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Soilless Cultivation Technique, Hydroponics-A Review

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

In India, with a growing population, soil and water resources are becoming increasingly scarce, highlighting the importance of maximising their usage for crop production. Due to urbanization, climate change, natural disasters and the indiscriminate application of herbicides and pesticides, all of which are reducing land fertility, poor yield and quality are currently affecting soil-based agriculture. So, now a days Hydroponic farming is gaining popularity around the world due to its effective resource management and high-quality food production. In this review article, types of hydroponics viz. wick system, ebb and flow, drip system, Nutrient Film Technique, deep water culture system and aeroponics; operations by this technique were discussed. These techniques have several advantages, including fewer growing times of crop than traditional methods, year-round production, low disease and pest incidence, and the elimination of weeding, spraying, and watering. Hydroponics play a great role in cultivating plants especially in urban areas, where very limited space available and water scarcity area.

Keywords: Aeroponics; NFT; open field hydroponics and soil-less culture.

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1. INTRODUCTION

By 2050, the world's population is expected to reach 9.7 billion people. At the same time, 50 percent of the world's arable land is expected to become unusable for agricultural [1]. In 1960 per capita land availability was 0.5 ha with 3 billion population over the world but it will become 0.25ha with 6billion people by 2050. It is further predicted to become 0.16 ha in future making it difficult to cater the food needs of the world's population using open field agricultural yields allown [2]. To meet the high demand, food production must be enhanced by 110 percent. Another reason is that poverty reduces food production in many countries, particularly in Southern Africa, as irrigation and fertilisers become inaccessible due to poor nutrient uptake by the root system in the soil media. The third reason is soil erosion and degradation caused by industrial agriculture methods that depend mainly on soil and hence deplete it of minerals and vitamins. Because of which, the world must come up and implement methods to increase the productivity of agriculture. Today's farming systems are mostly based on soil and water, and they are highly vulnerable to calamities. Hence, there is a dire need to change present economics policies of farming systems [3].

The industrial agriculture cannot meet the present and future food needs, the Food and Agriculture Organization (FAO) forecasts that by 2050, the world will need to produce 60% more food to feed a population of 9.7 billion people. Therefore, there is a wide scope to adapt a new agricultural technique that enhances plants growth faster. This system further able to meet the rapidly increasing demand at a very low cost and with minimum natural resource consumption. Hence, the main aim of this article is to develop an alternative system which meets present and future demand at a lower cost and with less natural resource consumption [3]. The unfavourable soil composition, soil erosion causing degradation, poor drainage, unsuitable soil reaction, presence of disease-causing organisms and nematodes etc. are some of them. Furthermore, conventional crop cultivation in soil (Open Field Agriculture) is somewhat difficult as it involves large space, lot of labour and large volume of water. Furthermore, in some places, such as metropolitan areas, soil is not suitable for agricultural cultivation, and there is a scarcity of fertile cultivable arable lands due to unfavourable geographical or topographical circumstances. Another major issue that has arisen recently is the difficulty in finding labour for open-field agriculture [4]. Soil-less culture can be successfully adopted to improve and raise the productivity of farming systems in such circumstances.

One of the soilless culture systems is hydroponics. The word "hydroponics" is derived from Greek words, "hydro" which means water and "ponos" which means labor [2]. Soilless culture is defined as "the method of growing plants without using soil as a rooting media, supplying essential nutrients through irrigation water." The fertilisers (which contain nutrients) are supplied by dissolving them in an appropriate amount of irrigation water [5].

2. HISTORY

Growing plants using different nutrient-rich water has been practiced for centuries [6]. 'HYDROPONIC' culture can be seen in Babylon's hanging gardens and the Aztecs' floating gardens in Mexico. Egyptian hieroglyphic records describe the growing of plants in water. The fundamental concepts for the hydroponics were established in the 1800s, by investigating how plants grow [7]. The stage was set for a paradigm shift in crop production from conventional cultivation in soil to soilless cultivation with the first successful application of hydroponics techniques in 1930's [8]. Initially only three crop species were grown when hydroponics was applied commercially: tomato, lettuce and herbs. Now wide range of crops are successfully grown hydroponically, e.g., pepper, strawberry, cucumber, potatoes, roses [7].

3. CLASSIFICATION OF HYDROPONICS SYSTEM

The main difference between an active and a passive system is that, the pumps are used to supply nutrients in active system while a wick is used to draw in the nutrient solution in passive system [9].

