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APPLICATION OF THE HYDROPONIC SYSTEM FOR SOILLESS CULTIVATION OF VEGETABLE PLANTS IN A CONTROLLED ENVIRONMENT

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ABSTRACT: *Hydroponics is a promising innovative technology by which the natural environment is modified for soilless cultivation, possessing soilless irrigation and fertigation systems to achieve optimum plant growth in nutrient solutions, with or without an artificial medium. The demand for more production of food with the changing trend in urbanization necessitated the need for hydroponics. The basic aim of this work is to contribute to the enhancement of the limited knowledge and venture of hydroponics. Thus, the water culture type of the hydroponic system was produced to hold five (5) tomato (Lycopersicum esculentum) stands at four (4) horizontal rolls (total of 20 pods), using the four (4) inches PVC pipe. This system housed the crops upon nursing and transplantation from their nursery to the stands, while cultivation features were studied for required results. Parameters like tomato pH, solution pH, solution temperature, environmental temperature, water use efficiency, relative humidity, and electrical conductivity were measured and recorded. Resultantly, the crops were of good and fresh quality. They were no physical variations with the naturally produced crops. It was thus concluded that, hydroponic is a technology that serves a crucial function in soilless approach of cultivation. Also, that indeed hydroponics can be used for food production without soil, especially in limited space. Recommendably, the economic movers, climate control agencies, agricultural innovation promoters, science and technology institute, etc., should enhance the public knowledge and venture of hydroponics.*
Keywords: *Growing Environment; Soilless Growing Methods; Aquaponics; Aeroponics; Fogponics; Hydroponics; Hydroponics System Type; etc.*

I. INTRODUCTION

As the global demand for sustainable food solutions rises, hydroponics is rapidly becoming a game - changer in agriculture [1], and innovative technology. This is because in the absence of soil,

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cultivation can still be carried out using promising soilless techniques like the hydroponics. Non - soil based production systems exist as sustainable options for food production [2]. Hydroponics existent is traceable to millennia with various advantageous purposes. The modern hydroponic system was developed in the middle of the 20th century as a solution to boost food production in locations with limited resources and space [3; 4]. As a significant fact, the global demand for more production of food increases on daily bases. The world population is on the increase even with a declining growth rate [5; 6; 7; 8] which can be seen in worldwide statistically available population values. The global human population size currently stands at 7.6 billion and it is expected to reach 9.8 billion in 2050 [9; 10]. Apart from the increase in population, changing consumer palate, climate change and natural resource scarcity make meeting the increased demand for food even more challenging [11]. There is need to adopt and develop innovative agricultural practices [12], to aid production through the introduction of instrumentative agricultural technologies. According to [13], agricultural engineers have deployed this mechanism towards increasing output in agricultural fields. Adoption of soilless technology provides great opportunityy in producing more with less cultivation area, more crops per drop of water, reduction of the toxic chemical load, and improve ecological footprint [14]. Furthermore, many agricultural lands are already lost due to urbanization infrastructural advancement, leading to farmland shortages [15]. Arising from the above stated and more, which interprets the major problems that calls for the need of this work, conservation necessitates hydroponics. It is estimated that over 80% of nitrogen (N) and 25 – 75% of phosphorus (P) applied to agricultural fields globally are lost to the environment, as well as the energy used to produce them [16], which are minimisable using control environment farming. The term controlled environment agriculture (CEA) encompasses a variety of systems that deploy a technology - based approach in farming [17]. One of the major advantages that CEA systems may have in regards to nutrient management is that monitoring of nutrients available to crops can be easily measured, and in some instances dynamically manipulated [18] [16]. The controlled environment agriculture (CEA) integrates both science and engineering based approaches in growing produce within a closed system where numerous variables are managed. Types of growing environment include; indoor farming, greenhouse farming, and vertical farming. The indoor farming involves cultivation within the indoor environment. In an indoor farming, the source of light that nourishes the plants is controlled for maximum efficiency. LED lights which are the primary tools used in indoor farming allows the farmers to have greater control over the growing environment and carry out farming any time with no seasonal effect round the clock. This innovative approach to agriculture encompasses a wide array of applications in cultivation of food, flavours, fragrances, and medicinal plants [19]. Indoor farming can be executed in any indoor space like large rooms, containers, factories, and even warehouses. Hydroponics is a type of soilless gardening that can be done either indoors or outdoors [20], at

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different sizes ranging from personal to industrial. The planting structural format may be in horizontal or vertical sequence. The major considerations for a successful operational management of an indoor vertical farming are: cultivation type, crop type, technology and location. These are vital for proper decision making in an indoor vertical farm. Examples of these steps are presented in figure one (1) below;

Figure 1: Considerations In Starting And Maintaining An Indoor Vertical Farm [21]

