International Journal of Environment and Climate Change

Volume 14, Issue 2, Page 872-882, 2024; Article no.IJECC.113671
ISSN: 2581-8627
(Past name: British Journal of Environment & Climate Change, Past ISSN: 2231–4784)

A Comprehensive Analysis of Technology in Aeroponics: Presenting the Adoption and Integration of Technology in Sustainable Agriculture Practices

Ashwini Kumar [a], Ayushi Trivedi [b++*], Nirjharnee Nandeha [c#], Girish Patidar [d++], Rishika Choudhary [e†] and Debesh Singh [f‡]

[a] R.A.K. College of Agriculture, RVSKVV, Sehore, India.
[b] Department of Natural Resource Management, College of Forestry and Research Station, MGUVV, Sankra-Patan, Durg, India.
[c] Department of Agronomy, Krishi Vigyan Kendra, Mahasamund, IGKV, Raipur, India.
[d] Medi-Caps University, Indore, India.
[e] Rajasthan College of Agriculture, MPUAT, Udaipur, India.
[f] RVSKVV, Krishi Vigyan Kendra, Morena, India.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJECC/2024/v14i24001

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/113671

Review Article

Received: 16/12/2023
Accepted: 21/02/2024
Published: 26/02/2024

[++] Assistant Professor;
[#] SMS;
[†] Ph.D Research Scholar;
[‡] Senior Research Fellow;
**Corresponding author: E-mail: ayushikhandwa@gmail.com;*

ABSTRACT

Aeroponics is a soilless farming method in which plants are grown by sprinkling a nutrient-rich fluid over their roots. Aeroponics has changed as a result of technology, which now offers advantages including automated nutrient supply, environmental management, and plant health monitoring. A key area of concern in light of the rising global food demand, climate change, and environmental issues is sustainable agriculture. This article highlights the integration of technology, sustainability, and socio-economic elements in modern agriculture by methodically examining the development of aeroponics practices from conventional ways to innovative modern techniques. When agronomic practices are viewed historically, they show a shift from labor-intensive, antiquated techniques to precision-based, technology-driven processes. Even though they were sustainable, traditional methods frequently had efficiency and scalability issues. A big change came with the arrival of the Green Revolution, which brought synthetic inputs and high-yield crop varieties. However, a reevaluation towards more sustainable practices was spurred by the approaches' long-term ecological implications. Precision agriculture, which makes use of sensor-based monitoring systems, artificial intelligence (AI), satellite and drone technologies, is a major feature of modern agronomy breakthroughs. According to the systematic research, Industry 4.0 and sensor technology are the most often used technologies in aeroponics. Numerous advantages, including time efficiency and sustainability, have come from these technologies. On the other hand, the research focused on power dependence and technical complexity as the primary obstacles in technology-assisted aeroponics.

Keywords: Aeroponics; sustainable agriculture; sustainable development goals; sustainability; technology integration.

1. INTRODUCTION

Aeroponics is a soilless farming method that utilizes air to spray a nutrient solution directly onto the plant roots. Despite not relying on soil as a medium, this technique is connected to sustainable agriculture through several aspects: Efficient Water Usage, Efficient Nutrient Usage, Better Environmental Control, Pesticide-Free Practices, Efficient Space Utilization, Cycling Nutrient Solutions, Enhanced Capability to Improve Plant Quality and Quantity, and Year-Round Farming. There is a continuing need to produce more food because of the growing world population. The sustainability of the globe is threatened by rising food production since it necessitates increased use of energy, water, and soil resources. Similarly, excessive land usage and intense farming methods can cause nutrient depletion, soil erosion, and a loss of soil fertility, all of which can eventually lower the land's productivity [1]. The Food and Agriculture Organisation, FAO [2], suggested using sustainable agriculture methods including aeroponics, hydroponics, and aquaponics to improve the problem. These are soilless methods that leverage technology to increase food production productivity without endangering the sustainability of the earth [3,4]. Aquaponics is the practice of growing plants and fish in water tanks with hydroponic equipment. Aeroponics is the practice of growing plants in the air or in a mist environment, while hydroponics is the practice of growing plants using a water-based fertiliser solution in place of soil. When it comes to growing plants and fish, aquaponics is the most often used method. On the other hand, hydroponics is quite popular if enough water resources are available but there is no interest in raising fish. Lastly, aeroponics is the method to use if there is no desire to raise fish and there are not enough water resources [5].

2. THE AEROPONIC SYSTEM

The technique of aeroponics involves growing plants without the use of soil, with their roots floating in the air and misted with a nutrient-rich water solution [6]. Pumps, timers, and spray nozzles are commonly used in aeroponic systems to provide a highly oxygenated mist of water and nutrients to the plant roots. Water and nutrients can be absorbed by the roots thanks to the mist's scheduled delivery.