Wick system: It is the simplest method of hydroponic which does not require any electricity, pump or aerators [10]. Plants are placed in soilless media like clay balls, vermiculite, perlite or coconut coir and lamp wick or wick made up of nylon or polyester is used to supply nutrients solution for the plant roots [9]. This system is mostly used for small plants, spices and herbaceous plants and it doesn't work for those plants that needs lot of water [10].

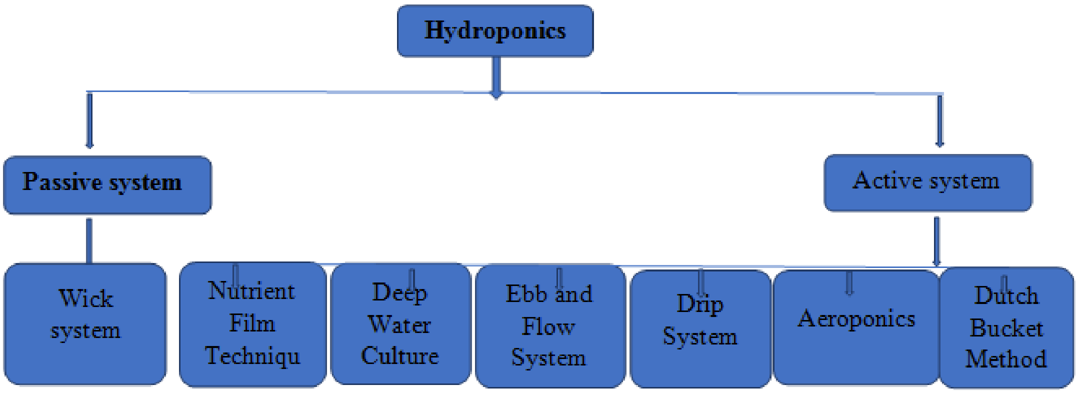

Fig. 1. Classification of Hydroponics [9]

Ferrarezi and Testezlaf, [11] conducted a study to evaluate two wick irrigation systems for greenhouse lettuce production by using self-compensating troughs which are filled with pine bark or coconut coir with a nutrient film technique hydroponic system. Daily monitoring of electrical conductivity and pH kept the experiment on track with recommended parameters for optimal lettuce growth. Electrical conductivity showed variation among troughs and salt accumulation in substrates, with pine bark having two times the EC of with coconut coir (ranging from 0.95 to 7.57 and 0.68 to 3.67 dS cm^{-1}, respectively), but pH values were constant over time. The same nutrients concentration was maintained in the plant till the end of experiment. With both substrates, the wick irrigation system produced higher productivity than nutrient film technique, with superior yield and plant quality in with coconut coir, showing its feasibility as a lettuce production system in greenhouses.

Types of Active System:

1. Nutrient Film Technique
2. Deep Water Culture
3. Ebb and Flow System
4. Drip System
5. Aeroponics
6. Dutch Bucket Method

Nutrient Film Technique: This system was developed by Dr. Alen Cooper in the mid -1960s in England. In this system nutrient solution gets circulated throughout the system and then enter into the growth tray via water pump [10]. It uses reservoir system and an automated pump to supply nutrients and water. Plants are grown in 'V' shaped inverted channel, which gives you the benefit of growing more produce in small area [9]. Nutrients are mixed accordingly to make the nutrient solution which is placed in primary reservoir from which it flows through the system continuously feeding the plants [12]. The NFT technique is most commonly used to grow small, fast-growing plants such as lettuce. NFT is also used by some commercial growers to grow various types of baby greens and herbaceous plants. system [4]. Different flow rates were assigned as 10, 20, and 30 L/h in an experiment. As a result, it is concluded that the flow rate of 20 L/h enhances the growth of lettuce rather than 10 L/ h and 30L/ h [13].