The greenhouse farming involves cultivation within the greenhouse. A greenhouse is a specialized controlled environmental structure that is made almost entirely out of polycarbonate or glass [7]. Other materials may be considerably used to condition the environment to a desireable cultivational requirement. The indoor vertical farming emerges as a sustainable paradigm, enabling crop cultivation in vertically layered ecosystems, under precisely controlled environmental parameters [22]. The vertical farming systems, particularly around heavily populated areas, can meet everyday consumer needs for fresh, nutritious products and, at the same time, also contribute to resilient food systems [15]. Vertical farming (agriculture on vertically inclined surface such as within a sky scraper) might contribute to a solution to the problems related to conventional agriculture, or, more specifically greenhouse production [23]. It helps the farmers to grow the plants vertically instead of only horizontally, thus offering incredible potential to maximize yield. Vertical farming has the potential to produce food in a climate – resilient manner while emitting no pesticides and fertilizers, using reduced land and water than conventional farming [15]. Types of growing methods include; aquaponics, aeroponics, fogponics, and hydroponics.

Aquaponics farming involves the combination of hydroponic farming and aquaculture in order to nourish the plants of an ecosystem. Aquaponics is an agricultural method that leverages the symbiotic relationship between fishes and plants in a unique combination of re - circulating aquacultural system (RAS) and hydroponics, in a closed - loop system [11]. The wastes produced by the fishes in one tank

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are directed to the plants growing in another tank thereby creating a self - sustaining ecosystem. The fish waste is known to contain urea and ammonium and this act as a natural and chemical - free fertilizer for plants. The fishes most often employed in aquaponics include; trout, perch, tilapia and cat fish. Aquaponics presents advantages such as reduced land usage due to potential for vertical implementation, less weed growth, less ongoing maintenance, less usage of water due to circular nature, and moveable infrastructure [11]. A lot of food can be produce using only 10% of the water needed to grow plants in the ground [24] or traditional cultured farming system. From an economic stand point, it has the potential to generate more profits from two components (fish and vegetables) for the producers [11]. The nutrient input for this system is by feeding fishes and converting the waste to nutrients for the plants [22] in an organize farm schedule. Water from the fish tank, rich with nutrients from fish wastes, are pumped into the grow beds for the plants extraction of the nutrients, thereby cleaning the water before it is returned to the fish tank [24] for re-use. The combination of the two food production systems simultaneously meets plants' need for essential nutrients for growth, while managing waste generated from fish production [2]. An aquaponics system has three parts - a fish tank, grow beds and a small pump that moves water between the two [24]. These features can be seen in figure two (2) below;

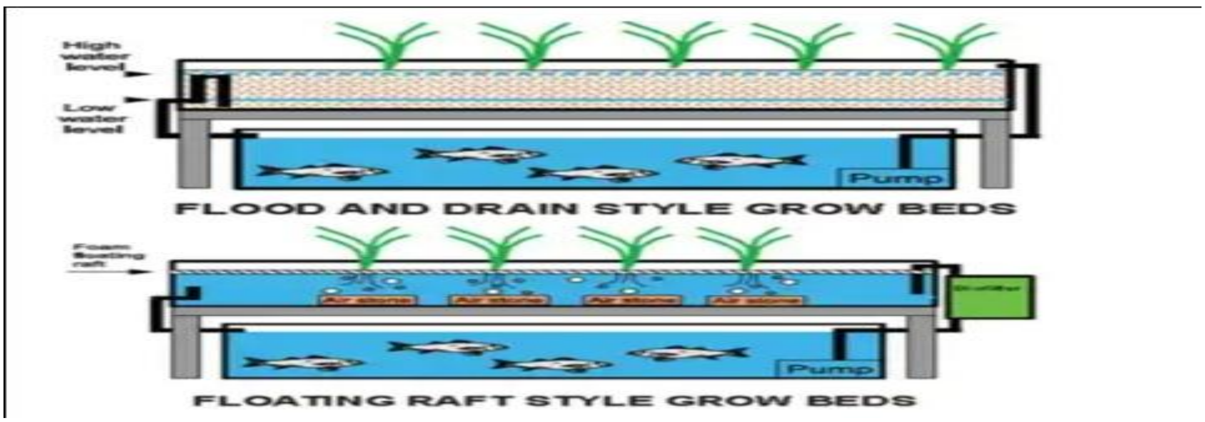

Figure 2: Two Most Common Styles Of Grow Bed [24]

