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Hydroponics: A Future-Oriented Approach to Farmer's Welfare

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Agriculture has long been a pillar of India's economy, providing livelihoods for millions of farmers and nourishing its large population. Soil-based agriculture is currently confronting numerous challenges, including rapid urbanization, natural disasters, climate change, water scarcity and the excessive use of chemicals and pesticides, all of which are contributing to the decline in soil fertility. To address these challenges, there is a need to upgrade farming techniques and methods, with hydroponics being one of the most effective solutions. It not only tackles the issues mentioned above but also stands as one of the most profitable industries.

Introduction

Hydroponics is a method of growing plants in nutrient solutions, with or without the use of an inert medium like gravel, vermiculite, rockwool, peat moss, sawdust, coir dust, coconut fiber, and others, to provide mechanical support. The term "hydroponics" is derived from the Greek words "hydro," meaning water, and "ponos," meaning labor, literally translating to "water work." The concept of hydroponics was first introduced by Professor William Gericke in the early 1930s to describe the process of growing plants with their roots suspended in water containing mineral nutrients. In 1940, researchers at Purdue University developed the nutriculture system. In the 1960s and 70s, commercial hydroponic farms began to emerge in countries such as the United States (Arizona and California), Abu Dhabi, Belgium, Denmark, Germany, the Netherlands, Iran, Italy, Japan, the Russian Federation, and others. Most hydroponic systems today operate automatically to regulate the water, nutrients, and photoperiod based on the specific needs of different plants (Resh, 2013).

As urbanization and industrialization rapidly increase, not only is cultivable land decreasing, but traditional agricultural practices are also leading to various negative environmental impacts. To sustainably feed the growing global population, agricultural methods must evolve. One viable alternative is modifying the growth medium, which can help conserve the rapidly depleting land and water resources. In this context, soilless cultivation presents a promising solution, offering a sustainable option for growing healthy food plants, crops, and vegetables (Butler and Oebker, 2006). Soilless agriculture includes techniques such as hydroponics, aquaponics, aeroponics, and substrate culture. Among these, hydroponics is gaining significant popularity due to its efficient resource management and food production capabilities. A wide range of commercial and specialty crops can be grown using hydroponics, including leafy vegetables, tomatoes, cucumbers, peppers, strawberries, and many others.

Regional Outlook for the Global Hydroponics Market

The hydroponics market size has grown rapidly in recent years. It will grow from $15.57 billion in 2024 to $17.3 billion in 2025 at a compound annual growth rate (CAGR) of **11.1%**. The hydroponics market size is expected to see rapid growth in the next few years. It will grow to $28.95 billion in 2029 at a compound annual growth rate (CAGR) of **13.7%.** Western Europe was the largest region in the hydroponics market in 2024. Asia – pacific is expected to be the fastest growing region in the forecast period. The regions covered in the hydroponics market report are Asia-Pacific, Western Europe, Eastern Europe, North America, South America, Middle East and Africa. The countries covered in the hydroponics market report are Australia, Brazil, China, France, Germany, India, Indonesia, Japan, Russia, South Korea, UK, USA, Canada, Italy, Spain.

Hydroponics: Indian Outlook

India is currently the 5 th largest economy in the world and is projected to become the 3 rd largest economy by 2030. India's Population growth during the same period is projected to increase to 1.5 billion. In order to cater our country's food needs the India need to focus on increasing food production, productivity. Now, With the latest technological advancements there are methods available that are within the reach of humans. In that one of the most spoken technology is Hydroponics. It enables a sustainable way of growing greens. The Hydroponics market in India is still nascent relative to markets such as US, UK, Europe, Singapore and China. According to meticulous research, as of 2020 the Hydroponics market in India stood at 13.90 million USD and witnessing an accelerated growth of **18% CAGR**. Currently India is lagging in comparison with its Asian counterparts China and Japan but has ample reason to cheer as it is expected to witness of continued growth.

