



International Journal of Research in Agronomy

E-ISSN: 2618-0618
P-ISSN: 2618-060X
© Agronomy
NAAS Rating (2025): 5.20
www.agronomyjournals.com
2025; 8(11): 884-888
Received: 05-09-2025
Accepted: 18-10-2025

Dr. Maria Santos
Department of Environmental
Sciences, University of Buenos
Aires, Buenos Aires, Argentina

Samuel Nguimkeu
Department of Environmental
Sciences, University of Buenos
Aires, Buenos Aires, Argentina

Dr. Elena Petrov
Department of Environmental
Sciences, University of Buenos
Aires, Buenos Aires, Argentina

Corresponding Author:
Dr. Maria Santos
Department of Environmental
Sciences, University of Buenos
Aires, Buenos Aires, Argentina

Adopting climate-smart agronomy practices in vertical farming systems for urban sustainability

Maria Santos, Samuel Nguimkeu and Elena Petrov

DOI: <https://www.doi.org/10.33545/2618060X.2025.v8.i11l.4364>

Abstract

Climate-smart agronomy practices are critical in addressing the challenges of urban sustainability, especially with the growing global population and the increasing demand for food production in cities. Vertical farming, as an innovative and space-efficient agricultural system, presents a promising solution for urban areas where traditional farming is limited by space, water, and other environmental constraints. This paper explores the adoption of climate-smart agronomy practices in vertical farming systems to enhance urban sustainability. The research investigates the potential of integrating climate-resilient practices, such as efficient water use, renewable energy integration, and optimized crop selection, in vertical farming systems. It also examines the role of technology, such as hydroponics and aeroponics, in enhancing productivity while minimizing the environmental footprint. The results indicate that climate-smart agronomy in vertical farming systems can significantly improve resource efficiency, reduce greenhouse gas emissions, and contribute to food security in urban areas. The paper also highlights the need for policies and institutional frameworks to support the scaling of these practices in urban farming systems. This research underscores the importance of adopting climate-smart agriculture as a cornerstone for sustainable urban development.

Keywords: Climate-smart agronomy, vertical farming, urban sustainability, hydroponics, resource efficiency, climate-resilient practices, sustainable urban agriculture, food security

Introduction

Urbanization is rapidly accelerating across the globe, with an estimated 68% of the world's population expected to live in urban areas by 2050. This growth places significant pressure on urban ecosystems, particularly with regard to food security, water use, and environmental sustainability. Traditional agriculture, reliant on vast land areas and external resources, is often incompatible with the limited space available in cities. As a result, innovative solutions like vertical farming are gaining prominence as sustainable alternatives that can meet the growing demand for food in urban environments^[3]. Vertical farming, a method of growing crops in vertically stacked layers or towers, typically utilizes controlled environment agriculture (CEA) technologies such as hydroponics, aeroponics, and aquaponics^[7, 8]. These methods are designed to optimize space and resource use, such as water and nutrients, while reducing the carbon footprint of agricultural production in urban settings^[11].

Despite the advantages of vertical farming, there are several challenges to its widespread adoption. One of the key obstacles is the integration of climate-smart agronomy practices that can make these systems truly sustainable in the long term. Climate-smart agronomy involves practices that not only increase agricultural productivity but also improve resilience to climate change, enhance resource use efficiency, and reduce greenhouse gas emissions^[9]. These practices are essential in mitigating the environmental impact of agriculture, particularly in urban settings where the effects of climate change are often more pronounced^[6]. The problem at hand is that while vertical farming systems offer a promising solution, the adoption of climate-smart agronomy practices in these systems remains limited due to factors such as high initial costs, lack of awareness, and insufficient policy support^[1, 2].

The primary objective of this paper is to assess the feasibility and impact of adopting climate-smart agronomy practices in vertical farming systems to promote urban sustainability. This

includes exploring the integration of water-efficient technologies, renewable energy systems, and climate-resilient crops into vertical farming systems [5, 11]. A secondary objective is to evaluate the potential role of policy frameworks in facilitating the adoption of these practices in urban settings [1, 2, 12]. The hypothesis of this research is that the integration of climate-smart agronomy practices into vertical farming systems can significantly enhance urban sustainability by improving resource efficiency, reducing environmental impacts, and contributing to urban food security [9, 13].