Aeroponics is the process of growing plants in an air or mist environment without the use of soil or misting the roots with hydroponic solutions, which are suspended in the air [14]. It is another method of growing crops without the use of soil and even without the use of water. Aeroponics is a subgroup of hydroponics where plant roots are suspended in a dark enclosure, while a nutrient - dense solution is sprayed on the roots at certain intervals [14]. In this system, roots are continuously or discontinuously kept in a dark environment saturated with a mist or an aerosol of nutrient solution [25]. Aeroponics provides better aeration to the roots for the plants to grow faster [22]. Water is supplied to the exposed roots through fogging/misting technology, where fine water droplets are produced through a sprayer; the water droplets are suspended in the air for a longer period, leading to an increased evaporative rate and drier plant canopy [26]. An aeroponics setup is presented in figure three (3) below;

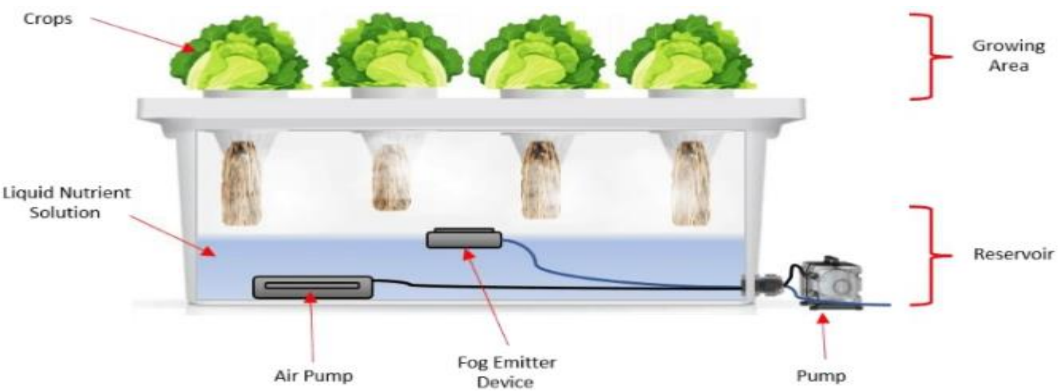

Figure 3: Schematic Diagram Of Aeroponics [27]

Fogponics or moistponics is a variation of aeroponic farming. It operates similarly like the aeroponics which uses soilless cultivation, and the process of growing plants is by suspending it in the air or a fog without relying on soil to give the nutrients required by plants for growth [28]. In line with photosynthesis requirements of crops, substitute for sunlight is made in the controlled environment. Fogponics has been shown to produce higher yields than hydroponics, using 40 to 60 percent less

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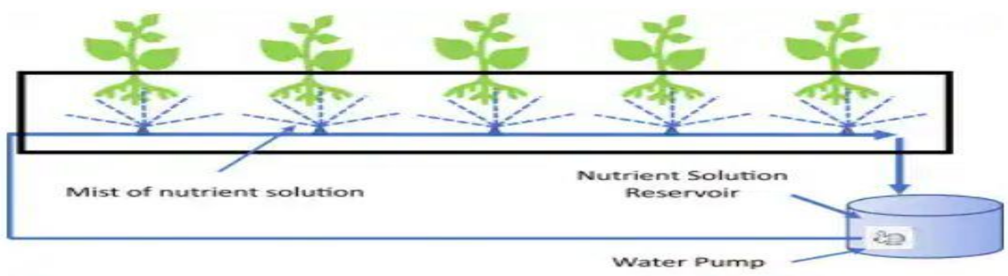

water, and more nutritious produce because of how the vapour delivers nutrients [29]. This kind of farming method has been practiced and introduced by NASA through a lot of researches and experiments [28]. The concept of bio regenerative life support systems, which integrate plant cultivation into closed - loop ecosystems, has gained momentum, offering hope for future self – sustaining colonies on the moon, mars, and beyond [30; 31; 32]. This method of soilless approach intended for space use is utilizable in earthly production. In fogponics, the vapour or mist is supplied in all sections of the plants including the roots, leaves and stems which have rapid and positive effect on the health of the plants. Recent studies have shown that fogponics systems possess more advantages compared with hydroponics [33; 12]. A typical example of the fogponics system is presented in figure four (4) below;

Figure 4: Conventional Fogponics System Diagram [32]

Hydroponics is the most well-known and widely applied method of controlled environment agriculture (CEA). Hydroponics is a plant cultivation technique that uses water as a growing medium [34]. Hydroponics is a method of crop production that has been successfully used for the growth of vegetables and flowers [35]. Hydroponics is a Latin word meaning “Working Water”. Hydroponics does not use soil [36] for cultivation. Soilless cultivation technique was first used on a large scale

