



THE GREEN REVOLUTION 2.0: HOW HYDROPONICS IS RE-IMAGINING INDIA'S FARMING FUTURE

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Abstract

Facing climate change, water scarcity and shrinking farmland, traditional agriculture struggles but hydroponics offers a “Green Revolution 2.0.” This soilless system grows crops in nutrient-rich water, cutting water use by up to 95% and boosting yields dramatically. From ancient Babylon to space stations and modern urban farms under LED lights, hydroponics has evolved with AI, IoT and precision techniques like NFT, aeroponics and aquaponics. It enables faster growth, year-round harvests, and efficient water use, providing a promising solution to feed a 10-billion-strong population. While costs and technical challenges remain, hydroponics is set to complement, not replace, traditional farming, and transforming food production in India and beyond.

Introduction: The Farm of the Future

Step into a city warehouse, and instead of boxes, you see walls of vibrant green lettuce glowing under purple LED lights. The air is cool,

water flows endlessly through gleaming pipes, and there's no soil in sight. This is hydroponics, quietly reshaping food production. With climate change, dwindling freshwater and a population nearing 10 billion by 2050, traditional farming struggles arable land per person has dropped 20% since 2000, and conventional agriculture uses around 70% of global freshwater. Hydroponics grows plants in nutrient-rich water, saving up to 95% of irrigation water while producing far higher yields than soil-based methods, offering a sustainable solution for feeding our growing world.

Traditional farming versus modern hydroponics

The global hydroponics market, valued at USD 6.80 billion in 2026, is projected to reach USD 11.10 billion by 2031, growing at a CAGR of 10.3% (Mordor Intelligence, 2026). Beyond the numbers, hydroponics is redefining agriculture itself enabling cities to be fed, conserving scarce water and growing crops in places once thought impossible, from

deserts to space stations. This article traces hydroponics evolution from ancient beginnings to today's high-tech innovations, exploring how this soilless farming revolution is transforming the way we grow food for the 21st century and beyond.

A Brief History: From Babylon to the Space Age

The idea of growing plants without soil dates back to ancient times. The Hanging Gardens of Babylon may have been an early hydroponic system, while the Aztecs cultivated "floating gardens" or chinampas on lake rafts to feed Tenochtitlan. Modern hydroponics began in the 17th century, with Francis Bacon's experiments in soilless cultivation, and advanced in the 1860s when Julius von Sachs and Wilhelm Knop developed nutrient solutions that proved plants could thrive in water. The term "hydroponics" was coined in 1937 by William Gericke, who demonstrated its commercial potential by growing towering tomato vines.

During WWII, the U.S. military used hydroponics to supply fresh vegetables on remote islands. Later, NASA explored hydroponics for space missions and today astronauts grow fresh crops aboard the International Space Station. With IoT, AI and automated climate control, hydroponics has transformed from curiosity to precision agriculture, becoming a key tool in the global pursuit of sustainable food production (Rajaseger, 2023).

How Hydroponics Works: The Science of Soilless Growing

Hydroponics works on a simple principle: plants don't need soil, they need what soil provides.

Soil anchors roots, stores water and nutrients, and allows gas exchange, but plants expend energy searching for these resources, limiting growth and yields. Hydroponic systems replicate these functions more efficiently, delivering nutrients directly to roots in precise concentrations. This allows plants to redirect energy toward faster vegetative growth and higher fruit production, making hydroponics a highly efficient alternative to traditional farming (Anusree *et al.*, 2024).

The Essential Elements

All hydroponic systems share several fundamental components:

1. **Growing Medium:** Even though hydroponics is "soilless" plants often need a medium for root support and moisture retention. Common options include coconut coir, perlite, vermiculite, rockwool and clay pellets. NFT systems with coconut peat often give excellent crop results (Dutta *et al.*, 2023).
2. **Nutrient Solution:** The lifeblood of hydroponics, this water contains essential macro- and micronutrients like nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, iron, zinc and more, tailored to each crop and growth stage.
3. **pH & EC:** Nutrients are absorbed best at pH 5.5–6.5. Electrical conductivity (EC) indicates nutrient concentration, monitored by sensors (Vishram *et al.*, 2024).
4. **Oxygenation:** Roots need oxygen, supplied via air pumps, water circulation or direct exposure.
5. **Light:** LEDs provide efficient, wavelength-specific lighting to boost photosynthesis.

