Promoting Environmental Sustainability Through Vertical Farming: A REVIEW

Abstract

Vertical farming presents a transformative approach to agriculture with the potential to address pressing environmental sustainability challenges. This abstract explores the role of vertical farming in advancing environmental sustainability. By utilizing innovative techniques like hydroponics and aeroponics, vertical farming optimizes resource use, reduces land footprint, and minimizes environmental impact. Through the vertical stacking of crops in controlled indoor environments, it maximizes land use efficiency and minimizes water consumption compared to traditional farming methods. Moreover, vertical farms located in urban areas reduce transportation emissions by shortening the food supply chain. However, challenges such as high initial investment costs and energy consumption remain barriers to widespread adoption. Collaborative efforts among researchers, policymakers, and industry stakeholders are crucial to overcoming these challenges and scaling up vertical farming practices. Despite obstacles, vertical farming holds significant promise for promoting environmental sustainability by enhancing food security, conserving natural resources, and reducing the ecological footprint of agriculture.

Keywords — Smart Farming, Food Sustainability, World-Changing Innovation and Vertical Farming.

INTRODUCTION

Vertical farming, employing minimal water and soilless cultivation in vertically stacked layers or repurposed structures like abandoned warehouses or skyscrapers, is a cutting-edge agricultural practice. Modern vertical farming incorporates indoor farming techniques and Controlled-Environment Agriculture (CEA) technology. This sophisticated method allows for precise adjustment of environmental parameters, including temperature, light levels, and humidity. Additionally, vertical farming supports the enhancement of crops' nutritional value via bio-fortification techniques, achieved through selective breeding methods. By harnessing these innovations, vertical farming not only optimizes resource usage but also holds promise for bolstering food security in an increasingly populated world while addressing nutritional deficiencies.

Fig. 1 Vertical Farming, Source of image; online platform

Vertical farming holds the promise of ensuring food security, particularly in urban areas, through the incorporation of nutritional supplements to sustain the burgeoning global population. Techniques such as vertical mushroom farming, hydroponically generated green manure, and the cultivation of select fruits, vegetables, chickens, and birds are either widely adopted or in advanced stages of development within vertical farming systems. Additionally, vertical gardens, often referred to as green walls, living walls, bio walls, or simply vertical gardens, are integrated into vertical farming practices. These innovative installations, as documented by Jain & Jankiram (2016), enhance urban landscapes with lush vegetation, providing both aesthetic appeal and potential for food production. Through the integration of these diverse methods, vertical farming emerges as a promising solution to address food insecurity challenges while promoting sustainability in urban environments.

A vertical garden is characterized by lush vegetation thriving in either organic or inorganic mediums, sometimes even incorporating soil, either fully or partially covering a space. It can exist as an independent area or as an integrated section of a building [24,25]. By employing hydroponics and vertical farming techniques, these gardens fulfil the need for natural, nutrient-rich produce devoid of pesticides, acaricides, and insecticides. Furthermore, such produce is distinguished for its elevated antioxidant content and minimal carbon footprint (Pant *et al.,* 2018). This amalgamation of innovative farming methods not only addresses sustainability concerns but also ensures the availability of wholesome, environmentally friendly food options.

The innovative concept of the vertical farm has finally come to pass. Imagine living in a future where every town has its own local food source that is grown in the most environmentally friendly manner and where not a single drop of water or particle of light is wasted. Intelligent agricultural practices significantly improve sustainable food production in the twenty-first century. This is due to the fact that water management techniques and environmental conditions have a direct impact on plant development. By 2050, it is anticipated that a significant percentage of the global population will be fed by innovative means such as vertical farming. establishing a farm close to the people it serves, protecting the planet's limited natural resources while providing cheaper, organic, and disease-free produce.

Important Features of Vertical Farming

- The producer may grow food on vertical farms.
- around the clock, 365 days a year,
- and safeguard crops from unpredictably bad weather.
- Repurposing water obtained from indoor environments
- Give locals and communities jobs.
- Reduce the usage of herbicides, fertilizers, and insecticides.
- Significant reduction in reliance on fossil fuels
- Prevent crop loss during long-distance transit, shipment, and storage.
- Eliminate agricultural runoff to save up to 90% of water.
- Delighted to produce food—an exuberant emotion
- teaching and preparing schoolchildren for the production of food

Vertical Farming Concept

The practice of cultivating crops in layers that are piled vertically is known as vertical farming. It usually includes controlled-environment agriculture, which tries to maximize plant development, as well as soilless farming methods like hydroponics, aquaponics, and aeroponics. Vertical farming systems are frequently housed in buildings, shipping containers, tunnels, and abandoned mine shafts.

