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Aeroponics in Vegetable Crops

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ABSTRACT: Aeroponics is a way of planting in which plants are suspended on the air and grow in a humid environment without soil. This technique has most advantages when compared to other planting techniques used in different parts of the world. With aeroponics one can control humidity, temperature, pH and water conductivity under a greenhouse. Since the roots are suspended on the air, it is possible to plant practically anywhere and cubic space can be used, and therefore, aeroponics can be applied in many different ways. The principles of aeroponics are based on the possibility of cultivating vegetables whose roots are not inserted in a substratum or soil, but in containers filled with flowing plant nutrition. In these containers' roots can find the best condition regarding oxygenation and moisture. These conditions allow for better plant nutrition assimilation in a more balanced way, with consequential faster development of the cultivated plants. The aeroponic system is more user-friendly as the plants are all separated, they are all suspended in the air and the roots of the plants are not in anything like soil or water. Also, the harvesting of crops is simple. Many vegetable crops like potato, yams, tomato, lettuce and some of the leafy vegetables are being commercially cultivated in aeroponic system.

Keywords: Soilless farming, Aeroponics, Vegetable Cultivation.

INTRODUCTION

In recent years, humanity has grappled with a range of challenges stemming from a philosophy of life that has led to the degradation of our environment. One such challenge is water scarcity, a critical issue exacerbated by the heavy water usage in agriculture and industry. Agriculture alone accounts for nearly 70% of all water consumption, contributing significantly to the depletion and contamination of underground water sources.

A staggering 60% of the water used for crops is wasted, with some lost to evaporation and the rest remaining in the soil, leading to flooding, oxygen deprivation for roots, and soil salinization. This inefficiency not only harms crop yields but also exacerbates the scarcity of arable land, driven by the increasing global population's demand for food. As more land is cleared for agriculture, forests are rapidly disappearing, further reducing the water-retaining capacity of the soil. These interconnected challenges demand a more efficient approach to water use, prioritizing human consumption over other activities like agriculture.

To address these pressing issues, innovative farming methods like aeroponics have emerged. In aeroponics, plants are suspended in the air, their roots sprayed with a nutrient-rich mist in a controlled environment. This method, often implemented in greenhouses for optimal environmental control, offers several advantages, including increased crop yields, precise control over plant nutrition, and a reduction in water usage. Moreover, aeroponics eliminates the need for pesticides, resulting in a cleaner and more sustainable form of agriculture.

HISTORY OF AEROPONICS

The history of aeroponics dates back to the 1920s when it was initially used for studying plant root structures. Over time, it evolved into a commercial cultivation system, gaining attention for its potential to revolutionize agriculture. In 1983, the first commercial aeroponics system, known as the Genesis Machine, was successfully launched, marking a significant milestone in the adoption of this innovative technique (Peterson and Krueger 1988). Since then, aeroponics has garnered interest worldwide and has been recognized for its ability to address key challenges in agriculture, making it a viable solution for sustainable food production.

Aeroponics is more than just a farming method; it represents a paradigm shift in agriculture, offering a sustainable and efficient alternative to traditional farming practices. By embracing innovative techniques like aeroponics, we can work towards a more sustainable and resilient agricultural system that meets the needs of a growing global population while preserving our precious water resources.

Vyvyan and Travell (1953) conducted successful experiments planting apple plants in a misty environment. Went (1957) extended this method by planting tomato and coffee plants in a sealed container at Earhart Laboratories, Pasadena, California, using a fine nutrient mist generated by a pressurized nebulizing syringe, naming the system "Aeroponics." Until 1966, this system was primarily employed as a tool for analyzing plant root structures in laboratory settings, but it was later adapted for commercial plant cultivation (Stoner and Schorr 1983). The public became aware of aeroponics with the opening of the Disney Epcot Center in 1982 (Peterson and Krueger 1988). Subsequently, the first commercial aeroponics system, known as the Genesis rooting system (Genesis Machine), was successfully launched in 1983. This system can be operated and controlled by various microchips connected to power outlets and water atomizer nozzles. Peterson and Krueger (1988) highlighted the effectiveness of aeroponics compared to other soilless culture techniques, as it allows plants to grow without soil interference. Researchers also studied the response of root microorganisms to factors such as drought, legume-rhizobia interaction, production of arbuscular mycorrhizal fungi, and differences in the growth of plant cultivars (Went, 1957; Tibbitts *et al.,* 1994).

