Chapter 3 : Soilless cultivation

1. History of Soilless Cultivation (Hydroponics)

Soilless agriculture, also known as hydroponics, is a cultivation technique in which plants do not grow directly in soil but are instead raised using a nutrient-rich water solution or on a neutral growing medium (such as clay pebbles, coconut fiber, rock wool, etc.) that provides all the elements necessary for plant growth without traditional soil.

A. Ancient Origins

The idea of growing plants without soil dates back to very ancient practices. For example:

- The Hanging Gardens of Babylon are often cited as one of the earliest examples of soilless or substrate-based cultivation.
- Peoples living near large lakes grew vegetable gardens on the surface of the water, while the Aztecs built floating gardens (rafts) to cultivate crops in marshy areas.

B. 19th Century – Scientific Beginnings

In the 19th century, researchers began studying what truly nourishes plants. Around 1850, Justus von Liebig conducted some of the first studies on plant nutrients, laying the scientific foundations of soilless cultivation by highlighting the importance of nutrients dissolved in water.

C. 20th Century – Birth of Modern Hydroponics

It was during the 20th century that soilless cultivation, as we know it today, truly developed:

In the 1930s, William F. Gericke began commercializing the first hydroponic systems in the United States. During this period, the term hydroponics was used for the first time to describe this cultivation method.

During World War II, soilless cultivation was used to produce fresh vegetables for American troops stationed on islands lacking fertile soil, demonstrating its practical value under extreme conditions.

In the 1970s, Dr. Alan Cooper developed the NFT (Nutrient Film Technique), which enabled the commercial expansion of hydroponics by allowing efficient circulation of the nutrient solution around plant roots.

D. Modern Developments

Since the 1970s, soilless cultivation has expanded significantly, integrating technological and agricultural innovations. Today, these systems allow for indoor installations, greenhouse farming, and even vertical farming in urban environments, enabling optimized year-round production.

Soilless cultivation is now recognized not only for its high yields and efficient water use but also for its ability to produce fresh food in environments where traditional soil-based agriculture is not feasible.

2. Definition

Soilless agriculture (or soilless cultivation) refers to a farming method in which plants complete their entire production cycle without their roots coming into contact with natural soil. Instead, the roots are continuously supplied with a liquid nutrient solution that provides water, dissolved oxygen, and all the mineral elements essential for plant growth.

3. Scope of application

Soilless agriculture, such as hydroponics, aeroponics, or integrated systems, is applied in several fields thanks to its specific advantages. According to this article, these fields include:

A. Controlled Environment Agriculture

One of the main applications is in controlled environment agriculture (CEA), where growing conditions (light, temperature, humidity, nutrients) are precisely regulated. This allows for the continuous production of vegetables and plants year-round, regardless of external climatic variations.

B. Urban Agriculture and Local Production

This type of agriculture can be installed in urban spaces such as greenhouses, renovated buildings, rooftops, or basements, bringing production closer to consumers. This reduces transportation distances and the associated carbon footprint while increasing the freshness of food products.

C. Reduced Land Use

Thanks to the use of stacked or vertical systems, soilless agriculture optimizes space by producing more in a smaller area, which is particularly beneficial in densely populated areas or those with limited farmland.

D. Reduced Resources and Efficiency

Soilless agriculture uses significantly less water and nutrients than conventional agriculture because water and nutrients are recycled within the system, making it suitable for regions where water is scarce or expensive.

E. Sustainable Production and Food Security

It offers the possibility of producing food more sustainably, with less dependence on climate or fertile soil, thus contributing to food security, especially in areas affected by climate change or where farmland is scarce.

4. The different soilless cultivation systems

A. Deep Water Culture (DWC)

Simply put, this is floating plants on recirculating water. There are many ways to do it but often it is done on styrofoam insulation boards (4ft x 8ft). By drilling tapered (conical) holes in the boards to the size of the growing media you select, you can drop in your germinated plant and it won’t fall through. The roots are suspended in about 6 to 18 inches of a well-oxygenated nutrient solution until harvest. It’s perfect for short-statured leafy greens and herbs as they do not require much root support. DWC systems often hold a large volume of water slowing any swings in the chemistry of the solution. Additionally, if there is ever a pump malfunction in a DWC system, you would have many hours to fix it before you ran into any significant problems, like the roots drying out.

