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14. Hydroponic and Aquaponics in Agriculture

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Abstract:

The chapter "Hydroponic and Aquaponics in Agriculture" explores the innovative techniques of soilless farming, focusing on hydroponics and aquaponics as sustainable agricultural practices. It provides a comprehensive overview of these systems, detailing their principles, design, and operation. Hydroponics, the method of growing plants in nutrient-rich water solutions, and aquaponics, which combines hydroponics with aquaculture, are highlighted for their efficiency in resource use, reduced environmental footprint, and potential to enhance food security. The chapter examines the benefits of these systems, including faster plant growth, higher yields, and the ability to cultivate crops in urban and arid environments. Challenges such as initial setup costs, technical expertise requirements, and system management are also discussed. Case studies from various regions demonstrate the practical applications and economic viability of hydroponics and aquaponics. By integrating these advanced agricultural technologies, the chapter emphasizes their role in promoting sustainable farming practices and addressing global food production challenges.

Keywords:

Hydroponics, Aquaponics, Soilless Farming, Sustainable Agriculture, Food Security, Resource Efficiency, Urban Farming

14.1 Introduction:

Growing plants in nutrient solutions using an inert medium—gravel, vermiculite, rockwool, peat moss, sawdust, coir dust, coconut fibre, etc.—with or without the use of mechanical support is known as hydroponics. The Greek terms "hydro" (meaning water) and "ponos" (meaning labour) are the source of the name "hydroponics," which literally translates to "water work." Professor William Gericke first used the term "hydroponics" in the early 1930s to refer to the practice of growing plants with their roots suspended in water that contains nutrients and minerals. Water helps plants survive in the absence of soil by supplying them with nutrients, water, and oxygen. Hydroponically grown flowers, herbs, and vegetables are placed in inert growth material and given access to water, oxygen, and nutrient- rich solutions. Stronger yields, faster growth, and higher quality are all encouraged by this method. When a plant is growing in soil, its roots are always looking for the nutrients it needs to survive. A plant doesn't need to use any energy to sustain life if its root system is exposed to food and water directly. It is possible to redirect the energy that the roots would have needed to get food and water towards the growth of the plant. Consequently, fruit and flower blossoming as well as leaf growth thrive.

Figure 14.1: Growing plants

Because hydroponic systems maximise exposure to nutrients and water while enabling fine control over environmental parameters like temperature and pH balance, they are incredibly successful. The basic idea behind hydroponics is to provide plants exactly what they require at the right time. Nutrient solutions are applied by hydroponic systems according to the requirements of the specific plant being produced. They provide you complete control over the amount and duration of light that the plants get. Moreover, pH levels may be checked and modified. Plant development speeds up in an environment that is highly tailored and regulated.

Numerous danger factors are decreased by managing the plant's surroundings. Numerous factors that are detrimental to a plant's health and growth are introduced to plants cultivated in fields and gardens. Plant diseases can spread by fungi found in the soil. Raccoons and other wildlife have the ability to steal ripe veggies from your garden. Locusts are one of the pests that may destroy crops in a single afternoon. Growing plants outdoors can no longer be unpredictable thanks to hydroponic systems. Seedlings can develop significantly quicker when the soil's mechanical barrier is removed. Hydroponic gardens provide considerably healthier and higher-quality fruits and vegetables since they do not use pesticides. Plants are free to develop quickly and strongly in the absence of impediments.

14.1.1 Basic Principles:

Nutrient Delivery: In hydroponic systems, plants receive essential nutrients directly from a water-based solution, eliminating the need for soil as a nutrient medium. The nutrient solution contains a carefully balanced mixture of essential minerals, including nitrogen, phosphorus, potassium, calcium, magnesium, and trace elements, necessary for healthy plant growth.

Root Support: Instead of soil, plants in hydroponic systems are typically supported by inert growing mediums such as perlite, vermiculite, coconut coir, rockwool, or hydroton. These mediums provide physical support for the plants' roots while allowing for adequate aeration and moisture retention.

