Soilless farming – the next generation green revolution

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In recent years, due to a rapid increase in world population, many challenges have come to limelight. One of these challenges is the reduction in per capita land available for soil-based farming, which leads to other agricultural and environmental issues. Under these critical circumstances, it became necessary to develop advanced technologies and techniques to withstand the current situation. Although several works were carried out on cultivation of plants in soil and in vitro, few of these are concentrated on soilless cultures. Soilless agriculture is a new promising method for improving cultivation of different cash crops. Besides reservation and restoration of cultivation lands, soilless farming, especially close-loop system, has various advantages: it utilizes recycled fixed amount of water, saves 85–90% of irrigation water, can be implemented in areas unfavourable for ordinary farming, almost zero environmental pollution, better yield than conventional cultivation. In the present study, various techniques of soilless farming are elaborated and a basic design of eco-friendly soilless farming unit is proposed.

Keywords: Hydroponics, land conservation, nutrient, soilless culture.

SOIL is not necessarily required for plant growth. It only provides all the essential macronutrients and micronutrients for growth and development of plants. Soil-based conventional agriculture has drawbacks like wastage of irrigation water, large land requirements, use of large quantity of chemical fertilizers, soil degradation, etc.[1–6]. The requirement of large quantity of nutritional food to fulfil the high demand of the population world wide, justifies the priority of introducing new and advanced technologies and techniques in agriculture, which synchronize water and nutrient demand in order to achieve optimum yield. New modern agriculture system has several benefits like water efficiently, high yield, and under controlled environment it can be designed for crop production throughout the year[7].

Advanced agriculture technology including hydroponics, aeroponics and aquaponics culture techniques utilizes nutritive medium for plant nourishment[8,9]. On an average, hydroponics system consumes 10–20 times less water compared to soil-based cultivation systems. Earlier studies have shown that the yield of closed-loop soilless farming (hydroponics) increased by almost 5% compared to open system[10–12]. Cultivating plants without soil open the pathway to extensive research for the evaluation and popularization of alternative farming systems. The present study is an overview of the most widely used soilless farming systems and it also proposes a basic model for mass cultivation using hydroponics technology.

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Origin of soilless culture methods

Although soilless cultivation technology came into existence since ancient times, the first known publication was in 1627 by Francis Bacon in his book *Sylva Sylvarum*. In 1699, experiments on soilless culture (water culture) of spearmint were reported by John Woodward. Soilless culture gained its popularity in the 20th century when W. F. G. Berkeley (1929) used solution culture for production of agricultural crop. He also introduced the term hydroponics in 1937 from Greek words 'hydro' = 'water', and 'ponos' = 'labour' meaning culture of plants in water. A preliminary success of hydroponics culture was identified on Wake Island, where this technique was utilized for growing vegetables for travellers. W. J. S. Duglas during 1946 started hydroponics in India and established a laboratory in Kalimpong area, West Bengal and also wrote a book on *Hydroponics The Bengal System*. In India, crops such as potato, tomato, green bean, carrot, cucumber, etc. were successfully grown by soilless culture. NASA has recently developed controlled ecological life support system (CELSS) based on extensive hydroponic research[9,13].

Categories of soilless farming

Two types of soilless farming methods are widely used: (i) open farming culture and (ii) close farming culture[14].

Open farming culture

In this method, diluted nutrients are utilized for every irrigation pattern. The plants uptake nutrient solutions which are usually delivered by dripping system. Through this method adequate amount of nutrients are synchronized in the root zone. Few techniques of open soilless culture are given below.

Root dipping technique: Under this process, plants are cultured in pots having small holes at the bottom. These are filled with substrate medium like coconut fibre and are placed in a container having nutrient solution. Minimum 1–3 cm of the lower portion of the pots remain in close contact with the nutrient medium. Only few roots are partly submerged in the nutrient media and some just hang in the air. This is a simple and cost-effective system to cultivate small herbs or flowering plants.

Hanging bag technique: In this technique, long cylinder shaped polythene bags are utilized. These are closed at the lower end and connected to PVC pipes at the upper portion. These are hanged vertically above a nutrient supplement tank. Planting materials such as seeds, fruits, etc. acclimatized in netted pots are firmly pressed into holes on the hanging bags. A micro sprinkler is used to circulate the nutrient medium to the top of each hanging bag. The nutrient solution is proportionately spread inside the hanging bag by the sprinkler. The solution stock tank is placed at the bottom of the bag for collection of excess nutrient solution. Tubes that contain the nutrient solution should be black in colour to prevent mould growth inside. Using this technique, vegetables such as lettuce, climbers, small flowering plants, etc. are grown.

