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Hydroponics for sustainable farming of future: A review

Ugyen Tshering and Barkha

Abstract
Hydroponics is the method of cultivating crops in a solution of water enriched with nutrients without the use of soil medium; it reduces loss of nutrients, deficiencies, requirement of large quantities of water and land area for cultivation. Hydroponics system is the solution to combat climate change, human wild life conflict, exploitation of non-renewable resources, and extinction of plants, wild animals as the crops are grown in controlled environment in a structure, there is no human wild life conflict, the environment pollution and waste of irrigation water and applied nutrients are substantially reduced.
This farming technologies enable the use of smart farming tools, big data, artificial intelligence and real time data to control, reuse and recover nutrients, monitor plant health, maturity, expected yield, quality and maturity, these technologies make the farming system attractive for the youths to take up as business enterprise and ultimately solve rural urban migration and migration of youths out of the country looking for better paid jobs.

Keywords: Hydroponics, human wild life conflict, migration, youth, climate change

Introduction
Hydroponics culture is perhaps the most intensive method of crop production in today's emerging agriculture industries mainly adopted in developed and developing nations for production of food, besides being productive, the input use efficiency is higher than the conventional agriculture and with time the cost of cultivation reduces as there is no requirement of large spaces, labors and smart agriculture technologies can be deployed to monitor the performance of the crop in real-time.
Hydroponics farming system has strong potential to mitigate the threats these issues pose to our agricultural system, it enables efficient use of limited resources like time and space (Payen *et al*., 2022) [23]. Growing crops in near optimal conditions using controlled environment agriculture (CEA) technology is one of the biggest benefits of hydroponic farming. Crops grown indoors and hydroponically can be grown anywhere on any time of the year, regardless of weather conditions, availability of cultivable land, or soil quality (Ezzahoui *et al*., 2021; Rizal *et al*., 2018) [7, 24].
Hydroponic farming has the potential to provide fresh, local food for areas with extreme droughts and low soil quality, such as in where access to leafy green vegetables is often limited (Malik *et al*., 2019; Pambudi *et al*., 2022) [19, 22]. Cultivation of ornamental plants like easter lily, dumb cane, medicinal and aromatic plants like corn mint and high value crops like lettuces and chilies in hydroponics were found to germinate faster, higher branches, better quality and yield (Alimuddin *et al*., 2018, Alcarraz *et al*., 2018, Bobby *et al*., 2021) [2, 1, 4].
Hydroponics can be defined as 'growing plants in water smart solutions in place of soil, meaning: soil-less cultivation of plants'. Here, soil does not serve as an anchor to the plants; the roots are brought in direct contact with the nutrient medium Vishwanath *et al*. (2022). The plants are provided with enormous oxygen in order to fasten the growth of the plants (Taghizadeh, 2021) [25]. And this characteristic of hydroponics, that is, quick growth of plants serves as the most remarkable benefit for adoption (Table 1). The water and nutrient use efficiency yield of barley fodder, tomatoes, potato tubers and cucumbers were substantially higher compared to open field and green house cultivations, the benefit cost ratios were higher in all the crops (Grewal *et al*., 2011; Nazionale, 2005, Baiyin *et al*., 2021; Goins *et al*., 2004; Joseph & Muthuchamy, 2014; Malik *et al*., 2018) [12, 20, 3, 11, 16, 19].

This cultivation offers various other advantages over the traditional method which are as follows

- Uses scientific and calculated methods for growing crops.
- Considers the specific requirements of single plant.
- Controls the nutrition profile of the plant.
- Eliminates use of pesticides.
- Hydroponic farms are located near large cities, providing the consumers with fresh produce.
- Eliminates all soil-borne pests due to its characteristic of soil-less nature
- Use of high quality, pre-treated purified water, the produce is safe for consumption in every single way.
- Offers completely residue-free produce to the consumers.

There are various types of hydroponics systems available based on ease of setting-up, of which seven are commonly used commercially. These systems are:

Wick System

Among various from of hydroponics system, wick system is the simplest and does not require aerators, pumps and electricity. The plants are directly cultivated on an absorbent substance such as perlite, vermiculite. Nylon wicks are used to cover the plant before being dripped into the nutrient solution. In this system small herbs and plants are cultivated which has relatively less water requirement.

Deep Water Culture

Deep water culture system is a simple hydroponic system that places the plant directly in the nutrient solution. This system makes use of diffuser or air stone to pump oxygen into the nutrient medium. The best part of this system is that the plant roots are directly in touch with the nutrient medium making easy absorption of nutrients by the plants resulting in quick growth. The system is suitable for any kind of plant irrespective of their size.

Re-circulating Deep Water System

Recirculation deep water system covers the shortcomings of the traditional or normal system. This system doesn't drain out the nutrient solution, meaning, the solution keeps on circulating throughout the structure. Buckets or containers used are linked to a large central reservoir and the nutrient media is circulated from one bucket to another. The system requires simple addition of water, oxygen followed by calibration of the reservoir.

Nutrient Film Technology (N.F.T)

This system is used for cultivation of high value crops like lettuce, the nutrients are circulated through tubes arrange side by side in rows connected from the central reservoir tank of nutrient solutions, the excess nutrient solutions are re-circulated, the nutrients are supplied at the base of the crop. In this system, an appropriate slope, length and flow rates are set to enhance the resource use efficiency.

Ebb and Flow (Flood and Drain)

In this system, water pumps fitted with timer and electricity is required for circulation of nutrient solution, the plants are cultivated on growth mediums like rock wool or perlite, these beds are flooded with nutrient-rich solution, timers and monitors are used to control the over flowing of the solution. When optimum nutrient solution is circulated, the water is drained out from the bed automatically and re-circulated back through pump. The system is feasible for both leafy and root crops.

