

Hydroponics and Sustainability: A Greener Approach to Modern Agriculture

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Hydroponics is the practice of growing plants in a nutrient-rich water solution instead of soil. The term "hydroponics" originated from the Greek- "hydro," which means water, and "ponos," which means labour. (Figure 1.)



Using hydroponics together with modern agricultural technology is a progressive and promising approach to sustainable and eco-friendly crop production. This method delivers nutrients directly to the roots of the plants, doing away with the need for soil and using less water. Smart farming uses technology like as sensors, automation, and the Internet of Things (IoT) to monitor soil conditions, nutrient levels, and plant health continuously for targeted management and improvement. With this technology-driven method, crop production is increased, boom rates increase, and optimal quality conditions are maintained throughout the year, unaffected by weather or environmental fluctuations. In addition, sustainable agriculture minimizes waste technology, promotes environmentally friendly pest control methods, and reduces consumption on chemical inputs. By promoting sustainable farming practices, improving food security, and encouraging localized food production, this innovative approach has the potential to completely transform rural areas. This comprehensive review

explores into the most recent developments in hydroponics, with a focus on smart farming systems, data collection, remote farming, artificial intelligence (AI) automation, and home automation (Domotics). The article also emphasizes different types and benefits of modern hydroponic farming, highlighting the critical components required to succeed in this modern field. It also looks at possible trends and future goals, providing a foundation for further developments in hydroponic smart farming.

Hydroponics, however, is a crucial feature of contemporary farming, especially in the context of "smart farming." It offers some benefits and addresses serious problems with traditional agricultural methods. Hydroponics has several advantages over conventional agricultural techniques like using soil and greenhouses. Hydroponics allows for economical water consumption, typically using as much as 90% less water than conventional farming methods.

Hydroponic Techniques

Hydroponics, unlike traditional farming, does not require soil to grow food. In this technique, plants are grown either on natural or man-made substrates, where the roots easily extract the nutrients from a prepared nutrient solution. There are different methods for growing food using hydroponics, and their application depends on the specific plant, local climate, and budget, among other factors. Most systems comprise a storage tank for the nutrient solution and an aerator, as illustrated in Figure 2.

