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Hydroponics: The Potential to Enhance Sustainable Food Production in Non-Arable Areas

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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

Hydroponics, a revolutionary soil-less cultivation method, has garnered significant attention in recent years for its potential to redefine modern agriculture. This review paper delves into the fundamental aspects of hydroponics, ranging from its inception to the cutting-edge developments that promise to reshape the future of food production. This provides an in-depth exploration of the basic principles of hydroponics, Through detailed discussions, we investigate the diversity of methods, from nutrient film technique (NFT) and deep water culture (DWC). A nuanced understanding of each system's mechanics, advantages, and limitations serves as a guide for hydroponic enthusiasts, researchers, and prospective farmers. Nutrient management, the lifeblood of hydroponics, is another focal point. We delve into the precise formulation, monitoring, and delivery of essential nutrients to optimize plant growth and yield. This section offers insights into pH and EC control, nutrient solutions, and the art of maintaining nutrient balance, all of which are crucial for successful hydroponic cultivation. The future of hydroponics beckons with boundless possibilities. The paper emphasizes the need for sustainable Eco-friendly, and efficient methods to feed a growing global population, making

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hydroponics a key contender. In a world with diminishing arable land and climate change challenges, hydroponics stands as a beacon of hope, promising to revolutionize agriculture and secure the future of food production. This review paper offers a comprehensive road map for anyone interested in understanding the basics of hydroponics, exploring its myriad systems, mastering nutrient management, and envisioning a greener future through hydroponic agriculture.

Keywords: Agriculture; conservation; farming; hydroponics; indoor; soil-less.

1. INTRODUCTION

The basis of hydroponics is plant growth without soil in which nutrients are directly delivered to the water in which they are grown. A balanced mixture of nutrients is dissolved in the water for Healthy plant growth without stress. One of the most significant advantages of hydroponic farming is the ability to grow crops in near optimal conditions using Controlled Environment Agriculture. Because of rising population and growing industrializing and urbanization, the land available for cultivation is shrinking at an alarming rate. Feeding such a vast population will become increasingly challenging in the coming years so Hydroponics is the new technique is introducing in the agriculture sector. The agricultural industry needs to solve the problems of food insecurity and provide high-quality and plentiful food. The primary benefits of hydroponics include a decrease in the use of chemical pesticides, fertilizers, and other fertilizers, as well as soil-less cultivation. Additionally, the use of land is more efficient, resulting in improved land surface area, reduced consumption, and better water management [1,2]. These benefits help to reduce the environmental impact of hydroponics and make it an attractive crop cultivation option in a controlled environment, although the high operational costs may limit its appeal [3]. Hydroponics is a great way to make food, even though it's not the same as soil cultivation [4]. It will delve into the techniques that underpin hydroponic systems, examine their environmental and resource efficiency benefits. The hydroponic cultivation approach is flexible and there are potential enhancements that can be achieved through the implementation of simplified models; a case in point is the proposal made by Bradley and Marulanda (2000). Their model proposed a simplified hydroponic cultivation model that required 25% of the land area used for land cultivation to be used for immediate hunger alleviation. Sharma et al. [5] By delving into the existing body of knowledge on hydroponics, this literature review aims to contribute to a deeper understanding of its potential role in shaping the future of sustainable food production, fostering resilience in agriculture, and addressing the evolving needs of our world.

2. SIGNIFICANCE OF HYDROPONICS

By providing a variety of benefits to areas where there is no perfect soil for growing crops, Hydroponics has an even greater impact on revolutionizing agriculture. By installing hydroponic units on land not used for farming, it can help to maximize its use. It creates opportunities for local people to create a source of income through the adoption of hydroponic facilities in areas where crops are not cultivated. The crops grown in hydroponics are not dependent on external environment a farmer can grow different crops in a limited space [6-8]. It is more effective to combine hydroponics with Aquaponics. Fish excreta will function as a source of nutrients for the plant, promoting healthy growth. Because of their superior development and intake of nutrients capabilities, lettuce and spinach are the most desirable species to grow in aquaculture and hydroponics systems.

Efficacy of Hydroponics over traditional Agriculture:

(a) Water Conservation: The utilization of water is a fundamental factor in the successful cultivation and production of crops. Hydroponics systems utilize water more efficiently than open fields. Furthermore, the water consumption in soil farming is significantly greater than that of Hydroponics. When water is applied to soil, most of the water is lost due to leaching, as it is not absorbed by the plant's roots. Conversely, in Hydroponics systems, the plant is grown directly in the nutrient solution, and water continues to flow through the pipes, meaning that the water is not wasted and can be recycled and reused for other purposes [9]. This cultivation offers a huge potential approach that is indisputable and ranges of advantages to environmental benefits because of its higher efficiency in using nutritional and water resources [10,11].

