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A REVIEW ON PLANT WITHOUT SOIL - HYDROPONICS

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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. In 1960 with 3 billion population over the World, per capita land was 0.5 ha but presently, with 6 billion people it is only 0.25 ha and by 2050, it will reach at 0.16 ha. Due to rapid urbanization and industrialization as well as melting of icebergs (as an obvious impact of global warming), arable land under cultivation is further going to decrease. Again, soil fertility status has attained a saturation level, and productivity is not increasing further with increased level of fertilizer application. Besides, poor soil fertility in some of the cultivable areas, less chance of natural soil fertility build-up by microbes due to continuous cultivation, frequent drought conditions and unpredictability of climate and weather patterns, rise in temperature, river pollution, poor water management and wastage of huge amount of water, decline in ground water level, etc. are threatening food production under conventional soil-based agriculture. Under such circumstances, in near future it will become impossible to feed the entire population using open field system of agricultural production only. Naturally, soil-less culture is becoming more relevant in the present scenario, to cope-up with these challenges. In soil-less culture, plants are raised without soil. Improved space and water conserving methods of food production under soil-less culture have shown some promising results all over the World.

Index Terms: Aeroponics, hydroponics, nutriculture, open field agriculture, soil-less culture

1. INTRODUCTION

Soil is usually the most available growing medium for plants. It provides anchorage, nutrients, air, water, etc. for successful plant growth^[1]. 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.^[2] 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^[2]. 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^[2]. Of late, another serious problem experienced since is the difficulty to hire labour for conventional open field agriculture^[3]. Under such circumstances, soil-less culture can be introduced successfully^[3].

Soil-less culture mainly refers to the techniques of Hydroponics⁴ and Aeroponics⁵. The term Hydroponics⁴ was derived from the Greek words *hydro* means water and *ponos* means labour^[2]. It is a method of growing plants using mineral nutrient solutions, without soil^[2]. 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. Hydroponics is the technique of growing plants in soil-less condition with their roots immersed in nutrient solution.^[4] 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^[3]. Aeroponics⁵ is another technique, more or less similar to hydroponics with only difference that under aeroponics plants are grown with fine drops (a mist or aerosol) of nutrient solution^[1]. In India, Hydroponics was introduced in year 1946 by an English scientist, W. J. Shalto Douglas and he established a laboratory in Kalimpong area, West Bengal. He has also written a book on Hydroponics, named as Hydroponics The Bengal System⁶. 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.

2. DIFFERENT AVAILABLE TECHNIQUES FOR SOIL-LESS CULTURE

Large numbers of hydroponic/soil-less culture techniques are available. However, following factors are considered in selecting a technique:

1. Space and other available resources
2. Expected productivity
3. Availability of suitable growing medium
4. Expected quality of the produce – colour, appearance, free from pesticides, etc.

We can classify the techniques as follows:

2.1 Techniques of hydroponics

It is also known as Liquid Hydroponics' method. Plants grown in solution culture have their roots suspended directly in a nutrient solution. It can further be classified into-

i) Circulating methods (closed system)/ Continuous flow solution culture

- a) Nutrient film technique (NFT)
- b) Deep flow technique (DFT)



a)

b)

Fig 1. Different circulating methods (a) Nutrient film technique, (b) Deep flow technique [4]

Flowing solution culture systems can provide a consistent nutrient environment for roots. They are highly amenable to automatic control but are subject to rapid plant desiccation if the flow of solution stops for any reason. Thus frequent attention is required.

ii) Non-circulating method (open systems)/ Static solution culture

- a) Root dipping technique
- b) Floating technique
- c) Capillary action technique



Fig 2. Different non-circulating methods (a) Root dipping technique, (b) Floating technique, (c) Capillary action technique [4]

Suitable vessels for static systems include polythene beakers, pots, glass jar and containers lined with black polythene film.

