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# AEROPONICS FOR A SUSTAINABLE FUTURE: TRANSFORMING AGRICULTURE IN A CHANGING WORLD

**SREEJITH B.[a1] AND MANEESH B.[b]**

[a]Department of Economics, Fatima Mata National College, Kollam, Kerala, India
[b]Department of Economics, MMNSS College, Kottiyam, Kollam, Kerala, India

## ABSTRACT

**Aeroponics, a subset of hydroponics, is a soilless growing technique in which nutrient-rich liquids are misted over roots that are suspended in the air. For various reasons, aeroponics farming is the pinnacle of sustainable farming. As the global population keeps growing, the need for food is predicted to increase. One of the most promising approaches to this problem is aeroponics farming, which provides a sustainable and eco-friendly means of increasing agricultural output. We therefore investigated the potential of aeroponics in promoting sustainable development in the face of rising global concerns such as food poverty, climate change, and limited resources. This study employed a thorough literature review to examine the role of aeroponics in achieving Sustainable Development. The study showed that the potential for aeroponics to transform agriculture and contribute to sustainable practices gets even more intriguing. Aeroponics, with its ability to improve agricultural efficiency and sustainability, holds the potential to reshape global food systems, enhance economic opportunities, and foster more resilient agricultural practices for the future.**

**KEYWORDS:** Aeroponics, Environment, Sustainable Development, Technological Innovations

In the quest for sustainable development, the agricultural sector presents both challenges and opportunities. Traditional farming methods, while foundational to human civilization, have often led to significant environmental degradation, resource depletion, and inefficiencies (Girip *et al.*, 2020). This raises an important question for farmers and the general public alike: How can we produce enough food for a growing global population without exacerbating these issues? Enter aeroponics—a cutting-edge agricultural technology that promises to revolutionize food production while promoting sustainable development (Singh *et al.*, 2024). Aeroponics, a subclass of hydroponics, is growing plants without soil by suspending their roots in the air and misting them with nutrient-rich fluids (Garzón *et al.*, 2023). Unlike traditional soil-based agriculture, aeroponics dramatically reduces the need for water, fertilizers, and pesticides (Lakhiar *et al.*, 2018). This method has garnered significant attention for its potential to deal with several pressing issues in modern agriculture, including water scarcity, land use efficiency, and the carbon footprint of food production (Singh *et al.*, 2024). Global population growth, estimated to reach 10.3 billion in the mid-2080s (UN; 2024), demands a corresponding increase in food production. Simultaneously, climate change presents new concerns, such as uncertain weather events and a rise in the occurrence of extreme weather conditions, which can devastate crops (Kumar *et al.*, 2022). Traditional agricultural methods contribute considerably to greenhouse gas emissions, deforestation, and biodiversity loss, making the need for sustainable alternatives more urgent than ever (Gamage *et al.*, 2023).

A promising solution to these challenges is aeroponics – Where plant develops in the air with the assistance of artificial support rather than soil or substrate culture (Lakhiar *et al.*, 2018). This system makes it possible to cultivate all year round, which can stabilize the food supply and reduce the vulnerability of crops to seasonal changes and climate impacts. This approach also ensures that plants get the ideal amount of oxygen, water, and nutrients, often leading to faster growth rates and higher yields compared to typical farming. According to the NASA paper, the aeroponic system may lowers water, nutrients, and pesticide use by 98, 60, and 100 percent, respectively, and boost plant production by 45 to 75 percent. The system can be highly controlled, allowing precise adjustments to the nutrient mix and environmental conditions, which can be adjusted to the specific needs of each plant species.

One of the most notable advantages of aeroponics is its efficiency. Traditional agriculture consumes vast amounts of water, much of which is lost to evaporation and runoff. In contrast, aeroponics uses even less water than hydroponics and 95% less than conventional farming practices, making it a feasible alternative in urban areas with water constraints (Al-Kodmany; 2018). Furthermore, because the roots receive

[1]**Corresponding author**

direct delivery of the nutritional solutions, there is minimal waste of fertilizers, and the necessity of insecticides is drastically reduced since the controlled environment minimizes pest infestations. For farmers, the adoption of aeroponics can represent a paradigm shift. The possible advantages include quicker growth rates, increased crop yields, and more effective resource usage (Chaudhry and Mishra; 2019; Lakhiar *et al.*, 2018). The soil-free environment minimizes the likelihood of soil-borne pests and diseases, enabling a more environmentally responsible and sustainable way of farming (Yang *et al.,* 2022). This flexibility can enhance food security and provide farmers with new market opportunities.