The importance of vertical farming

Growing in popularity is the practice of vertical eco-farming, particularly in the US, Canada, Western Europe, and Japan. It requires a lot of capital and advanced technology. It is extremely productive, land- and water-wise, and environmentally friendly.

Producing food locally, right at the customer's doorstep, eliminates the necessity for transportation, thereby reducing greenhouse gas emissions and minimizing food waste (AVF, 2013). Additionally, cultivating crops in skyscrapers not only diminishes the requirement for additional land but also generates accessible growing space in the air. Furthermore, cultivation in a controlled environment reduces water usage, minimizes waste production, and mitigates the spread of disease, all while yielding significantly higher crop yields. By enabling the production of local crops year-round, vertical farming reduces greenhouse gas emissions by eliminating the need for food transportation. Pesticides, pests, deforestation, and soil erosion are the main agricultural issues that hardly ever arise. Utilizing natural light is a crucial component of vertical farms' efficiency. Though Chinese cabbage, lettuce, basil, tomatoes, okra, cantaloupe, and bell peppers are the most profitable varieties, greenest leafy vegetables are growing well in the hydroponic subsystem. Additional vegetable species that thrive in an aquaponic system are radishes, strawberries, melons, onions, turnips, parsnips, sweet potatoes, taro, peas, kohlrabi, and herbs. Perhaps the sector in developing nations with the highest rate of growth is commercial vertical farming.

SCOPE AND POTENTIAL

1. Deforestation and land use should decrease. Less erosion and flooding result from this.
2. Unused or abandoned properties will find constructive use.
3. Harsh weather conditions, including floods, droughts, and snow, will not affect the crops.
4. A decrease in the use of automobiles since the generated crops are easily consumed.
5. Reduce pollution and CO_2 emissions by using fewer coal-burning products.
6. General well-being since agricultural buildings will receive direct access to municipal trash.
7. Water is utilized more wisely.

How does vegetal farming work?

There are four critical areas for understanding how vertical farming works:

1. Physical layout,

2. Lighting,
3. Growing medium, and
4. Sustainability features.

First and foremost, the main objective of vertical farming is to produce more food per square meter, which is why the crops are grown vertically in stacks. Second, to keep the ideal light level in the space, the ideal proportion of artificial and natural lighting is employed. Revolving beds stand as an exemplar of technology enhancing lighting efficiency. Furthermore, we will employ aeroponics (spraying water onto plant roots) or hydroponics (immersing roots in a nutrient solution) instead of soil, along with aquaponics growing media. In vertical farming, peat moss, coconut husks, and other non-soil media are frequently used. Lastly, the vertical farming technique offsets the energy cost of farming by utilizing a variety of sustainability characteristics. Compared to conventional farming, vertical farming actually consumes 95% less water.

Needs for vertical farming

1. With vertical farming, we can meet expanding demands within a small farming area without depending on the weather.
2. Increased water efficiency (less water used compared with traditional methods) Occupational duties like irrigation and other curable management are easy to perform.
3. Vertical farming results in reduced land use and deforestation. There will be less erosion and flooding as a result.
4. This method uses water more efficiently because drip systems are the main tool used.
5. Crops will be shielded from inclement weather, including snowfall, droughts, and floods.
6. Because the generated foods are easily consumed, there is less need for vehicle transportation.
7. Reducing the use of coal-burning items lowers pollution and CO_2.
8. General well-being, since municipal waste will be directed

