Review Article

SOILLESS CULTIVATION TECHNIQUE, HYDROPONICS-A REVIEW

ABSTRACT: The soil-based agriculture is facing some major challenges; most importantly decrease in per capita land availability. In 1960 with 3 billion population over the World, per capita land was 0.5 ha but presently, with 6 billion people it is only 0.25 ha and by 2050, it will reach at 0.16 ha. Urbanization, natural disasters, climate change, and the indiscriminate application of herbicides and pesticides, all of which are reducing land fertility, are currently affecting soil-based agriculture. So, now a days Hydroponic farming is currently gaining popularity around the world due to its effective resource management and high-quality food production. In this article types of hydroponics viz. wick system, ebb and flow, drip system, deep water culture and Nutrient Film Technique NFT) system and aeroponics; their operations by this technique were discussed. Several benefits of these techniques are less growing time of crops than conventional growing; round the year production; minimal disease and pest incidence and weeding, spraying, watering etc can be eliminated. Hydroponics play a great role in cultivating plants especially in urban areas, where very limited space available and water scarcity area.

Key Words: Aeroponics, Drip Irrigation, Dutch Bucket Method, DWC, Ebb and Flow, Hydroponics, NFT, Wick System

INTRODUCTION

World population projected to reach 9.7 billion by 2050. At the same time, it is estimated that 50% of the world's arable land will become unusable for farming (United Nation., 2017). As a result, to meet the high demand, food production must be increased by 110 percent. Another reason is that poverty reduces food production in many countries, particularly in Southern Africa, as irrigation and fertilisers become inaccessible. The third reason is soil erosion and degradation caused by traditional farming methods that depend mainly on soil and hence deplete it of vitamins and minerals.

Because of that, the world needs to develop and apply techniques to improve and increase the productivity of farming systems.

Today farming systems fundamentally based on soil, water and resilience to disasters. Hence, there is a need to change and develop the economic policies of current farming systems.

The traditional farming system does not meet the current and future food needs. Therefore, there is a real need for adapting new farming system that stimulates plants to grow faster. This system should cover the fast-growing demand with less cost and minimum consumption of natural resources.

Hence, the main aim of this article is to elaborate an alternative system that cover the current and future demand with lower cost and less consumption of natural resources. The unfavourable soil composition, soil erosion causing degradation, poor drainage, unsuitable soil reaction, presence of disease-causing organisms and nematodes are some of the serious limitations for plant growth (Dholwani *et al*., 2018). To eliminate these limitations, the world requires to invent techniques to improve and increase the productivity of farming systems.

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Hydroponics is one of the soilless culture systems. The word “hydroponics” is derived from Greek words, “hydro” which means water and “ponos” which means labor (Sardare and Admane, 2013). The method in which plants are grown without using soil as a rooting media ~~and~~ essential nutrients can be supplied through irrigation water” is said to be soilless culture. The fertilizers (containing nutrients) are supplied by dissolving in the irrigation water in appropriate amount (Savvas, 2003).

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History

Growing plants using different nutrient-rich water has been practiced for centuries (Tagle, *et al.*, 2018). The hanging gardens of Babylon and the floating gardens of Aztecs of Mexico are example of ‘HYDROPONIC’ culture. Egyptian hieroglyphic records describe the growing of plants in water. The basic concepts for the hydroponics growing of plants were established in the 1800s, by those investigating how plants grow (EI-Ramady, *et al*., 2014). 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 (Wahome, *et al*., 2011). 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 (EI-Ramady, *et al*., 2014).

Classification of Hydroponics system

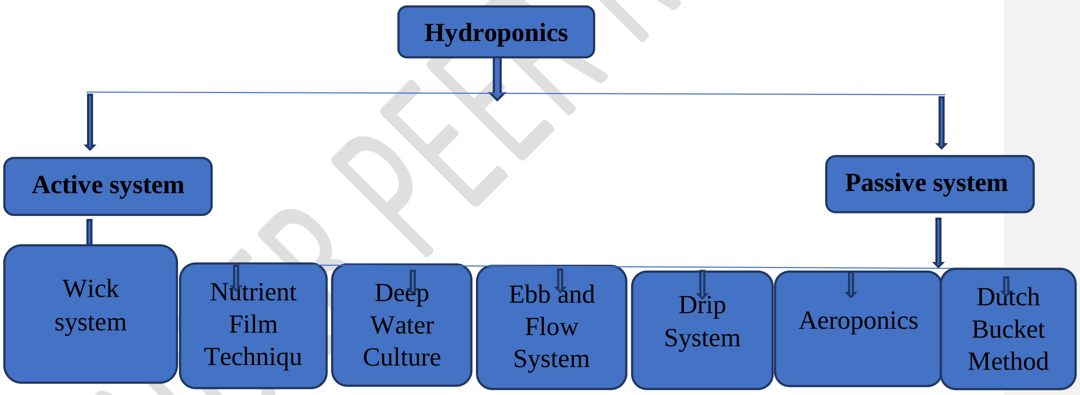

Fig.1 Classification of Hydroponics (George and George, 2016)

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 (George and George, 2016).