However, the transition to aeroponics also presents challenges. The initial setup cost for aeroponic systems can be high, which may deter some farmers, particularly those in low-income regions. Additionally, there is a learning curve associated with managing aeroponic systems, which require different skills and knowledge compared to traditional farming (Garzón *et al.,* 2023). Support from governments and agricultural extension services will be crucial in providing the necessary training and financial assistance to facilitate this transition (Behera *et al.*, 2023). The public stands to gain significantly from the widespread adoption of aeroponics. For urban dwellers, produce grown nearby can be fresher, nutrient-dense, and emit less carbon dioxide compared to food transported over long distances (Coelho *et al.,* 2017). Urban aeroponic farms can also contribute to local economies, create jobs, and promote community engagement with sustainable practices.

From a broader perspective, aeroponics aligns with several Sustainable Development Goals (SDGs) established by the United Nations. For instance, it supports SDG 2 (Zero Hunger) by improving food production efficiency and resilience. It also contributes to SDG 6 (Clean Water and Sanitation) through its water-saving capabilities and SDG 13 (Climate Action) by reducing the carbon footprint of agriculture. While the potential of aeroponics is clear, its widespread adoption will require concerted effort from various stakeholders. Governments can play a pivotal role by developing policies that encourage sustainable agricultural practices and by providing subsidies or financial incentives for farmers to adopt aeroponics (Barbosa; 2024). Further, the incorporation of technology into aeroponics has the potential to transform contemporary agriculture by promoting sustainable methods (Garzón *et al.,* 2023). Therefore, Educational institutions and research organizations should focus on advancing technology and making it more accessible and cost-effective. Collaboration between the private sector and non-governmental organizations can also drive innovation and scale up successful models.

Public awareness campaigns can highlight the benefits of aeroponics, encouraging consumers to support sustainably produced food. Community initiatives, such as urban gardening projects and local food networks, can further promote the adoption of aeroponics and integrate it into the social fabric. The promise of aeroponics extends beyond just a new way of growing food; it represents a fundamental shift toward more sustainable and resilient methods of agriculture. By leveraging advanced technology to minimize the impact on the environment and maximize the utilization of resources, aeroponics can play a vital part in achieving sustainable development (Garzón *et al.,* 2023). For farmers, it offers a pathway to higher efficiency and greater market opportunities. For the public, it promises fresher, more sustainable food options. As we advance into the future, the integration of aeroponics into mainstream agriculture holds the ability to transform the way we grow and eat food, fostering a healthier planet for generations to come.

## DATA SOURCE AND METHODS

The methodology for this study involved conducting a comprehensive literature review to assess the potential of aeroponics in advancing sustainable development. Relevant articles, reports, and case studies were sourced from academic databases such as Google Scholar, JSTOR, and ScienceDirect, focusing on studies published between 2006 and 2024. The selection criteria prioritized peer-reviewed publications that addressed key aspects of aeroponic farming, including technological advancements, environmental impacts, and economic and social implications. The gathered findings were then synthesized to offer an extensive and integrated comprehension of the role of aeroponics in achieving sustainable development goals.

## RESULTS AND DISCUSSION

The literature on aeroponics highlights its tremendous potential in addressing critical issues related to global food production, resource conservation, and sustainability. As explored in the reviewed studies, aeroponics offers innovative solutions to some of the most pressing challenges facing modern agriculture, like resource depletion, water scarcity, and the enlarging demand for food in urbanizing regions. The key findings from the literature are summarized below, providing a foundation for the ongoing exploration of this technology's practical application and future potential.

**Resource Efficiency and Sustainability**

A core strength of aeroponics, as identified in the literature (Garzón *et al.,* 2023; Oh and Lu; 2022; Nigadi *et al.,* 2024), is its ability to significantly reduce the use of critical resources such as water and land. Studies suggest that aeroponic systems can use up to 95% less water than traditional agricultural methods (Al-Kodmany; 2018), positioning it as a powerful tool for addressing water scarcity, especially in areas where fresh water is limited. This makes aeroponics an ideal solution for regions with chronic water shortages and could benefit greatly from a more resource-efficient farming method (Ullah and Shabir; 2023). By conserving water, aeroponics helps address the sustainability challenges associated with global water resources, contributing to achieving "Clean Water and Sanitation" (SDG 6).