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during World War II to produce food for the American troops stationed on the infertile Pacific islands [25]. Its promise to boost food production and sustainability, decrease water consumption, and raise crop yields has recently increased in popularity [3]. Growing systems can be designated as either liquid (closed) or aggregate (open or closed), with the closed - types requiring nutrient management techniques [37]. In hydroponics, there are numerous variations available based on the needs of the farmers. Some of the most popular subsection of hydroponic farming includes flood and drain farming, wick farming, water culture or deep water culture, and nutrient film technique. Hydroponics is usually applied to grow crops such as leafy greens, tomatoes, peppers, herbs and strawberries. [37] notably highlighted that hydroponics is used to cultivate ornamental crops, herbs, and multiple vegetable types including cucumbers, lettuce, peppers, and tomatoes. Hydroponic systems can be used as a treatment process for partially treated wastewater or reclaimed water (RW) before its release to the environment, as plants have the ability to uptake nutrients, toxic metals and emerging contaminants [35]. From water conservation to space efficiency, hydroponics offers solutions that traditional agriculture can't match, especially in urban settings [1]. Hydroponic systems are used commercially and in private homes to cultivate a wide variety of plant life [3]. The basic premise behind hydroponics is to allow the plants roots to come in direct contact with the nutrient solution, while also having access to oxygen, which is essential for proper growth [36]. The pH concentration plays vital role in a hydroponics system. [38] notably highlighted that accurate pH measurement in hydroponics offers several benefits: Optimal nutrient uptake (maintaining the correct pH to ensures that plants can access essential nutrients efficiently, thereby promoting healthy growth), disease prevention (proper pH levels contribute to a robust and disease – resistant plant), improved yields (by providing the ideal pH conditions, higher yields and better quality produce can be achieve), resource efficiency (accurate pH management prevents nutrient wastage and saves resources), and, pH troubleshooting (monitoring pH allows growers to identify and address issues promptly, while preventing potential problems). The recommended pH for hydroponic culture is between 5.0 and 6.0 because overall availability of nutrients is optimized at a slightly acidic pH, and the EC level should be 1.5 to 3 $dScm^{-1}$ [39]. [40] Noted that hydroponic plants perform optimally at pH of 5.8 to 6.2. It is therefore crucial to stabilize pH in the aquaponic system since it is critical to all living organisms within a recirculating system, i.e., fish, plants and microbes [41; 42; 10]. In practice, pH can be increased using potassium hydroxide and calcium hydroxide [43]. The pH scale, showing optimal range for various acidic, neutral, and alkaline materials are presented in figure five (5) below;

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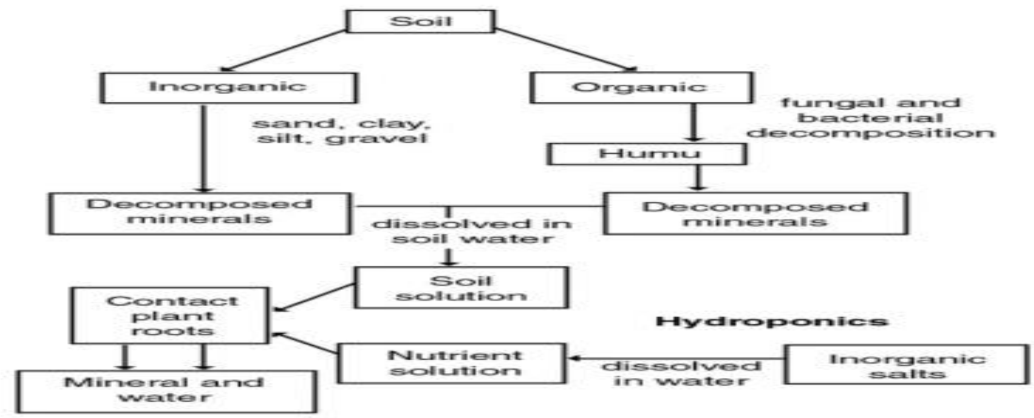

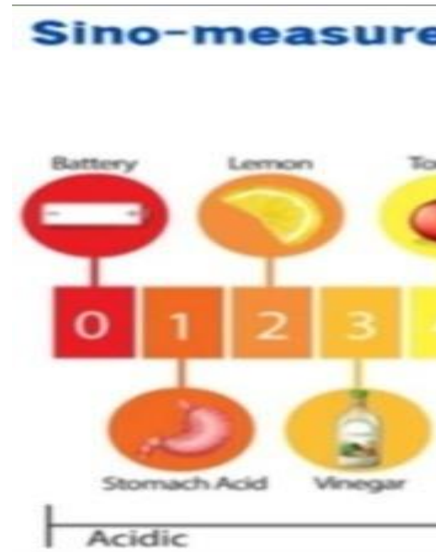

Figure 5: The pH Scale Showing Optimal Range [38]

