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Hydroponics and Its Role in Advancing the Sustainable Development Goals in Libya: Reality and Aspirations

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Abstract

The purpose of this study is to highlight the significance of hydroponics as a modern technology for achieving sustainable development goals in Libya and globally, and to present it as an alternative to traditional agriculture that improves plant growth, crop quality, and productivity by understanding the factors controlling the aquatic environment. It also aims to demonstrate and improve the efficiency of hydroponics as an environmentally friendly and resource-saving technology, and to focus on the practical and financial aspects to encourage wider adoption of these technologies. This study also aims to review the current state of hydroponics in Libya and its future trajectory. Groundwater constitutes over 90% of Libya's water reserves, with the agricultural sector the largest consumer, accounting for approximately 80%. Most reliable studies indicate that food productivity has decreased significantly relative to the water used for this purpose. This study concluded that adopting modern technologies such as hydroponics clearly reduces water consumption, thereby advancing sustainable development across sectors that depend on this water. Regarding the state of hydroponics in Libya, the Ministry of Marine Resources of the Government of National Unity launched the National Hydroponics Project. The project's organizational structure was approved by Resolution No. 53 of 2022, and numerous educational lectures and workshops were conducted in various Libyan cities. Licenses were also granted to several startups to begin operations, and fish feed was distributed to farmers. Those in charge of this project are striving to establish several model farms that will achieve self-sufficiency and the possibility of exporting to neighboring countries, while balancing this with environmental protection and providing a suitable legacy for future generations.

Keywords: *Hydroponics; Sustainable Development; Libya; Food Security; Plant Growth; Crop Quality.*

Introduction

Hydroponics is considered one of the most important modern and innovative methods for meeting the growing need for food, addressing global hunger, and offering new solutions to traditional agriculture. This technology has proven effective in accelerating plant growth and producing large quantities of high-quality crops, resulting in a significant increase in productivity and helping achieve food self-sufficiency. Furthermore, it eliminates the need for chemical pesticides and reduces costs. Hydroponics is a promising solution for poor and unsuitable agricultural soils, as it can be applied in resource-scarce regions or arid deserts, providing an effective alternative to overcome soil limitations. The idea of hydroponics is based on replacing soil with nutrient solutions, where a mixture of essential mineral elements is dissolved in water to create a balanced medium for root growth. The composition of the nutrient solutions varies with the stage of growth and the plant's requirements, thereby supplying the plant with its basic needs [4].

Plant physiology research has shown that soil is merely a medium for anchoring plants and supplying them with nutrients. In hydroponics, these nutrients are delivered directly to the plant in a dissolved form for easy absorption, eliminating the need for soil as a primary medium [23]. Several researchers have also demonstrated that relying solely on soil hinders increased agricultural production, weakening soil fertility and degrading its components. Consequently, alternative technologies have emerged in several countries, including the use of artificial growing media such as sand, rockwool, and perlite. These experiments have shown that hydroponics reduces water, fertilizer, and pesticide consumption while producing high-quality crops year-round [6].

According to [18], given rising food demand, climate and environmental changes, and dwindling water resources, hydroponics has become a leading solution for increasing crop production and achieving sustainable food security. Modern agriculture faces several environmental and economic challenges that threaten the sustainability of food production and the balance of ecosystems.

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Excessive use of fertilizers increases production costs and pollutes soil and groundwater. As climate change accelerates and natural resources become scarcer, the search for agricultural alternatives adaptable to environmental conditions has become imperative. Among the most prominent of these alternatives is hydroponics, which has proven effective in achieving high productivity in small areas while reducing water requirements by up to 90% compared to traditional agriculture.

Furthermore, hydroponics' reliance on vertical farming makes it an ideal option for densely populated cities with limited agricultural land, supporting food security and self-sufficiency. Hydroponics also allows precise control over nutrients and growing conditions, reducing the spread of agricultural pests and diseases compared to traditional agriculture. It also promotes sustainable agricultural production by reducing resource consumption, increasing water use efficiency, and lowering carbon emissions from agricultural activities [1]. Adopting hydroponics as an alternative to traditional agriculture is a crucial step in understanding its advantages and limitations and in exploring its ability to balance agricultural productivity, environmental sustainability, and resilience to climate change. Therefore, this research aims to discuss the pros and cons of hydroponics and highlight its role in achieving sustainable development goals, such as global food security, in light of the future challenges of climate change.

Maintaining a supply of freshwater suitable for human use is one of the greatest challenges, linked to global population growth and food demand. Seventy percent of freshwater is wasted in agriculture. Climate change, including rising temperatures, global warming, decreased rainfall, and increased salinity, has exacerbated drought and desertification in all its forms: climatic drought, characterized by reduced snow, rain, and hail; agricultural drought, resulting from decreased soil moisture; and hydrological drought, including reduced surface water runoff and groundwater depletion. Water resources are essential for humans, animals, and plants and are primarily used for agricultural irrigation. Water demand has increased with population growth and increased plant consumption. Freshwater is precious, making it imperative to use water efficiently and reduce the discharge of fertilizers and chemicals into natural water sources [22].

