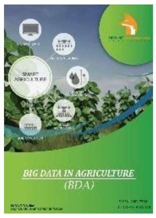
ZIBELINE INTERNATIONAL™ PUBLISHING
ISSN: 2682-7786 (Online)
CODEN: BDAIDR

Big Data in Agriculture (BDA)

DOI: http://doi.org/10.26480/bda.02.2024.106.112



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REVIEW ARTICLE

VERTICAL FARMING IN URBAN AGRICULTURE: OPPORTUNITIES, CHALLENGES, AND FUTURE DIRECTIONS

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ARTICLE DETAILS

Article History:

Received 23 May 2024
Revised 08 June 2024
Accepted 16 July 2024
Available online 25 July 2024

ABSTRACT

Vertical farming has turned out to be one of the modern and innovative methods of developing urban agriculture to meet necessities such as food security, sustainability, and effective use of resources as the world is increasingly turning into urban centers, besides facing a future of climatic change. This review article aims to review the state of the art, opportunities, issues, and prospects of vertical farming. By using the technological means of hydroponics, aeroponics, and aquaponics, vertical farming benefits from activities such as resource-saving, the lower use of water, and the ability to produce products year-round. The paper further analyzes the economic profitability, environmental advantage, and social relevancy of the vertical farming system, which includes decreasing transportation-related costs, minimizing the impacts on ecological life and producing quality crops without using many pesticides. However, such excellence comes with drawbacks that include, high capital investment, usage of energy, technicalities and regulations in vertical farming. Additionally, the range of crops that are currently produced in vertical farms remains rather limited, and there are issues related to the environmental consequences of nutrient runoff and waste management. It is therefore necessary to effort towards establishing ways and means to innovate, in consultation with other farmers as well as other stakeholders, and develop policies that will help to enhance the implementation of vertical farming to increase the production of such crops to meet the demands of the growing population in the future.

KEYWORDS

Aeroponics, Food security, Hydroponics, Sustainability, Urban farming

1. Introduction

The future global population, predicted to be 9 billion in 2050 proves it necessary to foster innovations and share accountability for different problems. (Despommier, 2013). However, by 2025, a significant majority, ranging from 60% to 85% of people, will live in urban areas (Tilman et al., 2001). Global food systems and growing cities are causing social, environmental, political, and economic problems worldwide, which run contrary to the urgent need for sustainability (Mougeot, 2005). This will lead to increased resource competition, pollution, damage to the environment, and urban food shortages (Alfsen-Norodom et al., 2004). Currently, around 800 million hectares, which is around 38% of the world's land, are dedicated to soil-based farming and 80% of total arable land is utilized globally (Despommier & Ellingsen, 2008). Urbanization is a dynamic and influential phenomena that constantly occur in developing countries (Thapa et al., 2008).

For instance, Nepal like many other developing countries is alarmed by food insecurity because of increasing urbanization, decreased land for cultivation and seasonal water shortage (Thapa and Murayama, 2009; Singh and Pandey, 2020). In the 1990s, Nepal's yearly urbanization rate was 6.6%, making it one of the highest in the Asia-Pacific region (Portnov et al., 2007). As food supply and security become increasingly important concerns, it is crucial to look into how we can get produce to cities in an ecologically friendly and energy-efficient way (Godfray et al., 2010). It's important to explore new methods to sustainably supply food to cities alongside traditional farming. One promising strategy is vertical farming, where fruits, vegetables, and grains are grown inside urban buildings using hydroponics (Fischetti, 2008). Vertical Farming is a modern agricultural technology in which plants, animals, and other species are grown vertically to produce food, fuel, fiber, and a variety of other products and services (Banerjee and Adenaeuer, 2014). Many cities across the globe are inclining towards Vertical farming because of its potential in agricultural fields. Agriculture close to the consumers' base thus requires less transportation costs. Currently, herbs and plants are grown in a controlled environment hence they are provided with the best environmental conditions while they use less water through recycling. This makes it suited to desert and drought-prone areas such as the Middle East, Africa, Israel, Japan, and the Netherlands (Benke and Tomkins, 2017). Vertical Farming is gaining popularity for increasing agricultural yields per square meter. The approaches range from small community gardens to massive commercial skyscrapers growing various crops (Beacham et al., 2019). Cultivation of crops in numerous tier-like structures or levels is another sure and efficient method of farming since it is environmentally appropriate, saves the planet's water/energy, promotes the economy, and decreases pollution. It has the possibility of initiating employment opportunities, enhancing the conditions of ecosystems, and thus enhancing people's access to healthy foods. Vegetation grown in protection is comparatively less vulnerable to pests and less at risk of factors such as nutrient inadequacies, contaminated irrigation water, insecticides and dirt (Touliatos et al., 2016). Vertical farms boost production using cutting-edge technology. Light, temperature, CO2, soil, water, and humidity are adjusted by the grower to optimize within conditions. Vertical farms in urban areas can strengthen local economies and supply fresh, healthy produce (Anbarashan Padmavathy and Gopalsamy Poyyamoli, 2011). Vertical farming approaches involve greater ways for the proper management of pests and diseases compared to traditional protected horticulture, such as the movement of both pests and

