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Design of Terrace-Based Hydroponic System using Hydraulic Ram Pump

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Abstract

The primary objective of the study is to design a terrace-based hydroponic system incorporating a hydraulic ram pump and to evaluate the effectiveness of the hydraulic ram pump in terms of drive head, flow rate, and delivery head, while also assessing its overall performance, particularly in terms of water loss percentage. The hydraulic ram pump can deliver a delivery head of 200 cm. To achieve this 200 cm delivery head, a drive head of 20 cm and a drive pipe length of 60 cm are necessary. The flow rate of the ram pump at the delivery pipe is 1.13 liters per minute. The water balance equation was employed to quantify water loss, considering parameters such as initial water volume in storage tanks, water collected in excess water collectors, and overall water losses during a system operation. The study's key findings reveal that during each 15-minute operational cycle, the terrace-based hydroponic system, incorporating a hydraulic ram pump, experienced an average water loss of 4.59 liters, equating to a 2.7% water loss percentage. This 2.7% loss could have a significant impact on sustainability if the system were to be upscaled.

Keywords: Energy-free, hydroponic system, hydraulic ram pump, nutrient flow technique

Introduction

Hydroponics is a soilless plant cultivation method that utilizes a nutrient-rich solution for the plants' growth. It has emerged as a popular agricultural technique to enhance the quality of vegetables produced. Additionally, hydroponic systems can be efficiently implemented in limited spaces (Harahap et al., 2020). Moreover, hydroponics presents a promising and contemporary approach to farming, addressing prevailing challenges such as water scarcity, climate change, population expansion, and pest issues (Biswas & Das, 2022). It offers versatility in implementation, as hydroponic farming can be carried out either indoors or outdoors, with the choice of the specific system adapted to the available resources.

According to Biswas and Das (2022), there are currently 16 hydroponic systems, in addition to other developing systems in practice, among which the Nutrient Film Technique (NFT) stands out as the most widely used. In the NFT system, plants are cultivated in grow tubes or baskets with a slight downward angle. This arrangement allows a small amount of nutrient-rich water to flow continuously beyond the root zone while exposing the upper part of the roots to air, ensuring adequate oxygen supply. The nutrient solution in the reservoir is pumped out and delivered to the roots through the back to the reservoir.

Hydroponic farming, specifically using the NFT system, employs electrically powered compressor pumps to aerate plants cultivated in a nutrient solution without the need for a solid medium (Santos & Ocampo, 2005). This adaptable and modular system delivers nutrient solutions to the crops via a water pump, utilizing components such as storage tanks, air compressors, air stones, NFT channels, and more (Tagle et al., 2018). Ensuring a continuous supply of nutrient solution is crucial for the smooth operation of a hydroponic system. However, the vulnerability of the system to rolling blackouts, particularly during natural disasters or extreme weather events, poses a significant challenge (Biswas & Das, 2022). While solar energy offers a potential solution, its effectiveness is contingent on site-specific factors and the availability of direct sunlight, making it susceptible to weather conditions (Wedashwara et al., 2021). Thus, there is a need to develop a new hydroponic system that does not depend on electrical energy to operate.

Moreover, harnessing the potential of hydroponics while minimizing environmental impact and energy usage is possible through the adoption of an energy-free approach. Instead of traditional power pumps, the implementation of a hydraulic ram pump offers a sustainable alternative. Denson et al. (2016) proposed the utilization of moving water to generate energy, which can be effectively captured and utilized for various tasks. The hydraulic ram pump, also known as a “hydram,” operates automatically, using the energy from flowing water to pump a portion of it to a higher elevation. This technology taps into the potential energy of water from a higher source (Hussin et al., 2017). Particularly useful in regions with limited access to electricity, the hydraulic ram pump proves to be a viable solution as long as a water source is readily available (Kumar et al., 2015). The hydroponic system using a hydraulic ram pump is an economically viable alternative because it eliminates the need for a conventional electric pump.

The objective of the study was to design a terrace-based hydroponic system utilizing a hydraulic ram pump and to evaluate the system's performance, specifically in terms of water loss percentage. Additionally, the study aimed to assess the performance of the hydraulic ram pump regarding the delivery head, flow rate, and drive head.

