

A comprehensive review on Soilless Cultivation for Sustainable Agriculture

ABSTRACT

With the growing challenges of food security and environmental degradation, there is an increasing need for sustainable agricultural practices. Soilless cultivation techniques offer a promising solution by minimizing land and water use while maximizing crop yield and quality. This review examines the potential of soilless cultivation methods in promoting sustainable agriculture. The purpose of this review is to evaluate the effectiveness of soilless cultivation techniques in sustainable agriculture. It aims to analyze the various methods used, their advantages and limitations, and their contributions to environmental sustainability and food security. A comprehensive literature review was conducted to gather information on soilless cultivation techniques, including hydroponics, aeroponics, and aquaponics. Relevant studies and reports were analyzed to assess the performance of these methods in terms of resource efficiency, crop productivity, and environmental impact. The review found that soilless cultivation techniques offer significant advantages over traditional soil-based farming, including higher crop yields, efficient water and nutrient use, and reduced environmental footprint. Hydroponic systems, in particular, have been widely adopted and have shown promising results in various crops. Additionally, soilless cultivation methods can be tailored to different environmental conditions, making them adaptable to a wide range of settings. In conclusion, soilless cultivation holds great potential for sustainable agriculture by addressing key challenges such as land and water scarcity, soil degradation, and climate change. While further research and technological advancements are needed to optimize these techniques and make them more accessible to farmers, the evidence suggests that soilless cultivation can play a significant role in achieving global food security and environmental sustainability goals.

Keywords: Comprehensive, soil-less, cultivation, hydroponics

1. INTRODUCTION

By 2050, there will be an additional two to three billion people on Earth [1]. Feeding them using standard agricultural methods was found to be unfeasible due to unpredictable conditions and inadequate farm management [2]. Due to high-priority challenges, the management of resource usage needs to be modified to give human food consumption precedence [3]. Irrigation is being increasingly widely used in agricultural activities, which affects soil quality and depletes groundwater supplies. There was less of a food scarcity as a

result of the population growth and loss of agricultural land brought on by fast urbanization and industrialization. Soilless farming is a potential answer to these problems. Two techniques for growing plants without soil are hydroponics and aeroponics [4]. Hydroponic and aeroponic crop cultures have been used by many farms all over the world for agricultural production and research. With its considerable advancements over the last half-century, the technology might currently be the most intensive crop production method employed in the contemporary agriculture industry [5]. A soilless culture can provide crops with comparable growth and production to field soil [6]. Soilless agriculture, often known as hydroponics, is a cutting-edge and highly effective approach to enhancing farming practices and maximizing crop production [8]. Hydroponically producing food could be the first move toward a more sustainable lifestyle [13]. By providing the nutrient solution, crops can be grown hydroponically in any type of growing medium [19]. A hydroponics plantation is a contemporary form of agriculture that offers total control over the distribution and delivery of nutrients to the plants. The earliest known example of hydroponics is found on the wall of the over 4,000-year-old Egyptian temple Dier El Bahari [18]. In commercial agriculture, the quantity of land required for crops is reduced by 75% when hydroponics is used. The water and nutrients in the system are efficiently and effectively regulated while maintaining proper environmental control thanks to the application of hydroponics techniques. Commercial crops like green vegetables, tomatoes, cucumbers, peppers, strawberries, and many more can be grown hydroponically [17]. The hydroponics subset known as aeroponics uses fertilizer solutions sprayed on suspended plant roots inside of a container [5]. Aeroponic cultivation is the practice of cultivating plants in a mist environment without the use of soil [4]. Pipes, spray nozzles, a pump, and a timer for misting inside the container make up a system for transferring nutritional solution from a nutrient tank [47]. Aeroponics is a soilless cultivation system that can be used as an alternative technique for growing crops in controlled environments such as greenhouses [3]. Aeroponic greenhouses are necessary due to the numerous drawbacks of traditional field farming techniques [32]. Regarding water usage, aeroponics recycles 99% of the water utilized. Due to the absence of pesticides or fertilizers, the fruits and vegetables are fresh and do not necessitate washing prior to consumption. The aeroponic method offers greater advantages than the hydroponic system when it comes to spraying the nutrient solution directly to the plant roots [27].

