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## Revolutionizing Agriculture: Soil-Free Farming for Global Food Security

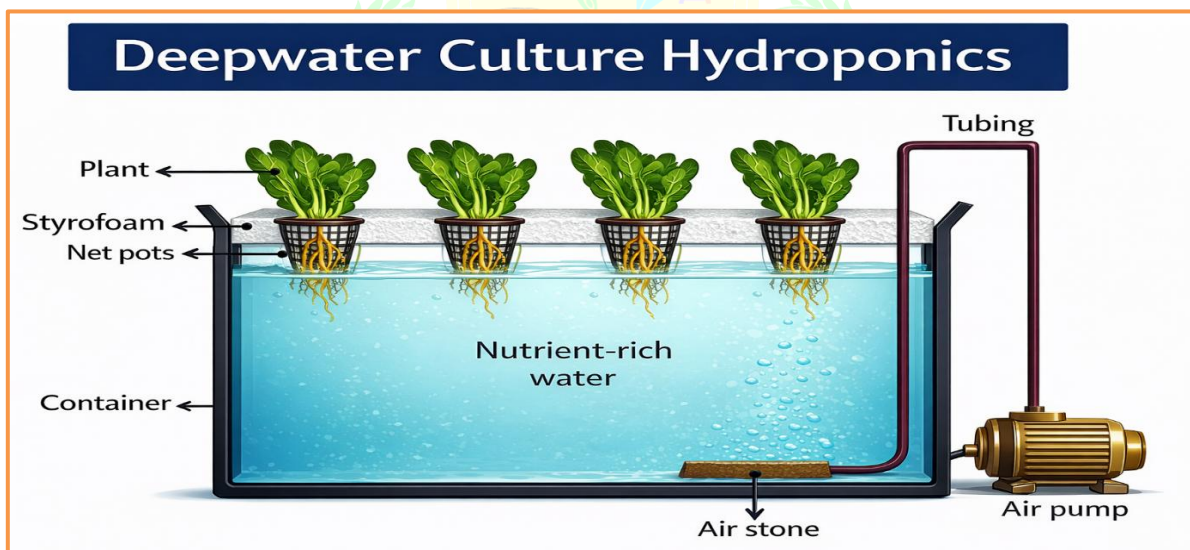
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Soil-free farming, including hydroponics, aeroponics, and aquaponics, revolutionizes agriculture by cultivating crops without soil through nutrient-enriched water, mist, or integrated fish-plant systems, enabling precise control over growth conditions (PMC, 2023). Amid escalating global challenges such as arable land loss, water scarcity, and climate disruptions that threaten food security for 9 billion by 2050, these methods deliver 3-10 times higher yields, use up to 90% less water, and enable year-round production in urban settings (Food and Agriculture Organization of the United Nations, 2009). Traditional soil-based farming faces unsustainable degradation, but soilless innovations like vertical systems and AI-driven precision farming enhance resilience, reduce emissions via shorter food chains, and align with 2025 market projections of \$15 billion growing at a 12% CAGR through 2033. Singapore's "30 by 30" initiative exemplifies this, targeting 30% local food via soil-free tech despite minimal arable land (PMC, 2020). These advancements position soil-free farming as pivotal for global food security, supporting UN goals for zero hunger and sustainable production into 2025 and beyond (Fu, G. 2022). Many studies confirmed that hydroponic farming is an effective tool for combating hunger and improving food safety, especially in developing countries with limited water resources and land (Vasiliadis et al. 2023).

**Keywords:** Hydroponics, soilless farming, NFT, DWC, organic fertilizer, aeroponics.



### Types of Hydroponic Systems

Six primary hydroponic systems exist, classified by nutrient delivery: passive (no pumps) or active (pumps required). Each suits different plants, spaces, and skill levels, with variations like recovery (recirculating) or non-recovery (draining excess) (Vasiliadis et al. 2023) (Table 1).

### 1. Wick Systems

Roots sit in inert media like perlite or coco coir, with wicks (felt or rope) drawing nutrient solution from a reservoir via capillary action. Fully passive and electricity-free, ideal for small herbs or beginners, but limits larger plants due to slow nutrient flow (Table 1).

