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Research Article

Construction and evaluation of a hydroponic system for cultivation of tomato

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Abstract

Hydroponic system applications can help alleviate problems caused by changes in agricultural land usage. Many hydroponic researches have been carried out growing different plants, however their applicability in Sindh Pakistan requires some amendment. The research was conducted at Sindh Agriculture University Tandojam to build and analyse a hydroponic structure with a continuous nutrition system for cultivation of tomato. PVC pipes were used to construct the hydroponic system. Tomato plants were grown in hydroponic cups after transplanting for 15 days. The result revealed that EC and pH of water ranged between 1.23 to 2.76 dS/m and 5.32 to 6.92 respectively. The temperature of water varied between 18 to 24 ºC with an average value of 21 ºC. Ambient temperature and solar radiations varied between 21 to 26 ºC and 250 to 325 W/m^2 respectively. Number of leaves per plant increased from 6 to 22 in 28 days after transplantation, and plant height increased from 15 to 32 cm. The total cost of construction of the hydroponic structure was 11,889/ PKR. The constructed hydroponic system proved to be a suitable technology for growing tomatoes in a protected environment with minimal space, fertilizer and water requirements.

Keywords: Construction; Evaluation; Hydroponic; Tomato

Introduction

Global food security is affected by climate, widespread farming soil pollution and limited freshwater supplies, as well as with an increasing urbanized population [1]. In comparison to traditional agriculture, hydroponics, a type of soilless crop growing provides a new option for sustainable food production by conserving soil and land resources, while reducing water consumption [2]. Hydroponics is an agricultural technology in which plants are grown in water systems with fertilizers and other growth-supporting media, rather than in soil [3]. Hydroponic systems can range from low-tech, passive systems to high-tech, fully automated systems, with system design easily suited to local requirements [4].

Deserts, dry coastal belts, and cities depend mostly on imported food supplies and are thus more vulnerable to food insecurity due to a lack of agricultural land or low soil quality [5]. Hydroponics in this case can help these communities in becoming more food self-sufficient, allowing for local control of food resources, and lowering greenhouse gas emissions associated with imported food, all while enhancing climate change resilience [6]. Hydroponic systems are mostly installed inside building so that the grower has complete control over the temperature, humidity and amount of light the plants take. Because of this control, hydroponic growers are less vulnerable to unpredictable environmental conditions such as weather patterns, droughts and soil erosion [7]. Wind, evaporation and runoff lose over half of the water utilized for irrigation, which is caused by poor irrigation methods and systems [8, 9]. Growing plants in a hydroponic system has several advantages, including the reduction of water usage, the minimum labor required to grow organic crops in an indoor system, the minimum space required and the ability to grow food at any place [10]. In aggregate-based hydroponic systems like drip-irrigated or flood-and-drain methods, soilless growth material is employed [11]. The use of soilless growing media in hydroponic systems can boost crop yields when compared to conventional soil-based cultivation since quantities of water, nutrient and oxygen transfer are greater and can be simply optimized [12]. Crops grown indoor are protected from the outside environment and allow farmers to produce crops out of growing season, where lack of availability can result in greater prices and maximize profits [13].

Aside from the environmental benefits, hydroponic systems give growers a number of practical advantages. Hydroponic systems allow producers to individually adjust nutrients, root zone pH, root and shoot temperature, which results in improved efficiency and yields per area [14]. These systems also assist growers in avoiding food contamination by keeping the growing space contained and clean [15]. The water in this system is being recirculated, minimizing its losses, whereas traditional agricultural procedures results in water seepage and with increasing evaporation rates [16]. Since agricultural use contributes significantly to the depletion of the World's freshwater resources, hydroponics offers a technique to grow food while conserving water [17]. The fertilizers in hydroponic are delivered to the closed system, so there is no nutrient loss via leakage into the ground or nutrients which are being washed away in runoff water as with field systems [18]. When compared to agricultural land, this closed system for nutrients reduces pollution of lakes and rivers, resulting in greater water quality [19, 20]. The study keeping the importance in view was carried to construct and evaluate a hydroponic system for cultivation of tomato.

Materials and Methods

Study area

The research was conducted at the Department of Farm Structures, Faculty of Agricultural Engineering, Sindh Agriculture University Tandojam, Pakistan to construct and evaluate a hydroponic structure in 2019. The hydroponic system was designed using a nutrient film technique system (NFT). The nutrient film technique system provides not only a steady supply of water and nutrients, but also oxygen-rich conditions.

