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Hydroponics: Environmentally sustainable practice in the agricultural system

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Abstract
With the advent of civilization, open field/soil-based agriculture is facing some major challenges; most importantly decrease in per capita land availability. Soil is usually the most available growing medium for plants. It provides anchorage, nutrients, air, water, etc. for successful plant growth. However, soils do pose serious limitations for plant growth too, at times. Presence of disease causing organisms and nematodes, unsuitable soil reaction, unfavorable soil compaction, poor drainage, degradation due to erosion etc. are some of them. Under such circumstances, soil-less culture can be introduced successfully. Hydroponics is the technique of growing plants in soil-less condition with their roots immersed in nutrient solution. This is important for long-range habitation of both the space stations and other planets. There are many advantages of growing plants under soil-less culture over soil-based culture. These gardens produce the healthiest crops with high yields and are consistently reliable; gardening is clean and extremely easy, requiring very little effort.

Keywords: Hydroponics, hydroponic systems, sustainable agriculture, soil-less culture

Introduction
Soil is usually the most available growing medium for plants. It provides anchorage, nutrients, air, water, etc. for successful plant growth (Ellis *et al*., 1974) [16]. However, soils do pose serious limitations for plant growth too, at times. Presence of disease causing organisms and nematodes, unsuitable soil reaction, unfavorable soil compaction, poor drainage, degradation due to erosion etc. are some of them. In addition, conventional crop growing in soil (Open Field Agriculture) is somewhat difficult as it involves large space, lot of labour and large volume of water. Moreover, some places like metropolitan areas, soil is not available for crop growing at all, or in some areas, we find scarcity of fertile cultivable arable lands due to their unfavorable geographical or topographical conditions (Beibel, J.P. 1960) [1]. Of late, another serious problem experienced since is the difficulty to hire labour for conventional open field agriculture. Under such circumstances, soil-less culture can be introduced successfully (Butler, J.D. and Oebker, N.F. 2006) [6].

The term Hydroponics was derived from the Greek words ‘Hydro’ water ‘Ponos’ labour. It is a method of growing plants using mineral nutrients without soil with their roots immersed in nutrient solution (Butler, J.D. and Oebker, N.F. 2006) [6]. Terrestrial plants may be grown with their roots in the mineral nutrient solution only or in an inert medium, such as perlite, gravel, or mineral wool (Maharana, L. and Koul, D.N.2011). This system helps to face the challenges of climate change and also helps in production system management for efficient utilization of natural resources and mitigating malnutrition (Butler, J.D. and Oebker, N.F. 2006) [6].

In India, Hydroponics was introduced in year 1946 by an English scientist, W. J. Shalto Duglas and he established a laboratory in Kalimpong area, West Bengal. He has also written a book on Hydroponics, named as ‘Hydroponics- The Bengal System’. Later on during 1960s and 70s, commercial hydroponics farms were developed in Abu Dhabi, Arizona, Belgium, California, Denmark, German, Holland, Iran, Italy, Japan, Russian Federation and other countries. During 1980s, many automated and computerized hydroponics farms were established around the world. Home hydroponics kits became popular during 1990s.

In Tokyo, land is extremely valuable due to the surging population. To feed the citizens while preserving valuable land mass, the country has turned to hydroponic rice production. The rice is harvested in underground vaults without the use of soil. Because the environment is perfectly controlled, four cycles of harvest can be performed annually, instead of the traditional single harvest (De Kreij *et al*., 1999) [10].

Hydroponics also has been used successfully in Israel which has a dry and arid climate (Van *et al*., 2002) [63]. A company called Organitech has been growing crops in 40-foot (12.19-meter) long shipping containers, using hydroponic systems. They grow large quantities of berries, citrus fruits and bananas, all of which couldn't normally be grown in Israel's climate (Van *et al*., 2002) [63]. There has already been a great deal of buzz throughout the scientific community for the potential to use hydroponics in third world countries, where water supplies are limited ((Butler, J.D. and Oebker, N.F. 2006) [6]. Though the upfront capital costs of setting up hydroponics systems is currently a barrier but in the long-run, as with all technology, costs will decline, making this option much more feasible (Singh, S. and Singh, B. S. 2012) [51]. Hydroponics has the ability to feed millions in areas of Africa and Asia, where both water and crops are scarce.