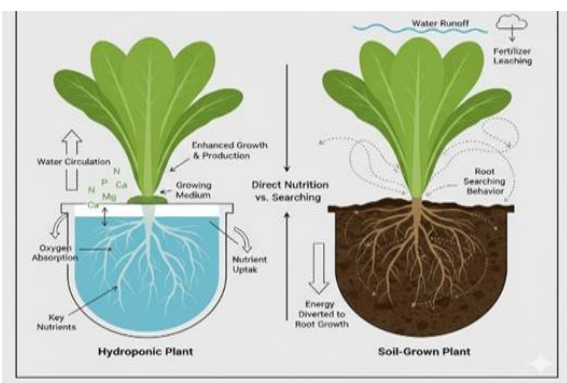


Fig. 2 The anatomy of hydroponic cultivation comparison

The Photosynthesis Advantage

By precisely regulating light, temperature, humidity, CO₂ levels and nutrient availability, hydroponic systems create optimal conditions for photosynthesis, enabling growth rates 30–50% faster than conventional farming (Pomoni *et al.*, 2023).

Crops such as lettuce, which typically require 60–120 days in field conditions, can be harvested within 30–40 days under controlled hydroponic environments, with high success rates reported across trials (Murphy *et al.*, 2023). This precision-driven approach transforms agriculture from adapting to natural constraints into engineering ideal growth systems, essential in a resource-limited future.

The Hydroponic Toolkit: Types of Systems

Hydroponics is not a single cultivation method but a diverse group of systems designed to suit different crops, scales, and production environments, highlighting the versatility of soilless agriculture.

Among the simplest methods is **Deep Water Culture (DWC)**, where plant roots are suspended in an oxygenated nutrient solution. Continuous aeration prevents root hypoxia, making DWC popular among small-scale

growers, although careful management is required to avoid root diseases (Muzamil *et al.*, 2023).

The **Nutrient Film Technique (NFT)** involves a thin, continuously flowing film of nutrient solution passing over plant roots housed in sloped channels. This design ensures efficient nutrient uptake and root oxygenation and is widely used for leafy vegetables and herbs in commercial greenhouses.

Studies have reported that vertical NFT systems can achieve 3.5–4 times higher yields than soil cultivation, along with significant gains in water-use efficiency and space savings (Velázquez-González *et al.*, 2022; Hasan *et al.*, 2025).

Ebb and flow (flood and drain) systems periodically inundate plant roots with nutrient solution and then drain it back to a reservoir, providing both nutrient supply and root aeration. These systems are flexible and suitable for a wide range of crops.

Drip systems, the most common commercial approach, deliver nutrient solution directly to the plant base through emitters and are ideal for large, fruiting crops such as tomatoes and cucumbers.

Advanced systems include **aeroponics**, where roots are misted with nutrient solutions while suspended in air, maximizing oxygen availability and minimizing water use (Kumar *et al.*, 2024).

Aquaponics integrates hydroponics with aquaculture, using fish waste as nutrients, producing both vegetables and protein in a closed-loop system, though with greater management complexity (Velázquez-González *et al.*, 2022).

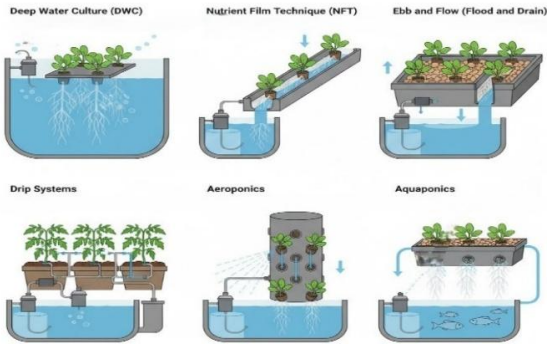


Fig.3 The six distinct approaches to soilless cultivation

The Water Revolution: Efficiency in Every Drop

The scale of water savings achieved through hydroponics is remarkable. Compared with conventional agriculture, hydroponic systems can reduce irrigation water use by up to 95% (Pomoni *et al.*, 2023). For example, producing one kilogram of lettuce under field conditions may require approximately 250 litres of water, whereas the same yield can be achieved in hydroponic systems using as little as 20 litres.

