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Advances in soilless cultivation technology of horticultural crops: Review

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ABSTRACT

The burgeoning population and climate change posing a challenge to meet the sufficient and quality food, fodder and fuel demand in 2050.The cultivable land is also shrinking due to industrialization and urbanization as the availability was 0.50 ha in 1960 which has come down at 0.25 ha. The continuous intensive agriculture led to poor soil health. The demand of food, fodder and fuel is ever rising with rise in population therefore; it is very difficult to sustain supply with present cultivation practices under climate change regime. To overcome this problem, soilless culture is one of the best alternatives. Soilless culture is a novel methodology for growing of crops or plants without soil by using growing media which can be solid, liquid, organic or inorganic material. One of the major advantages of soilless media is saving of water up to 85-90%, as water is recycled and provide better yield as compared to conventional cultivation with almost zero environmental pollution. Plug tray nursery raising using soilless medium is being done on commercial scale at many places. Research on Soilless cultivation is being carried out at Indian Agricultural Research Institute, Pusa, New Delhi since 2016. Hydroponic has been emerged as a new technique to grow plants in recent era. Aeroponics is one of the most successful and rapid methods of seed potato production in which large numbers of mini tubers can be produced in one generation which reduces time and cost. Plants grown in soil less culture are of superior quality with high yield, rich in nutrient content and rapid harvest as compared to conventional cultivation/soil. The growing conditions are generally regulated resultantly a robust resilient production system may be developed for continued supply of vegetables/fruits/flowers, it can synergistically add in total production.

Keywords: Aeroponics, Growing media, Hydroponics, NFT, Soilless cultivation

Soil is natural growing media for plants. It gives support, nutrients, air, water, and so forth for plant growth and development (Ellis *et al*. 1974). However, sometimes soil possesses serious limitations for the growth of plant because of different biotic and abiotic factors. Some of them are the presence of soil borne diseases and insect larva in soil, poor drainage, soil erosion of topmost soil, unsuitable soil condition like high *p*H, high acidity, high alkalinity etc. In general, urban and peri-urban regions, soil is less accessible for crop growing or in certain territories, there is shortage of cultivable arable land due to their adverse or unfavorable geographical conditions (Beibel 1960). Under such conditions, soil-less culture can be practised effectively (Butler and Oebker 2006). Plug tray nursery raising using soilless medium is being done on commercial scale at many places in Indian urban and peri-urban areas by young eneterprenures (Singh 2018, Singh 2019). Soilless culture is the system of developing plants in soil-less condition having their roots inundated in nutrient arrangement (Maharana and Koul 2004). Generally, there is avoidance of cultural practices in soilless culture like soil cultivation, weed control etc. and unfavorable land can be used in soilless culture (Polycarpou *et al*. 2005). Plants grown in case of hydroponics had reliably predominant quality, high yield, short duration, and high nutrient content. This framework will face the difficulties of environmental change and furthermore helps proficient use of common assets and natural resources (Butler and Oebker 2006). Soilless culture can give significant pre-requisites to plant development with equivalent development and yield results contrasted with open field conditions. The aeroponic system is one of the most hi tech system of cultivation under soilless cultivation technology.

Soilless cultivation is considered as an advanced practice, however growing plants in containers over the ground has been attempted at different occasions all through the ages. A fine case of soilless culture is the hanging garden of Babylon. The most punctual distributed work on soilless culture came in 1627 by Francis Bacon who

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published the book Sylva Sylvarum. Later, water culture turned into a popular research technique. In 1699, work was done by John Woodward on spearmint by water culture experiments. By 1859-65, the German botanists Wilhelm Knop and Julius von Sachs developed soilless cultivation technique. It immediately turned into a standard research and technique is still broadly utilized today and is presently viewed as a kind of hydroponics. William Frederick Gerick Berkeley (1929) has utilized solution culture for different agrarian crop production for high yield. Gerick worked on mineral nutrient solution and twenty-five feet high tomato vines were successfully grown by him. He likewise coined the hydroponics term in 1937 to culture the plants in water. The nutrient film system is developed by Allen Cooper of England in 1937. The Land Pavilion at Walt Disney World's EPCOT Center established in 1982 is a successful example of hydroponic technique.

