**Sustainable Urban Horticulture Practices: A Review**

**Abstract**

Urban horticulture contributes importantly to food security, biodiversity, and environmental sustainability. With the urban population growing, there has been a higher demand for green spaces, sustainable production of food, and optimal use of resources. In this review, different sustainable practices in urban horticulture, such as vertical gardening, hydroponics, aquaponics, rooftop gardening, composting, and rainwater harvesting, are presented. Moreover, it emphasizes the contribution of urban agroforestry, intelligent irrigation technologies, and integrated pest management in developing sustainable urban green spaces. The advantages and drawbacks of these practices are discussed, highlighting their contribution to urban ecology, climate resilience, socio-economic well-being, and environmental protection. The article concludes by making suggestions for policy integration, technological innovation, and public participation to ensure sustainability in urban horticulture. In addition, future visions for sustainable urban food production, new green technologies, and urban agriculture's incorporation into city planning are addressed to increase its long-term sustainability and efficacy.

**Introduction**

The widespread urbanization being experienced across the world has necessitated the integration of new and sustainable agricultural technologies into cities. Urban horticulture, defined as the practice of growing plants within urban centers, has various advantages, including enhancing air quality, mitigating the effects of urban heat island, food security, and psychological well-being (Khanpoor-Siahdarka, and Masnavi, (2025). Urban horticulture also promotes carbon sequestration, preservation of biodiversity, and climate change mitigation (Sia et al., 2023).

The fast urbanization of populations and the loss of land pose major challenges to sustainable crop production in cities. Throughout the globe, numerous people experience food insecurity and malnutrition, highlighting the necessity for innovative agricultural practices. Urban horticulture the production of vegetables, herbs, medicinal, and ornamental plants in and around cities provides a promising strategy for solving these problems (Priya, and Senthil, (2024).

But city farmers tend to face erratic seasonal temperatures, low yields, and losses, which necessitate embracing new methods and equipment to boost productivity (Sung et al., 2025). While the advantages of recent innovations in urban horticulture are evident, many recent innovations demand significant capital outlay, expertise, and access to production, processing, and marketing resources (Fei et al., 2025).

Yet, demands such as land availability, pollution, and resource management necessitate the incorporation of sustainable measures. Additionally, inefficient usage of water, lack of public awareness, and regulatory barriers present overriding challenges to its widespread adoption. Technology, policy initiatives, and public participation are needed to overcome these (Ndubuisi et al., 2025).

This review discusses major sustainable horticultural practices, their implications towards urban resilience and sustainability, and the contribution of innovative approaches such as smart agriculture, renewable energy integration, and urban agroforestry towards achieving a greener future.

**Purpose**

The purpose of this review is to assess and point out sustainable practices in urban horticulture for environmental, social, and economic benefits. This review seeks to:

Evaluate the efficiency of different sustainable urban horticultural practices in enhancing food security, minimizing environmental degradation, and improving urban beauty (Khan et al., 2020). Recognize challenges with the application of these practices in urban areas, such as economic, infrastructural, and policy-based limitations (Sashika et al., 2024). Discuss possible policy interventions, technological innovations, and best practices that can be embraced to improve the sustainability of urban horticulture programs (Sanyé-Mengual et al., 2019). Promote community engagement in urban horticulture programs through awareness, education, and cooperation among stakeholders such as local authorities, urban planners, researchers, and residents (Jahrl et al., 2021). Explore the potential of new technologies like artificial intelligence, precision agriculture, and climate-responsive systems in maximizing urban horticulture operations (Stephens, (2023). Study the economic viability of sustainable urban horticulture and its job creation, entrepreneurship, and self-sufficiency potential in urban communities (Ikerd, (2018).

**Sustainable Urban Horticulture Practices: Strategies for a Greener Future**

**Vertical Gardening**

Increases space efficiency and urban beauty by using walls and vertical surfaces for plant cultivation. This method is especially useful in highly populated cities where horizontal space is scarce (Mir et al., 2022). Vertical gardens improve air quality by purifying pollutants, offer building insulation to maintain temperature, and promote biodiversity through the creation of microhabitats for beneficial birds and insects (Praveen et al., 2015). Furthermore, they can also be used as a productive way of urban food cultivation, limiting dependence on outside sources of food and supporting local food security. Technologies like hydroponic and aeroponic vertical garden systems further optimize vertical gardening in urban environments in terms of sustainability and efficiency (Akintuyi, 2024).



Figure-1. Image of Vertical Farming Unit

Vertical farming is a novel agricultural method where crops are grown in vertically stacked layers in controlled environments. This method optimizes space use, which is especially useful in urban settings where land is limited (Vatistas et al., 2022; Linn, 2024). By incorporating cutting-edge technologies like climate control, artificial lighting, and automation, vertical farming optimizes growing conditions to produce crops year-round with minimal resource use.

An advantage of vertical farming is that it is adaptable to various soilless growing methods like hydroponics and aeroponics that further boost output while minimizing the use of water and nutrients (AlShrouf, 2017). The two offer precise nutrient supplementation and lower reliance on conventional earth-based agriculture and thereby eliminate exposure to threats emanating from land degradation, infestations, and disease. Moreover, the closed environment of vertical farm systems reduces exposure to external contaminants as well as unfavorable weather, which guarantees consistent and quality crop yields (Kalantari et al., 2018).

Apart from being more efficient in terms of food production, vertical farming is also a key component of sustainability. With less requirement for large expanses of land, less use of pesticides, and greatly reduced water requirements, it provides a sustainable alternative to traditional methods of farming. Additionally, being able to grow crops nearer to urban areas saves on transportation and related carbon emissions and makes the food supply chain more sustainable (Touliatos et al., 2016; Panotra et al., 2024).

Even with its several advantages, vertical farming is disadvantageous in terms of high initial equipment costs, massive energy expenditure for artificial lighting and environmental control, and the demand for expert technical knowledge (Benke, and Tomkins, 2017). Nevertheless, with progress in renewable energy integration, automation, and intelligent farming technologies, vertical farming remains a potential answer to global food security and environmental issues (Saad et al., 2021).

