Soilless Solutions: How Hydroponics is Shaping Modern Farming

Sadhana R Babar[1], Kavyashree C.[2], Vivek Devaranavadagi[3] and Yaswanth Reddy[4]

[1]AICRP on Pearl Millet, RARS, Vijayapur, University of Agricultural Sciences Dharwad, Karnataka, India

[2]Department of Agronomy, University of Agricultural Sciences, Raichur, Karnataka, India

[3]AICRP on Dryland Agriculture, RARS, Vijayapur, University of Agricultural Sciences Dharwad, Karnataka, India

[4]Department of Agronomy, Dr. PDKV, Akola, Maharashtra, India

Corresponding Author: kavya1341997@gmail.com

Introduction

Hydroponics is a method of soilless farming in which plants are grown using nutrient-rich water instead of soil. In this system, essential nutrients are delivered directly to plant roots, allowing for faster growth and significantly reduced water usage compared to conventional agriculture. Because hydroponics does not rely on soil quality, it can be practiced in areas where fertile land is limited or unavailable. The hydroponic process involves placing plants in specially designed systems through which nutrient-enriched water is circulated. As plant roots absorb the water and nutrients, the remaining solution is filtered, oxygenated, and reused. This closed-loop system enables high crop yields with minimal resource input.

Hydroponic farming addresses several modern agricultural challenges, including climate change, urbanization, and natural resource depletion. Using Controlled Environment Agriculture (CEA), crops can be grown year-round regardless of weather conditions. Advanced sensors and precision irrigation allow farmers to monitor nutrient uptake and water use, reducing water consumption by up to 90 per cent compared to traditional farming. Light optimization is another key feature of hydroponics. By targeting Photosynthetically Active Radiation (PAR), particularly blue and red wavelengths, indoor farms maximize photosynthesis and productivity. Vertical farming systems further improve efficiency by stacking crops in modular arrangements, allowing three to ten times more production per unit of land. In addition to improving yield and resource efficiency, hydroponic farming reduces exposure to pests and diseases, minimizing the need for harmful pesticides and herbicides. As a result, hydroponics offers a sustainable and efficient alternative for modern food production.

How hydroponics works

Hydroponics is a way to grow plants without dirt. The plants are grown in a water solution that is full of nutrients. With this method, you can precisely control the plant's surroundings, which speeds up growth and increases food yields. In hydroponics, the roots of the plants are supported by a growth liquid instead of dirt. The growth medium keeps the plants stable and keeps the water in perlite, rockwool, coconut coir, vermiculite and clay pellets are all popular types of growing material. In hydroponics, plants get all the nutrients they need from a mix that is mostly water. There are a good mixture of macronutrients (like nitrogen, phosphorus, and potassium) and micronutrients (like iron, zinc, and magnesium) in the food solution. The mix is generally pH-balanced to make sure that the nutrients are taken in properly. Several types of hydroponic systems get the fertilizer fluid to the roots of the plants. Deep water culture (DWC), nutrient film technique (NFT), ebb and flow (flood and drain), the drip system and aeroponics are some of these methods. Each method has its own way of getting the nutrition solution to the roots of the plants so they get the food they need.

For hydroponic systems to work, things like temperature, humidity, pH levels, and food amounts need to be carefully watched. Automated systems with monitors can help keep things in the best possible state, and changes can be made as needed to make sure plants get the right mix of nutrients and conditions to grow at their fastest. Artificial lighting systems, like LED or fluorescent lights, are used to give plants the light energy they need for photosynthesis since hydroponic plants are usually grown indoors or in controlled settings. The wavelengths and levels of light can be changed to meet the needs of the plants being grown. Hydroponics has many benefits over traditional farming in soil, such as better use of water, fewer chemicals, better use of room, and the ability to grow crops all year long. People like to use this way to grow a lot of different kinds of plants, from fruits and veggies to leafy greens and herbs.