### 2. Deep Water Culture (DWC)

Roots dangle directly into oxygenated nutrient solution in a reservoir, aerated by air stones and pumps. Simple for leafy greens like lettuce; the Kratky variant is passive for non-circulating setups. Susceptible to root rot if oxygen drops (Table 1).

### 3. Nutrient Film Technique (NFT)

Roots rest in sloped channels where a thin nutrient film flows continuously, draining excess back to the reservoir. Water-efficient and scalable for herbs; requires monitoring to prevent pump failure-induced drying (Table 1).

### 4. Drip Systems

Emitters drip nutrient solution onto plant bases in media like rockwool, with excess collected (recovery) or drained (non-recovery). Versatile for tomatoes or peppers; clogs demand regular maintenance (Table 1).

### 5. Ebb and Flow (Flood and Drain)

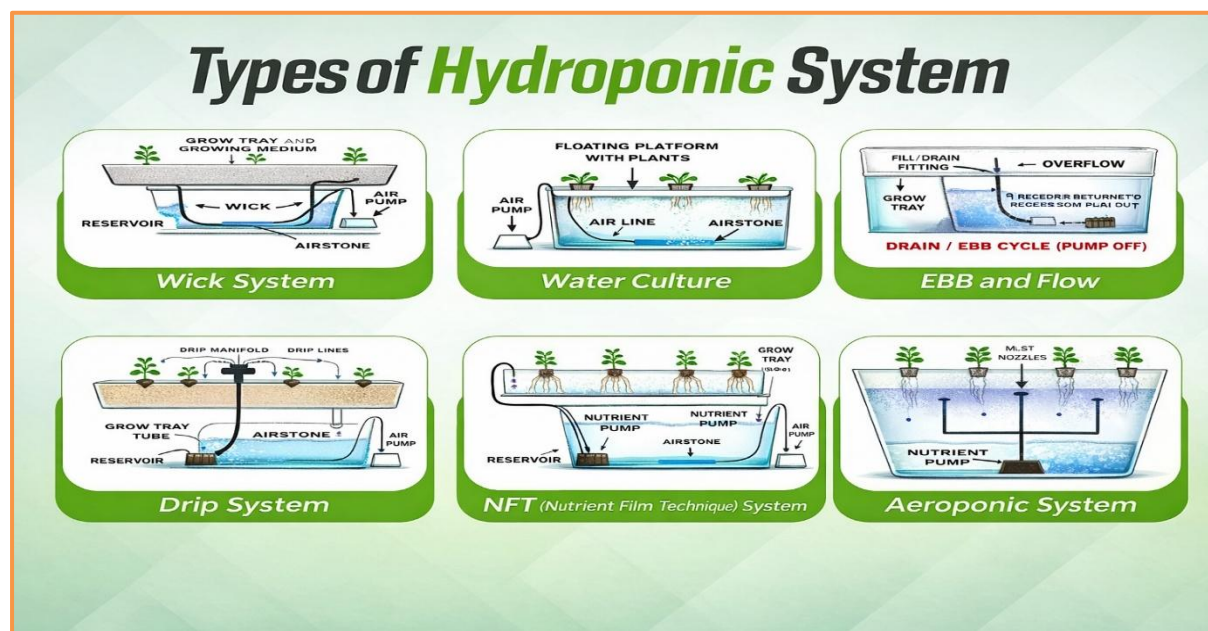
Timer floods grow trays with media periodically, then drains to oxygenate roots. Flexible for diverse crops; needs space and precise timing to avoid overwatering (Table 1).

### 6. Aeroponics

Roots hang in dark chambers, misted with nutrient fog from high-pressure nozzles every few minutes. Maximizes oxygen and efficiency for any plant; power failures pose a risk of quick failure, making it suitable for advanced users (Table 1).