The nutrient or minerals required for good growth of plants are: Macro elements of Nitrogen (N), Phosphorous (P), Potassium (K), Calcium (Ca), Magnesium (Mg), and Sulphur (S), and the micro elements of Iron (Fe), Manganese (Mn), Boron (B), Copper (Cu), Zinc (Zn), Molybdenum (Mo), Sodium (Na), Chloride (Cl), and Silicon (Si). These minerals, water, carbon dioxide, oxygen and sunlight (supplemental with LED lights) have effects on plant leaves and enable the plants to generate their own food from nutrient raw materials. The mineral or nutrient uptake processes for the plants are the same in both hydroponics and soil culture usage. The same elements available in the soil culture are made available in hydroponics system. Also, there are no physical variations in plants grown in both mediums. The nutrient processes are presented in figure six (6) below;

Figure 6: Origin of Essential Elements in Soil and Hydroponics [39]

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The various types of hydroponic system are the wick system, deep water culture (DWC) system, ebb and flow system (flood and drain), drip system, and nutrients film technique (N.F.T.).

i. The wick system works passively, uses no pumps and have no moving parts. It works on the same principle as an oil lamp [44], in terms of liquid transmission. It requires an axis that can combine or connect the nutrient solution with plants [45; 46]. In this technique, liquid solution is delivered to the growing medium or a tray through the wicks and then to the roots via the plant's capillary action [14]. The liquid solution flows up to the wick until the medium encompassing the roots is damp [44]. The wick system is the simplest hydroponic system and its application is quite wide spread [46]. Mainly, there are four major components in a wick system - the grow tray or plants containing medium, reservoir, wick, and aeration system [44]. It operates by drawing up nutrient solution from the reservoir to the plants through capillary movement like a wick into the growing medium.

ii. Deep water culture (DWC) system is one of the simplest hydroponics [47]. Bulbs, like hyacinths and tulips, thrive in a deep water culture hydroponic system [48]. [47] Noted that deep water culture is a hydroponic technique that allows continuous plant root submersion in water containing nutrients. In the DWC method, nutrient - rich oxygenated water is the medium wherein plant roots are suspended in about 6 – 18 inches until harvest [14], while new transplant may be introduced for cultivation. Thus, the plants suspended on the growing medium dangle their roots in the solution below for nutrient [49] uptake.

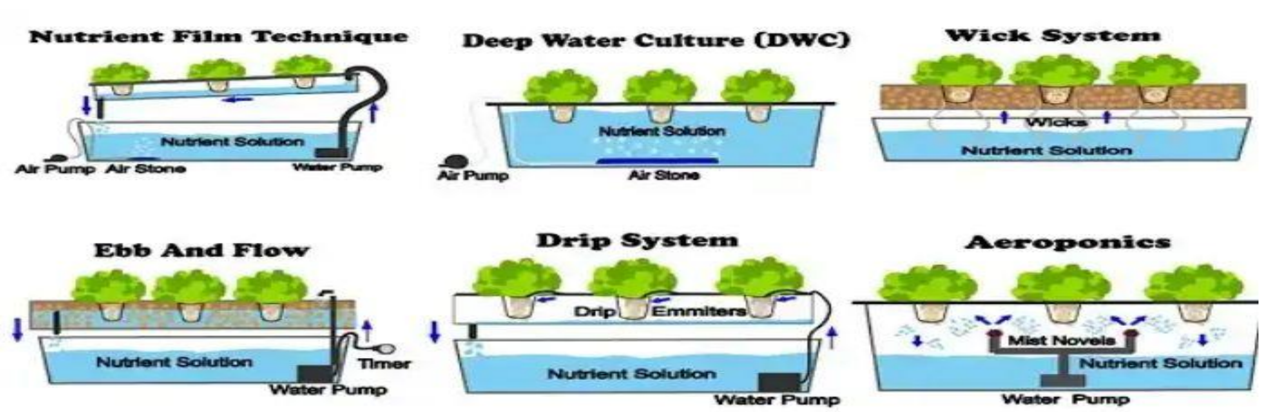
iii. Ebb and flow systems (flood and drain) are similar in operation as that of NFT, but the growing medium is temporarily flooded with solution every few hours, submerging the roots before returning to the reservoir [14]. The nutrient film technique (NFT) is described in subsection below. The hydroponic solution alternately floods the system, and is allowed to ebb away [50] prior time, from the growing medium. This technique is often used for seedling production and the production of potted plants in the floriculture industry [25], in most cases. Pots are filled with an inert medium which does not function like soil or contribute nutrition to the plants but anchors the roots, and functions as a temporary reserve of water and solvent mineral nutrients [50] for plants growth. The rooting medium may require washing to remove root debris and accumulated precipitates as well as sterilization if it is being reused [51], to ensure good plant health.

