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Advancement Of Agricultural Hydroponic Systems: A Promising Solution To The Agricultural Production

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ABSTRACT :

Horticulture, the science of cultivating fruits, vegetables, flowers, and ornamental plants, has witnessed significant advancements in recent years, driven by technological innovations, scientific research, and evolving consumer demands. This review article provides a comprehensive overview of the latest developments in horticulture, encompassing various aspects such as breeding techniques, cultivation practices, pest and disease management, and post-harvest technologies. The review begins by exploring recent trends in plant breeding, including the use of molecular techniques such as marker-assisted selection and genetic engineering to develop high-yielding, disease-resistant varieties with improved nutritional profiles and enhanced agronomic traits. It also discusses the emergence of precision horticulture, which integrates advanced technologies such as remote sensing, drones, and data analytics to optimize resource use and increase productivity while minimizing environmental impact. In addition, the review delves into recent developments in post-harvest technologies and value addition, including controlled atmosphere storage, modified atmosphere packaging, and novel processing techniques, which extend shelf life, maintain quality, and enhance marketability of horticultural products. Overall, this review provides valuable insights into the latest advancements in horticulture and underscores the importance of continuous innovation and sustainable practices to meet the growing demand for high-quality, nutritious, and environmentally-friendly horticultural products in a rapidly changing world.

Keywords: Horticulture, crops, nutrients, disease resistance.

Introduction :

Horticulture, derived from the Latin words "hortus" (garden) and "cultura" (cultivation), encompasses the science, art, and business of growing fruits, vegetables, flowers, and ornamental plants. It is a diverse and dynamic field that combines elements of biology, botany, ecology, agronomy, and economics to cultivate plants for food, aesthetics, medicine, and environmental purposes. Dating back to ancient civilizations, horticulture has been integral to human existence, providing sustenance, beauty, and medicinal resources. Early agricultural societies developed rudimentary techniques for plant cultivation, seed selection, and irrigation, laying the groundwork for the sophisticated horticultural practices we see today.

The evolution of horticulture can be traced through millennia of human history. From the domestication of wild plants to the development of modern agricultural practices, horticulture has undergone a remarkable transformation driven by innovation, experimentation, and cultural exchange. Ancient civilizations such as the Egyptians, Greeks, and Romans made significant contributions to horticultural knowledge, cultivating crops, establishing gardens, and documenting it.. Horticulture has seen remarkable advancements in recent years, driven by a combination of technological breakthroughs, environmental concerns, and evolving consumer preferences. With the world witnessing rapid urbanization and an increasing awareness of environmental sustainability, urban horticulture has emerged as a promising solution to solve pressing challenges in modern societies (Sashika,2024). Despite the significant progress made in horticulture, several challenges remain, including climate variability, pest and disease pressures, resource constraints, and socio-economic disparities. Addressing these challenges requires concerted efforts from researchers, policymakers, industry stakeholders, and the broader community. Future research endeavours should focus on developing resilient crop varieties, enhancing agroecosystem sustainability, improving post-harvest management practices, and fostering inclusive and equitable horticultural system. Horticulture is crucial to supplying fruit and vegetables, which are rich in essential nutrients and contribute significantly to global economies. (Opara,2024).

This dynamic field encompasses various disciplines, including crop production, landscaping, floriculture, and post-harvest management. This review paper aims to provide an overview of the recent advances in horticulture, highlighting key developments, emerging trends, and their implications for sustainable agriculture and horticultural practices. By synthesizing current research findings and exploring the multifaceted aspects of modern horticulture, this paper seeks to shed light on the transformative potential of innovative approaches in shaping the future of agriculture. In conclusion, recent advances in horticulture have opened up new possibilities for enhancing agricultural productivity, environmental sustainability, and food security. So, let's delve into some of the notable recent advancements shaping modern horticulture.

