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5. Soil Less Cultivation: Aeroponics and Hydroponics

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Abstract:

Soilless cultivation methods, such as aeroponics and hydroponics, represent innovative and sustainable approaches to agriculture that have gained prominence in recent years. These techniques offer precise control over nutrient delivery and environmental conditions, resulting in higher yields, faster growth, and reduced resource usage. Aeroponics is a method that suspends plant roots in a mist or air environment, delivering essential nutrients directly to the roots. This minimizes water consumption and optimizes oxygen exposure for plants, promoting rapid growth and minimizing the risk of diseases. Hydroponics, on the other hand, involves cultivating plants in a nutrient-rich water solution, eliminating the need for soil. It provides efficient nutrient uptake, reduces soil-borne diseases, and allows for year-round cultivation. Both aeroponics and hydroponics are highly adaptable and suitable for a wide range of crops, making them ideal for urban agriculture and vertical farming. Their ability to minimize soil requirements, water usage, and pesticide dependence contributes to sustainable food production, addressing the challenges of a growing global population while reducing the environmental footprint of traditional agriculture.

Keywords:

Aeroponics, Hydroponics, Risk, Farming, Nutrients, Diseases, Environment.

5.1 Introduction:

With rising population and purchasing power, demand for food and changing consumer preferences are building pressure on natural resources. According to UN about 828 million people were affected by hunger in 2021, 46 million people higher than at 2019. Looking forward, projections are that nearly 670 million people (8 per cent of the world population) will be facing hunger in 2030 (FAO 2022). Until 2050 the number of people living in urban areas are estimated to rise to more than 6 billion (UN, 2013) and our growing population will require 60% more food than we are able to produce today [1, 2, 3]. All this while 1.3 billion tons of global food production is lost or wasted annually [4]. According to FAOSTAT, 2012 arable land is also finite and water is a scarce resource too. Therefore, there is a need to find agricultural technologies that have neutral or positive impact on our environment. Use of soilless farming methods like hydroponics and aeroponics holds the promise of addressing these issues by enabling more food to be produced with less resource use and sale of these crops directly in city community, reducing transportation as opposed to the standard rural farming methods. The crop grown in soil less system uses small land, less water gives more yield than the conventional agricultural methods [5] and produce is high in nutritional quality [6]. This system can help to face the challenge of climate change and also helps in mitigating malnutrition. In country like India and China, where urban conglomerate is growing each day, there is no option but adopting soil less culture to help improve the yield and quality of produce to ensure food security of country.

5.2 Soilless Cultivation:

Soilless cultivation can be defined as "any method which is used to grow plants without using soil as a rooting medium and the inorganic nutrients absorbed by the roots are supplied through irrigation water". The nutrient containing fertilizers to be supplied to the crop are dissolved in the appropriate concentration in the irrigation water and the resultant solution is referred to as "nutrient solution". In crops grown without soil, the plant roots may grow either in porous media (substrates), which are irrigated along with nutrient solution, or directly in nutrient solution without the requirement of any solid phase. Nowadays, supplying nutrient solution to plants to improve crop nutrition (fertigation or liquid fertilization) has become a routine cultural practice, not only in soilless cultivation but also in soil grown greenhouse crops. Hence, the less volume of the rooting medium and its uniformity are the characteristics of soilless cultivated crops differentiating them from crops grown in the fields. Another advantage of soilless culture is that different types of stresses (biotic and abiotic) could also be managed in soilless farming since it is a controlled system. This approach has various socio-economic advantages, along with the capacity to deal with rising global food challenges, malnutrition, efficient utilization and management of natural resources, hence conserve ecological sustainability with continuous year round provision of enough and hygienic food supply. It is an excellent cropping approach for nations which have limited arable land, constantly changing climate and increasing food challenges with indigenous population [7]. Several soilless methods had been adopted to cultivate the plants in a controlled environment. Although, soilless farming technology mainly focuses on hydroponics, aeroponics, aquaponics and solid media cultures [8]. There are various crops which can be grown in soilless cultures including cereals, vegetables, fruits, flowers, condiments, medicinal and fodder crops [9]. Crop cultivation in soilless medium has enhanced yielding and nutritional capacity [10, 11, 12, 13, 14] which could easily serve as a measure to overcome the global threat of food security and malnutrition.

5.3 History of Soilless Farming:

The history of soilless farming dates back to past civilizations; however, adequate information is not available due to various reasons. However, there are various prime examples, including Aztecs and Egyptian hieroglyphics and hanging garden of Babylon, which reveals that soilless farming was followed in many ancient civilizations. However, the earliest published work on growing terrestrial plants without the use of soil was in 1627 in a book named Sylva Sylvarum by Sir Francis Bacon, father of the scientific method, which he nominated it “water culture”. Later in 1699, John Woodward proposed a more comprehensive publication concerning water culture. He concluded that the plants/vegetables cultivated in less pure water grew better than those planted in distilled water, which he ascribed to certain minerals in water derived from soil. Due to this, this soil-water mixture became the first human made hydroponic nutrient solution [15]. His research was followed by the majority of European plant physiologists in order to build various grounds. They proved that plant roots absorb water and nutrients, transferring through the stem and water escapes into the atmosphere via leaves and draws carbon dioxide from the air. Therefore, following the advancement, remarkable breakthroughs were accomplished in laboratory studies of plant physiology and nutrition between 1800s and 1920s. Later in 1937, Professor William Frederick Gericke gave the term “hydroponics” to describe crop cultivation with roots dipped in a nutrient solution. In 1940, he authored “Complete Guide to Soilless Gardening” and despite its limitation of being concerned with water only and his work is considered the foundation for all forms of hydroponic growing. Furthermore, Hoagland solution, which is being used in the current era, was developed by two plant nutritionists named Dennis R. Hoagland and Daniel I. Arnon at the University of California. As science progressed, more new and sophisticated approaches were developed, and one among them to soilless farming was the use of growth medium with alternate flooding and draining of both nutrients and air, which was pioneered by Robert B. and Alice P. Withrow. The practice of cultivation without soil (hydroponically grown vegetables) was also used to feed the passengers on a ship sailing in Pacific Ocean during 1930. Furthermore, in 1945, the United States Air force established one of the largest hydroponic farms on the Island of Hawaii. W. J. Shalto Duglas, an English scientist, introduced the hydroponic technique in India followed by the establishment of a laboratory in West Bengal. He even authored a book named “Hydroponics-The Bengal System”. As soilless cultivation gained popularity due to increased scientific acceptance coupled with technological advancement, commercial farms were established in numerous countries between 1960-70, including Abu Dhabi, Arizona, Belgium, California, Denmark, German, Holland, Iran, Italy, Japan, Russian Federation and others [7]. This lead to establishment of various computerized and self-automated hydroponics farms around the globe, as well as the widespread availability of hydroponic kits. NASA has conducted a lot of important hydroponic research in Arizona, Euro fresh Farms in Willcox for their Controlled Ecological Life Support System to grow plants in space [16, 17]. The Arizona farm hydroponically produced more than 200 million pounds of tomatoes [18] with no pesticide residues. In Canada, hundreds of acres of land are dedicated to commercial hydroponic greenhouses that produce tomatoes, peppers cucumbers and a variety of other vegetables [15]. Lately, many commercial firms have created AI-supported software to monitor and control the hydroponic system through mobile phones via the internet or Bluetooth facility [19].