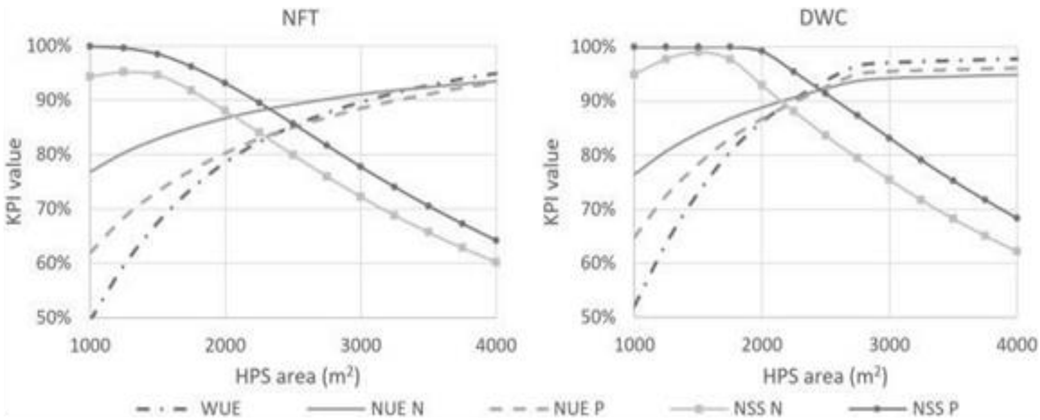

Fig. 1. Shows the water and nutrient use efficiency of Nutrient Film Technology (NFT), & Deep Water Culture (DWC) System
Source: [12]

(b) Nutrient Use Efficiency: The Nutrient use efficiency of hydroponics system is much greater than the Soil Farming. Controlling nutritional solutions and taking daily measurements of liquid nutrients is essential in order to prevent excessive salinization, as well as controlling microbial diseases and pests to prevent any loss of production [13].

Types of Hydroponic Systems:

1. Nutrient film technique: NFT is a hydroponic technique in which plants stand in a shallow stream of water containing all of the dissolved nutrients necessary for the growth of plants. This water flows between growing tanks holding plant roots. The roots of plants retrieve nutrients, and because the stream is shallow and the roots are floating in the air, the roots may also absorb oxygen [15]. The drawbacks of an NFT system are that it necessitates full coverage of all the piping systems through which the nutrient solution passes. Algae growth becomes dominant even with minimal exposure to semi-open conditions [16]. The NFT hydroponic technique was developed to improve agricultural production By the use of technology [17]. This method involves the continuous flow of nutrient water from a reservoir into the planting medium, which is then filtered through a gutter and distributed through the roots of the plants.

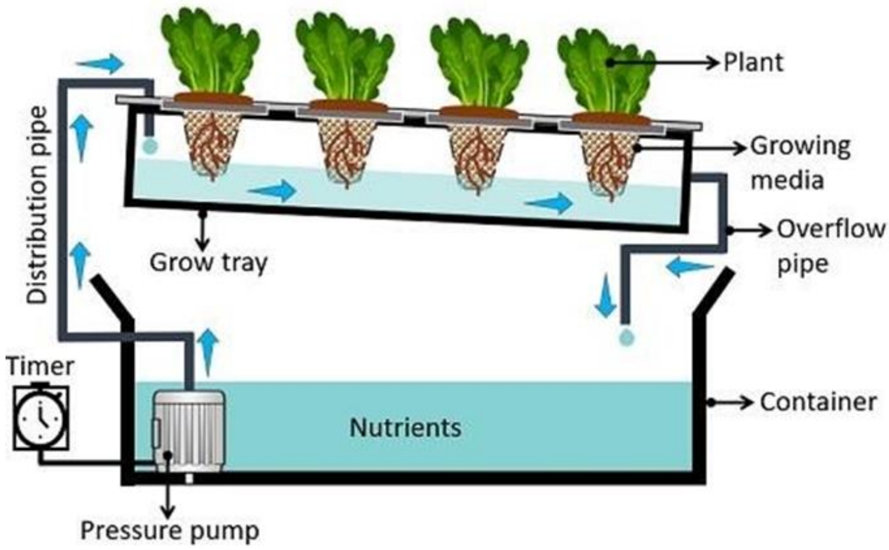

Fig. 2. Nutrient film technique.
Source [18]