iv. Drip system is another technique where a pump delivers a slow feed of solution to the base of each plant, prior a timer, while the remaining solution is either returned to the reservoir or not collected [14]. In hydroponics, it involves utilizing the same principles of delivering water and nutrients to plant roots by slowly dripping the solution directly to the growing medium. In soil - less hydroponic cultivation, drip systems excel in their ability to provide targeted irrigation, promoting optimal plant growth and maximizing resource efficiency [52]. In this system, nutrients are dripped directly onto the plant roots, ideal for precision growing [1] thereby minimizing wastage. A timer is set to schedule the submerge pump. In drip irrigation systems, nutrients are pumped through tubing from a reservoir, and then dripped through the growing medium from above [53] directly to the plants root for nutrient uptake.

v. Nutrients film technique (N.F.T.) is the most common system used in solution culture [25] in most developed countries. In the nutrient film technique (NFT), the plant roots are exposed to a thin layer of nutrient - rich water that runs through horizontal pipes [10]. [14] Stated that, NFT is a popular and versatile technique in which the system uses a pump to deliver water and the unused nutrient solution is recycled through a drainpipe. The NFT systems generally consist of a reservoir that holds water and nutrients, shallow troughs or trays that hold the plants, a pump to move water through the system, and tubing to connect the pump and trays [20], with slightly modified trough slope for flow imbalance. It works with constant flowing of the solution. However, NFT is only suitable for small vegetable species because the grow bed cannot support tall plants [54; 55; 10], unless with the introduction of an external support system to hold the plants. The various types of hydroponic systems are presented in figure seven (7) below;

Figure 7: The Various Types of Hydroponic System [52]

In figure seven (7) above, hydro or water presence can be seen in all types denoted by blue colour. In nutrient film technique, the water solution is introduced using a pumping medium which uses a pipe to deliver the solution at the highest topography allowing the solution to flow through the slighted slope to the lower reservoir (nutrient solution) for the pumping device to repeat the process again. In deep water culture, the hydro solution reservoir is filled, that the plants root system are deepen directly into the solution for nutrient absorption. In the wick system, about two wicks are allocated to a crop, usually in an upward direction for absorption of solution with nutrients. In ebb and flow technique, pumping devices are used to deliver solution to the upper chamber (plant zone) for nutrient availability before draining or flowing through the retaining materials to the lower chamber (nutrient solution). In drip system, pumping device is used to transfer solution to the upper chamber (plant zone) for nutrient uptake before dripping down to the lower chamber (nutrient solution) using emitters. The deep water culture type was used in this work relatively as described in the diagram above with modification.



The knowledge and application of hydroponics remain underemphasized even with the various research works referenced within (1, 3, 18, 20, 27, 34, etc), and more. Thus, this work intend to contribute to the existing knowledge by filling the gap of practical simplicity and wholeness of the application processes in hydroponics.

II. MATERIALS

The major material used in the course of this work is the research demonstration centre of the department of Agricultural Engineering, located in Delta State University of Science and Technology, Ozoro, Delta State, Nigeria, West Africa. Other materials used include; The 4 inches pipe, PVC gum, The ¾ pipe, The 4 inches plug, The ¾ ball valve, The ¾ adaptor, The ¾ union, The ½ inches nipple, The ¾ by ½ inches thread elbow, Threaded tape, Clip, Marker, Rope, Nail, Wood, Bucket, Marker, Sand papers, Cup, Soldering iron, Handsaw, The pH meter, Tomato seeds, NPK fertilizers, Litmus paper, The pH buffers, Water bath, Cotton wool, White itel LED electric bulb (5 W power, lumen of 450 lm, and rechargeable), etc.

III. METHODOLOGY

Upon well piloted literature, the deep water culture hydroponic bed stand of a total of 20 pods was produced using a 4 inches PVC pipe. This system was designed and produced with measurements of 9 ft length, 7 ft width, and 3 ft height, 1.2 ft PVC pipe circumference with 0.5 ft diameter, and plant root access diameter of 0.1 ft, and, a detachable reservoir with external stand. Adequate supply of nutrient solution of about ½ of the pipe storability was used in ensuring efficient plants roots nutrient absorption. Upon regular cleaning of the reservoir and replenishment of nutrient solution, algae and

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harmful pathogens that could possibly develop were regulated in the nutrient solution. In the first instance, a small bucket containably 10 litres of liquid was used to improvise the tank/reservoir. A hole was drilled at the bottom of the container providing attachability of a ½ inch nipple at the bottom - front of the container followed by ¾ by ½ inch threaded elbow, union and bulb valve used in controlling the flow of nutrient. At the base of the container, plastic nut was used to hold the nipple and afterwards the PVC gum was applied for leak proofing. A ¾ length pipe was attached to connect the tank to the plant stand. This ¾ inch pipe was attached to the both sides which were clipped to hold it firmly. The two sides were for inlet and outlet. At the inlet side, the attached pipe was connected to the reservoir to allow the nutrient solution to flow into the PVC pipe. At the outlet side (solution exit), the attached pipe at the bottom of the storage pipe transmit the dischargeable solution to another container below the stand which collects the discharged liquid. Ply - wood materials were used to construct the hydroponic stand for the bed using furniture making procedures whereby selected length was measured in respect to hydroponic bed size and cutted out using the handsaw. Hammer and nails were used in joining the various connecting parts of the stand. The base and top of the stand were rectangular in shape with the base larger than the top thereby providing the necessary carriage stability. A typical imagery of this system produced is presented in figure eight (8b) below.