**Table 1:** Benefits and drawbacks of each hydroponic system

System	Benefits of the System	Drawbacks of the System	Best For
Wick	Inexpensive, no electricity	Slow for big plants	Herbs, beginners
DWC	Low-cost, easy	Root rot risk	Leafy greens
NFT	Water-efficient, scalable	Pump-dependent	Herbs, small roots
Drip	Plant-flexible	Clog-prone	Fruiting plants
Ebb & Flow	Versatile media	Space-heavy	Mixed crops
Aeroponics	High oxygenation	Complex, costly	Advanced, vertical



### AI and Machine Learning Integration

Researchers have developed AI-powered automated hydroponic systems that integrate real-time environmental monitoring, automated nutrient management, and AI-based disease

detection to optimize plant growth and minimize manual intervention. A camera module captures plant images analyzed by a CNN (convolutional neural network) model to detect diseases like Anthracnose and Downy Mildew, enabling early intervention. AI-driven crop monitoring can detect nutrient deficiencies and pests, optimizing yields by up to 30%, while IoT-enabled systems allow remote control of nutrient delivery and light cycles, reducing manual labor by 50% (Vasiliadis et al. 2023).

### **Organic and Eco-Friendly Nutrient Solutions**

Organic hydroponic fertilizer innovations are rapidly gaining momentum in 2025, with eco-conscious formulations aiming to compete with synthetic fertilizer yields while drastically reducing negative environmental impacts, supported by AI-driven advisory platforms using satellite data and sensor analytics. Nutrients derived from organic sources are utilized as the primary source of nutrition in organic hydroponics, maintaining ecological balance through closed nutrient loops and reducing synthetic input dependence. Organic hydroponics promotes the cultivation of crops with higher quality, meeting consumer demands for environmentally friendly and residue-free products (Vasiliadis et al. 2023). e.g., of organic fertilizer, Compost tea, Fish emulsion, Seaweed.

### **Advantages of the Hydroponic System**

Hydroponics offers key benefits, such as superior water efficiency, faster plant growth, and higher yields, compared to traditional soil farming.

#### **Benefits List**

- Uses 90-98% less water through recirculation and direct root delivery, minimizing waste and evaporation.
- Enables 30-50% faster growth and harvests in half the time due to optimal nutrients and oxygen access.
- Delivers higher yields-up to 3-10 times more per space-via precise control and vertical setups.
- Reduces or eliminates pesticides, herbicides, weeds, and soil-borne pests/diseases for cleaner produce.
- Saves 99% land by enabling urban, vertical, or non-arable area farming year-round.
- Provides full environmental control over nutrients, pH, light, and climate for consistent results.
- Cuts labor with no weeding, cultivation, or transplant shock, plus automation potential.
- Produces healthier plants with less stress, supporting sustainability and food security.

### **Key Precautions for Hydroponics**

Hydroponics requires precautions to prevent system failures, contamination, and safety hazards due to its reliance on water, electricity, and precise conditions.

- Monitor and maintain pH, nutrient levels (using EC meters), and temperature daily to avoid imbalances, deficiencies, or toxicities that stress plants.
- Ensure electrical safety by using waterproof connectors, GFCI outlets, surge protectors, and keeping cords dry and elevated above water sources; avoid extension cords and test outlets regularly.
- Implement biosecurity with handwashing, protective clothing, foot baths for visitors, quarantine for new plants, and pest inspections to block pathogens and infestations.
- Block light from nutrient reservoirs and lines with opaque covers to prevent algae growth, and clean reservoirs, tubing, and trays routinely.
- Check for leaks, secure mounts, and replace worn parts promptly to avoid water damage, system failure, or plant harm.
- Store and handle chemicals properly, label them, and keep flammables away from heat/electrical sources.

## Challenges and Prospects

Initial costs and energy demand limit scalability, yet renewable integration and automation promise cost reductions. Policy incentives, like those in Singapore, and R&D in biocontrol position hydroponics as a cornerstone for sustainable intensification worldwide (Fu, G. 2022).

## Implications for Food Security

Hydroponics supports feeding 10 billion by 2050 via vertical urban farms, shortening supply chains, and enhancing resilience to climate extremes. In developing regions, it boosts local sovereignty, with studies noting elevated nutrient profiles in hydroponic produce versus soil-grown equivalents. Economic returns reach 60.6% IRR, driven by off-season yields and reduced post-harvest losses.

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