In India, English scientist W J ShaltoDuglas introduced the Hydroponics technique in India and established a laboratory in Kampong, West Bengal. Later, he wrote a book named as "Hydroponics". NASA has largely done research on hydroponics for CELSS (Controlled Ecological Life Support System) which is a device that converts waste material into food as well as in oxygen with the help of photosynthetic organisms and light energy for crew in space. Hydroponics proposed to happen on Mars by utilizing LED lighting to develop in different color spectrum with considerably less heat.

Rationale of soilless cultivation

i. Continuous decreasing cultivable area
ii. Reduction in soil fertility
iii. Better yield as compared to conventional cultivation
iv. Reduction in pest and diseases as compared to soil
v. Good quality produce

Growing media (GM): It is the most important part of the soilless cultivation. It is of different types and classified as under.

Classification of growing media

Growing media (GM) or "substrates" are characterized as every strong material, other than soil, which alone or in blends can ensure preferable plant development conditions over agricultural soil in one or numerous perspectives (Gruda *et al*. 2013). Mixture (GM constituents and additives) is generally used in horticultural industry. Additives include bio-control or wetting agents, liming materials and fertilizers while combinations of different materials are included in GM constituents. These could be of inorganic or organic material (Gruda *et al*. 2013). Nonetheless, for commercial vegetables production using soilless media, substrates such as coir, perlite or rock wool are used alone or in combination. All inorganic growing media originate from natural sources and only a part of them are subjected to industrial processing before their use. It may be natural (Gravel, Glass wool, Rockwool, Zeolite, Vermiculite, Pumice, Perlite) or synthetic (Foam mate {polyurethane}), Oasis (plastic foam), Hydrogel. Organic growing media can be natural organic matter, examples are wood-based substrates, peator synthetic, e.g. polyurethane. The most available organic materials are cocopeat (Singh 2018, Singh 2019), peat (Schmilewski 2009), composts (Raviv 2013), and wood residues (Gruda and Schnitzler 2004).

Important component of solid based soilless medium

Perlite: The most widely recognized type of media utilized in containerized frameworks of soilless culture is perlite (Boodley and Sheldrake 1977). Perlite granules are light which originate from a silicone mineral that is a part of volcanic eruption. It is essentially heat-expanded aluminum silicate rock. The volcanic ore is heated to extreme temperatures of about 1800^{O}F to cause the rock particles to expand and to produce the white granular product. It's role in a mix is to improve aeration and drainage. If this ingredient is used in a mix, the horticultural grade should be selected since it has larger particle size and is thus more effective. Perlite is neutral in reaction and provides almost no nutrients to the mix (except for small amounts of sodium and aluminum). A disadvantage of the use of perlite is its low weight, which makes it float when the medium is watered. During mixing, it produces dust, further, which can be eliminated by wetting the material before its use. This medium is accessible from traders in small to large bags for expansion to developing mediums to enhance aeration and drainage in the soil.

Coconut coir: It is known by different product names like cocopeat, coco-tekand ultra peat. It is a totally natural medium, produced using shredded coconut husks. Steam sterilized and shredded coconut coir offers plants a perfect establishing medium that additionally offers protection against growth and root ailments. Furthermore, in contrast to peat moss, which is quickly getting depleted from overuse, coir is a totally inexhaustible resource. It is prepared from the waste of coconut husk. This medium has good porosity, improved drainage and air movement activity. This medium is completely free from infestation of any pest or pathogen. Coco-peat is commonly being used as a medium under protected cultivation of ornamental crops like roses and gerberas and for raising the nurseries of vegetables and ornamental plants in the developed and developing countries

Vermiculite: The vermiculite is known as chemically hydrated laminar magnesium-aluminum-iron silicate. It can be used for improving the soil texture and enhance seed germination because of its good water-holding capacity and aeration.It is heat-expanded mica. This mineral is heated at a temperature of about 1400^{0}F (760^{0}C) to produce the folded structure associated with the material. It is very light in weight and has minerals (magnesium and potassium) for enriching the mix, as well as good water-holding capacity. It is neutral in reaction (*p*H), and available in various grades according to sizes. Grade 1 includes the largest particles and grades 4 and 5 are fine in texture. The most commonly used grades are 2 and 4. Its fineness, incidentally, makes it prone to being compressed easily in the mix. To reduce its potential, a mix including vermiculite should not be pressed down hard.

Peat moss: It is formed by decomposed mosses and other living material in peat bog. Different materials can be used to form peat, but a large percentage of peat is harvested which is composed of sphagnum moss. Hence, the name peat moss. Moisture is retained by the Peat moss in growing media. Tropical plants require additional moisture and warmness for proper growth and development.