Methods used in soilless culture

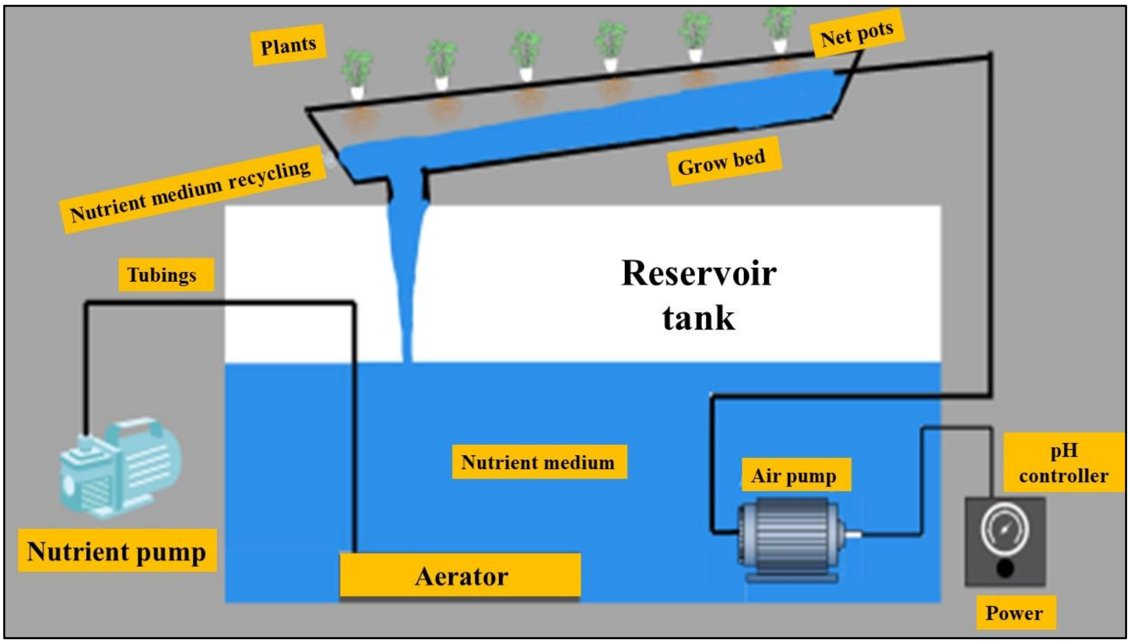
A few things must be checked and considered before choosing a hydroponics technique including, Availability of suitable medium for growth, Expected yield, Availability of Space, Optimum Resources present, Quality and quantity of the product generated.

Nutrient film technique (NFT)

The nutrient medium is poured into the reservoir tank. An air pump is used inside the reservoir that continuously bubbles air into the reservoir to supply oxygen to the nutrient medium (Figure 1). Another pump called 'Nutrient Pump' pushes the nutrient solution from the reservoir into the tube grow bed. Above the reservoir, there are small plastic baskets or pots used to hold the plants while the roots are all submerged in the nutrient solution. The roots absorb all the water, nutrients and oxygen needed by the plant to grow. Various studies on crop nutrient requirements in the NFT system across all growth stages have reported that fruits and vegetables such as paprika, tomato, and melon absorb relatively low nutrients until flowering but require maximum nutrients during flowering and early fruit development (Yeo et al., 2023).

The excess nutrient solution is pumped back into the tank by the other end of the tube as it is elevated from one side. Electrical conductivity and pH are checked regularly, and even timers are set to complete one cycle. It usually takes 8-10 hours to complete one cycle. The system is slightly tilted so nutrient solution runs through roots and back into a reservoir tank (Sharma et al., 2018). Chilli, tomato, capsicum, spinach, lettuce, coriander, strawberry, small flowering plants, and cucumber are some of the most successful products using this technique.

