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Aanchal Chandrakar
Research Scholar, Department of Soil and Water Conservation Engineering, SVCAET & RS, IGKV Raipur, Chhattisgarh, India

Narendra Agrawal
Assistant Professor, Department of Soil and Water Conservation Engineering, SVCAET & RS, IGKV Raipur, Chhattisgarh, India

Corresponding Author:
Aanchal Chandrakar
Research Scholar, Department of Soil and Water Conservation Engineering, SVCAET & RS, IGKV Raipur, Chhattisgarh, India

Evaluating the role of vertical hydroponics in reducing water usage compared to horizontal hydroponics

Aanchal Chandrakar and Narendra Agrawal

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Abstract
An experiment was conducted at the Department of Soil and Water Conservation Engineering, SVCAET & RS, IGKV, Raipur which focuses on water and water use efficiency in hydroponics. Two hydroponic systems i.e. vertical and horizontal hydroponic systems were used to evaluate the performance of the systems with respect to total yield and water. Plants were grown in nurseries before being transplanted in a vertical or horizontal system. In these systems, nutrient-rich water was constantly flowing over the plant roots. The results of the study showed that various growth parameters like average plant height, number of leaves and stem diameter were found to be maximum at 7, 14 and 28 days of transplantation in the vertical system as compared to the horizontal system.

The study also revealed that the water used by plants was seen to be a minimum of 1100 liters in the vertical system and 1500 liters in the horizontal system. Similarly, water use efficiency was found to be 0.0173 kg/litre in the vertical system and 0.0107 kg/litre in the horizontal system. The total production in the vertical system was recorded at 19 kg while in the horizontal system it was 16 kg. In the overall scenario, the vertical system with nutrient film technology is more water-efficient, requiring less water and nutrients, while also promoting plant growth and yield. These findings may contribute to more sustainable and resource-efficient hydroponic farming practices.

Keywords: Vertical hydroponics, horizontal hydroponics, water use efficiency, plant

Introduction
The increase in the world population greatly impacts the food demand, as it is estimated that, the global population could grow to around 9.7 billion in 2050, and 10.9 billion in 2100 when compared with the projected 7.7 billion people worldwide in 2019 (Nation 2024). The rapid development of the world's population and urbanisation has increased the demand for sustainable agriculture practices. Traditional soil-based farming methods frequently result in inefficient water use, necessitating the development of new agricultural approaches. Many challenges arise with traditional farming, including physical ploughing, weeding, pests, and climate. It also necessitates extensive usage of land. All of these issues are handled in hydroponic farming. Hydroponics farming produces crops faster, healthier, with less water, in a smaller space, and without illnesses, pests, or weeds. It is similar to traditional agriculture systems, thus the background required to apply this system will be the same in most cases, such as maintaining adequate nutrient levels, utilising suitable irrigation techniques, caring for the plant, and so on. Other vital information will be related the creation of a proper and reliable network with fail-safe mechanism (Patil *et al.*,2020) [10]. This farming technology that feeds plants with nutrient-rich water rather than soil. As technology progresses and people's living standards rise, hydroponic plants become an increasingly important element of our daily lives.

There are many types of hydroponic systems including the wick system, nutrient film technique (NFT), aeroponic system anddeep flow method (Nursyahid *et al.*, 2019) [9]. In the NFT technique, the water that contains nutrients circulates through plant roots. The advantage of employing this approach is that plant development is more easily controlled. (Chowdhury *et al.*, 2020) [4]. Vertical and horizontal systems have different benefits and problems with easy to maintain, space saving and increasing yield. Plants grown in vertical hydroponic systems are especially advantageous in urban environments with limited space each plant receive ample light. However, horizontal systems spread plants over a larger horizontal surface area, which could make access easier. (Alshrouf, 2017) [1].

Water usage efficiency (WUE) is defined as the amount of water utilised by plants or plant systems in relation to the amount of biomass generated (Shtaya and Qubbaj, 2022) [12]. For example, higher water use efficiency suggests that less water is necessary to reach a specified level of agricultural output, implying more efficient use of existing water resources. Water is an essential resource for plant growth; thus, its availability and quality have a substantial impact on crop quality and output. Growers in controlled environment agriculture (CEA), particularly in locations prone to drought or water constraints, want sustainable and efficient strategies to grow crops for high profit margins. Using NFT, assess the water-saving capacity of vertical and horizontal hydroponics systems, providing insights into their efficiency and sustainability for urban farming applications. (Frasetya *et al*., 2021) [5].