Material used for the construction of hydroponic structure

The hydroponic structure in this study was arranged with five main polyvinyl chloride pipes (PVC) with 4-degree slope, a water tank, five valves, several junction pipes and a motor (Fig. 1). The materials and specifications for the hydroponic systems are presented in Table 1 and detailed below.

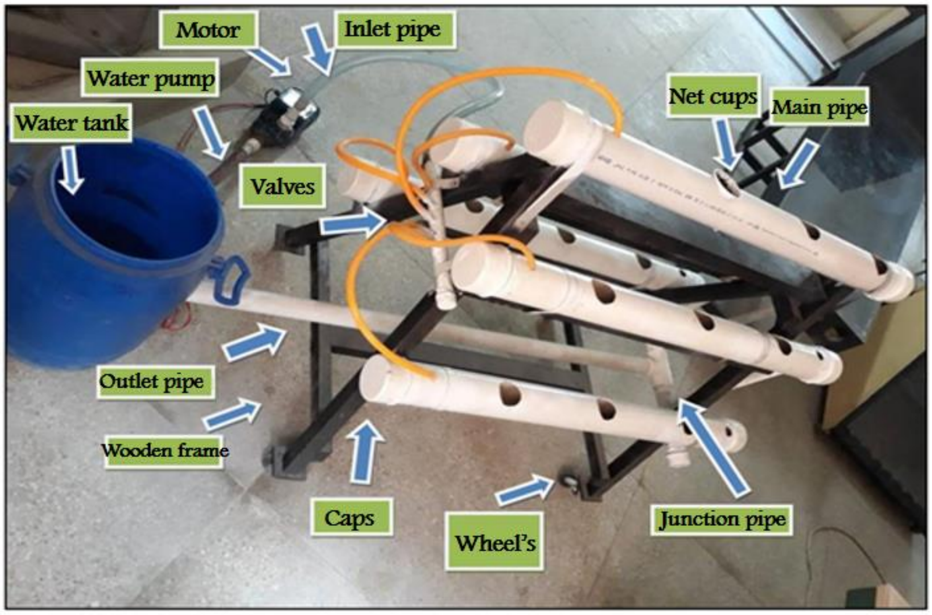

Figure 1. View of the hydroponic system

Table 1. Specifications for building a hydroponic system

Materials	Remarks
Pipes	PVC
Main pipes diameter	3.5 inch
Main pipes slope	4 degrees
Water tank volume	26 liters
Number of valves	5
Junction pipe	8.5 feet length and 1.5-inch diameter
Small pipe	12.22 feet length and ¾ inch diameter
Net cups	15
Wooden frame	34 feet wood used in frame
Water pump/ motor	3 feet head

Main pipes

The length of individually main pipe was 3 ft and 7 inches. The pipes had holes of 3 inches in which net-cups with coco-peat media were placed.

Junction pipes

Junction pipes of 1.5-inch diameter were used to connect the main pipe with each other.

Water tank

Plastic tank with a cover of 26 litter capacity was used for this study. Tank was filled with nutrient solution nearly to the top.

Valves

Inside the main pipes, valves were employed to control the depth and velocity of water flow. The water rate of each pipe was separately controlled as each valve was connected to various main pipelines.

Net-cups

The hydroponic medium in the net-cups was peat moss. The net-cups were extended to the main pipes so that plants with longer roots could collect fertilizers. The diameter of the net-cup was 2.7 and 3 inches at bottom and top respectively, while the total height of cup was 3.2 inch.

Wooden frame

A frame was required for the hydroponic system arrangement, wooden bars for that were employed as a frame for this system. The frame dimensions were 3 feet, 2.5 feet and 3.4 feet for its length, width and height, respectively.

Seedling tray

The seeds of tomato crop were germinated in seedling tray using peat moss as its growing media. Watering was done using garden sprayer so that it could not damage the plant.

Construction procedure of the hydroponic structure

The frame was constructed using 1×2 inch wooden strips. The horizontal supports for the 3.5-inch diameter main pipes were installed after the wooden frame was completed. To provide proper drainage, one side of the horizontal support was slightly lowered at a slop of four degrees. After the construction of the frame, 3-inch diameter holes were drilled in the main pipes for the cups carrying the plants to sit in. To ensure that all of the plants got direct sunlight, the holes were spaced one foot apart. Water was continuously circulated through the system to ensure that the plants had the access to water when they needed. The pump was sized and chosen based on the required pumping height, which was 3 feet. The water reservoir selected was of 26 litters, where the water was pumped out and drained back into the reservoir.