2. Hydroponics: Soil-Free Growing

Water culture and substrate culture are two forms of hydroponics, a method of cultivating plants without soil as a growth medium [9]. The quality of the harvest from soilless cultivation is considerably superior when compared to soil-based farming [8]. There is zero likelihood of encountering any weed infestation, pest or disease attack, or soil-borne insects. In hydroponics, nutrients are carefully supplied to the roots of plants, which enhances plant growth by accelerating their development [10]. A soilless culture, when compared to field soil, may effectively meet the essential requirements for crop growth and achieve comparable levels of growth and yield production [6]. Various types of growing medium are available,

such as coco-coir, hydro tons, perlite, vermiculite, peat moss, sawdust, and rock wool. Instead of soil, it utilizes an inert and non-organic substance as a soilless culture, serving as a medium [7]. It possesses several characteristics, including as porosity and a remarkable capacity to retain water. In soilless culture, the irrigation water is carefully controlled, resulting in a 50% reduction in water usage compared to typical soil-based vegetable production [12]. The soilless culture system is a method of growing plants that relies on nutritional solutions and porous growing media. This allows for the creation of a matrix that can maintain the ideal balance of air and water for plant growth [13]. Soilless agriculture is advantageous in urban areas due to its flexibility and capacity to create and maintain adequate conditions [14].

3. Hydroponics

Hydroponics is a method of cultivating plants in a nutrient solution, either with or without the addition of an inert media such as gravel, vermiculite, or rock wool, to give support [34]. There are two types of hydroponic systems: the Active system and the Passive system. In a passive system, the plant roots maintain touch with the nutritional solution, while the substrate serves as a means of support for the plants. The Wick system serves as an example of a passive system. In an active system, motor pumps are used to supply the plant roots with a nutrient solution, while a gravity system is employed to drain off any excess solution for recycling and reuse. NFT, Deep Water Culture, Ebb and Flow, Drip System, Aeroponic, and Dutch Bucket Method are all examples of active system types [16]. According to the researchers, the active system is more efficient than the passive system [22]. Hydroponics, a method of plant development without soil, offers more advantages compared to traditional soil-based agriculture. One significant benefit is the absence of pesticides and herbicides, resulting in reduced environmental pollution [17]. Hydroponics has proven to be effective on a large scale in areas with limited access to advanced technology, particularly in rural regions [18]. Hydroponics offers a primary advantage over traditional soil-based farming by significantly reducing water consumption. When comparing plants cultivated in soil vs hydroponics, the plant grown in hydroponics requires 50% less water [19]. Hydroponics, the rapidly expanding sector of agriculture, is projected to become the dominant approach to food production within a few years [20]. The pH and electrical conductivity (E.C.) have a significant influence on the health and vigor of crops in hydroponics. If the pH and electrical conductivity (E.C.) levels are over the optimal range, essential minerals and micronutrients will not be available for uptake by plants [21]. Prolonged exposure of plants to a single solution for over a week leads to significant alterations in the levels of dissolved oxygen, pH, and electrical conductivity (E.C.) of the nutrient solution. These changes have a profound effect on the growth and development of the plants [23]. Through the utilization of nutrients extracted from non-edible agricultural waste, the hydroponic system has shown favorable outcomes in crop production [24]. It is feasible to grow vegetables using an organic nutrient solution in hydroponic systems, as the nutrient solutions used are derived from chemical fertilizers [25]. Liquid organic fertilizer, composed of organic substances suitable for human consumption, can serve as a replacement for chemical nutrients in hydroponic systems that do not use chemicals [26]. A hydroponic system can be utilized for cultivating a diverse range of plants, encompassing vegetables, fruits, flowers, and medicinal crops [35].