### Table 1. List of different vertical farms in the words

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **S.**  **No.** | **Name** | **Location** | **Products** | **Technology** | **Year** | **Website** |
| 1. | The Plant Vertical Farm | Chicago | Artisanal brewery and Mushroom farm | Aquaponics system | 2013 | [www.plantchicago.com](http://www.plantchicago.com/) |
| 2. | Sky Greens Farm | Singapore | Leafy green vegetables | Aeroponics system | 2009 | [www.skygreens.appsfly.com/](http://www.skygreens.appsfly.com/) |
| 3. | VertiCrop | Canada | Leafy greens and Strawberries | Fully automated system | 2009 | [www.verticrop.com](http://www.verticrop.com/) |
| 4. | Nuvege Plant Factory | Japan | Leafy green vegetables | Automated rack system, LED grow lights | 2010 | [www.nuvege.com](http://www.nuvege.com/) |
| 5. | Plantlab VF | Holland | Beans, Corn, Cucumbers, Tomatoes,  Strawberries | Advanced LED Aeroponics and Hydroponics | 2011 | [www.plantlab.in](http://www.plantlab.in/) |
| 6. | Vertical Harvest | USA | Tomotoes, Lettuce | Recirculating hydroponics | 2012 | [www.verticalharvestjackson.com](http://www.verticalharvestjackson.com/) |
| 7. | AeroFarms | Newark | Kale, Greens | LED Lights  Recycle water technique | 2012 | [http://aerofarms.com](http://aerofarms.com/) |
| 8. | Green Sense Farms | China | Herbs Lettuces | Stacking vertical towers | 2014 | [www.greensensefarmss.com](http://www.greensensefarmss.com/) |

*Source, Mir* et al*., (2022)*

### Table 2. List of different vertical farm in India

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **S. No.** | **Name** | **Location** | **Year** | **Products** | **Website** |
| 1. | Growing Greens | Bangalore, Karnataka | 2012 | Mint, Spinach and Coriander | [http://growinggreens.in](http://growinggreens.in/) |
| 2. | Homecrop | Hyderabad, Telangana | 2017 | Coco peat and composting kits | [http://homecrop.in](http://homecrop.in/) |
| 3. | Pindfresh | Nayagaon, Punjab | 2016 | Clay balls, grow bags and net pots | [http://www.pindfresh.com](http://www.pindfresh.com/) |
| 4. | Urban Kisan | Vishakhapatnam, A. P | 2017 | Lettuce and hydroponic system | <http://www.urbankisaan.com/about> |
| 5. | Sure Grow | Coimbatore, T. N | 2017 | Lettuce and strawberry | <http://www.suregrow.in/about> |
| 6. | The Living Greens | Jaipur, Rajasthan | 2013 | Organic input kits and fruit bags | [http://thelivinggreens.com](http://thelivinggreens.com/) |
| 7. | City Greens | Bangalore, Karnataka | 2017 | Growing media and seed starters | [http://www.citygreens.in](http://www.citygreens.in/) |
| 8. | Ikheti | Mumbai, Maharashtra | 2011 | Seeds and gardening tools | [http://www.ikheti.co.in](http://www.ikheti.co.in/) |

*Source, Mir* et al*., (2022)*

**Hydroponics**

Hydroponics has many benefits over traditional farming techniques, such as effective water conservation, quicker plant growth, and the possibility of all-year-round crop yield (Rajaseger et al., 2023). But there are several issues that need to be overcome for its successful implementation and large-scale use. The first and foremost issue is the substantial up-front setup cost involving infrastructure, specialized machinery, and automation equipment for ensuring the right set of growing conditions (Manimozhi, and Krishnamoorthy, 2025). In addition, hydroponic production's technical requirement demands a high level of expertise among the human workforce in management of nutrients, maintenance of the system, and control of environment (Naresh et al., 2024).



Figure-2. Image of Hydroponic technic

Another drawback is the relatively high energy required for artificial illumination, climate manipulation, and the water circulation process, especially by commercial-scale agriculture (Shamshiri et al., 2018). The employment of sustainable alternatives, like photovoltaic electricity integration, will help reduce such energy demands over the long term. In addition, accurate nutrient management is key to plant health and obtaining maximal crop yields because imbalanced nutrient supply can result in deficiencies, stunted growth, or disease susceptibility (Selim et al., 2020). The possibility of root-borne diseases spreading quickly in a soilless culture further highlights the importance of sophisticated disease avoidance and control measures, including UV sterilization, biological control measures, and rigorous sanitation techniques (Khatri et al., 2024).

Notwithstanding these challenges, hydroponic agriculture has enormous potential in mitigating food security issues and addressing the limitations of traditional soil-based agriculture. Hydroponic agriculture makes it possible to grow crops in controlled conditions, doing away with reliance on soil quality and mitigating the effects of climatic variability. This renders hydroponics specially valuable in areas where arable land is limited, there is a harsh weather climate, or cities where roof-top gardens and vertical farming could help boost domestic food production (Varun Kumar and Verma, 2024).

As the world population keeps on increasing and urbanization increases, hydroponic technology offers a sustainable way to enhance agricultural productivity while preserving natural resources (Velazquez-Gonzalez et al., 2022). Automation, artificial intelligence, and precision agriculture will continue to improve its efficiency and scalability. With ongoing research and investment, hydroponics can transform contemporary farming to provide a stable and resilient food supply for the future (Sharma et al., 2023).

### Table 3. Comparing of hydroponic and traditional farming (Reddy et al*.,* 2023)

|  |  |  |
| --- | --- | --- |
| **Aspect** | **Hydroponics** | **Traditional Soil Farming** |
| Water usage | Significantly less, up to 90% less water | More, as water can be lost to soil and evaporation |
| Space usage | Less space required, suitable for vertical farming | Requires large tracts of land |
| Location | Can be done anywhere, even in urban settings | Mainly rural locations |
| Climate control | Year-round farming possible in controlled environments | Dependent on seasonal changes, weather conditions |
| Soil quality | Not dependent on soil quality | Highly dependent on soil quality and fertility |
| Pesticide usage | Reduced need for pesticides due to controlled environments | Often requires more pesticides |
| Growth speed | Faster growth rates due to controlled nutrition | Growth rates depend on various environmental factors |
| Yield | High yields due to optimized growing conditions | Yield can vary greatly depending on various factors |
| Startup costs | Higher initial costs for setup and technology | Lower initial costs but might require more long-term investment in soil and pest management |
| Sustainability | Sustainable; less water and land use | Can be less sustainable due to water, soil, and pesticide usage |
| Skill required | Requires specific knowledge and training | Traditional farming knowledge often sufficient |