Moreover, the reduced environmental impact of aeroponics extends beyond water conservation. The absence of soil in aeroponic systems eliminates the issue of soil degradation and reduces the need for insecticides and fertilizers made of chemicals, which often contribute to soil and water pollution (Wimmerova *et al.,* 2022). This highlights the potential of aeroponics to play a role in sustainable agriculture by mitigating the environmental footprint of traditional farming, contributing to environmental sustainability, particularly in the context of "Life on Land" (SDG 15), as it minimizes soil degradation and promotes healthier ecosystems.

**Urban Farming and Food Security**

Another key finding from the literature is the growing relevance of aeroponics in urban farming. As urbanization accelerates globally, there is an increasing need for locally sourced, fresh produce. Aeroponic systems, with their compact and vertical farming structures, can be integrated into urban spaces, such as rooftops and unused industrial areas, to cultivate crops year-round (M. A. Lakhiar *et al.,* 2020). This allows urban residents to access fresh, nutritious food while cutting down on the carbon footprint of long-distance food transportation (Puigdueta *et al.,* 2021). This leads directly to achieving "Sustainable Cities and Communities" (SDG 11). Furthermore, the increased resilience of urban food systems enabled by aeroponics is particularly valuable in times of climate change and global supply chain disruptions (Kaushik and Tare; 2024).

Urban aeroponics offers additional social benefits by promoting food sovereignty in cities, allowing urban populations to take control of their food sources, especially in areas where traditional farming is not feasible due to limited space or land availability (Oh and Lu; 2022). By decentralizing food production, aeroponics can reduce dependency on external food systems and help ensure food security in densely populated urban centers.

**Technological Advancements and Increased Productivity**

The adoption of modern technologies, such as the Internet of Things (IoT), has significantly enhanced the efficiency and effectiveness of aeroponic systems. Real-time monitoring of key environmental variables like humidity, temperature, and nutrient levels allows for precise alteration that maximizes the development of plants and productivity (Méndez-Guzmán *et al.,* 2022). This technological sophistication not only improves the health and growth rates of plants but also reduces the labor intensity required by traditional farming methods (Ikram *et al.,* 2024; Somashekhar *et al.,* 2024). The automation of these systems makes aeroponics an appealing option for both small-scale and commercial farmers, as it reduces the dependency on manual labor and offers greater scalability. Such innovations align with sustainable agriculture principles by promoting "Sustainable Consumption and Production" (SDG 12), as they contribute to more efficient and responsible farming practices.

Additionally, the development of customized nutrient delivery systems has been a game changer in improving crop yields and shortening growth cycles (Ikram *et al.,* 2024). These nutrient solutions are designed to satisfy the unique requirements of various plants, leading to healthier crops and increased yields. As a result, aeroponics can contribute to meeting the increasing global food demand, especially in light of a rapidly growing global population. By increasing food production while reducing resource inputs, aeroponics directly contributes to sustainable food systems, supporting the UN's goal of "Zero Hunger" (SDG 2).

**Economic Viability and Opportunities for Small-Scale Farmers**

One of the more promising aspects of aeroponics is its capability to foster economic growth, especially for small-scale cultivators (I. A. Lakhiar *et al.,* 2018; Jassem and Razzak; 2020). Traditional agricultural methods often place smallholders at a disadvantage due to high resource input costs and limited access to markets. Aeroponics, on the other hand, reduces resource consumption while potentially increasing yields, which can improve profitability for farmers. The scalability of aeroponic systems allows small-scale farmers to start with smaller setups and gradually expand as they gain expertise, making it a viable entry point into commercial farming. The economic utilization of resources and the potential for greater food production directly align with the goals of "Decent Work and Economic Growth" (SDG 8), as it creates opportunities for new businesses and encourages the selection of sustainable actions.

Moreover, the establishment of aeroponic farms in urban areas can generate new employment opportunities in the agricultural sector, supporting local economies and fostering community involvement (Benke and Tomkins; 2017; Partanen and Witikainen; 2022). This is key to achieving "Reduced Inequalities" (SDG 10). By leveraging local talent and resources, aeroponics can also encourage sustainable business models and community-driven agriculture, further reinforcing the economic benefits of this innovative farming method.

### Challenges and Future Directions

Despite its numerous advantages, the adoption of aeroponics encounters numerous challenges that need to be overcome to fully unlock its potential for sustainable development. One primary obstacle is the high initial setup cost of aeroponic systems. The specialized equipment, infrastructure, and technology required for aeroponic farming can be costly, which may make it less accessible for small-scale farmers, especially in developing regions (Méndez-Guzmán *et al.*, 2022). While the long-term operational costs tend to be lower compared to traditional farming, the upfront investment remains a significant barrier for many potential users.