Table 1. Nutrient use Efficiency, in closed Hydroponics system

Nutrients	Saving %
Phosphorus (P)	31.4%
Potassium (K)	52.1%
Calcium (Ca)	63.5%
Magnesium (Mg)	47.9%
Sulphur (S), Sulphate (SO4)	49.4%
Chlorine (Cl)	51.9%
Iron (Fe)	50.9%
Zinc (Zn)	47.9%
Manganese (Mn)	24.6%
Copper (Cu)	53.3 %
Boron (B)	47.2 %
Ammonium (NH4+) NO3 -	42.1%

Source Komosa et al. [14]

2. Dynamic root floating technique: The Taichung District Agricultural Improvement Station in Taiwan created the DRFT in 1986. The fertilizer solution is pushed through one end and circulated in the channels before being collected and returned to the tank reservoir. Instead of the NFT's continuously flowing nutrient solution system the water pump is constantly switched on and off to change the depth of the water. Alternatively, the pump can run continuously and a drainage system can be fitted to change the depth. The concave panels underneath the floating boards are a characteristic of the DRFT. This additional space permits roots known as aero roots to develop above the nutrient solution and so obtain more oxygen [15]. In a DRFT, the air space between the sheet that holds the plants in place and the nutrient solution is left open. The roots that take up the air above the nutrient solution are called "oxygen roots" and their main job is to oxygenate the plants. DRFTs don't use active aeration like hydroponic systems do, so they don't need as much electricity from the air pump and that means lower costs [19,20].

The DRFT resulted in a 78% decrease in electrical power consumption in comparison to the RAFT plant culture and a 10.3% decrease in total electrical power consumption for the system [21].

3. Deep water culture technique: The deep-water culture system is the easiest system to use. With this technique, known as Deep Water Culture One, you normally develop it using a reservoir that has a decent water holding capacity. Your fertilizer solution will be less volatile if you add additional water. A plant's roots remain suspended in a water and fertilizer solution that is well oxygenated in a D W C system [23]. The hydroponically cultivated lettuce crop is the most abundant in the world, accounting for approximately 99% of the hydroponic leaf area, and is priced approximately 40% higher than conventional lettuce in the DWC [13].

The DWC system, considered to be one of the most significant hydroponic systems, demonstrated a clear and efficient impact on vegetation growth, with the highest results for vegetative growth components for both lettuce varieties when compared to terrestrial farming systems [24].

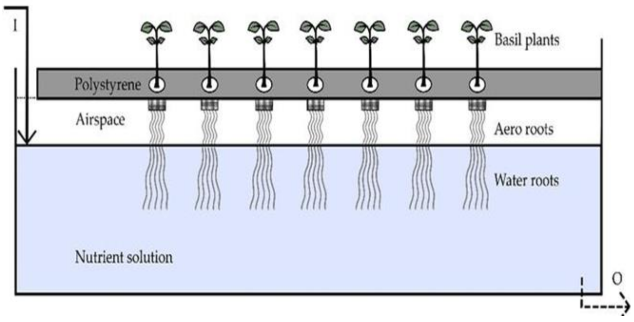

Fig. 3. Dynamic Root Floating Technique
Source Pasch et al. [22]

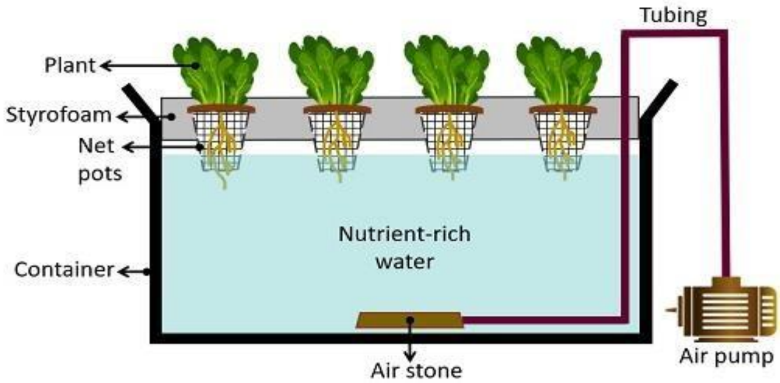

Fig. 4. Deep Water Culture Technique
Source [18]