B. Media culture

The media culture method has a solid medium for the roots and is named for the type of inert medium, e.g. sand culture, gravel culture or rock wool culture. There are two main variations for each medium, sub-irrigation and top-irrigation. However, it is classified as follows:

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



(a)



(b)



(c)



(d)

Fig 3. Different media culture method (a) Hanging bag technique, (b) Grow bag technique, (c) Trench or trough technique, (d) Pot technique [4]

2.2 Techniques of Aeroponics

Aeroponics is a method of growing plants where they are anchored in holes in Styrofoam panels and their roots are suspended in air beneath the panel. The aeroponics culture is

usually practiced in protected structures and is suitable for low leafy vegetables like lettuce, spinach, etc. There are two techniques under this group:

1. Root mist technique
2. Fog feed technique

2.3 List Of Crops That Can Be Grown In Soil-Less Condition

Condition

Everything starting from flower to fruit crops to medicinal plants can be grown using soil-less culture. List of crops are listed in Table 1, Table 2, Table 3.

Table1. List of crops that can be grown on commercial level using soil-less culture[5]

Type of crops	Name of the crops
Cereals	<i>Oryza sativa</i> (Rice), <i>Zea mays</i> (Maize)
Fruits	<i>Fragaria ananassa</i> (Strawberry)
Vegetables	<i>Lycopersicon esculentum</i> (Tomato), <i>Capsicum frutescens</i> (Chilli), <i>Solanum melongena</i> (Brinjal), <i>Phaseolus vulgaris</i> (Green bean), <i>Beta vulgaris</i> (Beet), <i>Psophocarpus tetragonolobus</i> (Winged bean), <i>Capsicum annum</i> (Bell pepper), <i>Brassica oleracea</i> var. <i>capitata</i> (Cabbage), <i>Brassica oleracea</i> var. <i>botrytis</i> (Cauliflower), <i>Cucumis sativus</i> (Cucumbers), <i>Cucumis melo</i> (Melons), <i>Raphanus sativus</i> (Radish), <i>Allium cepa</i> (Onion)
Leafy vegetables	<i>Lactuca sativa</i> (Lettuce), <i>Ipomoea aquatica</i> (Kang Kong)
Condiments	<i>Petroselinum crispum</i> (Parsley), <i>Mentha spicata</i> (Mint), <i>Ocimum basilicum</i> (Sweet basil), <i>Origanum vulgare</i> (Oregano)
Flower / Ornamental crops	<i>Tagetes patula</i> (Marigold), <i>Rosa berberifolia</i> (Roses), <i>Dianthus caryophyllus</i> (Carnations), <i>Chrysanthemum indicum</i> (Chrysanthemum)
Medicinal crops	<i>Aloe vera</i> (Indian Aloe), <i>Solenostemon scutellarioides</i> (Coleus)
Fodder crops	<i>Sorghum bicolor</i> (Sorghum), <i>Medicago sativa</i> (Alfalfa), <i>Hordeum vulgare</i> (Barley), <i>Cynodon dactylon</i> (Bermuda grass), <i>Axonopus compressus</i> (Carpet grass)

Table -2: Hydroponic averages compared with ordinary soil yields [5]

Name of crop	Hydroponic equivalent per acre	Agricultural average per acre
Wheat	5,000 lb.	600 lb.
Oats	3,000 lb.	850 lb.
Rice	12,000 lb.	750-900 lb.
Maize	8,000 lb.	1,500 lb.
Soybean	1,500 lb.	600 lb.
Potato	70 tons	8 tons lb.
Beet root	20,000 lb.	9,000 lb.
Cabbage	18,000 lb.	13,000 lb.
Peas	14,000 lb.	2,000 lb.
Tomato	180 tonnes	5-10 tonnes
Cauliflower	30,000 lb.	10-15,000 lb.
French bean	42,000 lb. of pods for eating	-
Lettuce	21,000 lb.	9,000 lb.
Lady's finger	19,000 lb.	5-8,000 lb.
Cucumber	28,000 lb.	7,000 lb.

Table- 3: Vegetable production under soil-less culture in India [5]

Vegetables	Production (g/m ² /day)
Carrot	56.5
Cucumber	226
Garlic	57
Ginger	57
Leek	57
Green Bean	113
Lettuce	226
Onion	56.5
Peapod	113
Potato	56.5
Salad greens	226
Tomato	113
Greens	113

Application of pesticides is generally avoided under hydroponics system. With reduced pest problems and constant feeding of nutrients to the roots, productivity in hydroponics is high, despite limited plant growth by the low levels of carbon-di-oxide in the atmosphere, or limited light[5]. To increase yield further, some sealed greenhouses inject carbon-di-oxide into their environment to help growth (CO₂ enrichment), or add lights to lengthen the day, control vegetative growth etc.

