Comparative Assessment of Tomato Production using Hydroponic Bed and Open Field Culture

ABSTRACT

This study presents the development of a novel hydroponic bed stand tailored for tomato production. Hydroponic systems have gained popularity in modern agriculture due to their resource-efficient and sustainable nature. The design, construction, and evaluation of this specialized hydroponic bed stand aimed to optimize tomato production while addressing key challenges faced by traditional soil-based farming. The design phase involved a comprehensive analysis of various factors, including nutrient delivery, water management, plant support, and environmental control. A modular and adaptable structure was developed, accommodating multiple growth stages and plant varieties. The construction phase utilized cost-effective, easily accessible materials and construction techniques, making it suitable for both small-scale and large-scale farming operations. The evaluation of the developed hydroponic bed stand included a series of experiments and trials, comparing it with conventional cultivation methods. Key performance indicators such as growth rate, yield, and resource efficiency were closely monitored. The results revealed that the novel hydroponic system significantly out-performed traditional soil-based methods, demonstrating higher yields, reduced resource consumption, and enhanced crop resilience. In conclusion, the development of this novel hydroponic bed stand showcases a promising avenue for modern agriculture, offering a sustainable solution for tomato cultivation. Its innovative design and construction, along with superior performance compared to traditional methods, highlight the potential of hydroponics in addressing global food production challenges while minimizing environmental impact. This research contributes to the ongoing efforts to enhance agricultural practices and meet the demands of a growing population which can be used in both commercial and small-scale settings.

Keywords: out-performed; modular; cost-effective; challenges; adaptable; structure

1.0: INTRODUCTION

Controlled Environment Agriculture (CEA) is a method of growing crops within a closed system and thereby managing the numerous variable that are required for efficient plant growth, (Amitrano, *et al.,* 2020). It also integrates both science and engineering-based approaches in providing artificial soil-less system for sustainable crop production (Amitrano, *et al.,* 2020). The purpose for controlled environment agriculture is to reduce the threat of disease and pests, water shortage, limited land for farming, measures efficiency, increased sustainability, improved crop yield and also to bring down the overall cost of operation (Ur-Rehman, *et al.,* 2023). In indoor farming systems, the source of light that nourishes the plants is controlled for maximum efficiency, natural sunlight and LED lights are primarily used in indoor farming to allow the farmers to have greater control over the growing environment to guarantee all year round farming (Ur-Rehman, *et al.,* 2023). Indoor farming can be executed in any indoor space which accounts for the method great versatility. Large rooms, containers and even warehouses can be converted into indoor farms around the world today (Ur-Rehman, *et al.,* 2023). A green house is a specialized structure that is made almost entirely out of polycarbonate or glass (Ashok, & Sujitha, 2021). This allows the building to trap sunlight with great efficiency and hence has positive benefits for the growth of crops (Ashok, & Sujitha, 2021). Within a greenhouse, a large number of variables can be closely controlled and monitored for efficient production of crops (Hemming, *et al*., 2019). Controlled environment agriculture enables the farmer have control over parameters like: temperature, humidity, moisture and sunlight (Chatterjee, *et al.*, 2020). Vertical farming is a method of controlled environment agriculture where plants are horizontally stacked or are grown within the confines of tall towers, which is an ideal method to consider for farming operation under a limited space or urban environment (Chatterjee, *et al.*, 2020). Vertical farming helps the farmers to grow the plants vertically instead of horizontally, thus offering incredible potential to maximize yield (Maurya, *et al.*, 2020). With over 50% of our habitable land currently being considered for use in traditional farming methods, vertical farming helps to save space without having effect on the output of the farming season (Avgoustaki, *et al.*, 2020).