Compared to conventional soil-based agriculture, aeroponics has a number of benefits, such as quicker growth rates, greater crop yields, and more economical resource utilisation [7,8]. A more environmentally responsible and sustainable method of farming is made possible by the soil-free environment's ability to lower the risk of soil-borne illnesses and pests [9]. However, expensive initial setup costs, maintenance requirements, and a high level of technical competence required are its key problems [10].

Despite being a relatively new technology, aeroponics has already been utilised to grow a variety of crops, such as tomatoes, lettuce, and strawberries [11]. Aeroponics has benefited greatly from technological advancements in that it allows plants to be cultivated year-round since some instruments and systems allow for the artificial control of environmental factors including temperature, humidity, airflow, and light intensity [12,13].

3. AEROPONICS TECHNOLOGY

Aeroponics is a success because of technology, which makes it possible to precisely control environmental parameters, conserve water, optimise space, and manage pests and diseases—all of which lead to better food production. In addition, compared to conventional agricultural practices, aeroponics may produce high-quality, nutrient-rich crops with a smaller environmental impact by utilising technology [8]. Technology-assisted aeroponic systems incorporate one or more of the following technology categories, per earlier research [5,13,14]: sensors, Sector Technologies connected to Industry 4.0, technologies for dispensers, and technologies for renewable energy.

Sensor-based environmental condition monitoring is one of the main uses of technology in aeroponics [15]. For instance, sensors enable farmers to make data-driven decisions about modifying circumstances to maximise plant development by providing real-time monitoring of environmental parameters (such as temperature, humidity, and nutrient levels) [16]. This can involve monitoring the health of the plants, regulating humidity and temperature, and altering the amount of nutrients. Additionally, sensors can be included into automated control systems to modify the environment in response to changing circumstances [17]. By doing this, the possibility of human error is decreased and it is guaranteed that growing plants will always have optimal environmental conditions. Furthermore, sensors have the ability to identify problems before they are apparent to the human eye, such as nutrient deficits, pests, and illnesses [11]. By detecting problems early on, crop loss can be avoided and healthy, productive plants can be guaranteed.

Industry 4.0 is another technology option that has grown in importance in aeroponics. It alludes to the fourth industrial revolution, which is defined by the creation of intelligent production processes through the integration of cutting-edge technologies like the Internet of Things (IoT), artificial intelligence (AI), and data analytics [18,41-55]. Industry 4.0 technologies are becoming more and more significant in aeroponics since they provide a number of advantages for maximising plant growth and enhancing productivity [11]. IoT, for instance, can be used to automate a number of processes, including pest control, environmental control, and nutrient supply [19]. This guarantees that plants always have the best growing circumstances and lessens the need for human intervention. However, by examining plant photos and recognising signs that might not be apparent to the unaided eye, artificial intelligence (AI) can be utilised to discover plant illnesses early on [20]. This can assist farmers in acting quickly to stop the spread of illnesses and keep their crops healthy. Analysing enormous volumes of data on plant development, weather patterns, and nutrient levels in a similar way allows data analytics to be used to precisely forecast the best conditions for plant growth [21]. By doing this, farmers may increase yields and optimise their aeroponic systems.

Aeroponic systems additionally require dispenser-related technology because these devices provide plants with water and nutrients [22]. This comprises water pumps, centrifugal pumps, atomizers, sprayers, nebulizers, and ultrasonic dispersion devices that are automatically controlled based on the demands identified by the sensors. Plants can be precisely dosed with nutrients and water thanks to dispenser technology [23]. This guarantees that the plants get the right amount of water and nutrients, all of which are essential to their development and growth. Dispenser technology can also be programmed to automatically provide water and nutrients based on real-time sensor data or at predetermined intervals [24]. This guarantees that the plants receive constant care and lessens the need for manual labour. Furthermore, it enables the customisation of water and nutrient supply according to the unique requirements of every plant [25], guaranteeing that every plant is given the best possible conditions for growth and development.

Renewable energy-related technologies are another set of innovations that contribute to aeroponics' sustainability. Aeroponic systems can be powered by alternative energy sources, such solar or wind power, which has several advantages for lowering energy consumption and enhancing sustainability [17,42]. This lessens the need for grid power, which can be costly and harmful to the environment. Aeroponic system operating expenses are also lowered by using renewable energy [26], which lowers the cost of system operation and maintenance for producers. For aeroponic producers, alternative energy sources are a more environmentally beneficial option because they are generally cleaner and more sustainable than traditional ones [27,41].

3.1 History

Aeroponics has long been used as a research tool in root physiology. The first soilless gardening techniques were developed in the 1920s by botanists studying plant root structure using rudimentary aeroponics [4].