*Source Khatri* et al*., (2024)*

**Aquaponics**

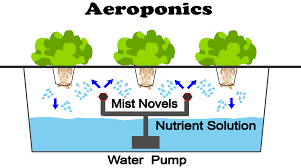
These new soilless farming methods minimize the use of water and maximize production in confined urban settings (Gómez et al., 2019). Hydroponics entails cultivating crops in water-based nutrient solutions, bypassing soil and enabling direct control of nutrients. Aquaponics is a combination of hydroponic plant growth with aquaculture, where fish waste nutrients are used naturally for plants, and a closed environment with no wastewater discharge (Rakocy, 2012). They are especially beneficial for use in arid areas and cities, providing high-yield space-conserving food production at low environmental cost (Enduta et al., 2011). Their efficiency and sustainability are further boosted through advances in automation and intelligent monitoring.

Figure-3. Image of aeroponics

Aeroponics is a sophisticated soilless growth method where the roots of the plants are held in the air and sprayed regularly with nutrient-infused water (Dutta, and Gupta, 2025). The fine spray allows for full aeration and exposes the highest surface area of the roots to the nutrients, enabling effective absorption of nutrients and fast plant development (Mir et al., 2022). Aeroponics differs from conventional hydroponic systems as it reduces the amount of water and nutrients consumed while maximizing the oxygen supply to the roots, which is very important for root health and crop production (AlShrouf, 2017).

One of the main benefits of aeroponics is its resource conservation feature and provision of best growing conditions. With the elimination of the use of soil, the system greatly minimizes the risk of soil-borne diseases as well as pest infections, resulting in healthier plants and less loss of crops (Kumar et al., 2024). In addition, the accurate regulation of environmental parameters, including humidity, temperature, and nutrient supply, allows year-round production, thus aeroponics is a viable food production alternative in urban areas, arid climates, and space-restricted environments (Martí Torra, 2023).

Nonetheless, its effective operation calls for precise technical sophistication and frequent care. The system is dependent on expert misting technology, sensors, and automatic nutrient delivery systems, all of which require frequent monitoring to avoid failure that can immediately reflect on plant health. Any interference in misting patterns or nutrient delivery can result in dehydration and stress, rendering the system susceptible to operational inefficiencies (Gurley, 2020).

In spite of these challenges, aeroponics is a promising new innovation in agriculture today, providing sustainable and efficient solutions to traditional farming. With the progress in automation, artificial intelligence, and resource utilization, aeroponics can potentially revolutionize food production and make it more climate change and resource constraint resilient, with maximum yield and quality (Qureshi et al., 2025).

**Table-4. Advantage and disadvantage of Hydroponics and Aeropnics**

|  |  |  |
| --- | --- | --- |
| **System** | **Advantages** | **Disadvantages** |
| Hydroponics | Efficient water and nutrient use High crop yields  Precise control over nutrient delivery Suitable for a wide range of crops | Requires specialized knowledge and equipment Dependence on electricity and pumps  Risk of waterborne diseases Limited root space |
| Aeroponics | Minimal water and nutrient use Excellent aeration for roots Reduced risk of plant diseases Faster growth rates | High initial setup costs  Requires precise control and monitoring Vulnerable to power outages  Limited to certain crop types |

*Source Panotra* et al*., (2024)*

**Table-5. List of vegetable grown in soil less culture**

|  |  |  |  |
| --- | --- | --- | --- |
| **Vegetable** | **Growing Method** | **Best System (Hydroponic/Aeroponic/Soil-Based)** | **Benefits** |
| Lettuce | Leafy Green | Hydroponic, Aeroponic | Fast growth, high yield |
| Spinach | Leafy Green | Hydroponic, Soil-Based | Rich in iron, continuous harvest |
| Kale | Leafy Green | Hydroponic, Aeroponic | Nutrient-dense, hardy plant |
| Cherry Tomato | Fruiting Vegetable | Hydroponic, Soil-Based | Compact growth, high productivity |
| Bell Pepper | Fruiting Vegetable | Hydroponic, Aeroponic | Rich in vitamins, thrives vertically |
| Cucumber | Vining Vegetable | Soil-Based, Hydroponic | Requires trellising, high yield |
| Beans | Climbing Vegetable | Soil-Based, Hydroponic | Nitrogen-fixing, supports soil health |
| Strawberries | Fruiting Plant | Hydroponic, Aeroponic | Compact, high yield in vertical towers |
| Basil | Herb | Hydroponic, Soil-Based | High-value culinary herb |
| Mint | Herb | Hydroponic, Soil-Based | Spreads easily, fresh aroma |

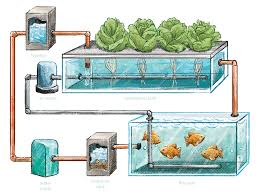
**Aquaponics**

Aquaponics is a holistic farming system that integrates hydroponics (soilless cultivation of plants) with aquaculture (raising aquatic life like fish, shrimp, or other aquatic species) to provide a symbiotic ecosystem (Eigenbrod & Gruda, 2015). This is a new, innovative method using the natural biological processes of plants and aquatic life to create a sustainable, closed-loop system.

In aquaponics, waste from the aquatic animals is used as an organic source of nutrients for plants. Fish waste is decomposed by beneficial bacteria into nitrates and other nutrients, which are utilized by the plants for growth. The plants, in return, purify the water by filtering out excess nutrients, providing a clean and healthy environment for the aquatic animals (Kumar et al., 2024). This natural process of filtration prevents water wastage and decreases chemical fertilizer requirements, thus making aquaponics an eco-friendly and resource-conserving farming practice (Nair et al., 2025).

Aquaponics has a number of benefits, such as effective water use, minimized use of synthetic fertilizers, and the capacity to grow both plant and animal food sources within the same system (Joyce et al., 2019). It can also be used in urban settings, greenhouses, and controlled environments, which makes it a viable option for sustainable food production. Nevertheless, proper system balancing, water quality monitoring, and technical expertise are needed to ensure optimal conditions for plants and aquatic life (Bhateria, and Jain, 2016).