This study was conducted to compare the water use efficiency and growth parameters of vertical and horizontal setups using the Nutrient Film Technique. The purpose of this study is to optimise hydroponic systems for greater water savings by analysing variables such as plant growth performance, evaporation rates, and water recirculation.

Materials and Methods

Study Area

The research was conducted at SVAET & RS, IGKV Raipur. It was located in central Chhattisgarh in latitude 21^0 14' 9" N and longitude $81^0$42'10" E, at an elevation of 302 metres above mean sea level. The area has a humid subtropical climate with an average annual rainfall of 1260 mm, primarily from the south-west, followed by the north-east monsoon. The experimental site has clay loam soil. The meteorological parameters of temperature, relative humidity, and light intensity were measured at the experimental site.

Materials used

- **Vertical Hydroponic Structure:** PVC pipes (diameter: 4 inches), water reservoir (50 liters), submersible pump (flow rate: 500 liters per hour), NFT channels (2 metres in length), Support structure (metal or plastic)
- **Horizontal Hydroponic Structure:** PVC pipes (diameter: 4 inches), water reservoir (50 liters), submersible pump (flow rate: 500 liters per hour), NFT channels (2 metres in length)
- **Plants and net pots**
  Spinach (Spinacia oleracea) seedlings, plastic net pots
- **Nutrient Solution and growing media**
  Commercial hydroponic nutrient solution, growing media (cocopeat and vermiculite)
- **Monitoring Equipment**
  EC (electrical conductivity) meter, pH metre**,** Water flow metres**,** Temperature and humidity sensors**,** Water level sensors, Timer for the pump.
- **Planting Materials**
  In plastic pro-trays, spinach crop seeds were planted with a soilless media made of a 3:1 mixture of coco peat and vermiculite. To keep the seedlings healthy and disease-free, they were raised in a polyhouse with natural ventilation. Place the seedlings in the NFT channels of both hydroponics systems after transplanting them into net pots.

Nutrient Solution Applied

The water-soluble NPK 19-19-19 is an essential component of the hydroponic nutrient solution, which is used in both vertical and horizontal systems. The nutritional solution is made by combining Solution A (NPK and Epsom salt) and Solution B (calcium nitrate) with water. Adjust the EC to 1.2-1.8 mS/cm and the pH to 5.5-6.5. Transfer the prepared fertiliser solution into each system's water reservoir.

System Setup

- **Vertical System:** Using the PVC pipes arranged in a vertical pipe arrangement, set up a vertical hydroponic system. Make sure the submersible pump is attached to each pipe that connects to the water reservoir. From the top pipe, the nutrient solution should cascade through each pipe below it before returning to the reservoir.
- **Horizontal System:** Set up a horizontal hydroponic system with the PVC pipes laid out horizontally. Connect the pipes to the water reservoir with the submersible pump, ensuring a continuous flow of nutrient solution through the channels.

System Operation

A pump constantly circulates the nutrient solution through the channels in both vertical and horizontal NFT systems, ensuring a consistent flow rate that ensures uniform distribution to plant roots. Maintain the ideal conditions for plant growth, it is essential to regularly evaluate the pH and electrical conductivity (EC) of the nutrient solution and make necessary adjustments to the nutrient concentrations. To ensure that the plants receive the right ratio of nutrients. Additionally, the growth environment's temperature and humidity were regulated and maintained to establish a steady and favourable atmosphere for plant development. Because they affect growth rates, nutrient uptake and crop performance overall

Growth parameter observations

- **Plant Height**
  Measure the height of the plant from the base of the stem to the tip of the highest leaf using a measuring tape. Plant height was measured 7 days after transplanting and measured every week.
- **Number of Leaves**
  Count the total number of leaves per plant manually. Number of leaves measured 7 days after transplanting and measured every week.
- **Stem Diameter**
  Measure the stem diameter at a standardized height using callipers. Stem diameter was measured 7 days after transplanting and measured every week.

