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Aeroponics: An emerging food growing system in sustainable agriculture for food security

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Abstract
Aeroponics is a relatively new soilless culture methods that is becoming popular because of its fast maturation, it is cheap, and it is different. This kind of technology allows for things like effective nutrition in root zone, climate control, and plant health diagnostics, which helps in transition to sustainable agriculture. By integration of aeroponics into food production, we can address global food security challenges while promoting sustainable agriculture. This systematic review of 47 studies provides an overview of the state and direction of aeroponic technology, its promise and its problems. Also, the TAISA model (Technology Adoption and Integration in Sustainable Agriculture). Besides the fact aeroponics allows for the maximum yield per square foot, but it also is environmentally friendly, which is a crucial answer for sustainable agriculture.

Keywords: Aeroponics, sustainable agriculture, food security, soilless culture, Taisa

Introduction
Aeroponics is a relatively new method of producing plants that is becoming more and more popular with many people because of its speed, cost, and novelty. It is a promising soilless farming approach for solving future food crises. Aeroponic farming is a sort of vertical farming and a variation of hydroponic farming. With this farming approach, the farmer has full access to the roots during the crop's life and can precisely regulate the nutrients, watering schedule, and environmental factors that affect the root zone. The technique of aeroponics grows plants in air without the need for soil. In other words, the entire plant's roots are all floating in midair. Two Latin words, "aero" (meaning air) and "ponos" (meaning labor), are the origin of the word aeroponics. Aeroponics is a viable option for individuals with limited crop-producing space. An aeroponics system is an enclosed habitat of water, nutrients, and air that supports plant growth in the absence of soil, less water, and direct sunshine (Birkby 2016) [13].
With the global use of potato varieties, there is a large gap between higher yields and lower yields among countries. Potatoes are a cash crop and an important part of the global diet. Therefore, low soil fertility, soil-borne diseases, poor water quality, and pests seriously affect potato production in developing countries. To improve potato quality and production, it is necessary for the modern world to improve its potato cultivation techniques. Aeroponics cultivation is an alternative technology of soilless culture for effectively adapting to areas of the world where soil and water are in critical condition. In addition, most developing nations should implement this method to enhance potato output. In addition, most developing nations should implement this method to enhance potato output. A crop of the genus Solanum, the potato (*Solanum tuberosum* L.) is an annual that originated in the Andes, close to the boundary between Bolivia and Peru in South America. In the 16th century, the potato made its way from South America to Europe, arriving in Spain. (Tunio *et al*. 2020) [33].
Aeroponics is a soilless farming method in which plants are grown by nutrient-rich fluid over their roots. Aeroponics has changed as a result of technology, which now offers advantages including automated nutrient supply, environmental management, and plant health monitoring. This research conducts a systematic review of 47 studies to establish the present status and trends in the use of technology in aeroponics, as well as the key possibilities and challenges.

The Technology Adoption and Integration in Sustainable Agriculture (TAISA) model is also discussed. There is a continuing need to produce more food because of the growing world population. Rising food production concerns global sustainability since it requires more energy, water, and soil resources. Similarly, excessive land use and intensive agricultural practices can result in nutrient depletion, soil erosion, and a loss of soil fertility, all of which can reduce the land's production. The Food and Agriculture Organization suggested using sustainable agriculture methods, including aeroponics, hydroponics, and aquaponics, to improve the problem. (Kumar *et al*. 2024) [16].

Crops grow faster in an aeroponics system because nutrients are delivered directly to the plants' roots. Aeroponics is also commonly used as a research tool for various plant species that are difficult to reproduce. The current study shows that, with the exception of leaf area, which was shown to be maximal in nursery conditions, plants grown in an aeroponics system were at their peak for all growth parameters. The treatments with the highest growth parameter values were T3 (three buds per cutting), T2 (two buds per cutting), and T1 (one bud per cutting). The mulberry, or *Morus* sp., is a common woody plant that is a member of the Moraceae family and genus *Morus*. *Bombyx mori* L, the silkworm, mostly feeds on its leaves, which is why it is cultivated for its economic significance in the silk industry. Mulberries are typically propagated in India using cuttings. Plants are most frequently multiplied via cuttings since it is a simple process, multiplies quickly, and is inexpensive. While stem cutting propagation is feasible and currently employed, promising genotypes' weak rooting capacity poses a significant obstacle to large-scale multiplication, which is a severe issue for mulberry breeders. The most readily available growing medium for plants is typically soil. For the growth of plants, it offers anchoring, nutrients, air, water, etc. But soils do offer a problem (Nishchitha *et al*. 2023) [22].