Barak *et al*. (1996) suggested that the nutrient mist system conserves water while providing an optimal environment for plant growth. NASA expressed interest in further research on aeroponics for space-based plant cultivation. Crops cultivated in aeroponic systems are noted for their ease of harvesting (Scoggins and Mills 1998). Additionally, studies have explored modern plant cultivation techniques for medicinal plants, herbs with root-based properties, and ornamental horticultural plants (Burgess *et al.,* 1998; Scoggins and Mills 1998). It has been concluded that in aeroponic systems, plant roots receive rapid nourishment under controlled conditions, leading to rich nutritional water around the roots (Martin-Laurent *et al*., 2000; Blais *et al.,* 1999).

AEROPONICS SYSTEM

Aeroponics technology has been tested in several African countries for the production of potato minitubers. Chang *et al.* (2012) suggested that aeroponics may be a suitable system for disrupting nutrient supply to produce potato minitubers, with the stolon growth phase significantly increasing root activity through restricted stolon growth. Overcoming non-tuber conditions, such as high temperatures and late-season varieties, is beneficial for utilizing this nutrient disruption technique.

According to Lakhiar *et al.* (2018a), aeroponics for plant cultivation is highly accepted and recommended in Europe, and it is currently practiced in various countries across the globe, including Australia, Brazil, Singapore, France, Spain, Thailand, Japan, Russia, Malaysia, Germany, New Zealand, Egypt, South Korea, Indonesia, Bolivia, Colombia, Ecuador, Ethiopia, Mongolia, Peru, Uzbekistan, Kenya, Sri Lanka, Iran, Italy, Korea, Vietnam, Bhutan, Canada, Greece, Nigeria, India, the Philippines, Poland, Abu Dhabi, Uganda, Tanzania, Mozambique, Malawi, Ghana, and Slovakia

The aeroponics system is a method of growing plants in an air or misty environment by applying a timed spray of all necessary nutrients without the use of soil or other supporting media. This technique, which shares similarities with hydroponics, allows plants to grow with support from fine droplets (fog or aeroponic mist) of nutrient solution, eliminating the need for soil or substrate. The term "aeroponic" originates from the Latin words "aero" meaning air and "póno" meaning works, representing a soilless cultivation method in a controlled environment. Aeroponics is known for promoting higher growth rates and producing healthy, uniform, and robust potato tubers, with yields potentially up to ten times higher than conventional production systems. This efficiency has led to improved potato production and reduced costs associated with seed multiplication and initial field quality.

IMPORTANCE OF AEROPONICS IN VEGETABLE CROPS

In vegetable crops, aeroponics represents an advancement in artificial life support systems for plant growth, seed germination, environmental control, and drip irrigation techniques traditionally used in agriculture. One of its primary advantages is excellent aeration, which has drawn attention from NASA due to its suitability for zero-gravity environments. Compared to conventional methods, aeroponics can significantly increase crop yields (by 45% to 75%) while using water more efficiently, with nearly 99% of water utilized. Since aeroponics does not require pesticides or soil-compatible fertilizers, the resulting fruits and vegetables are pure and do not require washing before consumption. Direct delivery of nutrients to plant roots also promotes faster crop growth and yields healthy, nutritious, and flavourful produce. Additionally, the aeroponic system is used for bio-pharming, allowing pharmaceutical compounds to be grown within plants in a closed-loop facility. Reports indicate that this system is ten times more successful than conventional techniques like tissue culture and hydroponics, while also conserving water and energy through nutrient solution recirculation. Aeroponics has been shown to improve root growth, survival rates, growth rates, and maturation times in cloning processes. Studies have demonstrated that aeroponics can effectively improve tuber yield compared to conventional methods, showcasing its potential for potato propagation. The system optimizes root aeration by suspending plants in the air, providing them with access to 100% of available oxygen and carbon dioxide concentrations necessary for photosynthesis, resulting in faster growth and enhanced nutrient absorption compared to regular hydroponic plants.

