

Revolutionizing Horticultural Crop Production: Soilless and Hydroponic Systems in Greenhouses and Vertical Farms

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Soil isn't an absolute necessity for supporting plant growth; its primary role lies in supplying vital macronutrients and micronutrients required for plant development. Traditional agriculture relying on soil presents several disadvantages, including inefficiencies in irrigation water use, extensive land demands, heavy reliance on chemical fertilizers, and soil degradation. The pressing need for substantial quantities of nutrient-rich food to meet global population demands underscores the urgency of introducing modern, progressive agricultural technologies and methodologies. These innovations aim to align water and nutrient requirements efficiently to attain maximum crop yields. Conventional farming methods, which rely heavily on soil as the primary growth medium, are undergoing a revolution brought about by innovative techniques like soilless cultivation and hydroponics. These advanced methods have found fertile ground in controlled environments like greenhouses and vertical farms, completely reshaping the landscape of horticultural crop cultivation. Soil-less cultivation primarily thrives in greenhouse environments, demanding high-tech infrastructure, substantial capital investment, and the expertise of skilled operators. However, the benefits are substantial: exceptional productivity, efficient use of water and space, and the prevention of soil and groundwater pollution through closed-loop systems. Hydroponics, another method within Controlled Environment Agriculture, allows plants to flourish without soil by utilizing precisely controlled nutrient-rich water solutions. This approach enables higher crop yields compared to traditional farming, as it permits a denser planting arrangement in less space while conserving water. It's especially appealing in regions with scarce water resources. Nevertheless, the initial setup costs and energy consumption pose significant hurdles to

its widespread adoption. Furthermore, limited crop diversity can be a challenge, as not all plants are well-suited to controlled environments.



The Rise of Controlled Environments: Greenhouses and Vertical Farms

In our pursuit of more effective, environmentally friendly, and consistently reliable crop cultivation, greenhouses and vertical farms have emerged as revolutionary solutions. These controlled settings provide the perfect environment for the flourishing of soilless and hydroponic systems. Greenhouses, which have long been recognized as sanctuaries for plant growth, have evolved into centers of precision agriculture. Within these controlled domains, the traditional dependence on soil has been replaced by innovative practices that prioritize soilless cultivation.

Plants thrive in inert growing mediums, where their growth is meticulously managed through the precise administration of nutrients, light, and environmental conditions. This transformative method facilitates year-round crop production, safeguards against adverse weather conditions, and optimizes the utilization of resources. In addition to this shift toward soilless cultivation, hydroponics, a

hydro-culture technique that eliminates the need for soil entirely, complements the controlled environments of greenhouses and vertical farms. In hydroponics, plants receive nourishment from nutrient-rich water solutions under meticulous control. The synergy between hydroponics and controlled environments, such as greenhouses and vertical farms, unlocks unparalleled potential. Hydroponics offers the advantage of increased crop yields, reduced water consumption, and efficient use of space, making it particularly attractive in densely populated urban settings. Collectively, the adoption of soilless cultivation and hydroponics within the confines of greenhouses and vertical farms signals a new era of sustainable agriculture. These practices provide solutions to challenges like seasonality, limited land availability, and resource conservation. By harnessing the capabilities of these controlled environments, we are reshaping the future of food production, ensuring a resilient and environmentally conscious approach to meet the ever-growing global demand for fresh, locally sourced agricultural products.

Soilless Cultivation: A Paradigm Shift



Conventional agriculture has traditionally depended on fertile soil as the fundamental medium for cultivating crops. However, soilless cultivation represents a departure from this conventional practice. In soilless systems, plants are cultivated in inert substances like coconut coir, perlite, or vermiculite, serving as a stable substrate. What makes

this approach groundbreaking is the meticulous control it offers over the precise delivery of essential nutrients to plants. This method not only minimizes the risk of soil-borne diseases but also enables precise optimization of resource utilization. In the realm of horticultural crop production, the term "soil-less cultivation" encompasses all systems that facilitate plant management in conditions devoid of traditional soil. Here, the supply of water and essential minerals is achieved through a nutrient solution, often without the use of a conventional growing medium. This may include substrates like rock-wool, peat, perlite, pumice, coconut fiber, among others.