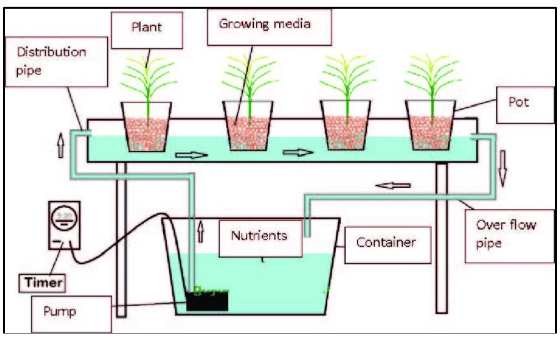

Fig. 2. Nutrient film technique

An automation system for Nutrient Film Technique Hydroponic system was developed to control and monitor the pH level, Electrical conductivity (EC), Dissolved Oxygen (DO), water temperature, water flow rate, and water level of the nutrients solution in the Hydroponics nutrient solution irrigation system suited for a specific plant [14]. Results revealed that the developed system works properly to monitor and control the environment nutrient solution parameters of Hydroponics. The field experiment also showed, that the vegetable plant sample grew well during cultivation and showed good quality crop yield with a harvest-time of around 3.5 weeks.

Deep Water Culture: In a deep-water culture system of hydroponics, plant roots are suspended in nutrient-rich water, and air is given directly to the roots via an air stone. A classic example of this technique is the hydroponics bucket system. Plants are grown in net pots with their roots suspended in a nutrients solution, where they grow rapid into a large mass. It is mandatary to monitoring oxygen and nutrient concentration, salinity and pH [15] as algae and moulds can grow quickly in the reservoir. This technique is suitable for larger fruit-producing plants, such as cucumbers and tomato.

In a deep-water culture system, tomato plants (*Solanum lycopersicum* L. 'Grandia') were cultivated with varied oxygen (O_2) concentrations in the nutrient solution. The number of side branches, increase in branch length, and number of flowers per plant were all plotted against time and found to produce different types of curves (exponential, logarithmic, and linear, respectively). The O_2 concentration in the hydroponic medium was linearly correlated to the slopes of the best-fit functions of these curves. The fresh and dry weights of roots and shoots were positively and exponentially affected by the concentration of oxygen in the nutritional solution. The ratios of root to shoot fresh and dry weights, as well as the ratios of dry to fresh weights of roots and shoots, showed no significant changes in response to O_2. Fruit production increased linearly with O_2 concentration around the roots. It was concluded that tomato plants in deep-water culture do not reach the theoretical maximum rate of O 5 uptake into the roots [16].

The purpose of controlling the level of hydroponic nutrient solution in the type of Deep-Water Culture in the box, one of the simplest hydroponics, is to ensure that the plant's roots are always submerged in nutrient solution so that the nutrients are still fulfilled. The results of controlling the level of hydroponic nutrient solution in the type of Deep-Water Culture (DWC) in the box are that when the level of nutrient solution is less than the specified threshold, the 12VDC pump relay will operate to drain the source water to the nutrient solution reservoir [17]. The HCSR04 sensor is used for reading the level of nutrient solution, so it has an effect on determining the pump life time. The accuracy of controlling the level of nutritional solution using linear regression linear calculation is 88.6 percent.

EBB and Flow System: Ebb and flow is also known as flood and drain system. This is the first commercial hydroponics system which works on the principle of flood and drain. Because of it’s low- maintenance and inexpensive set-up, it has been proved to be a popular system. Water and nutrient solution are flooded from reservoir using water pump to grow plants and it stays there for certain period of time to provide nutrients to plants. Root rot, algae, and mould are the most common problems in this system, so it has to be modified with a filtration unit. It can also be automated using computer [9]; [10].