Water Management: Water serves as the medium for delivering nutrients to plant roots in hydroponic systems. Unlike traditional soil-based agriculture, where water may be lost through runoff or evaporation, hydroponic systems are designed for efficient water use. Techniques such as recirculating systems and drip irrigation minimize water waste and ensure optimal hydration for plants.

pH and EC Regulation: Maintaining the proper pH (acidity or alkalinity) and electrical conductivity (EC) of the nutrient solution is crucial for ensuring nutrient availability and uptake by plants. pH levels are typically adjusted using acids or bases to keep them within the optimal range for plant growth, while EC levels indicate the concentration of dissolved nutrients in the solution.

Environmental Control: Hydroponic systems allow growers to exert precise control over environmental factors such as light, temperature, humidity, and CO_2 levels. By optimizing these conditions to mimic the plant's natural habitat, growers can maximize growth rates and overall plant health, leading to higher yields and superior crop quality.

Aeration and Oxygenation: Adequate oxygenation of the root zone is essential for promoting healthy root development and preventing issues such as root rot. Hydroponic systems employ techniques such as air pumps, air stones, or oxygen injectors to ensure sufficient oxygen levels in the nutrient solution, particularly in closed loop or deep-water culture systems.

14.1.2 History:

Evidence from historical civilizations including the Babylonians, Egyptians, and Aztecs suggests that hydroponics has ancient origins. These prehistoric societies cultivated crops in dry or hostile conditions by using a variety of hydroponic-like methods, such as suspending plant roots in solutions or growing plants in nutrient-rich waterways.

Crop nutrition has been studied for thousands of years. Theophrastus (372-287 B.C.) is said to have conducted a number of experiments, while Dioscorides (first century A.D.) is known to have written numerous works on botany (Douglas & James, 1975).

The first recorded account of cultivating terrestrial plants without soil was found in Francis Bacon's 1627 book Sylva Sylvarum, often known as "A Natural History," which was published a year after his death. His findings led to the widespread use of water culture as a research method. John Woodward reported his spearmint water cultivation research in 1699. He discovered that plants grew more vigorously in less pure water sources than in distilled water. Nine elements were thought to be necessary for plant growth by 1842. The method of soilless cultivation was developed as a consequence of the 1859–1875 findings made by German botanists Julius von Sachs and Wilhelm Knop.

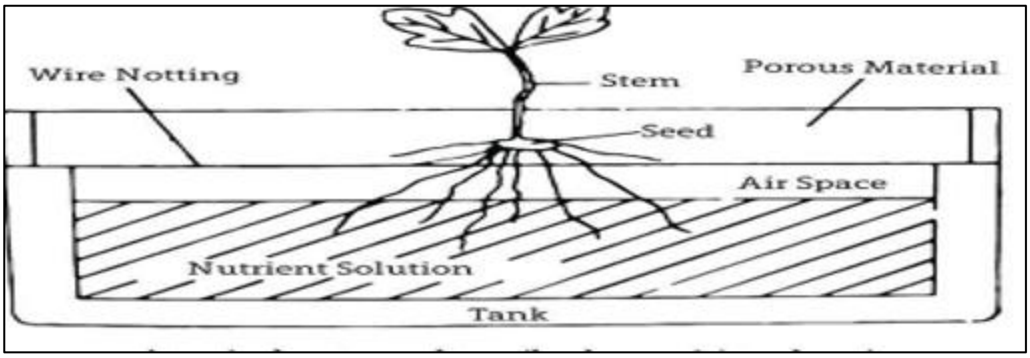

Figure 14.2: A Typical water-culture (hydroponic tank unit)

Plant nutritionists began studying plant diseases in the 1930s, and as a result, they noticed symptoms associated with salinity and other current soil conditions. Water culture studies were conducted in this context in an attempt to produce comparable symptoms in a lab setting. This method, imposed by Dennis Robert Hoagland, produced novel model systems (such the green algae, Nitella) and standardized nutrient formulations that are becoming more and more significant in contemporary plant physiology.

The University of California, Berkeley's William Frederick Gericke first openly advocated for the application of solution culture ideas to agricultural crop development in 1929. Initially, he called this type of cultivation "aquiculture," drawing a comparison to "agriculture," but he subsequently discovered that the name was already in use for the culture of aquatic species. By using mineral fertilizer solutions instead of soil to grow tomato plants 25 feet (7.6 meters) high in his backyard, Gericke caused quite a stir. Then, in 1937, he coined the name "hydroponics," or water culture, when W. A. Setchell, a phycologist with a background in the classics, suggested it to him. One of the first hydroponic farming achievements took place on Wake Island, a rugged island in the Pacific Ocean that Pan American Airlines utilized as a refueling station. There, in the 1930s, hydroponics was employed to grow vegetables for the passengers. Because Wake Island lacked soil and airlifting fresh veggies would have been prohibitively expensive, hydroponics was the only viable option.