Quick Response Code	Access this article online	
	Website: www.bigdatainagriculture.com.my	**DOI:** 10.26480/bda.02.2024.106.112

Cite The Article: Lalendra Gurung, Janak Singh Rawal, Puspa RC, Ganesh Raj Joshi, and Ashmita Mandal (2024). Vertical Farming in Urban Agriculture: Opportunities, Challenges, and Future Directions. *Big Data in Agriculture, 6(2): 106-112.*

beneficial insects between growth stages (Roberts et al., 2020).

The earliest large-scale indoor farming of cress was initiated by a Danish farmhouse in the 1950s. Today, such a concept of having fully controlled indoor urban farming is already being realized in Europe, Asia, the United States, Singapore, and South Korea to offer modern and fresh opportunities for urban agriculture (Ali and Srivastava, 2017). Vertical farming may produce food sustainably without pesticides or fertilizers in small areas and water. It supplies fresh vegetables daily, making it perfect for densely populated areas. Vertical farming grows fruits, vegetables, and herbs, but vertical farming needs better profitability, energy efficiency, public policy, and consumer acceptance as mainstream agriculture (van Delden et al., 2021). Climate change, poor-quality soil, and water shortages make farming harder. Vertical farming involves methods like hydroponics, aeroponics, aquaculture, and Rooftop farming. Such techniques involve the use of low amounts of land and water to produce food in areas that may be considered unsuitable (Mir et al., 2022). The global market for vertical farming has grown rapidly in the recent past owing to increased population density and urbanization. The industry was worth $4.4 billion in 2019, and it is predicted to grow to $15.7 billion by 2025 (Saad et al., 2021). Therefore, the purpose of this work is to identify the trends and issues of vertical farming and its potential future applications. It tries to find out how the system of growing crops vertically can be useful to tackle some of the problems in the world's food system caused by urbanization, climate, and resources. By studying vertical farming technologies, their economics, environmental aspects and their role in urban environments, the paper aims to contribute to the understanding of possibilities for sustainable agriculture and city development.

2. History of Vertical Farming

Vertical farming is not a new idea. It started in antiquity; the Hanging Gardens of Babylon, one of Philon's Seven Wonders of the World that was developed in 600 BC, served as an early example (Saad et al., 2021). In 1915, Gilbert Ellis Bailey introduced the Vertical Farming in his book. In the 1930s, William Frederick Gerick at UC Berkeley created hydroponics. In the 1980s, Swedish farmer Ake Olsson developed a spiral rail system for plant development and proposed vertical farming as a means of cultivating vegetables in urban areas (Despommier, 2010).

3. Types of Vertical Farming

Vertical farms are available in various configurations and dimensions, ranging from basic wall-mounted or two-level setups to large multi-story warehouses. However, one of three soilless plant nutrition systems aquaponic, aeroponic, or hydroponic is used by all vertical farms (Birkby, 2016). Nowadays, there are roughly thirteen different ways to conduct VF, and each one is so technologically advanced that it has the potential to completely transform agriculture (Beacham et al., 2019).