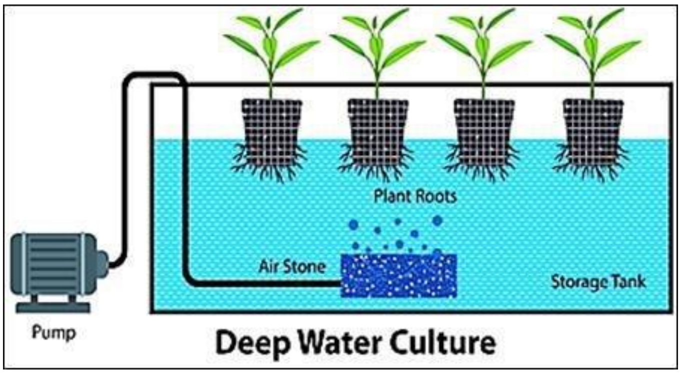

Fig. 3. Deep water culture systems

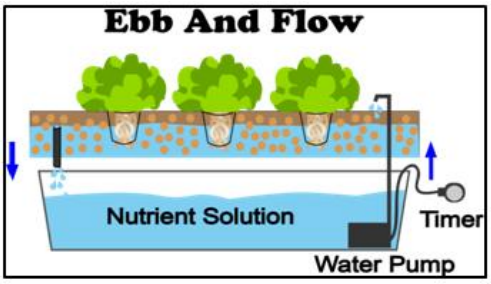

Fig. 4. EBB and Flow System

Son et al. [18] studied present sub-irrigation systems for potted plant production. In terms of system characteristics and plant growth, a nutrient flow wick culture system was developed and compared to other sub-irrigation systems such as an ebb and flow culture system and a nutrient-stagnant wick culture (NSW) system. The water content of medium in the nutrient flow wick culture and ebb and flow culture systems fluctuated from 30 to 40 percent and 50 to 60 percent (by volume), respectively, but the water content in the NSW system gradually increased to over 40% without fluctuation. Because of reduced evaporation from the trough and medium surfaces, water loss in the nutrient flow wick culture system was 50 - 70% lower than in other systems. The nutrient flow wick culture system was simple, water-saving, and efficient in terms of system characteristics. Furthermore, at a five-times-daily irrigation frequency, kalanchoe growth in the NFW system was similar to that in the NSW and EBB systems.

To control the pump's operation in distributing nutrient solution to the growing media, Daud et al. [19] introduced a fuzzy logic-based ebb and flow hydroponics system. The control system was developed using an Arduino UNO with transducer inputs from a temperature sensor and a soil moisture sensor, as well as dc motors operating as actuators to channel nutrient to the planting media. The finding shows that design of fuzzy logic control is able to realize and working properly. Several operating schemes were found during testing at 30 degrees Celsius, including: (1) fast-rotating pump when moisture reaches 0.1 percent relative humidity; (2) medium-rotating pump when moisture reaches 30 percent relative humidity; (3) slow-rotating pump when moisture reaches 50 percent relative humidity; and (4) pump-off when moisture reaches 74.2 percent relative humidity. Matlab simulation and manual mathematics calculations were used to validate the experimental results. The actual experiment was carried out by growing green bean plants to a height of 22 cm and 14 leaves after 28 days.

Drip System: Drip hydroponics is a common growing method for both home and commercial growers. With the help of a pump, water or nutrients solution from the reservoir is delivered to individual plant roots in an appropriate proportion [20]. Plants are usually grown on media that is moderately absorbent so that the nutrients solution drops slowly. Different crops can grow in a systematic way while conserving water. The main benefit of a drip system is that it can withstand short-term power or equipment failures while also conserving more water than other systems. This system can be very expensive and difficult to set because the supply of solution is timed. It is widely used to grow tomatoes and pepper resulting in very high-quality yield [9]; [10].

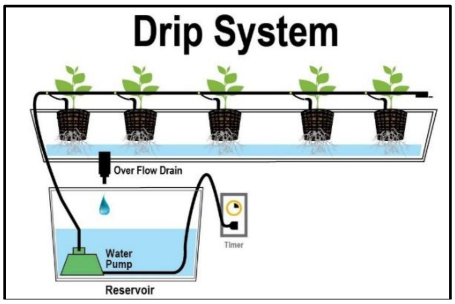

Fig. 5. Drip system

Smart Farming uses IoT and Big Data technologies were used in smart farming to renovate modern agricultural lands, allowing growers to reduce their use of natural resources while increasing efficiency. Inherently hydroponic drip systems save both water and nutrient. The present-day irrigation system facilitates soil moisture and temperature with the help sensors [21], explained that the system is used to observe the sensor values and for manipulating the nutrient values whenever required. There project is for drip control and how to apply it to hydroponics by the development of a link between humans and software which permit a monitor of pH and other sensors. This including the position of the plant, by capturing through camera and monitoring through mobile application. By using big data, the supply of nutrients values will get tracked and recorded. This recorded data will be useful for irrigation system automation.

Aeroponics: An aeroponics system was developed during 1973-1974 at the Cabot Foundation Laboratories. The principle of this system is to grow plants with their roots exposed to a nutrient mist [22]. The word aeroponic comes from two Latin words, “aero” which means air and “ponic” which means work. Aeroponics refers to growth achieved in an air culture [23]. Aeroponics is the development of plants without the use of soil or water as a substrate while maintaining all of the parameters important for plant growth (temperature, pH, humidity, electrical conductivity of nutrient solution, and so on) [24]. Aeroponics culture is suitable for low leafy vegetables loke lettuce, spinach, etc. [25].