As more and more people show interest in sustainable food and agriculture, aquaponics is a credible alternative to traditional farming, offering environmentally friendly and very productive forms of cultivation (Bonshock, 2021).



**Figure-4. Image of Aquaponics**

**Rooftop Gardening**

Rooftop gardening maximizes unused urban rooftop areas to grow plants, presenting an eco-friendly solution for food production, environmental uplift, and urban resilience (Hîrlav, 2024). By transforming rooftops into green areas, this practice presents various benefits, such as enhanced insulation, stormwater management, and urban beautification (Singh, 2024).

One of the major benefits of rooftop gardening is its ability to counteract the urban heat island effect a situation where cityscapes absorb and retain heat, causing it to rise. By using rooftops for vegetation, rooftop gardens cool surface temperatures, decreasing the need for air conditioning and total energy usage (Awal, 2023). They also clean the air by removing pollutants and releasing oxygen, helping to create a healthier city environment.

Aside from environmental advantages, rooftop gardens offer habitats for beneficial insects and pollinators, enhancing urban biodiversity (Lin, et al., 2015). They also offer local, fresh produce, lowering food transportation costs from far-off distances and improving food security in urban environments.

Innovative technology like solar-integrated green roofs and modular rooftop farming takes rooftop gardening to another level of functionality (Han et al., 2010). Modular systems enable easy installation and flexibility, and solar-integrated green roofs integrate renewable energy generation with plants, optimizing space efficiency and sustainability (Abera, 2023).

As urbanization progresses and green areas become more and more limited, rooftop gardening offers a feasible solution to enhance environmental sustainability, urban living standards, and local food systems (Fei et al., 2025). If planned and invested in properly, it can contribute meaningfully to the future of urban development (Huang, and Chang, 2021).



**(Source, Hamid et al., 2023)**

**Figure-5. Image of Roof top gardening**

**Composting and Organic Waste Management**

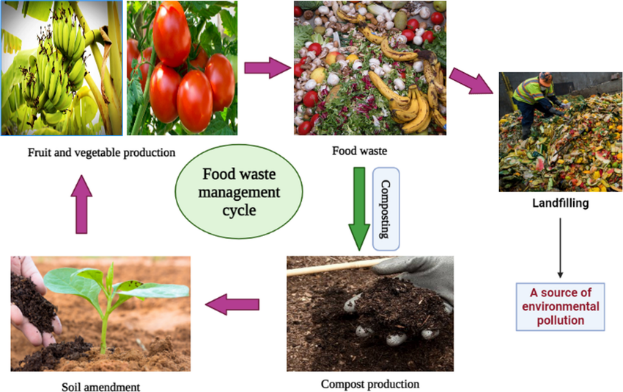
Composting and organic waste management are essential in decreasing landfill waste, improving soil fertility, and ensuring a circular economy through the recycling of organic waste into useful compost (Rashid, and Shahzad, 2021). This activity not only reduces the environmental footprint of waste disposal but also ensures sustainable agriculture by enhancing soil productivity and health (Shah, and Wu, 2019).

One of the most important environmental advantages of composting is reducing greenhouse gas emissions from landfills (Nordahl et al., 2023). Methane, a highly potent greenhouse gas, is generated by decomposing organic waste in landfills. By routing organic material into composting systems, emissions are eliminated, and mitigation of climate change is enhanced (Awasthi et al., 2018).

Soil amended with compost provides several agronomic advantages, such as increased soil structure, better water holding capacity, and the maintenance of beneficial microbial populations (Wang et al., 2022). These conditions promote plant well-being, lower the reliance on chemical fertilizers, and improve the overall soil resilience, thereby making composting a vital element of regenerative agriculture.

Cities can optimize waste management by various composting infrastructures, including: Community-level composting programs involving local people in sustainable waste management (Alimoradiyan et al., 2024). Vermicomposting, which uses earthworms to decompose organic matter into nutrient-enriched castings. Bio-digesters, which turn organic waste into biogas for energy generation while producing nutrient-enriched byproducts for farm use (Bhatia, et al., 2024).

By incorporating composting into urban planning and sustainable food systems, cities are able to efficiently deal with organic waste while creating a more resilient and environmentally friendly urban setting (Carvalho et al., 2022). Increasing awareness, infrastructure, and policy favoring composting will be essential in scaling up its advantages and making a more sustainable future (De Boni et al., 2022).



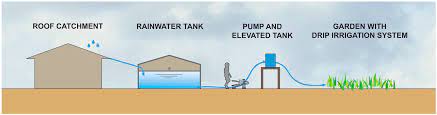
**Figure-6. Composting and Organic Waste Management**

**Rainwater Harvesting and Efficient Irrigation**

Efficient irrigation techniques and rainwater harvesting are key to preserving water resources, mitigating reliance on municipal water supply, and advancing sustainable urban farming (Russo et al., 2014). Urban growers can preserve a healthy growth rate for plants and reduce environmental harm through efficient capture and utilization of rainwater (Walters, 2018).

Rainwater harvesting systems include the collection and storage of rainwater from roofs, greenhouses, and other surfaces for use at a later time (Fernandes et al., 2015). Stored water can be used during times of drought, providing a steady supply of water for irrigation purposes (Traboulsi, and Traboulsi, 2017). The integration of filtering and storage mechanisms, including rain barrels, underground cisterns, and pervious surfaces, increases the efficiency of these systems while avoiding runoff and soil erosion (Maliva, and Maliva, 2020).

To further minimize waste and ensure adequate moisture supply for plants, effective irrigation practices help optimize water consumption. Some essential techniques are: Drip irrigation, where water is applied straight to the plant roots, keeping evaporation and runoff at minimum (Dasberg, and Or, 2013). Automated irrigation systems, which distribute water according to schedules or environmental data set in advance (Gutiérrez et al., 2013). Moisture sensors, which detect moisture levels in soil and irrigate accordingly, eliminating overwatering and saving water (Sapaev et al., 202).

By combining rainwater harvesting with sophisticated irrigation techniques, urban agriculture can minimize its water footprint, increase crop resistance to climate variability, and help ensure long-term sustainability (Lupia, et al., 2017). These measures not only promote effective resource management but also guarantee a greener, more water-secure future for urban populations.