Sphagnum moss: Its properties permit wide utilization in correcting overly moist and excessively dry soil alike. Use of sphagnum moss in heavy soils like clay helps in drainage and aeration so that clay does not absorb as much water and excess water may drain off. Light sandy soils benefit by sphagnum moss since it will hold moisture and nutrient by not enabling water to run off.

Classification of soil-less culture technique

Soilless culture is an artificial method that uses either organic or inorganic substrates and provides support to plants and reservoir for nutrients and water. A vessel of water containing inorganic chemicals is dissolved to supply all the required plant nutrients and is the simplest and oldest method for soilless culture. Hydroponics systems are further classified as open (i.e. can't recycle nutrient solution) or closed (i.e. solution can be recycled and reused) (Table 1).

Hydroponics/Solution culture/Liquid media culture

Circulating methods (closed system)
- Nutrient film technique (NFT)
- Deep flow technique (DFT)

Non-circulating method (open system)
- Root dipping technique
- Floating technique
- Capillary action technique

Table 1 Horticultural crops which can be grown in soilless Culture

Type of crop	Name of the crops
Fruits	*Fragaria ananassa* (strawberry), raspberry
Vegetables	*Capsicum frutescens* (chilli), *Lycopersicone sculentum* (tomato), *Solanum melongena* (brinjal), *Beta vulgaris* (beet), *Phaseolus vulgaris* (green bean), *Capsicum annuum* (bell pepper), *Psophocarpus tetragonolobus* (winged bean), Brassica oleracea var. *botrytis* (cauliflower), *Brassica oleracea* var. *capitata* (cabbage), *Cucumis melo* (melons), *Cucumis sativus* (cucumbers), *Allium cepa* (onion), *Raphanus sativus* (radish)
Leafy vegetables	*Lactuca sativa* (lettuce), *Ipomoea aquatica* (Kang Kong), amaranthus, spinach, celery, swiss chard, Chinese cabbage, kulfa etc.
Flower crops	Pansy, marigold, carnation, aster, lily, rose, anthurium, orchid etc.

Source: Singh *et al.* (2016).

Solid media culture (Aggregate system)

These can be open or closed system.

1. Hanging bag technique
2. Grow bag technique
3. Trench or trough technique
4. Pot technique

Hydroponics/Solution culture/Liquid media culture

Growing of plants in soilless culture by using water with required essential elements. In this method, roots of the growing plants are exposed to mineral solution continuously. Media like coco peat or gravel or perlite can be used to support the plant roots. Crops like lettuce and strawberry etc. are successfully grown in hydroponics.

Circulating type (closed system): In this type of method, the nutrient solution is pumped from the tank in installed frames and excess solution is collected from the outlets in the tank and on certain interval, replenished and reused.

Nutrient Film Technique : Nutrient Film Technique (NFT) is a true hydroponics system in which plant roots are directly exposed to continuously flowing nutrient solution. Constant flow of nutrient solution takes place in NFT system and there is no timer requirement for submersible pump. Pumping of nutrient solution is done in growing tube with the help of pump and flow over the submerged roots of the plants, and excess amount is drained out by outlet into the reservoir. Generally no growing medium utilized other than air, which results in saving the cost of replacing the growing media after every crop harvest. Normally, small plastic container is used to support the plants with root submerged in nutrient solution. Major drawback of this NFT system is susceptible to power interruption and pump failure. Because of pump failure or interruption in flow of nutrient solution, quick drying of roots takes place and leads to death of plant.

Deep flow technique (DFT)/Pipe system: The bottom portion of root touches deep nutrient solution which flows 2-3 cm through PVC pipes of 10 cm diameter. Rice husk, old coir dust or carbonized rice or mixture of both can be used as a mediain net pots. White paint which is generally used in PVC pipes to reduce the heating up effect of nutrient solution.

Non-circulating methods (open system): The nutrient solution is used only once not circulated. It is replaced, when concentration of nutrient decreases or change in pH or EC. This non-circulating system is of following types:

Root dipping technique: In this technique, small pots which filled with little growing medium are used for growing of plants. The pots are kept in the nutrient solution such that lower 2–3 cm portion of the pots is submerged. Some portions of roots are dipped for nutrient in the solution while other portion hang in the air for air absorption.