Vertical farming is an indoor agricultural system in which plants are grown in stacked systems. Together with emerging technology, it forms a rapidly growing sector. Indoor farms often use soilless techniques like hydroponics and aeroponics. The application of a nutrient aerosol to the roots of plants is known as aeroponics, and it can lead to higher plant productivity than hydroponic cultivation. Aeroponics is thought to resolve a variety of plant physiological constraints that occur within hydroponics systems [26].

Mangaiyarkarasi, [27] discussed that the aeroponic culture of whole plants with their roots fed by an air/water nutrient fog. Plants are supported in holes in Styrofoam panels and the roots will be suspended in the air behand the panel in aeroponics farming. The panel create a sealed box to hide light from getting out to enhance root growth and stop algae growth. The nutrient solution will be sprayed onto roots in a fine mist. For every 2-3 minutes, few seconds of mist will be allowed. This will be proper to keep roots wet and nutrient solution aerated. From the film solution which adheres to the roots, the plants will obtain nutrient and water.

Aeroponic farming outperforms traditional propagation methods in terms of aeration, water efficiency, time and space requirements, seasonal independence, disease-free plant propagation, large-scale plant production, and so on. Propagation, seed germination, seed potato production, tomato production, leaf crops, and micro-greens have all been commercially successful using aeroponic techniques. In an aeroponic system, vegetable crops such as potatoes, yams, tomatoes, lettuce, and various leafy vegetables are commercially grown. Aeroponics appears to be a very viable method for growing both aerial and root parts [28].

In commercial food production in the twenty-first century, the technologies of hydroponics and aeroponics play a crucial part. Natural media is used in this technology to help plants grow.

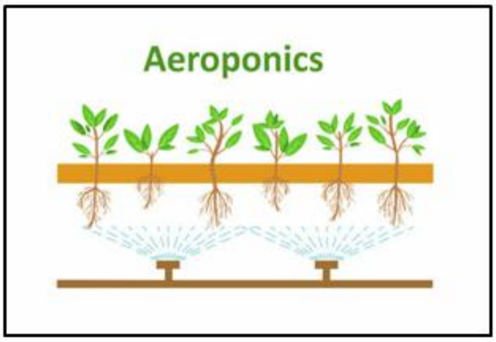

Fig. 6. Aeroponics

Fig. 7. Dutch bucket method

Sprayers, nebulizers, and foggers are used to create a fine mist of solution to deliver nutrients to plant roots. Plants will grow under optimal nutrient, temperature, aeration, and pH conditions. This technique introduces oxygen into the nutrient solution, making it easier for the roots to absorb nutrients. This facilitates stimulating the rapid growth, prevent algae formation and resulting high yields [23].

According to AlShrouf [29], due to the high demand for water resources and, as a consequence, food supply, various new farming trends have developed, including complicated agricultural production systems. Many studies of commercial-scale hydroponic, aeroponics and aquaponics production showed the potential positives role for those new technologies in the sustainable food security. The main benefits of these modern cultivation systems are the conservation of water and the use of fewer or no agrichemicals, which are harmful to the human body when used and especially when consumed in food.

Dutch Bucket Method: Dutch bucket method was used in Netherlands for the first time to grow cucumbers, tomatoes and roses. In this system a bucket (2.5 gallon) is used to grow plants. A pump is used to recycle the excess nutrient solution [9].

Cucurbita moschata Duchesne "Loche" was grown in a Dutch bucket hydroponic system, a technique not previously described for this crop, according to the researchers [30]. The structure of the "Loche" hydroponic vine is similar to that of plants cultivated in a high-temperature environment with constant water supply. Further research on this adaptation is needed to obtain female flowering and fruit using hydroponic technology.

4. CONCLUSION

Hydroponics is gaining popularity as a viable method for cultivating different crops. Because it is feasible to grow short-duration crops like vegetables round the year in limited places with low labour, hydroponics can make a significant contribution in areas where soil and water are scarce, as well as for the poorer and landless peoples. From the above review, it can be concluded that hydroponics is the alternative farming method which does not require soil or wide space and Nutrient Film Technique is most feasible among the all the systems. Hydroponic cultivation yield is 2-3 times more than traditional methods of cultivation. Adding to hydroponics, Aquaponics and Aeroponics also showed better advantages in many parts of the world. The popularization and commercialization of aeroponics is still of questionable through it offers advantages than hydroponics. Low-cost hydroponics material and automation are the need of hour to ensure high productivity and water use efficiency.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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