Water related observations

- **Water Used**
  Measure the volume of nutrient solution delivered to each system using flow meters. Measurement of total water used by the plants at specific intervals is very important.
- **Water use efficiency**
  The water use efficiency was obtained for each treatment was divided by the quantity of water used consumptively for the respective system. Water use efficiency was worked out and expressed in kg per cubic meter of water used.

$$\mathbf{WUE} = \frac{\mathbf{Tp}}{\mathbf{Tw}}$$

Where,
WUE = Water use efficiency (kg/liter)
Tp =Total production (kg)
Tw = Total water use (liter)

Results and Discussion

Plant growth in hydroponics systems

Measurements were taken for three plants in each hydroponic system at 7, 14, 21, and 28 days after transplanting (DAT). The data includes plant height, number of leaves, and average stem diameter.

Plant height

Fig 1 shows average plant height of vertical hydroponic system was more height than a horizontal hydroponic system. Because several things can be attributed for the difference in height. Plants in a vertical structure grow upward because they receive light from the top. As a result of this structure, plants can get taller as they attempt to reach the light source above. In a vertical system, the cascading flow of nutrients from top to bottom ensures that plants at each stage receive a new supply of nutrients, promoting rapid growth. Similar result obtained in Balashova *et al.*, 2019 and Voutsinos *et al.*, 2021 [2, 14].

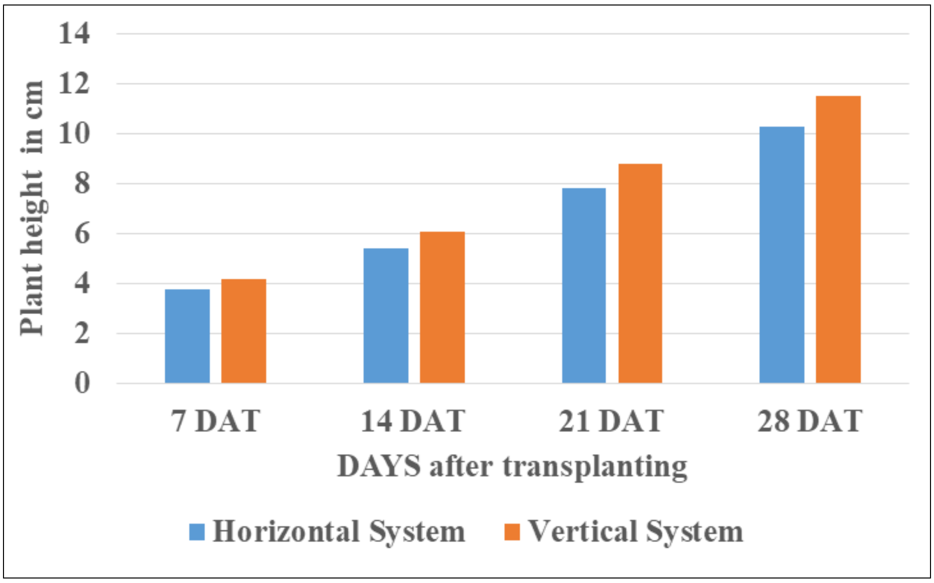

Fig 1: Plant height in Vertical and Horizontal Hydroponic Systems

Number of Leaves

Fig 2 show, average number of leaves vertical hydroponic system produces more leaves than a horizontal hydroponic system. Because the capacity of the plant to absorb light and carry out photosynthesis can be improved by having more leaves. The photosynthetic layer of a plant grows by more leaves, which enables the plant to create more energy and develop faster. By ensuring that every plant receives enough light and nutrients, steady delivery of nutrients, the vertical arrangement encourages the growth of more leaves. Similar result obtained in Matysiak *et al.*, 2023 [8].

