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Hydro propagation: Harnessing water for sustainable plant propagation and growth

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Abstract

Hydro propagation is a novel strategy for plant multiplication, and essential for sustainable agriculture. This approach does not require any soil at all; plant portions especially plant cuttings are simply immersed in nutrient-rich water solutions. It has many advantages including root development, water conservation, and effective nutrient delivery. Hydro propagation is a promising approach for easy multiplication and quality production of crops. It has exact control over growing conditions, increasing plant propagation success rates. Moreover, this technique is also helpful for environment as it does not involve any kind of pesticides application and soil borne diseases. This abstract reveals the fundamentals and advantages of hydro propagation, emphasizing how it can completely transform the traditional way of cultivation. The objective of this review paper is to compile the conclusions and results regarding hydro propagation till date. This paper also involves the future directions necessary for further research and awareness.

Keywords: Hydro propagation, multiplication, novel strategy, sustainable agriculture

Introduction

Definition and Evolution of Hydro propagation

The term hydroponics, which comes from the Greek terms "hydro" (which means water) and "ponos" (which means labour), refers to a technique for growing plants that uses mineral fertilisers solutions instead of conventional soil (Macwan *et al.*, 2020) [8]. The growing of edible and ornamental plants in a mix of water and dissolved nutrients is known as hydroponics, and it was first used by Dr. W.F. Gericke (1936). Although not all soilless culture is hydroponics, hydroponics is always soilless culture. Plants can be cultivated in sterile substrates that are devoid of microorganisms or in a simple nutrient solution.

1. Historical Overview

Asia, the Amazon, Babylon, Egypt, China, and India were all early adopters of hydroponics. Prototypes of hydroponic systems were actually the "hanging Garden of Babylon" and the floating farms of the Aztecs. The method for growing terrestrial plants without soil is described in Sir Francis Bacon's book "Sylva Sylvarum," which was first published in 1627 (Saroj *et al.*, 2021) [9]. Water culture emerged as a prominent study method following Bacon's work. John Woodward published the results of his spearmint-based water culture studies in 1699. He noticed that plants fared better in less pure water sources than they did in distilled water. The method of soilless culture came about as a result of the experiments conducted by German botanists Julius von Sachs and Wilhelm Knop (1859–1865) (Antony *et al.*, 2023) [10].

Plant scientists later coined the term "nutriculture" when they began to cultivate plants with particular nutrients for research objectives (Palm *et al.*, 2024) [11]. At the University of California, Dr. William F. Gericke was able to grow tomato plants up to 7.5 m tall in nutrient solutions in 1929. The 1990s saw a rise in popularity for home hydroponic systems. The development of more organic food without pollution or risks occurred through hydroponics in the 1920s.

2. Significance of Hydro propagation in agriculture/ horticulture

Hydroponic propagation holds significant importance in modern agriculture and horticulture due to its efficiency and precision in plant cultivation.

Hydroponics, in contrast to conventional soil-based techniques, uses a nutrient-rich water solution to directly supply vital components to plant roots, resulting in quicker and healthier growth (Ragaveena *et al.*, 2021) [12]. With this approach, environmental factors like pH, fertilizer concentrations, and water availability may be optimally controlled, increasing crop yields while using less resources. Because it reduces the need for fertile soil and the risk of soil-borne diseases, hydroponic propagation is especially beneficial in places with little arable land or poor soil conditions. Furthermore, year-round cultivation is made possible by the regulated atmosphere of hydroponics, guaranteeing a steady and dependable supply of food. As a sustainable, economical, and high-yield substitute for conventional growth techniques, hydroponic propagation represents a revolutionary development in the fields of agriculture and horticulture (Casey *et al.*, 2022) [13].