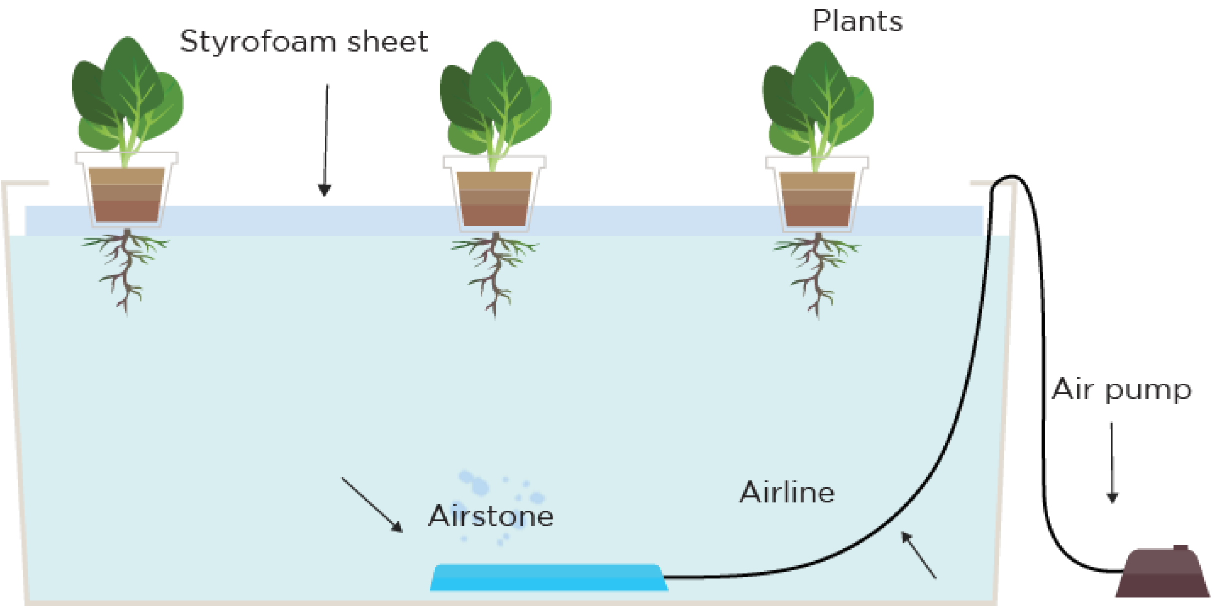

Fig.1. Deep Water Culture. https://www.agritecture.com

B. nutrient Film Technique (NFT)

This versatile technique uses channels or troughs, set up on a slight angle for drainage purposes, and running a very shallow stream of water to the roots. It can be done on a timer or with a continuous flow. The solution is held at the lowest point in a reservoir that contains a submersible pump and usually air stones for optimal dissolved oxygen levels and stagnation prevention. Once the water saturates the roots, it drains back into the reservoir. NFT is best for short-statured plants like DWC, but these systems hold much less water per plant and are more easily stackable, cleanable, and customizable for your grow space.