A reusable and affordable aeroponics system was developed based on an idea proposed by French engineer René Odorico. It consists of two main components: a commercial waterproof industrial humidifier with a silicone sealant and a modified garbage can with holes in it. Plant roots grow in a flood of hydrothermal fluid that is brought in and hangs from the holes in the lid of the garbage can. The aeroponics system is the workhorse of the laboratory, and the results of its use have been available to scientists for decades. Soil culture refers to the method of growing plants using an aerobic nutrient solution without the need for soil. Hydroponics has been developed from many sources, with different applications depending on the type of plant. Hydroponics has been developed in many ways, including different applications based on plant type, growing conditions, budget constraints, etc. Usually buried in nutrients-rich solutions. In some hydroponic systems, plant roots may be submerged in a regularly circulating nutrient solution in a pipe system or may involve placing plant roots in an aquaponic system, recycling nutrients from fish tanks (Barker *et al*. 2006) [4].

History of Aeroponics System

Aeroponics is a soilless cultivation method began with research programs in the 1920s, and was evolved slowly. It was obsolete in mid 1930s but saw limited use throughout World War II mostly as a research tool rather than commercial use. The first work on aeroponics was done by W. Carter in 1942 and described a process through which water vapor is used as the medium to feed plants at their root zone. Plants can be grown in water vapor to make it easier to examine their roots. This method was discovered by L. J. Klotz in 1944 while studying citrus and avocado root infections. G. F. Trowel later used this method to examine apple tree roots in 1952. The term "aeroponics" was coined in 1957 by Warmolt to describe this air-growing method (Kaur Gagandeep 2014) [15]. NASA research indicates that plants grown aeroponically have a dry weight up to of only 80% as compared to plants grown hydroponically. NASA has concentrated especially on aeroponic methods as a mist is simpler to manage in zero-gravity conditions than a liquid (Brunner *et al*. 2014) [5].

Types of aeroponics

1. **Low-pressure units:** Low-pressure Units: In most low-pressure aeroponic gardens, the plant roots are suspended above a reservoir that is either filled with nutritional solution or an internal channel that connects to a reservoir. The nutritional solution is supplied by a low-pressue pump through jets or ultrasonic transducers, which later drip or drain back the nutrients to the reservoir. when Plants are matured some dry spots appear in their root systems. which prevents them from taking up adequate nutrients. These devices can't clean the nutrient solution or get rid of unwanted bacteria or debris because of their high cost.
   For these units, benchtop growth is usually acceptable. It is also utilized for illustrating aeroponics.
2. **High-pressure units**: A high-pressure pump produces mist in high-pressure aeroponic devices. Additionally, it is typically used in the production of high-value crops. This technique uses low-mass polymers, pressured nutrition delivery systems, low-oxygen air and water purification, and nutrient sterilizing technologies.
3. **Commercial system:** The commercial system uses biological systems and hardware for high-pressure devices. The biological systems matrix has an increase for longer plant life and crop maturation.

Technical setup of the aeroponic system

Plants are grown in a sealed chamber in an aeroponics system. The chamber is lined with a black sheet to keep it dark and humid. Nutrient solution is sprayed onto the roots by nozzles on PVC pipes. A pump pushes the solution through the pipes. A timer controls the timing of fertilizer to be sprayed. The size of the system, the plants, the nozzle distance and pressure, the net pot spacing, the pump power, the nutrient spraying, and the time between sprays can all change. The pipes in the chamber connect to a nutrient tank that recycles the solution that drips from the roots (Sharma *et al*. 2018) [28]. Growing chambers and misting systems provide a controlled environment that meets every plant’s needs. Such systems create an environment where temperature, humidity, nutrients, and oxygen levels are managed correctly for favorable growth and development conditions (Amankwaa-Yeboah *et al*. 2022) [3]. This precision and control not only ensure healthy plants but also allow scientists to study plant physiology and breeding techniques in the controlled environment (Moffat *et al*. 2019) [21]. Additional sensors can be used to check how long and how often a nozzle is ON or OFF so as to regulate nutrient delivery. (Moffat *et al*. 2019) [21]. Unlike hydroponic systems, however, aeroponics systems come in many different shapes or sizes

Working of the Aeroponic System

Roots of plants are continually sprayed with a nutrient solution in an aeroponics system, which makes them constantly wet with

nutrient solution (Agina Effat *et al*. 2018) [1]. The irrigation system in the growth chamber gets the nutrient solution via pipes that pump it into the root zone (Chowdhury *et al*. 2020) [7]. The size of the tank depends on what type of crop grown and its water requirements. Aeroponics uses substrates in grow net pots. Inside the growth chamber, there is no substrate like soil for roots as they are free hanging. (Kasahyap S 2020) [14]. While the plant roots get nutrient solution sprayed on them, a drip-back system carries unused nutrients back to main tank (Priyanka BJ *et al*. 2020) [25]. Optimal temperatures and humidity can be maintained within these chambers for fasters growth. (Sumarni E *et al*. 2013) [30]. Sunlight is blocked from reaching the growth chamber through a black plastic sheet as to avoid algae formation. (Selvaraj *et al*. 2019) [27]. Since plants do not compete for space, within the clean and nutrient rich environment of Aeroponics system it is possible for them to grow more quickly and resulting in increased yield. (Tunio *et al*. 2020) [33].