**(Source, Wolterdorf et al., 2015)**

**Figure-7. Rainwater Harvesting and Efficient Irrigation**

**Use of Local and Drought-Tolerant Plants**

The use of local and drought-tolerant plants in urban areas boosts biodiversity, lessens maintenance requirements, and builds climate resilience (Wang et al., 2024). Indigenous plant species are already naturally acclimated to local environmental conditions, having low water, fertilizer, and pesticide requirements, hence a friendly and sustainable option for urban green spaces (Ignatieva et al., 2020).

Their major benefit when utilizing native and drought-resistant plants is that they can survive under low human involvement. These plants: Save water by adopting indigenous rainfall patterns, minimizing the necessity for irrigation. Reduce environmental risks by avoiding dependence on chemical fertilizers and pesticides (Baweja et al., 2020). Promote biodiversity by offering natural food and shelter for pollinators, birds, and other local fauna, thereby promoting an equilibrium ecosystem (Nicholls, and Altieri, 2013).

Apart from ecological value, incorporating native and water-conscious plants into the cityscape could alleviate the impacts of climate change (Rosen-Teeple, 2013). Their extensive root systems arrest soil erosion, enhance air purity through the assimilation of harmful substances, and maximize carbon absorption, making for a cleaner, more sustainable city life (Idowu, et al., 2024).

By prioritizing drought-tolerant and native plant species in landscaping, rooftop gardens, green belts, and public spaces, cities can minimize maintenance costs, enhance urban resilience, and encourage ecological balance while developing an attractive green environment (Zeng et al.,2022).

**Community and School Gardens**

Urban and school gardens are vibrant open areas that support local food production, environmental sensitivity, and social cohesiveness while providing students and residents with quality hands-on educational experiences (Kanosvamhira, 2025). Such collective green spaces create community for individuals of different ages and support sustainable agricultural use, promoting information on nutrition, biodiversity, and environmental protection (Barthel et al., 2015).

One of the most important advantages of educational and community gardens is that they can boost food security through access to fresh, locally grown produce (Galhena et al., 2013). They give people power over growing their own food, taking away from commercial food chains and promoting healthier diets (Goldberg, and Gunasti, (2007).

In addition, these gardens are sites for intergenerational knowledge transfer, where the elderly can impart ancient knowledge on farming to younger people, and cultural as well as agricultural heritage can be secured. They provide horticultural therapy, which supports mental health through stress reduction, increased mindfulness, and greater nature connection (Lu et al., 2023).

Ecologically, integrating native plant species and pollinator-friendly habitats into community gardens promotes urban biodiversity (Park, 2025). The gardens promote beneficial insects, birds, and pollinators, leading to a healthier and more resilient urban ecosystem (Lin et al., 2015).

Through the integration of community and educational gardens into city planning, cities are able to foster stronger social bonds, enhance public health, and develop environmentally sustainable landscapes, ultimately enriching urban life through education, conservation, and community involvement (Middle et al., 2014 and Vieira et al., 2022).

**Challenges and Future Directions**

Notwithstanding the benefits of sustainable urban horticulture, there are some challenges that inhibit its universal uptake. Unavailability of land, high capital requirements, and urban residents' unawareness are among the major constraints. Pollution, climate change, and poor policy support are also major challenges. Urban governance complexity, zoning, and land use competition further make it difficult to incorporate horticultural areas into city planning. Overcoming these challenges involves combined urban planning, economic incentives, and educational programs to promote sustainable horticulture participation. Governments and policymakers need to create definite guidelines to promote urban agriculture, simplify land use policies, and offer subsidies or tax credits to promote investment in sustainable horticultural methods.

Future studies must concentrate on creating affordable and scalable models of urban agriculture, incorporating cutting-edge methods like AI-based monitoring, precision farming, and automated resource allocation. Advances in automation, soil-less farming, and climate-resilient crops can increase productivity and sustainability while reducing environmental footprint. Green infrastructure, urban agroforestry, and waste-to-resource management policies need to be given top priority, along with incentives for urban farmers and enterprises embracing sustainable horticulture practices. Enhancing community involvement, private-public partnerships, and interdisciplinary among urban planners, environmental scientists, and agricultural specialists will be essential in building a sustainable and resilient city food system.

**Conclusion**

Sustainable city gardening practices are crucial to resolving urban environmental issues and promoting resilient food systems. Although these practices have numerous advantages, their effective adoption depends on supportive policies, technological advancements, and engaged community participation. The incorporation of green infrastructure, smart city planning, and climate-resilient farming practices can further support the sustainability of urban food systems. Future studies need to aim at establishing holistic urban horticulture models that strike a balance between productivity and sustainability in response to socio-economic constraints, policy constraints, and resource utilization to guarantee sustainable success in the urban context.

**Reference**

Abera, Y. (2023). Renewable Energy Integration with Sustainable Materials and Technologies. *Authorea Preprints*.

Akintuyi, O. B. (2024). Vertical farming in urban environments: a review of architectural integration and food security. *Open Access Research Journal of Biology and Pharmacy*, *10*(2), 114-126.

Alimoradiyan, H., Hajinezhad, A., Yousefi, H., & Giampietro, M. (2024). Fostering community participation in sustainable municipal solid waste management at multiple scales in Tehran, Iran. *Results in Engineering*, *22*, 102174.

AlShrouf, A. (2017). Hydroponics, aeroponic and aquaponic as compared with conventional farming. Am. Sci. Res. J. Eng. Technol. Sci, 27(1), 247-255.

AlShrouf, A. (2017). Hydroponics, aeroponic and aquaponic as compared with conventional farming. *Am. Sci. Res. J. Eng. Technol. Sci*, *27*(1), 247-255.

Awal, S. (2023). URBAN AGRICULTURE CENTRE: AN INTEGRATED SPACE FOR URBAN FARMING, RESEARCH AND INTERACTION.

Awasthi, M. K., Sarsaiya, S., Wang, Q., Wang, M., Chen, H., Ren, X., ... & Zhang, Z. (2018). Mitigation of global warming potential for cleaner composting. *Biosynthetic Technology and Environmental Challenges*, 271-305.