Materials and Methods

Designing a terrace-based hydroponic system with a hydraulic ram pump involves several crucial considerations. This system efficiently utilizes water for plant growth in a controlled environment, focusing on three key aspects: (1) selecting the appropriate hydroponic system, (2) choosing the right hydraulic ram pump, and (3) implementing effective water management to minimize water loss.

Hydroponic System Selection

The NFT hydroponic system was chosen because of its ease of assembly and maintenance. Most components use lightweight materials, and the system employs a conventional pump to transport the nutrient solution from the reservoir to the plants through the channels. Notably, the conventional pump can be substituted with a hydraulic ram pump. The NFT system is well-suited for small areas, such as a building's terrace.

Hydraulic Ram Pump Selection

The selection of the hydraulic ram pump should be determined based on factors such as the following:

1. Flow rate - The flow rate is recommended to range from 1 L/min to 1.5 L/min for hydroponics, as suggested by Genuncio et al. (2012).
2. Delivery head – The delivery head should meet the minimum requirement of 1.3 m for a designed terrace-based hydroponic system.
3. Drive head – the required drive head should not exceed the typical ceiling height of 3 meters and deliver sufficient delivery head since the drive head influences the delivery head.

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4. 4. Drive Pipe: The length of the drive pipe should be three times the drive head and should not exceed 2 meters, based on the hydraulic ram pump product specifications.

Water Management

The evaluation of the hydroponic system involves a comprehensive assessment of critical parameters, including flow rate, drive head, and delivery head. To measure the system's flow rate at the delivery pipe, the volume of water delivered within a specific timeframe was quantified and compared to the ideal range suggested by Genuncio et al. (2012).

The evaluation of the drive head includes measuring the vertical distance between the water source and the drive flow control valve and calculating the maximum delivery head it can provide using Equation 2. The delivery head is dependent on the drive head. Therefore, if the delivery head reaches the minimum required by the system, that is considered favorable.

$$D_r = 0.10\ D_e \qquad (1)$$

Where: D_r – Drive head
D_e – Delivery head

The terrace-based hydroponic system should incorporate a component for collecting excess nutrient solution. Many hydroponic systems are designed to capture and recycle runoff, thus reducing water and nutrient waste. To evaluate the system's performance, particularly in terms of water loss percentage, the concept of a water balance will be employed to assess the nutrient solution within the terrace-based hydroponic system. This involves quantifying and tracking nutrient solution inputs, outputs, and storage within the system. The objective of a water balance study is to comprehend how the nutrient solution flows through the system, how it is distributed, and how it can be managed sustainably. The water balance equation used was

$$ST = EWC + L \qquad (2)$$

Where: ST- water in the storage tank,
EWC - water in excess water collectors
L- water losses.

Design Components of the Terrace-Based Hydroponic System

Channels and Pipes

The first component was the hydroponic delivery system consisting of twelve pipes, also referred to as channels, responsible for distributing the nutrient solution to the plant roots. These channels are strategically positioned in three layers, with four pipes in each layer. Each channel contains nine holes designed to accommodate the growing medium, supporting the plants and ensuring root stability. In total, the entire hydroponic system comprises 108 holes. These pipes are meticulously arranged within a framework composed of 3/4-inch diameter PVC pipes.

Water Storage Tanks

The second part of the setup consisted of two high density polyethylene (HDPE) water storage tanks: a main tank, which could hold up to 100 liters, and a secondary tank with a capacity of 70 liters. The main tank was directly connected to the ram pump, while the secondary tank served as a backup.

Hydraulic Ram Pump

The third element in the system was the hydraulic ram pump. It consists of a 1-inch drive pipe with a ball valve, which is connected to the primary tank. The remaining 10% of the water is directed to the highest layer of the hydroponic system through a ½-inch delivery pipe. The drive pipe length should be three times the drive head, enabling it to lift a maximum height equivalent to 10 times the drive head.