3.1 Hydroponics

This word comes from the Greek terms "hydro" and "ponos," which mean "water working" or "water doing labor" (Mir et al., 2022). Hydroponics is a way to grow plants without soil. Instead, it uses a neutral medium and a nutrient solution to give plants everything they need for healthy growth and development (Roberto, 2005). Plants can be grown hydroponically, using artificial media or not, in a liquid nutrition solution. Brick shards, coir, expanded clay, perlite, vermiculite, polystyrene packing peanuts, and wood fiber are examples of commonly used media (Kuriyal et al., 2022). Hydroponic systems use 60-70% less water than conventional farming methods (Royston and Pavithra, 2018). Growers claim that hydroponic systems offer year-round production in a shorter growing season. Because of their regulated growth environment, these systems take up less space and can be installed practically anywhere, even in small areas (Hughes, 2017). Hydroponics produces higher yields and is not affected by weather conditions. The controlled environment produces higher-quality, uniform crops without wasting water or nutrients. Furthermore, hydroponics enables consistent production all year round (Okemwa, 2015; Sarah, 2017).

3.2 Aeroponics

Aeroponics is a method of growing plants without soil or any other media. The plants are suspended in the air and supported by an artificial framework; they do not require soil or a substrate to thrive (Osvald et al., 2001). Aeroponics involves hanging plant roots in a sealed, dark container and spraying them with nutrient-rich mist. The plant's leaves and top grow above the wet area, supported by an artificial structure. This arrangement uses nozzles or foggers to supply nutrients, promoting rapid development under controlled conditions (Mbiyu et al., 2012). Under an aeroponics system, plant roots absorb nutrients quickly and thrive under controlled conditions. Such conditions include constant nutrition levels, EC and pH values, temperature, humidity, light intensity, atomization frequency, spray duration, interval time, and oxygen availability. The growing chamber's sterile environment and available oxygen promote even faster plant growth (Mirza et al., 1998).

3.3 Aquaponics

Aquaponics combines fish and plant cultivation in a limited area through the use of hydroponic and vertical farming methods. This method converts fish waste into plant nutrients, creating a sustained and profitable cycle (Fernández-Cabanás et al., 2020). Aquaponics is the technique of cultivating plants and aquatic organisms in harmony. Plants absorb nutrients from the water to clean it, while the aquaculture effluent is transformed by microorganisms to provide nutrients for plant development (Hao et al., 2020). Water travels through many components in an aquaponics system, including the fish tank, bio filter, and hydroponic system, allowing fish waste to decompose into nutrients for plants, functioning as natural fertilizers (Nichols and Savidov, 2011). Researchers suggest that this method could serve as a model for sustainable food production by adhering to the 3Rs: reduce, reuse, and recycle (Mir et al., 2022).

4. Opportunities for Vertical Farming

Vertical farming provides a practical and eco-friendly way to tackle food security in urban areas. By using cutting-edge technology and creating controlled environments, it ensures a steady supply of high-quality produce, all while using fewer resources and reducing environmental harm.

4.1 Economic aspects

Vertical farming entails high capital outlay in the form of infrastructure and a high amount of energy needed for the farming practice but has opened specific economic opportunities such as farming in cities where conventional farming is not possible (Oh and Lu, 2023). However, costs associated with building infrastructure for a vertical farm and employing advanced technology for the growth of crops which may seem somewhat expensive may be cost-effective in the long run due to some factors such as the general reduction in transportation costs, resource utilization, and increased yields (Barui et al., 2022). By utilizing vertical space and filling them, vertical farming can produce much more produce per unit area hence the highest yields and the highest revenues (Sarkar and Majumder, 2015). Vertical farms, incorporating technologies and compact farm management systems, might improve crop productivity to a considerable level. Such strategies may help increase production numerous folds and turn vertical farming into an efficient and productive system of agriculture (Mir et al., 2022).

Challenges such as access to land and land ownership are paramount realities determining food production in urban areas. Vertical farming is a kind of farming that takes place vertically in a vertical structure this farming can happen in the city like on rooftops or any other structure that is empty. As opposed to conventional farming which focuses on the relentless occupation of new land space, vertical farming harnesses the use of space in vertical nature within the built space of cities(Kalantari et al., 2018). They eliminate the need for large expanses of agricultural land and cut wasteful use of water in closed-loop systems (Olabimpe Banke Akintuyi, 2024). Vertical farming can redefine the means of addressing the two significant issues of land and food security through urban agriculture by accumulating the feature of food production to the stack of city buildings (Thomaier et al., 2015). Also, indoor growth systems serve as a protective canopy for plants against the weather and other effects of climate change (Pinstrup-Andersen, 2018). This protective environment not only contributes to year-round crop production, free from the usual market chances of low yields due to changes in weather but also presents room for growing crops under conditions which would otherwise be unfavorable for common farming (Van Gerrewey et al., 2022). Also, reducing energy consumption decreases the cost involved in transporting foods, and minimizes the cases of food wastage since the structure is built in areas of high demand. Since vertical farms can be located in cities, direct marketing of foods is made possible, hence its feasibility. Direct selling to the consumer does not require the incorporation of intermediaries through which a significant portion of transportation expenses may amount to 60%. This strategy, while cutting down expenses, also adds to the freshness and quality of the produce which is advantageous for both, the farmer and the consumer (Al-Kodmany, 2016).