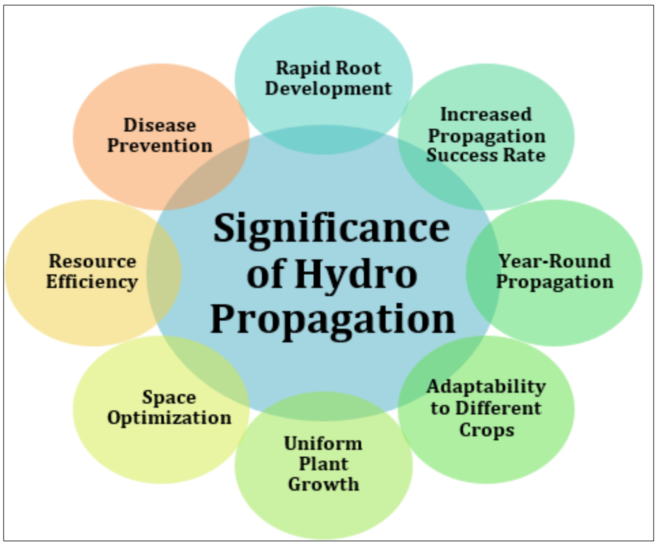

Fig 1: Significance of Hydro propagation

Table 1: Hydroponics Techniques: Unveiling the Science

S. No.	Hydroponic Technique	Characteristics	Specific Plants	Reference
1.	Nutrient Film Technique (NFT)	Thin layer of nutrient-rich water is continuously applied to the roots of the plants, allowing them to absorb the necessary nutrients. The extra liquid is recycled again.	Herbs, leafy greens, Beans, Radish, Cucumber, and Strawberries	Bhatta *et al.*, 2023 [1]
2.	Deep Water Culture (DWC)	Also known as Dutch bucket system, in which roots stay suspended in nutrient-rich water that is constantly oxygenated by an air pump. A regulated atmosphere for the best possible plant growth by using individual buckets packed with inert materials, such as perlite. Frequently used in commercial hydroponics because of its versatility, simplicity, and adaptability.	Leafy greens, Tomatoes, Cucumbers, Peppers, Herbs and Lettuce.	Rajaseger *et al.*, 2023 [2]
3.	Drip System	It provides the direct application of nutritional solutions to the roots. After dripping the solution onto the preferred growing medium, it is let to drain back into the container, and recycled.	Fruits, vegetables, herbs, and flowering plants.	Singh *et al.*, 2022 [3]
4.	Ebb and Flow (Flood and Drain)	Plants are periodically immersed in nutritional solution and then drained back into a reservoir. This cycle is repeated on a regular basis, which makes it easier for the roots to receive nutrients and oxygen.	Cucumbers, Peppers, Strawberries, Spinach, Radishes, and Tomatoes	Modu *et al.*, 2020 [18]
5.	Aeroponic	Roots are suspended in the air and are periodically sprayed or misted with a fine nutritional solution. More nutrition intake and oxygenation.	Herbs, Strawberries, Capsicum, Cauliflower, Chilli, Leafy Greens	Singh *et al.*, 2023 [5]
6.	Wick System	Passive hydroponic system, plants are placed in an inert growing medium, and the nutrient solution is moved uphill from a reservoir to the root zone with the help of a cotton rope wick.	Herbs, Low-Nutrient-Demanding Plants, and Small Plants	Verma *et al.*, 2023 [6]
7.	Krakty method	Simpler and less expensive techniques; Runs without the need for electricity or technological gadgets. Water and nutrients must be first administered to the entire crop, which makes the technique an efficient way to produce plants.	Herbs and Leafy Greens	Prabha *et al.*, 2022 [7]

Types of media and substrate used for hydro propagation

There are different types of media and substrate used in hydro propagation. Media plays an important role in determining moisture retention, irrigation cultural practices, production cost, and sustainability, and therefore, the choice of the growing media is critical. For hydroponic propagation, the perfect medium must be able to contain a lot of moisture while allowing extra water to drain out without suffocating the seeds (Gaikwad *et al.*, 2020) [14]. If the medium doesn't drain well, the roots could rot.

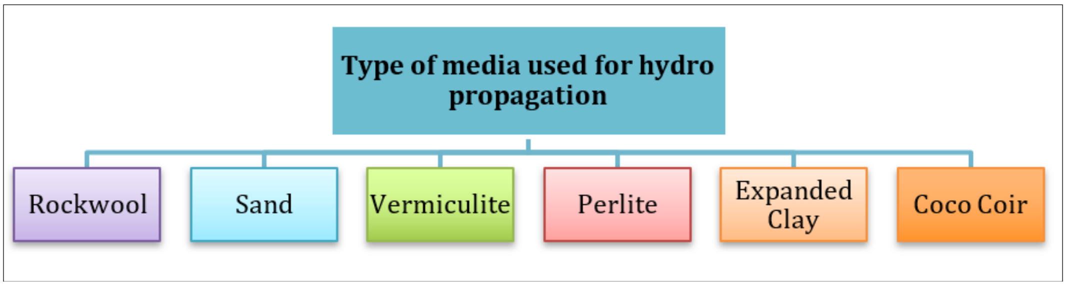

Fig 2: Types of Media used in Hydro Propagation

Rockwool

In hydroponics, rock wool, sometimes referred to as mineral wool, is the most commonly utilized medium. It functions as an inert substrate in recirculating and free drainage systems (Benko *et al.*, 2023) [15]. The main ingredients of rockwool, which is a non-biodegradable, sterile, porous material, are melted granite and/or limestone that are spun into tiny threads similar to cotton candy. Next, the rockwool is shaped into slabs, blocks, sheets, cubes, or flocking. Due to its high water absorption capacity, rockwool should not be excessively moist as this could suffocate the roots of plants and cause stem and root rot.