Although soilless culture is thought of as a modern technique, cultivating plants in containers above ground has been attempted on several occasions over the ages. The earliest known instance of plants grown in containers appears to be wall paintings discovered in the Deirel Bahari temple [35]. During the early 1940s, the technology was more often employed as a research tool than as a commercially viable means of producing crops. In 1942, W. Carter conducted the first studies on air culture growing and published a method for cultivating plants in water vapour to make root examination easier. In an assisted study of his research on diseases of citrus and avocado roots, L.J. Klotz was the first to discover vapour misted citrus plants in 1944. G.F. Trowel cultivated apple trees in a spray culture in 1952. Twenty-five years after [7] and [40]'s study, the air-growing method used in spray culture was dubbed "aeroponics." The Genesis Rooting System, also known as the Genesis Machine, was created by GTi in 1983 and was the first commercial aeroponics system. The gadget was just attached to a water tap and an electrical outlet, and it was controlled by a microchip.

Aeroponics has proven effective in growing a number of horticultural and decorative crops [5]. In Korea, the production of potato seed tubers has seen successful application of the aeroponic system [24,25]. Aeroponics is being utilised in agriculture all over the world as of 2006. A minituber output of 800 tubers/m2 at a plant density of 60 plants/m^2 was recorded by Farran and Mingo [15] over a period of five months, with weekly harvests. This corresponds to a 1:13 multiplication rate. They also observed the field performance of aeroponically produced tubers to be equivalent to minitubers grown from the pots. At the International Potato Centre (CIP) in Peru, yields of over 100 tuberlets /plant were obtained [38].

4. NUTRIENTS UTILISED IN AEROPONICS SYSTEM

An indoor aeroponics system consumes less water and nutrients because the plant roots are sprayed in intervals using a precise drop size that may be utilized most efficiently by osmosis to nourish the plant. Little surplus nutrient solution is lost via evaporation or runoff. Plant disease is decreased since the roots are left free to air, preventing soaking is a stagnant damp medium. Aeroponics gives possibilities to produce plants without soil or substrate, producing the optimal yield, saving water and fertiliser solutions and do not contaminate the environment [26]. Carbon, oxygen and hydrogen are present in air and water. Water may contain a range of elements with main nutrients such as nitrogen, phosphorus, potassium and secondary nutrients viz., calcium, magnesium, and sulphur, micro-nutrients are iron, zinc molybdenum, manganese, boron, copper, cobalt and chlorine. Roots consume nutrients as ions in water positively charged cations, or negatively charged anions. An example of a cation is ammonium, NH^{4+}, and an anion nitrate, NO^{3-}, both significant nitrogen sources for plants [1, 3,13,15,23,28,40]. As plants use the ions, the pH of the solution might vary, meaning it can lean too far positive or too far negative. The ideal pH for plant growth is between 5.8 and 6.3. In aeroponic system where water and nutrients are recycled, it is vital to measure the acid/base or pH measurement to allow plants to receive nutrients. Aeroponic employing spray to nourish roots require much less liquid leading in simpler management of nutrient content with greater pH stability.

5. RELEVANT LITERATURE

A few reviews of the literature have examined how various technologies are applied across the board in sustainable agriculture. For instance,

[11] looked into how digital technologies are starting to appear in sustainable agriculture methods. To determine the degree of digital technology adoption, service type, technology readiness level, and farming type (hydroponics, aquaponics, and aeroponics), the review included 148 empirical investigations. Only three of the sample's research dealt with aeroponics; none of them reached any conclusions about this kind of sustainable farming method. Similar comparisons were made between soil and soilless cultivation methods (aquaponics, hydroponics, and aeroponics) in the study conducted [28]. According to the study's findings, soilless procedures can benefit from the application of technical advancements in monitoring and automation, which can make them more profitable, efficient, secure, and environmentally beneficial. Lastly, as important advancements to ensure sustainable food production, the study [29] examined the affordances of digital technologies including sensors, robotics, AI, and data analytics. The paper makes the case that although intricate climate changes endanger food production, digital technologies are essential for managing these changes and realising sustainable agriculture. But like the other research, this one did not offer any specific findings regarding how technology might affect aeroponics.

However, a number of empirical studies have documented how certain technologies are used in aeroponic systems [15,33], how aeroponics technology uses natural resources effectively [31,32], and how the employment of particular technologies helps aeroponics enhance food production [23, 30]. To the best of our knowledge, no comprehensive assessment has been carried out to pinpoint every aspect of technology utilisation in aeroponics. Aeroponics technology application requires a systematic evaluation in order to identify research gaps, assess available data, offer practitioner assistance, and inform policy and decision-making. Additionally, it can promote technological advancement and maximise plant development while guaranteeing that politicians and researchers have access to the best available data.