4. Aeroponics

Aeroponics is the method used in contemporary agriculture to cultivate plants without the use of soil [1]. In an aeroponic system, the roots of the plants are moistened with a nutrient solution by the atomization of the nozzle. A nutrition solution is sprayed at intervals of two to three minutes. Crops can be cultivated in a soilless medium within an aeroponic system, utilizing artificial light instead of natural light. The aeroponic system consists of a growing chamber, net pots, an irrigation system, a motor, a digital timer, and a nutrient tank. This technique enables the growing of fresh and nutritious fruits and vegetables both indoors and on rooftops [27]. If a plant in an aeroponic system is being targeted by pests or diseases, it can be easily relocated. Continuous monitoring of pH and nutrient concentration ratios is essential in an aeroponics system. The aeroponics system requires additional oversight and meticulousness in order to establish a partially or fully enclosed environment [28]. The plants grown in the aeroponics growth chamber are specifically designed to get optimal aeration, resulting in accelerated plant development. This technique enhances the oxygen supply to the roots, hence creating a conducive environment for plant growth [29]. Growers in industrialized nations may benefit from improved access to high-quality seed through the use of aeroponics systems, which can enhance revenue and reduce production costs [30]. Within this setup, the plant has the potential to grow to a height ranging from 15 to 30 cm. The aeroponic system possesses the capacity to cultivate plants during periods of time when they are not typically grown. An aeroponic system can be used to raise several herbs by utilizing a single fertilizer solution [31]. Aeroponics is very suitable for studying water stress and root morphology due to its ability to precisely adjust the moisture content in the root zone and the amount of water provided [32]. Aeroponics has proven to be commercially successful in propagating plants, germinating seeds, producing seed potatoes, growing tomatoes, cultivating leaf crops, and cultivating microgreens [33].

5. The history of the Aeroponics system

W. Carter's 1942 work suggests that growing plants in water vapor can facilitate the examination of their roots. In 1944, L. J. Klotz discovered the vapor-misted citrus plant during their studies on citrus and avocado root illnesses. In 1952, G. F. Trowel cultivated apple trees using a spray culture technique and subsequently analyzed the roots. The technique of cultivating plants in a mist or air-based environment, known as spray culture, was officially named "Aeroponics" approximately fifteen years after the research conducted by Carter (1942) and Went (1957) [2].

6. Configuration of Aeroponic system

An aeroponic system involves suspending plant roots within an enclosed environment located in a growing chamber. To ensure optimal humidity and darkness in the chamber, a black poly sheet is used to line the growing chamber. In aeroponics, a nutrient solution is sprayed onto plant roots using nozzles that are installed in evenly spaced PVC pipes. The motor responsible for pumping the nutrient-rich solution at a high pressure is attached to the pipeline. A digital timer is linked to the pump in order to regulate the timing of the fertilizer

spraying within a designated timeframe. The size of the aeroponics unit system, the plant being grown, the distance between the nozzle and its pressure, the spacing of net pots on the growth chambers, the pump capacity of the motor, the nutrient spraying, and the interval between consecutive sprayings may vary. The growth chamber's pipe is linked to a nutrient tank that reuses the nutrient solution that drops from the suspended roots in the growth chamber [15]. The growth chamber and misting system have the ability to fully manage the root zone environment, which includes factors like as temperature, nutrition content, pH, humidity, misting frequency and duration, and oxygen availability [5]. Supplementary sensors can be employed to track the duration and frequency of a nozzle being in the "ON" and "OFF" states, with the purpose of controlling the quantity of nutrients being dispensed [35]. An aeroponic system offers more flexibility in terms of its design and size compared to a hydroponic system. Regardless of their orientation, both vertical and horizontal systems commonly employ the same mist delivery technology [36]. If there is a substantial distance between misting sprayers and the roots, the roots will experience a decrease in the availability and absorption of nutrients [37].