Wick system

It is the simplest method of hydroponic which does not require any electricity, pump or aerators (Sharma *et.al*, 2018). 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 nutrient solution to the plant roots (George and George, 2016). 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 (Sharma *et al*., 2018).

Ferrarezi and Testezlaf, (2016) conducted study was to compared the performance of two wick irrigation systems using self-compensating troughs filled with either pine bark (WPB) or coconut coir (WCC) with nutrient film technique (NFT) hydroponic system for greenhouse lettuce production. The daily monitoring of electrical conductivity (EC) and pH allowed the experiment management according to the recommended values for optimal lettuce growth. The EC showed variation among troughs and salt accumulation in substrates, with WPB exhibiting two times greater EC than WCC (ranging from 0.95 to 7.57 and from 0.68 to 3.67 $dScm^{-1}$, respectively), while the pH values were stable over time. Nitrate (NO3)-nitrogen (N), ammonium (NH4)-N, phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), boron (B), copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn) concentrations in plant shoot and root at the end of the experiment as well as the same nutrients, chloride, sodium, and bicarbonate concentrations in substrate and not significant determined weekly differed among the treatments ($P < 0.01$). The wick irrigation system with both substrates resulted in higher productivity than NFT, with higher yield and plant quality in WCC, indicating its feasibility as an alternative system for lettuce production in greenhouses.

Types of Active System

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

Nutrient Film Technique (NFT)

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 (Sharma *et al.,* 2018). 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 (George and George, 2016). 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 (Mohammed and Sookoo, 2016). NFT system is most commonly used for growing smaller and quick growing plants like lettuce. Some commercial growers also grow different types of baby greens and herbaceous plants using NFT. system (Dholwani, *et al*., 2018). 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 (Al-Tawaha, *et. al.,* 2018).

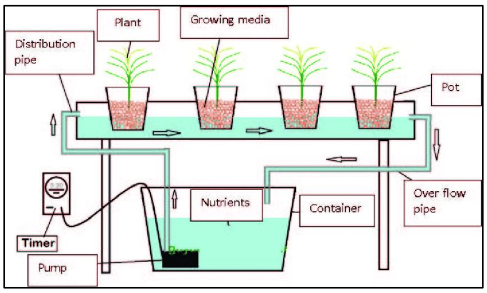

Fig.2 Nutrient Film Technique

An automation system for nutrient film technique (NFT) 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 nutrient solution in the Hydroponics nutrient solution irrigation system suited for a specific plant. (Kuncoro *et al.*, 2021) 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

The roots of plants are suspended in nutrient-rich water in a deep-water culture system of hydroponics, and air is delivered directly to the roots via an air stone. Hydroponics buckets system is classical example of this system. Plants are placed in net pots with their roots suspended in a nutritional solution, where they quickly grow in a large mass. It is mandatory to monitor the oxygen and nutrient concentrations, salinity and pH (Domingues *et al.*, 2012) as algae and moulds can grow rapidly in the reservoir. This system works well for larger plants that produce fruits especially cucumber and tomato, grow well in this system.

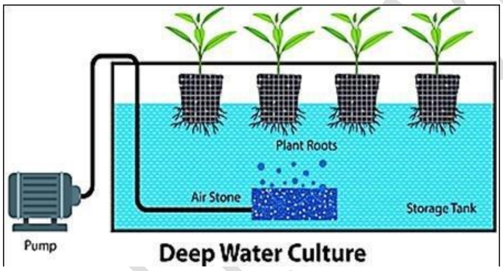

Fig.3 Deep Water Culture systems

Tomato plants (Solanum lycopersicum L. 'Grandia') were grown in a deep-water culture system, with varying oxygen (O_2) concentrations in the nutrient solution. Increase of branch length, number of side branches and number of flowers per plant were plotted against time and found to produce different types of curves (exponential, logarithmic and linear, respectively). The slopes of the best-fit functions of these curves were linearly correlated to the O_2 concentration in the hydroponic medium. The effect of O_2 concentration in the nutrient solution on the fresh and dry weights of roots and shoots was positive and exponential. There were no significant changes in response to O_2 in the ratios of root to shoot fresh and dry weights, or of the ratios of dry to fresh weights of roots or shoots. 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 (Zeroni *et al.*, 1983).