Trench method: In this method, small herbs and shrubs are grown on trenches constructed using bricks or concrete blocks on or above ground. To prevent the growth media from direct contact with the ground, the inner linings of trenches are covered with thick polythene sheets. The shape and size of the trenches vary from crop to crop grown in them. All nutrient supplements along with water are delivered through the dripping process. This system is suitable for growing herbs as well as tall vine plants.

Closed farming culture

In this technique, the diluted concentrations of nutrients are marked and balanced for reuse. It is difficult to maintain the calibration of nutrients in a hydroponic system as the dissolved supplements must be tested in a regular time interval to obtain better results. Closed farming models incorporate both primary as well as modern culture frameworks. Few techniques of closed soilless culture are given below.

Hydroponics technique: Vegetables, herbs, climbers and flowers are grown hydroponically. For growing plants hydroponically, inert media such as coconut fibre, rock pieces, etc. are used. The plants are fed with nutrient solution containing all minerals and nutrients. This system has a wide range of advantages which include high-yielding capacity, less pollution, better nutrient and water efficiency, etc. This method is highly beneficial which varies from simple setups to modern types[15].

Nutrient film technique (NFT): This technique was developed by A. Cooper in England during 1960s. NFT is an example of hydroponics system where the plant roots remain in contact with the nutrient solution.

In NFT, continuous supply of nutrient solution is maintained by submerged motor pump inside the culture vessel (Figure 1). Only air is used as a growing medium and plants are cultured inside containers with their roots hanging inside the nutrient media. As the solution remains in a continuous flow, there may be changes in the nutrient solution's salinity in comparison to the soil. One of its advantages is that plants can be grown in much higher salinity than soil-based cultivation[16].

Aeroponic technique: The aeroponics system is one of the most advanced types of hydroponics system (Figure 2). In this technique, the supplement solution is sprayed to create a fine mist around the root system inside the chamber. For growth of the plants, expanded polystyrene or other inert materials with holes are used. The roots of plants growing in the chamber are suspended in midair just below the panel and enclosed inside a spraying box. Just like other methods of hydroponics, a timer regulates the nutrient pump. However, in the case of aeroponics system, a short cycle timer is used to run the pump for 5–10 sec for every 2–3 min time interval. Mostly leafy vegetables like lettuce, spinach, etc. are grown through aeroponic culture. The most important advantage of this system is the utilization of minimum space. Through this culture system, plants can be grown on per unit floor area twice as compared to other systems. The major disadvantage of this process is that, if the nutrient spreading cycles are not working properly the roots will dry out rapidly, causing death of the plant.

Aqua agriculture (Aquaponics): In this technique (Figure 3) aquatic animals like fish, prawns, etc. are grown in water tanks in a symbiotic environment with combination of plants which are grown in hydroponics (Figure 3)[17,18]. The water from the tank gets cleaned and recycled back to the aquaculture system while moving through hydroponics system, whereas the byproducts are broken down by micro-organisms which live on the surface of the culture media and utilized by plants as nutrients.

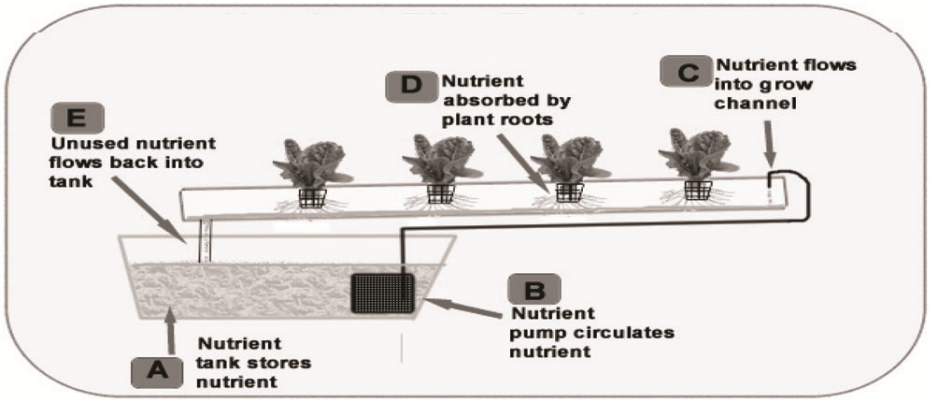


Figure 1. Nutrient film technique is simple yet advanced close soilless system where the plants are supplied with nutrients from the nutrient tank through pump circulation.