Advantages of hydroponics

Hydroponics is a modern farming technique in which plants are grown in nutrient-rich water without the use of soil. Essential minerals required for plant growth are supplied directly through the water in balanced proportions, allowing precise control over nutrient availability and pH levels. This controlled environment promotes better plant growth, faster development, and higher yields compared to conventional soil-based farming. One of the major advantages of hydroponics is efficient water use. Since water

is continuously recycled and reused within the system, hydroponic farming requires significantly less water than traditional agriculture. The absence of soil eliminates weed growth, reducing labour requirements and the need for herbicides. Hydroponic systems also experience fewer pest and disease problems, minimizing the use of chemical pesticides. Hydroponic farming allows crops to be grown year-round under controlled conditions, ensuring a consistent supply of fresh produce regardless of seasonal or climatic variations. Crops can be grown in protected structures that prevent damage from animals and soil-borne pests. Overall, hydroponics offers higher productivity, better resource efficiency, reduced chemical usage, and improved availability of locally grown food.

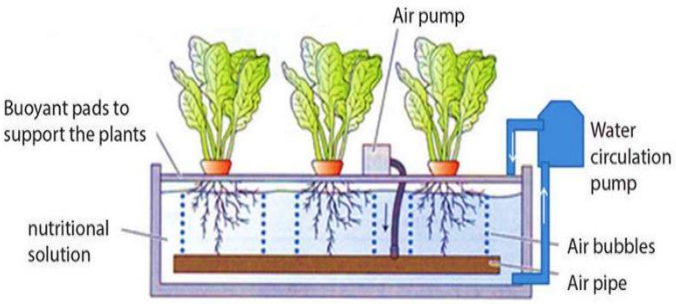
Integration of AI in hydroponics

Through the use of plant-specific formulations and daily monitoring, exact control over plant nutrients can be accomplished, allowing for optimum output per square foot. Quick turnover also provides for optimal profitability. A technology that utilizes artificial intelligence has been used by Glenn Dbritto and colleagues in order to maximize the conservation of both land and water during the hydroponic growing of Tomato F1 hybrid Suhyana seed. The system creates a controlled environment in which water, nutrient solution, and light are individually given to the roots of the plant. The system's objective is to maximize the development of the plant while simultaneously reducing the amount of water that is used and fostering sustainable land applications.

In order to control the parameters of the hydroponic system's efficiency, Mehra and colleagues developed and applied a Deep Neural Network (DNN). In order to determine the best times to harvest strawberries grown hydroponically, Sun Park designed an integrated system that makes use of the Internet of Things Edge, artificial intelligence, and the cloud. An algorithm for deep learning is used by the system in order to categorize strawberry maturity levels in photographs. The system also collects, organizes, and visualizes data that is associated with the circumstances in which strawberries are grown. This system, which is based on the concept of a virtualized container and the Internet of Things Edge Artificial Intelligence Cloud, is scalable and versatile. In order to evaluate its efficiency, the hydroponic strawberry environment was monitored for a period of four months.

Importance in urban farming

The Food and Agriculture Organization forecasts that by the year 2050, the global population will have reached 9.7 billion, which would need a sixty percent increase in the amount of food that is produced all over the globe.



According to estimates, over 11% of the world's population is under nourished, making food security a serious problem. Around eighty percent of the world's agricultural area is used for livestock farming, which means that it requires a much larger amount of land than farming for plant-based foods. About thirty percent of the world's food supply is lost or squandered every year. There are more people living in urban areas than there are in rural ones, which means that urban areas are home to the majority of the world's population. In the year 2050, it is anticipated that this percentage would rise to 68%.

Agriculture, on the other hand, has been able to satisfy their ever-increasing needs by producing food that necessitates a greater amount of energy, land, and water, and that also results in a rise in the emissions of greenhouse gases. One of the most important questions that has to be answered is whether or not agriculture can fulfil the ever evolving needs of urban populations in a sustainable manner, all while fostering agricultural wealth and eliminating poverty in both rural and urban areas. In the context of “smart farming,” smart farming is an essential component of modern farming, particularly in the context of “contemporary farming.”