This is consistent with the findings of Sun *et al.* (2004), who observed that the aeroponics system led to increased stomatal conductance of leaves, intercellular CO_2 concentration, net photosynthetic rate, and photochemical efficiency of leaves.

AEROPONICS GROWING SYSTEM

Aeroponics is recognized as one of the fastest methods of seed multiplication. In this system, an individual potato plant can produce over 100 minitubers in a single row, a stark contrast to conventional methods, which typically yield only about 8 daughter tubers in a year. Moreover, using soil in a greenhouse environment typically results in the production of only 5 to 6 tubers per plant over a 90-day period. Another advantage of the aeroponics system is its ability to easily monitor nutrients and pH levels. By providing precise plant nutrient requirements, aeroponics reduces the need for fertilizers and minimizes the risk of excessive residues entering the groundwater.

Furthermore, the aeroponics system allows for the measurement of nutrient uptake over time under varying conditions. For instance, Barak et al. (1996) utilized an aeroponic system to non-destructively measure water and ion uptake rates for cranberries. These findings collectively indicate that aeroponics serves as a valuable research tool for studying nutrient uptake, enabling the monitoring of plant health and the optimization of crops grown in closed environments. Additionally, aeroponics is known for its space efficiency, with plants requiring minimal room for growth.

In contrast to other methods like hydroponics and conventional systems, aeroponics utilizes vertical space more effectively for root and tuber development. Moreover, the controlled environment of aeroponics minimizes pest and disease occurrences, as plant-to-plant contact is reduced, leading to healthier and faster plant growth compared to plants grown in a medium. In case of disease, plants can be swiftly removed from the support structure without affecting neighboring plants.

As a result, aeroponics allows for higher plant density (plants per unit area) compared to traditional cultivation forms like hydroponics and soil-based methods. The system also facilitates faster cloning of plants, reducing the labor-intensive steps associated with techniques like tissue culture. Additionally, air-rooted plants can be cloned and transplanted directly into the field without the risk of wilting or leaf loss due to transplant shock.

The principles of aeroponics are founded on the concept of cultivating vegetables with roots suspended in a container filled with a flowing nutrient solution, distinct from hydroponics where roots are submerged in a substrate or soil. This method ensures optimal oxygenation and moisture for the roots, promoting better nutrient assimilation and faster plant development.

Containers used in aeroponics can be stacked vertically and are lightweight and portable, allowing for flexibility in agricultural setup. Within a greenhouse or shade house, plants are arranged in vertical columns, and nutrients trickle down through these columns. Initially, plants require direct sunlight during their vegetative stage, after which this exposure becomes less critical. To accommodate this, plant containers are periodically moved, with young plants placed at the top and gradually lowered using a rotational mechanical system. This rotation allows for continuous production without interruptions, creating a non-stop production cycle in the aeroponic system.

Nutrition in aeroponics is supplied in a closed circuit, limiting consumption to the quantities absorbed by the plants and resulting in significant water savings. For instance, while traditional land cultivation requires 200 to 400 liters of water to produce a kilogram of tomatoes, hydroponics requires about 70 liters, and aeroponics only needs around 20 liters. Additionally, the enclosed nature of the aeroponic system reduces the labor involved to a series of routine mechanical tasks, which are carried out daily throughout the year. This facilitates rapid skill acquisition for workers compared to the years of experience required in traditional agriculture.

Aeroponic equipment is housed in greenhouses or anti-hail coverings, depending on the location's latitude, with climate controls ensuring optimal growing conditions and high yields.