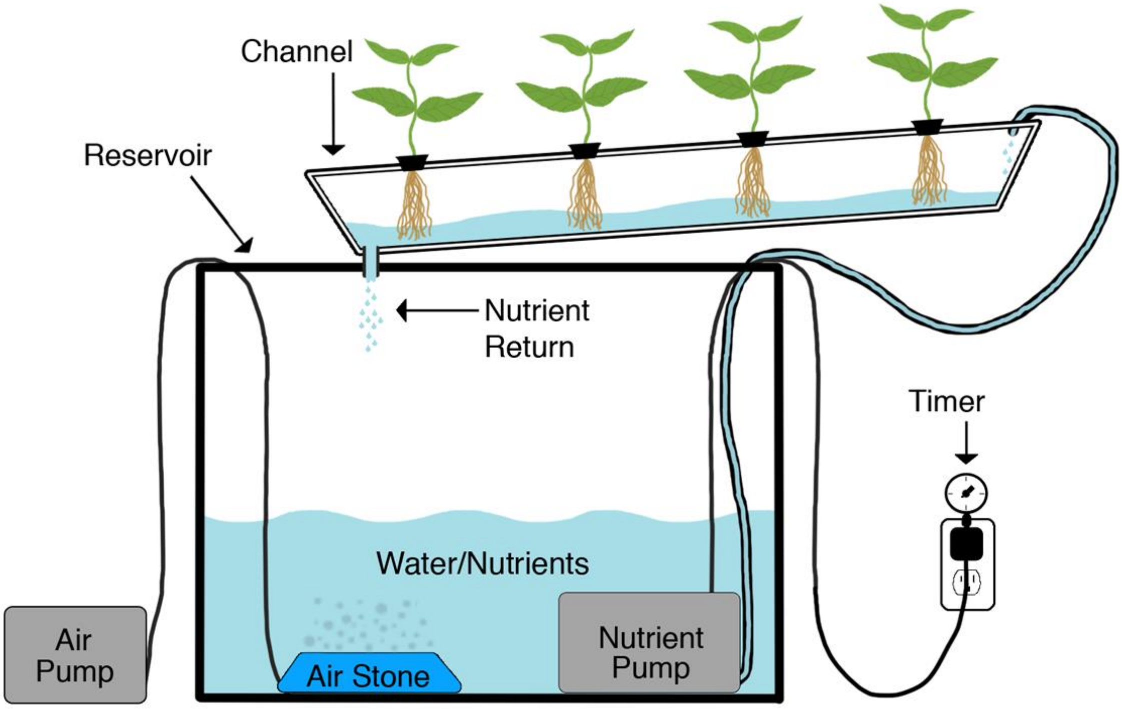

Fig.2. nutrient Film Technique. https://www.agritecture.com

C. Ebb and Flow (Flood and Drain)

Ebb and flow systems can be as basic as a small plastic bucket with some expanded clay pellets or other rock media that you hand water and drain. It can also be as complex as adding a large media filled bed onto an aquaponic system and flooding it with the liquid waste from the system. In every instance, the grow tray is temporarily flooded with solution every few hours, submerging the roots before returning to the reservoir. Because of the root support and oxygen levels they can provide, ebb and flow systems are great for growing pretty much anything, but especially fruiting crops. You just have to be sure that however it's being done, the setup can support the weight of all that media and water and your containers drain completely. This article from Upstart University shows how easy it is to get started with Bato Buckets. Ebb and flow systems are low maintenance and produce high yields, but like NFT systems, a pump failure can quickly become catastrophic for your plants.

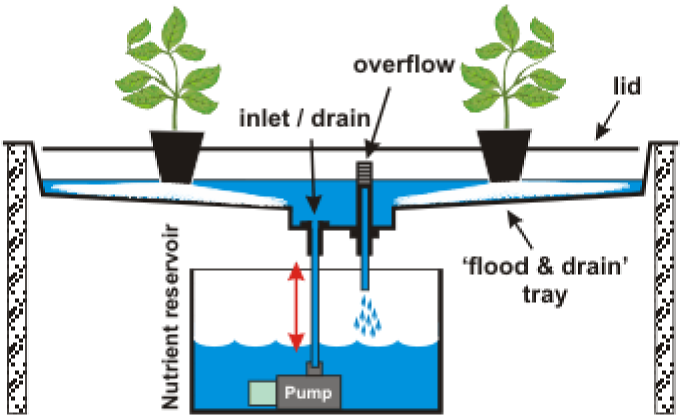

Fig.3. Ebb and Flow (Flood and Drain). https://www.agritecture.com

D. Drip System

Drip systems are another common and simple technique whereby a pump on a timer delivers a slow feed of the solution to the base of each plant individually. The excess solution can be either returned to the reservoir or not collected. It works well with growing mediums with high water retention (i.e. coco coir, peat moss, or rockwool). When the system is working correctly, it is very low maintenance and high output, but the drip lines can get clogged, which results in dried out plants. Synthetic nutrients are the logical choice for these systems because organic materials clog lines much faster.