5.4 Types of Soilless Cultivation:

There are two types of soilless vegetable cultivation system.

i) Open soilless cultivation system
ii) Closed soilless cultivation system

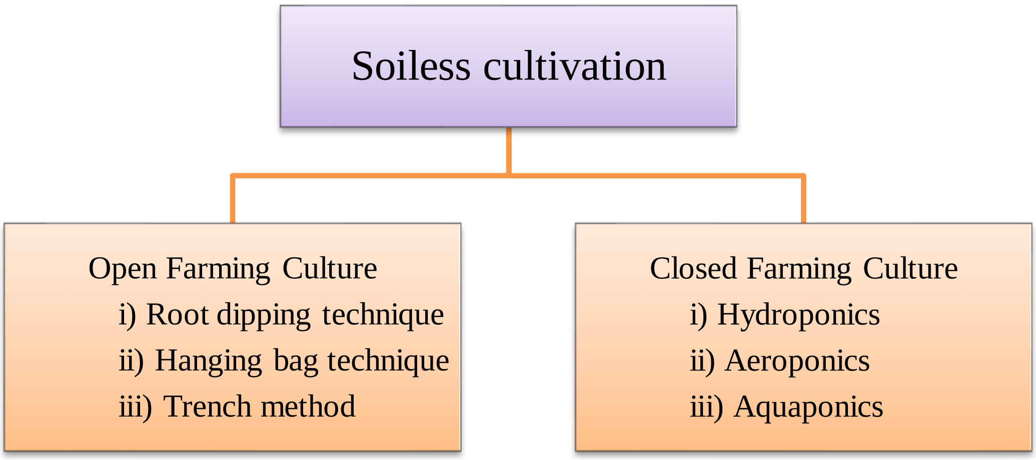

Figure 5.1: Classification of soilless culture systems

5.4.1 Open Soilless Cultivation System:

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

A. Root Dipping Technique: In this technique, plants are cultured in pots having small holes at the bottom. Pots are filled with substrate medium like coconut fibre and are placed in a container having nutrient solution. A minimum of 1-3 cm of the lower portion of the pots remain in close contact with the nutrient medium and only some of the roots are partly submerged in the nutrient media and rest just hang in air. This is a simple and cost-effective system to cultivate small flowering plants and small herbs.

B. Hanging Bag Technique: Under this technique, long cylinder-shaped polythene bags are utilized which are closed at the lower end and connected to PVC pipes at the upper portion. These are hanged vertically hanged above a nutrient source tank. Planting materials such as seeds, fruits, etc., which have previously been acclimatized in netted pots are pressed into holes on the hanging bags. Nutrient medium is circulated to the top of each hanging bag with the help of micro sprinkler. The nutrient solution is evenly spread inside the hanging bag by the sprinkler. The solution source tank is placed at the bottom of the bag to collect excess nutrient solution. Tubes that contain the nutrient solution are black in colour to prevent mould growth inside. This technique has been utilized in vegetables such as lettuce, climbers, small flowering plants, etc. are grown.

C. Trench Method: This method is used to grow small herbs and shrubs on trenches constructed using bricks or concrete blocks on or above ground. The inner linings of trenches are covered with thick polythene sheets to prevent the growth media from coming in direct contact with the ground. The shape and size of the trenches varies from crop to crop. All nutrient supplements along with water are delivered through the dripping. This system is suitable for growing herbs and tall vine plants.

5.4.2 Closed Soilless Cultivation System:

In this system, the diluted concentrations of nutrients are marked and balanced for using again and again. Closed farming models include both primary and modern culture frameworks. Few techniques of closed soilless culture are as follows:

A. Hydroponics: In this system, vegetables are growing without soil. Simply, it is defined as growing of vegetables in water. In hydroponic system the roots receive a balanced nutrient solution dissolved in water with all the chemical elements essential for the development of plants that can grow in a mineral solution only. This system has a wide range of advantages like high yielding capacity, less pollution, better nutrient and water efficiency, etc.

B. Aeroponics: In this system vegetables are grown in air and the roots of the crops are hanging in air. For nutrient solution reservoir, sealed root chambers are used which are covered with polystyrene or other material. Nutrient solution misting is done every few minutes around the root zone of the plant with the help of water pump [20]. It needs a short cycle timer that runs the pump for a few seconds every couple of minutes so a timer is fitted at the side of tank to control the nutrient pump much like other types of hydroponic technique. If the misting cycles are interrupted, roots will dry out rapidly because the roots are hanging out in the air. This system runs on three types of frameworks, the first framework is high pressure which don't generally used a water pump. The second framework is low pressure framework known as soakaponics. The water and nutrient solution is simply stream out of the sprinkler i.e. mister heads (more water pressure) by using standard submersible water pumps. The third framework is ultrasonic foggers that creates a fog.

C. Aquaponics: Aquaponics is a type of soilless culture where aquaculture in integrated with hydroponics for the purpose of producing both fish and vegetables in a synergistic environment [21], where the nutritious fish water is supplied to hydroponic system and nitrifying bacteria transform ammonia into nitrates. The closed circulation system leads accumulation of aquatic effluents, arising from leftover feed or rearing animals such as fish, which in turn becomes hazardous to aquatic animals in high proportion; however, it contains nutrients required for plant growth. A pump is used to extract the water from the fish tank and deliver to the plant growing container through a biofilter where nitrifying bacteria can grow and toxic compounds are broken down. The beneficial bacteria like *Nitrosomonas sp.* and *Nitrobacter sp.* convert ammonia to nitrites and nitrites are converted to nitrates through metabolic process, respectively [22]. This ammonia conversion is one of the significant activities in an aquaponic system since it minimizes the toxins for fish and permits the associated nitrate compounds to be assimilated for plant sustenance. The water is then cleansed and oxygenated before being returned to the aquaculture section, and the cycle continues. Many plants are suitable for aquaponics depending on the nutrient requirement of the plants. Green leafy vegetables having low to moderate nutritional demands thrive in less fish density and other plants with high nutrient requirement needs greater fish densities.