Excess Water Collectors

The fourth element of the system consisted of two types of excess water collectors: primary and secondary, both fabricated from galvanized iron to minimize water wastage. These collectors are designed to capture any water that might splash out from the ram pump's waste valve. The dimensions of the primary and secondary excess water collectors were 0.6 x 0.3 x 0.09 m and 1 x 0.8 x 0.17 m, respectively.

Suction Pipe

The last component of the system was a 1/2-inch diameter PVC suction pipe, which connects to the main water source, enabling water to be drawn from the excess water collectors.

Final Design of the Terrace-Based Hydroponic System

The final design of the terrace-based hydroponic system was composed of five major components, namely (a) channels and pipes, (b) water storage tanks, (c) a ram pump, (d) excess water collectors, and (e) a suction pipe, as shown in Figure 1.

Principle of Operation

Figure 2 shows how the nutrient solution started to flow from the water storage tank, passing through the drive pipe to the hydraulic ram pump, which pumped up 10% of the nutrient solution to the channels, exiting the excess water collectors. The remaining 90% was splashed out from the waste valve of the ram pump and was collected by the excess water collectors as well. The suction pipe brought back some of the nutrient solution to the water storage tank to continue the 15-minute operation

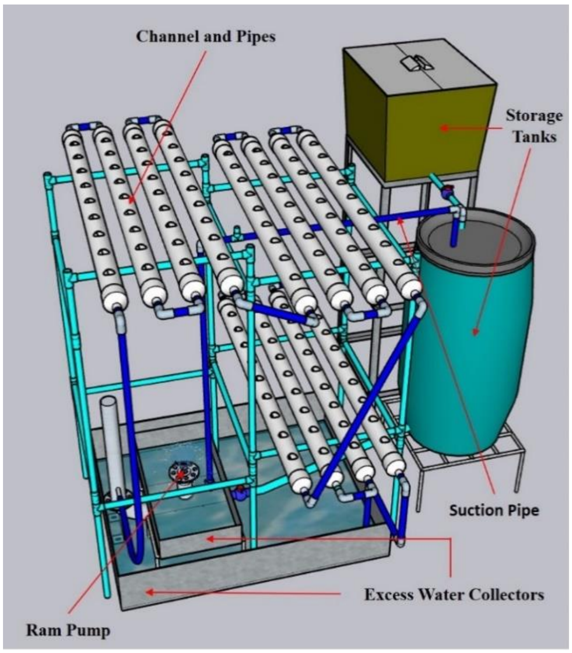

Figure 1. Conceptualized design of terrace-based hydroponics system using

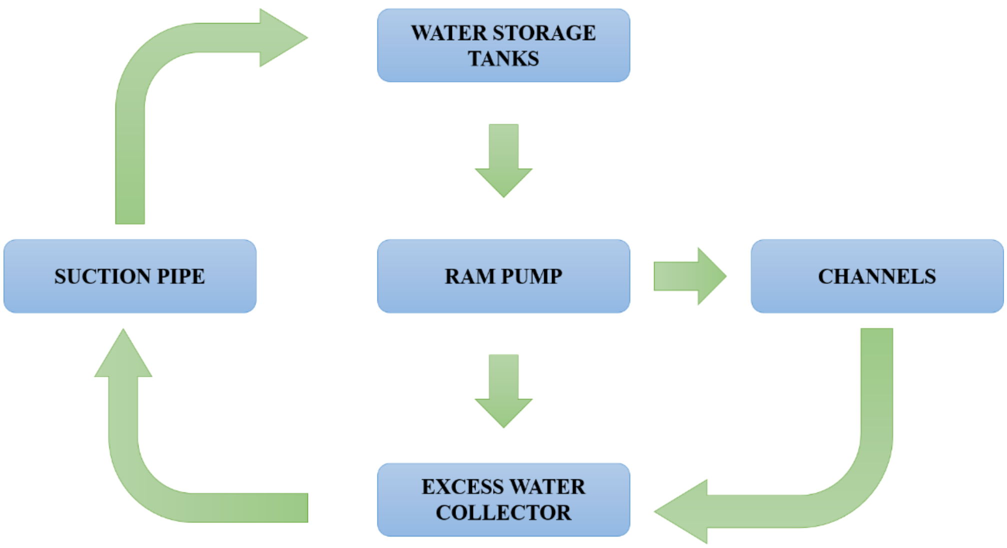

Figure 2. Hydroponic nutrient flow diagram

Results and Discussion

Description of the Terrace-Based Hydroponic System

The terrace-based hydroponic system is composed of five major components, namely (a) channels and pipes, (b) water storage tanks, (c) a ram pump, (d) excess water collectors, and (e) a suction pipe, as shown in Figure 3.