Soilless cultivation systems can be categorized into two primary groups:

- i) Systems that rely on a liquid medium without any additional support for plant roots.
- ii) Systems that utilize a solid medium, typically a substrate, to provide support for plant growth.

Moreover, soilless substrate-based cultures can be further classified into two subcategories:

- i) Open systems, in which the nutrient solution draining from the roots is not recycled.
- ii) Closed systems, where any excess nutrient solution is collected, adjusted, and reintroduced into the cultivation systems.

Soilless cultivation techniques have been introduced in protected crop settings and vertical farms to achieve several objectives:

- i) To liberate plant cultivation from traditional soil, eliminating associated issues such as soil depletion, soil-borne diseases (particularly following the prohibition of methyl bromide as a soil fumigant), secondary soil salinization due to excessive fertilizer use and insufficient rainfall, and the need for crop rotation.
- ii) To enhance control over the growth conditions of plants, including factors like root zone temperature, aeration, and the precise distribution of water and nutrients.

iii) To reduce the labor demands of crop management.

These innovations mark a significant departure from conventional soil-based practices, offering a pathway to sustainable and efficient crop production in controlled environments.

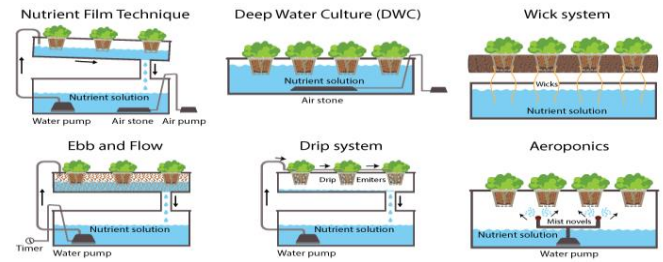
Hydroponics: Nourishing Plants with Precision



Hydroponics takes soilless cultivation to the next level. It entails the cultivation of plants in nutrient-enriched water solutions. This method directly supplies all the essential elements required for plant growth to their root systems. The precise regulation of nutrient delivery in hydroponics results in accelerated growth rates and enhanced yields when compared to conventional soil-based agriculture. The primary objective of all hydroponic systems is to improve control and efficiency in crop cultivation. In every scenario, the growth environment plays the pivotal role in determining crop productivity. In conventional outdoor farming, crops are subject to the unpredictability of weather and soil conditions. Transitioning from soil-based farming to hydroponic systems represents the initial step toward a trajectory of controlled environment production, ultimately culminating in fully indoor cultivation setups, as witnessed in the vertical indoor farming trend. Hydroponic innovations have demonstrated that direct exposure to nutrient-rich water can offer a more effective and adaptable approach to plant growth compared to traditional irrigation methods. Hydroponics represents a sustainable and effective agricultural technique that is gaining popularity,

particularly in urban regions with limited space for traditional farming practices.

Different types of hydroponic systems



i. Deep Water Culture (DWC): In DWC systems, plants are cultivated within a nutrient solution that receives continuous aeration to ensure the roots receive an oxygen supply. This method is favored for the cultivation of leafy greens and herbs.

ii. Nutrient Film Technique (NFT): In NFT systems, a thin film of nutrient solution circulates over the plant roots, delivering essential nutrients. This hydroponic approach is commonly employed for growing crops like lettuce and basil.

iii. Ebb and Flow: Ebb and flow systems involve growing plants in containers or trays that undergo periodic flooding with nutrient solution followed by drainage. This method is well-suited for cultivating a wide array of crops, including tomatoes, peppers, and strawberries.

iv. Aeroponics: Within an aeroponics system, plants are nurtured in a mist or fog of nutrient solution, with their roots suspended in the air. This highly efficient hydroponic technique is renowned for its high yields and is frequently used for growing crops like lettuce and strawberries.

v. Vertical Farming: Vertical farming entails the stacking of hydroponic systems in layers, facilitating high-density cultivation in confined spaces. This type of hydroponics finds favor in urban areas where available space is limited.

Benefits:

Soilless and hydroponic systems offer a plethora of advantages:

- 1. Year-round crop production and increased yields:** Controlled environments eliminate

seasonal limitations, enabling continuous crop cultivation. According to the Food and Agricultural Organization (FAO), soilless systems yield 20-25% more vegetables compared to traditional methods due to a higher plant density per square meter.