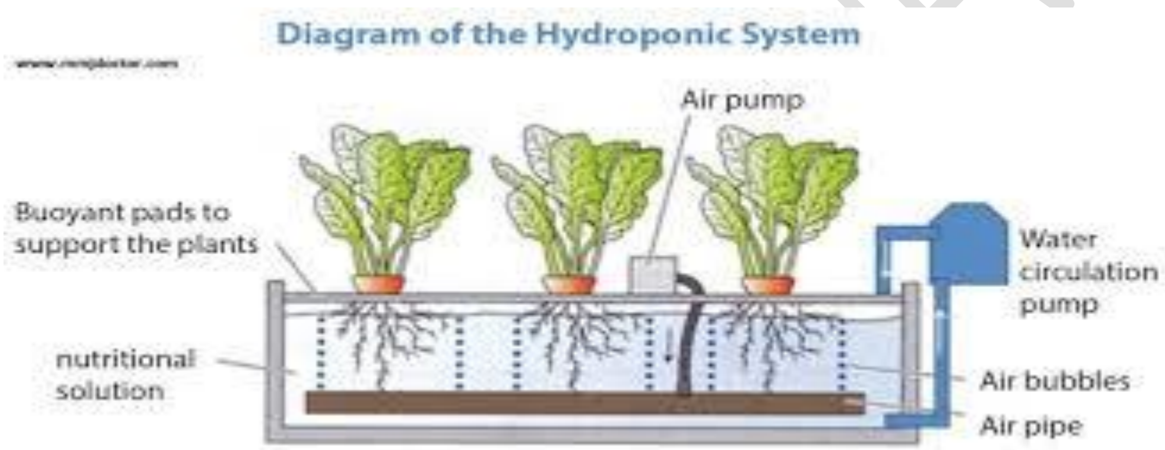
Innovations in vertical farming

Some of the following vertical farming innovations have the potential to support, supplement and improve existing agriculture techniques and technologies.

1. Hydroponics: soil cultivation or plant growth without soil.
2. Aeroponics: plants grown in a mist or fog with very little water and fertilizer and no soil.
3. Aquaponics is an ecosystem that combines raising fish and crops with roughly the same inputs.
4. Lokal: providing freshly harvested food in its natural habitat.
5. Aero Farms: This clever invention in vertical farming uses controlled environments and no sunlight to grow greens.
6. Plant capers: a structure that provides food for its people.

Techniques of vertical farming

1. **Hydroponics:**
"Hydroponics" is the name given to a technique for growing plants without soil. In hydroponic systems, the roots of plants are immersed in liquid solutions that contain macronutrients such as nitrogen, phosphorus, sulfur, potassium, calcium, and magnesium, along with trace elements including iron, chlorine, manganese, boron, zinc, copper, and molybdenum. Additionally, inert (chemically inactive) mediums like sand, sawdust, and gravel are employed as soil substitutes to give the roots support. Because hydroponic farms have regulated settings and tight certification laws, they provide a feasible solution for producing food in a more sustainable way without using toxic chemicals. Hydroponic farming is currently included in sustainable agriculture to help satisfy the growing need for food worldwide; therefore, it's far from being a pipe dream (Debangshi, 2021).



System requirements (Royston *et al*., 2018)

1	pH control	5 -7 or slightly acidic
2	Electrical conductivity	1.2 -3.5 mho
3	Horticulture lighting	Direct sunlight or supplement lighting for 8-10 hrs. Per day
4	Temperature	50 -70 degrees for fall plants and 60-80 degrees for spring plants.
5	Supplements	Nitrogen-phosphorus-potassium rich formula
6	Oxygen	Supplemental oxygen supply is required for optimal nutrient uptake
7	Structure & support	Stakes and strings are usually needed to support plants as they grow

2. Aquaponics

A kind of hydroponics known as aquaponics uses a closed-loop system to replicate nature's processes by growing both aquatic and terrestrial plants. A particle removal unit filters the nutrient-rich effluent from the fish tanks before sending it to a bio-filter, which transforms poisonous ammonia into nutrient-rich nitrate. Before reintroducing the effluent to the fish tanks, the plants first absorb nutrients and then purify them. In addition, the water in the fish tanks absorbs heat, and the plants absorb the carbon dioxide produced by the fish, enabling the greenhouse to keep a consistent temperature at night while using less electricity. Aquaponics, which also incorporates an aquaculture component, is not as popular as it once was since most commercial vertical farming systems concentrate on producing a small number of quickly developing vegetable crops.