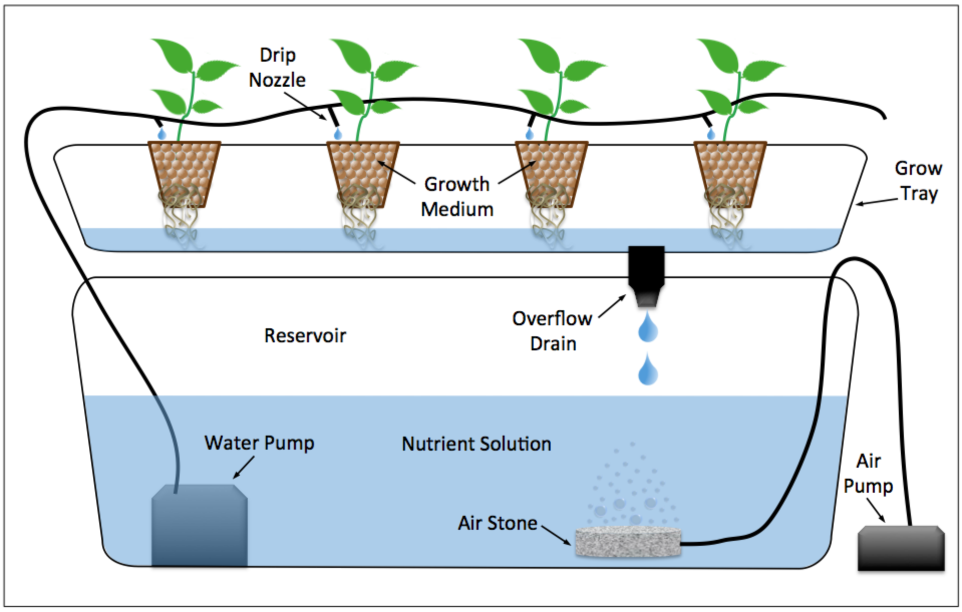

Fig.4. Drip System. https://www.agritecture.com

E. Aeroponics

This is an innovative technique of misting the roots, which are suspended in the air, with hydroponic solution. These systems are very precise with nutrient delivery and water usage, but if you are designing your own system, aeroponics might not be the place to start. The clogging issues can be even worse than drip system as the emitters have very tiny holes. But the roots have ample oxygen and high oxygen levels means faster growth. A-frame aeroponic systems are common, using tall cones made of PVC frames, which gives the root chamber a perfect environment.