According to the world bank, the EU's percentage of arable land has been consistently dropping since 1960 (Lowder, *et al.*, 2021). Today less than 25% of the regions land area is arable. The problem of declining arable land is heightened in central Europe with countries like Croatia, Estonia and Slovenia having less than 15% arable land (Némethová, *et al.*, 2022). Given the challenge of limited space and land that is suitable for growing crops, companies and cities are turning to controlled environment agriculture (Goodman, & Minner, 2019). The most well-known and widely applied method of Controlled Environment Agriculture (CEA) is hydroponics (Lodge, 2019). Hydroponics is the method of farming that is involved in soilless agriculture in which plants are grown in liquid solution without the use of soil (Sambo *et al.*, 2020; Macwan *et al.*, 2020). Growing medium such as rock wool or coconut fiber is utilized in order to hold the plants to place and offer nourishment (Macwan, *et al.*, 2020). Hydroponic systems can be used to grow a wide variety of plants, including tomatoes, pepper and vegetables. Hydroponic tomato cultivation offers several advantages over traditional soil-based cultivation, including: increased yields; reduced water and fertilizer usage; improved pest and disease control; and reduced reliance on arable land respectively Majid,, *et al.*, (2021). There are basically two main types of hydroponic systems: the nutrient film technique (NFT) systems and the deep-water culture (DWC) systems (Niu, & Masabni, 2022). In NFT systems, the nutrient solution is circulated through a shallow channel, and the roots of the plants are suspended in the nutrient solution (Niu, & Masabni, 2022). In DWC systems, the roots of the plants are submerged in a deep reservoir of nutrient solution. Hydroponic bed stands are a type of hydroponic system that is commonly used to grow tomatoes (Niu, & Masabni, 2022). Hydroponic bed stands typically consist of a metal or PVC frame that supports a growing medium, such as perlite or vermiculite (Buyeye, 2021). The nutrient solution is circulated through the growing medium, providing the plants with the nutrients they need to thrive (Buyeye, 2021).

Hydroponic is a technology for growing plant in nutrient solution (water and fertilizer) with or without the use of artificial medium (Bhattacharya, 2017). The artificial medium that can be used are sand, gravel, vermiculite (a hydrous day-like material), Rock woll, pest Moss (a dark brown decomposing material), coir (fibre from outs hell of coconut), and sawdust (Bhattacharya, 2017) . Ideally, all hydroponic system are enclosed in a greenhouse type structure to provide temperature control, reduce evaporative water loss and to prevent crops against the element of weather such as wind and rain Jain, *et al.,* (2023). Hydroponics makes us to understand that soil is hot really the ideal thing needed cultivation but the nutrient stored in it Kousar, *et al.,* (2023). They also have some harmful pathogen that can be very difficult to control which will lead to poor yield but with hydroponic where the environment is modified and the crops are supply with nutrient solution leads to a better yield Kousar, *et al.,* (2023). The result can be seen in the research carried out where hydroponically grown tomatoes did better than open field tomatoes Bozo, *et al.,* 2019). This can be as a result of harsh weather, lack of nutrient, pest disturbing the crops which as well taken care of in hydroponic system Bozo, *et al.,* 2019).

Hydroponically grown tomatoes typically produce higher yields than soil-grown Verdoliva,, *et al.,* (2021). According to Majid,, *et al.,* (2021) hydroponic tomato cultivation offers several advantages over traditional soil-based cultivation, including: increased yields; hydroponically grown tomatoes typically produce higher yields than soil-grown tomatoes; reduced water and fertilizer usage; improved pest and disease control; hydroponic systems offer a more controlled environment, which can help to reduce the risk of pests and diseases; reduced reliance on arable land; and Hydroponic systems can be used to grow tomatoes in a variety of environments, including urban areas and arid regions Majid,, *et al.,* (2021).

The objective of the study: (1) design of a novel hydroponic plant stand; (2) construction of hydroponic plant stand; and (3) comparing the yield between hydroponic production and open field cultivation. The outcome of this study on development of novel hydroponic bed will be useful to tomatoes farmers especially the small scale-low income farmers living in rural, semi-urban and urban areas across the globe.