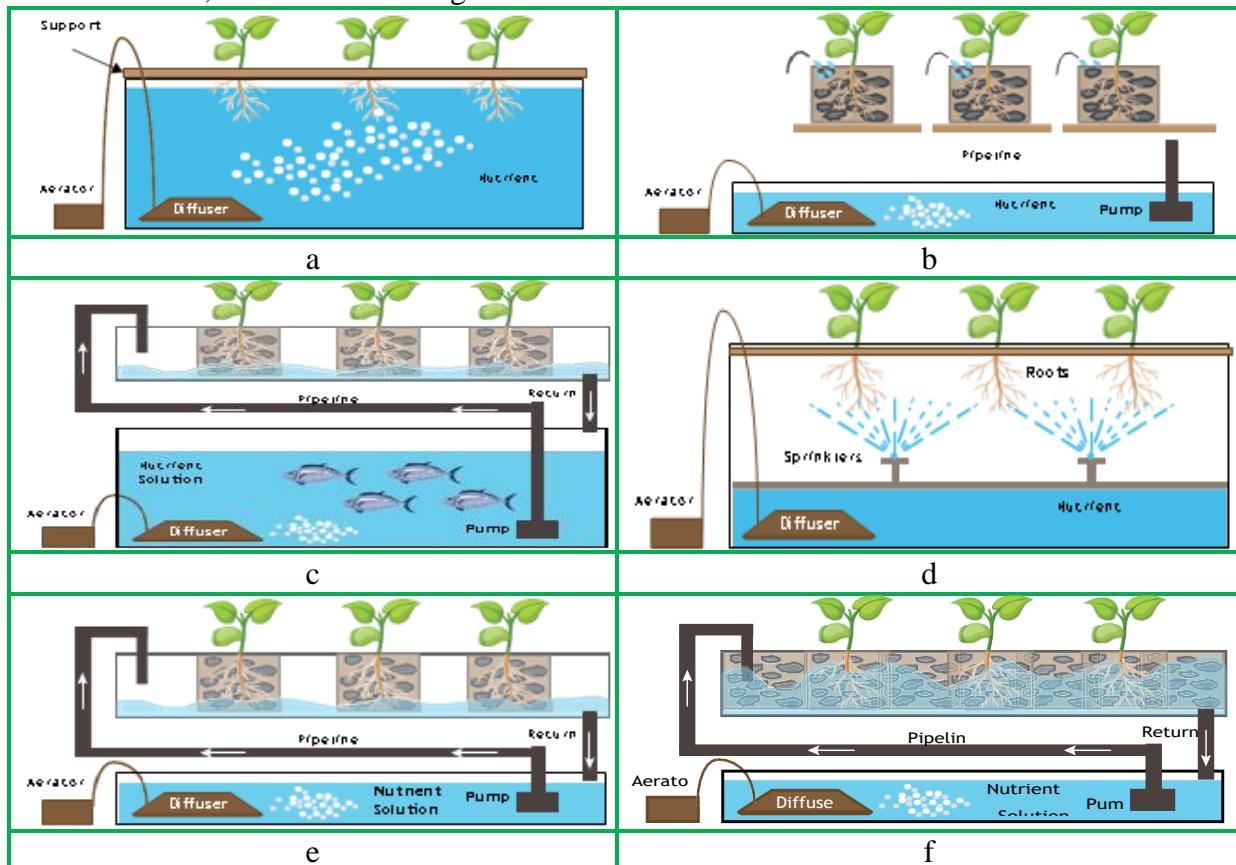


Figure 2. Different types of hydroponic systems. (a) Deep Water Culture. (b) Drip System. (c) Aero-ponics. (d) Nutrien Film Technique (NFT). (e) Ebb and flow. (f) Aquaponics.

a) **Floating Root System or Deep Water Culture (DWC):** In this technique, the plant's root is submerged in the nutritional solution, and the remaining portion of the plant is held above water using a variety of materials, including wood, cork bark, and polystyrene (Figure 1a).

b) **Drip Irrigation:** For crops which resemble tomatoes and peppers, this method of cultivation works successfully. In this case, a controlled flow of the nutrient solution is

injected directly to the plant roots. When using a closed system, the remaining solution is put back into the storage tank after being supplied at certain times (Figure 1b).

- c) **Aeroponics:** It works best with roots & tubers. With their roots floating in the air, the crops in this arrangement receive nutrients from a sprinkler system that sprays them periodically. This method's primary benefit is that oxygen is delivered with the sprayed nutritional solution, removing the need for an ailing system (Figure 1c).
- d) **Nutrient Film Technique:** Similar to the floating root system, this technique also referred to as NFT involves submerging the plant roots entirely in a flow of water that passes through a pipe system instead of the nutritional solution. Compared to the floating root system, NFT uses less nutrient solution, but it still needs more energy and parts to function. The flow of nutritional solution can be potentially periodic or continuous, with the excess solution gravitationally returning to the storage tank (Figure 1d).
- e) **Ebb and Flow:** Plants are set up in a tray that is frequently filled off with water that has been pumped from a reservoir below and is rich with nutrients. The water is recycled by the system by returning it to the reservoir by gravity (Figure 1e).
- f) **Aquaponics:** This method makes use of the symbiotic relationship between plants and animals to create a productive system where aquatic waste meets the plants' nutritional needs. Plants' ability to absorb nutrients and their microbial activities of nitrification and denitrification enables the recycling of fish tank water, creating a micro-ecosystem that is in balance (Figure 1f).

Table 1: Nutrients commonly used in hydroponic nutrient solutions.