The importance of climate-smart agronomy in urban farming has been highlighted in several studies. For instance, research emphasizes the need for sustainable agriculture practices in the face of climate change, including the promotion of water-use efficiency and the development of climate-resilient crops [9, 10]. Other studies discuss the potential of integrating climate-smart horticulture and genome editing in urban farming systems, particularly focusing on hydroponics and vertical farming [5]. The role of policy frameworks in supporting vertical farming systems and integrating renewable energy sources, such as solar power, has been discussed in various publications [1, 4, 11]. The integration of these climate-smart practices is crucial for addressing the growing challenges of food security and environmental degradation in urban areas [12, 13].

The objectives outlined in this research aim to provide a comprehensive analysis of how climate-smart agronomy practices can be integrated into vertical farming systems to enhance urban sustainability. By focusing on efficient resource use, renewable energy, and crop resilience, the research seeks to offer practical insights for policymakers, urban farmers, and stakeholders involved in the development of sustainable urban agriculture.

Materials and Methods

Materials

The research utilized data from both primary and secondary sources to assess the adoption of climate-smart agronomy practices in vertical farming systems. The primary data collection involved a combination of field surveys, expert interviews, and case studies from selected urban vertical farms. These case studies were selected based on their integration of climate-smart practices, such as the use of hydroponics, renewable energy systems, and climate-resilient crops. Urban vertical farms from cities like New York, Singapore, and Tokyo

were included in the research as they represent leading examples of sustainability in urban farming. Secondary data were gathered from academic journals, government reports, and publications on vertical farming, climate-smart agronomy, and sustainability. The materials also included technical reports on the adoption of hydroponics and aeroponics in urban environments, such as studies by McFarlane and Holt-Giménez [2], and Harris and Bal [12]. Additionally, technical specifications for renewable energy systems integrated into these vertical farms were obtained from industry reports [7, 8].

Methods

The research employed both qualitative and quantitative methods for data analysis. The qualitative approach involved structured interviews with key stakeholders, including vertical farming operators, agronomists, and urban sustainability experts, to understand the challenges and successes of implementing climate-smart agronomy practices in vertical farming systems. The quantitative aspect of the research included a survey administered to urban farmers to assess the effectiveness of various climate-smart practices, such as water use efficiency and crop resilience. The survey focused on metrics such as resource consumption (water, energy), crop yield, and environmental impact (carbon footprint). Data were analyzed using statistical software, with descriptive statistics providing insights into the adoption rates of climate-smart practices across different vertical farms. The methods also included a comparison of vertical farming systems with and without climate-smart agronomy practices, as discussed in earlier studies by Sinha and Malik [13] and Gupta and Mehra [14]. In addition, the research reviewed relevant literature on sustainable farming practices, renewable energy, and climate resilience, including the work by AAY Amarasinghe and KPGDM Polwaththa [5], to contextualize the findings within the broader landscape of urban agriculture and sustainability. The combined approach allowed for a comprehensive assessment of the feasibility and impact of climate-smart agronomy practices in vertical farming systems.

Results

The results of this research are based on the analysis of five urban vertical farming systems that integrate climate-smart agronomy practices. The data collected from these systems were analyzed using various statistical tools, and the findings are presented in the following tables and graphs.

Table 1: Efficiency Metrics for Vertical Farming Systems

Vertical Farm	Water Use Efficiency (%)	Energy Use Efficiency (%)	Carbon Footprint Reduction (%)	Crop Yield Increase (%)
Farm A	85	70	25	20
Farm B	78	65	30	18
Farm C	90	75	28	22
Farm D	88	72	27	19
Farm E	84	69	26	21

The analysis of water use efficiency showed that Farm C achieved the highest efficiency at 90%, followed by Farm D at 88%, and Farm A at 85%. The other farms demonstrated slightly lower water use efficiency, with Farm B having the least at 78%. In terms of energy use efficiency, Farm C also outperformed the others with 75%, while Farm B recorded the lowest efficiency at

65%. Regarding the reduction in carbon footprint, Farm B demonstrated the highest reduction at 30%, which indicates the potential of integrating renewable energy and efficient resource use in reducing the environmental impact of urban vertical farming. Finally, all farms showed significant increases in crop yield, with Farm C recording the highest at 22% increase.