Barthel, S., Parker, J., & Ernstson, H. (2015). Food and green space in cities: A resilience lens on gardens and urban environmental movements. *Urban studies*, *52*(7), 1321-1338.

Baweja, P., Kumar, S., & Kumar, G. (2020). Fertilizers and pesticides: Their impact on soil health and environment. *Soil health*, 265-285.

Benke, K., & Tomkins, B. (2017). Future food-production systems: vertical farming and controlled-environment agriculture. *Sustainability: science, practice and policy*, *13*(1), 13-26.

Bhateria, R., & Jain, D. (2016). Water quality assessment of lake water: a review. *Sustainable water resources management*, *2*(2), 161-173.

Bhatia, R. K., Ramadoss, G., Jain, A. K., Dhiman, R. K., Bhatia, S. K., & Bhatt, A. K. (2020). Conversion of waste biomass into gaseous fuel: present status and challenges in India. *BioEnergy Research*, *13*, 1046-1068.

Bonshock, B. (2021). Farming A Sustainable Fish: Exploring Consumer Support of Aquaponics and Preference for Aquaponic Tilapia.

Carvalho, C. A., Más-Rosa, S., & Ventura, A. C. (2022). Urban Gardens and Composting: Effective Government for Strengthening Urban Resilience and Community Waste Management. In *Water-Energy-Food Nexus and Climate Change in Cities* (pp. 217-241). Cham: Springer International Publishing.

Dasberg, S., & Or, D. (2013). *Drip irrigation*. Springer Science & Business Media.

De Boni, A., Melucci, F. M., Acciani, C., & Roma, R. (2022). Community composting: A multidisciplinary evaluation of an inclusive, participative, and eco-friendly approach to biowaste management. *Cleaner Environmental Systems*, *6*, 100092.

Dutta, M., & Gupta, D. (2025). Revolutionizing agriculture: Sustainable solutions for high-yield farming using vertical hydroponics. *GMSARN Int. J.*, *19*, 95-106.

Eigenbrod, C., & Gruda, N. (2015). Urban vegetable for food security in cities. A review. *Agronomy for Sustainable Development*, *35*, 483-498.

Enduta, A., Jusoh, A., Ali, N. A., & Nik, W. W. (2011). Nutrient removal from aquaculture wastewater by vegetable production in aquaponics recirculation system. *Desalination and water treatment*, *32*(1-3), 422-430.

Fei, S., Wu, R., Liu, H., Yang, F., & Wang, N. (2025). Technological Innovations in Urban and Peri-Urban Agriculture: Pathways to Sustainable Food Systems in Metropolises. *Horticulturae*, *11*(2), 212.

Fei, S., Wu, R., Liu, H., Yang, F., & Wang, N. (2025). Technological Innovations in Urban and Peri-Urban Agriculture: Pathways to Sustainable Food Systems in Metropolises. *Horticulturae*, *11*(2), 212.

Fernandes, L. F. S., Terêncio, D. P., & Pacheco, F. A. (2015). Rainwater harvesting systems for low demanding applications. *Science of the Total Environment*, *529*, 91-100.

G. J., ... & Pandey, S. K. (2024). Vertical Farming: Addressing the Challenges of 21st Century Agriculture through Innovation. *International Journal of Environment and Climate Change*, *14*(4), 664-691.

Galhena, D. H., Freed, R., & Maredia, K. M. (2013). Home gardens: a promising approach to enhance household food security and wellbeing. *Agriculture & food security*, *2*, 1-13.

Goldberg, M. E., & Gunasti, K. (2007). Creating an environment in which youths are encouraged to eat a healthier diet. *Journal of Public Policy & Marketing*, *26*(2), 162-181.

Gómez, C., Currey, C. J., Dickson, R. W., Kim, H. J., Hernández, R., Sabeh, N. C., ... & Burnett, S. E. (2019). Controlled environment food production for urban agriculture. *HortScience*, *54*(9), 1448-1458.

Gurley, T. W. (2020). Aeroponics: growing vertical. CRC Press.

Gutiérrez, J., Villa-Medina, J. F., Nieto-Garibay, A., & Porta-Gándara, M. Á. (2013). Automated irrigation system using a wireless sensor network and GPRS module. *IEEE transactions on instrumentation and measurement*, *63*(1), 166-176.

Hamid, B., Yatoo, A. M., Sayyed, R. Z., Dineshkumar, R., Al-Khayri, J. M., Bashir, Z., ... & Majeed, N. (2023). Microbial-based conversion of food waste for sustainable bioremediation and utilization as compost. *Biomass Conversion and Biorefinery*, 1-15.

Han, H. J., Jeon, Y. I., Lim, S. H., Kim, W. W., & Chen, K. (2010). New developments in illumination, heating and cooling technologies for energy-efficient buildings. *Energy*, *35*(6), 2647-2653.

Hîrlav, G. (2024). Transforming Urban Flat Rooftops in The Netherlands Into Sustainable and Productive Spaces.

Huang, A., & Chang, F. J. (2021). Prospects for rooftop farming system dynamics: An action to stimulate water-energy-food nexus synergies toward green cities of tomorrow. *Sustainability*, *13*(16), 9042.

Idowu, O. S., Ayoola, V. O., Adegbola, F., & Adeyeye, Y. (2024). Air, Water, and Soil Microbiomes as Catalysts for Smart Agriculture, Urban Ecosystem Revitalization, Climate Adaptation, and Public Health Advancements.

Ignatieva, M., Haase, D., Dushkova, D., & Haase, A. (2020). Lawns in cities: from a globalised urban green space phenomenon to sustainable nature-based solutions. *Land*, *9*(3), 73.

Ikerd, J. (2018). The role of urban horticulture in the sustainable agri-food movement. *Urban Horticulture: Sustainability for the Future*, 233-245.

Jahrl, I., Moschitz, H., & Cavin, J. S. (2021). The role of food gardening in addressing urban sustainability–A new framework for analysing policy approaches. *Land Use Policy*, *108*, 105564.

Joyce, A., Goddek, S., Kotzen, B., & Wuertz, S. (2019). Aquaponics: closing the cycle on limited water, land and nutrient resources. *Aquaponics food production systems*, *19*, 19-34.