There are different types of fishes that can be widely cultivated along with plants and are classified as air-breathing and water breathing fish. Some of the air-breathing fishes used are Anabas, Pangasius and gourami. Water breathing fishes used are Tilapia, Red-bellied natter, rohu, mrigal and catla. Even ornamental fishes can be grown in an aquaponics system and high yield can be obtained from both fish and plants [23]. Aquaponics system can ensure food security in urban area by cultivating vegetables where space is not sufficient and also where scarcity of fertile land, soil degradation, are and lack of freshwater and problematic soil [24, 25]. India, Israel, China and Africa are the emerging aquaponic leading nations [26].

5.5 Components of Soilless Cultivation:

5.5.1 Growing Medium:

Growing medium used is soilless cultivation is other than soil which is inert and non-organic material. It should have good water holding capacity, porosity and many other properties. It provides support for the plants for proper growth and development. There are various mediums used such as coco coir, hydroton, perlite, vermiculite, peat moss, saw dust, rock wool, coarse sand etc.

A. **Coco coir:** This medium has excellent moisture holding ability and inert characteristics. It is made from a brown husk of coconut shell. It is sold in small compressed packets which expand 6 to 8 times in volume when water is added. Though it has good aeration property however, it has certain disadvantages too such as it breaks down after several use and cannot drain out excess water quickly.
B. **Hydroton:** It is most versatile growing medium in soilless crop production. It is an expanded clay product and has a porous structure which makes it easy to absorb water and other nutrient solution, easy in exchange of Oxygen with roots. It is a pH neutral product and is good for crop growth.
C. **Perlite:** It is inert material having light weight and is inexpensive growing media. It is made by heating it expands like popcorn. It is porous and has good water retention properties so keeps plants more open to air. It cannot be used alone as it float away or move during the flooding cycle.
D. **Vermiculite**: It is natural lightweight mineral which is used as growing media in soilless cultivation. It is rot resistant growing medium. Continuous soil aeration helps to improves soil structure, also increases water and nutrient retention.
E. **Peat Moss:** Peat moss is made from sphagnum moss that is decomposed in peat bogs over thousands of years. It is dark brown fibrous product of other organic materials. It can hold moisture several times its weight and releases slowly to the plants roots.
F. **Sawdust:** It is made from wood and produced by sawing. It is 100% natural, eco - friendly and easily available soilless growing medium.
G. **Rockwool:** It is inorganic soilless growing media which is made into matted fibre. It is used especially for insulation and soundproofing. It can withstand extremely high temperatures since; it is fire resistant as well as noise resistant. It is more expensive than other medium and different from other insulating materials.
H. **Coarse Sand:** It is a sand particle having a diameter of 0.5- 1 mm. It is used in soilless mixes. It doesn't retain water but it improves drainage and aeration.

I. **Pea Gravel:** It is a small piece of stone having size of the size of a pea. It improves drainage, prevents weed growth and controls erosion as well.

Table 5.1: The percentage potential yield for different hydroponic soilless media as compared with sand as control substrate

Substrate	Potential Yield (%)
Perlite	112
Sand	100
Perlite and Peat (1:1)	106
Sand and Peat (1:1)	106
Sand, peat and perlite (1:1:1)	109
Rockwool	107
Coco peat	105

5.5.2 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.

The solution provided should be directly available to the roots, although it is advisable to avoid wetting the leaves in order to reduce damage and the occurrence of diseases. Under no circumstances should the plants suffer from water stress, as this impairs growth [27].

To conserve resources, the excess nutrient solution drained from the containers during daily watering should be reused during the next watering. However, excess nutrient solutions should be monitored for the growth of algae and the development of other undesirable organisms and should be disinfected as and when necessary, before reuse.

5.5.3 pH Level:

The availability of essential nutrients to the 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.

5.5.4 Electrical Conductivity:

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

5.5.5 Biological Properties:

A substrate needs to be free of pests and pathogens. Weeds should be biologically stable and non-toxic. The use of forest products as well and under decomposed compost is partly problematic with regard to the associated phytotoxicity. For example, high potassium and manganese content [28] or the presence of phenolic compounds [29], terpenes, organic acids and fatty acids [30] can lead to toxicity [31]. Methods such as composting, aging, washing, leaching and mixing have been used to reduce or eliminate phytotoxic substrate properties [29,32]. Furthermore, different structures and stabilities can be attributed to mineral and organic substrates, which in turn, influence the functionality of the bacteria [33].

Table 5.2: List of crops that can be grown on commercial level using soil-less culture

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

Source: Maharana and Koul (2011) [34]

5.6 Aeroponic System:

Aeroponics is the process of soilless cultivation of plants by suspending them in air or mist. Plant roots are brought in direct contact of air and are timely misted or sprayed with a nutrient solution or aerosol of nutrient solution. The word aeroponic is derived from the Latin word 'aero' which means air and 'ponic' which means labour/work. Aeroponics differs from both hydroponics and aquaponics in a way that in both these systems plants utilise high amount of water for their growth however in aeroponics plants do not require water as the key requirement. Plants which grow in soil are at high risk of improper growth due to vagaries of the environment and at the same time they are more prone to pests and diseases. In turn, the indiscriminate use of pesticides and fertilisers affects the quality of the soil and the final produce. Many plants die or yield less due to insufficient growing space and overcrowding of plants. Due to these shortcomings of using soil as a medium of growing plants we are slowly approaching towards techniques like aeroponics. Another remarkable advantage of aeroponics is the minimal contact between the support structure and plant which allows unconstrained growth of the plant and there is never an issue of insufficient oxygen.

5.6.1 History:

Different methods of growing plants without soil were developed in 1920s primarily as a research tool to study plant root structure and development [35]. W. Carter in 1942 was the first person who researched about air culture growing and elaborated a method of delivering nutrients to plant roots via water vapour to facilitate their examination. In 1944, L.J. Klotz discovered vapour misted citrus plants in research of his studies on diseases of citrus and avocado roots. The first known commercial aeroponics setup was the Genesis Rooting System, commonly known as the Genesis Machine, by GTi in 1983. The device was controlled by a microchip and connected to an electrical outlet and a water tap. Since 1990s, aeroponics has been widely used in NASA space research programmes since a mist is easier to handle than a liquid in a zero-gravity environment.

5.6.2 Types of Aeroponics:

A. **Low-pressure units**: In most of the low-pressure aeroponic units, plant roots are suspended above a source of nutrient solution or a channel connected to a source. The nutrient solution is delivered through a low-pressure pump via jets or ultrasonic transducers, which drip or drain the nutrients back into the source. These units lack the ability to purify the nutrient solution, remove debris and unwanted pathogens. They are usually suitable for bench top growing and for the demonstration of principles of aeroponics.

B. **High-pressure units**: In high-pressure aeroponic devices, mist is created via a high-pressure pump. They are generally used in the cultivation of high value crops. and include technologies for air and water purification, nutrient sterilization and low-mass polymers.

C. **Commercial system**: The commercial system utilizes high-pressure device hardware along with biological systems. An enhancement for extended plant life and crop maturation is included in the biological systems matrix.