COMPONENTS OF THE AEROPONICS SYSTEM

spray misters, which atomize water through nozzles at high pressure. These nozzles come in various patterns and sizes, with larger ones having higher flow rates but requiring more pressure to operate. The droplet size produced ranges from sub-microns to thousands of microns, with different classifications serving different purposes. For example, fine mist droplets (10 to 100 microns) are ideal for high-pressure aeroponics (HPA), while droplets in the 5–50-micron range are suitable for hydro atomization. The ideal droplet size for most plant species is 20–100 microns, with smaller droplets saturating the air and larger ones making better contact with the roots. Droplets larger than 100 microns tend to fall out of the air before reaching the roots, while those smaller than 30 microns remain in the air as a fog, potentially reducing oxygen availability to the roots.

Fig. 1.

High-Pressure Water Pump High-pressure aeroponics relies on a pump capable of pressurizing water to produce droplets of 20 to 50 microns. Typically, these pumps are diaphragm pumps or reverse osmosis booster pumps that maintain a steady 80 PSI with the required nutrient flow.

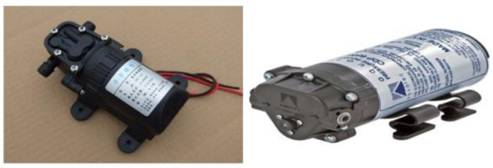

Fig. 2.

pH Meter The optimal pH for plant growth in aeroponics systems, where water and nutrients are recycled, ranges from 5.8 to 6.5. Monitoring pH is crucial for nutrient absorption, with nitrogen (N) being best absorbed at pH 6.0, and phosphorus (P) and potassium (K) at 6.25 and above. pH is measured on a scale of 0 to 14, with acidity below 7 and alkalinity above 7. Adjustments using "pH up" and "pH down" are made if the pH is too high or low. Specific pH ranges for some vegetables in aeroponics include cucumber (5.8-6.0), lettuce (5.5-6.5), onions (6.0-7.0), potato (5.0-6.0), spinach (5.5-6.6), tomato (5.5-6.5), and carrots (5.8-6.4).

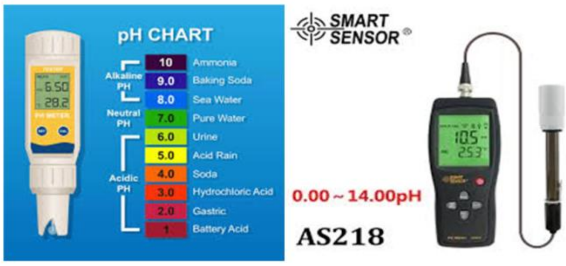

Fig. 3.

EC (Electrical conductivity). Electrical Conductivity (EC) Electrical conductivity (EC) measures the dissolved nutrients in a solution. Lettuce, for example, thrives with an EC of about 1.6. EC is expressed in milliSiemens per centimeter (mS/cm), with values typically ranging from 1.0 to 2.0 mS/cm for many crops. An EC above 4.0 mS/cm can be detrimental to plants, and adjustments in irrigation volume or frequency may be needed to maintain optimal levels.

Fig. 4.

Light and Temperature Artificial lighting, such as fluorescent tubes, is essential for plant growth in aeroponics, with recommended intensities of 15000-20000 lux for vegetative growth and 35000-40000 lux for flowering and fruiting. Temperature control is crucial, with an optimal range of 15°C to 25°C. This can be achieved through air conditioning, exhaust fans, and ventilation. Precise control of nutrient solution temperature is possible in aeroponics, allowing for tailored environmental conditions that are beneficial for plant growth.

Misting Frequency and Nutrient Reservoir Aeroponic systems can mist the root system continuously or intermittently. Intermittent misting can save energy and still maintain a nutrient-rich environment for the roots between mistings. Misting frequency can be adjusted based on light levels or programmed cycles. An ideal misting cycle is 1-2 minutes of misting followed by 5 minutes off. Some systems mist for 10 seconds at 20-minute intervals. Aeroponic systems may have separate nutrient reservoirs or an all-in-one design, with larger systems typically returning nutrient solution to a separate reservoir to prevent blockages as the root system matures

Aeroponics Working Method

In an aeroponic system, young plants can be raised as seedlings using specially designed lattice pots, or cuttings can be placed directly into the system for rapid root formation. Lattice pots allow the root system to develop down into the aeroponic chamber or channel, where it is regularly misted with nutrients. This method has been extensively used for researching root development in many plant species that are difficult to propagate. The base of the cutting is supplied with high levels of oxygen and moisture in a humid environment, preventing desiccation and promoting root formation.