7. Functioning of the Aeroponic system

In an aeroponics system, the roots are regularly exposed to a nutrient solution that is either sprayed continuously or at regular intervals [47]. The nutrient solution is transported by a motor through pipes that are connected to the irrigation system located within the growth chamber [38]. The size of the nutrient tank is determined by the type of crop and the required amount of water. The aeroponics system utilizes a substrate to cultivate plants within net pots. Within the cultivation chamber, the plant roots are suspended [39]. The nutritional solution is atomized and sprayed into the roots of the plants, after which it drains back into the nutrient reservoir for potential reuse [4]. To ensure optimal plant growth, the temperature and humidity levels in the growing chamber can be modified [40]. In order to inhibit the proliferation of the algae, a black sheet is positioned over the growth chamber to obstruct sunlight [41]. The presence of a pollution-free atmosphere and an ample supply of oxygen promotes rapid growth of plant roots in the growth chamber, resulting in increased plant yield in the aeroponics system [48].

8. Optimal droplet size for an Aeroponics system

An optimal droplet size for most plant species falls between the range of 20 to 100 microns. In this specific region, the minuscule droplets fill the air, ensuring that the humidity levels in the growth chamber are maintained. The roots come into the most contact with droplets that have a diameter between 50 and 100 microns. Spray droplets with a size lower than 30 microns tend to stay suspended in the air as a fog. Droplets with a size over 100 microns often descend to the ground prior to reaching any roots. The root system has reduced availability to oxygen when the water droplets are very large [3]. The aeroponic system's capacity to precisely regulate the size of the nutrient solution droplets can improve the conditions that promote successful development of plant roots [42].

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10. Difficulties in Hydroponics

The researchers found that exposing wastewater to air enhanced the effectiveness of nitrogen removal in a hydroponic system that utilizes artificial light. In addition, it was found that wastewater treated with carbon dioxide before distillation yielded the most favorable results. However, the decrease in nitrogenous forms was not influenced by artificial light [49]. This hydroponic system utilizes nutrient-rich fish feces as a source of nourishment for the plants. In return, the plants aid in the purification of the water by eliminating contaminants that could be detrimental to the fish [50]. Research suggests that the comparable crop outputs achieved by aquaponic plants and traditional plants may be attributed to the existence of microorganisms that enhance plant growth, especially in peppers, tomatoes, and cucumbers. Conventional hydroponics. Nevertheless, due to the notable reduction in nutrient levels, further investigation is necessary to effectively exploit the benefits of microbes for all types of plants [51]. Recycled hydroponics can be used to grow vegetables in a sustainable manner by adopting simple EC control of the nutrient solution [52]. Soilless farming is commonly employed in protected agriculture to preserve the quality of products, increase control over the growing environment, and eliminate uncertainties associated with soil water and nutrient levels. Implementing landless practices, such as cultivating crops on rooftops or in close proximity to urban areas, not only helps in water conservation but also facilitates food production [53].

11. Potential Prospects of Hydroponics in India

Hydroponic gardening in India lacks widespread public acceptance, much like the popularity of hydroponics on the moon. A significant number of individuals in India possess farms that are situated close to the poverty threshold. Consequently, their limited access to education, lack of investment, and reluctance to step out of their comfort zones are contributing to a negative and unfriendly stance towards hydroponics. Furthermore, hydroponics is not widely employed by rural farmers in India. Despite these limitations, hydroponic farming in India has promising possibilities for various reasons:

(i) Initially, India's megacities are struggling with a shortage of water, and agriculture is a significant consumer of water. By shifting from conventional agriculture to water-efficient technology such as hydroponics, it is feasible to achieve water savings of over 80%. The conserved water can then be diverted to the potable water system, thereby resolving an urgent problem.

(ii) Additionally, a substantial proportion of the veggies consumed in India contains lingering

chemicals that have the potential to be detrimental to one's health. India's methods for tracking and monitoring pesticide residue in food are not well-established, unlike those in wealthy countries. With the increasing recognition of health hazards, customers in India are actively searching for healthier items and are willing to pay a higher price for them. Hydroponically cultivated crops possess the capacity to offer food commodities that are free from chemicals, Therefore, fulfilling the requirement for items that are more secure.

Considering the expanding demand for organic products and the rising curiosity among farmers and researchers regarding its viability as a sustainable farming method, it is probable that India would gradually increase the cultivation of hydroponic crops. Additionally, it will be essential to consider the requirement of offering monetary and technical support to farmers, as well as the limitations on crop selection when utilizing hydroponic technology [54].

