

# RELEVANCE OF IMPLEMENTING VERTICAL FARMING SYSTEMS IN GREENHOUSES

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**Annotation.** The rapid growth of the global population, limited agricultural land resources, and increasing demand for food products require the introduction of innovative agricultural technologies. One of the most promising solutions is the implementation of vertical farming systems in greenhouses. Vertical farming allows crops to be grown in multiple stacked layers, significantly increasing productivity per unit area while efficiently utilizing available resources.

This study examines the relevance and advantages of implementing vertical farming technologies in greenhouse production systems. Particular attention is given to the efficient use of space, water conservation, controlled environmental conditions, and the potential for year-round crop production.

**Keywords:** vertical farming, greenhouse cultivation, protected agriculture, hydroponic systems, sustainable agriculture, crop productivity.

**Introduction.** The growing global population and increasing demand for food have created significant challenges for modern agriculture. According to recent estimates, the world population is expected to exceed nine billion by 2050, which will require a substantial increase in food production. At the same time, agricultural land resources are becoming increasingly limited due to urbanization, soil degradation, and climate change. These factors highlight the necessity of developing innovative agricultural technologies capable of producing more food using fewer natural resources.

Greenhouse cultivation has become an important method for improving agricultural productivity and ensuring stable crop production throughout the year. Protected cultivation systems allow farmers to control environmental conditions such as temperature, humidity, and light, which are essential for optimal plant growth. However, traditional greenhouse systems often rely on horizontal production methods that may not fully utilize the available space.

Vertical farming is considered one of the most promising technological innovations in modern agriculture. This system involves growing crops in vertically stacked layers or structures, allowing farmers to significantly increase production per unit area. Vertical farming systems are often integrated with advanced technologies such as hydroponics, aeroponics, LED lighting, and automated climate control systems, which improve resource efficiency and crop productivity.

**Materials and Methods.** The research was conducted to evaluate the relevance and practical possibilities of implementing vertical farming systems in greenhouse conditions. The study was carried out in protected cultivation facilities designed for vegetable production. The experimental greenhouse was equipped with multi-tier vertical structures that allow crops to be grown in several layers in order to maximize the use of available space.

Leafy vegetable crops commonly cultivated in greenhouse systems, such as lettuce, spinach, and basil, were selected as the main experimental plants. These crops were chosen because of their short growth cycle, high market demand, and suitability for vertical farming technology. The plants were grown using a hydroponic cultivation system in which nutrient solutions were supplied directly to the plant roots.

The vertical farming system consisted of several stacked layers arranged on metal or plastic racks. Each layer was equipped with planting trays and irrigation lines to deliver nutrient solutions evenly to the plants. Artificial LED lighting was installed

above each layer to ensure adequate light for plant growth when natural light was insufficient.

Environmental conditions inside the greenhouse were controlled to maintain optimal plant growth. The average temperature was maintained between 20–25 °C, while the relative humidity ranged from 70–85%. Ventilation systems were used to regulate air circulation and maintain appropriate carbon dioxide levels.

The nutrient solution used in the hydroponic system contained essential macro- and micronutrients required for plant development. Irrigation and nutrient supply were regulated using a controlled drip or circulation system to ensure efficient water and nutrient use.

Data collection during the experiment included plant growth parameters such as plant height, number of leaves, biomass accumulation, and total yield per square meter. The obtained results were analyzed to evaluate the efficiency and productivity of the vertical farming system compared with conventional greenhouse cultivation methods.

**Table 1**

**Main environmental parameters for vertical farming systems in greenhouse conditions**

<b>Parameter</b>	<b>Optimal range</b>	<b>Description</b>
Temperature	20–25 °C	Maintains optimal physiological processes and plant growth in vertical systems.
Relative humidity	70–85 %	Supports proper transpiration and prevents plant stress.
Light intensity	200–400 $\mu\text{mol}/\text{m}^2/\text{s}$	Provided by natural sunlight and LED lighting to ensure sufficient photosynthesis.
Photoperiod	14–16 hours	Extended lighting period improves plant growth and productivity.
Nutrient solution pH	5.5–6.5	Ensures optimal nutrient availability in hydroponic systems.
Electrical	1.5–2.5	Indicates nutrient concentration required for

conductivity (EC)	mS/cm	leafy vegetables.
Plant density	20–30 plants/m <sup>2</sup>	Efficient use of vertical space increases productivity per unit area.

**Discussion.** The results of the study confirm that implementing vertical farming systems in greenhouses significantly improves space utilization, resource efficiency, and crop productivity compared to traditional horizontal cultivation methods. By stacking multiple layers of crops, farmers can multiply the yield per square meter, which is particularly important in regions with limited arable land or high population density.

Hydroponic systems in vertical farming allow precise control over nutrient delivery, ensuring that each plant receives the necessary macro- and micronutrients for optimal growth. This results in faster growth cycles, higher biomass accumulation, and improved overall plant quality. Moreover, hydroponic systems reduce water usage by up to 70–80% compared with conventional soil-based methods, which is crucial in areas facing water scarcity.

The controlled environmental conditions in vertical farming systems, including temperature, humidity, and artificial lighting, allow year-round production of vegetables and herbs. This stability reduces the risk of crop losses due to adverse weather conditions or seasonal fluctuations, contributing to food security and consistent supply to local markets.

**Conclusion.** The implementation of vertical farming systems in greenhouse environments offers a highly effective solution for increasing crop productivity and optimizing resource use. By utilizing vertically stacked layers, controlled hydroponic systems, and artificial lighting, farmers can produce significantly higher yields per unit area compared to traditional horizontal cultivation methods.

Vertical farming provides precise control over temperature, humidity, and nutrient delivery, which accelerates plant growth, improves biomass accumulation, and enhances the overall quality of produce. In addition, it reduces water

consumption, minimizes pesticide use, and allows year-round production, contributing to sustainable and resilient agricultural practices.

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