2.0: Materials and Methods

2.1: Geographical Description of Experiment Site

Rumuohaulu community is a vibrant and bustling neighborhood located in the heart of Port Harcourt, Rivers State, Nigeria. Situated within the Obio/Akpor Local Government Area of Rivers State, in Nigeria. The Trans Amadi Road borders Rumuohaulu on the north, the Eleme axis borders Rumuokoro village on the south, the Port Harcourt International Airport borders Rumuohaulu on the east. The community's geographical coordinates are 4°48'27"N 7°2'1"E. The mean monthly maximum temperature (30.25oC) of the region is sufficient to generate significant monthly water evaporation (92.76mm), which saturates the atmosphere with water vapor (monthly maximum humidity = 93.73%). The water vapor then condenses and precipitates as monthly rain (203.03mm). The unique topography of Rumuohaulu is what makes it so distinctive; it mixes urban features with stretches of unspoiled greenery. The community's terrain is relatively flat, with an average elevation of around 10 meters above sea level. The Okrika River, which runs along the eastern boundary of the community, provides the majority of the area's drainage.

Rumuohaulu's proximity to the Port Harcourt International Airport and its strategic location along major transportation corridors have made it a hub for commercial and residential activities. There are a variety of companies in the village that serve the requirements of both locals and visitors, such as stores, eateries, and motels.The community's residential areas are characterized by a mix of traditional and modern housing styles. Single-family homes, duplexes, and apartment buildings are all common sights in Rumuohaulu. The community is also well-served by a range of public amenities, including schools, hospitals, and recreational facilities. Rumuohaulu's cultural landscape is as diverse as its physical terrain. The community is home to a variety of ethnic groups, including the Ikwerre, the Igbo, and the Ijaw just to mention a few. This cultural diversity is reflected in the community's vibrant festivals, traditional cuisine, and rich artistic heritage. Overall, Rumuohaulu community is a dynamic and multifaceted neighborhood that offers its residents a unique blend of urban convenience and cultural vibrancy. Its strategic location, diverse population, and well-developed infrastructure make it an attractive place to live, work, and pleasure.

2.2: Material Used for the study

Pen, field note, computer set, PH-meter, two complete lengths of 4-inch pipe, PVC gum, ¾ pipe, 4-inch plug, ¾ ball valve, ¾ adaptor, ¾ union, ½ by ½ inches thread elbow, thread tape, clip, marker pen, rope, nail, wood, bucket, sandpaper, cup, soldering iron, plastic tank, water borehole, 300g of Platinium F1 tomato seeds; NPK 15:15:15 fertilizer; and handsaw are among the materials used for this study.

2.3: Methods

Using the materials and equipment mentioned above, the hydroponic bed was built by using the fundamental measuring, marking, cutting, joining, fits, and assembly skills. The constructed hydroponic bed was set up at Rumuohaulu community, Port Harcourt, Rivers States, Nigeria. A well-designed layout was provided to improve the ease of maintenance and cleaning. Adequate space provided to accommodate the nutrient rich reservoir and storage tank to hold water. The study was carried out between months of July and October 2023.

2.3.1: Determination of Pipe Volume

32 feet convert to cm
1 feet = 30 cm
14 feet = 30 x 32 = 960 cm
Length of pipe = 960 cm
D = 4 inches ≡ 10 cm
Vol = A x L

$$= \frac{\pi D2}{4} \times L$$

$$= \Pi \times 10^2 \times \frac{960}{4} = 75{,}408 \text{ cm}^3$$

1 litres ≡ 1000 cm^3

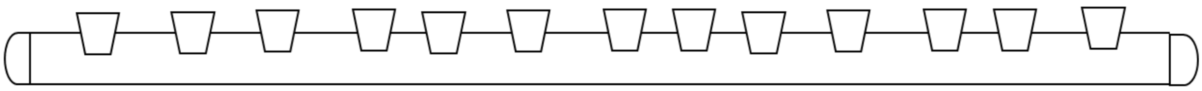
= 75.4 litres.