Need of Hydroponics

- Due to rapid urbanization and industrialization as well as melting of icebergs, the arable land under cultivation is decreasing. Reduction of Gross Cropped Area from 66.32 Lakh ha. (1990-91) to 58.90 Lakh ha. (2011-2012).
- On the other hand the open field agriculture involves large space, lot of labor and large volume of water more over due to continuous cultivation of crops has resulted in poor fertility which leads to poor yield and quality.
- Soil fertility status has attained a saturation level, and productivity is not increasing further with increased level of fertilizer application.
- Besides, poor soil fertility, frequent drought conditions and unpredictability of climate and weather patterns, rise in temperature, river pollution, and decline in ground water level are threatening food production under conventional soil-based agriculture. (Sardare and Admane, 2013) [39].
- Population is increasing day by day; per capita land availability is decreasing. It is projected that by 2050 the world will have a total of nine billion mouths to feed.
- Crisis occurred due to unfavorable climatic conditions resulted to drought or floods as they occur more frequently.
- Under such circumstances, in near future it will become difficult to feed the entire population. (Shraddha *et al*., 2019) [45].
- So to cope up with these challenges the soil less culture like hydroponics is becoming more relevant day by day.
- Hydroponics techniques produce a yield 1,000 times greater than the same sized area of land could produce annually.
- Best of all, the process is completely automated, controlled by robots using an assembly line-type system, such as those used in manufacturing plants. The shipping containers are then transported throughout the country (Singh, S. and Singh, B. S. 2012) [51].
- Hydroponics also will be important to the future of the space program.
- NASA has extensive hydroponics research plans in place, which will benefit current space exploration, as well as future, long-term colonization of Mars or the Moon (Van *et al*., 2002) [63].
- The benefits of hydroponics in space are twofold: It offers the potential for a larger variety of food, and it provides a biological aspect, called a bio-regenerative life support system.
- This simply means that as the plants grow, they will absorb carbon-di-oxide and stale air and provide renewed oxygen through the plant's natural growing process. This is important for

Long-range habitation of both the space stations and other planets (Singh, S. and Singh, B. S. 2012) [51].

History of hydroponics

The concept of hydroponics existed since long. Plants and algae growth on the oceans is the best example for it. The Hanging gardens of Babylon were the first known example of hydroponics. In 1600, the first research on hydroponics began scientifically, however they failed to understand that other than water and nutrients, carbon dioxide and oxygen is required (Shraddha *et al*., 2019) [45].

Around 600 BC - Hydroponic principles used in the creation of the Hanging Garden of Babylon.

Francis Bacon, British scientist, studies soil-less gardening Publication of his work sets of a wave of hydroponic research in 1699.

In 1699 – John Woodward, British scientist, concludes plants grow better in water with nutrients.

1937 – William, demonstrates the benefits of soil -less gardening. Credited for giving hydroponics its name.

1938 - Two other scientists, Dennis Hoagland and Daniel Arnon , publish “The Water Culture Method for Growing Plants Without Soil”, is most important text regarding hydroponics.

1985- Jensen and Collins published a complete review of hydroponics highlighting many new cultural systems developed in Europe and the United States.

In recent decades, NASA has done extensive hydroponic research for their ‘Controlled Ecological Life Support System’ (CELSS). Hydroponics intended to take place on Mars are using LED lighting to grow in different color spectrum with much less heat (Shraddha *et al*., 2019) [45].