Transplanting was carried out from the nursery to the hydroponic system after twenty one (21) days. This was done in the evening to minimize the stress undergone by the seedlings during transplantation. The transplanting was achieved upon plant removal from the nursery and soil removal from the root zone of the plant without damaging the root system of the plant, and the rinsing of the root in a water bath to remove the remnant of the soil. Cotton wool was attached round the stem to avoid injuries (bruises round the stem). Seven (7) days after transplanting, the tendrils were supported with the support lines to keep the stem growing upward not to be lying towards the ground.

The nutrient solution was duly mixed and introduced to root reach height at fourth quarter of the pipe circumference, and subsequently discharged within 72 hours interval to ensure good plant health. Upon re - introduction of the solution into the plant stands at maximum of twelve hours duration, the introduced solutions were allowed to stay for half an hour, preferably twenty to thirty (20 - 30) minutes, to permit optimum plant root aeration outside the solution, followed by plant root reintroduction to the system solution for absorption of nutrients. The nutrient solution used was NPK (15, 15, and 15) fertilizer dissolved in water, and tested with litmus paper for the pH level check of the solution. The below steps were utilized in pH monitoring in line with [38], while the calibration of the pH meter using pH 7 and pH 10 buffers was initiated. Half litre liquid sample of the nutrient solution was taken from the hydroponic system, maintaining freeness from debris and air bubbles which can influence the readings. This was followed by submersion by immersing of the pH probe in the

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obtained sample solution as well as allowing two (2) minutes gap for the stabilization of reading, before the pH value displayed on the meter was recorded after possible fluctuations.

The light level was slightly adjusted from daylight, while LED 5 W bulb was used to provide luminous at night hours (4 pm till dawn) using rechargeable assistance.

Flow chart of the method include; Construction of hydroponic stand - plant transplantation - introduction of mixed fertilizer solution - plant management for health and growth.

IV. RESULTS

The obtained results from the course of this work are presented below. The results of the nursed tomatoes and installed system upon production are presented in figure eight (8) below;

(a) Nursed Tomato (b) Produced Hydroponic System

Figure 8: Nursed Tomato for Transplant and Produced Hydroponic System for Vegetable Cultivation

With the absorption of the nutrient solution, plant growth flourished. The results of measured parameters are presented in table one (1) below;

Table 1: Measured Hydroponic Parameters

S/N	Parameters	Values
1	Tomato pH value	5
2	Minimum solution pH	5
3	Maximum solution pH	8
4	Average solution pH	5.9
5	Minimum solution temperature	28 ^{o}C
6	Maximum solution temperature	33 ^{o}C
7	Average solution temperature	29 ^{o}C
8	Average environmental temperature	38 ^{o}C
9	Water use efficiency	98 %
10	Nutrient use efficiency	98 %

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11	Humidity (Relatively humidity)	64 % RH
12	Average Electrical conductivity, EC	1.9 mS/cm

V. DISCUSSIONS

The design and production of the hydroponic system has no specific measurement range. The sizes can vary. However the choice of vertical design which saves more space or horizontal farming avails. Once the system is installed, lifespan of five (5) years and above is expected, because the systems make - up comprises of plastic materials which are corrosion free and requires little or no maintenance to provide the potential longevity while harbouring the plants in the hydroponic system. Hence, series of cultivation over a limitless period of time can be achieved in the hydroponic system over an extended period, without affecting system performance while requiring no significant maintenance. However, its output over time is subject to solution maintenance and plant management. In selected plant stands, it was noticed that, it took the crops minimum of twenty nine (29) days and maximum of sixty one (61) days to dry off upon root zone clogging. Thus, plant root aeration was improved upon clogging removal at root zone preferable within 72 hour intervals. Upon ejection of unwanted or long used solution and solution reintroduction, or introduction of fresh solution into the system, the plants root may be returned to solution reach after few minutes of about half an hour.