75.408 litres of liquid will be required to fully fill the pipe, however to half-fill the pipe will require $\frac{75.4}{2}$ which is equal to 37.5 liters of liquid. A 40-litre capacity plastic bucket was installed as storage tank for nutrient solution.

2.3.2: Construction of test Rig

40-litre container was installed as storage tank. In order to attach a ½ inch nipple to the front of the storage tank and control the flow of nutritional solution, a ¾ x ½ inch threaded elbow, union, and bub valve were bored into the bottom of the container. At the base of the container, bolt and nut was used to hold the nipple and later applied PVC gum to make it leak-proof. A desired length of ¾ pipe was attached to connect the tank to the plant stand.

2.3.3: Construction of Hydroponic Plant Stand



A 32 feet length, 4 inches diameter PVC pipe was used to construct a hydroponic plant stand which is meant to hold 26 tomatoes plants (two plants per stand). The plant stand was place at 36 cm (360 mm) apart. The two ends of the pipe were heated to soften to enable a 4 inches plug fit in. 6-inch length was then measured, marked from the edges of the pipe and hole was drilled on the marked points from both ends of the pipes. A ¾ inch pipe was then attached to the both sides and clipped to firmly hold it. The two ends were designated inlet and outlet ends respectively.

2.3.4: Construction of the Tank Stand

The tank stand was constructed using pieces polished of wood which were measured and cut into desired length using a handsaw. Hammer and nails were applied to join the various connecting parts to form a functional stand for the hydroponic bed. The base and top of the stand are rectangular in shape with the base larger than the top to provide the necessary stability for the weight.

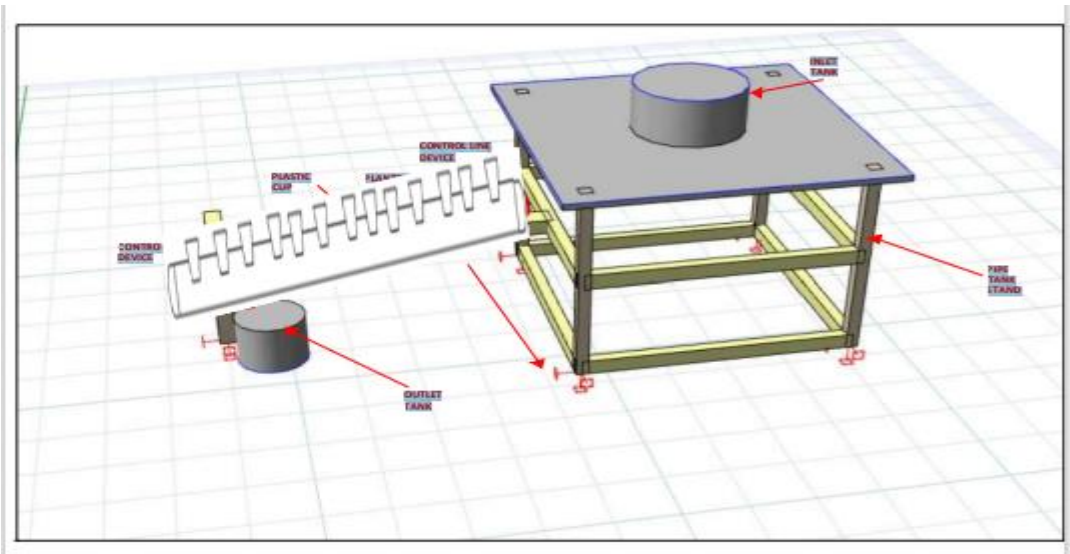


Figure 1. Test rig (**Hydroponic Bed for Sustainable Tomato Production) Authors' credit**

2.3.5: Construction of the Cups

Plastic cups were selected for use in order to allow the easy modification. The modifications made include drilling tiny pores at the base of the cups for the absorption of nutrients and at the top to allow for the fixing of wool to hold the young plants in position. The assembled hydroponic bed was drafted using AutoCAD software and presented in Figure 1.