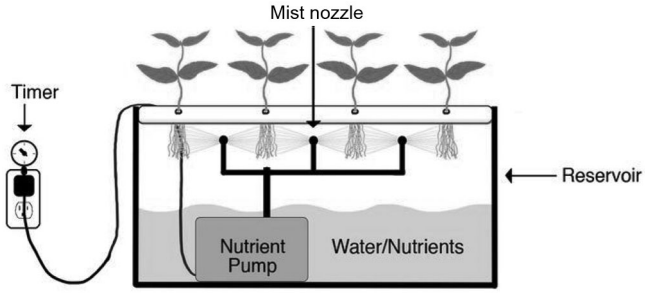


Figure 2. The plants in aeroponics system get nutrients from the thin mist formed by the sprayer at the root zone. The timer helps in maintaining the cycle of nutrient supply to the plants so that the roots do not dry up.

Important parameters in soilless farming

Nutrient solution

Soilless culture plants also need other essential elements (nitrogen, potassium, magnesium, calcium, sulphur, phosphorus, iron, copper, manganese, zinc, molybdenum, boron, etc.), which play important roles in plant growth and development. But the quantities of these nutrients required by particular plant species remain the same despite being cultivated on soil or in any soilless system. The soilless culture grower has the benefit of regulating nutrient concentrations in the solution for optimizing plant growth, proliferation and yield. This can also become one of the limitations of soilless farming as managing nutrients concentration in nutrient solution for different plants requires a couple of months of intensive training.

pH level

The availability of essential nutrients for plants is controlled by the pH of a nutrient solution. The pH of the nutrient solution ranges between 5.8 and 6.5 which is suitable for soilless cultures, but it mostly depends on the plant species to be cultured. If the pH of the nutrient solution is not regulated from the recommended range, it can create a barrier against the development of plants.

Electrical conductivity

The electrical conductivity (E_c) measured in dS/m represents the strength of nutrient solution. One of the drawbacks of E_c is, it indicates the concentration of the solution rather than the concentration of individual nutrient components. For hydroponics systems the ideal E_c ranges between 1.5 and 2.5 dS/m. Imbalance in E_c of solution can obstruct the uptake of nutrients by plants due to osmotic pressure, affecting plant growth and yield.

Large scale implementation of soilless agriculture

In the San Joaquin Valley of California while cultivating soil-based farming of tomato, the water used (kg tomato yield/m^3 water applied) in different irrigation methods were found to be 10–12 kg m^3 in flood method, 11–19 kg m^3 in sprinkler method and 19–25 kg m^3 in drip method[19,20]. However, with the implementation of hydroponic irrigation system where the unused water was not circulated for farming of tomato in the Netherlands and France, the water usage was found to be 45 and 39 kg/m^3 respectively[21]. While the water usage efficiency was found to be 66 kg m^3 in the Netherlands, it was 25 and 30 kg m^3 in the warmer climates of Spain and Italy respectively, where re-circulated water was used in closed irrigation system[22,23].

Letcetra Agritech is one of the indoor hydroponics farms present in India where pesticide-free, good quality vegetables are grown. It is located in Goa and produces leafy vegetables like varieties of lettuce and herbs over tonnes per annum. The Green SAGE which is initiated by

BitMantis helps individuals as well as small and large commercial growers to efficiently cultivate fresh herbs throughout the year. Green SAGE is a micro-edition kit that utilizes hydroponics techniques for efficient usage of water and nutrients. It is furnished with two different types of trays for growing green vegetables at one's own convenience. For developing soilless cultivation technology in India, Junga FreshnGreen which was started by Agritech has joined hands with InfraCo Asia Development Private Limited (IAD). A hydroponics-based agricultural facility at Junga in Shimla district, Himachal Pradesh was initiated under the Junga FreshnGreen project.