Nutrient selection

The MaxiGro fertilizer solution was used in this study, and was purchased from Agriculture Research Institute, Tandojam. The Table 2 shows the nutrient composition, which includes all primary, secondary and micronutrients. With every gallon of water, 10g of nutrient fertilizer was added.

Plant selection, germination and transplantation

Tomato crop was selected for this study. Tomato seeds were obtained from Agriculture Research Institute, Tandojam, and placed in the seedling tray for germination. After 15 days of germination the plants of tomato were transplanted from seedling tray to the hydroponic cups containing peat moss.

Observations

The observations with their methods as mentioned in Table 3 were noted during the experiment at an interval of seven days.

Construction cost

The hydroponic structure's overall construction cost was calculated. The total cost was computed by first calculating the materials used in the construction of the hydroponic structure, then multiplying each material by its unit rate and by adding them together.

Table 2. MaxGrow nutrient contents

Nutrients	Percentage
N	19
P	19
K	19
Ca	2
Mg	2
S	3
Fe	0.12
Mn	0.08

Table 3. Observations and methods used

Observations	Analyzing methods
EC of water (hydroponic solution)	EC meter
pH of water	pH meter
Temperature of water	Thermometer
Amount of water used	Area × depth
Ambient temperature	Dry bulb thermometer
Solar radiations	Pyrometer
Number of leaves	Counting
Plant height	Measuring tap

Results and Discussion

EC (electrical conductivity)

The results of EC of hydroponic water is given in Fig. 2a. The EC of water increased from 1.23 to 2.76 dS/m with an average of 2 dS/m throughout the study period. The EC was observed to be significantly different. The EC is a measurement of the nutrient concentration in a solution. However, each nutrient has a varied salt content, it may have a high concentration of one and a deficiency of another [21]. If tests are taken at the same pH value, the EC will then result for whether the solution has lost nutrients or water through evaporation. The nutrients should not be added if the EC goes too low (less than 70% of the initial value) [22]. This indicates that the plant has significantly altered the content of the solution, which then needs to be discarded and replaced. The EC of the hydroponic solution and its consumption by the plants are within a suitable range. The EC in current study increased with increasing salt concentrations and time.

pH

The results of pH of water is graphically represented in Fig. 2b. pH of water increased from 5.32 to 6.92, with an average of 6.14. Controlling pH is essential not only in hydroponics but also in soil. Fluctuation in pH results in plants to lose the capacity to absorb different nutrients in plants. pH ranging between 5.5 and 7 is considered suitable, where a sudden change in pH level puts too much stress on the plant [23]. The controller has the advantage of constantly reporting the pH level of the water (every five seconds). The interval of changing of nutrient solution depends upon pH range and the age of crop after transplanting [24].

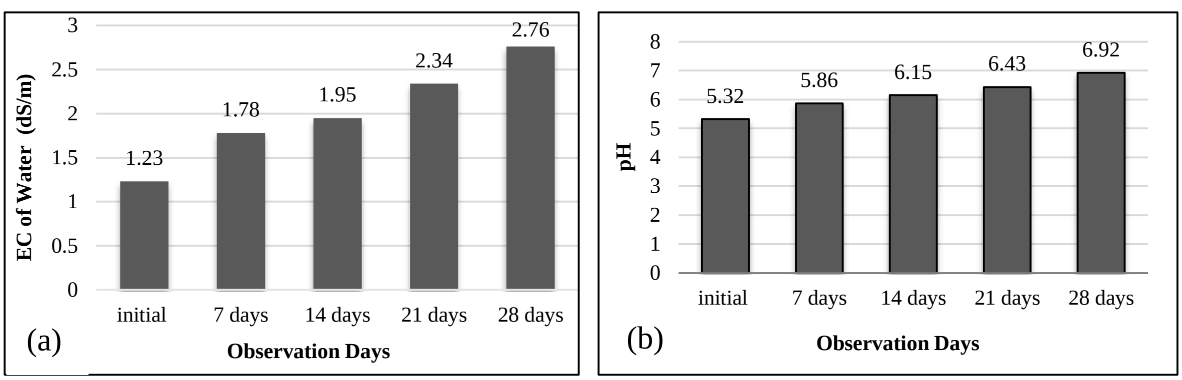

Figure 2. Variation in EC (a) and pH (b) of water used in hydroponic structure with time

Temperature of water

The results for temperature of water is shown in Fig. 3a. The temperature of water varied between 18 and 24 ºC, with an average value of 21 ºC. The temperature of the water is supposed to be in the range of 18-26 ºC for the nutrients to be efficiently absorbed by the plants.