Components of the Hydroponics Systems

Hydroponics systems require a number of different components to supply water and nutrients to the plants in the correct doses and at the right time, to provide a root zone environment for the plant to grow, and to provide physical support to the plants. The key components of a hydroponics system are

- Water supply
- Fertigation system
- Plant growth system
- Greenhouse facilities and climate control systems

Water Supply

All crops require a reliable supply of fresh water to grow. This is especially important with hydroponics systems as the high levels of production needed for a profitable hydroponics operation relies on sufficient high quality fresh water. Water sources can include city water supplies and ground water.

Fertigation system

Fertigation system is the method of fertilizer application in which fertilizer is incorporated with in the irrigation water by the drip system. It distributes the fertilizer solution evenly in drip system. It is used extensively in commercial agriculture and horticulture for both field and hydroponically grown vegetables. In this liquid and water soluble fertilizers are used. This system provides the crop with the water and nutrients they need to grow.

Plant growth systems

There are essentially two types of growth systems and support media used in hydroponics:

1. Plants are grown in a substrate which provides both physical support and the root environment required.
2. Plants are grown in water with no supporting medium for the roots, with the plants supported by floating platforms and the roots growing directly in the nutrient solution.

Green House Facilities and Climate Control Systems

- Hydroponically grown crops can either be grown directly in open or in greenhouses.
- Greenhouse facilities are often used in hydroponic production systems, as they protect the plants from harsh environmental conditions.
- Climate control systems are used to adjust the temperature and humidity inside the greenhouse to the optimum levels required by crop species to be grown at different stages.
- The plants grown through hydroponics are healthier and their nutritive value is also higher compared to soil based crops. Crops grown by hydroponics are easy to harvest and require very less space. They can be grown away from the farms and near to the consumers reducing the transportation cost and increasing the availability of fresh crops to the consumers (Jensen and Collins 1985) [25].
- Water hardness and pH level has to be continuously monitored and balanced as there are some nutrient which are absorbed quickly whereas others take time, which creates positive or negative ions dominant which leads to pH imbalance. It is suggested that this management should be done by automated system so as to avoid errors due to human negligence. Similar suggestion was also specified by (Pandey *et al.*, 2009) [36].

The Four important factors

1. **Water Quality:** The quality of the water used in Hydroponics has to be of a very high quality. Tolerable EC < 0.3, pH- 5.5-6.5.
2. **Solid Substrates:** Like Perlite, Coco Peat, Vermiculite, River sand etc. must be
   thoroughly washed to remove all traces of soil. Their EC and pH values must be tested before use.
3. **Nutrients:** Must be 100 percent highly processed "Technical Grade Nutrients" and of the highest quality. Nutrients must be mixed as per crop requirement and as per stages of growth
4. **Planting Materials:** Seeds, Cuttings, Root-stock, Runners & other transplants must be free of virus and bacterial infections.

Hydroponics Production System

A. Water culture systems

In this type of hydroponic system, plants are grown on and supported by floating platforms, usually made of Styrofoam and roots grow directly in the nutrient solution. The three most widely used types of water hydroponic systems are:

1. Nutrient film technique
2. Deep water culture
3. Aeroponics

1. Nutrient film technique

Plants are placed in a polypropylene-treated PVC pipes or troughs, through which a thin film of nutrient solution flows. Plants are suspended through holes in the trough, which is gently sloped so the nutrient solution is pulled back by gravity to the nutrient container. The collection of the solution back in the reservoir facilitates reused, however, the water volume is regulated by the slant position of the tray as well as the intensity of the water pump. Furthermore, due to the permanent contact of the root systems with water, they are highly susceptible to fungal infestation (Thinggaard, K. and Middelboe, A. 1989) [60].

2. Deep water culture

This is the most simple hydroponics system. Plants are fixed on the platform that drifts in the tank filled with nutrient solution. Originally, virtually all the hydroponic systems emanated from the deep system (Harris, D.1988) [19]. This system is well simplified, comprises of tank/reservoir, an air stone place at bottom of the reservoir, a timer and, tubing system, an air pump to facilitate air movement, as well a floating platform (Hoagland and Arnon 1950) [20].