Sand

Sand is frequently used as a growing media in hydroponic systems due to its resemblance to tiny rocks. The reduced particle size of sand slows down the moisture evaporation compared to larger rock mediums (Mir *et al.*, 2022) [16].

Coco Coir

The material left over after the fibers from the coconut's exterior shell are removed is called coco peat, sometimes referred to as coir or coco. Coir is a growing medium that is entirely natural (Khan *et al.*, 2022) [17]. Coco coir is ideal for hydroponics since it is an organic plant material that decomposes very slowly and won't supply nutrients to the plants growing in it. It is also pH neutral, retains moisture extremely well, and still permits proper root aeration.

Perlite

Volcanic rock is superheated to create extremely light expanded glass pebbles, which are then called perlite. It can be used loose or submerged in water in plastic sleeves. It also helps with drainage and reduces soil density in potting soil mixtures (Mridha *et al.*, 2021) [18]. In general, perlite stores less water and more air. Since perlite is lightweight and floats, it may not be the ideal option for flood and drain settings in hydroponic systems. Although it's frequently used in potting soils, it's best to think about using different growing media in hydroponic systems for best results.

Vermiculite

Similar to perlite, vermiculite is a silicate mineral that swells in extremely hot temperatures. With the exception of its somewhat higher cation-exchange capacity, which allows it to store nutrients for later use, vermiculite and perlite are fairly similar as growing media. In a passive hydroponic system, vermiculite can draw water and nutrients because it has a natural "wicking" quality that allows it to hold more water than perlite (Suryawanshi *et al.*, 2021) [19].

By progressively adding more perlite to the mixture, the medium's capacity to retain water can be lowered if the plant roots are surrounded by an excessive amount of water and insufficient air.

Expanded Clay

It is manufactured by baking clay pellets and is marketed as "Hydroton" or LECA (light expanded clay aggregate) (Kumar *et al.*, 2024) [20]. For hydroponic systems where every nutrient is meticulously regulated in a water solution, hydroton or enlarged clay pellets are appropriate. The clay pellets have no nutritional value and are inert and pH neutral. The clay is shaped into twenty-three spherical pellets and burned in rotary kilns at temperatures as high as 1200 °C (Singh *et al.*, 2023) [5]. The clay pops up and becomes porous as a result. The primary benefit of hydroton is its low weight and resistance to gradual compaction. The fact that this growing medium may be thoroughly cleaned and sterilized by rinsing it in solutions of hydrogen peroxide, white vinegar, or chlorine bleach makes it an environmentally friendly and recyclable growing medium. However, because root development can seep into the media, there is a belief that clay pebbles should never be used again, even after cleaning.

Composition of Nutrient solution in Hydro propagation

Hydroponically grown plants dissolve their nutrients, which are primarily inorganic and ionic forms. Many combinations of chemicals are employed to provide every component required for plant growth (Kumari *et al.*, 2018) [21]. In order to give plants the best conditions for growth and development, hydroponic farming depends on creating a nutrient solution with the correct ion ratio. Plants are able to take nutrients only when they are available in an absorbable state, which typically translates to the nutrients being absorbed as ions. The positively charged cations and negatively charged anions are the two types of electrically charged ions that comprise every nutrient.

These consist of Steiner Bollard, Hoagland and Snyder, Hoagland and Arnon, and other standard dietary solutions. These traditional methods are helpful as a general guide, but they are not tailored to individual growing conditions (Opdahl *et al.*, 2023) [22]. The goal of a hydroponic fertilizer solution is to supply the roots of the plants with soluble forms of essential minerals, oxygen, and water. The soluble salts of essential nutrients that plants require are frequently the inorganic ions present in feeding solutions. However, there may be some organic materials present, such as iron chelates.