4.2 Environment aspects

Agriculture practiced traditionally is exposed to several limitations, especially in supplies based on the number of productions and the resultant availability of food throughout the year as well as exposure to the effects of climate change. Vertical farming is thus a solution of great utility in logging towards food sustainability as climate change ails the production of crops in urban areas (K. Al-Kodmany, 2018). They point out that conventional agriculture is injurious to the natural environment mainly due to activities such as deforestation, erosion of soils, and emission of greenhouse gases. Vertical farming however reduces such ecological effects as pressure on land and water usage and the integration of renewable energy systems (Benke & Tomkins, 2017). Vertical farming is relatively more ecologically friendly than traditional farming and, hence is perceived as an ecological solution to farming. One of the most significant advantages is resource efficiency. Conventional farming is very expensive in terms of water usage, pesticides, and fertilizers, which are on many occasions unfavorable to the environment.

Hydroponics, aeroponics and aquaculture have been adopted in vertical farming techniques which require up to 5% of the amounts of water used in traditional farming. These systems reuse water, which cuts down on the amount that is wasted, and the amount of fresh water that is required (Kalantari et al., 2018). Further, there is no need to use pesticides, herbicides and fertilizers since pests and diseases cannot infiltrate the closed structures (Mir et al., 2022). By using fewer chemicals in the process, there is less pollution of the environment and a healthier system resulting from the reduction. In urban areas, using the excreta from domestic wastewater can be of great added value to satisfy the demand for fertilizer with less impact than the use of chemical fertilizers (Hilton et al., 2021). Vertical farming also helps in decreasing the headcount of emission of carbon that is normally emitted through the movement of foods from one region to another and also in incorporating new sources of energy such as energy from the sun and wind instead of the conventional sources of energy that support 'fossil' energy in the form of coal and gas (Tuomisto, 2019). In conventional extensive farming, phosphorous and nitrogen-based fertilizers have detrimental effects with Phosphorus and Nitrogen moving to other ecosystems and causing eutrophication in the aquatic and terrestrial ecosystems (Bol et al., 2018). But in vertical farming, the nutrient solution is recycled over and over at highly efficient rates which greatly reduces the external impacts. Such optimal utilization of nutrients could result in 70–90% less eutrophication an environmental advantage that the vertical farming system has over conventional methods (Van Gerrewey et al., 2022).

4.3 Social and political aspects

Vertical farming does not only improve the efficiency of food production and its sustainability indicators but also has multiple socio-economic advantages. They create various employment opportunities, especially in engineering, biotechnology, biochemistry construction, research and the environmental sciences (Benke and Tomkins, 2017). This efficient technique in agriculture not only solves problems related to food insecurity in cities but also triggers progress in technology and the generation of new professions, contributing to the advancement of the economy (Akintuyi, 2024). As a result of being near populated regions, vertical farming increases the community's participation and ties between producers and consumers. This cuts expenses, increases the quality and freshness of the produce as well as the generation of new social relations. Moreover, farmers have direct contact with the customers, which acts as a bonus to the community bonds (Specht et al., 2015). By implementing vertical farming, urban people's health is enhanced and they experience less stress since the environment gets closer to them. They also advance high technology and environmental industries, foster higher learning and cultivate a knowledgeable and healthy population (Al-Kodmany, 2018). It also has a type of use that is related to leisure and thereby contributes to the improvement of the quality of the social well-being of people in that particular society. Vertical farms with green spaces help residents of large cities experience the effects of contact with nature which helps in stress reduction and improving mental health (Thomaier et al., 2015). From a political viewpoint, vertical farming can improve the national and local food security policies and decrease reliance on food imports and their instability. Through vertical farming, governments will be in a position to address climate change commitments since vertical farming embraces both climate change adaptation and mitigation (Benke and Tomkins, 2017). Therefore, the implementation of vertical farming can demonstrate a progressive leadership factor in combating core issues of urbanization and still feed the nation as well as transform the environment.