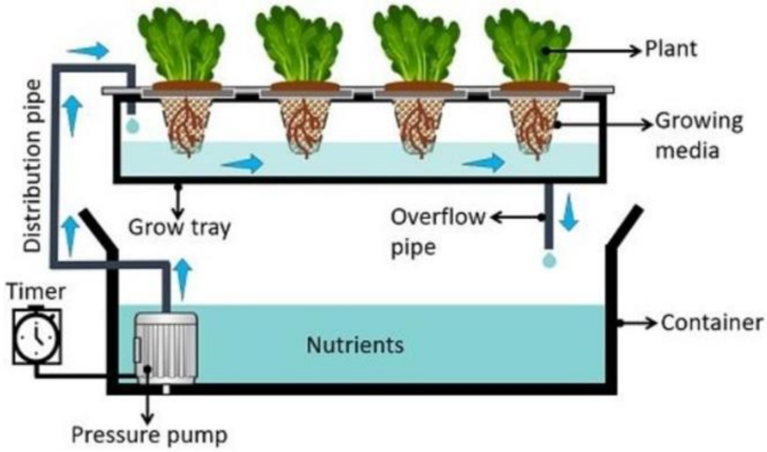

Fig. 5. Ebb and Flow Method
Source [18]

4. Ebb and flow method: The system consists of a grow tray and a reservoir filled with a nutrient solution. A pump is used to periodically flood the grow tray with the Nutrient solution which then drains away [25]. Fertilizer and water solutions are diluted gently into pro-trays; frequently, the water pump has a fixed timer that will rapidly fill growing beds at predetermined intervals.

The solution of fertilizer and water moves over the outlet and returns back into the tank when it reaches a targeted level. It releases the necessary oxygen for the growth of roots and plants. which results in oxygen and nutrients being supplied to the plants on an ongoing basis by flooding and drainage that promote healthy development [26].

The watering times are typically 20 to 30 min in most commercial ebb and flow systems, the substrate is capable of taking up at least 90% of the effective water holding capacity [27]. This is the first commercial hydroponics system to operate on the flood and drain principle. The system consists of a grow tray and a reservoir filled with a nutrient solution. A pump is used to periodically flood the grow tray with the Nutrient solution which then drains away [25]. Although a considerable amount of research has been conducted on various aspects of ebb and flow sub-irrigation systems, [28]. Greenhouse irrigation systems are often praised for their use of Ebb and Flow Sub irrigation Systems due to their advantages in terms of energy conservation compared to traditional irrigation techniques [29].

Nutrient Management in Hydroponics:

Managing nutrient solutions is crucial to ensuring adequate plant nutrition. To guarantee healthy plants, fertilizer solutions must be blended with a range of nutritional salts.

pH:

Another common parameter in hydroponic cultivation is pH. pH is a measure of the relative.

Concentration of hydrogen ions (H+) to hydroxide ions (OH^{-}). The plant growth is highly affected by the pH value of Nutrient Solution. Because plants can only ingest specific elements within a specified pH range, the pH of the root zone effectively dictates what nutrients are accessible to the plant. It states that the buffer agents are found very effective in maintaining the pH of the nutrient solution. The optimal pH range has been found **5-7** as this is the region where maximum total ion absorption occurs [18]. This study looked at how an automated system was used to control the pH and concentration of nutrients in lettuce plants. It was used to make hydroponic lettuce [30].

Higher pH values in aquaponic solution may limit the uptake efficiency of certain essential elements, like iron, which is already limited in aquaponic solution [31]. In order for the plants to be able to take all nutrients they need; it is necessary to maintain a pH values [32]. Any disturbance in the magnitude of Nutrient Uptake by plants in relation to the balance of anion over cation will affect the pH of Nutrient solution [33]. It is generally not advisable to use a pH lower than 5.5 When creating a hydroponic nutritional solution, certain nutrient deficiencies and inhibition of growth are often encountered outside of the acceptable range [11].