Drip Systems

Drip systems can be highly effective as its system set up can be changes according to the variety of the crops cultivated. Using pumps and small tubes, the nutrient solutions are circulated directly to the roots of the plant, drip emitters are placed at the end of each tube to control the amount of solutions circulated and flow can be regulated as per the plants requirement. Due to flexibility of changing the system according to plants, any variety of crops can be grown in this system.

Dutch Bucket System

This system is feasible for cultivation of vines and larger plants as they are cultivated in buckets connected with tubes or drip emitters which delivers the solution directly in drips at the base of the plant, usually 2-3 plants are placed in lines in a bucket fitted with delivery tubes, it is specially suitable for fruits and vegetables.

Vertical Hydroponic System

The plants are cultivated in stacks or in towers, these reduces the requirement of spaces, dozens of plants can be adjusted in a single tower and all the plants are fed with nutrients from the same system of delivery tubes. It is convenient to cultivate in greenhouse structures as the space or land requirement is reduced by 99% and efficiently saves 90% irrigation water. As the crops are cultivated in protected structures, pest and disease infestations are minimal.

Table 1: Hydroponics Vs conventional farming

Hydroponics	Conventional farming
Higher yield	Less yield
Less space	More space
Less water	Requires high amount of irrigation water
Higher nutrient use efficiency	Less nutrient use efficiency
Sustainable farming	Not sustainable
Seasonally agonistic	Not seasonally agonistic
Climate proof	Venerable

Affects of climate change, wild life, pest and diseases

The climate change would affect the hydrological systems, increase water scarcity, unpredictable drought and precipitation, emergence of pest and diseases, trigger of landslides, melting of snows or ice, sea level rise, increase salinity of surface and ground water in coastal areas, it is indicated that 25% of all economic losses in agriculture in the developing nations were inflicted by climate hazards (Ezzahoui *et al*., 2021; Rizal *et al*., 2018; Wilson, 2002) [7, 24, 27]. These factors increase cost of cultivation in agriculture besides affecting the quality of the farm products; it poses considerable risks to food security for the growing population in the developing nations besides land fragmentation as the families separate for settlement (Gitz *et al*., 2016) [10].

Studies have shown that exposure to extreme climates trigger shocks on agriculture production and food availability; this could cause market disruption, supply chain, storage and discourage investment in farming, accessibility to food and stability would be impacted, especially for the marginal

farmers and poorer section of the society, risk in agriculture and lower income from investment in agriculture can impact household ability to spend on health and education, ultimately this results in unemployment, rural urban migration and economic gaps within the society. The populations dependent on agriculture, natural environment and biodiversity for food and nutrition would be affected greatly when exposed to natural calamities like droughts, about 700 million populations live in rural areas, 800 million are hungry, 2 billion suffer from micro nutrient deficiencies, by 2030, a population of 653 million would be under nourished (Dewbre *et al*., 2014 and FAO, 2021) [5, 8].

To reduce distress migration, hunger, poverty, social inequality, land fragmentation and impacts of climate change, the next best option is to adopt the smart agriculture farming such as hydroponics, besides higher yielding and quality of the products, it reduces the need for clearance of natural environment to increase crop cultivation, most importantly this technology saves marginal farmers and youths living within or proximity to national parks and biological corridor from coming into conflict with wild life, which is major emerging issues in developing countries like Bhutan, Thailand, some parts of Indian and Nepal (Mahanti *et al*., 2018; Wangchuk *et al*., 2023) [17, 26].

With strict wild life conservation rules, the farmers loss about 25-30% of their crops to wild animals such as elephants, pigs, porcupines and deer, this exerts immense pressure on family income and food security, if these problems are not addressed strategically without disturbing the usual life of the farmers and investors in farming, it could trigger massive rural urban migration and social crimes. In future access to food, health, education for the rural population, specially women and young children could be greatly impacted due to income gaps and aging population (Mahanti *et al*., 2018; Wangchuk *et al*., 2023) [17, 26].

Conclusion

The technology of hydroponics put forward a bright future for crop cultivation which at present, is facing various challenges including pest resurgence, pesticide resistance, poor soil fertility, desertification, unavailability of water for irrigation, degraded arable land fragmentation. The most notable problem faced by the farming community is the ever changing and unpredictable weather, crop predation (ADB, 2024 and Gyelmo, 2020) [13], taking all these concerns into account, the all in one solution remains the adoption of hydroponics since the crops in here are grown in controlled, soil- less environment eliminating the chances of climatic challenges, pest attack (soil-borne) crop predation by wild life and unavailability of land.

The technology could also reduce the incidences of soil and water pollution to a large extends (Garza, 2012) [9]. This system also is proven to be highly efficient in saving water, thus giving new dimensions to farming, revolutionizing the conventional ideology of agriculture where youths are reluctant to take up the farming due to drudgery of agriculture work (Ezzahoui *et al*., 2021; Rizal *et al*., 2018; Wilson, 2002) [7, 24, 27].

Way forward and limitations

The initial establishment of hydroponics requires both skills and capital investment, if the technology is to be taken up by youths and women entrepreneurs, the central government must strategize ways to subsidize the material procurement. Technical skills trainings and easy financial access such as bank loans without collateral bonds or mortgages as usually these factors hinder rapid adaptation of new technologies.

Secondly the government must facilitate and support reliable market for the local agriculture products as in the initial years the farmers can't compete with well-established business owners or with price of imported products.

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