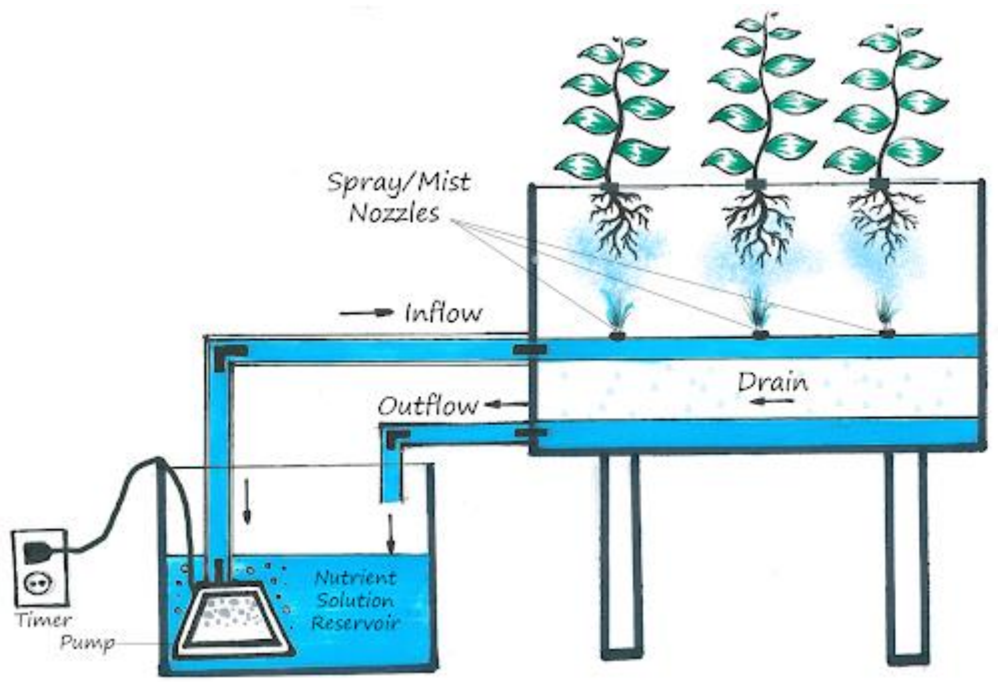

Fig.5. Aeroponics. https://www.agritecture.com

F. Wicking System

Wicking systems are the most basic and passive growing technique and another great starting point for beginners because of its low maintenance. The solution is delivered to a tray through the wicks and then to the roots via the plant’s capillary action. It has no moving parts and works great on a hobby scale, but is not the most efficient when it comes to nutrient use. There are a lot of great YouTube videos that can teach you how to easily build one of these systems, like Green Our Planet's How to Build a Wicking Hydroponic System and the Urban Gardener's How to Build a 5-Gallon Bucket Water Wicking Growing System.