With the progress of air circulation strategies to keep disintegrated oxygen, the profound deep system was developed, thus plants can be cultivated with roots continually suspended in the nutrient solution. To attain optimum growth conditions, it is very crucial to constantly monitor the oxygen, the concentration of nutrient, salinity as well as pH level (Domingues and Takahashi 2012) [13].

3. Aeroponics systems

Aeroponics is a system in which plant roots remain suspended in an enclosed growing chamber, where they are sprayed with a fog or mist of nutrient solution at short intervals (usually every few minutes).

B. Substrate or aggregate systems

Substrate or aggregate systems use an inert growing medium to support and surround the roots. Plants are grown in bags, pots or other containers filled with the substrate or growing medium, placed in rows and irrigated with nutrient solution through the fertigation system.

The advantage of using substrate over soil includes

1. Good water holding capacity
2. Low soluble salt level
3. Suitable pH (range of 5.5 – 6.5)
4. Provide a sterile media, free microorganisms and other contaminants
5. Ease of handling
6. Local availability

Types of substrate hydroponics systems

The two most widely used types of substrate hydroponics systems are:

1. Bag or container culture
2. Ebb and flow (flood and drain) system

1. Bag or container culture

The bag or container system is the most common type of substrate culture used. The containers are filled with a growing medium, placed in rows, and irrigated with nutrient solution using drippers, emitters or micro sprinklers.

2. Ebb and flow system

In this system, the growing media is flooded with the nutrient solution by a submerged pump connected to a timer and then allowed to drain. The other name for the ebb and flow technique is "flood and drain" technique due to the continuous and orbital rotation of pumping the nutrient solution into the tray that housed the plant and it draining back to the tank (Jones, J.B. 2016) [29].

Types of media for substrate hydroponics

Substrate media can either be organic or inorganic.

Inorganic

Expanded clay aggregate

Baked clay pellets are suitable for hydroponic systems in which all nutrients are carefully controlled in water solution. The clay pellets are inert, pH neutral and do not contain any nutrient value.

Perlite

This is a silicon mineral of volcanic origin. Lightness and uniformity make perlite very useful for increasing aeration and drainage. It is an effective an amendment for growing media.

Vermiculite

The ore is a mica-like silicate mineral. It is ground and heated and the resulting product is a lightweight granule containing numerous thin plates which have a large surface area, giving this substrate a very high water holding capacity.

Rockwool

Rockwool is produced by heating basalt, limestone, and coke at very high temperatures. It provides good aeration and drainage and also increases water holding capacity.

Sand or Gravel

Sand and gravel are basic components of soil, with particle sizes ranging from 0.02 to 2 mm in diameter and usually added to substrate media to increase bulk density. It has low cation exchange capacity, low water holding capacity, and little effect on pH.

Organic

Sawdust

The tree species from which sawdust is derived largely determines its quality and value for use in growing media. Sawdust has a high carbon to nitrogen ratio and must be thoroughly composted before use to avoid nitrogen immobilization.

Peat moss

Peat moss is formed as a result of plant decomposition under cool temperatures in poorly drained areas. The type of plant material and degree of decomposition largely determine its value for use in growing media.

Sphagnum peat moss

This is derived from the dehydration of acid swamp plants from the genus Sphagnum. It has a very high water holding capacity, holding up to 60% of its volume in water.

Coco peat

Coir fiber or pith is a natural and renewable resource produced from coconut husks. The husks are ground, long and medium fibers removed, the remaining coir consisting of granular pith with short fibers. It has high nutrient and water holding capacities but has a low cation exchange capacity.

Nutrient solution

Plant nutrients used in hydroponics are dissolved in water and are mostly in inorganic and ionic forms.