Fig. 5.

Once established in the aeroponics system, the root system rapidly develops in the chamber or channel. It is crucial to maintain the optimum droplet size for maximum efficiency. There is a wide range of aeroponic nozzles available, allowing for the selection of a droplet size range that best suits the plant and system used. Droplets smaller than 30 microns tend to remain in the air as a 'fog' and are not readily absorbed by the roots. The ideal droplet size range for most plant species is 20 - 100 microns. Smaller droplets saturate the air, maintaining humidity levels within the growth chamber, while larger droplets make the most contact with the roots. Droplets over 100 microns tend to fall out of the air before reaching the roots.

Fig. 6.

The principles of aeroponics are based on cultivating vegetables without soil, in a container filled with flowing plant nutrition. These conditions allow for better plant nutrition assimilation and balanced development, resulting in faster growth. Plant nutrition is supplied in a closed circuit, limiting consumption to only what is absorbed by the plants, thus saving water. For example, traditional land cultivation requires 200 to 400 liters of water to produce a kilogram of tomatoes, while aeroponics only uses about 20 liters.

Aeroponics in Space Feeding astronauts on long-term space missions is a challenge, as storing enough food is not viable. Processed food also lacks sufficient nutrition for long-term use. NASA has been interested in studying the effects of zero gravity on vegetables since the early years of space travel. Experiments have shown that zero gravity affects nutrient uptake, with some nutrients being absorbed more and others less.

NASA began examining aeroponics as a means of growing food in space in the late 1990s. Research focused on developing an aeroponics system that could efficiently grow food in a zero-gravity environment. The system would need to be self-contained and efficient in water usage, as well as not requiring a growing medium. In 1999, an inflatable aeroponic growing system was developed for use in space.

NASA has stated that aeroponics may be essential for future space missions, including a proposed moon base and manned missions to Mars. The efficiency of aeroponics in water usage and space requirements makes it a promising technology for space agriculture.

Case Study: Potato (Solanum tuberosum) Aeroponics in the North Eastern Himalayan Region of India. A study conducted at the Central Potato Research Station in Shillong evaluated the performance of three potato varieties in an aeroponics system installed under net cum polyhouse. The study found that Kufri Megha exhibited the best performance, with early tuber initiation and high yields. However, Kufri Himalini and Kufri Himsona showed delayed tuber initiation and reduced yields in the second year of the study.

Advantages of Aeroponics

— Requires less fertilizer and water compared to traditional methods.

— More cost-effective and less complex than hydroponics.

— Reduces disease spread among plants.

— Promotes faster and healthier growth due to improved oxygenation.

— Studies have shown an increase in flavonoids in plants grown using aeroponics.

Disadvantages of Aeroponics

— Can be more expensive for large-scale production.

— Requires skilled management.

— Misting spray heads may clog.

— Some consumers perceive aeroponically grown plants as less nutritious.

— Maintenance can be expensive.

CONCLUSIONS

The aim of this study has been to develop an automated aeroponic system for potential widespread adoption nationally and globally. As urbanization continues to grow, there is a need for food production to shift to urban areas to meet the needs of urban societies for food, transportation, water, and energy. Aeroponics, with its advantages over other planting methods, is poised to play a significant role in providing food for the inhabitants of these megacities. Current greenhouse technologies, such as water pumps, lighting, heaters, and fans, rely heavily on electric or fossil fuel energy sources. However, there is a plan to transition to cleaner energy sources like hydrogen fuel cells and solar cells in the near future. Additionally, there is an intention to integrate aeroponics into buildings designed with sustainable architecture. It is foreseeable that aeroponics will be a cornerstone of future food production methods for humanity.

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