Hydroponics for Fodder Production

Feeding high-quality green fodder to dairy animals plays a vital role in ensuring sustainable and cost-effective dairy farming. However, farmers often encounter several challenges in producing green fodder. These include limited land availability, lack of dedicated space for fodder cultivation, water scarcity or saline water, poor access to quality fodder seeds, high labor demands, need for manure and fertilizers, long cultivation periods (typically 45–60 days), fencing requirements to protect crops from wild animals, and vulnerability to natural disasters. Additionally, the inconsistent supply of quality fodder throughout the year further complicates efforts to maintain sustainable dairy practices. In light of these challenges and the limitations of traditional fodder cultivation methods, hydroponics has emerged as a promising alternative for growing fodder for livestock.

Systems of Hydroponics

1. Wick system: This is a basic hydroponic system that doesn't require electricity, pumps, or aerators. Plants are placed in an absorbent medium such as coco coir, vermiculite, or perlite, with a nylon wick connecting the plant roots to a reservoir of nutrient solution. The water or nutrient solution is delivered to the plants through capillary action. This system is best suited for small plants, herbs, and spices but is not ideal for crops that require large amounts of water.

2. Water culture system: The water culture hydroponic system is a simple and cost-effective type of hydroponic setup. The reservoir holds a nutrient-rich solution and is positioned just below the grow tray. The grow tray has holes with baskets or net cups where the plants are placed. The tray is arranged so that the plant roots are fully submerged in the nutrient solution within the reservoir. In deep water culture systems, the water depth is typically more than 8 to 10 inches, while in water culture systems, the depth is less than 8 inches. This method works particularly well for growing vegetables like cucumbers and tomatoes.

3. Ebb and flow system: This is first commercial hydroponic system which works on the principle of flood and drain.This system utilizes a grow tray and a reservoir that is filled with a nutrient solution. A pump periodically floods the grow tray with nutrient solution, which then slowly drains away. It is possible to grow different kinds of crops but the problem of root rot, algae and mould is very common (Nielsen et al., 2006) therefore, some modified system with filtration unit is required.

4. Nutrient film technique: NFT is the active system of hydroponics. In this method, a nutrient solution is pumped constantly through channels in which plants are placed.The depth of the recirculating stream should be very shallow, little more than a film of water, hence the name 'nutrient film'. When the nutrient solutions reach the end of the channel, they are sent back to the beginning of the system.

5. Drip system: Drip system is probably the most widely used types of hydroponics system in the world. Water or nutrient solution from the reservoir is provided to individual plant roots in appropriate proportion with the help of pump. Drip systems dispense nutrients at a very slow rate, through nozzles, and the extra solutions can be collected and recirculated, or even allowed to drain out. More water conservation. Both home and commercial hydroponic cultivators widely use this method.

6. Aeroponics: Most high tech types of Hydroponic farming used especially for research purpose. In aeroponic system, plants receive nutrients in the form of mist. In this system root are held in a soilless growing medium like Coco coir on the grow tray, on these roots nutrient rich solution is being sprayed by using specially designed misting devices.

Table: EC (dSm-1) and pH ranges for hydroponic plants(Sardare and Admane, 2013)

Crops	EC(dSm-1)	pH
Asparagus	1.4 to 1.8	6.0 to 6.8
Tomato	2.0 to 4.0	6.0 to 6.5
Broccoli	2.8 to 3.5	6.0 to 6.8
Cabbage	2.5 to 3.0	6.5 to 7.0
Cucumber	1.7 to 2.0	5.0 to 5.5

Growing media for hydroponics

Organic growing media

- Coco peat
- Rice husk

Inorganic growing media

- Expanded clay aggregate
- Perlite
- Sand
- Vermiculite
- Rock wool
- Oasis cubes

Advantages of Hydroponics

1. Efficient Use of Resources: Hydroponics is known for its efficient utilization of resources. It uses up to 90% less water compared to traditional soil-based farming because the water is recirculated within the system. Additionally, the nutrients are delivered directly to the plant roots in a dissolved form, which prevents waste and ensures optimal nutrient uptake.