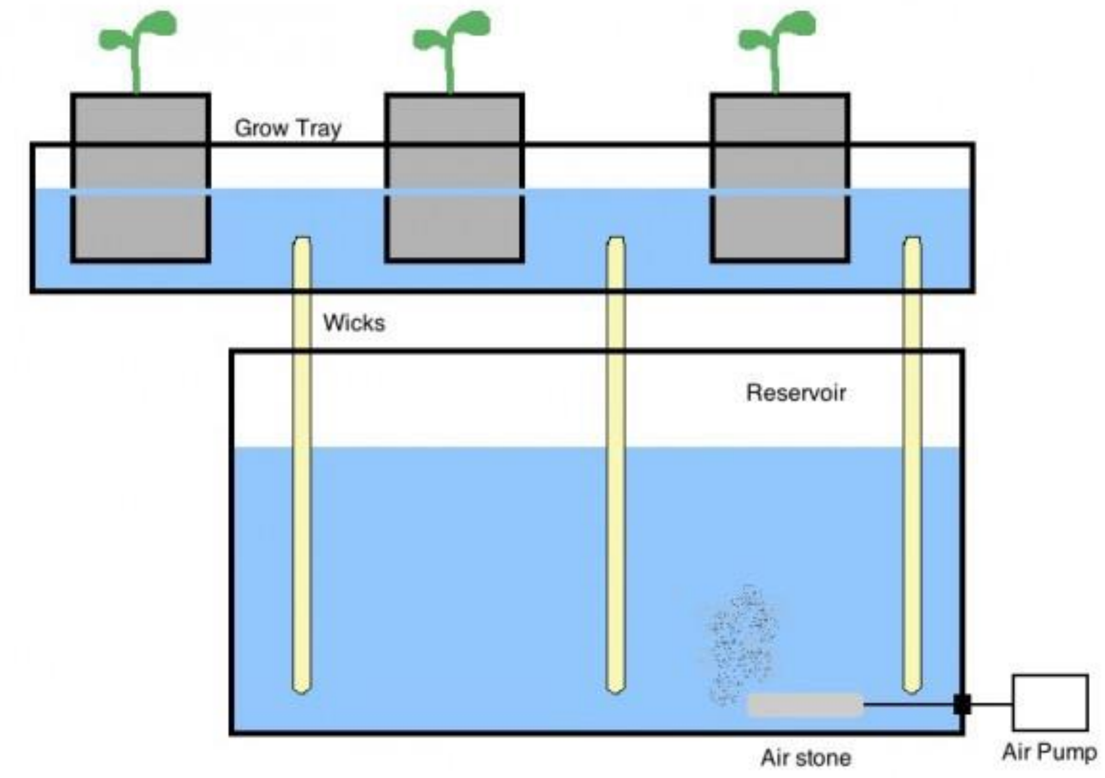

Fig.6. Wicking System. https://www.agritecture.com

G. Aquaponics and Organic Hydroponics

Hydroponics is not a new invention, it has been used and perfected over thousands of years throughout human history. Primitive examples of soilless techniques were discovered at the Floating Gardens in China and the Hanging Gardens of Babylon. These civilizations in many cases used aquaponics, which is raising fish and plants in the same water source. The fish actually provide the fertilizer for the plants and the plant roots filter the water for the fish. When fish are introduced to a freshwater source, they give off ammonia through their gills and waste (pee and poop!). Over time, nitrifying bacteria - naturally-occurring microorganisms - begin to grow on all the surface area under the water. This bacteria converts the fish waste into nitrites, and eventually nitrates, which is plant food. So aquaponic farms actually grow three separate, equally important things, plants, fish and beneficial bacteria. With the correct ratio of plants to fish, an aquaponic system can be a very sustainable and fun way to grow food.

That same nitrifying bacteria in aquaponics is also needed in organic hydroponic applications. Growing organically in hydroponics is biologically more closely related to aquaponics than to synthetic hydroponics. It can be a difficult and messy process, so many commercial scale operations use synthetic hydroponic methods. One reason for this is that with aquaponics and organic hydroponics, maintaining a healthy and vibrant bacterial colony is imperative, so sanitizing and flushing the majority of the water is not recommended and can cripple the overall health of the system. It can take months to “mature” your water, which is a way of saying the ammonia being introduced, through fish waste or organic nutrients, is effectively being converted to nitrates. Oxygen is the defining element of these systems so it is important to have a good flow rate and biofiltration to remove any oxygen consuming waste to avoid anaerobic activity (absence of oxygen).

