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REVIEW ARTICLE

Green Future with Hydroponic and Vertical Farming

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ABSTRACT

The growing urbanization and unsystematic climate conditions cause dramatic changes in many environmental and food production methods. In this situation, traditional farming faces land scarcity, carbon emissions, and water shortage. Hydroponics and vertical farming work as an alternative to traditional farming by minimizing the challenges that were faced in traditional farming. Hydroponic vertical farming collectively shows advancement in smart farming. This modern cultivation technique is suitable for urban and pre-urban areas, as it is done indoors with a limited space. In the method of hydroponics, plants are grown in nutrient-rich water in the absence of soil. By providing proper temperature using light-emitting diode (LED) light, plants can be grown in a shorter period of time. Vertical farming is a method of growing crops in vertical layers, and hydroponics is one of the most common types of vertical farming. In contrast to traditional farming, this method saves 90% of the water. Apart from it, this method follows pesticide- and chemical-free farming, making the food healthier, and it gives a year-round cultivation regardless of seasonal limitations. Moreover, it is independent of climate change, which means there is no risk of drought, flood, etc. It also has a lower carbon footprint as it reduces transportation, prevents stubble burning, and land degradation. There are four types of hydroponics: Deep water culture system, wick system, and nutrient film technology. Integration of the lot, sensors in this technique ensure precision control over nutrients, water, and the environment. By combining technology and sustainability, hydroponic vertical farming can transform agriculture into an eco-efficient and climate-resistant system.

Key words: Climate resilient, smart farming, sustainability

INTRODUCTION

Agriculture is the backbone of India, providing human civilization, food, and raw materials for centuries[1]. However, in the past years, it has become very difficult to cultivate due to growing urbanization, scarcity of land, water shortage, soil degradation, unpredictable climate changes, and excessive use of chemicals. Due to this, the traditional farming method is unable to meet the global food demands[2]. The global population is projected to increase to approximately 9.8 billion by 2050, and that will lead to high food demand across the world[3].

In order to establish sustainable and smart farming techniques, hydroponic and vertical farming serve as a great alternative to traditional farming. Hydroponics is a type of agricultural method where plants are grown in water that contains nutrients and minerals such as nitrogen, potassium, phosphorus, calcium, magnesium, etc (Table 1). This method saves 90% of water and incorporates vertical farming with hydroponics, helping to grow crops indoors with a limited space as the crops are grown in vertical layers[4]. This modern method is suitable for urban and pre-urban areas; thus, the transportation cost and burning of fuel would be reduced as people from urban areas can directly get

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Table 1: Types of hydroponic methods

Nutrient film technique	Deep water culture	Drip systems	Wicking systems
A thin film of nutrient solution flows over the roots.	Roots suspended directly in oxygenated nutrient solution	Nutrient solution depends on the plant root via the emitter.	Passive systems were wick draw solutions to the roots.
Efficient, oxygen-rich roots, high yields.	Fast growth, small systems, beginner-friendly.	Precise control, water efficient, suitable for many crops.	Low cost, no pump/electricity, easy steps.
Lettuce, spinach, herbs, and Strawberries.	Leafy greens, herbs, and some fruiting plants.	Tomatoes, cucumbers, strawberries, peppers.	Herbs, leafy greens, houseplants.

Table 2: Land use efficiency of hydroponic and traditional farming

Crop	Hydroponic yield (kg/m²)	Traditional yield (kg/m²)	Yield increase (%)
Lettuce	25.6	8.2	212
Tomato	45.3	15.7	188
Spinach	21.4	7.6	182
Strawberry	12.8	5.4	162

Table 3: Water consumption and water use efficiency of hydroponic and traditional farming

Crop	Hydroponic water use (L/kg)	Traditional water use (L/kg)	Water savings (%)
Lettuce	12.5	85.6	85
Tomato	18.3	120.4	85
Spinach	13.8	92.1	85
Strawberry	22.7	150.8	85

the food, and it prevents stubble burning in rural areas, which causes soil degradation, which helps in lowering the carbon footprint. Apart from it, this method follows chemical and pesticide-free farming that ensures healthier food with a year-round cultivation because it is independent on the climatic conditions[5]. Since the hydroponic method is machine-based, it follows advanced technology like LED grow lights for providing proper temperature, climate control systems, an automated nutrients doser for mixing and delivering the right amount of nutrients, an aeration system for supplying oxygen, IoT, and AI devices for monitoring[6]. In India, many startups use IoT hydroponics kits for urban terrace farming.

Thus, hydroponic and vertical farming work as a solution that can transform agriculture into a sustainable system by providing fresh, pesticide-free food not only from rural agriculture but also from urban agriculture by addressing the challenges of climate change and land scarcity. This method provides a future-ready model that integrates technology with sustainability.

METHODOLOGY

Vertical farming and hydroponics both are controlled and indoor design-based technologies. Vertical farming can be done by stacking multi-tier vertical racks as layers. In case of hydroponics, nutrient-rich water is used in place of soil. Hydroponic setup is mainly based on the circulation of the nutrient solution system, nutrient film technology, and deep water culture. These two systems ensure that the plants are getting continuous water, enough nutrient flow, and preventing oxygen depletion[7].

In both vertical farming and hydroponics using LED, we stimulate plant growth. LED light can give an extensive spectrum of light waves. Each light wave has a different type of role. Blue wavelength helps in vegetable growth, red lights stimulate the flowering and fruiting stage, and thus we can study plants and give the needed wavelength for their growth. LED lights also operate at cooler temperatures than traditional light sources, so they prevent excessive heat accumulation within the environment. As temperature control is crucial for plant growth, this idea will be helpful[8].

Vertical farming and hydroponic systems are independent of climate problems, such as drought and flood, and they give the product year-round, but to get this, climate control measures are also needed. Some advanced technology ventilation systems, cooling pads, and automatic heating devices can regulate the plant's health[3].

Growth (plant height, leaves, roots) and yield parameters need to be checked. Here, an IoT-based device can be integrated to take data:

- NDVI camera →monitors leaf health and chlorophyll activity
- Load cell + HX711 Amplifier →measure plant biomass
- pH and EC sensors →track nutrient solution quality.

RESULTS AND DISCUSSION

- Vertical farming and hydroponics have various advantages than traditional farming. It can be practiced in urban areas where traditional farming is difficult; both techniques can be useful (Table 2)[9]. The production crop will be able to meet the needs in that area. Although it uses less land or space than traditional fields, it produces more yields (Table 3)[8,10].

Both methods use fewer water resources than traditional farming, which also helps in water resource management and prevents the waste of groundwater[11].

CONCLUSION

- Expanding vertical farming in urban areas leads to fresh food delivery to the customers, reducing transportation costs and carbon footprint.
- Using modern devices such as IoT, AI, drones, and other sensor devices helps in monitoring the nutrients, water, and crop health.
- This type of method can be practiced in-house, in schools, and in various communities to promote self-sufficiency in food.
- Adopting this method by the startups and agritech companies can result in making a billion-dollar company.
- Future underground farming and space farming can also be done using hydroponics (NASA is already experimenting).
- Development of renewable-energy powered vertical farms (solar panels, biogas, and wind energy) to make farming 100% sustainable.

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