Fig. 6. pH Buffer Solutions
Source Hamza et al. [24]

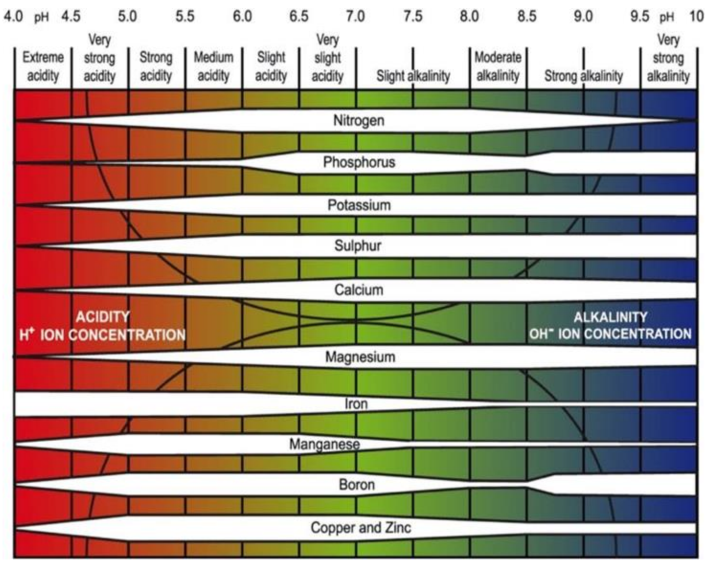

Fig. 7. Influence of soil pH on the availability of nutrient elements. The width of the white shaded areas indicates the relative nutrient availability to the plant root at a given pH value
Source Truog [34]

Electrical Conductivity:

One of those most critical factors involves maintaining the nutrition solution at the correct range of pH & EC values on a constant basis. Continuous evaluation and modification of these factors, often using pH and EC meters, ensures that the crops receive the necessary nutrients without deficits or toxicity [35]. Electrical Conductivity (EC) tells us how strong the mineral salts in the nutrient solution when they dissolved in water. The EC is important to find out the actual concentration of the salts in the Nutrient solution. It's used to monitor the use of fertilizers.

The Electrical Conductivity of the nutrient solution is Maintained between **2.6-3.4 mS cm-1** [33]. Higher levels of EC may Hinders nutrient uptake due to an increase in osmotic pressures, while lower EC levels may have a detrimental effect on plant health and yield, as demonstrated by the work of [36].

Why EC is Important: Monitoring the EC will give you a better idea of what is really going on in your nutritional feed. There are three situations arises with EC one time EC remains Unchanged and one time EC goes Down and sometime EC will Higher. These situations will totally dependent on the plant nutrient uptake capacity.

When EC remain unchanged (Constant): This situation indicate that the plant nutrient uptake is equal to the plant water uptake.

When EC goes Down: This Indicates that the plant Nutrient uptake is more than the water uptake.

When EC goes up: This Indicates that the Plant water uptake is more than the nutrient uptake. To manage this situation, you need to dilute the solution [37].

Crop Selection and Growth in Hydroponic System:

Table 2. List of crops that can be grown on commercial level using soil-less culture.

Type of Crops	Crops
Condiments	*Ocimum basilicum (Sweet basil), Petroselinum crispum* (Parsley), *Origanum vulgare* (Oregano) *Mentha spicata* (Mint)
Leafy vegetables	*Ipomoea aquatica (Kang Kong)* *Lactuca sativa* (Lettuce), *Brassica rapa subsp. chinensis* (Pak choi)
Medicinal crops	*Aloe vera* (Indian Aloe), *Solenostemon scutellarioides* (Coleus)
Vegetables	*Phaseolus vulgaris (Green bean), Lycopersicon esculentum* (Tomato), *Solanum melongena* (Brinjal), *Beta vulgaris* (Beet), *Brassica oleracea var. botrytis* (Cauliflower), *Psophocarpus tetragonolobus* (Winged bean), *Capsicum frutescens (Chilli),* *Capsicum annum* (Bell pepper), *Cucumis sativus* (Cucumbers), *Raphanus sativus* (Radish), *Allium cepa* (Onion) *Brassica oleracea var. capitata* (Cabbage), *Cucumis melo* (Melons),
Fruits	*Fragaria ananassa* (Strawberry)
Fodder crops	*Axonopus compressus (Carpet grass) Sorghum bicolor* (Sorghum), *Hordeum vulgare* (Barley), *Cynodon dactylon* (Bermuda grass), *Medicago sativa* (Alphalfa),
Cereals	*Oryza sativa* (Rice), *Zea mays* (Maize)
Flower / Ornamental crops	*Rosa berberifolia (Roses),* *Tagetes patula* (Marigold), *Chrysanthemum indicum (Chrysanthemum)* *Dianthus caryophyllus* (Carnations)

Souce Singh and Singh [15]

Table 3. Elements with maximum level of allowable in water for Hydroponics use:

