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Revolutionizing Sustainable Agriculture Through Vertical Farming Innovation

N. Sandeep[1], Dr. Ch. Vijayakumar[2], K. Ravikumar[3], B. Lakshmi Keerthi[4]

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Abstract: The world population is rapidly increasing and is projected to reach around 9 billion by 2050. This population increase will exert significant strain on existing natural resources and generate a need for enhanced food production. Climate change is a worldwide concern, and agriculture is a contributing factor that requires an effective resolution. Consequently, the Vertical agricultural approach may diminish pollution levels by using 80-95% less water compared to conventional agricultural methods. Moreover, Vertical Farming addresses the escalating food needs of the population while employing less area, water, and chemicals, and cultivating nutritious crops. Nonetheless, food costs will be 5-10% more than those of traditional farming, but this disparity is expected to diminish with additional technological developments. Vertical farms cannot replace conventional farms; rather, they will serve as complementary systems to satisfy future food requirements. It is fiscally prudent, ecologically sustainable, technologically advanced, and, most importantly, health-conscious.

Keywords: population, agriculture, conventional agricultural, Vertical Farming.

INTRODUCTION

Approximately one fourth (almost 27%) of the Earth's total land mass is terrestrial, whereas the remainder consists of water (approximately 73%). Of this landmass, only three-fourths is arable, while the remainder consists of steep mountains, cold deserts, and hot deserts. Throughout the years, humanity has been capable to convert about 57% of arable land for the production of diverse crops for sustenance, often at the cost of forests and grasslands (43%). As urbanization becomes a global phenomenon, it is projected that over 60% of the world's population will reside in cities by 2030. During the same timeframe (by 2030), the human population is projected to increase from 7.6 billion to 8.6 billion, thereafter escalating to 9.8 billion by 2050 and surging to 11.2 billion by 2100.

Conversely, growing urbanization is exerting pressure on the limited land resources, which are seeing a steady but persistent loss in cultivated land globally (Ali and Srivastava, 2017). Urbanization has led to the proliferation of many concrete edifices, both small and huge, primarily to house the increasing population, sometimes at the cost of agricultural land. The skyline in major metropolitan areas is increasingly punctuated by high-rise buildings, although peri-urban agriculture cultivating vegetables and other food remains mostly unseen. The urban population will undoubtedly continue to increase, exerting pressure on food production, which has already reached a plateau for some crops. In some areas, arable ground has almost been depleted, leaving little opportunity for further agricultural production.

In India, the arable land has remained almost unchanged for numerous years. Any land area that is recovered is often offset by a comparable productive area allocated for building and other infrastructure development. Arable land has emerged as a constraining issue, with land prices surging in recent years. The conveyance of food from rural production locations to urban areas would exacerbate the issue, particularly for perishable and semi-perishable items, notably those derived from horticulture crops with limited shelf life. An innovative solution to partially address the aforementioned issue is the cultivation of food products inside urban environments, namely in residential buildings, on rooftops, and in public places. The current enhanced agricultural techniques exert significant strain on limited resources, resulting in declining returns on land, water, and energy; nevertheless, the novel technology of vertical farming is anticipated to alleviate this pressure substantially.

LITRETURE SURVEY

600 BC - The first instance of a "vertical farm" may be the renowned Hanging Gardens of Babylon, constructed by King Nebuchadnezzar II about 2,500 years ago. The gardens included a succession of domed terraces, layered vertically, adorned with various species of trees and flowers. The gardens, reaching a height of 20 meters, were likely watered using an early technical breakthrough known as chain pumps. These pumps likely used a system of buckets and pulleys to transport water from the

[1,3,4]*assistant Professor, Department Of Agricultural Engineering, International School Of Technology And Sciences For Women, A.P, India.*
[2]*professor, Department Of Agricultural Engineering, International School Of Technology And Sciences For Women, A.P, India.*

Euphrates River, located at the base of the garden, to a pool at the summit.