12. Conclusion

Anticipated future industrialization is set to experience a significant surge as the quality of soil for farming becomes increasingly difficult. Given the continuous expansion of metropolitan regions, it is advisable to implement soilless cultivation as a means to enhance both the productivity and quantity of plants. Both hydroponics and aeroponics have the ability to generate substantial quantities of top-notch crops on a huge scale. Furthermore, it can greatly enhance the per capita availability and utilization of fruits and vegetables. Hydroponics and aeroponics systems are more efficient than traditional agricultural methods in terms of water utilization. They significantly reduce water losses and improve water usage efficiency. By embracing cutting-edge technologies and innovative methodologies, vegetable growing can be elevated to the realm of next-generation science.

References

1. Mangaiyarkarasi R. Aeroponics system for production of horticultural crops. *Madras Agriculture Journal*. 2020;1(3):1-7.
2. Gopinath P, Vethamoni I, Gomathi M. Aeroponics soilless cultivation system for vegetable crops. *Chemical Science Review and Letters*. 2017;6(2):838-849.
3. Sahoo D. Aeroponics system of cultivation in horticultural crops. *Just Agriculture*. 2020;1(1):32-40.
4. Priyanka BJ, Sharma R, Somanna AG, Sathyamurthy SK, Aruna M. Digital Farming Using Aeroponics. *Journal of Emerging Technologies and Innovative Research*. 2020;7(10):17-24.
5. Yeboah PA, Yeboah S, Baffour NK, Agyare WA, Otoo E. The design and technical performance of two aeroponic systems in Ghana. *Journal of Agricultural Science*. 2020;14(5):104-115.
6. Goswami B, Yadav V. Soil-less culture – a review. *Just Agriculture Multidisciplinary e-Newsletter*. 2022;2(12):1-12.
7. Arumugam T, Sandeep G, Maheshwari MU. Soilless farming of vegetable crops - an overview. *The Pharma Innovation Journal*. 2020;10(1):773-785.
8. Gohul Ram SS, Lokeshwar R, Deepa N. A review article on soilless cultivation. *International Journal of Creative Research Thoughts*. 2022;10(7):74-82.
9. Tuzel Y, Gul A, Tuzel IH, Oztekin GB. Different soilless culture systems and their management. *Journal of Agricultural, Food and Environmental Sciences*. 2019;73(3):07-12.