Benefits and Advantages of Hydroponics

Hydroponics offers several advantages, including efficient water use and recycling, increased crop yields, and the potential for year-round, sustainable food production. It also optimizes space utilization and reduces environmental impact, especially in urban areas and on limited land, because hydroponic systems provide ideal growing conditions. Furthermore, hydroponic systems are less susceptible to pests than traditional agriculture, and the controlled environment reduces the need for pesticides, making them more sustainable and environmentally friendly [26].

Hydroponic systems can be installed in diverse locations, allowing local food production with less labor and reducing the carbon footprint associated with transportation. They also produce crops free of heavy metals and enable the cultivation of fresh produce closer to consumers. Thanks to precise nutrient delivery and controlled environmental conditions, hydroponic systems produce consistently high-quality crops free of weeds and pests such as nematodes, insect larvae, or root-disease fungal spores, eliminating the need for sterilization. This helps reduce soil erosion and environmental impact. It also reduces the risk of nutrient leaching and runoff, minimizing the environmental impact on adjacent water bodies. This is achieved by delivering nutrients directly to the roots, ensuring rapid and efficient absorption. Furthermore, hydroponics provides educational opportunities for students and researchers to conduct practical experiments on plant growth, nutrient management, and sustainable agricultural practices, and it encourages innovation in agriculture. In addition, hydroponics is characterized by higher growth rates, productivity, and crop quality compared to soil-based agriculture [1]. Water is recycled multiple times within the agricultural system, conserving up to 90% of water compared to traditional agriculture. Reduced use of chemical pesticides supports the production of healthy, safe crops. Hydroponics also enables continuous production year-round. Furthermore, it is suitable for arid and urban environments, allowing the establishment of hydroponic farms in cities, desert regions, and enclosed spaces using artificial lighting and environmental control techniques [5].

Media Used in Hydroponics

Soilless agriculture relies on growing roots in porous or non-porous solid materials, providing plants with a suitable medium for growth without the need for soil. These materials may be inert and non-biodegradable or partially biodegradable. Among the most prominent are organic and inorganic media that have proven suitable as mediums for root growth [2].

Organic Growing Media

- **Peat Moss:** One of the most widely used growing media worldwide, peat moss is a naturally occurring, decomposing organic material formed from the accumulation of mosses and grasses in moist, waterlogged areas. It decomposes slowly and is used as a growing medium on its own or mixed with other media such as vermiculite, perlite, or sand to improve agricultural properties. Peat moss is characterized by several properties, most notably its high-water retention capacity, low pH, high organic matter content (94-99%), and high porosity (95-98%), which allow for good root aeration. The darker the color of the peat moss, the higher its decomposition rate, which increases its efficiency as a growing medium [16].

- **Wood Shavings, Straw, Tree, and Plant Residues:** These organic materials are abundant in agricultural and rural environments and are used as supplements or alternative growing media in soilless systems. They are used alone or mixed with other media, such as peat moss or sand, to improve physical and chemical properties and meet plant growth requirements. These media are characterized by several properties, most notably: moisture distribution, light weight, good water retention capacity while providing adequate root aeration, and high cation exchange capacity, which helps retain nutrients for appropriate periods. However, these materials face several challenges, the most important of which are: susceptibility to rapid decomposition and vulnerability to breakdown by microorganisms when high humidity is present, which leads to the depletion of essential nutrients.
- **Rice Husks** are a widely used agricultural byproduct because of their distinctive physical traits. They are lightweight, porous, and aerated, especially when combined with materials like peat moss or perlite. However, they tend to decompose quickly because of microbial activity, which results in the loss of structure and aeration, necessitating frequent sterilization [14].
- **Coconut Fiber:** One of the modern and alternative environments to traditional agriculture, this fiber is widely used in soilless agriculture, especially in greenhouses, where coconut fiber is characterized by its use for long periods that may exceed a year without changes in its nature, slow decomposition, and its ability to retain water and provide the necessary aeration for the roots inside the medium.