Salt / Reagent of Macro and Micro nutrient	Concentration in hydroponic solution
KNO_3	1.250 mM
KH_2PO_4	0.625 mM
$MgSO_4$	0.500 mM
$Ca(NO_3)_2$	0.500 mM
H_3BO_3	17.50 µM
$MnCl_2$	5.500 µM
$ZnSO_4$	0.500 µM
Na_2MoO_4	0.062 µM
$NaCl_2$	2.500 µM
$CoCl_2$	0.004 µM
FeEDTA	12.50 µM

Hydroponic plants receive all the macro and micronutrients they require from nutrient solution, which is composed of fertilizer salts dissolved in water. The main element influencing the success or failure of hydroponic systems is the rigorous nutrient control regimen. Hydroponic farming demands precise control over the nutrient solution's pH, temperature, and electrical conductivity (EC), as well as refilling when necessary (Sambo *et al.*, 2019) [23]. A nutritional solution's chances of success diminish as it moves further away from the ideal pH range. For hydroponics, the ideal E.C. range is 1.5 to 2.5 dS/m (Hosseini *et al.*, 2021) [24]. Higher EC will impede nutrient absorption due to osmotic pressure, whereas lower EC will negatively impact plant health and yield (Sharma *et al.*, 2018) [25].

Hydroponic propagation technique

Selection of plant material (cuttings)

The choice of plant material, particularly cuttings, is an important first stage in hydroponic propagation that has a big impact on the outcome of the entire process. Plants that are disease-free and in good health are usually better choices for cutting sources because they encourage strong, robust root development. In addition, depending on the species and desired qualities, the selection process may entail picking particular plant parts, such as the tips, middle sections, or basal areas. While root formation during hydroponic propagation is directly impacted by the general vitality of the selected plant material, it is crucial (Atherton *et al.*, 2023) [26].

Preparation of the cutting

Cutting preparation in hydroponic propagation is a methodical procedure that guarantees the healthy emergence of new plants (Rather *et al.*, 2023) [27]. First, choose donor plants that are disease-free and in good health, ideally those that are in the vegetative growth stage. Take 4 to 6 inch stem cuttings with a clean, sharp cutting instrument, making sure each cutting has a section of the stem and at least one set of mature leaves. To reduce water loss, remove as many leaves as possible from the lower nodes, leaving just a few at the top. To promote the growth of roots, submerge the cuttings in a solution containing rooting hormones. After that, the prepared cuttings are carefully put into a nutrient solution or rock wool, or any other sterile, water-based growing media (Baras and Tyler 2018) [28].

Types of water-based mediums (e.g., plain water, nutrient solutions)

1. **Plain Water:** Cuttings can be easily disposed of by just putting them in plain water. Although it keeps the cuttings moist, it is deficient in vital nutrients for sustained growth (Ur-Rahman *et al.*, 2019) [29].
2. **Nutrient Solutions:** The ingredients required for initial root development are provided by using a nutrient-rich water solution. Common hydroponic fertilizer solutions are made with care to sustain soilless plant development (Thakur *et al.*, 2023) [30].

Table 2: Hydro Propagation in Different Fruit Crops

Fruit Crop	Examples
Strawberry	June-bearing varieties such as 'Chandler', 'Camino Real'; Everbearing varieties like 'Seascape'
Tomato	Cherry tomatoes ('Sweet 100', 'Sun Gold'); Beefsteak varieties ('Brandywine', 'Beefmaster')
Blueberry	Highbush varieties such as 'Bluecrop', 'Jersey'; Rabbiteye varieties like 'Climax', 'Premier'
Raspberry	Red raspberry cultivars ('Heritage', 'Autumn Bliss'); Black raspberry varieties ('Bristol', 'Jewel')
Blackberry	Thornless varieties ('Apache', 'Navaho'); Thorny varieties ('Kiowa', 'Chester')
Grape	Table grape varieties ('Thompson Seedless', 'Red Globe'); Wine grape cultivars ('Cabernet Sauvignon', 'Chardonnay')
Kiwifruit	Green kiwifruit ('Hayward', 'Bruno'); Gold kiwifruit ('Hort16A', 'Zesy002')
Fig	Common fig varieties ('Brown Turkey', 'Celeste'); Adriatic figs ('White Genoa', 'Kadota')
Pineapple	Smooth Cayenne, MD-2, Queen Victoria
Avocado	Hass, Fuerte, Reed

