



Vertical farming and led based controlled environment in agriculture

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Abstract

Rapid population growth, urbanization, climate change, and the reduction of arable land have created significant challenges for conventional agriculture. Global food demand is projected to increase by nearly 50% by 2050, while opportunities for expanding cultivable land remain limited. In this context, vertical farming integrated with LED-based controlled environment agriculture (CEA) has emerged as a promising approach for sustainable, year-round food production. Vertical farming involves cultivating crops in vertically stacked layers within buildings, containers, or underground structures under precisely controlled conditions of light, temperature, humidity, CO₂, and nutrients. It primarily employs soilless techniques such as hydroponics, aeroponics, and aquaponics, which significantly reduce water use and enhance resource efficiency. Advances in LED lighting and automation have accelerated commercial adoption, particularly in developed and urbanized regions. Vertical farming offers high productivity per unit area, reduced pesticide use, and improved food safety. However, challenges such as high initial investment, energy demand, technical complexity, and limited crop diversity remain barriers to large-scale adoption.

Introduction: -

Rapid population growth, urbanization, climate change, and shrinking arable land have placed enormous pressure on conventional agricultural systems. According to global projections, food demand is expected to increase by nearly 50% by 2050, while cultivable land expansion remains extremely limited. In this context, vertical farming combined with LED-based controlled environment agriculture (CEH) has emerged as a promising solution to ensure sustainable and year-round food production. Vertical farming involves growing crops in vertically stacked layers under controlled environmental conditions, often using soilless cultivation techniques such as hydroponics, aeroponics, and aquaponics.



Concept and Evolution of Vertical farming :-

The term vertical farming was first introduced in 1915 by Gilbert Ellis Bailey, who used it to describe crop production in vertically arranged soil layers. However, the modern concept of vertical farming was popularized by Dr. Dickson Despommier of Columbia University in 1999, who proposed integrating agriculture into urban buildings. Since the early 2000s, advancements in LED lighting, automation, and soilless culture have accelerated the development of commercial vertical farms in countries such as Japan, the USA, Singapore, and several parts of Europe.

Vertical farming systems are typically housed in buildings, shipping containers, or underground structures (deep farms). These systems allow precise control over temperature, humidity, light, carbon dioxide, and nutrient supply, thereby minimizing dependence on external climatic conditions.

Techniques Used in Vertical Farming :-

Vertical farming primarily relies on three major soilless cultivation techniques:

1. **Hydroponics** involves growing plants in nutrient-rich water solutions without soil. Essential macro- and micronutrients are supplied directly to plant roots, resulting in faster growth, higher yields, and up to 70–90% water savings compared to conventional agriculture.
2. **Aeroponics**, originally developed by NASA for space research, suspends plant roots in air and periodically sprays them with a fine nutrient mist. This method is considered the most water-efficient, using up to 90% less water than hydroponics, while enhancing oxygen availability and nutrient uptake.
3. **Aquaponics integrates hydroponics with aquaculture.** Nutrient-rich wastewater from fish tanks is biologically converted into plant-available nutrients, which plants absorb while purifying the water for reuse by fish. Although environmentally sustainable, aquaponics is less commonly adopted in large-scale commercial vertical farms due to system complexity.

Key Notes:

1. Background & Need

Rapid population growth and urbanization increase food demand. Climate change and shrinking arable land limit traditional agriculture. By 2050, global food demand expected to rise by ~50%. Vertical farming offers sustainable, year-round food production.

2. Vertical Farming

Cultivation of crops in vertically stacked layers. Practiced in buildings, containers, warehouses, or underground farms. Uses controlled environmental conditions (temperature, light, humidity, CO₂). Minimizes land use and dependence on weather.



3. Historical Development

Term introduced by Gilbert Ellis Bailey (1915) Modern concept popularized by Dr. Dickson Despommier (1999).

Commercial expansion after 2000 due to LED and automation advances. Major adoption in Japan, USA, Singapore, and Europe.

4. Soilless Cultivation Techniques

a) Hydroponics

- Plants grown in nutrient solution without soil.
- Faster growth and higher yields.
- Saves 70–90% water compared to conventional farming.

b) Aeroponics

- Roots suspended in air and sprayed with nutrient mist.
- Highly oxygen-efficient and water-saving.
- Developed initially by NASA.

c) Aquaponics

Combines fish farming with hydroponics. Fish waste provides nutrients for plants. Environmentally sustainable but technically complex.

5. LED-Based Controlled Environment Agriculture

LEDs provide precise light spectrum control (red, blue, far-red). Improves photosynthesis, plant morphology, and yield. Energy-efficient and long-lasting. Enables crop-specific light recipes.

6. Advantages

- High productivity per unit area.
- Year-round cultivation.
- Reduced water and pesticide use.
- Suitable for urban and space-limited areas.
- Improved food quality and safety.

7. Limitations

- High initial investment.
- Energy consumption (lighting and climate control).
- Technical expertise required.
- Limited crop diversity (mainly leafy vegetables).



References

- Despommier, D. (2010). *The Vertical Farm: Feeding the World in the 21st Century*. Thomas Dunne Books.
- Kozai, T., Niu, G., & Takagaki, M. (2020). *Plant Factory: An Indoor Vertical Farming System for Efficient Quality Food Production*. Academic Press.
- Al-Chalabi, M. (2015). Vertical farming: Skyscraper sustainability? *Sustainable Cities and Society*.
- Benke, K., & Tomkins, B. (2017). Future food-production systems: Vertical farming. *Agriculture and Food Security*.
- FAO (2017). *The future of food and agriculture – Trends and challenges*.
- Resh, H. M. (2013). *Hydroponic Food Production*. CRC Press.
- NASA (2006). *Aeroponic plant growth systems research reports*.