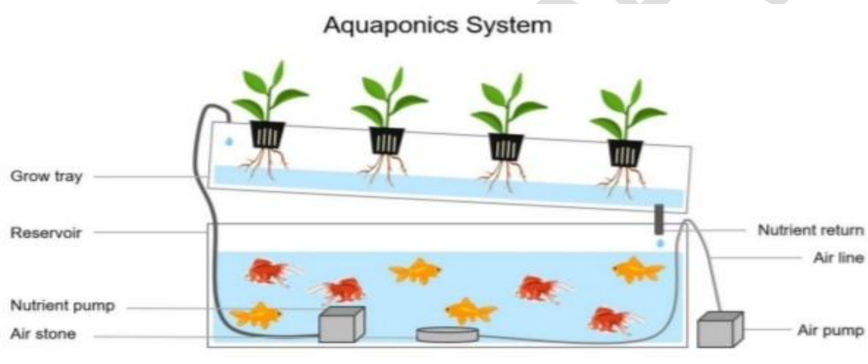


Fig. 3: A model of aquaponics

3. **Aeroponics**

Aeroponics was developed as a result of NASA's (National Aeronautical and Space Administration) 1990s ambition to find a productive approach to cultivating plants in space. Unlike hydroponics and aquaponics, aeroponics grows plants without the need for a liquid or solid growing medium. Alternatively, the plants are suspended in air chambers that are sprayed with a nutrient-rich liquid solution. By far the most environmentally friendly method of soilless cultivation, aeroponics uses up to 90% less water than even the most advanced traditional hydroponic systems while not requiring the replacement of growing media. Aeroponic systems also save energy since they may be structured vertically without a growing medium. This is because excess liquid in hydroponic systems is naturally drained away by gravity, while in standard hydroponic systems, excess solution is often controlled by water pumps. Although they haven't been used much in vertical farming yet, aeroponic systems are beginning to gain a lot of interest.

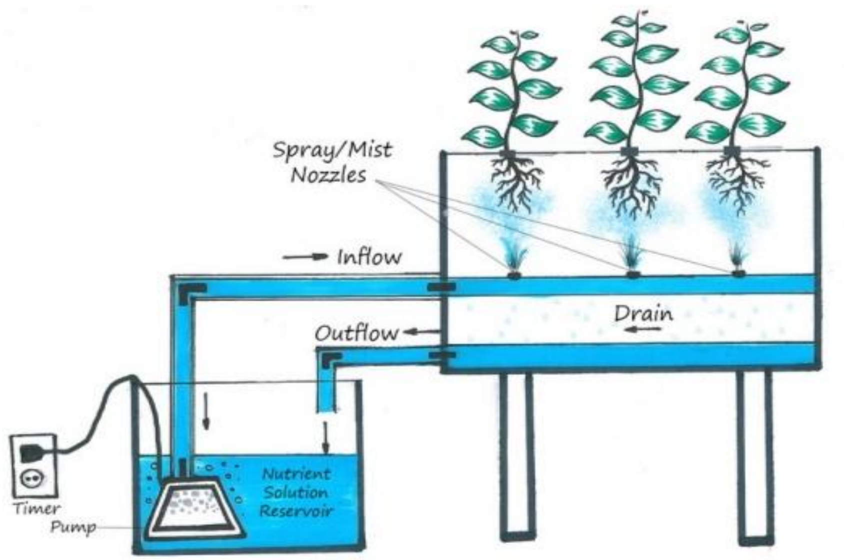


Fig. 4: A model of aeroponics

4. **Controlled-environment agriculture**

Controlled-environment agriculture (CEA) involves changing the natural environment to extend the growing season or boost crop productivity. In enclosed facilities like greenhouses or buildings, environmental parameters, including air, temperature, light, water, humidity, carbon dioxide, and plant nutrition, may be monitored. This is where CEA systems are typically housed. In vertical farming systems, CEA is frequently used in conjunction with soilless farming methods, including hydroponics, aquaponics, and aeroponics**.**

5. **Livestock production**

Similar to a fish farm, pasture-based livestock offers some social and environmental advantages when it is integrated into vertical farming. It benefits from a multitude of cultural influences. As per the Times (Despommier, 2010), the livestock industry in wealthy nations has prioritized animal health, environmental concerns, food security, and human welfare over manufacturer quality. To make sure that the livestock division can meet the increasing demand for items derived from animals, further research is needed. To allay worries about the environment, food safety, and the ethics of animal welfare, they ought to take into account the detrimental environmental effects of livestock production. It is also possible to bring up poultry farming, which uses the least amount of room but yields the greatest meat in terms of kilograms.

Types of vertical farming

1. **Building-based vertical farms**: Vertical farming often makes use of abandoned buildings. One such example is "The Plant," a Chicago farm that was transformed

from an old meatpacking plant. However, vertical farming systems are also frequently housed in newly constructed structures.