2. Faster Growth and Higher Yields: Plants grown hydroponically often grow faster and produce higher yields. This is because they have constant access to water, oxygen, and nutrients in a controlled environment. The absence of environmental stress and competition from weeds also contributes to enhanced productivity.

3. Space-Saving and Suitable for Urban Areas: Hydroponics requires significantly less space, as plants can be grown in stacked vertical systems. This makes it highly suitable for urban settings where land is scarce. It enables farming in rooftops, greenhouses, and even indoors using artificial lighting.

4. Reduction in Pests and Diseases: Since hydroponic systems do not use soil, they avoid many soil-borne pests and diseases. Controlled indoor environments further minimize the risk of infestation, thereby reducing the need for chemical pesticides and resulting in healthier crops.

5. Year-Round Production: Hydroponic farming can be done throughout the year, regardless of the external weather conditions. This is particularly advantageous in areas with extreme climates or limited growing seasons, as it ensures continuous and stable food production.

6. Lower Environmental Impact: Hydroponics is environmentally friendly. It eliminates soil erosion and reduces water pollution due to the efficient use of fertilizers. Moreover, by enabling local production, it decreases the carbon footprint associated with transporting food over long distances.

7. Improved Crop Quality and Taste: Crops grown hydroponically are often superior in taste, texture, and nutritional value. Controlled conditions and the absence of chemical residues contribute to producing cleaner and more wholesome produce.

8. Integration with Technology and Automation: Hydroponic systems can be easily integrated with modern technology. Automation of irrigation, lighting, and nutrient delivery allows for precise control over the growing environment, making farming more efficient and less labor-intensive.

9. Viable in Challenging Climates: This method is highly beneficial in areas with poor soil quality, desert conditions, or regions affected by climate change. It provides a sustainable solution for growing food in environments where traditional farming is not feasible.

10. Cleaner and Sustainable Farming: Hydroponics supports clean farming practices. Without the mess of soil and with minimal use of chemicals, it contributes to a healthier environment and promotes sustainable agriculture.

Limitations of Hydroponics

1. High Initial Investment: Setting up a hydroponic system requires significant initial capital. The cost of equipment like grow lights, pumps, nutrient solutions, containers, and automation systems can be quite high. This may limit its adoption, especially among small-scale and resource- poor farmers.

2. Technical Knowledge Required: Hydroponics demands a good understanding of plant nutrition, water chemistry, and system maintenance. Farmers need training to manage pH levels, electrical conductivity (EC), and nutrient concentrations. A lack of technical expertise can lead to poor crop performance or system failure.

3. Risk of System Failure: Since plants depend entirely on the hydroponic system for water and nutrients, any malfunction—such as a power outage, pump failure, or clogging—can quickly harm or kill the entire crop. This makes it essential to have backup systems and regular monitoring.

4. Limited Crop Variety: Hydroponics is better suited for certain crops, particularly leafy greens, herbs, and small fruits. Large or deep-rooted crops like maize, potatoes, and trees are less compatible or require highly specialized systems, making hydroponics less versatile than soil farming.

5. Energy Consumption: Indoor hydroponic systems, especially those using artificial lighting, consume a considerable amount of electricity. This can increase operational costs and limit environmental sustainability if renewable energy is not used.

6. Dependence on Inputs: Hydroponic farming depends heavily on purchased inputs like nutrient solutions, growth mediums, and electricity. Any disruption in supply chains or price hikes in these inputs can negatively impact production and profitability.

7. Constant Monitoring and Maintenance: Unlike traditional farming, hydroponic systems require continuous monitoring of the growing environment. Parameters like pH, nutrient levels, and temperature need to be constantly checked and adjusted, which can be labor-intensive and time-consuming.

8. Limited Awareness and Acceptance: In many regions, hydroponics is still a new concept. Limited awareness, skepticism, and cultural resistance may hinder its wider adoption, especially among traditional farmers and consumers unfamiliar with soil-less agriculture.