6. VARIOUS AEROPONIC TYPES

a. Low-pressure Units: The roots of the plants are suspended above a nutrient solution reservoir or an interior channel that is connected to a reservoir in the majority of low-pressure aeroponic gardens. A low-pressure pump delivers the nutrient solution via jets or ultrasonic transducers, which drain or drip the nutrients back into the reservoir. When plants reach maturity, they experience dry patches in their root systems, which prevents them from absorbing enough nutrients. Because they are expensive, these machines do not have functions to remove debris and undesired microorganisms from the nutrient solution or to purify it. Benchtop growth is typically OK for these units. Additionally, it is employed to illustrate the fundamentals of aeroponics.

b. High-Pressure Devices: A high-pressure pump (or pumps) produces mist in high-pressure aeroponic devices. Additionally, it is typically employed in the production of high-value crops. This technique uses low-mass polymers, pressurised nutrient delivery systems, low-oxygen air and water purification, and nutrient sterilisation technologies.

c. Commercial System: The commercial system includes biological systems and high-pressure device hardware. The biological systems matrix includes an upgrade for longer plant life and crop maturation.

6.1 Working

Aeroponics is a method of growing vegetables in the air without the use of soil. In this system, nutrients are sprayed directly onto the plant roots, and a mist of water containing nutrient solutions is sprayed until it reaches the plant roots. The suspended plant roots absorb the nutrient solution, allowing for efficient nutrient uptake. The foundation of aeroponics is the ability to grow vegetables in containers with flowing plant nourishment rather than with roots placed in a substratum or soil, as is the case with hydroponics. The fundamental idea behind aeroponic gardening is to grow plants suspended in a closed or semi-closed space by misting the lower stem and dangling roots of the plant with an atomized or sprayed solution of water that is rich in nutrients.

To maximise the benefits of aeroponic farming, a suitable monitoring and control system for the delivery of nutrients and water is part of the setup. The spray from a nutrient solution storage tank must be distributed using a system of pipes, spray nozzles, a pump, and a timer. It makes use of a tiny internal microjet spray to finely sprinkle the roots in the rooting chamber with nutrient-rich solutions from the nutrient reservoir under high pressure. The high-pressure aeroponic pump is turned on by means of a controlled cyclic timer. After adding nutrients to water in a reservoir basin, the mixture is filtered and pumped into a pressurised holding tank where it is misted onto the root system on a regular basis.

Developed root hairs aid in the moisture-absorption of nutrients. Additionally, feeding the plant with various nutrients through its roots is simpler. There is very little nutritional solution waste since the spray particles are so tiny. Additionally, root rot is entirely prevented when there is a sufficient supply of oxygen.

Around the hung roots, misting frequently occurs every several minutes. Normally, the system only briefly turned on every two to three minutes. If the misting cycles are stopped, the roots will quickly dry out because they are exposed to the air.

Similar to other hydroponic system types, the aeroponics system requires a short cycle timer to run the pump for a few seconds every few of minutes. This timer controls the nutrient pump. But, the chamber needs to be completely filled with lightless materials to keep the roots functionally dark and to prevent the growth of algae, which would obstruct plant growth and contaminate the system.

In aeroponics, the size of the droplets in a nutrient mist is very important. The amount of oxygen may be decreased by an enormous droplet. An undersized droplet may encourage the establishment of root hair, which inhibits the growth of lateral roots and reduces aeroponic system efficiency. The size of the water droplets must be both large enough to deliver enough nutrients to the roots and small enough to prevent them from precipitating out of the root mass right away. Remaining solution falls into the unit's base where it is filtered, strained, and then pumped back into the reservoir. The advantage of an aeroponics system is simple pH and nutrition monitoring. Aeroponics allows for minimum touch between the plant and the support framework, allowing for unrestricted plant growth.