14.2 Classification of Hydroponic system:

A. Wick hydroponic system:

The wick method is the simplest for indoor hydroponics. The system is considered self-feeding because it is passive and doesn't include a water pump.

The nutrient solution from the reservoir flows into the growth media via capillary action with the aid of a wick, typically constructed from nylon. Wick systems, a type of passive hydroponic system, are distinguished by their simplicity.

It all comes down to the simple attraction of water to itself. When you wet a glass surface and it results in beads, you may see this.

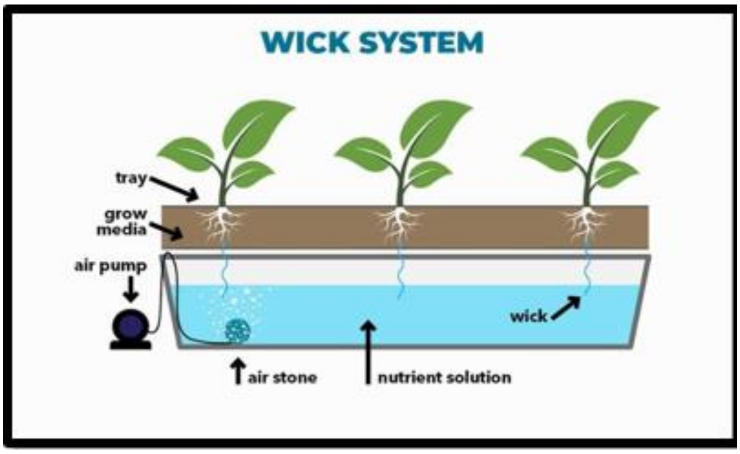

Figure 14.3: Wick System

The molecules of water are joining together. A portion of the water in the jar is drawn to the fibre when a wick is inserted. All the molecules and the other water molecules stick to its surface. They draw into the fibre simultaneously. A few molecules of water will rise over the first. Additionally, they will cling to the fibre and drag a few small companions with them. One of the most less expensive hydroponic techniques is wick system.

B. Drip system hydroponics:

Drip system hydroponics provides regular nutrition and watering through the use of pipes, hoses, and growing media. Similar to drip irrigation in soil gardening, this technology is becoming more and more widespread in hot, dry climates, setting standards for the industry. Crops are irrigated using long pipelines and hoses, which conserve water and reduce evaporation. A pump distributes water or fertilizer solution to specific plants or pots based on an automated timer. The main advantage of this approach is that it uses less water. A drip system is resilient to both temporary power cuts and equipment breakdowns.

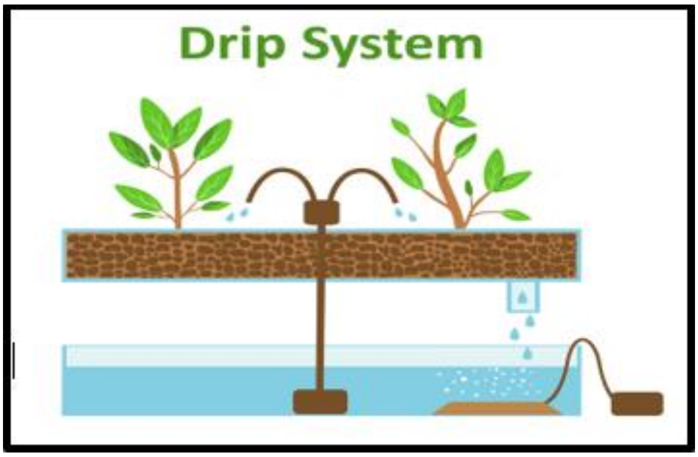

Figure 14.4: Drip System

With a drip system, moisture levels are easily managed. In soil and hydroponic systems, crop cultivation is aided by adequate oxygen transmission. In this mechanism, extra nutrients can also be recirculated.