Cost-Benefit Analysis of Hydroponic Farming: Growing Lettuce Under Nutrient Film Technique In India (Thanushree *et al*. 2024)

The study is intended to analyze the cost-benefit analysis of hydroponic farming for growing lettuce under Nutrient Film Technique in India. In the study various elements involved in the total cost are identified and analyzed. With the help of econometrics the analysis has been done. The results are going to provide inputs for the new investors in hydroponic farming to make investment decisions. For this study the data is collected through both primary and secondary data. Primary data is collected through questionnaires and interview method with hydroponic farmers. Secondary data is collected through referring journal, articles and other cost statements. This study is conducted for the area of 5000 sqft.

Nutrient Film Techniques (NFT) system setup

Various elements required	Cost for the element
Poly house shelter	Rs. 600000
Pipes (4 inches)	Rs. 700000
Pipes (2 inches)	Rs. 12000
Pipe connectors	Rs. 120000
Stand platform (includes 40 Stands and 32 pipes for each)	Rs. 100000
20000 ltrs. Tank	Rs. 55000
1000 ltrs. Plastic tanks(2 no.)	Rs. 15000
5000 ltrs. Plastic tank	Rs. 22000
Water pumps (1 hp) and 4 no.	Rs. 30000
Water pumps (0.5 hp) and 2 no.	Rs. 10000
Net cups	Rs. 100000
Water cooler	Rs. 60000
Reverse Osmosis system	Rs. 50000
PH meter	Rs. 1200
TDS (Total Dissolved Solids) meter	Rs. 2000
Labour cost	Rs. 10000
Total cost	Rs. 18,87,200.

Following is the table that represents various elements and cost incurred for each element

Sr .No.	Variables	Lettuce
01.	Initial investment / one time setup cost	Rs.18,87,200
02.	Total number of harvests p.a	5 times
03.	Net production capacity per harvest	2200 kg
04.	Total production per annum	11,000kg
05.	Price per kg	Rs.350
06.	Total revenue per annum	Rs.38,50,000
07.	Operating expenses per cycle	Rs.1,92,000
08.	Total operating expenses per annum	Rs.9,60,000
09.	Estimated life of the growing system	5 years
10.	Discount rate	10%
11.	Depreciation	Rs.3,77,440

Note: Depreciation is provided under straight line method.

Results: Following is the data relating to cost- benefit analysis of hydroponic farming in India.

Various cost- benefits analysis techniques	values
Net Present Value (NPV)	Rs 81,47,057
Benefit – cost ratio	5.317
Other econometrics are :	
Payback period	9.43 months
Internal rate of return	60.6 %
Profitability index	4.31

This study is conducted for the area of 5000 sqft. The analysis shows that there is a NPV is Rs.81,47,057 for the duration of 5 years, Benefit-cost ratio is 5.317, PBP is less than 1 year i.e 9.43 months, Internal Rate of Return is 60.6% and profitability Index is 4.31. The study shows that the investment required for hydroponic farming is high but still it can be recovered within one year and sometimes it may take 1.5 years. Net present value is also high and Benefit cost ratio is greater than 1 hence it's also a good indication of adopting NFT in growing Lettuce. Internal rate return is ascertained considering 5% and 20% discount rate.

Conclusion

- Hydroponic culture is possibly the most intensive method of crop production in today's agriculture industry mainly used in developed and developing countries for food production in limited space.
- Hydroponics is not just a modern trend but a necessity for future food security and environmental sustainability.
- It enables farmers to produce more with fewer resources while adapting to climate change and land constraints.
- It is highly productive, conserves water, protective for environment and can be done in limited land and space.
- hydroponic farming has a number of significant advantages over conventional techniques in terms of productivity, sustainability, and profitability.
- It shows that its beneficial for the farmers who are willing to enter into hydroponic because they can able earn huge profits when they have sufficient capital and importantly skilled and highly qualified human resource who is going to operate and monitor the hydroponic farm.

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