2.3.6: Application of Nutrient Solution

NPK (15:15:15) fertilizer was dissolved in water and PH-meter was used to check the PH level of the solution. This was to ensure appropriate PH level of the solution.

2.3.7: Transplanting

Tomatoes seeds were planted in a prepared nursery bed and nurtured for three weeks. In order to reduce the stress that the seedlings would feel while transplanting, the transplanting process was completed from the nursery to the hydroponic system at approximately 5:30 p.m. when the sun had set. Cotton wool was attached round the stems of the young plants to avoid injuries (bruises round the stem) 7 days after transplanting, the tendrils was supported with the support lines to keep the stem growing upward not to be lying on the ground. With the absorption of the nutrient solution, the plant was growing well and producing fruits.

2.3.8: Provision of Supporting Lines

This is the provision of ropes as supports to stems of the growing tomatoes. The growing stems of the young plants climb the ropes as the grow. The stems were tied to the longer ropes using shorter ropes of about 10 cm in length.

2.3.9: Description of Daily Activities

The daily operations include: (1) The tank valve is opened to permit the inflow of nutrient solution to be discharged into the hydroponic system; (2The hydroponic system is half-filled and left for 20 to 30 minutes to allow the plants to absorb the nutrients optimally before the tank is refilled and discharged a second time. Then, the output is directed into another tank for subsequent recirculation.; (3) Every twelve hours, at 6:00 and 6:00 pm, the test rig was filled and emptied. Four weeks after transplantation, fruiting began. Upon maturity, ripe tomatoes fruits were harvested every three days, weighed and recorded. Data of harvested tomato fruits is presented in Table 1.

2.3.10: Control Plot (Open field)

A plot of land measuring 4 x 15 feet was chosen, cleared and used as control plot which is the basis for comparison. After 21 days of planting in nursery, 26 young tomatoes plants were transplanted into the control plot. NPK (15: 15: 15) fertilizer was applied at 20 g per plant stand. Weeding was carried out regularly. Upon maturity after about four weeks post-transplanting, ripe tomatoes fruits were harvested every three days, weighed and recorded. Data of harvested tomato fruits is presented in Table 1.