10. Sardare MD, Admane SV. A review on plant without soil hydroponics. *International Journal of Research in Engineering and Technology*. 2013;2(3):299-304.
11. Waiba KM, Sharma P, Sharma A, Chadha S, Kaur M. Soilless vegetable cultivation a review. *Journal of Pharmacognosy and Phytochemistry*. 2019;9(1):631-636.
12. Savvas D, Gruda N. Application of soilless culture technologies in the modern greenhouse industry – a review. *European Journal of Horticultural Science*. 2018;83(5):280-293.
13. Joshi D, Nainabasti A, Bhandari R, Awasthi P. A review on soilless cultivation-the hope of urban agriculture. *Archives of Agriculture and Environmental Sciences*. 2022;7(3):473-481.
14. Banerjee H, Sengupta A. Soil-less culture in modern agriculture. *World Journal of Science and Technology*. 2012; 2(7):103-108.
15. Sharma U, Meena B, Shekhawat NS, Vinod K. Aeroponics for propagation of horticultural plants: an approach for vertical farming. *Horticulture International Journal*. 2018;2(6):433-444.
16. Pandya D, Mankad A, Pandya H. Review on soilless method: hydroponics. *International Journal of Recent Scientific Research*. 2021;11(1):37122-37127.
17. BA, Pakeerathan K. Organic nutrient solutions for hydroponic spinach (*Basella Alba*) production in urban farming. *Journal of Agriculture Science*. 2022;18(1):01-13.
18. Velazquez-Gonzalez RS, Garcia-Garcia AL, Ventura-Zapata E, Barecines-Sanchez JO, Sosa-Savedra JC. A review on hydroponics and the technology associated for medium and small-scale operations. *Multidisciplinary Publishing Institute*. 2020;12(646):2-21.
19. Sonawane MS. Hydroponics - an upcoming and innovative way of future farming. *International Archive of Applied Sciences and Technology*. 2018;9(1):69-74.
20. Dholwani SJ, Marwadi SG, Patel VP, Desai VP. Introduction of hydroponics system and its methods. *International Journal for Research Trends and Innovation*. 2018;3(3):69-73.
21. Kulkarni BP, Mohite AS, Pai SV, Yedake PR. Automation of hydroponics system. *International Journal of Science Technology and Engineering*. 2017;3(9):600-602.
22. Rosa-Rodriguez RD, Lara-Herrera A, Terjo-Tellez LI, Padilla-Bernal S, Solis-Sanchez LO, Ortiz-Rodriguez. Water and fertilizers use efficiency in two hydroponics systems for tomato production. *Horticulture Brasileira*. 2020;38:47-52.
23. Dhansakaran D. Performance of foliage ornamental in hydroponic nutrient solution. *Journal of Floricultural and Landscaping*. 2020; 6:09-13.
24. Garland LJ, Mackowiak CJ, Sager JC. Hydroponics crop production using recycled nutrients from inedible crop residues. *The Engineering Society for Advancing Mobility Land Sea Air and Space International*; c1993. (ISSN 0148-7191).
25. Ezziddine M, Liltived H, Seljasen R. Hydroponic lettuce cultivation using an organic nutrient solution from aerobic digested aquaculture sludge. *Multidisciplinary Digital Publishing Institute*. 2021;11(1):2-13.
26. Upendri LH, Karunarathna B. Organic solution for a hydroponic system. *Academia Letters*; c2021. Article -1893. <https://doi/10.20935/AL1893>.
27. Barkavi M, Mubeen MI, Moneesha V, Naveen K, Sathya. Y. Urban based agriculture technology. *International Research Journal of Engineering and Technology*. 2019;6(3):2182-2185.
28. AlShrouf Ali. Hydroponics, Aeroponics, and Aquaponics compared with conventional farming. *American Scientific Research Journal for Engineering, Technology, and Sciences*. 2017;27(1):247-255.

29. Gohel KD, Nilesh R, Vispute, Sapate SS, Choudhari HP. Smart farming using automatic aeroponics system. *International Journal of Creative Research Thoughts*. 2018;6(2):166-170.
30. Ali LI, Jianmin G, Naz ST, Ali CF, Noman BA. Modern plant cultivation technologies in agriculture under controlled environment: A review on Aeroponic. *Journal of Plant Interactions*. 2018;13(1):338-352.
31. Padmashree, Rohan GS. To study the correlation between the traditional techniques and aeroponic system for conservation of water and land. *International Journal of Engineering Development and Research*. 2018;6(3):205-212.
32. Mithunesh P, Gupta K, Ghule S, Hule S. Aeroponic based controlled environment based farming system. *Journal of Computer Engineering*. 2015;17(6):55-58. Korter GO, Ehiagwina FO, Kolawole SK, Awe AS,
33. Akinola TE, Lawal PO. Development of aeroponics stand using locally source materials. *Iconic Research and Engineering Journals*. 2023;7(1):19-23.
34. Sharma N, Acharya S, Kumar K, Singh N. Hydroponics as an advanced technique for vegetable production – an overview. *Journal of Soil and Water Conservation*. 2019;17(4):364-371.
35. Moffat SA, Morrow RC, Wetzell JP. Astro-Garden aeroponic plant growth system design evolution. 49th International Conference on Environmental Systems. 2019;195:1-13.
36. Doll MJ, Boring NJ, Taylor MB, Sunkle CL. Hydro-Aeroponic Design. William Honors College, Honors Research Project; c2019. p. 924. http://ideaexchange.uakron.edu/honors_research_projects/924.
37. Georgios S, Savvas D, Agyropoulou K, Tarantillis PA. Yield and nutritional quality of aeroponically cultivated basil as affected by the available root-zone volume. *Emirates Journal of Food and Agriculture*. 2015;27(12):911-918.
38. Chowdhury M, Kabir SN, Chung S. Method of pump, and tank selection for aeroponic nutrient management systems based on crop requirements. *Journal of Agriculture Engineering*. 2020;8(1):119-128.
39. Kasahyap S. Soil based, aeroponic and hydroponics system in space with microgravity and hypo gravity conditions. *International Journal of Advance Research, Ideas and Innovations in Technology*. 2020;6(4):707-713.
40. Surmani E, Suhardiyanto H, Seminar KB, Saptomo SK. (Temperature distribution in aeroponics system with rootzone cooling for the production of potato seed in tropical lowland. *International Journal of Scientific and Engineering Research*. 2013;4(6):799804.
41. Selvaraj MG, Montoya-P ME, Atanbori J, French AP, Pridmore T. A low-cost aeroponic system for storage root development: Unravelling the below-ground secrets of cassava. *Creative Attribution International License*. 2019;15(131):2-13.
42. Devederkin IV, Antonov SN, Permyakov AV. Aerosol management of nutrients in aeroponic potato mini-tubers cultivation technology. *Earth and Environmental Sciences*. 2021;858:1-6.
43. Trejo-Tellez LI, Gomez-Merino FC. Nutrient solutions for hydroponic systems; c2012. <https://www.researchgate.net/publication/221928014>.

