Vertical Farming and Hydroponics
Future Urban Agriculture

Hydroponics and vertical farming offer efficient and sustainable solutions to urban agriculture challenges. Hydroponics maximises resource use, enables year-round crop production, and increases yields, potentially revolutionising food cultivation, especially leafy vegetables. It reduces waste by conserving water, nutrients, and space, promoting sustainability. The integration of smart technologies and automation enhances agricultural productivity in vertical farming.

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Addressing the rising global food and nutritional demand with a growing global population, diminishing farmlands, declining soil fertility and increasing urbanisation has prompted the adoption of advanced farming methods that are crucial for sustainable and efficient food production systems. Vertical farming and hydroponics, innovative techniques capable of addressing urban agriculture challenges, have gained prominence. Countries that have long struggled with sustainable domestic food production and supply constraints are implementing these technologies to achieve future food security and nutrition. In India, hydroponics and vertical farming are gaining importance considering the increasing demand for leafy, green vegetables and fruits viz. strawberries and blueberries.

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By 2050, the global population is projected to reach 9.8 billion, with 70% living in cities. Globally, 55% of people live in urban areas, and urbanisation is on the rise. In India, 53% are expected to live in cities by 2050 (United Nations, 2018). Limited agricultural land for conventional farming necessitates the exploration of innovative food production technologies like Urban Farming (UF) including vertical and hydroponic farming, which can ease pressure on agricultural lands for a healthier and more sustainable future. The worldwide vertical farming market is projected to reach USD 33.02 billion by 2030, with an anticipated compound annual growth rate (CAGR) of 25.5% from 2022–2030. According to IMARC Group's latest research report, the India vertical farming market is expected to demonstrate a CAGR of 25.4% during the period 2023–2028.

Understanding Vertical Farming and Hydroponics

Vertical farming (VF) revolutionises traditional agriculture by employing soilless cultivation in a multi-level, protected indoor environment, departing from conventional soil-based farming and horizontal crop growth on a single level. Prof. Despommier is acknowledged as the founding father of 'Vertical Farming,' who created high-tech vertical farms as an alternative solution to address nutritional needs, particularly in megacities. Despommier proposed that overcoming challenges like diminishing agricultural resources and changing climate could involve the concept of vertical farming, a contemporary practice of cultivating crops in stacked layers within protected indoor environments. Vertical farming has the potential to enhance food production, maintain quality and contribute to sustainable urban farming. It is an indoor urban technique involving large-scale food production within multistorey buildings. Successful commercialised urban farms exist in European countries like France, Germany, the Netherlands, and the United Kingdom. The significance of urban agriculture and vertical farming is particularly crucial in low-and lower-middle income countries, such as sub-Saharan Africa and parts of Southern Asia.

Vertical farming adopts a unique approach to maximise space and efficiency by cultivating plants in vertically stacked layers or inclined surfaces, often within controlled environments like greenhouses or warehouses. This method proves particularly advantageous in densely populated urban areas where space is limited, allowing for optimal use of available space. This farming method involves growing crops in vertically stacked layers indoors, frequently utilising controlled-environment agriculture (CEA) techniques to optimize factors such as light, temperature, humidity, and nutrients as shown in Fig 1.

Fig. 1- Vertical farming technology at ICAR-IARI, New Delhi

Various shapes and sizes of vertical farms worldwide employ one of three nutrient-providing methods: Hydroponics, Aeroponics, or Aquaponics (Farkhondehmonfared, 2022).

Hydroponics: This prevalent technique in vertical farming involves growing plants on soil-free substances continuously irrigated with nutrients. Plant roots are submerged in a nutrient solution, and the system uses 60–70% less water than traditional agriculture, making it widely utilised in numerous vertical farms worldwide.

Aeroponics: Developed by NASA in the 1990s for space plant growth, aeroponics cultivates plants in a soil-free mist environment with roots hanging down in a closed-air container. This method uses 90% less

water than hydroponics, making it a highly efficient system of food production. Plants grown aeroponically absorb more nutrients, resulting in healthier and more nutritious produce. Globally, the largest aeroponic vertical farm is currently situated in New Jersey.