3. SUPPLY OF NUTRIENTS TO THE PLANTS

In hydroponics, because of limited nutrient-buffering capacity of the system and the ability to make rapid changes, careful monitoring of the system is necessary[5]. Two aspects of nutrition need to be considered: the supply of nutrients from

the nutrient delivery system and the plant nutrient response. For most common crop plants critical levels for most nutrients have been determined. Sources of nutrient elements with their characteristics are given in table 4.

Sources of nutrient elements

Table -4: Sources of nutrient elements with their characteristics [5]

Source	Element	Characteristics
Potassium nitrate KNO ₃	N, K	Very soluble salt
Potassium phosphate monobasic KH ₂ PO ₄	P, K	Corrects phosphorus deficiency
Magnesium sulfate MgSO ₄	S, Mg	Cheap, highly soluble, pure salt
Iron chelate	Fe Cit	Best sources of iron
Boric acid H ₃ BO ₃	B	Best source of boron
Calcium nitrate Ca(NO ₃) ₂	N, Ca	Very soluble salt

The frequency and volume of the nutrient solution applied depends on the type of substrate used (volume and physical-chemical characteristics), the crop (species and stage of development), the size of the container, the crop and irrigation systems used and the prevailing climatic conditions. Plants should be fed daily[5]. The best time to administer the nutrient solution is between 6.00 and 8.00 am, though water requirements will vary considerably throughout the day, and from one day to another. The solution should be applied to the roots, trying to avoid wetting the leaves to prevent damage and the appearance of diseases. Under no circumstances should plants be allowed to suffer from water stress, as this will affect their final yield[6]. It is generally recommended that you apply only water to the plants once a week, in order to flush away any excess salts that have remained. Use double the amount of water normally applied, but without adding nutrients. Between 20 and 50% of the solution should be drained-off to prevent the accumulation of toxic ions and an excessive increase of electrical conductivity in the root area[5]. The excess nutrient solution that is drained away from containers during daily watering can be reused in the next watering. At the end of the week, this liquid can be discarded. Flow chart of supply of nutrients to the plants under soil-less culture has been depicted below:

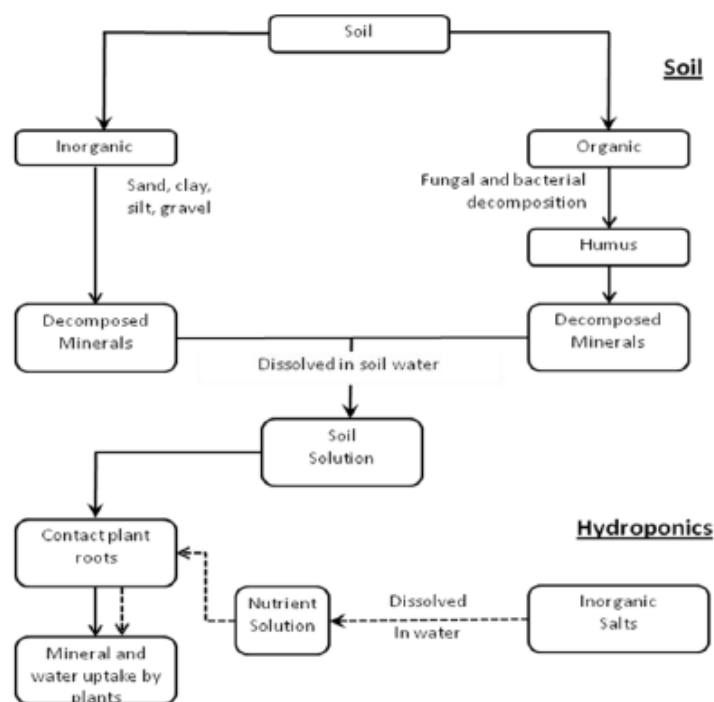


Fig- 4: Flow chart of supply of nutrients to the plants
(<http://cpamoneyshop.com/make-money-online-2/hydroponics>)

4. DESIRABLE pH RANGE OF NUTRIENT SOLUTIONS

In hydroponic systems, pH is constantly changing as the plant grows. Changes in pH of less than 0.1 unit are not significant[6]. Thus pH control is a necessity in hydroponic solutions. The pH range of 5.5 to 6.5 is optimal for the availability of nutrients from most nutrient solutions for most species, but species differ significantly and several can grow well outside of this range[6].