The first component is the hydroponic delivery system, which comprises twelve pipes, also known as channels, tasked with distributing the nutrient solution to the plant roots. These channels are strategically arranged in three layers, with four pipes in each layer. Each channel is equipped with nine holes designed for the growing medium, providing support for the plants, and ensuring the stability of their roots. Overall, the complete hydroponic system consists of 108 holes. These pipes are carefully organized within a framework constructed from PVC pipes with a 3/4-inch diameter.

The second component of the setup included two HDPE water storage tanks: a main tank capable of holding up to 100 liters and a secondary tank with a capacity of 70 liters. The main tank was directly connected to the ram pump, while the secondary tank served as a backup, ensuring a consistent water supply for a continuous operational period of 15 minutes.

The third component of the system was the hydraulic ram pump, which comprises a 1-inch drive pipe equipped with a ball valve connected to the primary tank. When the ball valve is opened, approximately 90% of the water flows from the main tank towards the waste valve, where it is collected by the waste collector. The remaining 10% of the water is channeled to the highest layer of the hydroponic system through a ½-inch delivery pipe. The hydraulic ram pump features a drive pipe length three times that of the drive head, allowing it to lift to a maximum height equivalent to 10 times the drive head. For the entire operation of the hydroponic system, a minimum delivery head of 130 cm was necessary, indicating that the minimum drive head required was only 13 cm. However, the system was designed with a drive head of 20 cm, resulting in a delivery head of 200 cm, incorporating a safety allowance factor. The flow rate of the ram pump stood at approximately 1.13 liters per minute (LPM), falling within the range recommended by Genuncio et al. (2012).

The fourth component of the system comprised two types of excess water collectors: primary and secondary, both constructed from galvanized iron to minimize water wastage. These collectors are specifically designed to capture any water that may splash out from the waste valve of the ram pump.

The final component of the system was a 1/2-inch diameter PVC suction pipe that connected to the main water source, facilitating the drawing of 1% of the water from the excess water collectors. No electric pump was used to circulate the water; only the suction pipe was employed.

The nutrient solution initiated its flow from the water storage tank, traversing through the drive pipe to reach the hydraulic ram pump. The pump then directed 10% of the nutrient solution to the channels, where it exited into the excess water collectors. The remaining 90% was expelled from the waste valve of the ram pump and gathered by the excess water collectors. Simultaneously, the suction pipe drew back a portion of the nutrient solution to the water storage tank, sustaining the 15-minute operational cycle.

Water Balance

The water balance (Equation 2) was used to quantify the percentage of water loss. The parameters that influenced the amount of water removed and remained during a 15-minute system operation included water in storage tanks, water collected in excess water collectors, and water losses. In every 15-minute system operation, the storage tank had an initial water volume of 170 liters. The average water remaining in the excess water collectors was 165.41 liters. Consequently, the average water loss was 4.59 liters, resulting in a 2.7% water loss. This loss occurred because the excess water collectors were unable to fully capture the water splashing out from the waste valve of the hydraulic ram pump. To minimize water loss, it is recommended that the height of the excess water collector be increased to adequately catch the splashed water from the waste valve. In contrast, conventional systems using electric pumps do not experience water loss due to splashing. Increasing the height of the excess water collector by 0.3048 meters will help reduce water loss

Figure 3. Fabricated terrace-based hydroponics system using hydraulic ram pump

Conclusion

In conclusion, the development of a Loop- The implemented terrace-based hydroponic system, utilizing the Nutrient Film Technique (NFT) and powered by a hydraulic ram pump, showcased a strategic combination of efficiency and sustainability. The chosen NFT system, with its lightweight materials and adaptability to small spaces, demonstrated ease of assembly and maintenance. The hydraulic ram pump, with its specified drive head and delivery head parameters, operated successfully, ensuring a continuous nutrient flow to the hydroponic channels.