Cucumbers and other similar crops grow in drip irrigation systems. In comparison, better tomatoes and peppers usually grow higher in the drip system since it offers adequate stability.

The drip system's primary drawback is that it is prone to blockage and algae development, requiring frequent cleaning. Nutrients are fed into the system slowly.

C. Ebb and flow hydroponic system:

It is a more popular approach in which plants are kept in large grow beds that are often filled with growing media. The environment's nutritional solution flow is controlled by the timer.

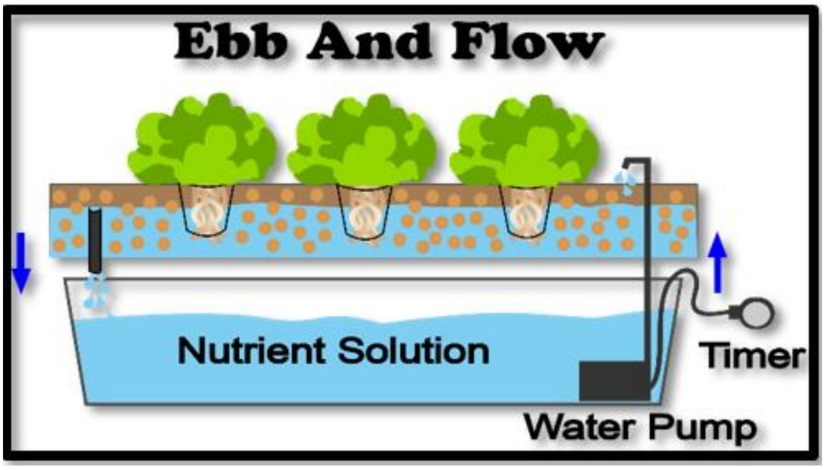

Figure 14.5: Ebb And Flow

The nutrient solution in the growth tray can circulate if the timer activates the pump; if it is turned off, the nutrient solution is pumped back into the reservoir. The other term for it is the flood and drain system.

D. DWC (Deep water Culture):

DWC consists of an air stone, reservoir, air pump, tubing, and floating platform hydroponic system that is being developed.

This system includes of a grow tank (also known as a tank with nutrients) and a pump that provides oxygen to the roots.

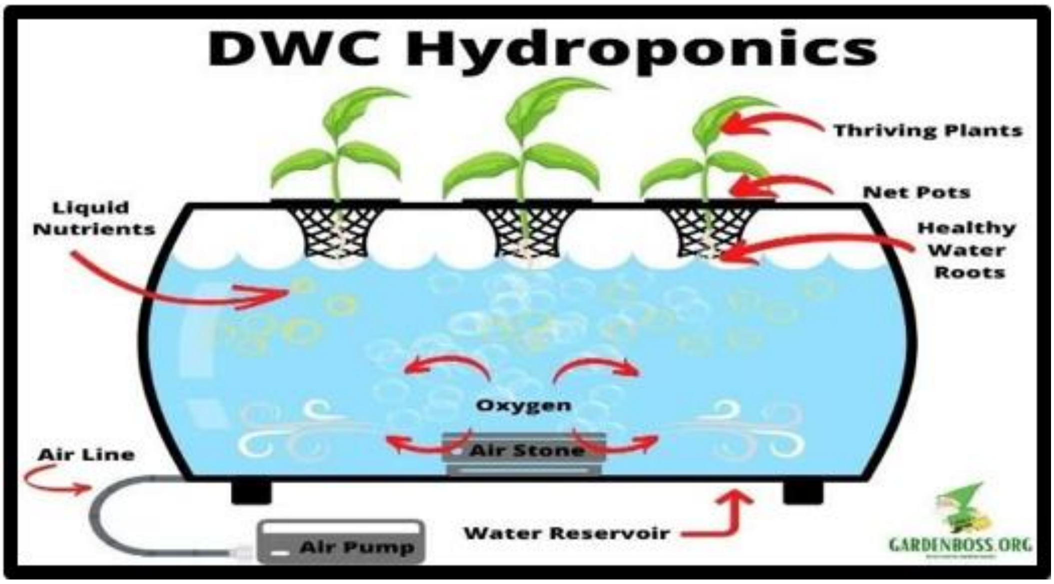

Figure 14.6: DWC Hydroponics

An air pump allows for the growing of more plants in a single grow tank. Usually, plant roots float in liquids that contain nutrients, oxygen, and water. For optimal results, salinity, pH, oxygen, and fertilizer levels require to be monitored.