Droplet size for Aeroponics system

For most plants, mist droplets between 20 and 100 microns are ideal. These small droplets saturate the air and keep the chamber humid. Large droplets between 50 and 100 microns in diameter contact the roots best. Smaller droplets (under 30 microns) tend to float as fog. Larger droplets (over 100 microns) usually fall before reaching the roots. Large droplets can also limit oxygen access to the roots (Sahoo D.2020) [26]. By precisely controlling the droplet size of the nutrient solution, aeroponics systems can create optimal conditions for plant root development. (Devederkin *et al*. 2021) [10]

Nutrient solution used for the soilless culture

The nutrient solution is primarily composed of inorganic ions from soluble salts that are essential for plant growth. While most plants require 17 elements (Carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, iron, copper, zinc, molybdenum, manganese, boron, chlorine, and nickel), the nutrient solution provides by the nutrient solution but carbon and oxygen, which are obtained from the atmosphere. (Trejo-Tellez *et al*. 2012) [32] Hydroponic and aeroponics growers might use similar methods to absorb fertilizers and water. The quality and quantity of produce will grow and fast and better with a constent supply of nutrients (Eldrigde *et al*. 2020) [11].

Table 1: Concentration of nutrient in a commercial aeroponics system (Cooper A. 1988) [8]

Nutrient	Cooper (1988) [8]
N	200-236 mg/L
P	60 mg / L
K	300 mg / L
Ca	170-185 mg /L
Mg	50 mg /L
S	68 mg /L
Fe	12 mg / L
Cu	0.1 mg /L
Zn	0.1 mg /L
Mn	2.0 mg /L
B	0.3 mg /L
Mo	0.2 mg /L

Use of computer intelligence in aeroponics

Modern agriculture, conducted in controlled environments, requires advanced technologies to maximize efficiency and profitability. Automated computer systems can provide valuable decision-making support and monitoring capabilities, reducing human intervention and optimizing system performance (Tik LB *et al*. 2009) [31]. A recent study explored the use of computer intelligence and advanced wireless networks in different industries. The researchers found that agriculture is a promising area for these technologies. They believe that by incorporating computer intelligence into controlled agricultural environments, we can significantly improve farming efficiency (Akyildiz *et al*. 2002) [2].

"Aeroponics, a soil-free plant cultivation method, requires precise control of environmental conditions. This can lead to various challenges related to nutrient solutions, equipment failures, and environmental factors like temperature, humidity, and light. To prevent plant damage and ensure optimal growth, growers must carefully monitor and manage these issues. Modern technologies, such as artificial intelligence, can help automate monitoring and provide valuable insights for addressing these challenges (Pierce FJ. 2008.) [24]. The researchers found that a neural network system is effective at identifying mechanical and biological problems in a deep trough system. The system can detect faults related to sensor data like nutrient solution levels, pH, humidity, temperature, and light and biological factors like transpiration rate light intensity, temperature, ventilation (Pala M, *et al*. 2014) [23].

Mechanization and optimizes aeroponice root condition

Humans have long sought to understand and control their environment, including plants and their ability to thrive in different conditions. Research has shown that the availability of essential minerals plays a crucial role in creating a favorable root environment for plant growth

Hayden (2006) [12] reported that plant root development stated that there are several stages, including the growth of new root axes. The structure of the root system is influenced by the surrounding environment, with changes in growth patterns and branching likely mediated by plant hormones. These hormonal responses contribute to genetic variations in root architecture and plasticity.

(Lynch *et al*. 2012) [18] plant root growth and development rely on a sufficient supply of carbohydrates produced through photosynthesis. Factors that influence photosynthesis, such as water availability, light intensity, temperature, and nutrient levels, can indirectly affect root growth by impacting the availability of carbohydrates.

(Sumarni *et al*. 2013) [30] Adequate oxygen supply, efficient water absorption, and the presence of mineral-rich mist create optimal conditions for plant root growth. Plant root structure responds to conditions in the root zone by changing the branching and growth patterns. Therefore, only aeroponics offers a host of benefits, such as the ability to freely extend the root system, direct and adequate intake of oxygen, quick and consistent delivery of nutrient spray mist, and the optimal root growth environment.