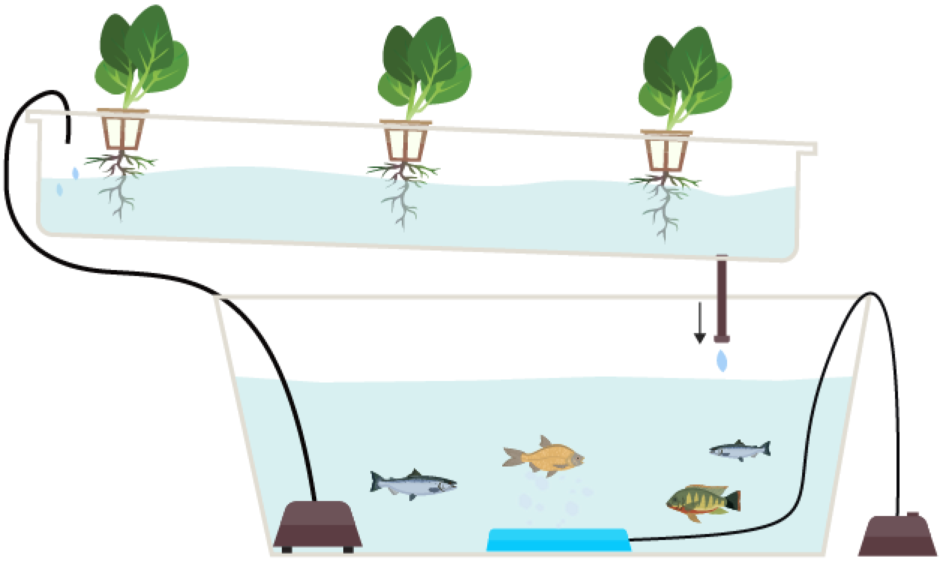

Fig.7. Aquaponics and Organic Hydroponics. https://www.agritecture.com

5. The substrates

Substrates are a fundamental component of hydroponic systems, as they provide physical support for plant roots and facilitate the uptake of water, nutrients, and oxygen. These substrates vary in their physical and chemical properties, which directly influence plant growth and productivity. The following is an overview of the most commonly used substrates in soilless cultivation:

- **a. Peat** is an organic material formed from the decomposition of sphagnum moss and other plant residues under waterlogged conditions. It is characterized by a high water-holding capacity, adequate aeration, and relatively stable structure. Peat typically has a low pH ranging from 3.5 to 4.5, which may require adjustment through the addition of lime. Its high cation exchange capacity enables it to retain nutrients and make them available for plant uptake over time.
- **b. Coconut** coir is a natural material derived from coconut husks and is considered a sustainable and environmentally friendly alternative to peat. It exhibits good water retention, sufficient aeration, and a stable physical structure. The pH of coconut coir generally ranges from 5.5 to 6.8, which is close to neutral and suitable for a wide variety of crops without significant pH adjustment. Coconut coir has a moderate cation exchange capacity, contributing to the retention and availability of nutrients for plant absorption.
- **c. Perlite** is an inorganic material produced by heating volcanic rock to high temperatures, causing it to expand into lightweight, porous granules. It is widely recognized for its excellent drainage and aeration properties. Perlite has a near-neutral pH and a low cation exchange capacity, meaning it has minimal influence on nutrient availability. It is commonly used in combination with other substrates to improve aeration and drainage.
- **d. Vermiculite** is an inorganic mineral obtained by heating and expanding mica minerals, resulting in a lightweight, sponge-like structure. This structure provides good water retention, adequate aeration, and thermal insulation. Vermiculite typically has a neutral to slightly alkaline pH and a high cation exchange capacity, allowing it to retain nutrients and gradually release them for plant uptake.
- **e. Rockwool (stone wool)** fibrous, inert substrate made from spun volcanic rock; excellent water and air balance.
- **f. Sand and gravel** simple mineral substrates with basic drainage properties.
- **g. Expanded clay, pumice, zeolite** – other mineral aggregates sometimes used alone or in blends.
- **h. Rice hulls, bagasse** – agricultural byproducts used in some substrate blends.
- **i. Synthetic materials** such as foam or specialized fibers may also be included in engineered substrate mixes.

The selection of an appropriate substrate for soilless cultivation depends on several factors, including crop type, cultivation system, and the desired physical and chemical properties of the growing medium. Each substrate has its own advantages and limitations; therefore, growers often combine different materials to create a balanced medium that optimizes water retention, aeration, nutrient availability, and pH conditions to meet plant requirements.

6. Nutritional solutions

In soilless agriculture, plants rely entirely on the nutrient solution as the sole source of essential nutrients, due to the absence of soil, which is traditionally the primary provider of these elements. The nutrient solution is considered the key factor for the success of soilless cultivation systems, as nutrients are dissolved in water at precise concentrations that meet plant requirements throughout different growth stages. The nutrient solution contains macronutrients such as nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur, in addition to micronutrients including iron, manganese, zinc, copper, boron, and molybdenum, all of which are essential for proper plant growth.

The concentrations of these nutrients must be carefully balanced, as any deficiency or excess can lead to nutritional disorders that negatively affect plant growth and productivity. The salinity level of the nutrient solution also plays an important role, as excessive salinity may hinder the ability of plant roots to absorb water and nutrients. Furthermore, pH is a critical factor influencing nutrient availability and uptake, and it is recommended to maintain the nutrient solution within a pH range of 5.5 to 6.5 to ensure optimal nutrient availability.