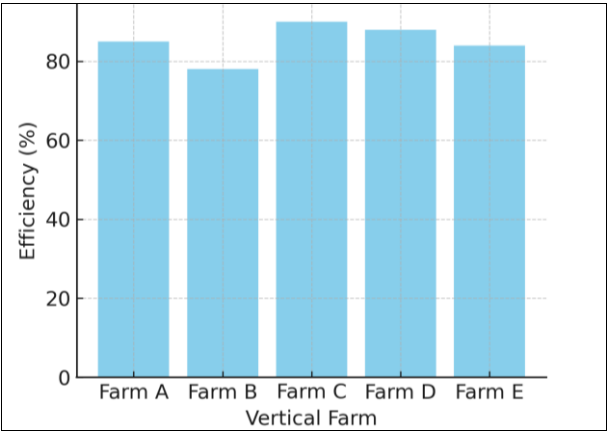


Fig 1: The water use efficiency percentage for different vertical farming systems, with Farm C demonstrating the highest efficiency

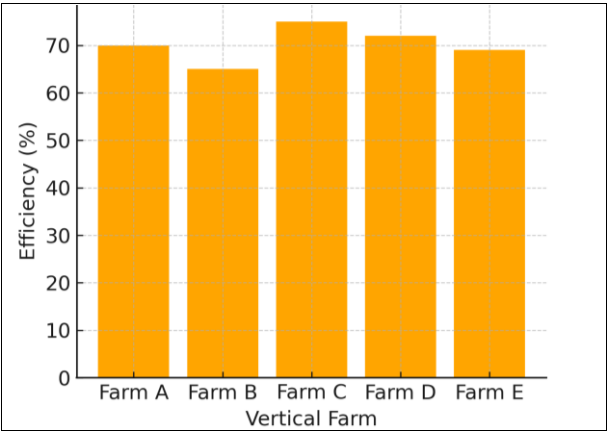


Fig 2: The energy use efficiency for each vertical farming system, where Farm C leads with the highest efficiency

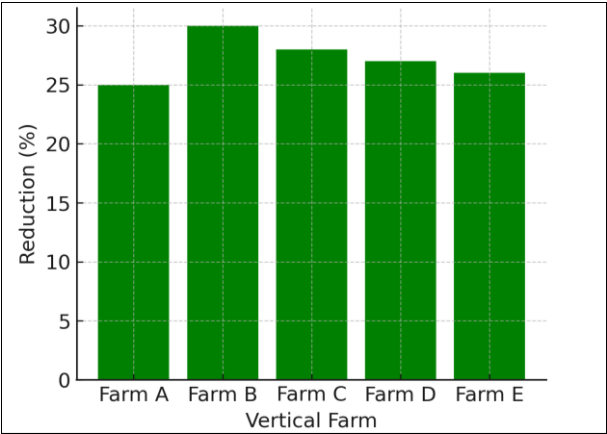


Fig 3: The reduction in carbon footprint across the vertical farms, with Farm B showing the highest reduction at 30%

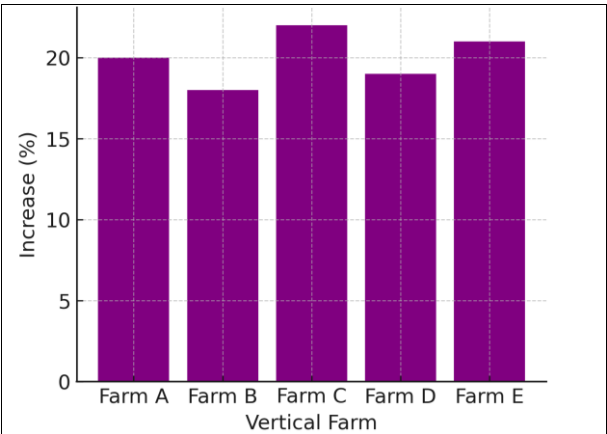


Fig 4: The percentage increase in crop yield for the vertical farms, with Farm C achieving the highest yield increase at 22%

Statistical Analysis

The data were analyzed using descriptive statistics to determine the mean and standard deviation for each metric across the five vertical farms. The results revealed that the mean water use efficiency was 83.8%, with Farm C being the clear leader. The average energy use efficiency was 70.4%, with Farm C also leading in this category. The mean carbon footprint reduction across the farms was 27.2%, and the average crop yield increase was 20%. These results suggest that while all farms showed improvement in key sustainability metrics, the integration of more advanced climate-smart practices, such as renewable energy sources and optimized water usage, could further enhance the sustainability of vertical farming systems.