E. Nutrient Film Techniques (NFT):

NFT is a recirculating hydroponic system that consists of grow channels that are powered by mechanical pumps to circulate a layer of nutrient solution that is usually 1-2 cm high. The nutrient film (NFT) use is the most popular among growers. This method is useful for growing small vegetables.

The roots of the plant are continuously submerged in a nutritional solution. Since just a portion of the root comes into contact with the nutritional solution while using this technique, plants receive more oxygen from the air. Although there is a lot of potential for automation and plant density optimization with such systems, producing crops with a growth cycle longer than four to five months is constrained by the scarcity of water and premature aging of root systems. Additionally, this setup minimizes or eliminates the need for growing material, which decreases the possibility of pH fluctuation that might otherwise occur.

A number of factors must be taken into account when developing an N.F.T. system:

a. Require a nutrition reservoir container.
b. Require a water pump.
c. Pipe is required for the distribution of nutrients, and seedlings must be kept in small plastic pots or baskets.

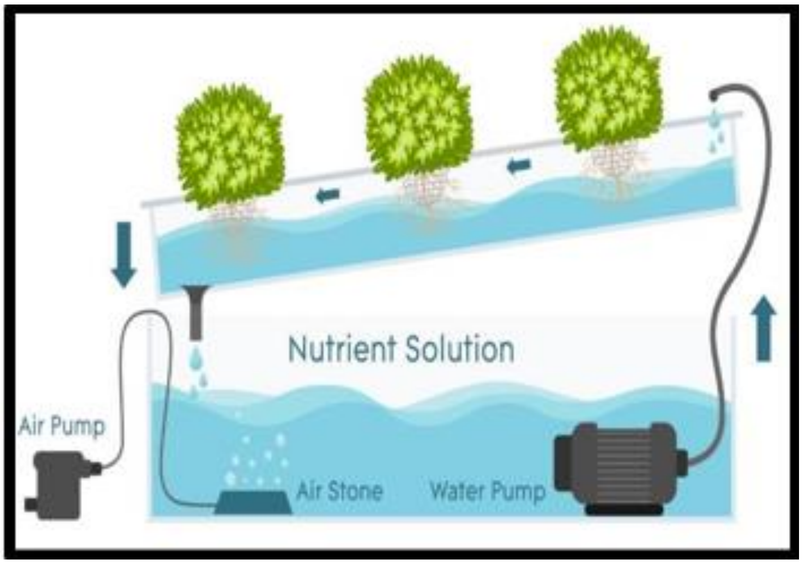

Figure 14.7: Nutrient

d. It is necessary to guarantee that. the nutrient solution returns to the reservoir.

F. Deep Flow Techniques (DFT):

The floating techniques is the variant of NFT techniques instead of the thin nutrient film, the plant is surrounded by an approximately 4cm high nutrient solution.

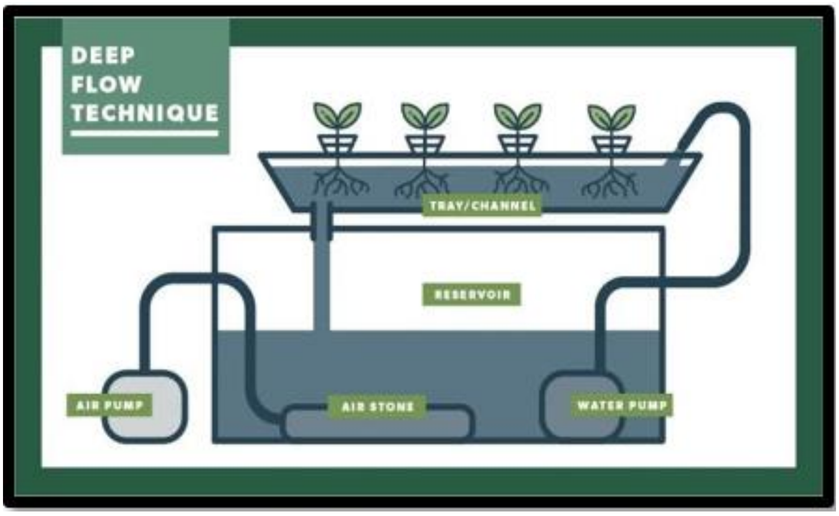

Figure 14.8: Deep Flow Techniques

The basic procedure is same but there is no slant. The system is working recirculating with 2-3cm deep nutrient solution slows in 10 cm deep diameter PVC pipe.