5.6.3 Components of Aeroponics System:

A. **The Reservoir:** This is where all the water and the nutrient solution is stored. It is a closed-loop system in which the nutrients not absorbed by the plants get circulated back into the reservoir to be re-sprayed.
B. **Water/Nutrient Pump:** At the base of the reservoir is a water pump that is used to pump the water through the pipes to the misting nozzles.
C. **Repeat Cycle Timer:** Used to control the amount of water dispersed in the reservoir.
D. **Misting Nozzles:** Different aeroponic systems have a different number of misting nozzles used inside the chamber. The best range is between 5 and 50 microns for the water droplets. The finer the droplets the better the plants can absorb them.
E. **Net Cups /Growth Chambers:** Separation of the plant roots from the plant tops is done using a lid with precisely cut holes to insert net cups that are used as growth chambers.

5.6.4 Working of Aeroponics System:

Aeroponic system is a never-ending process in a limited space and therefore it reduces agricultural labour. The basic principle of aeroponics is to grow plants suspended in a closed or semi-closed environment by spraying the plant's hanging roots and lower stem with an nutrient-rich water solution. This set up includes an optimized monitoring and control system for water and nutrients distribution. A distribution system includes pipes, spray nozzles, pump and a timer to distribute a spray of nutrient solution from the storage tank.

A programmable cyclic timer triggers the high-pressure aeroponic pump to go on. Nutrients are mixed with water in a storage tank, which is then filtered and pumped into a pressurized holding tank that is intermittently misted on to the root system. Developed root hair help in absorbing nutrients from the moisture making it easier to administer nutrients various to the plant via the root system. Misting is done every 2-3 minutes around the growing roots and the roots dry out quickly if the misting cycles are interrupted. The rooting chamber must be kept lightless so that the roots remain in darkness and algal growth is inhibited.

The droplet size of a nutrient mist is a vital element. An oversized droplet may reduce the supply of oxygen and an undersized droplet might stimulate root hair growth thus preventing lateral root growth. The water droplets must be big enough to efficiently carry the nutrients to the roots, but small enough to not immediately precipitate out of the roots. Unused solution drips down into the base of the unit and is further strained, filtered, and pumped back into the source.

5.6.5 Nutrients used in Aeroponics System:

Carbon, oxygen and hydrogen are present in air and water. Along with them, the water may contain a number of primary nutrients such as nitrogen, phosphorus and potassium, secondary nutrients like calcium, magnesium and sulphur and various micro-nutrients like iron, zinc, manganese, molybdenum, boron, cobalt, copper and chlorine. Roots utilize nutrients present in water as positively charged cations like ammonium or negatively charged anions like nitrate [36].

Nutrients mainly used in aeroponics:

Nutrient	Concentration (g/L)
N-NH_4	0.54
P	0.40
N-NO_3	0.35
K	0.35
Ca	0.17
Fe	0.09
Mg	0.08
Na	0.04
B	0.03
Zn	0.03

5.6.6 Water used in Aeroponics:

Water to be used in aeroponics should have a low EC, not exceeding 1mS/cm.The optimum pH for plant growth is between 5.8 and 6.3. Water should be free from biological contamination. Water from wells located near urban areas, is likely to be contaminated with coli form bacteria including Pectobacterium, therefore, water obtained from suspicious sources should be made to undergo microbiological analysis. In case no alternative is available, water should be boiled before use.

5.6.7 Plant Material used in Aeroponics:

Generally, in- vitro plants are preferred in aeroponics due to sanitary reasons. Plants need to be handled with proper care by experienced technicians. These plants should be the optimal age and size and should undergo an acclimatization period before going into the greenhouse. Planting materials such as rooted cuttings and tuber sprouts should be clean and free from diseases. The presence of any sign or symptom of a disease should be sufficient enough reason to discard the whole batch of plants.

Table 5.3: Basic monitoring and control parameters in the aeroponic system.

Parameters	Common value	Instruments
Nutrient atomization	Mist/spray/aerosol/droplet size at high pressure from 10 to 100, low pressure from 5 to 50, and ultrasonic foggers from 5 to 25 microns, respectively	Atomization nozzle (high and low pressure, atomization foggers)
Growing medium	Plant holder	Any artificial root supporting structure
Desirable pH of the nutrient solution	The pH value depends on the cultivar (onion 6.0–7.0, cucumber 5.8–6.0, carrot 5.8–6.4, spinach 5.5–6.6, lettuce 5.5–6.5, tomato 5.5–6.5, and potato 5.0–6.0)	pH measuring device
Desirable EC of the nutrient solution	The EC value depends on the cultivar (onion 1.4–1.8, cucumber 1.7–2.2, carrot 1.6–2.0, spinach 1.8–	EC measuring device

Parameters	Common value	Instruments
	2.3, lettuce 0.8–1.2, tomato 2.0–5.0, and potato 2.0–2.5 ds·m−1)	
Humidity	Provide 100% available moisture	Humidity measuring device
Temperature	Optimum 15° C–25° C and should not increase to 30° C and less than 4° C	Temperature measuring device
The light inside the box	The light inside the growth box must be dark enough	Cover the growth chamber with locally available material
Atomization time	Depends on the cultivar growth stage	Manually operating the system with timer
Atomization interval time	Depends on the cultivar growth stage	Manually operating the system with timer

5.6.8 Some Key Benefits of Aeroponics:

a. **Year-round cultivation**: Since the crops are grown in a controlled environment they can be grown throughout the year.
b. **Less water requirement**: Plants require less water in comparison to hydroponics.
c. **Faster plant growth**: Plants grow faster as their roots have access to a lot of oxygen.
d. **Reduced Disease Damage**: Since the plants are grown separately from each other an infection in one plant has a much lower chance of spreading to the other plants.
e. **Easy maintenance**: In aeroponics only the container housing the roots requires regular disinfecting,
f. **Mobility**: Plants, even whole nurseries, can be moved around effortlessly.
g. **High educational value**: Plants growth analysis in laboratories is easier.
h. **Easier fruit harvest**: Fruits produced through this system are easier to harvest.