Nutrient	Classification	Function in Plant	Major Source	Deficiency Symptoms
Nitrogen (N)	Macro	Essential for growth, leaf development, and protein synthesis	Nitrate (NO ₃ ⁻) and Ammonium (NH ₄ ⁺)	Stunted growth, yellowing leaves
Phosphorus (P)	Macro	Key role in root development, energy transfer, and flower/fruit formation	Phosphate (PO ₄ ⁻)	Poor root growth, purplish leaves
Potassium (K)	Macro	Vital for overall plant health, nutrient uptake, and disease resistance	Potassium (K ⁺)	Weak stems, yellowing edges of leaves
Calcium (Ca)	Macro	Essential for cell wall structure and overall plant stability	Calcium (Ca ²⁺)	Blossom end rot, stunted growth
Magnesium (Mg)	Macro	Crucial for chlorophyll production and enzyme activation	Magnesium (Mg ²⁺)	Yellowing between leaf veins
Sulfur (S)	Macro	Important for protein synthesis and overall plant vigor	Sulfate (SO ₄ ⁻)	Yellowing of younger leaves
Iron (Fe)	Micro	Required for chlorophyll formation and enzyme functions	Iron (Fe ²⁺ and Fe ³⁺)	Yellowing leaves with green veins
Manganese (Mn)	Micro	Necessary for photosynthesis and enzyme activities	Manganese (Mn ²⁺)	Yellowing between leaf veins
Zinc (Zn)	Micro	Essential for enzyme activation and hormone regulation	Zinc (Zn ²⁺)	Stunted growth, malformed leaves

Advantages of hydroponic smart farming

This modern method has multiple advantages that make agriculture a more environmentally friendly and highly productive enterprise. These are some major advantages:

- a) **Water Conservation:** Compared to traditional soil-based farming, hydroponic systems use significantly less water. Because hydroponics is a closed-loop system, water can be recycled and reused, which lowers overall water usage and helps to allay increasing concerns about water scarcity.
- b) **Decreased Effect on the Environment:** The use of hydroponics reduces soil erosion and degradation by minimizing the need for soil. This decrease in soil disturbance reduces pollution through facilitating protection plant habitats and preventing fertilizer and pesticide runoff into nearby water resources.
- c) **Control of Pests and Diseases:** The lack of soil in hydroponic systems reduces the possibility of soil-borne diseases and pests. This promotes a more nutritious and environmentally balanced farming system by reducing the dependency on chemical pesticides and fungicides.
- d) **Energy Efficiency:** Hydroponics maximizes the use of support by allowing for the precise transportation of nutrients to flowers. This efficiency translates into less strength intake, particularly in agricultural settings with controlled conditions where artificial lighting and weather control are essential.
- e) **Shorter Growth Cycles:** Because of their shorter production cycles, plants grown in hydroponic systems sometimes face higher boom expenses. This not only enhances overall performance but also enables farmers to react to market demands and consumer demands more quickly.
- f) **Promotion of Sustainable Agriculture Practices:** By minimizing resource inputs, reducing environmental impact, and promoting long-term ecological stability, hydroponics is consistent with the principles of sustainable agriculture. Using hydroponic techniques advances the global movement toward stronger and sustainable food systems.

Future Objective

With only 1% of arable land, it will need careful planning, creativity, and the use of numerous solutions to achieve 30% food sustainability by 2030. To achieve this purpose, some important factors to take into account are:

- a) Hydroponics in hospitals
- b) Vertical Farming and Rooftop Gardens
- c) The practice of indoor agriculture
- d) High-Yield Crop Selection
- e) Efficient Resource Utilization
- f) Agro-technology and Automation

Conclusion

In summary, hydroponics provides an extensive amount of possibilities for the future of agriculture. The benefits of this innovative vegetable gardening technique are numerous and effectively manage the negative aspects of conventional agricultural methods. Hydroponics has the potential to completely change the way we grow food because of its capacity to maximize resource efficiency, facilitate year-round crop production, and improve yields. We can maximize space, water, and nutrients by using hydroponics, which lowers waste and encourages sustainability. Higher crop yields and faster growth rates are attained by precisely controlling the growing parameters in hydroponic systems' controlled surroundings. As a result, there is a greater supply of fresh, locally farmed vegetables, less reliance on imports, and increased food security. Moreover, by reducing chemical inputs, preventing soil erosion, and integrating with environmentally friendly pest management techniques, hydroponics

provides an approach towards environmental sustainability. Additionally, it creates opportunities for urban agriculture, bringing farming closer to urban centers and enabling food production in constrained areas. Hydroponics' potential is further enhanced by incorporating automation, data analytics, and smart technologies as technology progresses. Real-time monitoring, accurate control, and automation of several processes are made possible by this connection, which increases productivity overall and decreases the need for labor.