7. AEROPONICS ADVANTAGES

- Year-round cultivation: Because plants are produced in a controlled environment, crops can be grown all year round without being impacted by the weather or atmospheric conditions outside.
- Rapid plant growth: Because their roots have ample access to oxygen, crops grow quickly.
- Simple system maintenance: When using aeroponics, the root chamber the container holding the roots as well as the irrigation lines and reservoir only need to be cleaned occasionally.
- Reduced nutrient and water requirements: Because aeroponic systems have a greater rate of nutrient absorption and plants typically respond to them by sprouting more roots, they use less water and nutrients overall.
- Mobility: Since all that's needed is shifting the plants from one collar to another, plants even entire nurseries can glide about with little difficulty.
- Low area requirements and large yield: By stacking aeroponic systems, vertical farms can be built with a lot less area needed than those using traditional farming methods.
- Excellent educational value: Students and researchers can more easily examine plants and root growth in lab settings.
- Appropriate root growth: Plant roots have enough room in this system to develop properly. that they don't sag or deteriorate.
- No transplant shock: Once roots have developed, plants can be moved to any growing media system without experiencing transplant shock.
- Simpler fruit harvesting: The system produces fruits that are simpler to harvest.
- Produce free of disease: Plant infections and illnesses are greatly reduced in clean, sterile growth conditions.
- Producing fruits at moon stations: This method enables fruit cultivation at zero gravity, or on moon stations.
- Homes can cultivate indoor or rooftop plants that may be more nutrient-dense and healthier.
- Nurseries can grow healthy, harvestable plants from seeds and cuttings far faster than they can with conventional techniques.
- Aeroponic systems can optimise agricultural yields while reducing water usage by 98%, fertiliser usage by 60%, and pesticide usage by 100%.
- Short power interruptions do not cause any harm to plants.

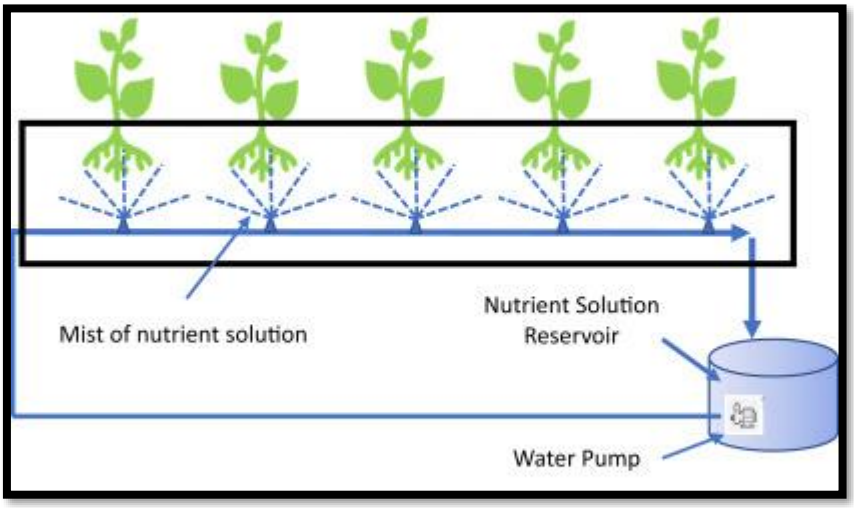

Fig. 1. Schematic diagram of aeroponics

8. THE DRAWBACKS OF UTILISING TECHNOLOGY IN AEROPONICS

The results of the major drawbacks of technology-assisted aeroponics are presented and discussed in this part. We looked through the abstract, findings, discussion, and conclusion portions of each study to find the documented drawbacks. Although integrating technology has many advantages, there are still certain issues that need to be resolved in order to fully utilise this new production method. In eight research (17%), at least one drawback or difficulty with technology-assisted aeroponics was mentioned. To create a shorter list, we categorised the drawbacks into five groups. In this regard, the most frequently mentioned drawback is its technical complexity, which makes it difficult for this farming method to become widely used. The most frequently mentioned difficulty with utilising technology in aeroponics was technical complexity (13% of the studies). That is, a system will be more complex the more technological components it contains [34,35] brought attention to this difficulty by pointing out that complicated aeroponic systems with several interconnected components can result from sophisticated technology. The authors came to the conclusion that the biggest obstacles to success in contemporary aeroponics can be assuring compatibility and reliability among diverse components, including as pumps, misting systems, nutrient delivery methods, and sensors.

A problem with power dependency was noted in 6% of the research. Energy consumption is frequently increased by integrating technology, particularly when sophisticated lighting and environmental control systems are employed. More significantly, crop damage can result from power outages. Sani et al. [12] argued in their study that energy efficiency and technological benefits must be balanced for sustainable operations. Thus, the authors emphasised the significance of utilising renewable energy sources to lessen the adverse consequences of aeroponics power consumption.

In the study conducted [36-39], the advantages of incorporating technology into aeroponics were linked to setup cost, maintenance and monitoring, and learning curve. Although it's common knowledge that aeroponics technology is a long-term solution, certain stakeholders may not be able to finance the early fees. Likewise, incorporating technology into aeroponics necessitates keeping that technology up to date and under observation. As a result, production schedule disruptions and lower yields could result from downtime for maintenance and repairs. Last but not least, technology integration calls for sufficient technical know-how to guarantee the system operates as intended. As a result, this circumstance can call for recruiting specialists or more training.

- System Dependency: High pressure pumps, timers, and sprinklers are the usual parts of an aeroponics system. If any of these fall apart, it's easy to damage or destroy your plants.
- Technical expertise needed: First, some training is necessary for system maintenance. An aeroponic system requires a certain level of skill to operate.