Kalantari, F., Tahir, O. M., Joni, R. A., & Fatemi, E. (2018). Opportunities and challenges in sustainability of vertical farming: A review. Journal of Landscape Ecology, 11(1), 35-60.

Kanosvamhira, T. P. (2025). Growing together: unveiling the potential of school-based community gardens to foster well-being, empowerment, and sustainability. *Urban Transformations*, *7*(1), 2.

Khan, M. M., Akram, M. T., Janke, R., Qadri, R. W. K., Al-Sadi, A. M., & Farooque, A. A. (2020). Urban horticulture for food secure cities through and beyond COVID-19. *Sustainability*, *12*(22), 9592.

Khanpoor-Siahdarka, M., & Masnavi, M. R. (2025). Assessment of Community Gardens’ role in mitigating air pollution and expanding social opportunities: Lessons from a neighborhood with limited green infrastructure in Tehran city. *Energy Nexus*, *17*, 100363.

Khatri, L., Kunwar, A., & Bist, D. R. (2024). Hydroponics: Advantages and Challenges in Soilless Farming. Big Data Agric.(BDA), 6, 81-88.

Kumar A, Mehta A, Yadav A, Kumari K.(2024) Advanced Horticultural Techniques: Hydroponics, Aquaponics and Aeroponics for Optimal Crop Production. Int. J. Plant Soil Sci.;36(8):884-92.

Kumar, P., & Dey, S. R. (2024). Hydroponics Phytoremediation: An Overview. Hydroponics and Environmental Bioremediation: Wastewater Treatment, 361-396.

Lin, B. B., Philpott, S. M., & Jha, S. (2015). The future of urban agriculture and biodiversity-ecosystem services: Challenges and next steps. *Basic and applied ecology*, *16*(3), 189-201.

Lin, B. B., Philpott, S. M., & Jha, S. (2015). The future of urban agriculture and biodiversity-ecosystem services: Challenges and next steps. *Basic and applied ecology*, *16*(3), 189-201.

Lu, S., Liu, J., Xu, M., & Xu, F. (2023). Horticultural therapy for stress reduction: A systematic review and meta-analysis. *Frontiers in Psychology*, *14*, 1086121.

Lupia, F., Baiocchi, V., Lelo, K., & Pulighe, G. (2017). Exploring rooftop rainwater harvesting potential for food production in urban areas. Agriculture, 7(6), 46.

Maliva, R. G., & Maliva, R. G. (2020). Low impact development and rainwater harvesting. *Anthropogenic Aquifer Recharge: WSP Methods in Water Resources Evaluation Series No. 5*, 765-825.

Manimozhi, R., & Krishnamoorthy, G. (2025). Innovative Techniques in Agriculture: Transitioning From Traditional Farming to Precision and Hydroponic Agriculture. *Environmental Quality Management*, *34*(3), e70047.

Martí Torra, J. (2023). Design of a modular facility for sustainable indoor farming in Greenland.

Middle, I., Dzidic, P., Buckley, A., Bennett, D., Tye, M., & Jones, R. (2014). Integrating community gardens into public parks: An innovative approach for providing ecosystem services in urban areas. *Urban forestry & urban greening*, *13*(4), 638-645.

Mir, M. S., Naikoo, N. B., Kanth, R. H., Bahar, F. A., Bhat, M. A., Nazir, A., ... & Ahngar, T. A. (2022). Vertical farming: The future of agriculture: A review. *The Pharma Innovation Journal*, *11*(2), 1175-1195.

Mir, M. S., Naikoo, N. B., Kanth, R. H., Bahar, F. A., Bhat, M. A., Nazir, A., ... & Ahngar, T. A. (2022). Vertical farming: The future of agriculture: A review. The Pharma Innovation Journal, 11(2), 1175-1195.

Mir, Y. H., Mir, S., Ganie, M. A., Shah, A. M., Majeed, U., Chesti, M. H., ... & Wani, F. J. (2022). Soilless farming: An innovative sustainable approach in agriculture. *Pharma Innovation Journal*, *11*(6), 2663-75.

Nair, C. S., Manoharan, R., Nishanth, D., Subramanian, R., Neumann, E., & Jaleel, A. (2025). Recent advancements in aquaponics with special emphasis on its sustainability. *Journal of the World Aquaculture Society*, *56*(1), e13116.

Naresh, R., Jadav, S. K., Singh, M., Patel, A., Singh, B., Beese, S., & Pandey, S. K. (2024). Role of hydroponics in improving water-use efficiency and food security. *International Journal of Environment and Climate Change*, *14*(2), 608-633.

Ndubuisi, O. G., & FNisafetyE, F. I. S. P. O. N. (2025). Assessing the Effectiveness of Environmental Law and Regulation: A Review of the Impacts on Environmental Degradation, Climate Change and Biodiversity Loss.

Nicholls, C. I., & Altieri, M. A. (2013). Plant biodiversity enhances bees and other insect pollinators in agroecosystems. A review. *Agronomy for Sustainable development*, *33*, 257-274.

Nordahl, S. L., Preble, C. V., Kirchstetter, T. W., & Scown, C. D. (2023). Greenhouse gas and air pollutant emissions from composting. *Environmental science & technology*, *57*(6), 2235-2247.

Panotra, N., Belagalla, N., Mohanty, L. K., Ramesha, N. M., Tiwari, A. K., Abhishek,

Panotra, N., Belagalla, N., Mohanty, L. K., Ramesha, N. M., Tiwari, A. K., Abhishek, G. J., ... & Pandey, S. K. (2024). Vertical Farming: Addressing the Challenges of 21st Century Agriculture through Innovation. International Journal of Environment and Climate Change, 14(4), 664-691.

Park, C. (2025). *Urban Pollinator Vertical Garden: Design Strategies for Sustainable Human-Pollinator Interaction in Urban Environments* (Master's thesis, Rochester Institute of Technology).

Praveen, G., kashi Vishwanath, N., Sree, C. C., & Rohith, D. (2025). CLIMATE-RESILIENT URBAN PLANNING. *International Journal of Advances in Agricultural Science and Technology*, *12*(3), 226-234.

Priya, U. K., & Senthil, R. (2024). Framework for Enhancing Urban Living Through Sustainable Plant Selection in Residential Green Spaces. *Urban Science*, *8*(4), 235.