Inorganic Growing Media

- **Sand:** One of the oldest materials used as a solid growing medium, granite or siliceous sand is preferred. It can be improved by mixing it with other materials such as peat moss or compost, making it an effective medium for soilless agriculture.
- **Perlite:** A volcanic rock formed from lava, ranging in color from white to gray, composed of aluminum, sodium, and potassium silicates. It is processed industrially by grinding and heating it between 900 and 1000 degrees Celsius, causing internal expansion and the formation of air spaces within the grains, resulting in its lightness and high porosity. Perlite's advantages include: a stable physical structure, although it lacks cation exchange capacity; it is lightweight, easy to handle and transport; it has a high-water retention capacity while allowing for easy drainage; and its high porosity provides good aeration for plant roots. Its grains exhibit capillary action, which facilitates water distribution below the surface.
- **Vermiculite:** A mineral material extracted from mica mines, composed of iron, aluminum, and magnesium silicates. It is obtained by heating the raw ore to 1000°C, which causes moisture to evaporate, the internal layers to expand, and the siliceous layers to separate into small, lightweight, highly porous flakes. This process improves aeration and helps retain water and nutrients for extended periods. Vermiculite's advantages include water retention, essential element content such as magnesium and potassium, and excellent water absorption. It is recommended to use it in conjunction with other materials to prevent waterlogging, which can hinder root aeration.
- **Pumice:** A type of volcanic rock composed of sodium aluminum silicate, it also contains calcium, magnesium, iron, and potassium. It has porous spaces formed by the release of gases and steam during lava cooling. It is extracted naturally and requires no heating or thermal treatment; processing is limited to crushing and grinding for agricultural use, particularly in soilless farming systems. Pumice properties: It is harder and less brittle than perlite, does not readily absorb water, and does not retain it for long periods, making it an excellent drainage medium. Its porosity also promotes good root aeration, contributing to improved soil ventilation and drainage, thus creating a balanced environment for plants.
- **Rock Wool:** First produced in Denmark in 1969, its use spread rapidly. It is a fiber made from 60% diabase (volcanic rock), 20% limestone, and 20% coke. This mixture is melted at a very high temperature to form fibers, which are then formed into mats with a diameter of 5 microns and pressed into sheets [9]. Phenol is usually added to reduce surface tension and to act as an adhesive, holding the rock wool fibers together and creating a spongy or porous environment. Rock wool is characterized by its high-water retention capacity, good root aeration, ease of sterilization and reuse, chemical stability, and ease of shaping and use.

Requirements for a Hydroponic Growing Environment

The growing medium in soilless growing systems stabilizes the plant, balances water and air, and facilitates nutrient absorption. Therefore, the growing medium must possess the following characteristics: porosity, water, and air retention capacity. For healthy root growth, media with a high porosity of 85% are ideal to ensure good aeration and adequate moisture retention. Lightweight and appropriate bulk density: To facilitate transport in large commercial farms or suspended systems, and because density affects the aeration and moisture retention capacity of the medium. Physical stability: The medium should not disintegrate or change shape with repeated irrigation and frequent use, which can lead to clogged irrigation systems or loss of aeration due to particle accumulation in the spaces between the soil. Chemical inertness: The medium should be chemically inert and free from harmful salts or heavy metals. Its pH should be relatively neutral, between 5.5 and 6.5, to avoid affecting nutrient absorption. Hygiene and pathogen-free environment: Sterilizing the growing medium helps eliminate weeds, fungi, and bacteria.

Permeability and good drainage: A balance between permeability and drainage is essential for any growing medium. The ability to partially dry out (dry-back): Air renewal within the medium prevents moisture buildup, which is essential for fungal growth. Media that remain constantly saturated with water reduce aeration efficiency, thus impairing root activity. Stability of physical and chemical properties: Large changes in acidity (pH) or salinity (EC) can disrupt nutrient absorption, negatively impacting plant growth and productivity [17].

Hydroponic Systems:

Hydroponic systems are either liquid or compound. Liquid systems do not include a root support medium, whereas compound systems do. Hydroponic systems are also classified as open systems (once the nutrient solution reaches the roots, it is not reused) or closed systems (excess solution is recovered, renewed, and recycled) [27].

- **Closed System:** This system is economical and uses nutrient membrane technology. However, continuous monitoring and adjustment of the nutrient solution are essential. Chemical tests should be conducted every two to three weeks for the major elements (N, P, K, Ca, Mg) and every four to six weeks for the trace elements (Na, B, Cu, Fe, Mn, Mv, Zn). Fertilizers must be added to the nutrient solution at carefully calculated concentrations to prevent the accumulation of some elements and the depletion of others. The system may require daily or weekly chemical additions. A quantity of the solution is added initially, and at the end of the first week, half the initial quantity is added. At the end of the second week, the tanks are emptied, their contents discarded, and the process is restarted.
- **Open System:** The nutrient solution is not recycled or covered, and it does not require monitoring or adjustment because the components are consumed from the time they are mixed until they are depleted. The quality of the irrigation water in this system is not important, allowing the use of water containing 500 parts per million of salts. The growing medium in which plants grow in saline irrigation water, or the medium exposed to warm sunlight, must be monitored, with sufficient irrigation water applied to prevent salt accumulation. The filtered water must also be tested periodically to measure the amount of total dissolved salts in it. If its concentration exceeds 3,000 parts per million, the system must be flushed with ordinary water [8].

Table 1: Differences between Closed and Open Systems

Parameters (%)	Hydroponic system			
	Media soilless System		Nutrient solution System	
	Open	Closed	Open	Closed
Irrigation water saving	80	85	85	90
Fertilizer saving	55	80	68	85
Productivity increase	100	150	200	250
Water productivity	1000	1600	2000	3500

- **Solid Systems** use flat or vertical plastic bags and are considered open systems, while rock wool systems can be either open or closed. A rock wool system is considered closed when excess nutrient solution is stored and reused. If the nutrient solution is not reused, sensitivity to the medium's composition and water salinity is reduced.
- **Liquid System:** It does not require placing the roots in a solid medium. It is a closed system in which the roots are directly exposed to the nutrient solution without any medium. The solution is also recycled and reused.