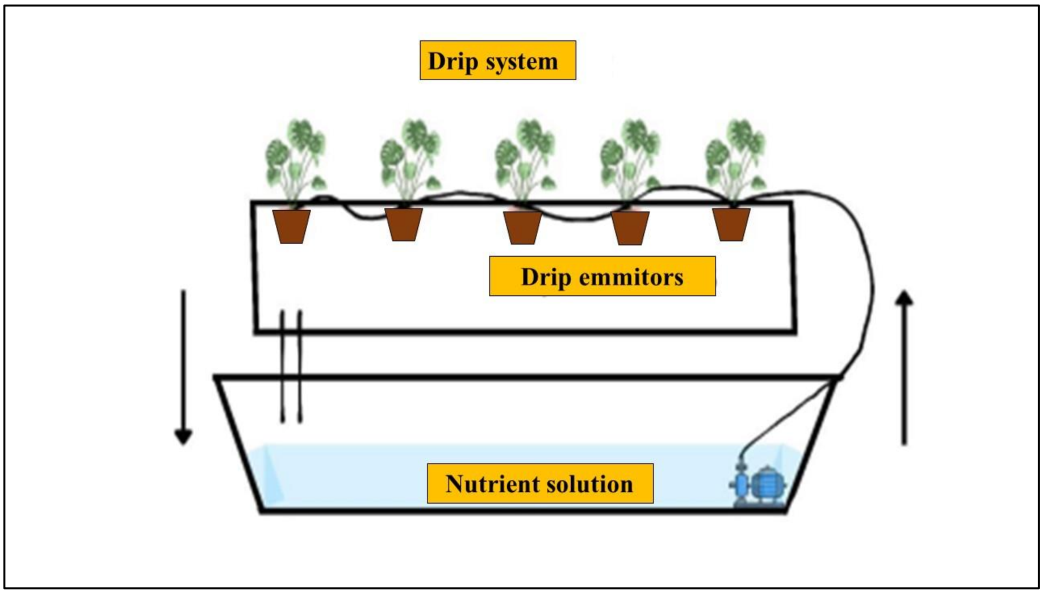
The nutrient film technique was developed by Allen Cooper late in 1960s at the Glasshouse Crop Research Institute in Littlehampton, England. To date, many small modifications have been made to improve their technology. Mostly one litre/m of Nutrient Medium is filled at once in the reservoir. Least to no wastage is recorded, and good product yield is generated. It is an altered method made to overcome the demerits of the Ebb and Flow Method. Sometimes, this setup leads to fungal infection as the roots are constantly dipped in the nutrient medium. Graves, 1983 gives a complete description of this NFT.



Deep flow technique (DFT)

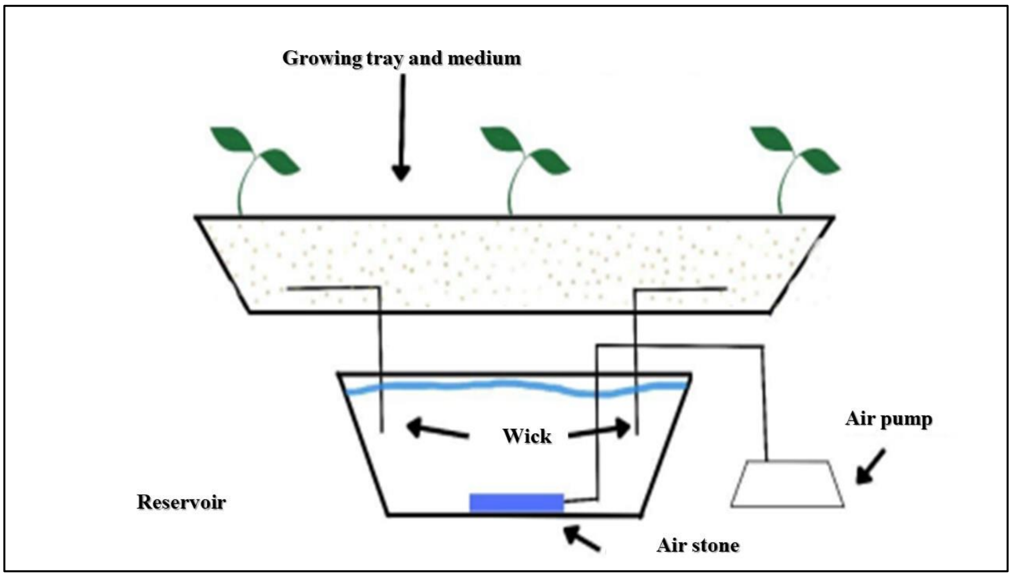
The deep flow technique is also known as the pipe system. In 1976, this method was created by Jensen and Collins for cultivating the lettuce and other leafy vegetables on a floating raft of an expanded plastic. This method was first introduced by Arizon and Massantini 1976 in Italy. This was a hit in Caribbean, because by combining this method and with the cooling of the nutrient solution, the production of the lettuce made possible and the lettuce was also saved from bolting. In this system, the plants float above a water tray like a polystyrene or Styrofoam board structure, with the roots immersed in an oxygenated solution, consisting of water and nutrients. (Rapisarda et al. 2022). The plants are placed inside plastic perforated containers, with the roots hanging out and then holes are drilled into the board (Figure 2).