The purpose of the application of controlling the level of hydroponic nutrient solution in the type of Deep-Water Culture (DWC) in the box one of the simplest hydroponics is to ensure that the roots of the plant are always submerged in nutrient solution so that the nutrients are still fulfilled. (Nursemaid, *et al.*, 2021) results obtained from controlling the level of hydroponic nutrient solution in the type of Deep-Water Culture (DWC) in the box is when the level of nutrient solution is less than the specified threshold then the 12VDC pump relay will live to drain the source water to the nutrient solution reservoir. The HCSR04 sensor is used for reading the level of nutrient solution, so it has an effect on determining the pump life time. Controlling the level of nutrient solution based on linear regression linear calculation has a good accuracy of 88.6%.

EBB and Flow System

Ebb and flow system 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. The major problem seen in this system is root rot, algae and mould and therefore, modified system with filtration unit is required. It can also be automated using computer (George and George, 2016); (Sharma *et. al*, 2018).

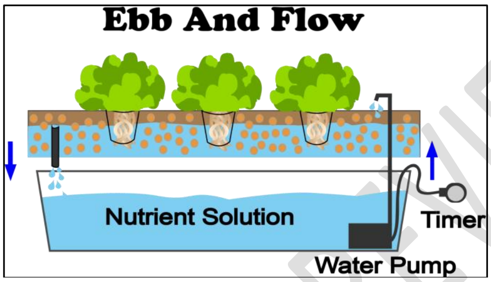

Fig.4 EBB and Flow System

Son *et al.* (2006) discussed the current subirrigation systems used for production of potted plants. A nutrient-flow wick culture (NFW) system was developed and compared with other subirrigation systems, such as an ebb and flow culture (EBB) system and a nutrient-stagnant wick culture (NSW) system in relation to their system characteristics and plant growth. The water contents of medium under the NFW and EBB systems showed fluctuations from 30 to 40% and from 50 to 60% (by volume), respectively, whereas the water content under the NSW system gradually increased to over 40% without fluctuation. Relative to other systems, the water loss in the NFW system was 50-70% due to the reduction in the evaporation from the surfaces of the trough and medium. With regard to system characteristics, the NFW system was simple, water-saving and efficient. In addition, the growth of kalanchoes in the NFW system was similar to those in the NSW and EBB systems at an irrigation frequency of five times a day.

Daud *et al.* (2018) proposes the ebb and flow hydroponics system based on fuzzy logic to control the working of pump in distributing the nutrient solution to the growth media. The control system was implemented using Arduino UNO with temperature sensor and soil moisture sensor as a transducer input and dc motors as actuators channelling nutrients to the planting media. The results confirm that design of fuzzy logic control is able to realize and working properly. There are several operating schemes obtained during testing at temperature of 30 °C including: (1) fast-rotating of pump upon reaching moisture of 0.1% RH, (2) medium-rotating of pump at moisture is 30% RH, (3) slow-rotating of pump at moisture of 50% RH, and (4) pump-off at moisture of 74.2% RH. The experimental results were validated with Matlab simulation and manual mathematics calculation. The actual testing was performed by growing green bean plants resulting 22 cm height of plants with 14 leaves after 28 days.

Drip System

Drip hydroponics is a popular technology used by both residential and commercial growers. With the help of a pump, water or nutrient solution from the reservoir is delivered to individual plant roots in an appropriate proportion (Rouphael and Colla, 2005). Plants are usually placed in moderately absorbent growing medium so that the nutrient solution drips slowly. Various crops can be cultivated in a systematic manner while conserving water. The major advantage of drip system is that it is able to withstand short-term power or equipment failure and it conserves more amount of water as compared to 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 (George and George, 2016); (Sharma *et al.*, 2018).