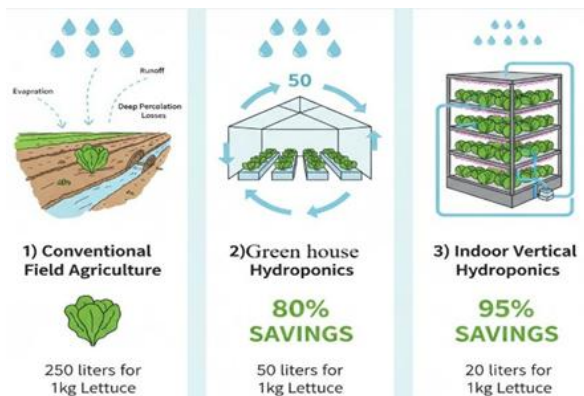


Fig. 4 The water efficiency revolution

How Hydroponics Saves Water

- 1. Recirculation:** Most hydroponic systems recirculate nutrient solution continuously. Water that isn't absorbed by plants returns to the reservoir for reuse, rather than seeping into soil or evaporating.

Recirculating systems can reuse the same water for weeks, only requiring top-ups to replace what plants actually consume (Araya *et al.*, 2024).

- 2. Elimination of Runoff:** In conventional irrigation, much water never reaches plant roots it runs off fields, carrying nutrients into waterways and causing pollution. Hydroponics delivers water directly to roots in controlled amounts, eliminating runoff entirely (Ghorbel *et al.*, 2021).
- 3. Reduced Evaporation:** Closed or semi-closed hydroponic systems, particularly indoor operations, dramatically reduce evaporation losses. In field agriculture, especially in hot climates, evaporation can account for 50% or more of water loss.
- 4. Precision Delivery:** Modern hydroponic systems use sensors and automation to deliver exactly the amount of water plants need, when they need it. This precision eliminates the overwatering common in conventional agriculture (Vishram *et al.*, 2024).

Challenges on the Horizon: The Obstacles to Overcome

Despite its advantages, hydroponics faces several constraints that limit its large-scale adoption. High capital costs remain a major barrier, with turnkey vertical farms costing around USD 1,000 per m² and payback periods often exceeding seven years, as seen in failures such as Kalera. Energy demand is another challenge, as indoor systems consume significantly more electricity than conventional farming and become uneconomic when power

prices approach USD 0.12 per kWh. Hydroponics also requires advanced technical expertise in nutrient management, plant physiology and system maintenance. Environmental concerns include nutrient solution disposal and plastic waste, while technical failures in power or pumps can cause rapid crop losses. Market and regulatory uncertainties further restrict adoption. However, modular systems, renewable energy integration and IoT-based optimisation are improving economic and environmental performance.

Conclusion

Hydroponics is often viewed as a departure from traditional agriculture, yet it represents a return to fundamental plant needs rather than reliance on soil itself. By precisely supplying water, nutrients, oxygen and light, hydroponic systems can achieve up to 90–95% irrigation water savings, deliver multiple-fold yield increases and enable crop production in environments where conventional farming is limited, including urban areas, deserts and cold regions. These advantages, combined with shrinking arable land and increasing climate uncertainty, are driving rapid global adoption. However, high capital investment, energy dependence and technical complexity remain significant challenges, positioning hydroponics as a complementary rather than replacement strategy. Its greatest contribution lies in decoupling food production from fertile land and transforming agriculture into a data-driven, sensor and AI-enabled system capable of year-round, resource-efficient production an essential component of sustainable food systems for a growing global population.

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