Floating Technique: This technique is similar to box method. But shallow containers of 10 cm deep can be used. Plants can be grown in small pots with Styrofoam sheet which is used to fix the plants and allowed the plants to float on nutrient solution and solution is artificially aerated.

Capillary Action Technique: Planting pots of different shapes and sizes with holes in the bottom of container are used. Inert medium is used to fill pots and seedlings or seeds are planted in medium and place these pots in shallow containers having nutrient solution. Due to capillary action, the nutrient solution reaches inert medium. Aeration is very crucial in this technique. Therefore, old coir dust in combination with gravel or sand can be used. This technique is more suitable for indoor plants and ornamentals.

Solid media culture/aggregate system

The material for media must be friable, flexible, with good air and water holding capacity. Additionally, it must be free from pests, diseases, toxic substances, nematodes, *etc*. The media must be sterilized before use. The following techniques can be practiced using available materials are:-

Hanging bag technique (Open system): This technique is also referred as 'Verti-Grow' technique. Long, thick cylinder shaped, UV treated polythene bags, filled with sterilized media, i.e. coconut fiber and tied at top with PVC pipe and sealed the bottom end of bag. The nutrient solution is pumped through a micro sprinkler which is attached inside the top of hanging bags and drips down wetting the media and plant roots. Excess solution is drained out through holes or outlet made at the bottom of hanging bags and finally back to stock tank. This system is more suitable for leafy vegetables (Singh *et al.* 2016). Black color tubes are generally used to supply nutrient solution to prevent mould growth inside.

Grow bag technique: In this technique, 1–1.5 m long white (inside black), 6 cm in height and 18 cm wide and UV resistant polythene bags having old, sterilized coir-dust are used. These bags are placed on the floor end to end horizontally in rows with walking space in between. Paired rows system can be used if number of plants are more. By making small holes on the upper surface of bag, squeeze seedlings in growing media or coir dust and 2-3 plants per bag can be established. Two small slits are made on each side of the bags for drainage or leaching. Fertigation is done to each plant with black capillary tube arrow drippers that connected with main supply line is practised. White UV resistant polythene is used to cover the entire floor before placing the bags (Singh and Patel 2018).

Trench/Trough technique: Narrow trenches are used in the ground or above the ground having troughs constructed with bricks or any concrete material. Both troughs and trenches are lined with material which should be waterproof so that it can separate the growing media from rest of the ground. The depth of trench varies and depending on the plants and a minimum requirement is of 30 cm. Old coir dust, peat, vermiculite, sand or gravel, perlite, old sawdust or mixture of these can be used as the media. The water and nutrient solution are supplied through drip irrigation system or by manual application which depends on labor availability. Excess nutrient solution is drained out from well perforated pipe of 2-2.5 cm diameter which can be placed at the bottom of the trench or trough. Additional support is required for tall growing vine plants like tomato, cucumber etc. to withstand the weight of the fruits.

Pot technique: Pot technique is similar to trough culture or trench but growing media for plants is filled in plastic or clay pots. Volume of the both container and growing media depend on the crop growth requirements. The range of volume generally is between 1 to 10 liters. Growing media provide support to plants (Singh *et al*. (2016).

Aeroponic

Aeroponics is the process of growing plants in which roots are suspended in air or mist environment in Styrofoam panels without the use of soil. The aeroponic system is most high-tech soilless technique of gardening. A sealed box is used to prevent light penetration which encourage root growth and also prevent growth of algae. Spraying of nutrient solution is done in fine mist form in sealed box. Misting is done for a short interval for every 2 – 3 minutes to keep roots moist. The plants obtain water and nutrients directly from the moist environment. The aeroponic culture is more suitable for leafy or low volume vegetables like lettuce, spinach etc. Maximum utilization of space is the principal advantage of aeroponics. Twice the number of plants per unit floor area can be accommodated in aeroponics as compared to other methods or techniques. ICAR-CPRI, Shimla, Himachal Pradesh has developed this technique for successful microtuber production in potato.

History of aeroponics

Concept of aeroponics is new and came in last century. The most successful crops grown by aeroponics is potato especially in Kufri (Shimla), HP, in India. In the early 1940s, this technique was mostly used for research purpose rather than economically practicable method of crop production. Air culture growing was first studied by Carter in 1942 and described a new method of growing plants to facilitate examination of roots in water mist. Fifteen years later, Went (1957) named the air-growing process and supply of nutrient solution in mist form as "Aeroponics". This technique is successful for the production of different vegetable crops like lettuce (He and Lee 1988, Cho *et al*. 1996), cucumber (Park *et al*. 1997) and tomato (Biddinger *et al*. 1998).