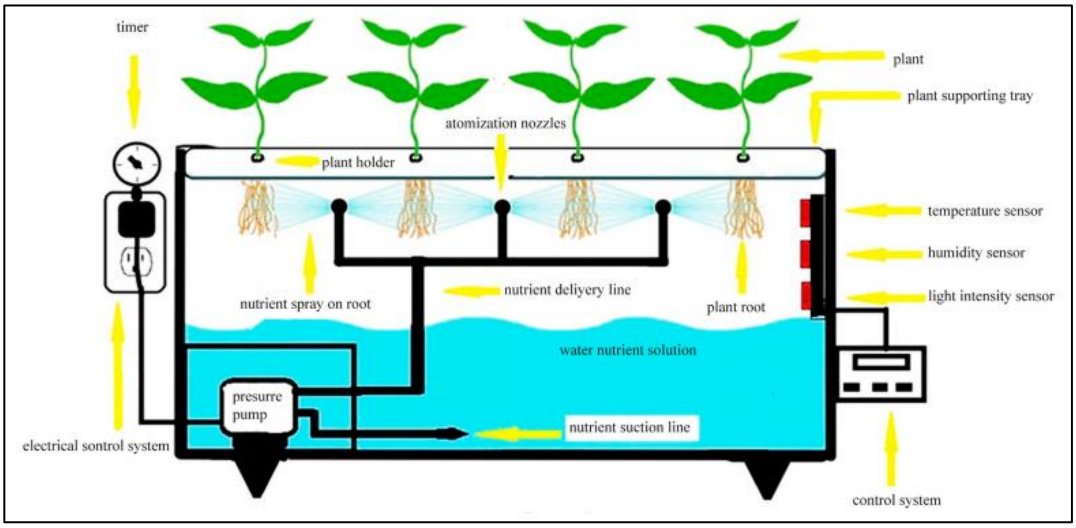

Figure 5.2: Aeroponics plant growing system

5.6.9 Disadvantages of Aeroponics:

a. High initial cost and expensive for large scale production.
b. Ordinary farmers cannot manage all these sophisticated instruments.
c. Knowledge of nutrients amounts required by various crops is essential.
d. Mister spray heads may get clogged and not produce mist when needed.
e. For a long time period power loss may cause irreversible damage.
f. Poor sanitary conditions can lead to diseases in plants.

5.7 Hydroponics System:

The word 'Hydroponics' was coined by Dr. W.F. Gericke in 1936 to describe the cultivation of edible and ornamental plants in a solution of water and dissolved nutrients. This word is derived from Greek word ‘Hydros’ (water) and ‘Ponos’ (working). Soilless culture/cultivation is a broader term than hydroponics. It can be rightly said that Hydroponics is always soilless culture but not all soilless culture is hydroponics. Hydroponics uses less than 1/10th - 1/5th of the water used in soil culture.

Hydroponics was practiced many centuries ago in Amazon, Egypt, Babylon and even in China and India. The “hanging Garden of Babylon” and the “Aztec’s floating farms” were actually types of hydroponic systems. Later, when plant physiologists started to grow plants with specific nutrients for experimental purposes, they used the name “nutriculture.” In 1929, Dr. William F. Gericke of the University of California succeeded in growing tomato vines which were about7.5 m in height in nutrient solutions. During 1990s home hydroponics kits became popular.

It is one of the most used soilless farming techniques where plants are cultivated using mineral nutrient solutions. The nutrient solutions used contain precise quantities of fertilizers required for a particular plant [37] and inert materials supplied with nutrient solution are also used for root growth [38, 39].

Hydroponics has been used effectively to raise a wide range of crops including lettuce, cucumber, tomato, herbs and many kinds of flowers [40]. Hydroponics has several benefits over traditional cropping methods, including rapid growth, higher productivity, efficient water use [5] and reduced fertilizer use [41].

In addition, roots do not have to search for mineral elements, and crops can grow closer together, leading to increased output from less space [42]. As a result, it is increasingly being adopted by commercial industries to enhance the production. The nutrient concentration of solution is managed and monitored to detect the symptoms and nutrient deficiencies or toxicity in the plant system [43].

Additionally, this approach has a tendency to eradicate the soil-borne biotic and abiotic stresses [44]. Therefore, it becomes financially viable and lucrative, while simultaneously laborious for large areas. Hydroponics has proven to be extremely beneficial in toxicological investigations on the build-up of numerous toxins in plants, in the execution of scientific research on native and exotic crops for economical or therapeutic uses, and also in conventional crops such as vegetables and ornamentals. Therefore, the combination of all the benefits makes hydroponics system more productive than soil based cultivation system. The global hydroponic market was of a value of 9.5 billion USD in 2020 and is anticipated to account for USD 17.9 billion by 2026, increasing at cumulative annual growth rate (CAGR) of 11.3% during the forecasting period [45]. This rise in hydroponic sector can be ascribed to increased acceptability of controlled environment agriculture.

5.7.1 Basic Requirements of Hydroponics:

These include Nutrient solution, Temperature, Air, Supporting materials, Water, Mineral nutrient, Light and most important Growing media like Saw dust, Bark, Chips, Straw, Gravel, Rockwool, Perlite, Sand and vermiculite etc.

- **A. Growing Chamber:** In this chamber, plant roots are grown that provide plant support, as well as access to nutrient solution. Here the roots are protected from light, heat, and pests. It is important to keep the root zone cool and light proof as prolonged light will damage the roots and high temperature will cause heat stress. This in turn will affect the growth of plant and there would be increase in drop of fruits and flowers.
- **B. Nutrient Reservoir:** Nutrient reservoir stores solution that consists of plant nutrients (salts, minerals, hormones) dissolved in water. Depending on the type of hydroponic system, the nutrient solution is pumped from the reservoir/source up to the growing chamber where the roots are present in cycles using a timer, as well as continually without a timer, or the roots can even hang down into the reservoir 24*7, making the reservoir the growing chamber also. Reservoir need to be light proof to discourage the growth of algae and micro-organisms that begin to grow in even low light levels.
- **C. Submersible Pump:** It is used to pump nutrient solution from the reservoir to the growing chamber. These are of wide variety of sizes depending upon the size (length and breadth) of overall hydroponic system. To avoid any contamination, it should be taken all apart on regular basis and cleaned thoroughly, both the pump and filter.
- **D. Management of Nutrient Solution in Hydroponics:** All essential nutrients (macro and micro) are supplied to the plants in the form of nutrient solution, which consists of various fertilizer salts dissolved in water. The success or failure of hydroponic techniques depends primarily on the strict nutrient management programme. The pH level of nutrient solution, temperature, electrical conductivity (EC) and replacing the solution whenever necessary should be carefully manipulated. The pH of a nutrient solution from recommended pH range, the greater the odds against the success. The ideal EC range for hydroponics is between 1.5 and 2.5 dS/m. Higher EC prevents nutrient absorption due to osmotic pressure and lower EC severely affect plant health and yield of plant.
- **E. Preparation of Nutrient Solution:** Though growers can individually formulate their fertilizer mixtures to prepare nutrient solutions using completely water soluble nutrients salts, a number of formulations are present in the market to choose from. However, some fertilizer salts react with each other and produce insoluble precipitates. Phosphate fertilizers act problematic in the presence of high calcium and magnesium concentrations which causes precipitation of low soluble phosphates. Therefore, selection of fertilizers should be such that they are compatible with each other.