Factors influencing for successful hydroponic propagation

1. **Hormones and Growth Regulators:** Hormones like auxins play an important role in root development in cuttings. Rooting hormone therapy can improve root initiation and growth, increasing propagation success rates (Chen *et al.*, 2023) [43].
2. **Light Conditions:** Photosynthesis and general plant health during propagation depend on the provision of suitable light levels and spectrum. In indoor hydroponic systems, where natural light may be limited, adequate lighting is crucial to ensuring optimum energy for root and shoots development (Sipos *et al.*, 2020) [46].
3. **Temperature and Humidity:** Maintaining proper temperature and humidity levels creates an ideal environment for root growth. Rooting normally occurs within a specific temperature range, and maintaining consistent humidity levels helps to prevent excessive transpiration and dehydration of cuttings (Wang *et al.*, 2023) [43].
4. **Water Quality:** A clean, high-quality source of water is necessary for the proper proliferation of hydroponic plants. Pathogens or poisons that impede root development and general plant health can be introduced by low-quality water (Inosako *et al.*, 2020) [43].
5. **Cutting Orientation and Size:** The size and direction of cuttings have a big influence on how well they root. The ideal cutting size varies based on the species and cultivar of the plant; larger cuttings usually have more reserves of stored energy for root initiation (Druege *et al.*, 2019) [47]. Cutting direction also affects water and hormone intake, therefore the location and angle of the incision can have an impact on the results of rooting. Appropriate methods guarantee effective uptake of nutrients and water, which promotes strong root growth.

Physiological and Molecular Aspects

1. **Factors Influencing Adventitious Root Formation:** The complicated process of adventitious root production is impacted by a number of internal and external variables. In response to environmental stimuli,

hormone signaling is essential for initiating and directing root development. The cambial and pericycle tissues' cell proliferation and differentiation are stimulated by auxins, especially indole-3-acetic acid (IAA), which is a major regulator of adventitious roots. Auxins and other phytohormones, like ethylene and cytokinins, can work in concert or against each other to influence adventitious root development (Betti *et al.*, 2021) [31]. Moreover, environmental elements that affect root emergence and development include temperature, humidity, light, and substrate composition. Cutting rooting efficiency can be increased by adjusting these variables by physical therapy, the administration of exogenous hormones, or environmental management (Campbell *et al.*, 2021) [32].

2. **Origin of Adventitious Roots along the Stem:** Certain plant species and even distinct cultivars within the same species differ in the exact place along the stem where adventitious roots first appear. As axillary buds and leaf primordia are found near nodes, adventitious roots frequently originate in herbaceous plants. Meristematic cells in these nodes have the ability to dedifferentiate and start root primordia in response to hormone signals (Novikova *et al.*, 2018) [33]. Adventitious roots in woody plants can also emerge from internodal areas, especially in species where adventitious root development is highly prevalent. It might be easier for adventitious roots to separate from the vascular tissues if there are prepared vascular bundles and cambial activity in specific stem segments (Martins *et al.*, 2022) [34].
3. **Molecular Mechanisms of Adventitious Root Formation:** Genetic insights into adventitious root production regulation have been made possible by recent developments in molecular genetics. The processes of adventitious roots involve the mediation of auxin-responsive gene expression by transcription factors, including the ARF (Auxin Response Factor) and LBD (Lateral Organ Boundaries Domain) families (Neogy *et al.*, 2019) [35]. The arrangement of adventitious roots is controlled by auxin transporters, which include PIN (PIN-FORMED) proteins. These transporters control the directional flow of auxin within the stem. Furthermore, it has been shown that microRNAs and epigenetic changes regulate the expression of genes related to adventitious root growth. Gaining insight into the genetic networks that control adventitious root formation could be beneficial for improving tissue culture procedures and breeding crops with better rooting traits (Vielba *et al.*, 2020) [35].

Advantages of Hydro propagation over Conventional Propagation Method

Today, hydroponics is an established branch of agronomical science. Progress has been rapid and results obtained in various countries have proved it to be thoroughly practical and to have very definite advantages over conventional methods of agriculture/horticulture. The two chief merits of the soilless cultivation of plants are, first, much higher crop yields, and secondly, the fact that hydroponics can be used in places where ordinary agriculture or gardening is impossible (Koriesh *et al.*, 2020) [37]. Besides these, there are other advantages listed below.