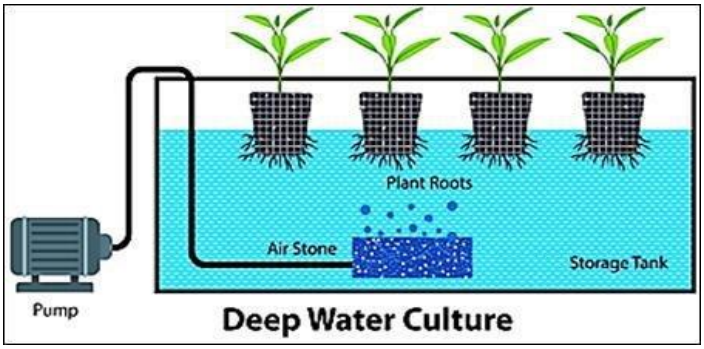
In comparison to traditional farming methods, hydroponics has a number of benefits, including a lower percentage of water use, a higher crop yield per unit area, and a higher return on investment (ROI) than conventional farming techniques. As a result of its vertical farming approach, which makes the most effective use of the space that is available, hydroponics enables a better crop yield per unit area than other farming methods. It is possible that the incorporation of artificial lighting into Vertical Farming Systems (VFS) might result in even better yields. This is due to the fact that hydroponic systems are less likely to be affected by diseases and pests, which in turn reduces the overall need for chemical pesticides.

Furthermore, hydroponics enables continuous production throughout the year, regardless of the weather conditions that are present outside, which ensures a consistent supply of fresh veggies. Hydroponic lettuce production has the potential to provide much better yields

per acre compared to soil based farming, with claimed increases of up to 20 times. This is according to the conclusions of research that was conducted. The cultivation of lettuce using hydroponics in a controlled environment provides continuous and stable crop output throughout the whole year, overcoming any seasonal limits that may be present. The authors proved that it is possible to achieve continual tomato production independent of the external weather conditions by creating a controlled environment and accurate nutrient management. This would make it possible to supply the market throughout the whole year. In another study, the outcomes of the research suggested that the use of hydroponic culture techniques and controlled environmental parameters permitted a consistent strawberry output, regardless of the limits that were imposed by the seasons. Having these advantages demonstrates that growing leafy greens hydroponically is not only feasible but also long lasting.

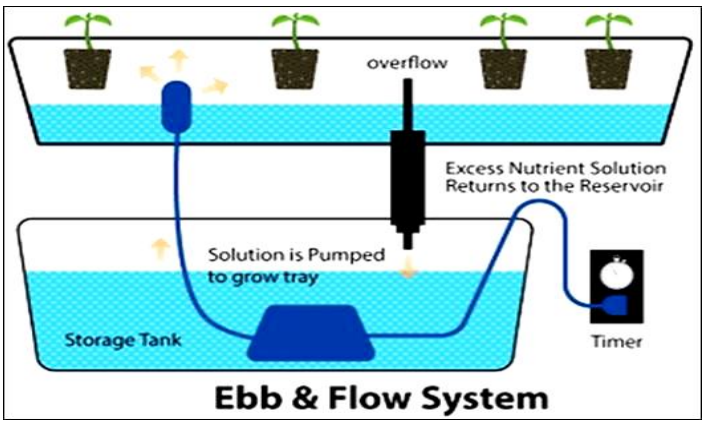
Techniques of hydroponics

Deep Water Culture



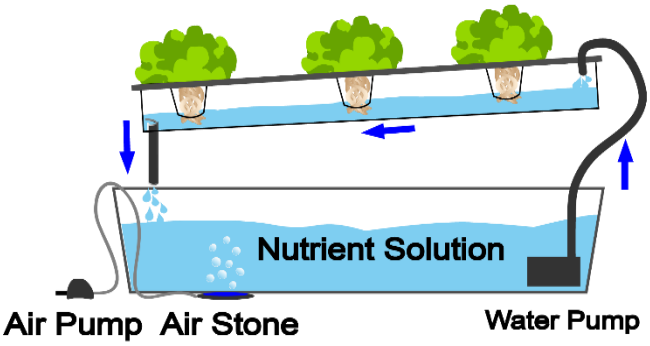
This system involves active moving parts where roots of the plant are totally dipped into the water which contains the specific Growth nutrient. The oxygen is supplied trough air pumps for the roots to breathe. Few plants other than lettuce can do well in this type of system. In this systematic hydroponic system the plat forms used are usually made of Styrofoam and floats directly on the nutrient solution.