5.7.2 Types of Hydroponic System:

A. Wick System:

Wick system is the most basic form of hydroponic system which contains no mobile parts and does not require electricity nor uses water circulation pump [46]. Hence, the nutrient solution is not recirculated but instead the plants absorbs solution via capillary action of the roots and fibres [47]. It is quite useful in areas with negligible or no access to electricity. The wick is a component, connecting the potted plants and nutrition, aiding in the circulation of nutrient solution to the root zone. An outcome of a study revealed a significant effect of this system on plant height, leaf number, leaf area, dry weight, harvest index and fresh weight in *Brassica chinensis* [48]. However, it is not suggested for long-term cultivation [49].

Advantages:

- **Simple:** Wick system can be installed by anyone and does not require to much attention after it is running
- **Space efficient:** This system can be installed anywhere as they do not require electricity to operate.

Limitations:

- Lettuce and various fast-growing herbs like rosemary, mint, and basil do not demand large quantities of water. Tomatoes, on the other hand, find it difficult to thrive in a this system because of their high demand for nutrients and water. Other plants cannot thrive in an environment that is moist all the time. Root vegetables like carrots and turnips do not succeed in a wick system.
- **Susceptible to rot:** A hydroponic wick system always remains humid and damp. This creates a risk of fungal outbreaks and rotting of roots.

B. Water Culture or Deep-Water Culture (DWC):

In this technique seedlings are immersed in nutrient rich, fresh water, and plants acquire the required nutrition for their growth and development. Rectangular containers of 10-20 cm depth filled with nutrient solution are used, containing seedlings hovering in panels on the surface [50]. Hence, it is often referred as deep flow technique, floating raft technology or raceway. It is mostly used to grow short-term, leafy greens and herbs.

The oxygenation is achieved through the use of an air stone connected to an air pump, which generates bubbles and oxygenates the surrounding water, and (or) by using appropriate amounts of hydrogen peroxide (H_2O_2). In order to optimize growth, the concentration of oxygen, conductance, and pH must be maintained [51], as plants grow & utilize resources, the pH and EC of the water fluctuates. Therefore, regular surveillance is required since nutrient availability to plants is dependent and would be impeded if the pH is too high or low. Lettuce, Chinese cabbage, spinach, and other vegetables are commonly cultivated in this framework.

Advantages:

- **Low maintenance:** Once a DWC system is set up, it requires very little maintenance. Its operations are easy just replenish the nutrient solution when needed and make sure pump is running oxygen to the air stone. The nutrient solution typically only needs replenishing every 2-3 weeks, but this does depend on the size of plants.
- **DIY appeal:** Unlike many hydroponic systems, deep water culture systems can be made cheaply and easily at home, with easily available air pump and nutrients.

Limitations:

- Herbs and lettuce can be grown successfully but they struggle with larger and more slow-growing plants. DWC systems are not ideal for anything that flowers.
- **Temperature control:** It's important that water solution does not exceed 68°F and does not go below 60°F. In a DWC system, water is non circulating and static, so it becomes more difficult to regulate temperature.

C. Ebb and Flow system:

This method is comparable to the trickle system utilizing an identical set of containers. Ebb and Flow are two tide phases, with Ebb being the exiting period when water drains and Flow being the entering period when water rises again. The pots contain an inert material that acts as a transitory reservoir of water and aqueous mineral nutrients. A pump is used to flood the system periodically with nutrient solution for a brief period of time (5 to 10 minutes), submerging the roots before turning off the pump to allow the system to drain. This result in the provision of the nutrients to plants and the solution is re-circulated. The rate of flooding the system depends on the medium's water retentive capacity. The highly retention media require only one flooding a day, whereas others necessitate 2 to 6 flooding per day, with every "flood" round lasting merely few minutes. Therefore, the quality of medium determines the plant growth and success of this system. All sorts of vegetables can be grown and is also appropriate for crops with enormous root balls [52].

Advantages:

- **Versatility:** In ebb and flow system, you can grow much larger plants than in most other hydroponic systems. Fruits, flowers and vegetables respond very well to ebb and flow hydroponic system.
- **DIY appeal:** Easy to setup as material used for construction is easily available in market.

Limitations:

- **Pump failure:** Hydroponic system is reliant on a pump, if the pump ceases to work, plants die. Proper monitoring of ebb and flow system should be done to ensure that the system's performance is not compromising the health of plants. If the water is rushing in and out too fast, plants will not receive an adequate amount of water and nutrients.

- **Rot & disease:** Sanitation and maintenance are essential in ebb and flow system. If the bed is not drained properly, root diseases and rot can set in. A dirty ebb and flow system can grow mold and attract insects. If cleanliness is neglected, crops suffer. Additionally, some plants do not respond well to the rapid pH change that occurs as a result of the flooding and draining extremes.

D. Drip Hydroponic System:

In this approach, the system is built using two containers, one at the top and another at the bottom, with vegetables grown in the top container and nutrient solution kept in the bottom container. As the name implies, it uses small emitters to deliver the solution directly to the plants. The water is pumped from the reservoir via main line, and further divided into lateral lines that run directly alongside plants. Hence, it is also called trickle or micro irrigation system. Oxygenation of water is achieved by using an aquarium stone [38]. There are two types of drip system such as recirculating or recovery system and non-recovery or non-circulating system. When water is delivered to the artificial medium, the roots do not absorb all of it. Therefore, the excess water in recovery method is permitted to drain back into the tank, but excess water in the non-recovery system is permitted to run off as waste. Although drip systems are relatively conservative, the magnitude of wastage is generally small, making it very appealing to commercial growers since it requires minimal reservoir management. Conclusively, a drip system is a diverse and practical approach of hydroponics. It is appropriate for wide range of plants and herbs and provides greater regulation of water and fertilizer delivery.

Advantages:

- **Variety:** A drip system can easily support much larger plants than most other hydroponic systems. This is one of the reasons it is so famous between commercial growers. Melons, pumpkins, onions, and zucchinis can all be easily supported by a properly established drip system. Drip systems hold greater quantities of growing media than other systems, allowing them to support the larger root systems of these plants. Drip systems work best with slow draining media, like rockwool, coco coir, and peat moss.
- **Scale**: Drip systems can easily support large-scale hydroponics operations. If a grower desires to add more plants, new tubing can be connected to a reservoir and divert solution to the new vegetation. New crops can be introduced to an existing drip system, as additional reservoirs can be added with differing timer schedules tailored to fit the needs of the new plants. This is another factor that makes drip systems popular commercial hydroponics.

Limitations:

- **Maintenance:** There is a significant amount of maintenance involved if non-recovery drip system is used. Consistent monitoring of pH and nutrient levels in solution, draining and replacing if necessary. Recovery systems lines can also become clogged by debris and plant matter, so regular washing and flushing of delivery lines has to be done.

- **Complexity:** Drip systems can become elaborate and complex to handle. This matters less for professional hydroponics, but it is not the most ideal system for home growers. There are many much simpler systems, like ebb and flow, that lend themselves better to at-home hydroponics.