1150 AD - Approximately one thousand years ago, the Aztec civilization used a hydroponic farming technique called “chinampas” to cultivate crops in wetland regions next to lakes. The marshy terrain in these regions was unsuitable for farming; so, the Aztecs built rafts from reeds, stalks, and roots, which they then coated with mud and sediment from the lakebed. The rafts were then floated out into the lakes. The structural support provided by the rafts facilitated upward crop growth while enabling the roots to extend downward into the water. Frequently, several rafts were interconnected to create floating "fields."

1627 - The first published theory of hydroponic gardening and agricultural techniques was presented in the book Sylva Sylvarum, authored by the English scholar and politician Sir Francis Bacon. In this work, Sir Bacon created and examined the feasibility of cultivating terrestrial plants without soil.

1699 - English scientist John Woodward improved the concept of hydroponic gardening via a series of water culture experiments with spearmint. Woodward discovered that plants exhibited superior growth in water containing contaminants compared to pure water. This resulted in his significant discovery that plants get essential nutrients from soil and other additions incorporated into aqueous solutions.

1909 - Life Magazine released the first illustration of a "modern" vertical farm. The illustration depicts open-air tiers of vertically arranged residences situated inside an agricultural environment, all producing food for consumption.

1915 - The phrase “vertical farming” was introduced by American geologist Gilbert Ellis Bailey in his eponymous publication. Notably, Bailey concentrated on farming “down” rather than “up,” investigating a form of subterranean agriculture wherein farmers employed explosives to access deeper layers, thereby augmenting their total cultivable area and facilitating the cultivation of crops over a larger expanse.

1929 - William F. Gericke, an agronomic at the University of California, Berkeley, is recognized with pioneering contemporary hydroponics. In his December 1929 essay “Aquaculture: A Means of Crop Production,” Gericke first delineated the method of cultivating plants without soil, using sand, gravel, or liquid supplemented with nutrients.

1937 - The name "hydroponics" originates from an article in Science magazine, taken from the Greek terms "hydro," meaning water, and "ponos," meaning work. The name was proposed to Gericke as a substitute for "aquaculture," which was previously used to denote fish-breeding methods, by the botanist William Albert Setchell, his colleague at the University of California.

1940 - The hydroponic cultivation of crops on a large scale was first implemented in modern history during World War II, resulting in the production of over 8,000 tons of fresh vegetables on South Pacific Islands to sustain the allied forces stationed there (Kojai et al., 2015).

1964 - A vertical farm designed as a tall glass tower was shown at the Vienna International Horticulture Exhibition.

1989 - Architect and environmentalist Kenneth Yeang envisioned mixed-use structures that are harmoniously linked with green areas, facilitating the cultivation of plant life in open-air environments inside buildings. Yeang characterized this as "vegetated architecture." In contrast to several other vertical farming methodologies, his perspective emphasized personal and communal use rather than extensive output and commercialization.

1999 - The current vertical farm idea was established in a seminar conducted by Drs. Despommier and Carter, Professors of Environmental Health Sciences at Columbia University, in 2011. Despommier and his students conceived the concept of a multi-story structure where crops could be cultivated on each level to sustain New York's population solely via urban rooftop agriculture, essentially a modern vertical farming tower. Despommier has now emerged as the preeminent authority and advocate for vertical farming. In 2010, he wrote a book titled The Vertical Farm: Feeding the World in the 21st Century, in which he articulated the concepts and methods of contemporary vertical farming in urban areas and inside buildings, as opposed to horizontal development on land. Regrettably, his approach has yet to be implemented on a global basis. Nevertheless, India started its agricultural endeavors in the 20th century, mostly cultivating lettuce, a limited variety of green vegetables, strawberries, and herbs on a modest scale, in addition to hydroponic fodder, mushrooms, and poultry.

