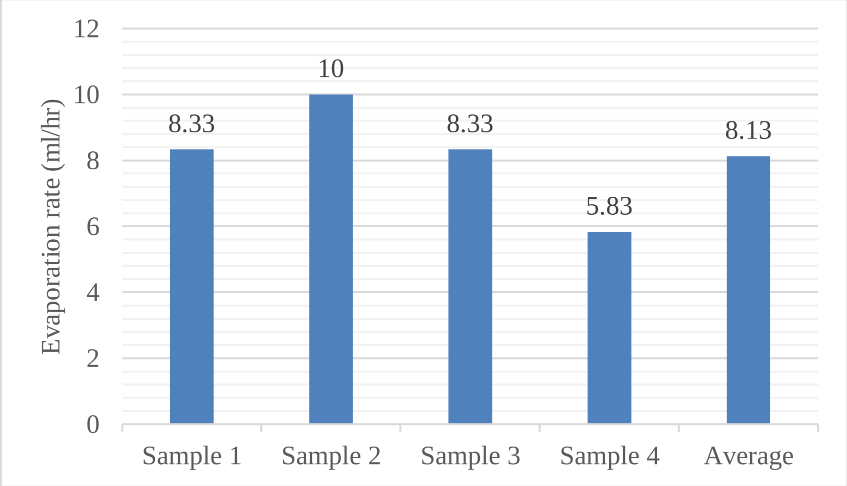

Figure 4.
Evaporation Rate (ml/hr).

3.3. Water Supply Management with Smart Plug-Based Timer.

The water management was performed by regulating the switch button of the water pump using a smart plug controller via a mobile application. The smart plug could be paired to a mobile phone, and the water pump can be switched on or off remotely as long as the phone is connected to an internet connection. The application has several functions, such as manually turning on and off the switch, setting a schedule, and doing an on/off cycle within a certain interval. The irrigation management is done by using the scheduling function. The schedule is set for some time, several times a day, and throughout the week. The duration of each session is calculated by considering the actual water flow rate, coefficient of variance of emitter, and EDR value.

4. Conclusion

Implementing automated drip irrigation and mist sprayer systems has helped Was Surya Makmur reduce the labor for manual irrigation practices, keep a consistent watering schedule, and increase resource utilization efficiency.

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