14.2.1 Advantages:

Scarcity and surplus: As cities get more populated, the already limited amount of land becomes even more scarce. In the city, there is not enough room for people to live. In addition, the demand for food is rising daily as more people live in cities. In fact, Reuters' Mike Segar put it this way: "People are hungry everywhere." This highlights the crucial need to make arrangements for extra food and amply illustrates the disparity between the availability and demand for food. Geoponics, or farming on a large scale, does not seem to be a practical choice in this situation. In order to reduce these, some are attempting to switch to hydroponic farming, which has the benefit of allowing for the growth of crops in a much smaller area.

a. **Farming at heights**: Farming at heights uses less area to produce a large volume of products. This is made feasible by the vertical extension of hydro farms in even locations, such as water- scarce areas, within warehouses, and marginal lands. This is not feasible with geoponics for obvious reasons, thus when comparing the two scenarios, it is clear that hydroponics produces more output per cubic foot and is therefore more lucrative and successful (Goenka, 2018).
b. **Pesticide-free:** In geoponic farming, producers typically apply fertilisers and pesticides to enhance crop quality, resulting in non-organic, medicated, and subpar fruit. This is not a concern with hydroponics. This is due to the fact that the crop absorbs the necessary minerals from the nutrient-rich water without the farmer having to use any form of fertiliser, and it has also been demonstrated that greens grown hydroponically have superior flavour. Thus, hydroponics prevails over geoponics in this regard as well (Goenka, 2018).
c. **Improved growth rate:** A plant will probably develop as healthily as genetically possible if you feed it exactly what it needs, when it needs it. This is especially true with hydroponics, where it is quite feasible to add artificial lighting or air conditioning to a space that is surrounded by four walls. The plants will provide superior outcomes in terms of being fresher, greener, and more appetising to consume since the atmosphere generated will be best matched according to the demands of the various plants (Qureshi, 2017).
d. **Water conservation**: Compared to a normal way of fodder cultivation that uses 60–80 litres, producing one kilogramme of lush green fodder only takes two to three litres of water.
e. **Shortened fodder growth period**: Compared to traditional fodder, which takes 60–80 days to mature, green fodder only takes 7 days from seed germination to a fully developed plant measuring 25–30 cm in height. Additionally, the biomass conversion ratio is up to 7-8 times higher. Increasing the nutritional value of fodder: To produce high-quality milk from dairy animals, extra growth boosters, nutrients, etc., can be added to the fodder in hydroponic systems.
f. **Fodder quality**: When comparing hydroponically produced green forage to traditionally produced green forage, the hydroponic green forage's content of organic matter (OM) and non- fibrous carbohydrates (NFC) dropped, but the amounts of crude protein (CP), neutral detergent fibre (NDF), acid detergent fibre (ADF), and calcium increased. (Fazaeli et al., 2012; Kide et al., 2015; Mehta and Sharma, 2016; Abdullah, 2001). Rich in minerals (Bhise et al., 1988; Chung et al., 1989; Fazaeli et al., 2012), antioxidants including β-carotene, thiamin, riboflavin, niacin, biotin, and free folic acid,

hydroponic fodder is a great source of vitamins A, E, and C. Hydroponic fodder is also a major source of bioactive enzymes, according to research by Shipard (2005) and Naik et al. (2014) (Bakshi et al., 2017).

g. Greater palatability: Compared to traditionally produced fodder, hydroponically grown fodder is more succulent, appealing, and nutritious, which increases the production of milk and meat (Ramteke et al., 2019). Decreased work requirements: While hydroponics requires just two to three hours of labour every day, conventional fodder production requires continuous, strenuous labour for the growing of fodder.