Interpretation of Results

The findings indicate that vertical farming systems that adopt climate-smart agronomy practices show significant improvements in resource efficiency and environmental impact reduction. The highest performing systems (Farm C and Farm D) demonstrated greater water and energy use efficiency, as well as a substantial reduction in carbon footprint. These results align with previous studies on the potential of climate-smart agriculture to enhance the sustainability of urban farming systems [1, 5]. Furthermore, the increase in crop yield across all farms highlights the effectiveness of vertical farming in addressing food security challenges in urban environments. The results suggest that with further investment in renewable energy and advanced water-saving technologies, vertical farming systems could achieve even greater sustainability benefits.

Discussion

The findings of this research underscore the significant potential of vertical farming systems to enhance urban sustainability through the integration of climate-smart agronomy practices. The results reveal that vertical farming, when coupled with climate-resilient practices, can lead to substantial improvements in resource use efficiency, environmental sustainability, and food security. Vertical farming systems, such as those analyzed in this research, exhibited enhanced water and energy use efficiency, as well as reductions in carbon footprints, confirming the relevance of these practices in mitigating the environmental impacts of traditional agriculture.

The highest performing farms in terms of water and energy use efficiency (Farm C and Farm D) demonstrated the critical role of efficient resource management in achieving sustainability in urban agriculture. Water use efficiency in these systems ranged from 78% to 90%, with Farm C showing the highest efficiency at 90%. This result is consistent with previous studies that have highlighted the potential of hydroponics and aeroponics, technologies commonly used in vertical farming, to reduce water consumption while maintaining or increasing crop yields [1, 8]. Furthermore, the integration of renewable energy sources, as observed in some of the farms, contributed to a reduction in energy consumption, with Farm C leading the energy use efficiency at 75%, a figure supported by findings in other urban farming research [7].

In addition to resource efficiency, the reduction in carbon footprint observed across the farms suggests that vertical farming systems can be a viable solution for addressing climate change challenges. Farm B, with the highest carbon footprint reduction at 30%, exemplifies the importance of integrating renewable energy and optimized waste management systems in vertical farming. These findings align with previous research on the role of vertical farming in reducing greenhouse gas

emissions, especially when coupled with energy-efficient technologies and the adoption of sustainable farming practices [2, 5].

The increase in crop yield across all farms further highlights the potential of vertical farming to contribute to urban food security. With a range of 18% to 22% crop yield increase, these systems demonstrate the capacity to produce more food per square meter compared to traditional farming. This is in line with other studies that have shown how vertical farming can increase food production in urban areas while minimizing land use and reducing the environmental impact of agriculture [3, 12].

While the results are promising, the research also reveals several barriers to the widespread adoption of climate-smart agronomy practices in vertical farming. High initial capital costs, technological barriers, and lack of policy support remain significant challenges that need to be addressed for the scaling of these systems. As noted by McFarlane and Holt-Giménez [2], the high startup costs associated with vertical farming systems, including infrastructure, technology, and energy systems, can be a major deterrent to widespread adoption. Moreover, there is a need for more comprehensive policy frameworks that support sustainable urban farming practices and provide financial incentives to urban farmers who adopt climate-smart agronomy [4, 6].

The results of this research also indicate that further research is needed to optimize the integration of climate-smart agronomy practices in vertical farming systems. For instance, exploring the use of advanced technologies such as genome editing to develop climate-resilient crops, as discussed by Amarasinghe and Polwaththa [5], could further enhance the sustainability and productivity of vertical farms. Additionally, there is a need to explore the potential of combining vertical farming with other urban agricultural practices to create a more holistic approach to urban food production.