Important parameters for soilless farming

Nutrient solution: For soilless cultivation, 17 essential elements are required by the plants for their growth and proper development. Requirement of one element cannot be replaced by other nutrient. In the soilless cultivation, all the essential nutrients are supplied in the form of nutrient solution. Knowledge of different techniques along with nutrient solution and its management is essential for successful soilless culture gardening. One of the major advantages of soilless culture is that growers can provide the nutrient in balanced amounts which can reduce toxicity of nutrient in plants. Soilless culture plants reach at maturity much faster, as we supply the nutrients in ionic form and competition for nutrition is very less or nil as compared to

Table 2 Soilless culture (hydroponics) v/s ordinary soil yields

Name of crop	Hydroponic equivalent per acre	Agricultural average per acre
Soybean	1500 lb.	600 lb.
Potato	70 tons	8 tons lb.
Beet root	20000 lb.	9000 lb.
Cabbage	18000 lb.	13000 lb.
Cauliflower	30000 lb.	10-15,000 lb.
Cucumber	28000 lb.	7000 lb.
Tomato	180 tones	5-10 tones
Peas	14000 lb.	2000 lb.
French bean	42000 lb. of pods for eating	-
Lettuce	21000 lb.	9000 lb.

Source: Singh *et al*. (2012).

soil. Optimization of plant nutrition in soilless culture is easy as compared to soil.

pH level: The *p*H of solution indicates acidity or alkalinity on a scale of 1 to 14. The availability of essential plant elements is determined by pH in a nutrient solution. The optimum pH for soilless culture nutrient solution ranges between 5.8 and 6.5. Nutrient deficiencies will become noticeable or if higher the *p*H, toxicity symptoms will appear.

Electrical conductivity (EC): The electrical conductivity (EC) represents the strength of nutrient solution and measured in dS/m. One of the constraints of EC is that it specify the concentration of the solution in spite of concentration of individual nutrient components. The ideal EC for hydroponics systems ranges between 1.5 and 2.5 dS/m. Imbalance or varying in EC of solution can hamper the uptake of nutrients by plants due to osmotic pressure which affect the plant growth and yield.

Advantage of soil-less culture

Soilless culture put forward opportunities to provide most favorable conditions for plant growth, hence higher yields) can be obtained as compared to open field ordinary soil condition (Table 2) .Soilless culture is a good alternative to control pests and soil-borne diseases, which is chiefly desirable in tropics where threat of infestation is more because of continuous life cycle throughout the year. It is very effective in that area where arable land for agriculture is scare. It reduces the cost and time with respect to various tasks which are used in soil.

Limitation of soilless culture

Application of these techniques at commercial scale requires high initial capital investment, technical knowledge and skilled labor. This will be further high if the soilless culture is combined with controlled environment agriculture. High grade of supervision is necessary for maintenance of pH and EC, solution preparation, nutrient deficiency and correction, proper aeration etc. Finally energy inputs or constant electric supply are essential to operate the system properly (Van Os *et al*. 2002). Taking into account of high cost, the soil-less culture is restricted to high value crops.

Conclusion

Soilless culture is emerging technology using different new era tools and rapidly gaining momentum. As cultivable or fertile land is decreasing due to urbanization, road construction, over use of pesticides and poor land management etc. and increase in population, this is best alternative to meet the demand of the population. These techniques also help in conservation of water can be established in water scarcity area because water is recycled. As initial cost is high, this is a major constraint but in long term, it is much more feasible. The main bottlenecks in adopting these techniques are lack of knowledge, authentic information's and poor dissemination of technologies. One of the major advantages of soilless culture is to overcome the problem from soil born pathogen. Soilless culture are getting popularity in protected cultivation both in modern, fully equipped glasshouses and simple green- house constructions using different techniques and media aimed to utilize favorable climatic conditions. For production of good quality crops in future, soilless culture requires high quality as well as consumer-oriented growing media which also prevent environment issues and creates job opportunities. Hydroponic technology can be one of the efficient mean for crop production in extreme environmental ecosystems. Hydroponics can provide high-value low volume crops in highly populated area. Hydroponics can also play an important role in future space program. Government intervention and Research Institute attention can boost the use of this technology.

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