Elements	Concentration, mg/L (ppm)
Boron (B)	<1
Calcium (Ca)	<200
Magnesium (Mg)	<60
Chloride (Cl)	<70
Zinc (Zn)	<1
Sodium (Na)	<180
Carbonates (CO_3)	<60

Source Jones [40]

Irrigation Water Management in Hydroponics:

The primary rationale for concentrating our efforts on hydroponics is due to the increasing evidence that hydroponics is more sustainable in economic terms than traditional agriculture [38]. All hydroponic growth techniques need a substantial quantity of clean water. The best home water supplies or agricultural water usually contain compounds and components that can impact either positively or negatively on Plant growth. When it comes to hydroponic businesses, fertilizing and irrigation are two processes that go hand-in-hand. Basically, fertilizers are dissolved into the irrigation water, while irrigation water is made up of inorganic nutrients [39]. The growth of plants in hydroponic systems is contingent upon the availability of water, nutrients, and oxygen. The supply of water and nutrients can be regulated through the implementation of an effective irrigation system and the adjustment of the irrigation frequency. Similarly, the distribution of oxygen, carbon dioxide, and ethylene within the root zone has been demonstrated to be affected by medium and irrigation growth [35]. Generally, the primary purpose of irrigation is to ensure a sufficient amount of readily accessible free water (high water potential), to supply essential minerals to the plants, and to enhance oxygen levels in the root zone [39] The open system was found to be the most water-efficient of the three systems tested, namely field culture, a closed system, and an open hydroponic substrate system [33].

Technological Advancements and Future Prospects:

Hydroponics, has witnessed remarkable technological advancements in recent years. This environmentally friendly form of food production is expected to be the preferred agricultural technique in the future to meet the growing demands of the world's population [12]. One of the most recent innovations in the field of hydroponic farming is automated growth system. Sensors in this system continually track and update environmental conditions, Hydroponics may be an essential element in the future of exploration in outer space, as no soil has been identified that can sustain life in outer space and the transportation of soil through space shuttles appears to be impracticable [41,42] Producer are able to monitor and adapt the environment for plant Development using cultivation technologies and eliminating the need of human involvement. Furthermore, smart nutrient delivers the appropriate balance of nutrients and organic compounds to encourage healthy development without sacrificing performance to assist with crop management, these equipment's may be managed remotely and connected with mobile application [43]. LEDs offer several unique advantages over traditional lighting systems since they are the most energy-efficient and environmentally friendly lighting technologies currently available [44]. The advancement of LED technology, with its capacity to pick particular wavelengths, allows for the invention of personalized light compositions for manipulating the structure of plants. Plant quality (energy distribution among various wavelength) is frequently a combination of particular plant properties such as branching, compact size, roots, and the expansion of leaves, all of which are substantially impacted by the spectral makeup of LED light [45]. The low heat output means the light source can be positioned near the canopy, allowing for a consistent spectrum distribution while avoiding tissue damage caused by photo stress [46]. The careful selection of components of the light spectrum by using LED lighting technology can significantly improve the quality-related properties/characteristics of ornamental products by influencing several physiological and metabolic processes, such as flowering, branching, rooting, pigment biosynthesis, and vase life [47].