14.2.2 Disadvantages and Limitations:

While hydroponics offers numerous advantages, it also has its limitations and challenges that growers must consider. Here are some key limitations of hydroponics:

Costs associated with the initial investment: Installing a hydroponic system may need a large outlay for infrastructure, technology, and equipment. Expenses might include things like climate control systems, pH metres, grow lights, pumps, and nutrition solutions. These upfront expenses might be exorbitant for hobby or small-scale farmers, which can discourage uptake.

Technical Know-How: To properly design, set up, and operate a hydroponic farming system, one needs a certain amount of technical know-how. To guarantee ideal plant development and production, growers need to be knowledgeable about the fundamentals of plant biology, fertiliser management, pH regulation, and environmental control. Inadequate knowledge or instruction in hydroponics might result in less-than-ideal outcomes and a higher chance of crop failure.

a. **Maintenance Requirements:** In order to guarantee optimal performance and avoid problems like fertilizer imbalances, root infections, and equipment failures, hydroponic systems need to be regularly monitored and maintained. In addition to carrying out standard duties like cleaning, trimming, and pest control, growers also need to keep an eye on the pH, temperature, humidity, and carbon dioxide levels. Inadequate system maintenance may lead to decreased agricultural production or plant mortality.
b. **System Failure Vulnerability:** Hydroponic systems are vulnerable to a number of system failures, including as pump malfunctions, nutrient solution leakage, and power outages. Hydroponic plants are totally dependent on the artificial environment that the grower creates, in contrast to typical soil-based farming, where plants have access to a natural buffer of nutrients and water in the soil. Any alterations to this habitat may have detrimental effects on the production and health of the plants.
c. **Dependency on External Inputs:** In order to maintain plant development, hydroponic systems rely on external inputs such fertilizer solutions, water, and electricity. To prevent production delays, growers need to secure dependable supply chains and get high-quality inputs. Furthermore, if hydroponic farming is not done appropriately, the use of artificial fertilizers and energy-intensive equipment may raise questions about the sustainability of the practice for the environment.
d. **Restricted Crop Selection:** Although a variety of crops can be grown hydroponically, some plant species could be better suited for soil-based farming or might need specific hydroponic systems. Certain crops may be difficult to grow in conventional hydroponic

systems due to their large root systems or particular nutritional needs. Furthermore, large fruiting plants or perennial crops could need more room and resources than hydroponic farming can provide.

e. **Zoning and regulatory issues:** Hydroponic farming may be restricted by zoning laws or regulations in some areas, which might prevent it from being used or expanded. Hydroponic farmers may be subject to additional compliance requirements from local regulations pertaining to water consumption, fertiliser runoff, waste disposal, and land use, which might result in higher operating costs and administrative hassles.

14.3 Aquaponic System:

Aquaponics is the technique of growing plants and fish together in a designed, recirculating environment while converting fish waste into plant food via the use of natural bacterial cycles.

Figure 14.9: Aquaponic

Aquaponics research began in the late 1970s at the University of Virgin Islands, Virgin Islands (USA) with Dr. J. Rakocy. created a raft hydroponic system, with an aquaculture component focused on red tilapia and lettuce production. Rakocy et al. (1997; 2007)

A. Why Aquaponic system:

Aquaponics are needed currently, more than a billion people worldwide suffer from undernourishment (World Food Programme, 2014). Given that 38% of the world's agricultural land is thought to be degraded, lower yields are typically the result of insufficient or absent nutrients (The World Bank, 2015).

Large-scale aquaculture requires more area, water, and financial resources. Aquaponics: a method for supplying fish and plants with all the food they need in one resource.

B. Components:

a. **Tanks**: It should have flat bottoms and a round shape. Low-density polyethylene (LDPE) tanks made of inert plastic or fibre glass. Colour: White or various light colours.
b. **Mechanical filter:** Clarifiers, or mechanical separators Bio balls are the biofilter media of the Fish Tank Biofilter.
c. **Air pump**: A mechanical separation for solids that is linked to the biofilter Top view of the biofilter-connected mechanical solids separator.
d. **Aerator Sump Tanks:** A sump is an area where liquid runoff accumulates. In an aquaponics system, the sump is located below the grow beds and serves as the tank into which the grow beds drain. Aeration can be accomplished utilizing a variety of equipment and methods, such airlift pumps, water sprays, and compressors.