IMPORTANT FEATURES OF VERTICAL FARMING

• Vertical farms allow the producer to:

- Cultivate food continuously, 24/7, throughout the year

- Shield crops from erratic and detrimental weather conditions

- Recycle water harvested from the interior atmosphere

- Generate employment opportunities for local citizens and communities
- Reduce the use of insecticides, fertilizers, and herbicides

- Significantly decrease reliance on fossil fuels
- Mitigate crop loss during storage, shipping, and extended transportation

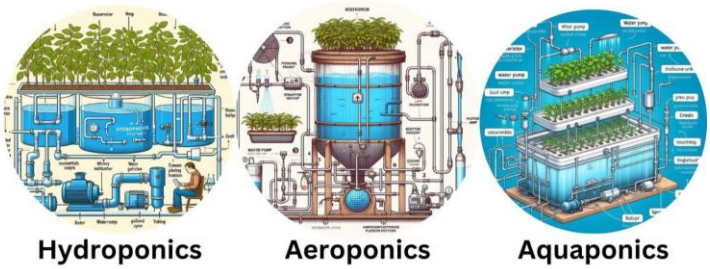
- Eliminate agricultural runoff, achieving water conservation of up to 90%
• Pride in food production - an exhilarating emotion
• Instruction and training for schoolchildren in food production

The Rise of Vertical Farming

Vertical farming, or indoor farming, is the growth of crops in vertically stacked layers, sometimes incorporated inside buildings like skyscrapers or converted warehouses. This approach employs controlled environment agriculture (CEA) technologies, such as hydroponics, aeroponics, and aquaponics, to provide ideal growth conditions for plants without soil. Utilizing artificial lighting, temperature regulation, and sophisticated irrigation systems, vertical farms can cultivate a diverse array of crops throughout the year, irrespective of exterior weather conditions. Vertical farming is a comprehensive word for a three-dimensional approach that encompasses food production via buildings using both horizontal and vertical space. This three-dimensional innovation is facilitated by the selective application, circulation, and regulation of water and nutrients essential for plant growth.

Approaches Used in Vertical Farming

Vertical farming utilizes many new methods to enhance spatial efficiency and improve resource use. Hydroponics, aeroponics, and aquaponics are prominent techniques for crop cultivation in vertical environments.



Hydroponics

Hydroponics is a method of cultivating plants without soil, using liquid solutions that provide needed nutrients for development. This approach has several benefits, such as enhanced production per unit area and less water use relative to traditional agriculture. It facilitates year-round cultivation and accelerated development, making it appropriate for both indoor and outdoor environments. Hydroponic systems vary from small-scale configurations to large commercial enterprises, offering adaptability and scalability in vertical farming methodologies.

Aeroponics

Aeroponics, a kind of hydroponic cultivation, entails hanging plants with their roots exposed to air. The roots are continuously misted with microdoses of water and nutrients, facilitating optimal nutrient absorption and expedited plant development. This technique was developed by NASA and is very advantageous for space-efficient and resource-conserving agriculture, making it appropriate for vertical farming implementations. Aeroponic systems are mostly used for cultivating leafy greens, culinary herbs, strawberries, tomatoes, and cucumbers, among many other crops.

Aquaponics

Aquaponics integrates hydroponics with aquaculture, creating a symbiotic ecosystem in which fish excrement supplies nutrients dissolved in water for plant cultivation. This integrated methodology enhances both plant growth and fish production, providing a sustainable and resource-efficient technique for vertical farming.

SUSTAINABLE VERTICAL FARMING

Mushroom Production

Mushrooms need little light for growth and serve as a healthy food source that recycles organic waste. Mushroom cultivators have used vertical farming techniques for a far longer duration than plant growers. It is suitable for urban or indoor farming on vertical beds and is being implemented in various metropolitan and peri-urban regions. Mushroom cultivation exemplifies effective, cost-efficient, and sustainable vertical farming.

Poultry Production (Broiler and Eggs)

Poultry, primarily layers (egg producers) and broilers (meat birds), are reared in either multi-storey structures or battery cages. Battery cages house a greater number of birds, hence enhancing the profitability of the enterprise. Despite its popularity in both urban and rural regions, animal protection groups have significant qualms and do not endorse it.

Plants suitable for bio/ living walls

The selection of appropriate plants is the paramount factor for the success of garden walls. Species that flourish in the local climate are optimal. Additionally, they should exhibit compact growth to ensure a thick and dense cover. Plants characterized by a short growth habit, shallow fibrous root systems, and extended life cycles are most

suitable for this application. Furthermore, they must be adaptable to both full sun and full shade conditions based on their placement. The most frequently utilized plants in bio/living walls include.