44. Eldridge BM, Manzani LR, Graham CA, Rodgers B, Farmer JR, Dodd AN. Getting to the roots of aeroponic indoor farming. *New Phytologist Foundation*. 2020;228:1183-1192.
45. Aguas AK, Flora AJ, Gojo MD, Manalo D, Monera FI, Abuan D, et al. Micro-controller based aeroponics farming management system. *DLSU Research Congress, De la Salle University, Manila, Philippines*; c2019. Hayden AL, Yokelson TN, Giacomelli GA, Hoffman JJ.
46. Aeroponics: An alternative production system for high-value crops. *Acta Horticulturae*. 2004;629:207-213.
47. Effat AA, Mohamed SM, Ali SA, Khayat EL. Using Aquaponics, hydroponic and Aeroponic system for gladiolus production. *Middle East Journal of Agriculture*. 2018;7(4):1885-1894.
48. Tunio MH, Gao J, Shaikh SA, Lakhair IA, Qureshi WA, Solangi KA, et al. Potato production in Aeroponics: An emerging food growing system in sustainable agriculture for food security. *Chilean Journal of Agricultural Research*. 2020;80(1):118-132.
49. Bawiec A, Pawęska K, Pulikowski K, Kajewska-Szkudlarek J. Influence of Insolation on the Efficiency of NO₃ Removal from Wastewater Treated in the Hydroponic System. *Water, Air, and Soil Pollution*. 2018;229(7).
50. Kumar Sharma P, Stephan Sampath J, Pawan Kumar Sharma PK, Kumar JSS, Anand S. Aquaponics: A boon for income generation in water deficient areas of India like Rajasthan. *International Journal of Fisheries and Aquatic Studies*. 2018;6(6):170–173.
51. Yep B, Zheng Y. Aquaponic trends and challenges – A review. *Journal of Cleaner Production*. 2019;228:1586–1599.
52. Chowdhury M, Islam MN, Reza MN, Ali M et al. Sensor-based nutrient recirculation for aeroponic lettuce cultivation. *Journal of Biosystems Engineering*. 2021;46(1):81–92.
53. Fussy A, Papenbrock J. An overview of soil and soilless cultivation techniques. *Chances, Challenges and the Neglected Question of Sustainability*. *Plants*. 2022;11(9).
54. Aurosikha Swain, Subhrajyoti Chatterjee, Viswanath M, Anindita Roy, Amit Biswas. Hydroponics in vegetable crops: A review. *The Pharma Innovation Journal* 2021;10(6):629-634.