Plant growing system

Aeroponics, unlike hydroponics, does not use a nutrient-rich solution as a growing medium. Instead, plants are cultivated in a mist environment, providing essential nutrients directly to the roots (Lakkireddy *et al*. 2012) [17].

(Zobel *et al*. 1976) found that the environment surrounding the roots is crucial for healthy plant growth and high-quality seed production.

(Soffer and Burger 1988) [29] reported that when plants are atomization systems, their roots experience optimal aeration.

The lower part of the plant hangs freely in a mist-filled environment, providing the root organisms with everything they need. The base of the cutting receives ample oxygen and moisture, creating a humid environment that helps the plant absorb 100% fresh air. This promotes root metabolism and accelerates root growth.

Nutrient solution management in aeroponics systems

The essential nutrient constituents required for life are potassium (K), nitrogen (N), and zinc (Zn). The carbon (C) and oxygen (O) are coming from the atmosphere. The absence of these factors cannot make a plant survive and none of these can be replaced by some other nutrients. Therefore, in the aeroponics system, the plant is grown without soil by providing nutrient mist through atomization nozzles. This supplies nutrients at the right time with the right concentration. Many researchers applied various nutrient concentrations for nutrient-enriched water production. Dennis, Hoag-land, and Daniel knew some technique for making mineral-nutrient solutions for the water culture technique. Knop and other plant physiologists have proven that K, Mg, Ca, Fe, and P

All of the following are essential nutrients, including S, C, N, H, and O, elements for plant life (Lakkireddy *et al*. 2012) [17].

Aeroponics engineering and potential challenges

The aeroponics system is a relatively new method of plant cultivation that has not yet been fully adopted worldwide. This system faces several potential challenges that could be addressed through further research. The primary challenge in aeroponics systems is the size of the water nutrient droplets. Larger droplets can limit oxygen availability to the root zone, while smaller droplets may lead to excessive root hair growth without developing lateral root system. Most studies on aeroponics have focused on plant growth, yield, and quality, with limited research on the impact of droplet size on plant yield and nutrient solution properties. A significant drawback of the system is the constant need for power, as interruptions can disrupt nutrient supply and damage plants. Additionally, the ultrasonic transducers may require maintenance and could be susceptible to component failure (Bucksetha *et al*. 2016) [6].

Advantages of aeroponics systems

Aeroponics, a modern agricultural technique, offers a promising solution for large-scale plant cultivation, especially in areas with unsuitable soil. By cultivating plants indoors in a nutrient mist, aeroponics minimizes water consumption by 98%, fertilizer use by 60%, and eliminates the need for pesticides and herbicides. This innovative approach has the potential to increase plant yield by 45-75% compared to traditional hydroponics or soil-based methods. Aeroponics is particularly well-suited for reforestation efforts in humid regions, as it can cultivate tree saplings with essential soil microorganisms like AM fungi (Martin-Laurent *et al*. 1999) [20].

Disadvantages of aeroponics system

- Expensive for long scale production
- The plant grower must need a specific level of proficiency to operate the system.
- The grower must have the information about the appropriate quantity of required nutrient for plant growth in the system.
- It is important to supply the required concentration of the nutrients. There is no any solid culture to absorb the excess nutrients if supply excess plant will die.
- The system design material is little expensive. As the well-designed system requires advanced equipment. It mainly constant high-pressure pumps, atomization nozzles, EC, and pH measuring devices, temperature, light intensity and humidity sensors and timer to control the system (Macwan *et al*. 2021)

Table 2: Yeild comparision of aeroponics and soil-based agriculture (De Bakker *et al*. 2023) [9]

Plant Type	Medium	Average fruit	Total Fruit Mass
Tomatos	Aeroponics	40	850 g
Tomatos	Soil-based	30	650 g
Cucumbers	Aeroponics	25	1000 g
Cucumbers	Soil-based	18	750 g
Bell Peppers	Aeroponics	20	500 g
Bell Peppers	Soil-based	14	390 g

Conclusion

In conclusion, aeroponics is an innovative method of soilless cultivation that has great potential for addressing global food security challenges and promoting sustainable agriculture. This technology allows for precise nutrient supply at root zone, climate control, and plant health monitoring, leading to faster and healthy crop growth and higher yields. The use of aeroponics, especially in areas with unsuitable soil, minimizes water consumption, reduces fertilizer use, and eliminates the need for pesticides and herbicides, making it an environmentally friendly solution. However, challenges such as power dependency, maintenance, and droplet size optimization need further research to maximize its potential.

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