2. **Shipping-container vertical farms:** Repurposed shipping containers are becoming a more popular option for hosting vertical farming systems. The shipping containers function as standardized, modular chambers for growing a variety of plants. They are frequently equipped with LED lighting, vertically stacked hydroponics, smart climate controls, and monitoring sensors. Furthermore, by stacking the shipping containers, farms may save even more room and increase their production per square foot.
3. **Deep farms:** A "deep farm" is a vertical farm built out of repurposed mine shafts or subterranean passageways. Deep farms require less heating energy because the temperatures and humidity below the surface are often moderate and steady. Utilizing adjacent groundwater can help deep farms save money on their water supply. Saffa Riffat, head of sustainable energy at the University of Nottingham, claims that deep farming, for its low cost, may produce seven to nine times as much food on the same amount of land as typical above-ground cultivation. When paired with automated harvesting systems, these subterranean farms have the potential to be fully self-sufficient.

Working Principles of Vertical Farming

There are four critical areas for understanding how vertical farming works:

- **Physical layout**: The primary goal of vertical farming is to produce more food per square meter, so the crops are stacked vertically to grow.
- **Polymer:** ETFE (ethylene tetrafluoroethylene), a translucent, self-cleaning polymer, is used to construct the building's façade. Because of its transparency, 95% of the light in the room can enter the building. Depending on the strength of the sun, the pressure differences between the ETFE layers enable the screen to open and close.
- **Lighting:** In vertical farming, lighting plays a significant role in controlling crop development. To keep the ideal amount of light in the space, the ideal blend of artificial and natural lighting is used. Revolving beds are one example of a technology that increases lighting efficiency. Artificial illumination could be solar cells or LEDs. To improve crop growth, a range of light intensities is required (Saravanan *et al*., 2018).
- **Growing medium**: Rather than using soil, we'll utilize hydroponics, aeroponics, or aquaponics, which involve submerging the plant roots in a nutrient solution. In vertical farming, non-soil media like peat moss, coconut husks, and the like are frequently used (Saravanan *et al.,* 2018). It is important to remember that the medium needs to be able to hold moisture well and provide enough nutrients.

Sustainability features of vertical farming

According to Debangshi and Mandal (2021), a sustainable city is one that provides for the requirements of its current inhabitants without jeopardizing the resources available for future generations. The vertical farming technique reduces farming's energy costs by utilizing a number of sustainable elements. Compared to conventional farming, vertical farming actually consumes 95% less water.

Socio-economic dimensions of vertical farming

By utilizing less land, water, pesticides, and fertilizers and improving overall efficiency, vertical farming has the potential to dramatically improve food production while lessening the environmental impact of the agricultural industry. The economic viability of vertical farming is still a significant barrier, despite the well-established environmental advantages. Vertical farming has substantial upfront expenses; however, these are greatly outweighed by the financial gains from improved productivity, less resource consumption, and increased sustainability.

- Vertical farms use less space and water to produce the same amount of food as traditional agricultural operations.
- External environmental factors that impose additional costs on farmers have very little effect on vertical farms compared to traditional agricultural production.
- Optimizing plant growth and nutritional value can also be achieved by regulating environmental temperatures and nutrient levels.
- Reducing the necessity for lengthy transportation equals lower costs.

The price of vertical farming in India varies according to the product. However, it only costs about Rs. 4 to 5 thousand, which you can increase to Rs. 8 to 10 thousand depending on your demands if you are not starting it professionally and are only using it for your own family. On the other hand, women's contributions to urban agriculture are mostly in the areas of income generation and family food security. Selling extra goods from their urban agricultural endeavors is one way that female farmers can make money. There are several chances for women to work in vertical farming, including managing water levels, adding nutrients, harvesting, and threshing, all of which are frequently performed by women due to their precision.

The future of vertical farming

The world population is predicted to increase from 7.8 billion in 2020 to 9.9 billion by 2050, according to the 2020 World Population Data Sheet. This is an incredible amount. In addition, it is anticipated that there will be more than 6 billion urban dwellers by 2050, 90% of whom will reside in developing nations (UN, 2013). Megacities are growing at an unprecedented rate, which might have severe effects on the environment and be unsustainable. Additionally, according to global forecasts, agricultural land can only be expanded by 2% until 2040 (FAOSTAT, 2016). New technologies like vertical farming offer a competitive alternative to traditional agricultural methods in order to feed a growing population.

Advantages of vertical farming (Sonawane, 2018)

- High productivity per unit area: vertical farming yields over 80% greater harvest per unit of land.