5. Case Studies and Examples

5.1 Sky Greens, Singapore

Sky Greens in Singapore is the latest hydraulic-driven vertical farm recognized as the world's first low-carbon plantation which adopts green urban solutions in its production of vegetables as well as clean, fresh and healthy to consumers through the least use of land, water and energy. Sky Greens is currently the innovation arm of its' parent company Sky Urban Solutions Holding Pte Ltd which makes it advance in the development of new urban agriculture concepts. The vision of the company is to be the world's premier integrated sustainable, green urban agriculture technology company. Sky Greens aims to dedicate efforts to enhance the sustainability of farming strategies to support the food security and safety of cities. Their mission entails the use of low-carbon agriculture to make it common for people to embrace it in their city life thus fostering sustainable city development (Sky Greens, 2024).

5.2 AeroFarms, Danville, Virginia, US

AeroFarms has been providing some long-needed solutions to the world of agriculture since 2004, always focusing on sustainability and innovation. They are a Certified B Corporation using innovative technologies such as Indoor Vertical Farming, Artificial Intelligence and Plant Biology to transform the food system. The AeroFarms proprietary system produces superior tasty crops with high levels of identity, and food safety. They lead in commercial indoor farming, using aeroponics to grow plants with 95% less water and no pesticides. Combining horticulture with technology, AeroFarms is capable of growing over 550 plant varieties employing a farming mechanism that is traditional yet untraditional at the same time, within a year (AeroFarms, 2024).

5.3 Skyfarm, Toronto, Canada

Skyfarm by Gordon Graff, located in Toronto, Canada, is a planned 59-storey agricultural building for an intelligent farming system in the urban context. Stretching over about 8 million square feet it employs hydroponics to produce. By incorporating a biogas plant and an anaerobic digester in Skyfarm, waste will be prepared as methane for developing electricity creating sustainable food production and urban sustainability. This new structure exhibits the possibilities of Vertical farming in meeting food security challenges in urbanized regions (Al-Kodmany, 2018).

5.4 Plenty, California, USA

Plenty, started in San Francisco, is one of the few most notable companies in vertical farming which seeks to meet global problems such as global warming and scarcity of fertile soil. With the help of indoor vertical farming, Plenty minimizes the degree of natural resource consumption by large-scale agriculture, opening up new opportunities for farming in urban areas and zones regarded as unfavorable for agriculture. Their strategy merges hydroponics, robotics and machine learning to enhance plant raising, freshness of produce free from pesticides and shielding from pollution. It establishes a precise climate control of light, water, and nutrients which ensures that delicious crops are grown all year round. Built on the principles of efficiency, Plenty attains high yields within confined areas, which may not be well received by conventional farming practices that require extensive space (Plenty, 2024).

5.5 The Plant, Chicago, Illinois, USA

This Plant in Chicago, Illinois, represents a new kind of vertical farm after converting from a former meatpacking business to a net-zero energy facility. It includes aquaponics, hydroponics, mushroom farming, waste heat and organic recycling included in their production procedure. A former four-storied 93,500-square-foot warehouse built in 1891 has been converted into an edible city. The Plant for instance uses its food waste to produce electricity and heat through an anaerobic digester that produces biogas. It is also involved in incubating new food businesses, and research as well as being a training hub for vertical farming (Plant Chicago, 2024).

5.6 Green Spirit Farms - New Buffalo, Michigan, US

Green Spirit Farms based in New Buffalo, Michigan converts old industrial buildings into Vertical hydroponic systems to produce fresh vegetables such as greens, and herbs all year round. Working out of a 40,000-square-foot building on a 27-acre site, GSF practices vertical stacking to offset some space issues. The farm provides pesticide-free, natural, locally grown, non-GMO foods for people in cities thus contributing to food security and sustainability while revitalizing vacant buildings (Green Spirit Farms, 2024).