Amount of water used (liter)

The amount of water used by plant and in evaporation was observed during the experiment. The data of water used is represented in Fig. 3b. The result showed that amount of water used ranged between 4.565 to 5.652 liters. The total water used was 20.651 litter throughout the experiment.

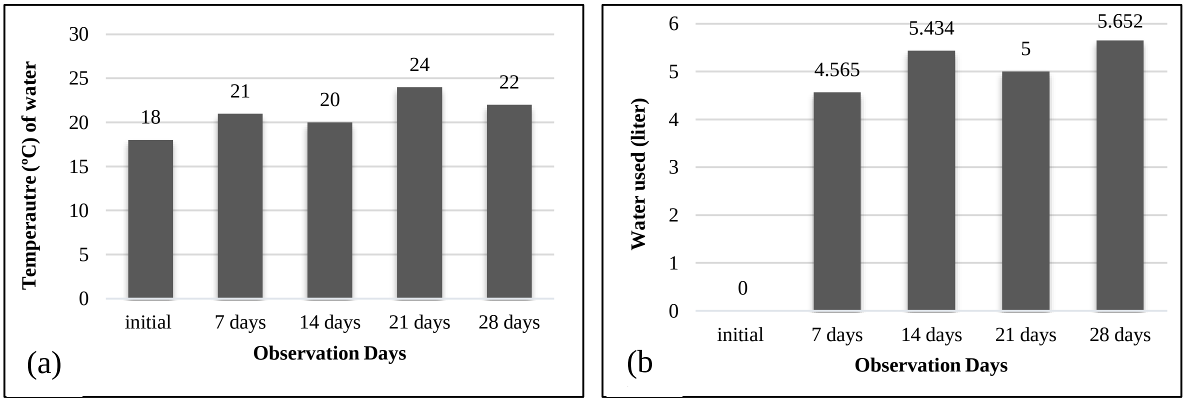

Figure 3. Variation in temperature of water used in hydroponic system with time (a) and amount of water used (b)

Ambient temperature

The result of air temperature surrounding the hydroponic structure is graphically represented in Fig. 4a. The temperature fluctuated between 21 and 26 ºC, with an average value of 23.2 ºC. Surrounding temperature greatly affected the plant growth and temperature of the water used inside the hydroponic structure.

Solar radiation

The result of solar radiations recorded during the experiment is shown in Fig. 4b. The solar radiations ranged between 250 to 325 w/m^2, with an average value of 285 w/m^2. Light plays an important role in plant growth and development [25]. Photo-sensory systems detect the quantity, quality, and direction of light, and use this information to regulate plant development, presumably to keep photosynthetic efficiency high [26]. Photo-oxidative damage, or the formation of reactive oxygen species (ROS) in chloroplasts in response to light is the primary cause of cell damage and death in plants exposed to environmental stressors [27].

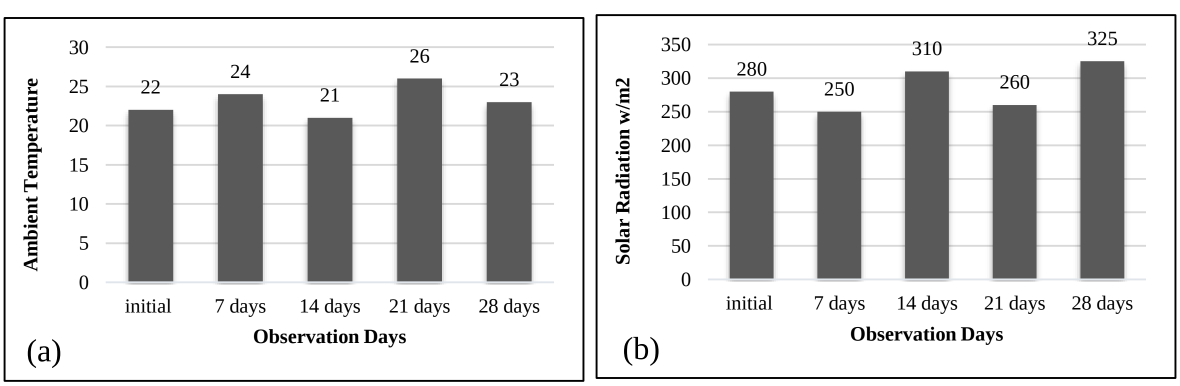

Figure 4. Variation in ambient temperature (a) and solar radiation (b) during the experiment

Number of leaves per plant

The number of leaves per plant were counted and recorded. As shown in Fig. 5a the number of leaves on tomato seedlings cultivated in a hydroponic system increased with increasing days. Six number of leaves were observed initially, which then increased to 22 number of leaves after 28 days.