3.0: Result and **Discussion**

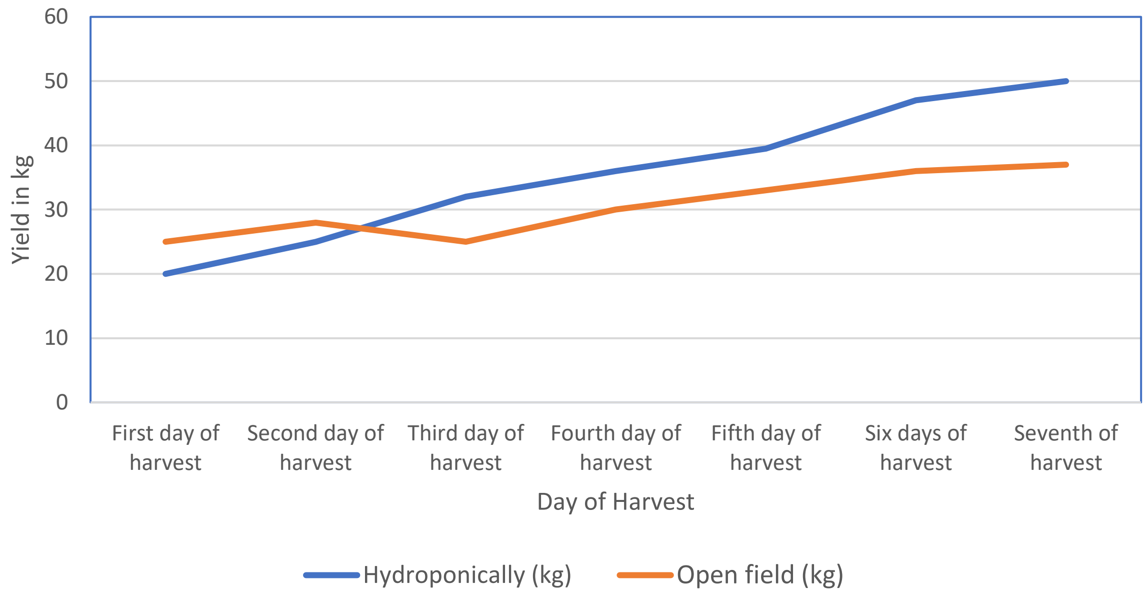


Figure 2: Comparison Tomato Harvested from Hydroponic and Open Field

Table 4.1: The result of tomatoes yield

Day of Harvest	Hydroponically (kg)	Open field (kg)
First day of harvest	20	25
Second day of harvest	25	28
Third day of harvest	32	25
Fourth day of harvest	36	30
Fifth day of harvest	39.5	33
Six day of harvest	47	36
Seventh day of harvest	50	37
Total	**249.5**	**214**

Hydroponic average = 249.5 ÷ 26 = 9.6 ≈ 10 kg
Open field average = 214 ÷ 26 = 8.2 ≈ 8 kg.

The ratio of hydro to open field =10:8 = 5:4

Result of harvested tomato fruits is presented in Table 1 and Figure 2. The hydroponic grown tomatoes with 26 stands produced a total of 249.5 kg, while, the open field having 26 stands produced 214 kg during the period of data collection. The ratio of yield of hydroponic grown to open field grown tomato is 5:4 indicating 25% improvement by using the developed novel hydroponic bed over open field culture for tomato production, this result is slightly different from the views of Sharma, 2008.

The tomato plants grown inside the hydroponic bed had greener leaves with bigger tomato fruits and more aesthetically appealing compared to those of the open field grown tomato. The observed difference could be because the hydroponically gown tomatoes had nutrients in their right proportion in an intensively controlled environment. This led to healthier plant growth, development and higher yield compared to those of the open field culture in which leaching occurs and plants compete with weed for nutrient and and space. This view was corroborated by Kousar *et al.,* (2023).

The use of eco-friendly materials significantly reduces the environmental footprint by the hydroponic bed compared to traditional systems. The use of eco-friendly materials is fast-growing, renewable resource that requires minimal maintenance and has a high strength-to-weight ratio. The design of the novel hydroponic bed promotes efficient water and nutrient utilization in tomato production, in which the closed-loop system minimizes water loss through evaporation and leaks, ensuring that nutrient content of the solution is continuously monitored and adjusted for optimal plant growth. The research suggests that the novel hydroponic bed can achieve higher tomato yields compared to soil-based, which is likely due to the controlled environment of the hydroponic system that provides constant nutrient and water availability, leading to optimal plant growth conditions. The simplicity of the design and the use of readily available materials makes this hydroponic bed system potentially scalable and affordable to small-scale farmers as well as home gardeners, which could contribute to promoting sustainable food production in various settings, particularly in regions with limited land or water resources.

5.0: Conclusion

This research presents a promising approach to sustainable tomato production using hydroponic bed constructed with eco-friendly materials thereby making significant advancement in agricultural technology. This innovative system offers the potential to address the challenges of conventional tomato production while enhancing productivity and environmental sustainability. The design offers numerous advantages, including reduced environmental impact, improved water and nutrient efficiency, optimizes fertilizer usage, high yield potential, and scalability. Hydroponics may be used in underdeveloped countries for food production in limited space. It is even feasible to grow hydroponically in areas of poor soil conditions such as deserts.

Conclusively, hydroponic systems can be used to grow crops all year round, there is no seasonality while using the system. It will provide a regular and steady source of income to the farmer. The principal advantage of hydroponic controlled environment agriculture are high crop density, maintain high crop yield, a virtual indifference to ambient temperature, more efficient use of water and fertilizers. This research outcome raises hope for innovative based sustainable agricultural practices that can significantly address the growing challenges of food security and environmental protection which are of global concerns. Further research is recommended to validate the long-term performance and economic feasibility of the system, while exploring its potential for growing other crops and incorporating renewable energy sources.

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