This hydroponic setup contains horizontal rectangular tanks arranged in a line in a huge plastic. Those developed by Jensen were 4 m long, 70 m wide and 30 cm deep. The nutrient solution was then monitored at regular intervals. It was recirculated, and a pump was used to keep the system aerated. The rectangular tanks were used because of their two benefits: the reach of maximum direct sunlight to the plants and frictionless conveyor belts for planting. Here 2-3m deep nutrient solution flows through the 10-cm PVC pipes. In which the plastic net pots are fitted. The bottom of the pots is connected to the solution that flows into the pipe. This hydroponic system is best for both tall and short plants. The material used in the net pots is a mixture of rice husk and old coir dust. In the base, a small piece of net cloth is used to protect from spilling the material from the pot into the nutrient medium. The nutrient solution gets aerated when the recycled solution falls into the stock tank. The pipes must have a slope to maintain the proper flow of the nutrient solution.



Ebb and flow technique

This technique is also known as the flood and drain method of Hydroponics, which is the principle of this technique. In this method, the nutrient solution is pumped into a growing medium from a reservoir. The preparation of seedlings for hydroponic systems to be successful includes germination and transplantation (Riggio et al.,2019). It is allowed to flow there for 5 to 10 minutes. Then the solution is allowed to flow from the medium to the reservoir (Figure 3). The outflow of nutrient solution from the growing area brings air into the that area and provides an oxygen source to it. But, here, the plants experience a change of environment which sometimes is not beneficial for optimum plant growth. This system also has some root algae and mould issues and that's why some necessary modifications are still needed. Which is why, this method is commonly used as a hobby only and for all the gardening enthusiasts and not for commercial production. The medium used here has perlite, clay, pebbles and rock wool as chief components.



Drip method

This method is used to grow long term crops like cucumber, tomato etc. An emitter dripper or a pump is used to deliver nutrients to the plants. Here, a solution is provided to individual plants in a timely manner. These emitters work according to the exposure of sunlight and growth stage of the plant. It is totally a soilless technique as all the requirements are provided by the system only. There are two types of Drips. First, the recoverable method, where the solution can be reused. Second, is a Non-recoverable method where all the nutrients solution goes off as waste. Out of the both Recoverable method is budget friendly. The nutrient medium used here is mildly absorbent in nature to the plant roots, and hence, the drippers deliver the medium slowly.

Wick method

This is the simplest hydroponic system requiring no electricity, pump or aerators. Here plants are arranged in a growth medium with vermiculture and pertile, with the wick or thin thread running from the plant's roots into a reservoir tank of nutrient solution. Here water is provided to the plants by the capillary action of the wick. As wick can hold a limited amount of water, this method is useless for a large amount of water requiring crops.
These are also some commonly used and studied methods of hydroponics like Aeroponics, Aquaponics, float raft system, deep water culture, root dipping method, hydroponic plant growth systems, static solution culture, passive sub-irrigation systems, and top irrigation systems are other hydroponic techniques (Figure 4).