INDUSTRY SCENARIO

The indoor farming sector has shown continuous growth since 2017, garnering significant investments from prominent businesses. Vertical farms such as Plenty secured $200 million in funding from the SoftBank Vision Fund and Jeff Bezos. AeroFarms secured in excess of $80 million via two fundraising rounds, along with a $1 million grant from the Foundation for Food and Agriculture Research. The magnitude of these investments and the engagement of prominent private entities indicate the industry's development. The growing interest in indoor farming arises at a pivotal moment for our food supply chain. The global population is increasing, and to satisfy the escalating food need, Vertical Farming may provide a solution. Vertical farming is the most effective method for producing greater quantities of food with less resources than traditional agriculture, independent of arable land availability and external climatic variables.

GROWTH IN VERTICAL FARMING MARKET

The Vertical Farming market is projected to have a value of USD 7.3 billion by 2025, up from USD 2.9 billion in 2020, with a compound annual growth rate (CAGR) of 20.2%. The primary catalysts for market expansion are superior yield and several advantages of Vertical Farming compared to traditional agriculture, such as innovations in light-emitting diode (LED) technology, year-round crop cultivation regardless of climatic conditions, and less resource requirements.

Commercial growers on the property extensively use the hydroponics growing system. This mechanism is easier to establish, incurs lower costs, and yields a high return on investment (ROI). The Aeroponics system necessitates a greater initial expenditure than the hydroponics system. The hydroponic system maximizes water recycling with little waste, making it the most water-efficient agricultural technique. Regulating the quantity of nutrients supplied to plants may be executed rapidly, facilitating management of the development process and affecting variables such as growth rate and size. In the hydroponic system, plants can endure power outages due to a growth medium that consistently provides water and nutrients. In aeroponics, plants may perish within hours owing to the malfunction or failure of spraying nozzles.

Companies engaged in Vertical Farming throughout the Asia Pacific area are investing and extending their operations across several nations.

In 2019, Sustenir, an agri-tech firm based in Singapore, started a 30,000 square foot hydroponic vertical farm in Tuen Mun, Hong Kong. Hong Kong is a heavily populated region with little land available for agriculture. The output from traditional agriculture is insufficient to satisfy local demand, resulting in a significant reliance on imported goods. Vertical Farming is a way to diminish reliance on imported food items and mitigate food waste during transit by cultivating necessary food locally in limited spaces, leading to the proliferation of farms by corporations in the Asia Pacific area.

MAJOR CHALLENGES IN ADOPTING VERTICAL FARMING

The major challenges in vertical farming include:

1. Consideration of vertical farming as supplementary agriculture.

2. Partial or no plant-nature interaction.

3. Cost intensive cultivation.

4. Lack of expertise and infrastructure.

5. Development of suitable varieties and/or hybrids of suitable crops.

6. Generation of unpleasant odour/smell over the period (*cannot be called a totally environment friendly technology*).

CONCLUSION

Vertical farming may meet the needs of a growing population while employing less land, water, and pesticides, and producing nutritious crops. Food prices are 5-10% higher than those of conventional farming and decline with further technological advancements. The fast population growth, heightened immigration to urban centers, and rising demand for fruits and vegetables have resulted in recurrent food shortages, inflation in food costs, and occasional food crises in markets. Agriculture is inherently reliant on climate, and any variations in output and productivity in rural regions may result in losses. Comprehending these factors would indicate that Vertical Farming is a viable alternative. The evolution of cities from mere consumers of food to producers of agricultural goods enhances sustainability, promotes health, and alleviates poverty. Vertical farming has significant market potential globally since it is an emerging sector. Although there are fewer investors, the majority of prominent companies see the market's potential and are progressively investing over time. While vertical farms cannot be anticipated to replace conventional farms, they will likely need to coexist in order to satisfy future food requirements. It is fiscally rational, ecologically sustainable, tech-savvy, and most importantly, health-sensitive.

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