There is no soil to absorb excess or wrongly supplied nutrients, therefore it is imperative to know how much your plant requires.

- Root chamber sanitation: In order to prevent diseases from attacking the roots, the root chamber needs to be kept free of contaminants. Thus, we need to periodically clean the root chamber. As a disinfectant, hydrogen peroxide is frequently employed.
- High price: The majority of aeroponic systems are not inexpensive. Aeroponic systems could go into the hundreds of dollars per unit.
- Power outage: Over an extended length of time, power outages may result in permanent harm.

9. CONCLUSION

The global economy depends heavily on water. The agricultural sector uses over 70% of the fresh water that humans utilise. Out of that, extravagant irrigation methods waste forty-five percent of the crop. Because aeroponic systems use recirculatory systems, we can conserve 98% of the water used in the system. Aeroponic systems provide year-round access to fresh, hygienic, healthful, efficient, and quick food production. It is possible to overcome any limitation associated with soil culture production with this soilless culture. India will soon be among the top exporters and growers due to its increased production free of illness. Improved vegetative development may be achieved with an aeroponic system without the need for artificial hormones, insecticides, or pesticides. In a controlled setting, aeroponics is still a fantastic approach to learn about the demands of plants and how to master their growth. Occasionally, aeroponic gardening is the only feasible option for apartment-dwelling urbanites who want to garden. Additionally, aeroponics offers the most efficient way to produce plants on arid terrain, avoiding this issue altogether. Although they are thought of as a novel approach to agricultural development, soil cultures are not an easy technique to use. However, producers and horticulturists in many nations lack the technical foundation of the new technique, necessitating the necessity for highly trained personnel. Furthermore, the majority of substrates are sold worldwide, which makes them pricey. It is therefore preferable to search locally for reasonably priced high-quality substrates.

Growers are able to customise soilless systems based on their requirements, system location, and financial capacity. In any event, the system must closely monitor and carefully control the factors that are necessary for healthy plant growth, including nutrient concentrations, light, oxygen in the plant's root zone, water quality, pH, disinfection, solution temperature, and more. Crop production will become easier with the aeroponics technique, which is the way of the future because it conserves water, land, and nutrients perhaps it could be added to support sustainable agriculture.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Wimmerova L, Keken Z, Solcova O, Bartos L, Spacilova MA. Comparative LCA of Aeroponic, Hydroponic, and Soil Cultivations of Bioactive Substance Producing Plants. Sustainability. 2022; 14:2421.
2. FAO. The Future of Food and Agriculture—Trends and Challenges; FAO: Rome, Italy; 2017.
3. Kumar P, Sampath B, Kumar S, Babu B, Ahalya N. Hydroponics, Aeroponics, and Aquaponics Technologies in Modern Agricultural Cultivation. In Trends, Paradigms, and Advances in Mechatronics Engineering; IGI Global: Hershey, PA, USA. 2023;223–241.
4. Balasundram SK, Shamshiri RR, Sridhara S, Rizan N. The Role of Digital Agriculture in Mitigating Climate Change and Ensuring Food Security: An Overview. Sustainability. 2023;15: 5325.
5. Bhakta I, Phadikar S, Majumder K. State-of-the-Art Technologies in Precision Agriculture: A Systematic Review. J. Sci. Food Agric. 2019;99:4878–4888.
6. Gurley TW. Aeroponics, 1st ed.; CRC Press: Boca Raton, FL, USA; 2020. ISBN 9780367810078.
7. Chaudhry AR, Mishra VP. A Comparative Analysis of Vertical Agriculture Systems in Residential Apartments. In Proceedings of the 2019 Advances in Science and Engineering Technology International Conferences (ASET), Dubai, United Arab Emirates, 26 March–10 April 2019.