Another challenge is the need for ongoing technical support and system maintenance. Aeroponic systems require regular monitoring to ensure they are functioning optimally. Any failure to maintain proper nutrient balances or environmental conditions can lead to crop failure, making these systems vulnerable to operational difficulties (Ikram *et al.*, 2024). To address this challenge, future developments should focus on making aeroponic systems more user-friendly and easier to maintain, reducing the technical expertise required for their operation.

Looking forward, there is significant potential for further research and innovation in aeroponics. Advancements in automation, AI, and machine learning could optimize system operations, making them even more efficient and scalable. Increased investment in research and development can help lower costs and enhance the design of aeroponic mechanisms, making them more accessible and adaptable to different regions and contexts (Roshitha *et al.*, 2024). Collaborative efforts between researchers, policymakers, and industry leaders will be essential to overcoming these challenges and fostering the widespread adoption of aeroponics as a mainstream agricultural practice, thus supporting the achievement of Sustainable Development Goals of the United Nations, notably those pertaining to sustainable agriculture, food security, and environmental sustainability.

## CONCLUSION

Aeroponics offers a viable remedy to a multitude of problems of contemporary agriculture, like resource depletion, water scarcity, food insecurity, and the environmental impacts of traditional farming practices. Its integration with state-of-the-art technologies, such as IoT and customized nutrient systems, offers significant potential to improve productivity, enhance sustainability, and create economic opportunities for farmers. To fully realize its potential, continued research, investment, and collaboration will be essential to overcoming current limitations and enabling the widespread adoption of aeroponics as a mainstream agricultural practice. As the entire world struggles with issues like climate change and rising population, aeroponics offers a sustainable path forward to ensure food security and environmental resilience in the coming decades.

## REFERENCES

Al-Kodmany K., 2018. The vertical farm: a review of developments and implications for the vertical city. Buildings, **8**(2): 24.

Barbosa M.W., 2024. Government Support Mechanisms for Sustainable Agriculture: A Systematic Literature Review and Future Research agenda. Sustainability, **16**(5):2185. https://doi.org/10.3390/su16052185

Behera B., Mallick B. and Saikanth, 2023. Bridging the Gap: The Crucial Role of Agricultural Extension in Advancing Digital Agriculture in India. In Advanced Farming Techniques (Vol.2). BS Global Publication House. https://www.researchgate.net/publication/374006548

Benke K. and Tomkins B., 2017. Future food-production systems: vertical farming and controlled-environment agriculture. Sustainability Science Practice and Policy, **13**(1): 13–26. https://doi.org/10.1080/15487733.2017.1394054

Chaudhry A.R. and Mishra V.P., 2019. 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.

Coelho F.C., Coelho E.M. and Egerer M., 2017. Local food: benefits and failings due to modern agriculture. Scientia Agricola, **75**(1): 84–94. https://doi.org/10.1590/1678-992x-2015-0439

Gamage A., Gangahagedara R., Gamage J., Jayasinghe N., Kodikara N., Suraweera P. and Merah O., 2023. Role of organic farming for achieving sustainability in agriculture. Farming System, **1**(1):100005. https://doi.org/10.1016/j.farsys.2023.100005

Garzón J., Montes L., Garzón J. and Lampropoulos G., 2023. Systematic Review of Technology in Aeroponics: Introducing the Technology Adoption and Integration in Sustainable Agriculture Model. Agronomy, **13**(10): 2517. https://doi.org/10.3390/agronomy13102517

Girip M., Mărăcine D. and Dracea L., 2020. Environmental impact of conventional agriculture. (DOAJ: Directory of Open Access Journals). https://doaj.org/article/ef184b85ec9f40f2b1b71c9cbad7c018

Ikram M., Ameer S., Kulsoom F., Sher M., Ahmad A., Zahid A. and Chang Y., 2024. Flexible temperature and humidity sensors of plants for precision agriculture: Current challenges and future roadmap. Computers and Electronics in Agriculture, **226**: 109449. https://doi.org/10.1016/j.compag.2024.109449

Jassem S. and Razzak M.R., 2020. Entrepreneurship in Urban Jungles through High-Tech Vertical Farming. In Intech Open eBooks. https://doi.org/10.5772/intechopen.93667

Kaushik K. and Tare K., 2024. Aeroponics Farming System: A Step Towards Modern Agriculture. Food and Scientific Reports, **5**(5): 48-52.