2. **Enhanced water efficiency:** Hydroponics and soilless systems substantially reduce water usage compared to conventional agriculture, making them environmentally friendly choices, especially in water-scarce regions.
3. **Effective space utilization:** Vertical farming optimizes limited urban spaces, reducing the necessity for expansive agricultural land.
4. **Reduced resource consumption:** Lower and more efficient resource utilization allows for the widespread adoption of this alternative farming method by various stakeholders.
5. **Control of pests and diseases:** Soilless cultivation minimizes the risk of soil-borne pests and diseases, reducing the need for chemical interventions.

Challenges and Innovations

While the future of soilless and hydroponic horticulture is promising, it's not without its challenges. Maintaining the delicate balance of nutrients, managing the systems, and addressing energy consumption are areas that continue to see innovations and improvements. One of the primary constraints lies in the substantial initial capital outlay needed to establish the infrastructure and equipment for indoor farming, a financial burden that may prove impractical for small-scale farmers. Additionally, there's the issue of heightened energy consumption associated with indoor farming, resulting in increased electricity expenses and elevated carbon emissions. Water usage remains a limitation as well, given that hydroponics still demands a substantial volume of water to sustain the system effectively. The range of crops that can be cultivated is restricted due to the size and structure of the indoor growing environment.

Table 1: Compilation of crops suitable for large-scale cultivation using soilless cultivation techniques

Type of crops	Name of the crops
Fruits	<i>Fragaria ananassa</i> (Strawberry)
Vegetables	<i>Lycopersicon esculentum</i> (Tomato), <i>Capsicum frutescens</i> (Chilli), <i>Solanum melongena</i> (Brinjal), <i>Beta vulgaris</i> (Beet), <i>Psophocarpus tetragonolobus</i> (Winged bean), <i>Capsicum annum</i> (Bell pepper), <i>Brassica oleracea</i> var. <i>capitata</i> (Cabbage), <i>Phaseolus vulgaris</i> (Green bean), <i>Brassica oleracea</i> var. <i>botrytis</i> (Cauliflower), <i>Cucumis sativus</i> (Cucumbers), <i>Cucumis melo</i> (Melons), <i>Raphanus sativus</i> (Radish), <i>Allium cepa</i> (Onion)
Leafy vegetables	<i>Ipomoea aquatica</i> (Kang Kong), <i>Lactuca sativa</i> (Lettuce)
Condiments	<i>Petroselinum crispum</i> (Parsley), <i>Mentha spicata</i> (Mint), <i>Ocimum basilicum</i> (Sweet basil), <i>Origanum vulgare</i> (Oregano)
Flower / Ornamental crop	<i>Tagetes patula</i> (Marigold), <i>Rosa berberifolia</i> (Roses), <i>Dianthus caryophyllus</i> (Carnations), <i>Chrysanthemum indicum</i> (Chrysanthemum)
Medicinal crops	<i>Aloe vera</i> (Indian Aloe), <i>Solenostemon scutellarioides</i> (Coleus)

Source: Sardare and Admane, 2013, Singh and Singh, 2012

Regulatory hurdles, including zoning regulations and agricultural policies, may further restrict their implementation in specific regions. Nevertheless, despite these challenges, the potential benefits offered by vertical farming and hydroponics are substantial. To overcome these limitations and promote their

broad adoption in agriculture, further investments and ongoing innovations are essential.

Conclusion: A Greener Tomorrow

The shift toward soilless and hydroponic systems in controlled environments aligns with the global push for sustainable agriculture. These methods are at the forefront of efforts to reduce the carbon footprint of food production, conserve water, and ensure food security in a rapidly changing world. As the global population continues to surge at an unprecedented pace, it becomes imperative to investigate sustainable and efficient approaches for generating an adequate food supply capable of meeting the requirements of every individual. The transformation of horticultural crop production through soilless and hydroponic systems in greenhouses and vertical farms represents a promising chapter in agriculture. It's a journey that combines technology, sustainability, and innovation to meet the ever-growing demand for fresh, nutritious produce. As we look to the future, the integration of these methods into mainstream agriculture could hold the key to a more sustainable and food-secure world. The revolution is underway, and its impact on our dinner plates and the planet cannot be underestimated.

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