However, the system encountered a minor setback with a 2.7% average water loss, attributed to the inefficiency of excess water collectors in capturing splashed water. To address this issue, it is recommended to optimize the height of the excess water collector, with an additional 0.3048 meters suggested for enhanced effectiveness. Additionally, it is recommended to arrange the pipes in a pyramid setup to ensure all plants receive sufficient sunlight, and the length of each pipe should be shortened to promote even nutrient distribution.

The integration of the water balance equation provided valuable insights into the system's performance, highlighting parameters influencing water removal and retention. Despite the observed water loss, the overall functionality of the terrace-based hydroponic system appears to be satisfactory. Future improvements could focus on refining collector design to further minimize losses and enhance the sustainability of this innovative hydroponic approach. It is also recommended to consider potential long-term wear and maintenance challenges associated with the hydraulic ram pump to ensure a more comprehensive assessment of its durability and efficiency. Conclusively, the study contributes to the evolving field of hydroponics.

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References

Biswas, S., & Das, R. (2022). Hydroponics: A Promising Modern Intervention in Agriculture. *Agriculture & Food E-Newsletter*. Retrieved on February 22, 2022 from https://www.researchgate.net/publication/357478287

Denson, M. D., Galad, M. N., & Malamug, J. J. F. (2016). Design and fabrication of a hydraulic diaphragm pump. *CLSU International Journal of Science & Technology* 1(1), 11-17. doi: https://doi.org/10.22137/ijst.2016.v1n1.02

Genuncio, G. D. C., Gomes, M., Ferrari, A. C., Majerowicz, N., & Zonta, E. (2012). Hydroponic lettuce production in different concentrations and flow rates of nutrient solution. *Horticultura Brasileira, 30*, 526-530. doi: https://doi.org/10.1590/S0102-05362012000300028

Harahap, M. A., Harahap, F., & Gultom, T. (2020, March). The effect of Ab mix nutrient on growth and yield of pak choi (*Brassica chinensis* L.) plants under hydroponic wick system condition. In *Journal of Physics: Conference Series* (Vol. 1485, No. 1, p. 012028). IOP Publishing. doi: 10.1088/1742-6596/1485/1/012028

Hussin, N. S. M., Gamil, S. A., Amin, N. A. M., Safar, M. J. A., Majid, M. S. A., Kazim, M. N. F. M., & Nasir, N. F. M. (2017, October). Design and analysis of hydraulic ram water pumping system. In *Journal of Physics: Conference Series* (Vol. 908, No. 1, p. 012052). IOP Publishing. doi: 10.1088/1742-6596/908/1/012052

Kumar, H., Beyene, T., Ofgaa, G., Kaso, M., Rao, P. N., & Negassa, T., (2016). Pollution free design and manufacturing of hydraulic ram pump for villages in hill areas. *Int. J. Mech. Eng. Res. and Tech, 2(2),* 15. https://www.irjmets.com/uploadedfiles/paper/issue_6_june_2022/25493/final/fin_irjmets1654755505.pdf

Santos, P. J. A., & Ocampo, E. T. M., (2005). Snap hydroponics: development & potential for urban vegetable production. *Philippine Journal of Crop Science, 30(2),* 3-11. https://www.cabdirect.org/cabdirect/abstract/20053176287

Tagle, S., Benoza, H., Pena, R., & Oblea, A., (2018). Development of an indoor hydroponic tower for urban farming. In *Proceedings of the 6th DLSU International Conference on Innovation and Technology Fair, Manila, Philippines* (pp. 22-23). https://www.dlsu.edu.ph/wp-content/uploads/pdf/conferences/ditech/proceedings/volume-3/paper-10.pdf

Wedashwara, W., Jatmika, A. H., & Arimbawa, I. W. A., (2021). Smart solar powered hydroponics system using internet of things and fuzzy association rule mining. In *IOP Conference Series: Earth and Environmental Science* (Vol. 712, No. 1, p. 012007). IOP Publishing. doi: 10.1088/1755-1315/712/1/01200