3. Recent Advancements

3.1. Vertical Farming and Urban Agriculture

As urban populations burgeon and arable land becomes scarcer, vertical farming has emerged as a sustainable solution. By stacking layers of crops in vertical structures and employing hydroponic or aeroponic systems, horticulturists can efficiently utilize limited space and resources while minimizing environmental impact. Vertical farming involves cultivating crops in vertically stacked layers or inclined surfaces within controlled environments, such as skyscrapers, warehouses, or specially designed structures.(Akintuyi,2024). In European countries, urban agriculture is expected to handle the societal transformations of both urban and rural areas, such as ageing in the agriculture (Oh,2023).

3.2. Smart Farming Technologies

The integration of Internet of Things (IoT) devices, sensors, and data analytics has revolutionized farming practices. Through real-time monitoring of environmental conditions, soil moisture levels, and plant health parameters, horticulturists can make informed decisions to optimize irrigation, nutrient management, and pest control. Smart farming (SF), that is particularly based on information and communication technologies into machinery, equipment, and sensors in agricultural production systems, allows a large volume of data and information to be generated with progressive insertion of automation into the process. (Pivoto,2018). Smart technologies in agriculture will boost the production of farm crops and livestock since autonomous systems will be able to control actuators effectively, improve the utility, control resource usage, and ensure products conform to market requirements while maximizing profit and minimizing the cost of production (Idoji,2021)

3.3. Precision Horticulture and Genetic Engineering

Advances in genetic technologies, including CRISPR-Cas9 gene editing, have accelerated crop improvement efforts. Horticulturists can now precisely manipulate plant genomes to enhance desirable traits such as disease resistance, drought tolerance, and nutritional content. Additionally, marker-assisted selection techniques facilitate the breeding of new crop varieties with improved yield potential and adaptability to changing environmental conditions. Finally, precision application technologies embrace variable-rate application technologies, precision irrigation and weeding and machine guidance. (Balafoutis,2017)

3.4. Biological Control and Integrated Pest Management (IPM)

With growing concerns over chemical residues and pesticide resistance, horticulturists are increasingly turning to biological control methods for pest management. A fundamental paradigm of IPM is that the use of multiple tactics provides crop protection that is less risky, more technically efficient and more cost-effective than the use of a single tactic (Bottrell,2018). Beneficial insects, nematodes, and microbial agents are deployed strategically to suppress pest populations while minimizing harm to beneficial organisms and the environment. Finally, IPM is a sustainable process that combines biological, cultural, physical, and chemical tools to identify, manage, and reduce risk from pests and pest management tools and strategies in a way that minimizes overall economic, health, and environmental risks.(Dara, 2019).

3.5. Nutrient Recycling and Circular Economy

Efforts to minimize waste and maximize resource efficiency have led to the adoption of circular economy principles in horticulture. Technologies such as anaerobic digestion and composting enable the recycling of organic waste into valuable inputs like biogas and organic fertilizers. Additionally, innovative approaches like aquaponics, which integrate fish farming with hydroponic crop production, create symbiotic systems where nutrient-rich fish waste fertilizes plant growth, closing nutrient loops and reducing dependency on external inputs. For example, Potting soil production could be a possible solution for minimizing urban waste accumulation and recycling nutrients during ornamental plant production.(Dede,2023). These recent advancements underscore the transformative potential of horticulture in addressing pressing global challenges, including food security, environmental sustainability, and climate resilience.

Conclusion :

Hydroponics technology discussed so far can be the answer to all the questions when it comes to do soilless culture. No doubt conventional process also gives exact same results But, if we compare this process with the traditional process, the Hydroponic techniques decreases the overall production cost and increases the profit. The soil is getting infertile, the water is getting polluted, and most croplands are getting barren from intensive cropping on them. With the help of this technique, the demand and supply gap can be filled, providing fresh and better-quality foodstuff. Also, the consistency in the supply chain can be maintained.

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The author declare that they have no competing financial interest or personal relationship that could have appear to influence the work reported in this paper.

Availability of data and materials:

The data and materials that support he findings of the study are available from the corresponding author upon request

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