6. Challenges of Vertical Farming

6.1 Economic challenges

Based on economic factors, one of the major problems of vertical farming is that it entails significant expenditure. Implementing a vertical farm also entails hefty costs in building construction, growth media, growing platforms, nutrients delivery system, workforce, supplies, and renting or purchasing urban land, which may be costly (Lubna et al., 2022; Van Gerrewey et al., 2021). Only construction costs are extremely high: for comparison, the initial costs per square meter of growing space are ten times higher than in hi-tech greenhouse (Erekath et al., 2024). On the same note, the costs associated with the running of vertical farms are high too for instance. They are costs that are incurred continuously like energy costs, labor costs, and expenses on maintenance and where energy is a significant operating cost. The main energy load is lighting at 65% followed by cooling at 20% and dehumidification having the least share of 10% (Arabzadeh et al., 2023). The other economic challenge is market competitiveness since vertical farming has to compete with traditional farming, which most of the time is subsidized by the government, making their produce cheaper (Banerjee and Adenaeuer, 2014). Due to this financial inequality, it becomes difficult for vertical farming to gauge its efficiency as a cheaper solution.

6.2 Environmental challenges

Despite its many benefits, the concept of vertical farming unfortunately has large-scale environmental problems, largely in terms of energy. The power needed to illuminate the growing zones is high and it largely contributes to the emissions of greenhouse gases (Martin and Molin, 2018). Vertical farms can utilize energy that is approximately 100 times more as compared to conventional agricultural practices and it has a high global warming impact of 2.51 kg CO2-eq for 1 kg of lettuce (Song et al., 2022). Secondly, although the usage of water and land is optimized in the vertical farm, the utilization of photovoltaic electricity to illuminate the farms makes the land usage between five and fourteen folds of that of the farms. These are realized through recirculating and mechanical dehumidification; however, the approaches require a large amount of energy, thus presenting the key environmental difficulty (Stanghellini and Katzin, 2024). Nutrients used in vertical farming hazardously may pollute the main urban water system as a result of excess consumption. Consequently, large volumes of waste such as plant debris and other physical cluttering materials may develop in and around the buildings where vertical farming is done (Barui et al., 2022).

6.3 Agronomic challenges

Other concerns about vertical farming include some agronomic as mentioned below: pollination and crop species (Birkby, 2016). Due to the limited access to natural pollinators in vertical farms, the process of moving pollen from the male organs of a plant to the female organs is done by hand, which is a very tedious process taking a lot of time and requires lots of workforce (Barui et al., 2022). Furthermore, the current models of vertical farming are also restricted in terms of crop selectivity. These farms are especially centered around high-value, fast-growing, small area requirements and short-generation plants like lettuce, basil, and other such greens (Mir et al., 2022). To realize the full potential of vertical farming the possibilities of crop variety are limited and need to be expanded to make farming efficient and commercially viable (Birkby, 2016).

6.4 Technological challenges

Vertical farming technology has various issues most especially on automation and lighting. Automated systems are ideal as they provide real-time monitoring and are ten to thirty times faster when it comes to planting and sowing. Still, these systems are 2-3 times more expensive than the semi-automated technologies (Kabir et al., 2023). Also, challenges are experienced in the usage of LED lighting in Vertical Farming, the flexibility of vertical farming lighting spectra, and changes towards better growth, color, and flavor. The scheduling of light and light quality is not easily predictable depending on the type of crop, and even between varieties in the same type of crop; this makes it challenging to transfer results studied in one type of crop and the findings to another type (Wong et al., 2020). Thus, vertical farming systems are quite complicated since they use hydroponics or aeroponics, lighting, climate control systems, and data-gathering tools. For that reason, the coordination of the different parts has to be tightly managed and is not always easy to achieve (Oh and Lu, 2023).

6.5 Social and regulatory challenges

The limitations of vertical farming also extend to social and regulatory issues. Social challenge is in the form of peoples' perceptive where some of the consumers may develop perceptions such as vertical farm produce is not natural. Changing the public perception is a function of strategy hence the constant public enlightenment programs, and information sharing on the advantages and safety of initiating vertical farming (Benke and Tomkins, 2017). Furthermore, vertical farming as a method of agriculture in urban areas requires tackling many; legal frameworks. Thus, although the driving forces of vertical farming are positive, improved and friendly legislation that addresses the issues of land rights, food safety, and the environment must be in place for vertical farming to become sustainable. A proper legal environment can act as a solution to some of the bureaucratic issues that farmers encounter when venturing into the vertical farming industry (Tooy et al., 2023).