3. CONCLUSION

Hydroponics has the promising approach to agriculture for sustainable food production in urban areas. The initial investment required to establish a hydroponic system can also be substantial, and the ongoing upkeep of the system can also be a challenge. However more research is needed to be done in Hydroponics to completely understand the potential of hydroponics in urban areas and make it cost effective so that the cost of establishment is not become the barrier for small farmers. So, it will become affordable and accessible to small scale farmers. Hydroponics may be an essential element in the future of exploration in outer space, as no soil has been identified that can sustain life in outer space and the transportation of soil through space shuttles appears to be impracticable.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Christie E. Water and nutrient reuse within closed hydroponic systems; 2014.
2. Frick J, amp Mitchell CA. Stabilization of pH in solid-matrix hydroponic systems. Hort Science. 1993;28(10):981-984.
3. Jan S, Rashid Z, Ahngar TA, Iqbal S, Naikoo MA, Majeed S, .amp NazirI. Hydroponics–A review. International Journal of Current Microbiology and Applied Sciences. 2020;9(8):1779-1787.
4. Gwynn-Jones D, Dunne H, Donnison I, Robson P, Sanfratello GM, Schlarb-Ridley B, amp Convey P. Can the optimisation of pop-up agriculture in remote communities help feed the world?. Global Food Security. 2018;18:35-43.
5. Bradley P, amp Marulanda C. Simplified hydroponics to reduce global hunger. In World Congress on Soilless Culture: Agriculture in the Coming Millennium. 2000 May;554:289-296.
6. Jansen L, amp Keesman KJ. Exploration of efficient water, energy and nutrient use in aquaponics systems in northern latitudes. Cleaner and Circular Bioeconomy. 2022;2:100012.
7. Resh HM. Hydroponic food production: a definitive guidebook for the advanced home gardener and the commercial hydroponic grower. CRC press; 2022.
8. Singh H, Dunn B. Electrical conductivity and pH guide for hydroponics. Oklahoma Cooperative Extension Service; 2016.
9. Sharma N, Acharya S, Kumar K, Singh N, amp Chaurasia OP. Hydroponics as an advanced technique for vegetable production: An overview. Journal of Soil and Water Conservation. 2018;17(4):364-371.
10. Goddek S, Joyce A, Kotzen B, amp Burnell GM. Aquaponics food production systems: combined aquaculture and hydroponic production technologies for the future Springer Nature. 2019;619.
11. Sambo P, Nicoletto C, Giro A, Pii Y, Valentinuzzi F, Mimmo T, amp Cesco S. Hydroponic solutions for soilless production systems: Issues and opportunities in a smart agriculture perspective. Frontiers in plant science. 1020;19:923.
12. Technological Advancements Driving the Way for Hydroponics Farming | Industry Outlook. (n.d.). Avauilable:https://www.theindustryoutlook.com/services-and-consulting/panorama/technological-advancements- driving-the-way-for-hydroponics-farming-nwid-2817.
13. Lages Barbosa G, Almeida Gadelha FD, Kublik N, Proctor A, Reichelm L, Weissinger E, amp Halden RU. Comparison of land, water, and energy requirements of lettuce grown using hydroponic vs. conventional agricultural methods. International journal of environmental research and public health. 2015;12(6):6879-6891.
14. Komosa A, Piróg J, Weber Z, amp, Markiewicz B. Comparison of yield, nutrient solution changes and nutritional status of greenhouse tomato grown in recirculating and non-recirculating nutrient solution systems. Journal of Plant Nutrition. 2011;34(10):1473-1488.
15. Singh S, Singh BS. Hydroponics–A technique for cultivation of vegetables and medicinal plants‖. In Proceedings of 4th Global conference on Horticulture for Food, Nutrition and Livelihood Options. Bhubaneshwar, Odisha, India. 2012;220.
16. Mohammed SB, amp Sookoo R. Nutrient film technique for commercial production. Agricultural Science Research Journal. 2016;6(11):269-274.