5. CONTROL OF CONTAMINANTS

Maintenance of sterile root-zone environment is essential to have good plant vigour under soil-less culture. It is extremely difficult to achieve and critical to minimize population of plant pathogens in the root zone[7]. Commonly encountered disease in hydroponic solution is wilt, caused by *Fusarium* and *Verticillium*. Species of *Pythium* and *Phytophthora* destroys all but the main roots. No effective fungicides are there which can be safely used in hydroponics[8]. Only Metalaxyl has been found highly effective for control of *Pythium* on vegetable crops, but it is not registered for the use. Heat treatment of nutrient solution has also been found effective in keeping the root-zone free of pathogens[7]. Root death of tomatoes by *Pythium* was overcome by heating nutrient solutions at 20-22°C. In aeroponic system with heated nutrient solution, the

roots of ginger plants matured faster and produced slightly higher fresh rhizome yields than plants in the same medium without bottom heat[5].

6. ADVANTAGES OF SOIL-LESS CULTURE

There are many advantages of growing plants under soil-less culture over soil-based culture[8]. These gardens produce the healthiest crops with high yields and are consistently reliable; gardening is clean and extremely easy, requiring very little effort[9]. Here nutrients are fed directly to the roots, as a result plants grow faster with smaller roots, plants may be grown closer, and only 1/5th of overall space and 1/20th of total water is needed to grow plants under soil-less culture in comparison to soil-based culture[9]. There is no chance of soil-borne insect pest, disease attack or weed infestation too. Overall soil-less culture provides efficient nutrient regulation, higher density planting, and leading to increased yield per acre along with better quality of the produce. It is also effective for the regions of the World having scarcity of arable or fertile land for agriculture[10].

7. LIMITATIONS OF SOIL-LESS CULTURE

Despite of many advantages, soil-less culture has some limitations[10]. Application on commercial scale requires technical knowledge and high initial investment, though returns are high[10]. Considering the high cost, the soil-less culture is limited to high value crops. Great care is required with respect to plant health control. Finally energy inputs are necessary to run the system[11].

8. FUTURE SCOPE OF THIS TECHNOLOGY

Hydroponics is the fastest growing sector of agriculture, and it could very well dominate food production in the future[3]. As population increases and arable land declines due to poor land management, people will turn to new technologies like hydroponics and aeroponics to create additional channels of crop production[4]. To get a glimpse of the future of hydroponics, we need only to examine some of the early adopters of this science[5]. 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[6]. 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[12].

Hydroponics also has been used successfully in Israel which has a dry and arid climate[11]. 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[11]. The hydroponics techniques produce a yield 1,000 times greater

than the same sized area of land could produce annually[12]. 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[5].

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[3-6]. 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[5-7]. Hydroponics has the ability to feed millions in areas of Africa and Asia, where both water and crops are scarce.

Hydroponics also will be important to the future of the space program[12]. 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[11]. As we haven't yet found soil that can support life in space, and the logistics of transporting soil via the space shuttles seems impractical, hydroponics could be key to the future of space exploration[11]. The benefits of hydroponics in space are two-fold: It offers the potential for a larger variety of food, and it provides a biological aspect, called a bio-regenerative life support system[12]. 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[5].

CONCLUSIONS

The industry is expected to grow exponentially also in future, as conditions of soil growing is becoming difficult. Specially, in a country like India, where urban concrete conglomerate is growing each day, there is no option but adopting soil-less culture to help improve the yield and quality of the produce so that we can ensure food security of our country. However, Government intervention and Research Institute interest can propel the use of this technology.

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