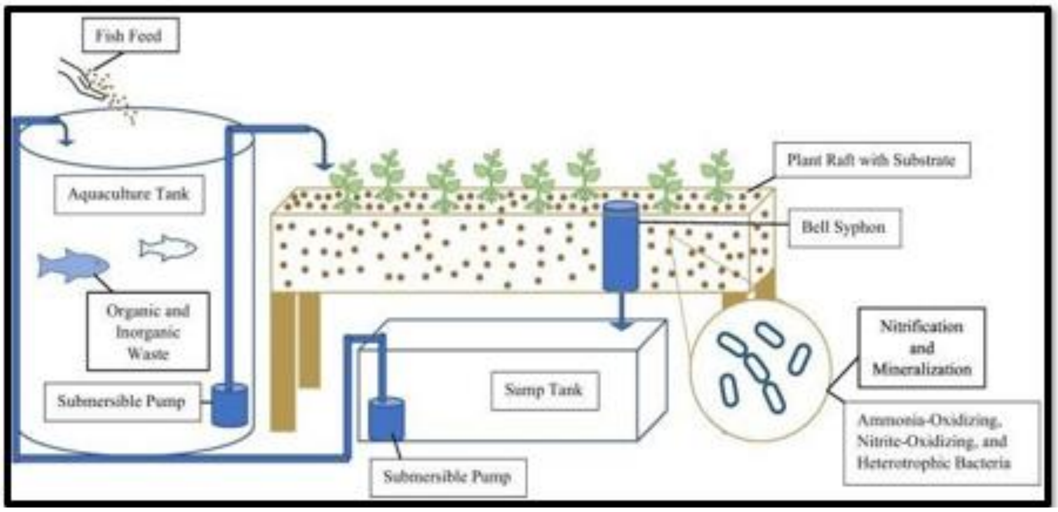

Figure 14.10: Components

14.3.1 Principles of Aquaponics:

Aquaponics is a hybrid system that, in contrast to traditional hydroponics, which needs inorganic fertilisers, uses fish waste as a nutrient for plant development. This method promotes a symbiotic relationship between fish, microbes, and plants, so encouraging the sustainable use of water and nutrients, including recycling. Unlike when conducted individually, this synergistic connection minimises the requirement for nutrient input and waste output, turning the ecological weaknesses of hydroponics and aquaculture into strengths.

Both macro- and micronutrients are necessary for the development of plants. With the exception of C, H, and O, these elements are present in hydroponic solutions in ionic form. Fish waste that has been dissolved and is rich in nutrients is added to plant nutrient input from fish tanks in aquaponics systems. The fish excrement is then dissolved in water and taken up by the plants.

Plant development depends on the concentrations of macro- and micronutrients, and it may be essential to make periodic modifications to these concentrations, such as adding iron to fish waste. Numerous microbial populations involved in the digestion and solubilization of fish waste are necessary for aquaponic systems. Microbial conversion to nitrate is required to stop fish urine and gill discharge from containing hazardous amounts of ammonia. The primary source of nitrogen for plant development in aquaponics systems, nitrite and nitrate are produced from ammonia by the nitrifying autotrophic bacteria consortium, which is made up of nitroso- and nitro-bacteria. Nitrate is less hazardous to fish. Intensive nitrification usually requires a specialised biofiltration device.

To achieve the proper balance between fish nutrient output and plant absorption in different systems, the ideal ratio of plants to fish is essential. For leafy greens growing on raft hydroponic systems, the feeding rate ratio—the quantity of feed per day per square metre of plant varieties—is suggested. A variety of elements, including fish kinds, food composition, feeding frequency, hydroponic system type and design, plant types and physiological stages, sowing density, and water chemical composition, must be understood and experienced in order to find the proper balance. For ideal growing circumstances, environmental factors like as pH, temperature, and mineral concentrations should be balanced.

14.3.2 Benefits of Aquaponics:

- A sustainable and intense food production system.
- A single nitrogen source (fish food) yields two agricultural outputs (fish and veggies)
- Extremely water-efficient
- The growth of plants does not require the presence of soil.
- Doesn't use fertilizers or toxic pesticides.
- Higher yields and better-quality production.
- Increased biosecurity and reduced hazards from external contaminants.
- Improved efficiency in production, resulting in decreased losses.
- Suitable for use on non-arable land, including deserts, damaged soil, and salty sandy islands.
- Generates little waste.

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