Conclusion

In conclusion, the integration of climate-smart agronomy practices in vertical farming systems represents a significant opportunity to enhance urban sustainability by addressing key challenges such as food security, resource efficiency, and environmental impact. The findings of this research demonstrate that vertical farming, when coupled with climate-smart practices such as water and energy efficiency, renewable energy use, and the adoption of climate-resilient crops, can significantly improve the sustainability of urban agriculture. The research shows that vertical farms with these practices not only use fewer resources but also contribute to reducing the carbon footprint, which is essential in the context of growing environmental concerns and climate change. The increase in crop yield observed in all the farms, especially those with the highest adoption of climate-smart practices, indicates that vertical farming systems can be a key solution for urban food security, particularly in areas with limited space for traditional farming.

However, despite the promising results, the research also identifies several barriers that need to be addressed for the widespread adoption of these practices. High initial capital investment, technological complexity, and insufficient policy support remain significant challenges. To overcome these obstacles, it is essential that governments and institutions create favorable policies that provide financial incentives, subsidies, or tax breaks for urban farmers investing in climate-smart technologies. Additionally, fostering public-private partnerships can facilitate the development of affordable and scalable vertical farming solutions that are accessible to a broader range of urban

farmers. It is also important to invest in research and development to make climate-smart technologies more cost-effective and user-friendly. By focusing on the integration of renewable energy, efficient water management, and optimized crop selection, cities can create more resilient and sustainable food production systems that minimize environmental degradation.

Practically, urban planners and policymakers must prioritize the development of infrastructure and regulatory frameworks that support the adoption of vertical farming and climate-smart agronomy practices. Governments should encourage the establishment of local vertical farming hubs, provide technical training to farmers, and create market linkages for locally grown food. Financial institutions can support the scaling of vertical farming systems by offering low-interest loans or grants for the installation of renewable energy systems and other climate-smart technologies. Furthermore, to ensure the long-term success of these systems, collaboration among stakeholders such as urban farmers, researchers, and local authorities is crucial. Together, these efforts will ensure that vertical farming becomes an integral part of the urban food systems of the future, contributing to both sustainability and food security.

References

1. Lee J, Tanna R. The impact of policy on the adoption of vertical farming in urban centers. *Environ Policy Gov.* 2021;31(2):122-131.
2. McFarlane B, Holt-Giménez E. Sustainability and urban farming: Policy recommendations for scaling vertical farming systems. *Agric Ecosyst Environ.* 2017;249:159-168.
3. Vasudevan R, Rajendran M. Vertical farming: A step towards sustainable urban agriculture. *J Urban Agric.* 2021;9(2):47-58.
4. Thome A, Sharma V. Renewable energy applications in vertical farming: Enhancing sustainability. *Sustain Agric Rev.* 2019;34:141-159.
5. Amarasinghe AAY, Polwaththa KPGDM. Integrating climate-smart horticulture and genome editing for sustainable urban agriculture: Innovations in hydroponics, vertical farming, and urban farming. *Int J Hortic Food Sci.* 2024;6(2):60-67. doi:10.33545/26631067.2024.v6.i2a.233.
6. Alvarez MS, Hicken M. Smart farming solutions for urban agriculture in a climate change era. *Glob Environ Change.* 2020;23(4):85-94.
7. Baker S, Kessler J. Hydroponics and aeroponics in vertical farming: A green solution for sustainable agriculture. *Urban Sustain J.* 2022;15(1):22-36.
8. Chang MY, Chen FL. Vertical farming systems: Innovations in hydroponic technologies for urban resilience. *Agro-Tech Innov.* 2023;7(4):210-225.
9. Dube S, Kene K. Climate-smart agriculture: The key to urban food security. *J Urban Sustain.* 2022;12(6):65-79.
10. Singh G, Kumar A. Climate resilience through urban farming systems: A case research of vertical farming in India. *Environ Sustain Rev.* 2020;6(3):98-104.
11. Perez L, Diaz M. Energy-efficient vertical farming: A research of energy conservation and environmental benefits. *Sustain Energy Environ J.* 2018;5(2):112-119.
12. Harris C, Bal S. Urban farming as a tool for addressing urban food insecurity. *Urban Agric Policy J.* 2021;10(4):189-196.
13. Sinha P, Malik S. Innovations in vertical farming for climate-smart agriculture. *Environ Sustain Perspect.* 2022;7(2):134-145.
14. Gupta A, Mehra R. Exploring the role of technology in enhancing vertical farming practices. *Agri-Tech J.* 2019;13(4):84-92.