8. Lakhiar IA, Gao J, Syed TN, Chandio FA, Buttar NA. Modern Plant Cultivation Technologies in Agriculture under Controlled Environment: A Review on Aeroponics. J. Plant Interact. 2018;13: 338–352.
9. Yang X, Luo Y, Jiang P. Sustainable Soilless Cultivation Mode: Cultivation Study on Droplet Settlement of Plant Roots under Ultrasonic Aeroponic Cultivation. Sustainability. 2022;14:13705.
10. Niu G, Masabni J. Hydroponics. In Plant Factory Basics, Applications and Advances; Elsevier: Amsterdam, The Netherlands. 2022;153–166.
11. Abbasi R, Martinez P, Ahmad R. The Digitization of Agricultural Industry—A Systematic Literature Review on Agriculture 4.0. Smart Agric. Technol. 2022;2:100042.
12. Sani M, Siregar S, Kumiawan A, Jauhari R, Mandalahi C. Web-Based Monitoring and Control System for Aeroponics Growing Chamber. In Proceedings of the 2016 International Conference on Control, Electronics, Renewable Energy and Communications (ICCEREC), Bandung, Indonesia, 13–15 September. 2016;162–168.
13. Khan M, Akram M, Janke R, Khan R, Al-Sadi A, Farooque, A. Urban Horticulture for Food Secure Cities through and beyond COVID-19. Sustainability. 2020;12:9592.
14. Lakhiar IA, Gao J, Syed,TN, Ali Chandio F, Tunio MH, Ahmad F, Ali Solangi K. Overview of the Aeroponic Agriculture—An Emerging Technology for Global Food Security. Int. J. Agric. Biol. Eng. 2020; 13:1–10.
15. Lakhiar IA, Jianmin G, Syed TN, Chandio FA, Buttar NA, Qureshi WA. Monitoring and Control Systems in Agriculture Using Intelligent Sensor Techniques: A Review of the Aeroponic System. J. Sens.2 018; 8672769.
16. Rahmad I, Tanti L, Puspasari R, Ekadiansyah E, Agung Fragastia V. Automatic Monitoring and Control System in Aeroponic Plant Agriculture. In Proceedings of the 2020 8th International Conference on Cyber and IT Service Management (CITSM), Pangkal, Indonesia, 23–24 October. 2020;1–5.
17. Fasciolo B, Awouda A, Bruno G, Lombardi FA. Smart Aeroponic System for Sustainable Indoor Farming. Procedia CIRP. 2023;116:636–641.
18. Lasi H, Fettke P, Kemper HG, Feld T, Hoffmann M. Industry 4.0. Bus. Inf. Syst. Eng. 2014;6: 239–242.
19. Roffi TM, Jamhari CA. Internet of Things Based Automated Monitoring for Indoor Aeroponic System. Int. J. Electr. Comput. Eng. 2023;13:270.
20. Torres-Tello J, Ko SB. Interpretability of Artificial Intelligence Models That Use Data Fusion to Predict Yield in Aeroponics. J. Ambient Intell. Humaniz. Comput. 2023; 14:3331–3342.
21. Ragaveena S, Shirly Edward A, Surendran U. Smart Controlled Environment Agriculture Methods: A Holistic Review. Rev. Environ. Sci. Bio/Technol 2021;20:887–913.
22. Morgunov AP, Kirgizova IV. Control Unit for the Dosed Feeding of the Nutrient Solution into the Industrial Aeroponic Installation System. J. Phys. Conf. Ser. 2019;1210:012099.
23. Eldridge BM, Manzoni LR, Graham CA, Rodgers B, Farmer JR, Dodd AN. Getting to the Roots of Aeroponic Indoor Farming. New Phytol. 2020;228:1183–1192.
24. Sumarni E, Hardanto A, Arsil P. Effect of Root Zone Cooling and Evaporative Cooling in Greenhouse on the Growth and Yield of Potato Seed by Aeroponics in Tropical Lowlands. Agric. Eng. Int. CIGR J. 2021;23:28–35.
25. Devederkin IV, Antonov SN, Permyakov AV. Aerosol Management of Nutrients in Aeroponic Potato Mini-Tubers Cultivation Technology. IOP Conf. Ser. Earth Environ. Sci. 2021;852: 012021.
26. Ramalingannanavar N, Nemichandrappa M, Srinivasa Reddy GV, Dandekar AT, Kamble JB, Dhanoji MM. Design, Development and Evaluation of Solar Powered Aeroponic System—A Case Study. Int. J. Curr. Microbiol. Appl. Sci. 2020;9:3102–3112.
27. Klarin B, Garafulić E, Vučetić N, Jakšić T. New and Smart Approach to Aeroponic and Seafood Production. J. Clean. Prod. 2019;239:117665.
28. Fussy A, Papenbrock J. An Overview of Soil and Soilless Cultivation Techniques—Chances, Challenges and the Neglected Question of Sustainability. Plants. 2022; 11:1153.
29. Basso B, Antle J. Digital Agriculture to Design Sustainable Agricultural Systems. Nat. Sustain. 2020;3:254–256.