17. Alipio MI, Cruz AEMD, Doria JDA, amp; Fruto RMS. On the design of Nutrient Film Technique hydroponics farm for smart agriculture. Engineering in Agriculture, Environment and Food. 2019;12(3):315-324.
18. 6 Different types of hydroponics (and their pros and cons!) | Plants Heaven. Plants Heaven; 2023. Available:https://plantsheaven.com/different-types-of-hydroponics/
19. Kao TC, Hsiang T, amp, Changhua ROC. The dynamic root floating hydroponic technique: year-round production of vegetables in roc on Taiwan. Taipei, Taiwan: ASPAC Food & amp; Fertilizer Technology Center; 1991.
20. Kratky BA. A suspended net-pot, non-circulating hydroponic method for commercial production of leafy, romaine, and semi-head lettuce. Veg Crops. 2010;1:1-19.
21. Silva L, Gasca-Leyva E, Escalante E, Fitzsimmons KM, amp Lozano DV. Evaluation of biomass yield and water treatment in two aquaponic systems using the dynamic root floating technique (DRF). Sustainability. 2015;7(11):15384-15399.
22. Pasch J, Ratajczak B, Appelbaum S, Palm HW, amp, Knaus U. Growth of basil (*Ocimum basilicum*) in DRF, raft, and grow pipes with effluents of African catfish (*Clarias gariepinus*) in decoupled aquaponics. Agri Engineering. 2021;3(1):92-109.
23. Espiritu K. deep water culture (DWC): What Is It and How To Get Started. Epic Gardening; 2014. Available:https://www.epicgardening.com/deep-water-culture-get-started/
24. Hamza A, Abdelraouf RE, Helmy YI, amp El-Sawy SMM. Using deep water culture as one of the important hydroponic systems for saving water, mineral fertilizers and improving the productivity of lettuce crop. Int. J. Health Sci. 2022;6:2311-2331.
25. Nielsen CJ. Ferrin DM, amp Stanghellini ME. Efficacy of biosurfactants in the management of Phytophthora capsici on pepper in recirculating hydroponic systems. Canadian Journal of Plant Pathology. 2006;28(3):450-460.
26. N. What Is Ebb And Flow Hydroponics? - No Soil Solutions. No Soil Solutions; 2014, August 13. Available:https://www.nosoilsolutions.com/ebb-flow-hydroponics/
27. Elliott GC. Imbibition of water by rockwool-peat container media amended with hydrophilic gel or wetting agent. Journal of the American Society for Horticultural Science. 1992;117(5):757-761.
28. Ferrarezi RS, Dove SK, amp van Iersel MW. An automated system for monitoring soil moisture and controlling irrigation using low-cost open-source microcontrollers. HortTechnology. 2015;25(1):110-118.
29. Jani AD, Meadows TD, Eckman MA, amp Ferrarezi RS. Automated ebb-and-flows ubirrigation conserves water and enhances citrus liner growth compared to capillary mat and overhead irrigation methods. Agricultural Water Management. 2021;246:106711.
30. Domingues DS, Takahashi HW, Camara CA, amp; Nixdorf SL. Automated system developed to control pH and concentration of nutrient solution evaluated in hydroponic lettuce production. Computers and Electronics in Agriculture. 2012;84:53-61.
31. Alam SM. Effects of solution pH on the growth and chemical composition of rice plants. Journal of Plant Nutrition. 1981;4(3):247-260.
32. Mayavan RRS, Jeganath R, amp Chamundeeswari V. Automated hydroponic system for deep water culture to grow tomato using atmega328. In Proceedings of Technoarete International Conference. Chennai, India; 2017.
33. Lizarraga A, Boesveld H, Huibers F, amp Robles C. Evaluating irrigation scheduling of hydroponic tomato in Navarra, Spain. Irrigation and drainage. 2003;52(2):177-188.
34. Truog EMIL. Soil reaction influence on availability of plant nutrients. Soil Science Society of America Journal. 1947;11(C):305-308.
35. Schwarz M. Soilless culture management. Springer Science & Business Media. 2012;24.
36. Samarakoon UC, Weerasinghe PA, amp Weerakkody WAP. Effect of electrical conductivity [EC] of the nutrient solution on nutrient uptake, growth and yield of leaf lettuce (*Lactuca sativa* L.) in stationary culture. Tropical Agricultural Research. 2006;18:13.
37. Why EC Is Important In Hydroponics. What's on the Grow; 2017. Available:https://hollandhorticulture.co.uk/news/why-ec-is-important-in-hydroponics/

38. Treftz C, amp Omaye ST. Hydroponics: Potential for augmenting sustainable food production in non-arable regions. Nutrition & Food Science. 2016;46(5):672-684.
39. Mavrogianopoulos GN. Irrigation dose according to substrate characteristics, in hydroponic systems. Open Agriculture. 2016;1(1):1-6.
40. Jones Jr JB. Complete guide for growing plants hydroponically. CRC Press; 2014.
41. Bhattacharya N. Hydroponics: Producing plants In-vitro on artificial support medium. Int. J. Sci. Eng. Res. 2017;8:224-229.
42. Sardare MD, amp Admane SV. A review on plant without soil- hydroponics. International Journal of Research in Engineering and Technology. 2013;2(3):299-304.
43. P. A Closer Look At The Latest Technologies In Hydroponics - Hydroponic Way. Hydroponic Way; 2023. Available:https://hydroponicway.com/latest-technologies-in-hydroponics
44. Bantis F, Smirnakou S, Ouzounis T, Koukounaras A, Ntagkas N, amp Radoglou K. Current status and recent achievements in the field of horticulture with the use of light-emitting diodes (LEDs). Scientia horticulturae. 2018;235:437-451.
45. Paradiso R, amp Proietti S. Light-quality manipulation to control plant growth and photomorphogenesis in greenhouse horticulture: The state of the art and the opportunities of modern LED systems. Journal of Plant Growth Regulation. 2022;41(2):742-780.
46. Morrow RC. LED lighting in horticulture. Hort Science. 2008;43(7):1947-1950.
47. Trivellini A, Toscano S, Romano D, amp Ferrante A. LED lighting to produce high-quality ornamental plants. Plants. 2023; 12(8):1667.

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