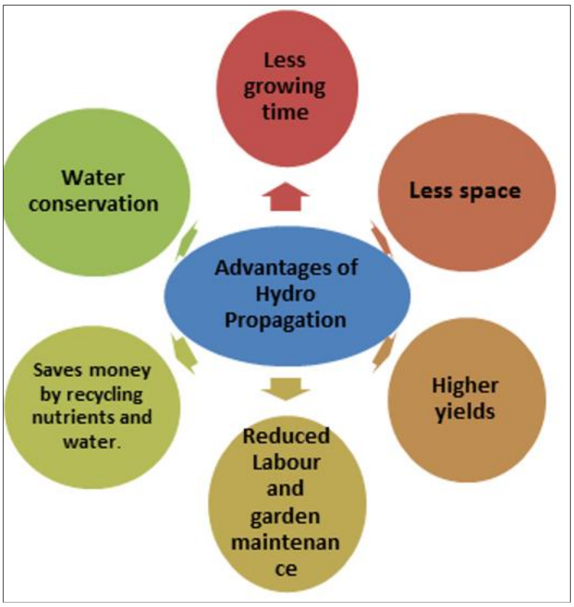

Fig 3: Advantages of Hydro propagation over conventional methods

Current Advancements in Hydro Propagation

For the cultivation of various crops, hydroponics is one of the most preferred methods in the future. It is expected that tomatoes, lettuce, and other leafy vegetables are produced more using hydroponic systems. In developing countries like Europe and Asia pacific, people opt for the use of hydroponic method for green-house crop cultivation for its excellent quality of crop yield (Gumisiriza *et al.*, 2022) [38]. In addition to tomatoes and peppers, crops like cucumber, cucurbits, and cantaloupe are successfully grown using this system. With quick urbanisation, increased population, and also the increase of community-sponsored programmes has paved the way for the cultivation of crops using hydroponics as the incidence of recollection of crops has played a significant role in the development of hydroponic industries globally. Aeroponics and hydroponics are developing technologies for agriculture, as in the case of expanding population and also by the decreased land resources. Using hydroponics systems, the demand for the growth of crops has been enlarged (Swain *et al.*, 2021) [39]. This advancement has shown to be more environmentally friendly wherein the need for human performance is limited.

Future Research in Hydro Propagation

The future of hydro propagation research holds promise for advancing sustainable and efficient methods for plant propagation, with a focus on addressing challenges and enhancing the technology's applicability across diverse horticultural contexts (Kabir *et al.*, 2023) [40]. Researchers are expected to delve deeper into understanding the molecular and physiological mechanisms governing root development in hydroponic environments. By unraveling the intricacies of how plants respond to water-based propagation systems, scientists can fine-tune nutrient formulations and environmental parameters to optimize root growth and overall plant health. Tailoring nutrient solutions and protocols for specific plant species can unlock the full potential of this technique across a broader spectrum of horticultural crops, including those with unique propagation challenges or economic importance. Collaborative efforts between horticulturists, agronomists, and biotechnologists will be crucial in designing hydro propagation systems that cater to the diverse needs of global agriculture (Nguyen *et al.*, 2023) [41].

In the future, hydro propagation research is also likely to explore the scalability of this technology for large-scale commercial production. Innovations in system design, automation, and cost-effective implementation could make hydro propagation more accessible to a wider range of growers, fostering its integration into mainstream horticultural practices (Pathak *et al.*, 2022) [42]. As environmental concerns and resource limitations continue to shape the future of agriculture, hydro propagation research holds significant potential in contributing to sustainable, efficient, and resilient plant propagation methods.

Conclusion

Hydro propagation presents exciting opportunities for the progress of horticulture and agriculture by using water to sustainably propagate and grow plants. In contrast to conventional soil-based approaches, this technique promotes faster and healthier root development because plants are rooted and grown in a water-based media. By improving nutrient intake and reducing the chance of soil-borne infections, the method supports sustainable farming techniques. Hydro propagation also makes it easier to precisely manage environmental parameters like pH, nutrient concentration, and water availability, which helps to optimize growing circumstances for different plant species. Because of its versatility, it can be used for a variety of purposes, including indoor and outdoor growing as well as large-scale commercial farming. A viable option for long-term plant multiplication and growth is hydroponics, which has advantages such as faster root formation, better fertiliser uptake, and water conservation. Using this method can make a big difference in reaching goals for agricultural sustainability and guaranteeing food security in the face of environmental difficulties.