Future Farms located at Chennai develops kits to facilitate hydroponics that helps in effective and accessible farming of cleaner, fresher and healthier produce without causing environmental pollutions. The company initiates own systems and solutions made from premium, food grade products that are efficient and cost effective. It mainly focuses on rooftop farming and precision agriculture which are environment friendly. In Regional Plant Resource Centre, Bhubaneswar, India, germplasm collection of many endangered wild orchids varieties as well as many commercial orchids varieties are cultured in soilless pots.

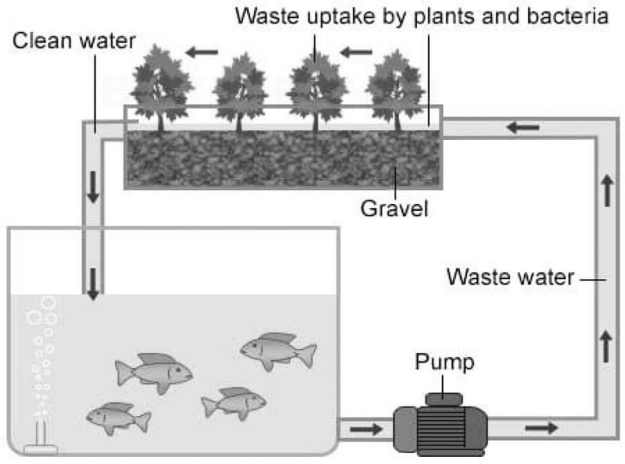


Figure 3. Aquaponics system established a co-relationship between soilless cultivation and aquaculture. Water from the water tank in which the fishes are grown is supplied to the plants as nutrition source which returns back after getting filtered.

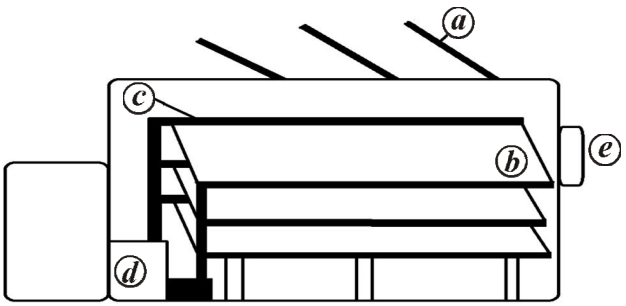


Figure 4. Basic design of eco-friendly soilless farming unit (EFSFU). ***a***, solar panels; ***b***, culture racks; ***c***, nutrient supplying system; ***d***, control panel; ***e***, air circulation system. The front entrance has an extra chamber to keep all sterilized tools, equipments and clothing.

Eco-friendly soilless farming unit

Eco-friendly soilless farming units (EFSFUs) are frameworks which can be established anywhere on a larger scale for mass cultivation of different crops (Figure 4). These units work on the principle of closed-loop hydroponics and aeroponics technology. It is eco-friendly as it uses solar energy to run the electrical equipments used in the units through solar panels attached on the roofs. The air flowing between the outer and inner environment will be filtered to prevent emission of greenhouse gases as well as entry of disease-causing pathogens. The units have a separate chamber at the entrance which contain sterile equipments to wear before entering the culture chamber. The plants will be cultured on inert natural media like coconut fibre, pebbles and sawdust or in artificial media like sponge, glass wool on a plastic platform slanted by 30°. This will make the nutrient solution flow downwards.

On the bottom of each rack, two rows of fluorescent bulbs/tubes are attached so that light is provided evenly to each corner. A supplement tank is attached to a corner of the unit from which the nutrient solution will be distributed through pipes connected to the top of each culture rack. At the bottom of each rack, there will be another pipe system to collect the excess nutrient solution. The pipes collecting excess solution are slanted at 10°–15° to prevent storage of solution in pipes which may cause contamination. The excess solution will be pumped back to supplement tank by passing through a filtering unit.

Conclusion

Soilless cultivation has many advantages and disadvantages, but with the gradual decline of arable land all around the world it becomes necessary to seek new alternate technologies for mass production of crop. Soilless farming may not seem significant at present but it has tremendous potential in the coming future. The technologies and techniques involved in soilless culture can be called as next-generation crop science because, if it is explored and evaluated properly it will open a doorway to establish a new civilization in outer space.

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