Hydroponic Farming Methods

Hydroponics includes several techniques such as: Nutrient Film Technique, Raft Technique, Ebb & Flow Technique, Drip Technique, Aeroponic Technique, and Wick Technique. Several other systems are either derived from or a combination of these methods.

- **Deep Water Culture Systems:** Deep water culture (DWC) is one of the simplest and most common hydroponic methods. Mesh pots containing plants are suspended above a deep tank of oxygen-rich solution. The roots are immersed in the solution, and oxygenation is vital for plant survival. This is achieved by adding an air stone connected to an air pump at the bottom of the tank to supply the entire system with oxygen. Based on Park & Kurata (2009), the bubbles from the air stone help circulate the nutrient solution. This technique is easy to assemble using a clean bucket or water basin to hold the solution and a floating surface, such as Styrofoam, on top to house the mesh pots. Only the roots are submerged in the solution, and about 2.5 cm of roots can be left above the waterline. This technique is characterized by low equipment purchase and maintenance costs, requiring only the renewal of the nutrient solution every two to three weeks. A drawback is that it is a limited system for growing herbs and lettuce, and is not ideal for any flowering plant. However, plants such as tomatoes, peppers, and squash can be grown. Another disadvantage is the difficulty in regulating the water solution temperature, which should ideally be between 15 and 20 degrees Celsius.

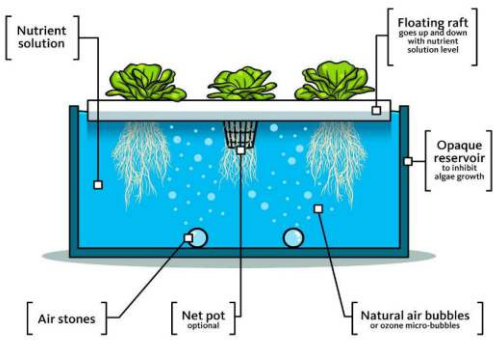

Figure 1: Deep Water Culture System (DWC)

- **Wickling Technology:** In this technique, plants are placed in a growing medium on a tray above a reservoir containing a nutrient-rich aqueous solution. Wicks extend from the reservoir to the growing tray, and water and nutrients flow up the wicks, saturating the growing medium around the roots and facilitating the transport of the aqueous solution. Wicks are made of rope, twine, or felt, and the technique relies on capillary action to transport the aqueous solution. This technique does not require mechanical parts, such as pumps, to operate because the wicks are placed close to the roots. Although the Wickling technique does not require aeration, an air stone and an air pump can be added to the wick system's reservoir, providing additional oxygen to the hydroponic system. The advantages of wick irrigation include its simplicity of construction and operation, and the continuous watering of plants, thus eliminating the risk of drying out. This technique is also space-efficient. However, its disadvantages include a limited range of crops that can be grown, such as fast-growing lettuce, rosemary, mint, and basil [10]. Additionally, this technique can be susceptible to rot, increasing the risk of fungal growth.
- **Nutrient Film Technique (NFT) Systems:** NFT systems suspend plants above a continuously flowing stream of nutrient solution. Water flows along the growth tray before draining into a reservoir, which is aerated by an air stone. In this technique, the roots are not submerged; instead, the stream flows only over the root tips, removing moisture and allowing the exposed roots access to oxygen. This prevents water from pooling or clogging the root systems. Therefore, the nutrient solution must be renewed weekly. This technique is a popular commercial system due to its ease of mass production and suitability for growing lightweight plants such as mustard, kale, lettuce, spinach, and strawberries. Heavy fruit-bearing plants such as tomatoes and cucumbers require trellises to support their weight [12]. One advantage of nutrient membrane technology is that it does not require large quantities of water, nutrients, or growing medium. It is also very easy to expand and fertilize with a separate reservoir. However, the pump's performance must be monitored and protected from malfunctions, and plants should not be planted too close together to avoid blocking the nutrient dams supplying the roots.