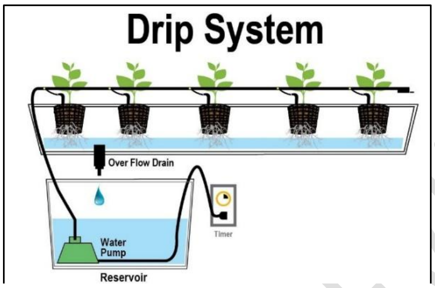

Fig.5 Drip System

Modern Agricultural lands are renovated through Smart Farming using the IoT and Big Data technologies which help farmers to reduce the usage of natural resources to increase efficiency. Inherently hydroponic drip irrigation systems save both water and nutrient. The present irrigation system provides only soil moisture and the surrounding temperatures with sensors. (Ani and Gopalakrishnan, 2020) explained that the system is used to record the sensor values and can manipulate the nutrient values when required. This work is all about the drip control and applying it to hydroponic farming by developing an interface between human and software which allows a continuous monitor of pH and all sensors, including the position of the plant by capturing via camera and monitoring via mobile application. Using big data, the supply of nutrient values gets tracked and recorded. This recorded data gets useful to automate the irrigation system further.

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 (Zobel *et. al*, 1976). 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 (Lakkireddy, *et al.*, 2012). The cultivation of plants without using soil or water as medium by maintaining all the parameters (temperature, pH, humidity, electrical conductivity of nutrient solution etc.) essential for growth of plants is called aeroponics (Kaur and Kumar, 2014). Aeroponics culture is suitable for low leafy vegetables like lettuce, spinach, etc. (Khan, *et al.*, 2018).

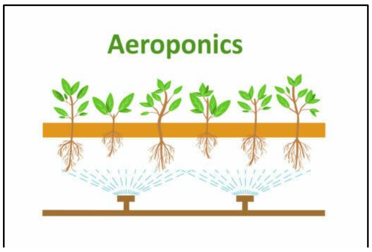

Fig.6 Aeroponics

Vertical farming is a type of indoor agriculture where plants are cultivated in stacked systems. It forms a rapidly growing sector with new emerging technologies. Indoor farms often use soil-free techniques such as hydroponics and aeroponics. Aeroponics involves the application to roots of a nutrient aerosol, which can lead to greater plant productivity than hydroponic cultivation. Aeroponics is thought to resolve a variety of plant physiological constraints that occur within hydroponic systems (Eldridge *et al.*, 2020).

Mangaiyarkarasi, (2020) discussed that the aeroponic is the culturing of whole plants with their roots fed by an air/ water nutrient fog. Aeroponic is a method of growing plants where they are anchored in holes in styrofoam panels and their roots are suspended in the air beneath the panel. The panels compose a sealed box to prevent light penetration to encourage root growth and prevent algae growth. The nutrient solution is sprayed in fine mist form to the roots. Misting is done for a few seconds every 2-3 minutes. This is sufficient to keep roots moist and nutrient solution aerated. The plants obtain nutrients and water from the solution film that adheres to the roots.

This aeroponic farming is superior in terms of excellent aeration, water use efficiency, less time and space requirement, seasonal independence, disease free plant propagation, and large-scale plant production etc. than the conventional methods of propagation. Aeroponic techniques have proven to be commercially successful for propagation, seed germination, seed potato production, tomato production, leaf crops, and micro-greens. Vegetable crops like potato, yams, tomato, lettuce and some of the leafy vegetables are being commercially cultivated in aeroponic system. Aeroponics appeared to be a highly feasible method for the production of both aerial parts and roots (Kumari and Kumar, 2019).

The technology Hydroponics and Aeroponics plays very crucial role in 21st century in soilless culture in commercial food production. In this technology natural media is helpful to grow the plants. The main principle involving the use of sprayers, nebulizers, foggers to create a fine mist of solution of deliver nutrients to plants roots. Plants will grow under optimal conditions like nutrient, temperature, aeration, and pH. In this technique oxygen is influenced into the nutrient solution, allowing the roots to absorb nutrients quicker and more easily. This facilitates stimulating the rapid growth, prevent algae formation and resulting high yields (Lakkireddy *et al.,* 2012).

AlShrouf, (2017) reported that due to huge demand on water resources and subsequently food supply, many new trends in the farming innovative methods which include a complex agricultural production system have been evolved. 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 advantage of those modern cultivation systems is the conservation of water and less or no use of agrichemicals which are dangerous to the human body when applying and especially when eating in the 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. (George and George, 2016).

Fig.7 Dutch Bucket Method

Vasquez and Vasquez, (2017) explained the Cucurbita moschata Duchesne "Loche" was stablished in the Dutch bucket hydroponic system, technique no previously described for this crop. "Loche" hydroponic vine structure resembles those of plant being grown in a high temperature environment with constant water supply. Further research on this adaptation is needed to obtain female flowering and fruits through hydroponic technology.

CONCLUSION

Hydroponics has recently gained popularity as a viable method for growing 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.

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