Plant height (cm)

After the transplantation of the tomato plants in the hydroponic structure, plant height of tomato was then measured at an interval of seven days. The result of tomato plant height is graphically represented in Fig. 5b. The plant height increased from 15 cm to 32 cm, with an average of 22.2 cm throughout the experiment.

Hydroponic structure fabrication cost

The cost of materials used in the manufacture of the hydroponic structure was assessed to determine the economy of hydroponic systems. The Table 4 represents the overall cost of the fabricated hydroponic structure, which was 11,889 PKR.

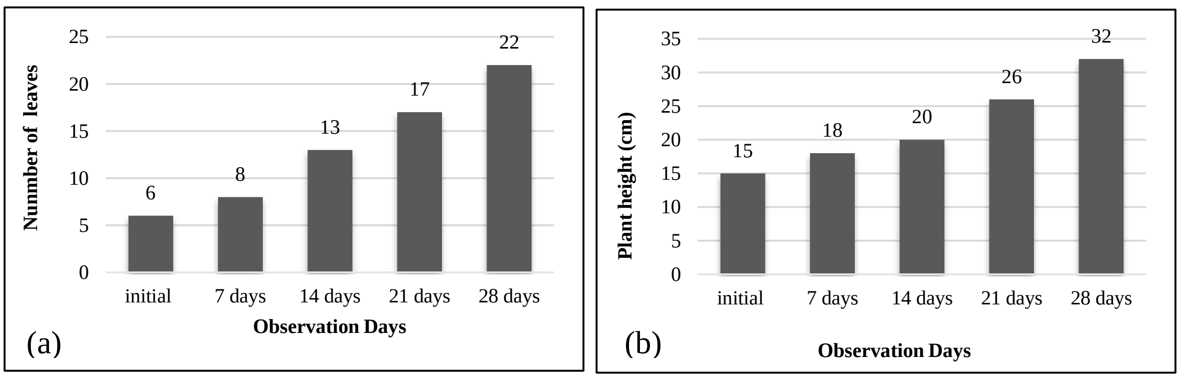

Figure 5. Number of leaves (a) and plant height (b) in hydroponic system with time

Table 4. Cost analysis of hydroponic structure

Materials	Quantity (PKR /unit)	Cost (PKR)
Peat-moss	1.5kg (800/kg)	1,200
Main Pipe (3.5 inch dia)	18.5 ft (60/ ft)	1,110
Outlet Pipe (1.5 inch dia)	8.6 ft (40/ft)	344
Drainage From Main Pipe ¾ dia	12.2 ft (30/ ft)	390
Wooden bars (1 by 2 inch)	34 ft (80/ ft)	2,720
Inlet Distributer Pipe	6 ft (20/ ft)	120
Electric wire	33 ft (20/ ft)	660
Motor	1 (2600/ no.)	2,600
Tank (26 liters)	1 (650/ no.)	650
No: of valves	5 (20/ no.)	100
No: of wheel	4 (90/ no.)	360
No: of cups	15 (15/ no.)	225
No: of joints	4 (60/ no.)	240
No: of caps	13 (90/ no.)	1,170
Total amount	--	**11,889**

Conclusion

The results concluded that the EC and pH of water ranged between 1.23 to 2.76 dS/m and 5.32 to 6.92 respectively. The temperature of water varied between 18 to 24 ºC, with an average value of 21 ºC. Ambient temperature and solar radiations varied between 21 to 26 ºC and 250 to 325 W/m^2 respectively. Number of leaves per plant increased from 6 to 22 in 28 days after transplanting, and plant height increased from 15 to 32 cm. The total cost of construction of the hydroponic structure was 11,889/ PKR. The constructed hydroponic system proved to be a suitable technology for growing tomatoes in a protected environment with minimal space, fertilizer, and water requirements. The farmers are therefore suggested to adopt this technology as an alternate medium of soil for deserts, dry coastal belts and urban areas.

Authors' contributions

Conceived and designed the experiments: A Lund & SH Chattha, Performed the experiments: A Lund, MA Leghari & K Lund, Contributed materials/ analysis/ tools: SH Chattha & BN Mirani, Wrote the paper: SA Soomro & G Zahid.

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