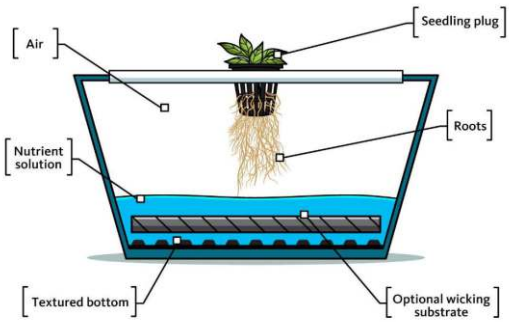

Figure 2: Nutrient Film Technique

- **Ebb and Flow Hydroponic System:** This system floods the growing layer with a nutrient solution from a reservoir. Gravity then slowly drains the water from the growing layer and returns it to the reservoir. The system includes an overflow pipe to prevent the water level from exceeding a set point and damaging plant stems and fruit. In an ebb and flow system, plants are not constantly submerged, which helps maintain ample oxygen and nutrients, promoting rapid, vigorous growth. This system is easily customizable and versatile, accommodating almost any type of plant; therefore, it is one of the most popular systems. Rocks and clay pebbles are among the most common growing media in tidal hydroponics due to their ease of cleaning and reuse, lightweight, and ability to retain moisture. However, care must be taken to maintain the pump's functionality and prevent the plants from rotting or becoming infested with insects. Furthermore, some plants do not respond well to the rapid pH changes caused by the tides [24].
- **Drip Irrigation Systems:** Drip irrigation is among the most widely used systems. A nutrient-rich solution is pumped through a network of pipes to individual plants. The solution drips slowly into the growing medium surrounding the root system, keeping plants well hydrated and supplied with nutrients. Drip irrigation can be used for individual plants or large-scale operations. There are two types of hydroponics in drip systems: recoverable and non-recoverable. In recoverable systems, excess water is drained from the growing layer back into the reservoir for recycling. In non-recoverable systems, excess water is drained from the growing medium and becomes waste. Although non-recoverable drip systems may seem wasteful, they are designed to deliver precisely the required amount of solution to keep the growing medium around the plant moist. Non-recoverable drip irrigation systems use precise timers and feeding schedules to minimize losses [21]. One advantage of drip irrigation is its versatility; it supports a wide variety of plants and works best with slow-draining media such as rockwool, coconut fiber, and sphagnum moss. Drip irrigation can easily support large-scale hydroponic systems, and additional reservoirs can be added.
- **Aeroponics Technology:** This technology suspends plants in the air and exposes the roots to a nutrient-rich mist. Water and nutrients are stored in a reservoir and pumped through a nozzle that atomizes the solution, distributing it as a continuous fine mist around the roots. Aeroponics does not require a substrate, as the constant exposure of the roots to air allows for oxygen absorption and accelerated growth. This means it uses less water; aeroponics crops require 95% less water than irrigated fields. Furthermore, because the roots are exposed to maximum oxygen levels, aerobic plants grow faster.

This technique allows for year-round harvesting of crops like tomatoes, peppers, and eggplants, which thrive in an aerobic environment. However, large, heavy fruit trees and root vegetables such as carrots and potatoes cannot be grown aerobically [15]. Aeroponics, with its excess oxygen, is one of the most environmentally friendly and versatile systems, achieving high-quality results. It is also easy to transport. However, it requires regular maintenance and is expensive.

- **Aquaponics:** This modern technology combines hydroponics and fish farming. It uses fish waste as a natural source of nutrients, while plants purify the water, making it suitable for fish. This combination represents an ideal model for sustainable agriculture, creating a highly efficient closed-loop ecosystem [7].

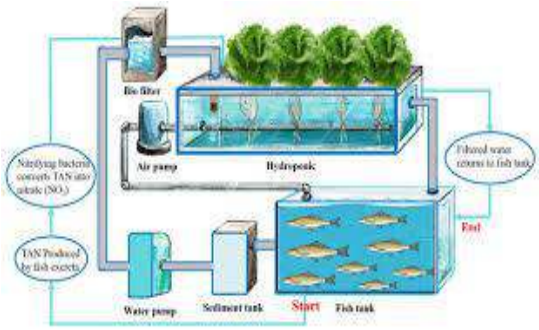

Figure 3: Aquaponics System

Hydroponic Equipment and Supplies

Hydroponics requires several devices and tools, so it is expensive to set up and requires expertise in adjusting pH, EC, and soil solution levels. This necessitates having these tools available for periodic measurement to prevent malfunctions in the hydroponic system.

pH and EC Meters

- **PH Adjustment:** A slightly acidic to neutral pH is optimal for hydroponic plant growth. The ideal pH range is 6.5-7, though each plant has specific needs. If the pH drops below 6 or rises above 8, some nutrients begin to precipitate and become insoluble, while others are absorbed more readily, leading to plant toxicity and death. If the pH is too high, it can be adjusted with acids such as phosphoric or nitric acid. If it is too low, it can be adjusted by adding potassium or calcium carbonate. The importance of pH adjustment lies in ensuring optimal and rapid nutrient absorption and maintaining plant health. Fluctuations can lead to nutrient deficiencies or toxicity, negatively impacting plant growth. pH meters help in the early detection of pH imbalances [11].
- **EC Adjustment:** The optimal water concentration for hydroponic irrigation is approximately 750-850 ppm. Each plant has specific needs; some are salt-tolerant, while others are not. In these cases, salinity is adjusted by adding more water and reducing fertilizer application. Salinity measurement is crucial for controlling nutrient dosages and avoiding both over- and under-nutrient deficiencies.

Salinity levels affect nutrient uptake by plants, impacting their growth and development. Monitoring salinity helps prevent nutrient imbalances that can lead to plant toxicity. By controlling salinity levels, nutrient concentrations can be optimized to maximize plant productivity.