Aquaponics: Going beyond hydroponics, aquaponics integrates fish production into plant cultivation. The system utilises fish-produced nutrient-rich waste as a feed resource for plants, and plants, in turn, purify and recycle wastewater for fishponds. While this system offers ecological benefits, its complexity and higher cost make it less common in vertical farming.

Hydroponic farming presents an intriguing alternative to traditional soil-based agriculture by nurturing plants in nutrient-rich water solutions instead of soil, fostering quicker and more efficient growth. This soil-less approach proves versatile, cultivating a diverse range of crops, from vibrant leafy greens to fruitful plants. In India, hydroponics is a relatively new concept gaining popularity among entrepreneurs and innovative farmers seeking sustainable and efficient crop cultivation methods. Currently, this technology is primarily utilised in urban farming, rooftop gardening, and commercial farming. Moreover, vertical farming often integrates hydroponic systems, contributing to a sustainable and compact cultivation approach.

Different Hydroponic Systems

When considering hydroponic systems, numerous options exist, each with distinct advantages and limitations. The choice of the best hydroponic system for growing vegetables depends on factors like space, budget, and the specific crops you intend to cultivate. Here are some popular hydroponic systems to consider (Rajaseger et al., 2023).

1) **Deep Water Culture (DWC):** Plant roots are submerged in a nutrient solution. It is a straightforward and low-cost system suitable for beginners. This method involves suspending the plant roots in a solution of nutrient-rich, oxygenated water that promotes nutrient absorption.

2) **Nutrient Film Technique (NFT):** NFT involves a constant flow of nutrient solution over the roots, providing them with a steady supply of nutrients and oxygen.

3) **Ebb and Flow System:** This method involves cyclic submersion of plants in the nutrient solution, providing nutrients and oxygen to the roots through periodic drainage back into a reservoir.

4) **Drip System:** Drip system directly deliver nutrient solutions to plant roots using tubes and drippers. The solution is dripped onto the growing medium, like perlite or coco coir, and can be drained back for potential reuse.

5) **Aeroponics:** In aeroponics, plant roots are suspended in the air and misted with a nutrient solution, promoting rapid growth.

6) **Wicking System:** Plants in an inert medium use a cotton rope wick to draw nutrient solution from a reservoir to the root zone.

7) **Vertical Tower Systems:** These systems allow plants to grow vertically, making the most of limited space.

8) **Krakty Method:** A cost-effective hydroponic system that doesn't require electronic devices or electric current. It involves an initial administration of water and nutrients, proving efficient for plant production while minimising water wastage.

Combining hydroponics and vertical farming enhances the efficiency and productivity of resources used for food production. This approach, successful in urban farming, particularly for leafy green vegetables, allows year-round cultivation of crops like lettuce, kale, and spinach in controlled environments. Hydroponic vertical farming optimises space and resources, making it an attractive choice for food production in urban areas as depicted in Fig. 2.

Crop Management in Hydroponics

Plants grown hydroponically thrive in slightly acidic conditions, with a pH range of 5.5 to 6.5, optimising nutrient uptake. Neutral water is preferred for the hydroponic system. The pH of the nutrient solution should be adjusted twice a day to stay within an acceptable range. Acids like sulphuric, nitric, phosphoric, citric, or acetic are used to lower pH and potassium hydroxide, sodium hydroxide, or bicarbonate of soda are used to raise it. The strength of nutrient solution, measured by an Electrical Conductivity (EC) meter, impacts plant growth.

Fig. 2- Hydroponics and Vertical Farming Facilities at ICAR–IARI, New Delhi

Maintaining the optimum conductivity for each crop is crucial for maximising productivity. Auto hydroponic systems automatically manage nutrient solution EC, while manual measurement requires daily checks for adjustments. Maintaining optimal pH and EC is crucial. A favourable temperature significantly influences crop growth, with an ideal range of 15–18°C for leafy and exotic vegetables, although they can tolerate temperatures as low as 7°C. Adequate oxygen in the nutrient solution is crucial for root absorption, and plants benefit from aeration, avoiding waterlogged conditions. The solubility of oxygen in water decreases with rising temperatures (Singh and Ranjan, 2022).