All the 17 elements viz. C, H, O, N, P, K, S, Mg, Ca, Fe, Mn, Cu, Zn, B, Cl, Mo and Ni essential for plant growth are supplied using different chemical combinations. Though numerous 'recipes' for hydroponic solutions are available but all combinations of chemicals reach to a similar total final compositions.

Plants need balanced nutrition and must be given as per stage of the crop and nutrient solutions must be prepared accordingly. The pH/EC must be monitored to ensure that there is no nutrient toxicity and salt stress at the roots.

Advantages of Hydroponics

- Use in places where in-ground, soil based, plant growth is not viable.
- Isolation from diseases and pests found in the soil.
- Direct and immediate control of nutrient content, salinity and acidity, and root zone environment.
- Higher and more stable yields as compared to other methodologies and crops grow two times faster as all the parameters are controlled in this.
- The amount of water required is approximately 20 times less compared to soil based techniques as water can be circulated.
- Used for cultivation of medicinal plants without losing its originality and medicinal values.
- This will decrease the necessity to relay on forest as the only source for herbal medicine.
- Less prone to weeds.
- No cultivation or preparation of soil before planting.
- It is also cost effective as nutrient can be preserved from leaching.
- This technique can be claimed as 100% organic as there is no requirement of pesticides if plants are provided sterile environment.
- Decreased use of hazardous pesticides.
- More predictable yield and time of harvest.
- This process is much less dependent of humans and labor requirement is also less.
- The plants grown through hydroponics are healthier and their nutritive value is also higher compared to soil based crops.
- Easy to harvest and require very less space (Savas, D. 2002).

Disadvantages of Hydroponics

1. Higher set up cost, relative to conventional production systems.
2. Higher level of operational skills, relative to conventional production systems.
3. Not economically viable for all crops.
4. Greater risk that crop will suffer nutrition problems.
5. System failure results in rapid plant death.
6. Requires constant attention and good technical knowledge about the subject. (Sonneveld, C. 2000) [57].
7. Hydroponically grown crops are prone to disease

infections if extra care is not taking. In the "open system," disease infection risk is considerably low because nutrient solution and water drain away freely living the crop root less prone to disease attack (Jensen, M.H. 1999) [27].

8. However, in contrary, crops grown under "closed system" are prone to disease infections because excess drain continuously flows through the roots of the plant in a circular pattern, once there is any traces of disease causative pathogen in the system, the whole plants may suffer terrific infection attack (Jensen, M.2013) [23].

How Hydroponics does impacts the Environment

- Increased water conservation
- No nutrition pollution is released into the environment because of the controlled system
- No pesticide damage
- Less land is needed
- Faster growth
- Makes greater use of natural resources
- Limits fossil fuel consumption
- With commercial hydroponics farming, there is less demand to clear the environment (Like Forest) for the farmland.
- Hydroponic cultures may supply also supplement in part the output of Forest nurseries for the trees which exhibit a very slow growth in nursery beds and also improves their quality (Wilde, S.A and Spridakis, D.E. 1967) [66].

Challenges in agriculture

- Marginalization of land holdings - Declining farm size and income
- Deteriorating soil health
- Depleting natural resource base particularly water, both ground and surface water
- Declining public investment in agriculture
- Shortage of Labour force
- Incomplete adoption of location specific cropping system
- Poor adoption of improved crop management practices
- Inadequate post-harvest technologies, uncertain market prospects and linkages

Hydroponics in Production of Green Fodder

This method of producing green fodder is highly feasible. 1 kg of grain can produce 6-10 kg of fodder sprouts. There is approximately 12% loss on dry matter basis due to consumption of carbohydrates to energy for germination and other metabolic activities for growing sprouts. The amount of sprouts produced/yield depends on the following factors:

1. Grain- Grain quality, variety and treatments
2. Environment- temperature, humidity and external infestations
3. Management of the system – water quality and pH, soaking time, nutrient supply, depth and density of the grains in tray and growing duration (Sneath and Mclntosh 2003) [55].

Another aspect of this method is the water use efficiency. This minimizes wastage and optimizes efficient water usage (Sneath and Mclntosh 2003) [55].