- **Temperature Control:** Each plant has an ideal temperature for growth, which is maintained by cooling systems such as fans or heating. Temperature control is crucial in hydroponics for providing optimal growing conditions by preventing stress and strain on plants, which can negatively impact their health, productivity, and disease resistance. Using temperature control systems allows for improved energy efficiency and reduced operating costs in hydroponic environments. Automatic adjustments are also possible, ensuring precise temperature management in hydroponics.
- **Air Hygrometer:** This device monitors and controls the environment around plants, especially in enclosed spaces. If humidity falls below the required level, the control unit activates humidification and dehumidification systems. The importance of air hygrometers for growing media lies in their ability to help determine the appropriate amount of water plants need to prevent root rot. Maintaining suitable humidity levels for nutrient absorption positively impacts growth and productivity, enhancing crop efficiency and quality.
- **Air Pump or Oxygen Stones:** The hydroponic system should include an air pump, air stones, or air diffusers to increase oxygen levels in the growing medium and nutrient solution for optimal plant growth.
- **Pruning and Staking Tools:** Proper pruning with tools like shears promotes airflow and light penetration, reducing disease risk and supporting healthy plant growth. Staking tools such as trellis netting and plant ties provide support, prevent breakage under the weight of fruit, and maintain a structured growth pattern suited to the greenhouse height. They are also used for layering crops like tomatoes and cucumbers, providing low-stress training.
- **Nutrient Tank (Nutrient Solution Container):** The nutrient tank serves as the entry and exit point for the nutrient solution to and from the system. It must be clean, free of sediment, dark in color, and of sufficient capacity to accommodate the size of the farm. Irrigation lines extend from this tank to the growing system.
- **Submersible Water Pump:** This device pumps water from the tank to the plants. The pump may be located outside the nutrient tank.
- **Planting Tubes and Basins:** Planting tubes and basins may be vertical, terraced, or tubular. A tube system provides natural aeration without artificial aeration because the tubes are not filled with water and only come into contact with the plant roots. Oxygen is generated as the water returns to the basin. In basin systems, however, there is almost no aeration, so water circulation or an oxygen generator is required.

- **Seedling Cups and Supports:** Seedlings are placed in perforated cups filled with a stabilizing medium such as rocks, most commonly tufa or perlite, to prevent movement. Cups are available in various sizes depending on the plant type and its stage of life, and they are inexpensive and readily available. The seedling cups are placed in pre-prepared openings in the tubes or basins at appropriate intervals according to each plant's specific needs.
- **Irrigation Connections:** These are standard irrigation lines, and the connections can be controlled based on farm conditions and construction methods. Their purpose is to ensure the nutrient solution reaches the plants from the nutrient reservoir and returns without issues. These connections also include special fittings for extension, facilitating connection, and irrigation control.

Nutrient Solutions

Properly making them requires expertise, so they are readily available in the market. They come in two sets: one containing macronutrients and the other containing micronutrients. They also include containers for adjusting the solution. Beginners can make a nutrient solution from an infusion of organic fertilizers, adjusting only the pH and EC, and then use it to grow leafy vegetables.

Essential Nutrients

Plants cannot function without essential nutrients. These nutrients are necessary for the vital processes of plant growth and development. Essential nutrients are broadly classified into macronutrients and micronutrients. Macronutrients include carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, sulfur, calcium, and magnesium. Micronutrients include iron, manganese, zinc, boron, molybdenum, chlorine, copper, and nickel. The difference between macronutrients and micronutrients lies in the quantity required by the plant. Plants need macronutrients in larger quantities than micronutrients. Plants obtain carbon, hydrogen, and oxygen from the air and water. The remaining nutrients come from the soil or, in hydroponics, from nutrient solutions or collection media that provide nutrients available to plants [25].

pH (potential of hydrogen)

In hydroponics, attention must be paid to the pH of the water used to prepare nutrient solutions and irrigate plants. The optimal pH range for hydroponic vegetable cultivation is between 5.0 and 7.0. It is also important to consider the water's alkalinity. Alkalinity is a measure of water's ability to neutralize acid. When total alkalinity is low, the water's capacity to neutralize acids is poor. As a result, the pH changes easily depending on what is added. When total alkalinity is high, the water's pH tends to be high. Acid can be added to the irrigation water to lower the high pH. The amount of acid required depends on the water's alkalinity.