E. Nutrient Film Technique (NFT):

NFT is a closed hydroponic system designed by Allan Cooper in England in the 1960s. In this method, dissolved nutrients in a solution are circulated through the bare roots of plants as shallow stream of water in a watertight gully, known as channels. The depth of the circulating flow is quite shallow not more than a thin film of water, ensuring the root mat developed at the bottom of channel receives an appropriate air exposure. A thin layer develops on the roots, from where the plants acquire required oxygen and nutrients [53]. Upon comparison to the protected soil-based growth system, NFT has proved to be an effective hydroponic approach that provided nutritionally improved and greater harvests [14]. Some main advantages of NFT over other systems are the absence of substrate and the reduced volume of nutrient solution required, resulting in significant savings in water and fertilizers and reduced environmental impact and costs related to the disposal of the substrate. On the other hand, owing to the low water volume, the nutrient solution is subjected to major temperature changes along the channel and during growing seasons. Moreover, NFT has very little buffering against interruptions in water and nutrient supplies, and there is a considerable risk of the spread of root-borne diseases. Technically most crops could be grown in a NFT system, but it works best for short-term crops (30-50 days), such as lettuce, because plants are ready to harvest before their root mass fills the channel.

Advantages:

- **Low consumption:** NFT hydroponic system recirculate the water hence, they do not demand large quantities of water or nutrients to function. The constant flow also makes it harder for salts to accumulate on the plant's roots. Nutrient film technique systems also don’t require growing media, so no extra expense of purchasing media and the hassle of replacing it.
- **Modular design:** Nutrient film technique systems are perfect for large-scale and commercial endeavours. Once one channel is set up and functioning, it is very easy to expand. Greenhouse can be filled with multiple channels supporting different crops. If each channel is fed with a separate reservoir, then if pump failure occurs or disease spreads in the water, complete loss of operations can be avoided.

Limitations:

- **Pump failure:** If the pump fails and the channel is no longer circulating the nutrient film, plants in system will dry out. In a matter of hours entire crop can perish if it is not being supplied with water.
- **Overcrowding:** If the plants are spaced too close together or the root growth is too proliferate, the channel can become clogged. If the channel is obstructed by roots, water will be unable to flow and your plants will starve. This is especially true of the plants at the bottom of the channel.

Table 5.4: The optimum range of EC and pH values for vegetables grown in hydroponics crops [9]

Crops	EC (dSm-1)	pH
Asparagus	1.4-1.8	6.0-6.8
Bean	2.0-4.0	6.0
Broccoli	2.8-3.5	6.0-6.8
Cabbage	2.5-3.0	6.5-7.0
Celery	1.8-2.4	6.5
Cucumber	1.7-2.0	5.0-5.5
Egg Plant	2.5-3.5	6.0
Leek	1.4-1.8	6.5-7.0
Lettuce	1.2-1.8	6.0-7.0
Pak Choi	1.5-2.0	7.0
Peppers	0.8-1.8	5.5-6.0
Parsley	1.8-2.2	6.0-6.5
Spinach	1.8-2.3	6.0-7.0
Tomato	2.0-4.0	6.0-6.5

Table 5.5: Composition of Modified nutrient solution

Compounds		Concentration of stock solution (mM)	Vol. of stock solution per litre of final solution (ml)
Macronutrients	KNO_3	1000	6
	$Ca(NO_3)_2.4H_2O$	1000	4
	KH_2PO_4	1000	2
	$MgSO_4.7H_2O$	1000	1
Micronutrients	KCL	25	
	H_3BO_3	12.5	2
	$MnSO_4.H_2O$	1.0	
	$ZnSO_4.7H_2O$	1.0	
	$CuSO_4.5H_2O$	0.25	
	MoO_3	0.25	
	Fe Na EDTA	64	1

Advantages of Hydroponics:

- Crops can be easily grown where non-productive land exists or where the soil is contaminated with disease.
- Labor cost for tilling, cultivating, fumigating, watering, and other traditional practices is minimized.

- Maximum yields are obtained, making the system economically feasible in high-density and expensive land areas.
- Conservation of water and nutrients