Qureshi, W. A., Gao, J., Elsherbiny, O., Mosha, A. H., Tunio, M. H., & Qureshi, J. A. (2025). Boosting Aeroponic System Development with Plasma and High-Efficiency Tools: AI and IoT—A Review. *Agronomy*, *15*(3), 546.

Rajaseger, G., Chan, K. L., Tan, K. Y., Ramasamy, S., Khin, M. C., Amaladoss, A., & Haribhai, P. K. (2023). Hydroponics: current trends in sustainable crop production. *Bioinformation*, *19*(9), 925.

Rakocy, J. E. (2012). Aquaponics—integrating fish and plant culture. *Aquaculture production systems*, 344-386.

Rashid, M. I., & Shahzad, K. (2021). Food waste recycling for compost production and its economic and environmental assessment as circular economy indicators of solid waste management. *Journal of Cleaner Production*, *317*, 128467.

Reddy, K. J., Mishra, R., Sreekumar, G., & Saikanth, D. R. K. (2023). Future of hydroponics in sustainable agriculture. Advanced Farming Technology, 108.

Rosen-Teeple, R. S. (2013). *A Planetary Place: Popular Press Constructions of the Global Environment*. University of California, Davis.

Russo, T., Alfredo, K., & Fisher, J. (2014). Sustainable water management in urban, agricultural, and natural systems. *Water*, *6*(12), 3934-3956.

Saad, M. H. M., Hamdan, N. M., & Sarker, M. R. (2021). State of the art of urban smart vertical farming automation system: Advanced topologies, issues and recommendations. *Electronics*, *10*(12), 1422.

Sanyé-Mengual, E., Specht, K., Grapsa, E., Orsini, F., & Gianquinto, G. (2019). How can innovation in urban agriculture contribute to sustainability? A characterization and evaluation study from five Western European cities. *Sustainability*, *11*(15), 4221.

Sapaev, J., Arifjanov, A., Ramazonov, K., & Sapaev, I. B. (2023). Smart technologies for determining water flow in irrigation systems. In *E3S Web of Conferences* (Vol. 383, p. 02012). EDP Sciences.

Sashika, M. N., Gammanpila, H. W., & Priyadarshani, S. V. G. N. (2024). Exploring the evolving landscape: Urban horticulture cropping systems–trends and challenges. *Scientia Horticulturae*, *327*, 112870.

Selim, M. M. (2020). Introduction to the integrated nutrient management strategies and their contribution to yield and soil properties. *International Journal of Agronomy*, *2020*(1), 2821678.

Shah, F., & Wu, W. (2019). Soil and crop management strategies to ensure higher crop productivity within sustainable environments. *Sustainability*, *11*(5), 1485.

Shamshiri, R., Kalantari, F., Ting, K. C., Thorp, K. R., Hameed, I. A., Weltzien, C., ... & Shad, Z. M. (2018). Advances in greenhouse automation and controlled environment agriculture: A transition to plant factories and urban agriculture. *International Journal of Agricultural and Biological Engineering*, *11*(1), 1-22.

Sharma, S., Lishika, B., Shahi, A., & Kaushal, S. (2023). Hydroponics: The Potential to Enhance Sustainable Food Production in Non-Arable Areas. Current Journal of Applied Science and Technology, 42(39), 13-23.

Sia, A., Tan, P. Y., & Er, K. B. (2023). The contributions of urban horticulture to cities' liveability and resilience: Insights from Singapore. *Plants, People, Planet*, *5*(6), 828-841.

Singh, A (2024). Smart strategies and interventions for rooftop gardens. *Indian Horticulture*, *69*(5), 36-42.

Stephens, R. (2023). Green Cities Artificial Intelligence.

Sung, W. P., Liao, M. C., Peng, H. L., Huang, C. T., Chuang, Y. J., & Wang, J. J. (2025). The Role of Urban Food Forests in Promoting Environmental Sustainability and Public Health: A Focus on Temperature Regulation and Mental Health. *Sustainability*, *17*(7), 2875.

Touliatos, D., Dodd, I. C., & McAinsh, M. (2016). Vertical farming increases lettuce yield per unit area compared to conventional horizontal hydroponics. Food and energy security, 5(3), 184-191.

Traboulsi, H., & Traboulsi, M. (2017). Rooftop level rainwater harvesting system. *Applied Water Science*, *7*, 769-775.

Velazquez-Gonzalez, R. S., Garcia-Garcia, A. L., Ventura-Zapata, E., Barceinas-Sanchez, J. D. O., & Sosa-Savedra, J. C. (2022). A review on hydroponics and the technologies associated for medium-and small-scale operations. *Agriculture*, *12*(5), 646.

Vieira, C. L. Z., Rumenos, N. N., Gheler-Costa, C., Toqueti, F., & de Lourdes Spazziani, M. (2022). Environmental education in urban cities: Planet regeneration through ecologically educating children and communities. *International Journal of Educational Research Open*, *3*, 100208.

Walters, S. A., & Stoelzle Midden, K. (2018). Sustainability of urban agriculture: Vegetable production on green roofs. *Agriculture*, *8*(11), 168.

Wang, D., Lin, J. Y., Sayre, J. M., Schmidt, R., Fonte, S. J., Rodrigues, J. L., & Scow, K. M. (2022). Compost amendment maintains soil structure and carbon storage by increasing available carbon and microbial biomass in agricultural soil–A six-year field study. *Geoderma*, *427*, 116117.

Wang, D., Xu, P. Y., An, B. W., & Guo, Q. P. (2024). Urban green infrastructure: Bridging biodiversity conservation and sustainable urban development through adaptive management approach. *Frontiers in Ecology and Evolution*, *12*, 1440477.

Woltersdorf, L., Liehr, S., & Döll, P. (2015). Rainwater Harvesting for Small-Holder Horticulture in Namibia: Design of garden variants and assessment of climate change impacts and adaptation. *Water*, *7*(4), 1402-1421.

Zeng, X., Yu, Y., Yang, S., Lv, Y., & Sarker, M. N. I. (2022). Urban resilience for urban sustainability: Concepts, dimensions, and perspectives. *Sustainability*, *14*(5), 2481.