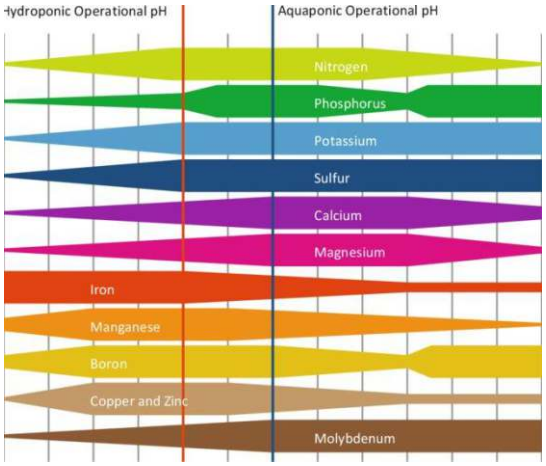

Figure 4: The relationship between nutrient availability and pH in hydroponic systems (Red line represents a normal operating pH for a hydroponic system; the blue line represents that for an aquaponic system)

Nutrient Antagonism and Interactions

Plants absorb nutrients from the nutrient solution in roughly equal amounts. However, when one nutrient is in excess, it can be absorbed in greater quantities at the expense of another. This is known as antagonism. In this case, the concentration of one nutrient in the nutrient solution may be sufficient, yet the plants still suffer from a deficiency of that nutrient.

Table 2: Nutrient Incompatibility

Antagonal	Nutrient
Nitrogen	Potassium
Phosphorus	Zinc
Potassium	Nitrogen, Calcium, &Magnesium
Sodium	Potassium, Calcium, & Magnesium
Magnesium	Calcium
Iron	Manganese

Nutritional Problems:

Nutrient problems can cause rapid symptoms in plants. Therefore, proper nutrient solution formulation and regular monitoring of the plant's nutrient status are crucial.

- **Damage from Soluble Salts:** Plant damage from soluble salts can result from over-fertilization, poor water quality, salt accumulation in the collection medium, or inadequate filtration. This damage can be identified by symptoms such as wilting, leaf margin drying and burning, and root death despite adequate irrigation. Therefore, soluble salt levels should be monitored by tracking the electrical conductivity (EC) of irrigation water, nutrient solutions, and leachate. Dissolved salts can be removed by using purified water [13].

Conditions That Must Be Met in the Nutrient Solution

- The nutrient concentration in the nutrient solution must not exceed the required level, as this can lead to stunted plant growth and death. Therefore, when calculating the quantities of nutrients to be added, the concentration of salts (nutrients) in the water used to prepare the nutrient solution must be determined first.

- When preparing the nutrient solution, the plants' nutritional needs must be considered based on the plant species and growth stage.
- The pH of the nutrient solution must remain stable, ideally between 5.5 and 6.5.
- The properties of the water used to prepare the nutrient solution must be known. If well water is used, its nutrient content may vary by region. Therefore, it must be analyzed before use to ensure that the concentration of certain elements is not excessive.

Factors Affecting the Success of the Nutrient Solution

- The nature of the raw materials used to prepare the nutrient solution plays a significant role in the quality of the nutrient solution itself.
- The purity of the raw materials (fertilizers); the higher the purity of the raw materials, the more readily the nutrient solution elements dissolve and become available to the plant without causing stress.
- The temperature of the nutrient solution plays a major role in the solubility of nutrients within the solution.
- The hydroponic system used; the components of the nutrient solution are constant, but the management of the nutrient solution, the method of adjusting its concentration, and the amount of added nutrient solution vary.
- The nature of the crops grown; nutrient solution management varies from one crop to another, depending on the crop's characteristics and variety.

Disadvantages of Hydroponics

Hydroponics is expensive to set up and operate, requiring specialized equipment such as water flow systems, pumps, environmental control systems, and artificial lighting in some cases, as well as the preparation of nutrients and chemicals. It consumes significantly more water than traditional agriculture, which can be a particular problem in water-scarce regions or arid environments. Many hydroponic systems require electricity to power pumps, control systems, and artificial lighting, and this can have a negative environmental impact if unsustainable energy sources like coal or fossil fuels are used. Hydroponics also requires complex techniques, specialized knowledge, and meticulous management. Hydroponics can lead to infections and environmental pollution, and pollution can occur in hydroponic systems if chemical nutrients are used incorrectly or if chemicals leak into groundwater or nearby wetlands. Hydroponic systems rely heavily on advanced technology and specialized equipment, which can be both financially and technically challenging. Some traditional plant varieties may be difficult to cultivate, reducing the genetic and biological diversity of the crops grown. Hydroponics requires continuous work and regular monitoring of the crops. Despite these drawbacks, hydroponics is popular nowadays because of its environmental and economic benefits, and some of these drawbacks may be addressed through future technology and innovations [3].

Hydroponic Diseases and Their Control

[20] reported that root rot is one of the most common diseases in hydroponics. It damages plants and can destroy entire crops, unlike diseases that affect flowers and outdoor plants. Common signs of root disease include: yellowing of leaves, especially the lower ones, which may indicate the roots are at risk; wilting and drying, even with adequate watering, which suggests the roots are not absorbing enough water; and slow growth, which indicates root problems. These signs can be identified by monitoring changes in root color, as diseased roots appear brown or black. A foul odor emanating from the root area is also a clear indication of root rot or the presence of harmful bacteria and fungi. Common hydroponic diseases mainly involve water-borne root pathogens and fungal infections that thrive in high humidity. Major offenders include Pythium root rot, Fusarium, and Botrytis (gray mold), as well as foliage problems like powdery and downy mildew. These issues often lead to wilting, brown, mushy roots, and overall stunted growth. Preventing these conditions effectively requires strict sanitation, careful temperature regulation, and proper nutrient management.