References

1. Bhatta S, Savita. Cultivation of Underutilized Vegetables in a Hydroponic and Aeroponic System. In: Production Technology of Underutilized Vegetable Crops. Cham: Springer International Publishing; c2023. p. 355-368.
2. Rajaseger G, Chan KL, Tan KY, Ramasamy S, Khin MC, Amaladoss A, *et al*. Hydroponics: current trends in sustainable crop production. Bioinformation. 2023;19(9):925.
3. Singh SR, Rajan S. Vertical hydroponics: A future technology for urban horticulture. Indian Horticulture, 2022, 67(2).
4. Modu F, Adam A, Aliyu F, Mabu A, Musa M. A survey of smart hydroponic systems. Advances in Science, Technology and Engineering Systems Journal. 2020;5(1):233-248.
5. Singh B. New Systems of Vegetable Production: Protected Cultivation, Hydroponics, Aeroponics, Vertical, Organic, Microgreens. In: Vegetables for Nutrition and Entrepreneurship. Singapore: Springer Nature Singapore; c2023. p. 31-56.
6. Verma RC, Chaithanya G, Sachan P, Thilagam P, Bahadur R, Kumar N, *et al*. Exploring Hydroponics and the Associated Technologies for Use in Medium-and Small-scale Operations: A Review. International Journal of Environment and Climate Change. 2023;13(10):4474-4483.
7. Prabha L, Ekka A. A Review on Hydroponics: A Sustainable Approach for Plant Cultivation. Journal of Coastal Life Medicine. 2022;10:832-838.
8. Macwan J, Pandya D, Pandya H, Mankad A. Review on soilless method of cultivation: hydroponics. Int. J Recent Sci. Res. 2020;11:37122-37127.
9. Saroj NL, Singh S, Yadav S. Strawberry: A wonder crop suitable for Hydroponics. J Hort. 2021;8(2):10-35248.
10. Antony Samy ER. Assessing the effect of planting density on romaine lettuce growth and quality in a controlled hydroponic environment.
11. Palm HW, Knaus U, Kotzen B. Aquaponics nomenclature matters: It is about principles and technologies and not as much about coupling. Reviews in Aquaculture. 2024;16(1):473-490.
12. Ragaveena S, Shirly Edward A, Surendran U. Smart controlled environment agriculture methods: A holistic review. Reviews in Environmental Science and Bio/Technology. 2021;20(4):887-913.
13. Casey L, Freeman B, Francis K, Brychkova G, McKeown P, Spillane C, *et al*. Comparative environmental footprints of lettuce supplied by hydroponic controlled-environment agriculture and field-based supply chains. Journal of Cleaner Production. 2022;369:133214.
14. Gaikwad DJ, Maitra S. Hydroponics cultivation of crops. Protected cultivation and smart agriculture; c2020. p. 279-287.
15. Benko B, Uher SF, Radman S, Opačić N. Hydroponic Production Systems in Greenhouses. In: Climate Smart Greenhouses-Innovations and Impacts. Intech Open; c2023.
16. Mir MS, Naikoo NB, Kanth RH, Bahar FA, Bhat MA, Nazir A, *et al*. Vertical farming: The future of agriculture: A review. Pharma Innov. J. 2022;11(21):1175-1195.
17. Khan T, Singh B, Ahmad KA, Pai R. Extraction of coir fibers by different methods. In: Coir Fiber and its Composites. Woodhead Publishing; c2022. p. 19-42.
18. Mridha N, Ray DP, Singha A, Manjunatha BS, Biswas S, Saha B, *et al*. Prospects of Natural Fibre Crop Based Plant Growth Substrate in Soilless Crop Production System: A Review.
19. Suryawanshi YC. Hydroponic cultivation approaches to enhance the contents of the secondary metabolites in plants. In: Biotechnological approaches to enhance plant secondary metabolites. CRC Press; c2021. p. 71-88.
20. Kumar P, Dey SR. Hydroponics Phytoremediation: An Overview. In: Hydroponics and Environmental Bioremediation: Wastewater Treatment; c2024. p. 361-396.
21. Kumari S, Pradhan P, Yadav R, Kumar S. Hydroponic techniques: A soilless cultivation in agriculture. Journal of pharmacognosy and phytochemistry. 2018;7(1S):1886-1891.
22. Opdahl LJ. Lactate-Bound Metals: A Sustainable Alternative to Inorganic Micronutrient Fertilizers. Washington State University; c2023.
23. Sambo P, Nicoletto C, Giro A, Pii Y, Valentinuzzi F, Mimmo T, *et al*. Hydroponic solutions for soilless