In addition, the quality of the water used to prepare the nutrient solution directly affects the success of soilless agriculture systems. Water quality is commonly assessed by measuring electrical conductivity (EC) and pH. Proper management of these parameters contributes to improved efficiency in water and fertilizer use, enhanced plant growth, and higher productivity in soilless cultivation systems.

7. Water supply control

In soilless agriculture, such as hydroponics and aquaponics, water is the primary medium for delivering nutrients to plants, as the plants do not come into contact with soil or rainfall. These systems use aqueous nutrient solutions containing all the essential elements for plant growth, which are delivered directly to the plant roots.

Precise water management is critically important, as it is not merely about providing water to the plants, but about supplying the **right amount at the right time**, since the water carries dissolved nutrients that must be carefully balanced to avoid deficiencies or excesses.

The method of water management varies depending on the type of system:

- In NFT systems (Nutrient Film Technique) and closed-loop systems, water moves continuously or periodically, requiring careful management of the **flow rate and circulation of the nutrient solution**.
- In systems using substrates such as coconut coir or rockwool, the **frequency and duration of irrigation are very important**, as some substrates retain water poorly, necessitating carefully timed and repeated irrigation cycles.

One of the main advantages of soilless agriculture is water conservation, as closed or recirculating systems allow **unused water to be reused**, reducing waste. However, reuse requires **continuous monitoring of water quality**, including pH and electrical conductivity (EC), to ensure that plants receive a balanced nutrient solution each time.

If water is not properly managed, problems may occur, such as:

- Clogging of irrigation heads or pipes due to salt or calcium carbonate buildup,
- Or high salinity in the water, which can negatively affect plant growth if not corrected before irrigation.

To achieve optimal water management, the focus should be on:

- Providing water according to the plant’s needs,
- Avoiding water stress or over-irrigation,
- Enhancing nutrient uptake efficiency,
- And reducing water waste while maintaining a stable and healthy root environment for the plants.

8. Phytosanitary and environmental aspects in soilless cultivation

A. Phytosanitary Aspects

From a phytosanitary point of view, hydroponic cultivation provides favorable conditions for plant health. The absence of soil helps prevent many soil-borne diseases and pests, which leads to a significant reduction in the use of chemical pesticides. In addition, the absence of weeds prevents competition for water and nutrients and eliminates the need for weeding operations.

However, hydroponic cultivation requires precise and continuous monitoring, as plants depend entirely on the nutrient solution. Therefore, it is essential to control the pH level, water temperature, and oxygen concentration. Any imbalance in these parameters may lead to nutrient deficiencies or the spread of diseases, making this system sensitive to technical errors.

In closed systems (nutrient solution recirculation), the appearance of a single pathogen can lead to its rapid spread among all plants through the nutrient solution if it is not properly treated.

Some water-borne pathogens, such as Pythium and Fusarium, can proliferate in the nutrient solution or in humid environments.

B. Environmental Aspects

From an environmental perspective, soilless cultivation is an efficient system for saving water, as it can use significantly less water than traditional soil-based agriculture. This makes it a suitable solution for addressing water scarcity and climate change. It also allows cultivation on polluted soils without affecting the safety of agricultural products.

Furthermore, hydroponic cultivation enables vertical farming, which helps optimize space use, especially in urban areas, and reduces pressure on agricultural land.

Despite these advantages, soilless cultivation remains environmentally debatable due to its reliance on industrial equipment (often plastic-based) and energy consumption for lighting, ventilation, and heating in greenhouses, in addition to the heavy dependence on industrial fertilizers.

These systems help reduce soil and groundwater pollution by minimizing the loss of fertilizers and nutrients compared to soil-based cultivation. Moreover, reducing exposure to diseases decreases the need for insecticides and fungicides, thereby mitigating the negative environmental impact of chemical inputs.

However, the high energy consumption for lighting, cooling, heating, and ventilation can reduce environmental sustainability if renewable energy sources are not used.