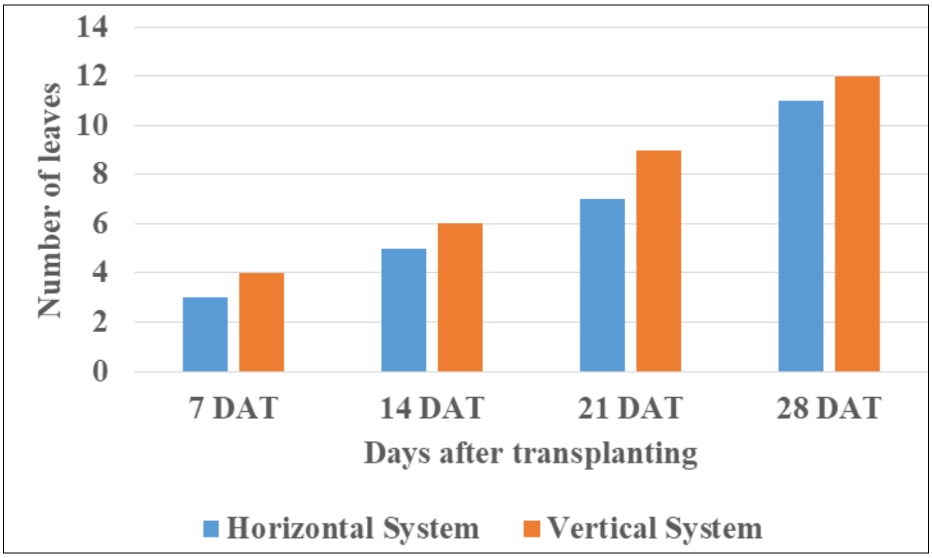

Fig 2: Number of Leaves in Vertical and Horizontal Hydroponic Systems

Stem Diameter

Fig 3 show, average stem diameter of vertical system produces more stem diameter than a horizontal hydroponic system. Because more dense stems on plants produced in a vertical hydroponic system indicated improved structural development. There are several factors that thicker stems could be beneficial. Uniform growth and thicker stem development may result from the vertical arrangement's potential to provide a more uniform and even distribution of nutrients throughout the root zone. Similar result obtained in Lim *et al.*, 2025 [7].

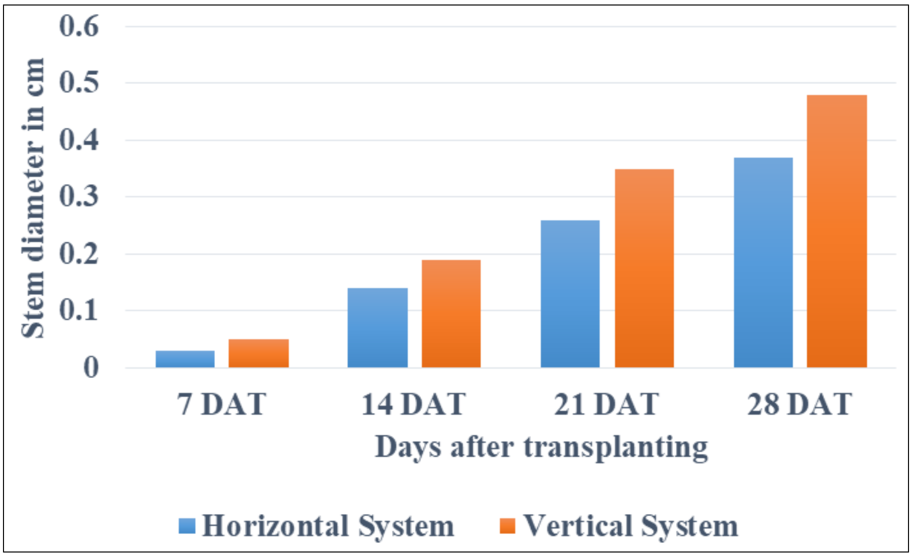

Fig 3: Stem Diameter in Vertical and Horizontal Hydroponic Systems

Comparison of total water used between VS and HS Structures:-
Fig. 4 clearly shows the water used by the plants at different stages of plant growth in both the systems. By accurately determining and meeting water requirements, growers can ensure optimal hydration for plants, aiding their growth and overall health.