The hydroponic solution temperature of 28 ^{o}C and environmental temperature of 38 ^{o}C were maintainable through controlled environment offered by farm shade. The sun radiation temperature were being reduced by structural coverage to prevent high temperature rising. In other words, in an uncontrolled or natural environment, the sun could have increased the temperatures above the obtained range. The controlled atmosphere provided to the hydroponics also increased moisture availability to the crops. Solution pH of 5.9 was utilizably recorded, falling within [40] pH range of 5.8 to 6.2 required for plant utmost performance. Humidity plays an important role but was not altered. The natural humidity level was used without adjustment in the controlled environment. Electrical conductivity, EC, an indirect indicator used in monitoring the total dissolved nutrients in the solution, was deployed in the regulation of nutrient concentration, and in ensuring that the fertilizers were properly mixed with accuracy. This basically minimizes fertilizer negative effects on root clogging, and thus, aided in preventing plant root rot in the hydroponic solution. EC (expressed in milliSiemens per centimeter, mS/cm) decreased with nutrients absorption by plants and increases upon salt concentration from fertilizers. Also, EC was 1.9 dS/cm, which fall within [39] EC range of 1.5 to 3 $dScm^{-1}$. Excess EC made the solution toxic for plants, requiring the addition of water to dilute the solution, for stability of the system.

Hydroponics provides the knowledge that soil is not really the ideal thing needed for cultivation but the nutrient stored in it. In this hydroponic system, the environment was modified and the crops were supplied with nutrient solution which aided the production of better yields and also helped in controlling some harmful pathogens that would have been very difficult to control. The disease management points to the destabilization of potential pathogens through solution flushing in and out of the system, as well as the hygiene provided while doing so. Apart from better yield, the quality of hydroponically grown tomatoes was more. This was because they were not exposed to harsh weather conditions or prone to environmental pollution. Also, compare to the conventional soil-based cultivation, it is economically viable, requiring no irrigation and saves fertilizer loss while being nutrient efficient. It allows usage of various fertilizer compositions like NPK 15:15:15 or any other ratio. The inorganic salts mixed with water in a solution, provides mineral and water to crops upon reach to their roots as described in figure six (6). The nutrients however the mixture, are reusable with 98 % efficiency. This is because the hydroponic solution is flexibly adjustable in nutrient content, pH, EC, temperature, etc. Hydroponics in some cases are required than soil cultivated system. It is even feasible to grow hydroponically in areas of poor soil conditions such as deserts. Finally, the popularity of hydroponics has increased dramatically, leading to an increase in experimentation and research in the areas of indoor and outdoor hydroponic cultivation.

VI. CONCLUSION

Hydroponic is a technology that serves a crucial function in soilless approach of cultivation. The crops were of good and fresh quality. They were no physical variations with the naturally produced crops. Hydroponics is a soil and water conservation reliable innovation of soil and water engineering. It can be used for food production without soil, especially in limited space. Hydroponic also guarantees a sustainable agriculture, especially in providing alternatives to urbanization and drought which prevail as major challenges in urban and arid regions of the earth.

The practical implications of hydroponics are verse but points to the opportunity of sustaining agriculture where lack of space, soil adequacy, water availability, etc., abound. It provides alternative to future possible mishaps of earth's nature resources, thereby guaranteeing hope to food cultivation in the expected occurable climate change negative impacts, since hydroponics in controlled environment can be utilized in any location on earth and other planets.

Time series for the soilless cultivation of tomatoes were: Within < 0 week (seeds in propagation ray), 0 - 6 weeks (transplant leaves cluster), 6 - 12 weeks (flowers cluster), and > 12 weeks (fruit ripening). This time series were relatively associable to conventional traditional agriculture or soil culture. Thus, the system proved time efficient at all cultivation stages. The water use efficiency (98 %) led to the conclusion that hydroponic guarantee optimum water conservation. This is because the same water in the hydroponic liquid solution was re - usable all - round the work period in the first instance. However good hygiene was maintained and nutrient wastage was minimal. The nutrients were also reusable with the solution reintroduction. Generally, from the above, the system was of good cultivation efficiency ranging from time, water use, nutrient use, etc.

In summary, the intent of this work "Application of the Hydroponic System for Soilless Cultivation of Vegetable Plants in a Controlled Environment" was to cultivate the idea of soil less farming. This was established using the rigorous literatures and validatively through experimental processes deployed and presented for replication simplicity, expected to pave way for relative future practical applications, as well as welcoming research. Also, calling on the economic movers, climate control agencies, agricultural innovation promoters, science and technology institute, etc., on the enhancement of the public knowledge and venture of hydroponics, to increase national and global output.

Authors Contribution

Okolotu G.I. (Conceptualization; Funding acquisition; Methodology; Project administration; Supervision; Writing - original draft; Writing - review & editing). Ikikiru D.F. (Investigation; Visualization; Resources; Coordinating). Umunna M.F. (Investigation; Visualization; Resources). Eze C.S. (Data curation; Formal analysis; Writing - review & editing).

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