Kumar L., Chhogyel N., Gopalakrishnan T., Hasan M. K., Jayasinghe S.L., Kariyawasam C.S., Kogo B.K. and Ratnayake S., 2022. Climate change and future of agri-food production. In Elsevier eBooks (pp. 49–79). https://doi.org/10.1016/b978-0-323-91001-9.00009-8

Lakhiar I.A., Gao J., Syed T.N., Chandio F.A. and Buttar N.A., 2018. Modern plant cultivation technologies in agriculture under controlled environment: a review on aeroponics. Journal of Plant Interactions, **13**(1): 338–352. https://doi.org/10.1080/17429145.2018.1472308

Lakhiar M.A., Gao J., Syed T.N., Chandio F.A., Tunio M.H., Ahmad F. and Solangi K.A., 2020. Overview of the aeroponic agriculture – An emerging technology for global food security. International Journal of Agricultural and Biological Engineering, **13**(1): 1–10. https://doi.org/10.25165/j.ijabe.20201301.5156

Lakhiar I.A., Jianmin G., Syed T.N., Chandio F.A., Buttar N.A. and Qureshi W.A., 2018. Monitoring and control systems in agriculture using intelligent sensor techniques: A review of the Aeroponic system. Journal of Sensors, pp. 1–18. https://doi.org/10.1155/2018/8672769

Méndez-Guzmán H.A., Padilla-Medina J.A., Martínez-Nolasco C., Martinez-Nolasco J.J., Barranco-Gutiérrez A.I., Contreras-Medina L.M. and Leon-Rodriguez M., 2022. IoT-Based monitoring system applied to aeroponics Greenhouse. Sensors, **22**(15): 5646. https://doi.org/10.3390/s22155646

NASA Spinoff., 2006. Innovative Partnership Program, Publications and Graphics Department NASA Center for Aerospace Information (CASI).

Nigadi R., Ramalingannanavar N., Kumari N., Bhagwat S., Rawat G., Kadam G., Khadatare M., Keskar P. and Jagtap D., 2024. Assessment of water use efficiency and fertilizer use efficiency of solar-powered aeroponic system. International Journal of Research in Agronomy, **7**(6): 220–223. https://doi.org/10.33545/2618060x.2024.v7.i6d.844

Oh S. and Lu C., 2022. Vertical farming - smart urban agriculture for enhancing resilience and sustainability in food security. The Journal of Horticultural Science and Biotechnology, **98**(2): 133–140. https://doi.org/10.1080/14620316.2022.2141666

Partanen H.R. and Witikainen T., 2022. How to attract new target groups to address the SDG objectives: The case of an intelligent aeroponic community garden: Workings of Transformation. The Journal of Sustainability Education, Part Two (General Issue).

Puigdueta I., Aguilera E., Cruz J.L., Iglesias A. and Sanz-Cobena A., 2021. Urban agriculture may change food consumption towards low carbon diets. Global Food Security, **28**: 100507. https://doi.org/10.1016/j.gfs.2021.100507

Roshitha T., Sekhar, Kumar D., Ramesh, Kumar M. and Prasad S., 2024. IoT enhanced Smart

Aeroponics System. International Journal for Research in Applied Science and Engineering Technology, **12**(5): 3183–3193. https://doi.org/10.22214/ijraset.2024.61714

Singh P., Singh S. and Upadhyay A., 2024. Aeroponics: Innovations and Challenges in Modern Farming Technique. In Innovative Approaches towards Horticultural Sustainability (pp. 1–10). Golden Leaf Publishers.

Somashekhar, Keshavamurthy and Prakash, 2024. Sustainable Farming Using Aeroponics Cultivation. In Futuristic Trends in Network & Communication Technologies (pp. 72–90). https://doi.org/10.58532/v3bgnc2p2ch3

Ullah M.K. and Shabir S., 2023. The significant effects of agricultural systems on the environment. Journal of World Science, **2**(6): 798–805. https://doi.org/10.58344/jws.v2i6.291

Wimmerova L., Keken Z., Solcova O., Bartos L. and Spacilova M., 2022. A comparative LCA of aeroponic, hydroponic, and soil cultivations of bioactive substance producing plants. Sustainability, **14**(4): 2421. https://doi.org/10.3390/su14042421

World Population Prospects, 2024. Department of Economic and Social Affairs, United Nations.

Yang X., Luo Y. and Jiang P., 2022. Sustainable Soilless Cultivation Mode: Cultivation Study on Droplet Settlement of Plant Roots under Ultrasonic Aeroponic Cultivation. Sustainability, **14**(21): 13705. https://doi.org/10.3390/su142113705