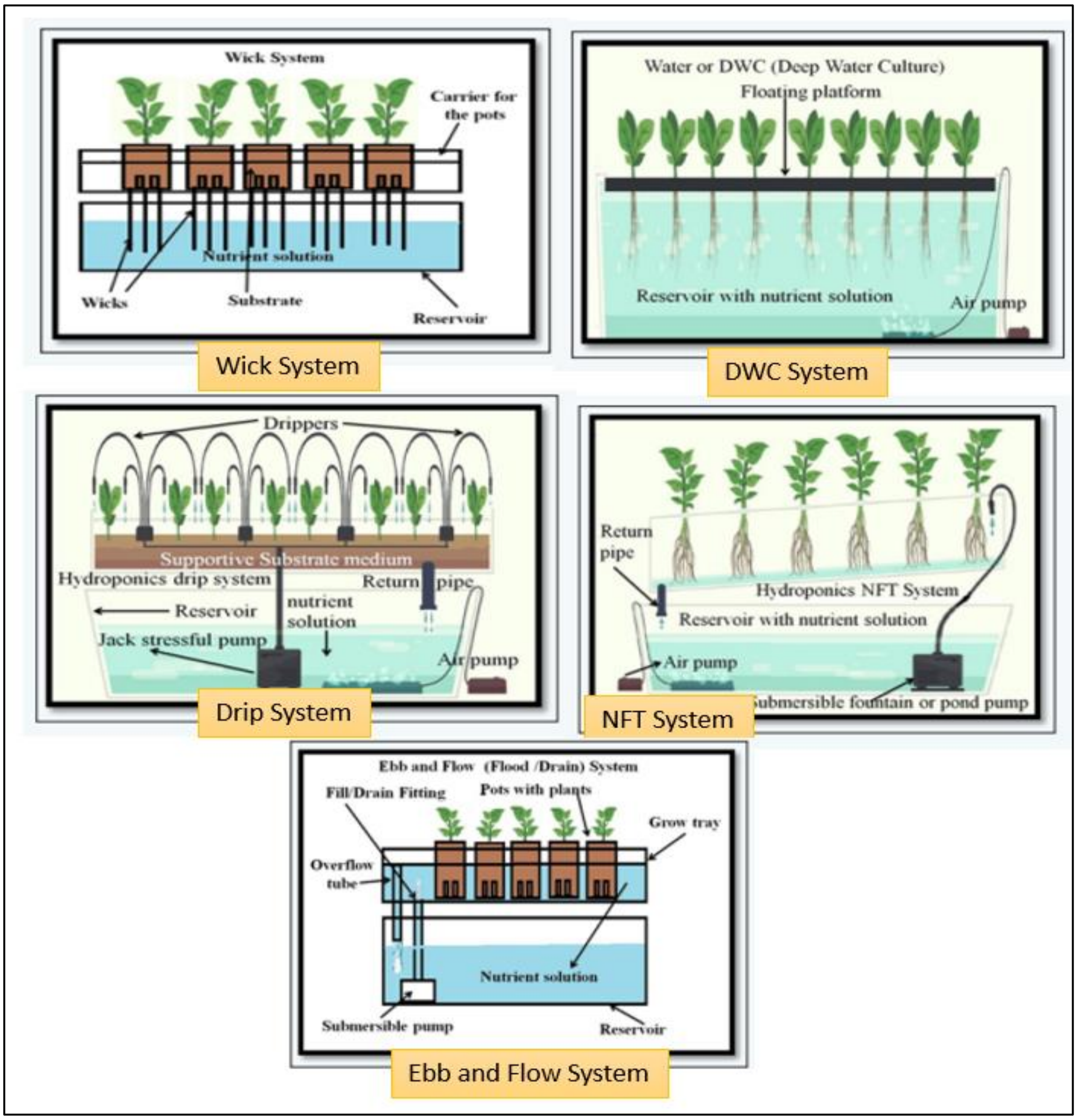

Figure 5.3: Different Hydroponic Systems

- Soil-borne plant diseases are more readily eradicated and managed in closed systems.
- Complete control of the environment (i.e. root environment, timely nutrient feeding, or irrigation), and in greenhouse type operations, the light, temperature, humidity, and composition of the air can be manipulated.
- Having direct access to the water and nutrients, plants grown in hydroponic system does not need to develop large root systems and will therefore offer the grower a shorter harvest time.

Disadvantages:

- High cost of construction.
- Trained personnel are required. Knowledge of how to grow plants and of the principles of nutrition is important.
- Soil-borne diseases and nematodes may spread to all beds on the same nutrient tank of a closed system very quickly.
- More research needed for development of varieties that can be grown successfully in hydroponic system.
- Require daily attention.

Similarities and Differences between Aeroponics and Hydroponics:

Aeroponics vs hydroponics they are both equally efficient at crop production without the use of a soil medium to turn out higher yielding, healthy and fresh produce. Although aeroponics and hydroponics are similar in the way that both uses nutrient-rich water, yet they are distinctly different. Hydroponics uses a media other than soil that retains and distributes nutrient rich water evenly to the plants, whereas aeroponics uses a misting system to deliver these nutrients.

Aeroponics succeeds more in vertical growing arrangements and uses space efficiently. Both Hydroponic and aeroponics promote self-sustainability in an environmentally friendly way. Hydroponics uses only 10% of water resources when compared to conventional methods giving the grower complete control over nutrient delivery. In aeroponics there is virtually no growing medium used and a nutrient rich solution is sprayed onto the root system and thereby providing maximum nutrient absorption to plant. Aeroponics system requires constant attention but hydroponics system may be easier for beginners. However, both systems are much more efficient than soil-based agriculture, and both of them have provided flexibility to control the irrigation schedule and nutrient applications.

Aeroponics systems can reduce water usage by 98 percent, percent, fertilizer usage by 60 and pesticide usage by 100 percent, all while maximizing crop yields. Plants grown in the aeroponics systems uptake more minerals and vitamins, making the plants healthier and potentially more nutritious There are a few other advantages aeroponics has when compared to hydroponics. One of these is that the plants can be transplanted more easily, since they don't suffer from transplantation shock. Aeroponics also allows easy observation of plants directly without disturbing them, which allows easy adjustment of the nutrient mix used. Under the hydroponic system the nutrient solution is passed between plants, it is possible for water-based disease to travel rapidly between them. Also, hydroponic systems, including aeroponics, rely on electricity and require costly generators as a back-up to cover up for power outages. Hydroponic systems can also be expensive to set up due to the nature of the equipment involved. However, once the system set up have been completed, it is cheaper than a conventional farming to operate. Since the plant roots are isolated and there is no planting medium under the aeroponics system, plants that are grown with this suspended, misted system will get maximum nutrient absorption. Aeroponics are sensitive and require constant attention to pH and nutrient density ratios. Aeroponics systems are favoured over other methods of hydroponics because the high aeration of nutrient solution provides more oxygen to plant roots, stimulating growth and preventing pathogen spread. The deciding factors in choosing one method over the other are the ancillary benefits. For certain hydroponic systems, this includes greater buffering capacity and room for error [54].

Difference between aeroponics and hydroponics

	Aeroponics	**Hydroponics**
Roots	Remain suspended in air or in an enclosed environment. Plants are able to directly absorb nutrients from water vapour and remain oxygenated.	Immersed in a nutrient-rich medium such as water, soil or any other inert media such as moss, gravel or perlite.
Solution	Sprayed onto the plants as fine mist of nutrients	Dissolved in the medium
Yield	Better quality and quantity of produce due to better aeration of roots	Poorer quality and quantity of produce due to a limited amount of oxygen and nutrients
Disease spread	Less	High
Water requirement	Less	High

Table 5.6: Percentage of water and fertilizer consumption, vegetables yield percentage and the percentage of water productivity for different new farming systems as compared with conventional farming system [54].

Parameters	**Hydroponic system**				
	Media Soilless system		**Nutrient solution system**		**Aeroponics**
	Open	Closed	Open	Closed	
% Irrigation water saving	80	85	85	90	95
%Fertilizer saving	55	80	68	85	85
% Productivity increase	100	150	200	250	300
% Water productivity	1000	1600	2000	3500	8000

Advantages and Disadvantages of Soilless Cultures:

Soilless cultivation offers favourable environment to plants and provide a year-round production with minimum usage of water and nutrients compared to conventional agriculture. The controlled system of soilless farming also reduces the effect of biotic and abiotic stresses, thus sustain crop growth. The conservation of resources and ecological sustainability is amongst the profound advantages of soilless farming.

Despite several merits, it also has certain demerits including technical knowhow requirement to operate the system is more as compared to conventional practices, higher initial investment, surveillance of various plant growth parameters (pH, EC, nutrient concentration etc.), and electricity requirement.

5.8 Conclusion:

Soilless cultivation may have various advantages and disadvantages, but a slow decline of arable land throughout the world makes it necessary to seek new alternate agricultural technologies that have neutral or positive impact on our environment and maximum contribution towards mass production of crops. Soilless cultivation practices may not seem important at present but they are full of tremendous potential in the coming future. The technologies and techniques utilized in soilless cultivation of crops can be referred to as next-generation crop science. If they are explored and evaluated properly, they will open a doorway to establish a new civilization in outer space. Soilless methods are also being used for space programmes which will pave avenue for space research and eventual habitation on Moon and Mars. Progress has been rapid and results obtained in various countries have provided proof that this technology is practical and has very definite advantages over conventional methods of crop production. People living in crowded city streets, without gardens, can grow vegetables and barren lands can be made productive at relatively low cost.

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