7. Future Prospects of Vertical Farming

Several opportunities and exciting areas of innovation appear as vertical farming progresses further. The number of new megacities is rapidly increasing because of high population growth and intensification of urbanization. People move from rural areas to urban areas in search of better employment, education, health care and living standards hence causing the expansion of cities leading to the development of megacities with immense population density (Mir et al., 2022). The increasing population, growth of towns and cities, reduction in water supply and the ever-changing climatic conditions have all led to reduced available land per person (Satterthwaite et al., 2010). It is expected that vertical farming will be relevant to smart cities in which urban growth is based upon the use of smart technology and data. Vertical farming as a concept is relatively new and closely linked to smart city technology systems that collect real-time data, analyze it using the capabilities of artificial intelligence, and connect it to the smart city infrastructure (Saad et al., 2021). Vertical farming aims at increasing production and reducing the effects of climate change by practicing controlled indoor agriculture in city buildings that can be represented as high rises (Benke and Tomkins, 2017). Vertical agriculture holds a great deal of promise for developing sustainable solutions to address future global food needs by integrating technology and artificial intelligence into digital farming commodities and practices. In smart agriculture, there are several opportunities for vertical farming, such as explainable AI technologies for tracking crop development, forecasting the nutritional requirements of plants, detecting their health state, and targeting pests and diseases (Siregar et al., 2022). With the arrival of novel technologies including artificial intelligence, machine learning, and the interconnected world of the Internet of Things (IoT), vertical farming will have significant roles to embrace in the following periods.

Increasing Robotics and automation is enabling precision with concern to the use of resources in farming (Olabimpe Banke Akintuyi, 2024). The shift from fossil fuels to nuclear and renewable energy makes vertical farming additional and supportive to conventional farming thus improving food safety and security because of the expanding urban dwellers. Currently, vertical farming minimizes the necessity for food transport and water utilization, as well as decreases eutrophication (Van Gerrewey et al., 2022). With newer technologies like hydroponics, aeroponics, and aquaponics integrated into greenhouses; the prospects of vertical farming have been significantly boosted. This brings new approaches to the practice of farming, educating people and providing them with viable solutions for feeding the world's population concentrates in urban settings. Since they require less maintenance and can increase yields, they are promising elements for the advancement of urban farming (Al-Kodmany, 2018). The mentioned methods such as hydroponics aeroponics and aquaponics have proved to be some of the most effective soilless farming techniques that can hold solutions to future food shortages. These activities are beginning to receive popularity because they are efficient, cheaper and also unique in the current world (Tajudeen and Taiwo, n.d.). It offers several benefits over conventional farming techniques such as good aeration, conservation of water, time, and space, not being bound to seasons, a disease-free way of propagating plants, and its capability of mass production (Mir et al., 2022). The future of vertical farming is promising because of the new directions, advances in technologies, and novel concepts. However, to guarantee the long-term functionality, and economic feasibility of these systems, the communities of practice need to fill the existent gaps in knowledge and center research on the priorities (Olabimpe Banke Akintuyi, 2024).

8. Conclusion

More people mean more mouths to feed and as those people move into cities for a better standard and living, sustainable food production methods are essential. Vertical farming is a contemporary method of farming brought about by urbanization and food insecurity, and sustainability through the use of hydroponics aeroponics, and aquaponics. Such systems allow the successful cultivation in urban areas thus possibly saving agricultural land and water and at the same time these systems offer economic benefits like less cost of transport, improved means of resource use, and possibly higher yields per unit area. Environmentally, vertical farming diminishes the emission of greenhouse gases in the atmosphere, significantly reduces the use of pesticides and optimality in reuse and regeneration of nutrients making it the premier environmentally friendly way of farming. However, there are certain factors which constitute barriers towards the large-scale application of this technique namely; high fixed capital costs, high energy demands and technological issues associated with controlled environment and crop production diversification. To address these problems renewable power sources must be incorporated into the systems, solutions that are cheaper and energy savers are designed and implemented, and there should be an interdisciplinary approach and constant research. Another point is social acceptance and supportive regulation; in terms of policies and incentives, the governments need to come up with policies that can promote investments and also address issues to do with land use and food safety standards. Other issues like source water pollution originating from nutrients and wastes in urban areas must be controlled. The success of vertical farming itself is based on effective further development, teamwork between professions and a suitable political environment. Automation, Artificial intelligence and renewable energy will further improve the efficiency and profitability of this model. When properly backed up, vertical farming can establish steady food systems in urban areas hence boosting world food security and at the same time extending long-term environmental conservation. Dealing with the economic, technical, and social aspects, as well as the environmental issues, would create a path for the development of vertical farming as one of the key components in urban farming systems.

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