Several studies had been carried out with outcome favouring hydroponics as the best in terms of yield and quality with little efforts when compared with the conventional methods (Silberbush and Ben-Asher, 2001) [48].

Current Water Resource Usage- India vs World

The world uses 69 percent of its water resources for agriculture, India uses 83 percent. As the Indian Economy and its Population grows, there will be more need for water for Industrial and Domestic use, which will put a great strain on resources needed in agriculture. This means that Hydroponics is a better water saving technology.

Table 1: Comparison of Traditional and Hydroponics System of Production:

	Conventional	Hydroponics
Production duration	Seasonal	Year round
land use efficiency	Less due to Variation in soil fertility Competition with weeds	As no soil is used so no such problems thus there is high plant density
Soil degradation	High due to poor irrigation efficiency, high dosage of fertilizer and pesticides resulting in problems such as water logging and salinity	No soil is used in this system thus no damage is done to it.
Resource utility	More land, labour and capital is required	Efficient and profitable utilization of natural and artificial resources
Resource conservation	All natural resources such as water fertilizer are used in a non-cyclic way.	All natural resources such as water fertilizer are used in cyclic way
Competition with weeds	High competition	Little or no risk of weeds
Benefit cost ratio Source: HGTIPL, India	Less	High

Hydroponic agriculture: The global outlook

Main countries using hydroponics are Holland, Spain, Australia, USA, Italy, Canada, Mexico, and China. Even our neighbor Pakistan has adopted Hydroponics cultivation with major government support. Main crops are Cucumbers, Tomato, Lettuce, Strawberry, Herbs, Capsicums, cut flowers etc. Source: HGTIPL, India

Hydroponics in India

- India needs technology in agriculture that can contribute towards water savings, positive impact on food production and availability.
- In India, Hydroponics was introduced in year 1946 by an English scientist, W. J. Shalto Duglas and he established a laboratory in West Bengal. (Sardare and Admane, 2013) [39].
- A start-up called Future farm has the first and largest hydroponic farm in India (Chennai).
- Presently it is being practiced by some floriculturists in Gujarat, Maharashtra and Karnataka.

Market Analysis

- The Global hydroponics market has crossed USD 21203.5 million in 2016. The market is expected to register a CAGR of 6.5% during the forecast period, 2018 to 2023.

- Europe is traditionally the largest market that is implementing advanced techniques in hydroponics. Asia-Pacific forms the second-largest market for hydroponics, which is further expected to grow at a steadily during the forecast period.
- Global hydroponics market is segmented into the aggregate hydroponic system and liquid hydroponic system.
- The aggregate hydroponic system has the largest market share of 82.6%.
- Moreover, the market is expected to witness faster growth in case of liquid hydroponics system, which is expected to register a CAGR of 10.8%. Source: Mordor Intelligence (2018).

The advanced technology of hydroponic system is growing at alarming rate in the agricultural sector across all the Arabia peninsula countries, and no doubt it has the potential to dominate the future food production (Moustafa *et al*., 2011) [33]. The population keep growing and the land availability declines because of the pressure exerted from the construction of infrastructures coupled with the uncultivable of the arid lands. Due to these facts, the best alternative is to employ new technologies such as hydroponics in order to enhance food production (Belgacem *et al*., 2017) [3].

Conclusion

Hydroponics is a versatile technology, appropriate for both village production systems to high-tech space stations. Hydroponic technology can be an efficient mean for food production from extreme environmental ecosystems such as deserts, mountainous regions, or arctic communities. In highly populated areas, hydroponics can provide locally grown high-value crops such as leafy vegetables or flowers.Natural green fodder is the key to success of farming and reduces the cost of milk production. Due to non- availability of land and higher labour cost, hydroponics becomes the most viable and sustainable option for feeding of mulch animals with fixed output per day unlike soil based agriculture. The industry is expected to grow exponentially

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