Ebb & Flow System (Flood & Drain)



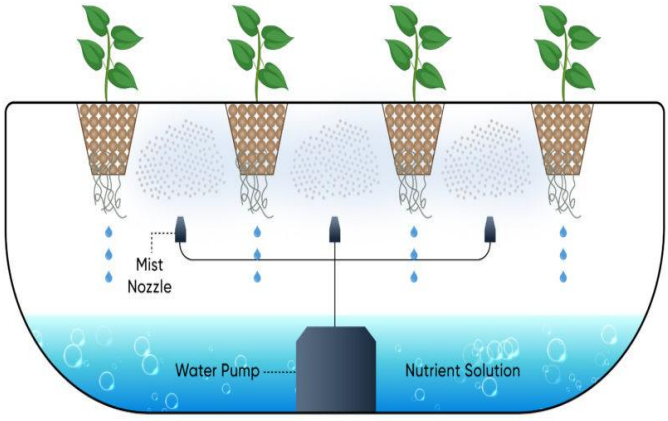
This hydroponic system works by flooding the growth trays temporarily. The nutrient solution from a reservoir surrounds the roots before draining back. This is an automated system with a water pump with a timer in it.

NFT System



The Nutrient Film Technique (N.F.T) system is the most dominant kind of hydroponics these days. It includes u a constant flow of the Growth Technology nutrient solution with no timer being included here. The nutrient solution is pumped from a reservoir into the growing tray. The growing tray requires has no growing medium or soil or organic manure. The roots extracts the nutrients for their growth and demand from the flowing solution provided through the channels. The downward flow is turned back into the reservoir for further recycling. Pump and electric maintenance should be constant because failure of them may result into drying out of roots rapidly when the water flow stops in that case.

Aeroponic System



Unlike N.F.T system, growing medium here is primarily air. The roots are hanged in air with spraying of nutrient solution in the form of mist. The misting of roots done are very frequently in every few minutes. In case of any interruption roots will dry-out. A timer is needed here like other hydroponic systems as well.

Disadvantages

Hydroponic farming is a sustainable and eco-friendly method of growing crops, but it also faces several challenges. High initial investment costs for infrastructure and technology, along with the need for technical expertise in nutrient and pH management, are major limitations. These systems rely heavily on electricity for lighting, water circulation, and climate control, making them vulnerable to power failures and increasing operating costs. Hydroponic systems are also prone to system breakdowns and the rapid spread of pathogens such as *Pythium* and *Fusarium*, which makes continuous monitoring and proper sanitation essential. Maintaining optimal pH and nutrient levels is critical, as improper management can lead to over-fertilization and plant toxicity. Crop diversity may be limited, since not all plants perform well under hydroponic conditions. Environmental disturbances, supply chain dependence, regulatory compliance, high energy consumption, and consumer scepticism further add to management challenges. Despite these limitations, careful planning, technological support, and precise monitoring can improve the efficiency and reliability of hydroponic farming.

Conclusion

In conclusion, the transformative role of hydroponics in reshaping modern agriculture. From its early beginnings to its growing adoption today, hydroponics has emerged as a sustainable solution to challenges such as food security and environmental sustainability. By integrating advanced technology, hydroponic systems optimize resource use, reduce ecological impact, and offer a strong alternative to conventional farming. As global food demands rise under changing climatic conditions, hydroponics presents a promising pathway toward a resilient, efficient, and sustainable agricultural future, with continued research and investment unlocking its full potential.

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