Crops Suitable for Vertical Farming and Hydroponics

The most commonly grown commercial crops under vertical farming and hydroponics are given in the table:

Leafy greens and vegetables	Lettuce, spinach, kale (karam Saag), pak choi, arugula, coriander, chard, collard green tomatoes, pepper, broccoli, cucumber, beans
Herbs	Chives, basil, mint, oregano, fennel and parsley
Fruits	Strawberries, blueberries

ICAR-CISH, Lucknow, has initiated the standardisation of vegetable, herb, and strawberry cultivation in subtropical climates. The institute demonstrated four hydroponic systems: aeroponic, ebb and flow, Nutrient Film Technique, and drip hydroponic. The drip system is found suitable for indeterminate tomatoes, cherry tomatoes, and parthenocarpic cucumber, and nutrient film techniques for leafy vegetables, indeterminate tomatoes, and capsicum. The ebb and flow system proved effective for growing leafy vegetables and seedlings (Singh and Ranjan, 2022).

ICAR-Indian Institute of Horticulture Research, Bengaluru (IIHR) has developed a variant of hydroponics, "Cocoponics" or the soilless production of vegetables, using cocopeat as a substrate. The Institute has developed the complete production technology including a liquid nutrient formulation (Arka Sasya Poshak Ras) for soilless cultivation of zucchini, colour cabbage, chilli, brinjal, palak, amaranthus, coriander, etc. and exotic leafy vegetables viz., lettuce, parsley, broccoli, bok choy, etc. on arka fermented cocopeat (substrate) under open as well as in protected conditions (PIB, 2023).

Some examples of hydroponics companies in India are: Nutrifresh, India's largest hydroponic farm. Akarshak hydroponics, involved in the cultivation of hydroponic saffron and indoor saffron. Urban Kisaan, Future Farms, Rise Hydroponics, Evergreen Farms, and many more are yet to come. Vertical farming presents a range of benefits and challenges that make it a compelling option for future agriculture. Here are some advantages and disadvantages listed below:

Advantages

- Hydroponics in conjunction with vertical farming utilises 99% less land compared to traditional farming due to the concentrated root system

- Hydroponics require less water compared to conventional farming practices
- Enables the creation of a controlled microclimate, allowing year-round indoor cultivation of regional or seasonal crops
- Protects crops from soil-borne pests and diseases, and adverse weather conditions, thereby reducing the need for pesticides and fertilisers
- Flexible to set up locations anywhere, to reduce transportation and warehouse costs, streamlining the supply chain
- Facilitates access to fresh produce, ensuring reliable and sustainable food sources
- Vertical farming enhances plant productivity per unit area compared to horizontal hydroponic methods
- Automated monitoring and control systems enable growers to optimise growing schedules and provide optimal environmental conditions for crops
- In urban areas, vertical farming provides both environmental benefits, such as biodiversity and sustainability, and socio-economic advantages, including leisure and education

Disadvantages

- High upfront infrastructure costs pose a significant hurdle to the widespread adoption
- Shortage of expertise and the need for a controlled growing system necessitate a highly educated workforce, leading to elevated labour costs
- It is energy-intensive and requires artificial lighting, temperature, and humidity requirements, which increases the cost of production
- The absence of natural pollinators in controlled conditions can result in poor fruit sets and the production of small, misshapen fruits
- The range of crops cultivated commercially is usually confined to leafy vegetables and microgreens
- Require continuous attention and care, with components like pumps and nutrient delivery systems needing regular maintenance

Way Forward

Vertical farming, though expensive, is more affordable by utilising cheap and available shipping containers and abandoned warehouses. Collaborative research is important to bring together current technology practices for increased sustainability. Hydroponics and vertical farming offer efficient and sustainable solutions to urban agriculture challenges. Hydroponics maximises resource use, enables year-round crop production, and increases yields, potentially revolutionising food cultivation, especially leafy vegetables. It reduces waste by conserving water, nutrients, and space, promoting sustainability. The integration of smart technologies and automation enhances agricultural productivity in vertical farming. While hydroponics and vertical farming can be a good solution, they need more acceptance for widespread adoption. Research shows that supportive policies and incentives, like grants and tax benefits, can encourage investment and promote urban agriculture through agri-startups. ❑

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