production systems: issues and opportunities in a smart agriculture perspective. Frontiers in plant science. 2019;10:465257.
24. Hosseini H, Mozafari V, Roosta HR, Shirani H, van de Vlasakker PC, Farhangi M, *et al*. Nutrient use in vertical farming: Optimal electrical conductivity of nutrient solution for growth of lettuce and basil in hydroponic cultivation. Horticulturae. 2021;7(9):283.
25. Sharma N, Acharya S, Kumar K, Singh N, Chaurasia OP. Hydroponics as an advanced technique for vegetable production: An overview. Journal of Soil and Water Conservation. 2018;17(4):364-371.
26. Atherton HR, Li P. Hydroponic cultivation of medicinal plants - plant organs and hydroponic systems: Techniques and trends. Horticulturae. 2023;9(3):349.
27. Rather AMUD, Hajam MA, Bhat MSA, Malik MI. Horticulture: Principles and practices. Academic Guru Publishing House; c2023.
28. Baras T. DIY hydroponic gardens: How to design and build an inexpensive system for growing plants in water. Cool Springs Press; c2018.
29. Ur-Rahman I, Sher H, Bussmann RW. Reference guide on high value medicinal and aromatic plants–sustainable management and cultivation practices. University of Swat, Pakistan; c2019.
30. Thakur P, Wadhwa H, Kaushal S. Nutrient Dynamics for Hydroponic Production System. International Journal of Plant & Soil Science. 2023;35(21):982-993.
31. Betti C, Della Rovere F, Piacentini D, Fattorini L, Falasca G, Altamura MM, *et al*. Jasmonates, ethylene and brassinosteroids control adventitious and lateral rooting as stress avoidance responses to heavy metals and metalloids. Biomolecules. 2021;11(1):77.
32. Campbell SM, Anderson SL, Brym ZT, Pearson BJ. Evaluation of substrate composition and exogenous hormone application on vegetative propagule rooting success of essential oil hemp (*Cannabis sativa* L.). Plos. one. 2021;16(7):e0249160.
33. Novikova TI, Zaytseva YG. TDZ-induced morphogenesis pathways in woody plant culture. In: Thidiazuron: from urea derivative to plant growth regulator; c2018. p. 61-94.
34. Martins M, Gomes AFG, da Silva ÉM, da Silva DF, Peche PM, Magalhães TA, *et al*. Effects of anatomical structures and phenolic compound deposition on the rooting of olive cuttings. Rhizosphere. 2022;23:100557.
35. Neogy A, Garg T, Kumar A, Dwivedi AK, Singh H, Singh U, *et al*. Genome-wide transcript profiling reveals an auxin-responsive transcription factor, OsAP2/ERF-40, promoting rice adventitious root development. Plant and Cell Physiology. 2019;60(10):2343-2355.
36. Vielba JM, Vidal N, José MCS, Rico S, Sánchez C. Recent advances in adventitious root formation in Chestnut. Plants. 2020;9(11):1543.
37. Koriesh EM, Abo El-Soud IH. Medicinal plants in hydroponic system under water-deficit conditions - A way to save water. In: Technological and Modern Irrigation Environment in Egypt: Best Management Practices & Evaluation; c2020. p. 131-153.
38. Gumisiriza MS, Ndakidemi P, Nalunga A, Mbega ER. Building sustainable societies through vertical soilless farming: A cost-effectiveness analysis on a small-scale non-greenhouse hydroponic system. Sustainable Cities and Society. 2022;83:103923.
39. Swain A, Chatterjee S, Vishwanath M. Hydroponics in vegetable crops: A review. The Pharma Innovation Journal. 2021;10(6):629-634.
40. Kabir MSN, Reza MN, Chowdhury M, Ali M, Samsuzzaman, Ali MR, *et al*. Technological trends and engineering issues on vertical farms: a review. Horticulturae. 2023;9(11):1229.
41. Nguyen MTP, Knowling M, Tran NN, Burgess A, Fisk I, Watt M, *et al*. Space farming: Horticulture systems on spacecraft and outlook to planetary space exploration. Plant Physiology and Biochemistry. 2023;194:708-721.
42. Pathak H, Mishra JP, Mohapatra T. Indian agriculture after independence. Indian Council of Agricultural Research, New Delhi. 2022;110(001):426.
43. Chen H, Lei Y, Sun J, Ma M, Deng P, Quan JE, *et al*. Effects of Different Growth Hormones on Rooting and Endogenous Hormone Content of Two Morus alba L. Cuttings. Horticulturae. 2023;9(5):552.
44. Wang X, Liu L, Xie J, Wang X, Gu H, Li J, *et al*. Research Status and Prospects on the Construction Methods of Temperature and Humidity Environmental Models in Arbor Tree Cuttage. Agronomy. 2023;14(1):58.
45. Inosako K, Diéguez ET, Saito T, Vega GL. 2-3 Technical Manual for Open Culture Using Aquaponics Wastewater 2-3-1 Technical Manual for Water and Soil Management of Open Culture. In: Technical Manual of Aquaponics Combined with Open Culture Adapting to Arid Regions; c2020. p. 67.
46. Sipos L, Boros IF, Csambalik L, Székely G, Jung A, Balázs L, *et al*. Horticultural lighting system optimalization: A review. Scientia Horticulturae. 2020;273:109631.
47. Druege U, Hilo A, Pérez-Pérez JM, Klopotek Y, Acosta M, Shahinnia F, *et al*. Molecular and physiological control of adventitious rooting in cuttings: phytohormone action meets resource allocation. Annals of botany. 2019;123(6):929-949.