30. Ríos J, Candelo J, Hoyos F. Growing Arugula Plants Using Aeroponic Culture with an Automated Irrigation System. Int. J. Agric. Biol. Eng. 2020;13:52–56.
31. Lucero L, Lucero D, Ormeno-Mejia E, Collaguazo G. Automated Aeroponics Vegetable Growing System. Case Study Lettuce. In Proceedings of the 2020 IEEE ANDESCON, Quito, Ecuador, 13–16 October; 2020.
32. Tunio MH, Gao J, Shaikh SA, Lakhiar IA, Qureshi WA, Solangi KA, Chandio FA. Potato Production in Aeroponics: An Emerging Food Growing System in Sustainable Agriculture for Food Security. Chil. J. Agric. Res. 2020;80:118–132.
33. Jamshidi A, Moghaddam A, Ommani A. Effect of Ultrasonic Atomizer on the Yield and Yield Components of Tomato Grown in a Vertical Aeroponic Planting System. Int. J. Hortic. Sci. Technol 2019;6:237–246.
34. Puentedura R. Transformation, Technology, and Education. Available:http://www.hippasus.com/rrpweblog/archives/2013/05/29/SAMREnhancementToTransformation.pdf (accessed on 22 September 2023).
35. Hamilton ER, Rosenberg JM, Akcaoglu M. The Substitution Augmentation Modification Redefinition (SAMR) Model: A Critical Review and Suggestions for Its Use. TechTrends. 2016;60:433–441.
36. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, Shamseer L, Tetzlaff JM, Akl EA, Brennan SE, et al. The PRISMA 2020 Statement: An Updated Guideline for Reporting Systematic Reviews. Syst. Rev. 2021; 10:105906.
37. Kitchenham B, Charters S. Guidelines for Performing Systematic Literature Reviews in Software Engineering Version 2.3; Keele University: Keele, UK; Durham University: Durham, UK; 2007.
38. Krippendorff K. Content Analysis: An Introduction to Its Methodology; Sage Publications: Thousand Oaks, CA, USA; 2018.
39. Cohen J. Weighted Kappa: Nominal Scale Agreement Provision for Scaled Disagreement or Partial Credit. Psychol. Bull. 1968;70:213.
40. Went FW. The Experiment Control of Plant Growth. Ronald Press, NewYork; 1957.
41. Trivedi A. Reckoning of Impact of Climate Change using RRL AWBM Toolkit. Trends in Biosciences. 2019;12(20):1336-1337.
42. Trivedi A, Awasthi MK. A Review on River Revival. International Journal of Environment and Climate Change. 2020; 10(12):202-210.
43. Trivedi A, Awasthi MK. Runoff Estimation by Integration of GIS and SCS-CN Method for Kanari River Watershed. Indian Journal of Ecology. 2021;48(6):1635-1640.
44. Trivedi A, Gautam AK. Hydraulic characteristics of micro-tube dripper. LIFE SCIENCE BULLETIN. 2017;14(2):213-216.
45. Trivedi A, Gautam AK. Temporal Effects on the Performance of Emitters. Bulletin of Environment, Pharmacology and Life Sciences. 2019;8(2):37-42.
46. Trivedi A, Gautam AK. Decadal analysis of water level fluctuation using GIS in Jabalpur district of Madhya Pradesh. Journal of Soil and Water Conservation. 2022;21(3):250-259.
47. Trivedi A, Gautam AK, Pyasi SK, Galkate RV. Development of RRL AWBM model and investigation of its performance, efficiency and suitability in Shipra River Basin. Journal of Soil and Water Conservation. 2020;20(2):1-8.
48. Trivedi A, Gautam AK, Vyas H. Comparative analysis of dripper. Agriculture Update TECHSEAR. 2017;1 2(4):990-994.
49. Trivedi A, Nandeha N, Mishra S. Dryland Agriculture and Farming Technology: Problems and Solutions. Climate resilient smart agriculture: approaches & techniques. 2022;35-51.
50. Trivedi A, Pyasi SK, Galkate RV. A review on modelling of rainfall – runoff process. The Pharma Innovation Journal. 2018; 7(4):1161-1164.
51. Trivedi A. Pyasi SK. Galkate RV. Estimation of Evapotranspiration using CROPWAT 8.0 Model for Shipra River Basin in Madhya Pradesh, India. Int. J. Curr. Microbiol. App. Sci. 2018;7(05): 1248-1259.
52. Trivedi A. Pyasi SK, Galkate RV. Impact of Climate Change Using Trend Analysis of Rainfall, RRL AWBM Toolkit, Synthetic and Arbitrary Scenarios. Current; 2019.
53. Trivedi A, Pyasi SK, Galkate RV, Gautam VK. A Case Study of Rainfall Runoff Modelling for Shipra River Basin. nt.J.Curr.Microbiol.App.Sci Special. 2020; 11:3027-3043.

54. Trivedi A, Singh BS, Nandeha N. Flood Forecasting using the Avenue of Models. JISET – International Journal of Innovative Science, Engineering & Technology. 2020; 7(12):299-311.

55. Trivedi A, Verma NS, Nandeha N, Yadav D, Rao KVR, Rajwade Y. Spatial Data Modelling: Remote Sensing Sensors and Platforms. Climate resilient smart agriculture: approaches & techniques. 2022;226-240.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/113671