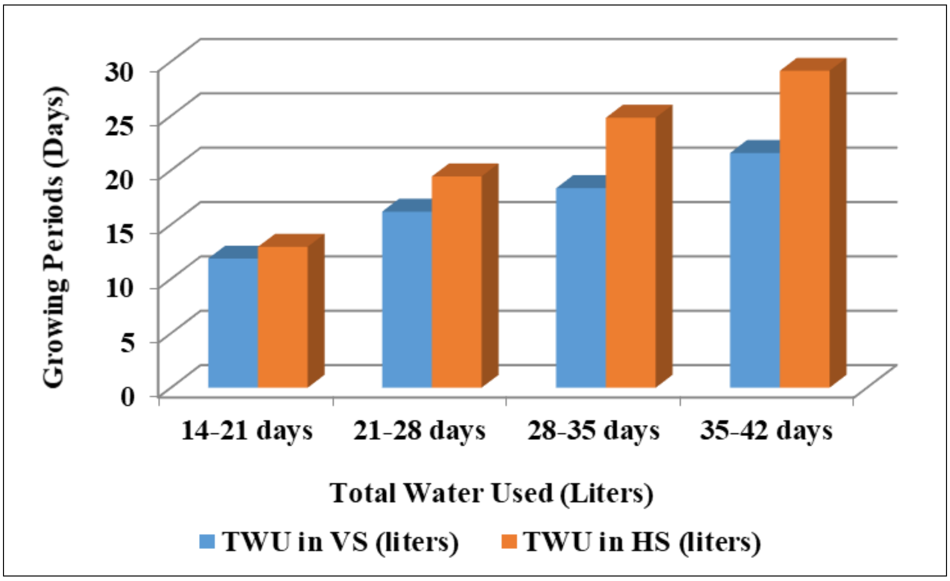

Fig 4: Total water used by the plants at different stages in both systems

Fig. 4 also shows that in both the systems the water absorbed by the plants increased gradually with their growth period. The reason behind this is that as plants develop larger root systems and more leaves, their transpiration rate increases, leading to more water loss through evaporation from the leaves. This increased transpiration places a greater demand for water from the hydroponic system to support plant growth, nutrient absorption and metabolic processes.

By implementing a vertical hydroponics system, growers can achieve higher water use efficiency, conserve water resources, and optimize plant growth. The efficient use of water in a vertical system not only benefits the environment, but also contributes to improved crop productivity and overall sustainability in hydroponic farming. Overall, vertical hydroponics system showed better growth, water application, nutrient application and yield than horizontal hydroponics system due to efficient use of water and nutrients by the plants. Similar result obtained in Pomoni *et al*. 2023 [11].

Water use efficiency in VS and HS Hydroponics
Table 1. presents water use efficiency values for both horizontal and vertical hydroponics systems. Water use efficiency was determined by dividing the total yield from the system by the total water used by the plants. This calculation allows an assessment of how effectively water was used in relation to the yield achieved, giving information about the efficiency of the system in water used.

Table 1: Water use efficiency in HS and VS hydroponics

S. No.	Systems	Total Yield (kg)	Total Water Used (liter)	Water Use Efficiency (kg/ liter)
1	Horizontal hydroponics system	11.90	97.20	0.12
2	Vertical hydroponics system	17.20	78.84	0.22

Table 1. shows that in the horizontal hydroponics system, the total yield recorded was 11.90 kg, corresponding to which the water used by the plants was 97.20 liters similar result obtained in kaur *et al*. 2023 [6] The water use efficiency obtained by dividing the total yield by the total water used is 0.12 kg per liter. Similarly, the vertical hydroponics system shows a high total yield of 17.20 kg. The water used by the plants for this system was 78.84 liters, resulting in a calculated water use efficiency of 0.22 kg per liter.

These values reflect the efficiency with which each system uses water to produce a given amount of yield. Higher water use efficiency implies that a higher yield is obtained per unit of water consumed, indicating a more efficient use of water resources. (Carotti *et al.*, 2023) [3]

Comparing the two systems, the vertical hydroponics system demonstrates higher water use efficiency compared to the horizontal system. This suggests that the vertical system is more effective in producing a greater yield using a relatively lower amount of water.

Conclusion

The objective of this study was to evaluate the water use efficiency and plant development characteristics through a comparative study on water savings in vertical and horizontal hydroponic systems. The result shows that it was discovered that the vertical hydroponic system used less water than the horizontal system. The vertical system fared better than the horizontal system, which had a water use efficiency (WUE) of 0.12 kg/L. The vertical system's WUE was 0.22 kg/L. This showed that less water was needed in the vertical system to compare to the horizontal system give a higher amount of yield. The vertical hydroponics system allows for the reuse of nutrient solutions. This uniform flow of nutrients also promotes growth of the plant, and give greater plant height in the vertical system compared to the horizontal system. The horizontal structure required more water and yielded slightly less, but it allowed for quicker and consistent nutrient delivery. Plant growth data showed that the horizontal system produced more leaves and had thicker stem diameters, but the vertical system increased plant height more than the horizontal system. The trade-offs between the two systems are highlighted by these variations. The vertical system is especially well-suited for urban farming and regions with limited water resources because of its space-efficient design and increased water savings. The study's overall findings highlight the possibilities of vertical hydroponic systems as an effective and sustainable substitute for urban agriculture that maximises water use without sacrificing plant development and yield.

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