- Sustaining food production all year round without being vulnerable to natural disasters such as floods, high precipitation, snowfall, droughts, pest and disease outbreaks, etc.
- It lowers the price of moving food from rural to metropolitan locations.
- Additionally, there is a significant decrease in the amount of fossil fuel used to transport farm produce from rural areas to cities.
- Compared to traditional farming, vertical farming consumes 70–95% less water.
- It also requires less or no soil, which prevents pest and disease infestations.

Sustainable agriculture is essential for meeting the growing global food demand while minimizing environmental impacts. Vertical farming, an innovative approach to agriculture, offers unique advantages compared to conventional farming methods. This paper examines these advantages in detail, focusing on resource utilization, space utilization, environmental health, energy utilization, and other sustainability indicators.

Resource Utilization: Vertical farming optimizes resource utilization by minimizing water and land usage. Studies (Smith *et al.*, 2019) have shown that vertical farming requires significantly less water compared to traditional soil-based agriculture due to its efficient hydroponic and aeroponic systems. Additionally, vertical farming maximizes land productivity through vertical stacking of crops, reducing the need for extensive land clearance and preserving natural habitats (Despommier, 2010).

Space Utilization: One of the key advantages of vertical farming is its efficient use of space. Traditional farming methods require vast expanses of land, leading to deforestation and habitat destruction. In contrast, vertical farming utilizes vertical space, enabling high-density cultivation in urban areas where land availability is limited (Goddek *et al.*, 2018). This efficient use of space minimizes the environmental footprint of agriculture while increasing food production capacity.

Environmental Health: Vertical farming promotes environmental health by minimizing the use of synthetic pesticides and fertilizers. Conventional farming methods often rely on chemical inputs, which can contaminate soil, water, and air, leading to ecosystem degradation and human health risks (Pretty, 2008). Vertical farming employs controlled indoor environments that reduce the risk of pest infestations and diseases, eliminating the need for harmful chemicals (Graamans *et al.,* 2018).

Energy Utilization: Energy utilization is a critical aspect of sustainable agriculture. Vertical farming has the potential to reduce energy consumption compared to conventional farming methods. Controlled indoor environments allow for the efficient use of energy, particularly when coupled with renewable energy sources such as solar panels (Zhang *et al.*, 2020). In contrast, traditional farming relies heavily on fossil fuels for mechanized equipment and transportation, contributing to greenhouse gas emissions and climate change (Tilman *et al.,* 2011).

Other Sustainable Indices: In addition to resource, space, and energy utilization, vertical farming excels in various other sustainable indices. It promotes biodiversity conservation by reducing habitat destruction associated with traditional agriculture (Foley *et al.,* 2005). Vertical farming also enhances food security by providing consistent yields year-round, independent of weather conditions (Specht et al., 2014). Furthermore, vertical farming can contribute to local food resilience by shortening supply chains and reducing reliance on long-distance transportation (Liu *et al.*, 2017).

Disadvantages of vertical farming

1. The primary issue is the initial cost of setting up the vertical farming system. It covers the price of automated racking and stacking systems, climate control systems, remote control systems, and software, among other things.
2. High energy consumption occurs due to the exclusive reliance on artificial lighting for plant growth, while crop pollination poses a challenge as vertical farming systems lack natural insect pollinators.
3. The primary urban water supply may become contaminated by excess nutrients utilized in vertical farming.
4. With vertical farming, a lot of waste, plant leftovers, etc., can be produced around the structures.
5. Initially, there won't be skilled staff, so they will require training.

Major Challenges in Adopting Vertical Farming

The major challenges in vertical farming include

1. Taking into account vertical farming as an additional form of agriculture.
2. There may be minimal or no plant-nature interaction.
3. Expensive agricultural practices.
4. Insufficient infrastructure and experience.
5. The creation of appropriate crop hybrids and/or variations.
6. Over time, the technology produces an offensive odour or scent, making it unfit for use in an environmentally beneficial manner.

Conclusion

It will need a range of strategies to pave the way for the green insurgency of the twenty-first century. We can draw the conclusion that a little knowledge of vertical farming can greatly enhance food security. In addition to revolutionizing the greenhouse sector, aeroponic technologies and pest-free plant growth have opened the door for innovative farming techniques, including rooftop farming. Because of all of this, local food production is now possible in densely populated cities where there is an unmet demand for food and an increasing number of people. Along with flexibility and environmental advantages, vertical farming also presents options for architectural and urban design, and it has a lot of promise. The risk of famine will disappear, and detrimental climate change will be mitigated, if its use becomes commonplace and widespread around the world.

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