How to Prevent Plant Diseases in Hydroponics

Diseases spread rapidly in hydroponic environments where humidity and suitable temperatures are ideal for their growth and reproduction. They can wipe out the crop within a day or two because there is no soil, sunlight, or weather conditions to slow their spread. Therefore, it is crucial to take all necessary preventive measures to avoid the emergence of any disease. These measures include:

- **Providing Adequate Ventilation:** It is important to continuously monitor humidity levels inside the greenhouse and maintain a relative humidity of 50-70%. This range provides the best compromise for disease prevention. Use fans to circulate fresh air around the plants. Also, maintain spacing between plants and reduce foliage density through appropriate pruning to allow air to circulate.
- **Preventive Water Treatment:** It is important to add a preventive fungicide when preparing the nutrient solution to eliminate potential pathogens. Continuously monitor water quality to ensure it is free of contaminants or pathogens, and check the pH level and nutrient concentration.
- **Use Water Filters:** Use mesh, ion exchange, or reverse osmosis filters to remove sediment and harmful contaminants, improve water quality, and reduce the risk of algae growth.
- **Ensure Good Drainage Within the System:** Use a growing medium that provides good drainage. Ensure there are no blockages that could cause waterlogging and increased humidity in the root zone.
- **Avoid Stressing the Plant:** Provide appropriate temperature and light, supply adequate nutrients, and maintain the correct nutrient concentration and pH.

- **Use Healthy Seeds and Seedlings:** Seeds and seedlings can be a source of diseases and pests. To prevent this, disinfect them with a preventive fungicide.
- **Clean and Disinfect the Entire Water System After Each Crop Cycle** by removing plant remains and growing media, disassembling the system, manually cleaning each part, then filling the tank with a water solution containing a disinfectant and running the pump several times over 24 hours until traces of the disinfectant disappear.

The Reality of Hydroponics in Libya

Many economic and technical studies have proven the existence of great potential for establishing a developed and highly productive fish farming sector in Libya. Although attempts to develop this sector began in the seventies of the last century, specifically in 1977, with the planting of 220,000 fingerlings of carp in the waters of the Wadi Al-Majinin Dam Lake, followed by several farming operations in inland lakes and dam waters, the first fish farm established with its equipment was the Ain Al-Ghazala farm in Tobruk in 1989. Many plans were put in place to develop aquaculture by establishing model farms in different locations, but a very limited number of farms were actually established, some of which entered production, some were not completed, and others stopped due to technical errors. It is expected that the reasons behind the absence of fish farming activity, despite the existence of capabilities and resources, are due to the absence of a national project that manages, leads, invests in the capabilities of this sector, raises its efficiency, and involves it in the overall development process in Libya. For this reason, this national project for aquaculture was created.

The National Hydroponics Project seeks to develop the fish farming sector, rehabilitate stalled projects, and establish modern projects that contribute to expanding both hydroponics and fish farming activity. The project also aims to strengthen partnerships with the private sector and attract domestic and foreign investments. The general vision of the national project is a developmental and reformist vision built according to the data of sustainable development, to achieve a set of goals that serve the fisheries sector and contribute to its growth and development, making it not only a source of food, but also an important wing of Libya's economic launch. Over the past decades, the Libyan government has established public sector projects at various times. These projects are currently either inactive or operating very poorly and require rehabilitation. They will be among the objectives of the National Aquaculture (Fish) Project, and their rehabilitation will be based on the degree of malfunctions and problems they face, and according to the available rehabilitation and repair capabilities.

Conclusion

To conclude, hydroponics is a key modern agricultural technology, emerging in response to rising global food demand, limited arable land, and worsening soil degradation and pollution. This technology feeds plants directly through a nutrient solution without soil, making it an effective alternative to traditional agriculture, especially in arid regions or areas with limited water resources.

- Hydroponics offers faster plant growth and higher crop quality, conserves water by up to 90%, reduces reliance on pesticides, and enables year-round production in controlled environments. It also helps address food security and climate change. Among the most important hydroponic systems are Nutrient Film Transplanting (NFT), Aeroponics, and Deep-Water Culture (DWC). Several growing media are used in hydroponics, both organic (peat moss, coconut fiber, sawdust, etc.) and inorganic (sand, perlite, rockwool, etc.). Each medium has its own characteristics, advantages, and disadvantages. These media must meet requirements for porosity, lightness, aeration, cleanliness, and chemical and physical stability. Hydroponics requires a range of supplies and equipment, as well as sterilization and disease prevention. Therefore, it is essential to know the proper methods for controlling these diseases. In the near future, hydroponics seems to have good chances of making money when combined with strategies including solar power and rainwater management systems. Given the anticipated 70% rise in global food consumption by 2050, hydroponics also has a significant role in feeding the growing population because of its effective use of resources and production. The technology can include many future foods supply solutions; thus, more research and development on less

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