REVIEW ARTICLE

Aeroponics System for Production of Horticultural Crops

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ABSTRACT

Aeroponic is the culturing of whole plants with their roots fed by an air/ water nutrient fog. Aeroponic is a method of growing plants where they are anchored in holes in styrofoam panels and their roots are suspended in the air beneath the panel. The panels compose a sealed box to prevent light penetration to encourage root growth and prevent algae growth. The nutrient solution is sprayed in fine mist form to the roots. Misting is done for a few seconds every 2 – 3 minutes. This is sufficient to keep roots moist and nutrient solution aerated. The plants obtain nutrients and water from the solution film that adheres to the roots.

Keywords: Air, styrofoam, panels, spray, horticulture

INTRODUCTION

Earth's population is expected to grow in more than two billion people in fourthcoming years. It was found that feeding them would require approximately more than a hundred hectares of additional conventional farmland. This product was designed to survive the long journey and extend shelf life in local stores. Good quality and delicious, limited-quantity products are available for a few months in a year, so off-season farming doesn't matter. Another issue is that crop yields are highly dependent on the weather. A single poor growing season can cause thousands to starve in many areas of the world.

Aeroponics is the process of growing plants in an air or moist environment without the use of soil or an aggregate medium (NASA Spinoff, 2006). In aeroponics, plants are grown in an air or mist environment without engaging soils or any aggregate or soil medium (Arunkumar & Manikand, 2011). Aeroponics gives room for easy access to plant roots since it is not planted in any aggregate media (Pagliarulo & Hayden, 2002). The main idea behind the aeroponic greenhouse in intelligent space is full automation, scalability, anytime-anyplace access monitoring, and fault diagnostic for home or enterprise farming. Aeroponic plants require nutrients from a nutrient-rich water solution that is sprayed onto their dangling roots and lower stem several times an hour. The main advantage of nutrient delivery using aeroponics systems is that the plant is kept in a relatively closed environment, so diseases are not spread rapidly. Another advantage of aeroponics is that suspended plants receive hundred per cent of the available oxygen and carbon dioxide to the root zone, stems, and leaves, thus accelerating growth and reducing rooting times (Martin Pala *et al*., 2014). Plants grown aeroponically always show proper root hair development due to the highly aerated environment surrounding the root system (Weathers and Zobel, 1991). The growth chamber and fertigation system employed in aeroponics give room for complete regulation of the root zone setting, including temperature, humidity, pH, nutrient concentration, mist application frequently and duration. Plants grown using aeroponics often show signs of accelerated growth and early maturity (Mirza *et al*., 1998). These abilities have made the technology a popular research tool for studying root growth and nutrient uptake (Barak *et al*., 1998). The aeroponic technology has also been successfully used for crops that are vegetatively propagated, the most recent being the successful application of technology in the propagation of yams (Maroya *et al*., 2014). The technique could be a practical solution for commercial farming in the anthropocene where world is facing huge scarcity of freshwater and agricultural land to meet the food demand of 7.6 billion. Moreover, it could be the way forward for sustainable and productive farming technique in space (Udit Sharma *et al*., 2018). Aeroponics optimizes root aeration, a major factor leading to a yield increase as compared to classical hydroponics (Soffer & Burger, 1988).

History

Carter (1942), who first studied the growth of air culture, identified a method of growing water vapour plants to promote root inspection. Later, Klotz (1944) was the first to discover misted vapour citrus plants in his study of citrus and avocado roots disease research.

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The term 'aeroponics' was coined by F.W Went in 1957 for the air growing process while growing the coffee and tomato crops through the same technique (Udit Sharma *et al*., 2018). Stoner is considered the father of commercial aeroponics. Stoner's aeroponic systems are in major developed countries around the world. His aeroponic designs, technology and equipment are widely used at leading agricultural universities worldwide and by commercial growers.

COMPONENTS AND ATOMIZERS REQUIRED FOR AEROPONICS SYSTEM

Spray misters and droplet size

Aeroponics is a method used to cultivate modern-day plants in agriculture. The supply of essential nutrients for plant growth needs no single soil particles. Nevertheless, the roots of plants in aeroponics produce nutrient spray mist ejecting from the nozzles of atomization. The method of atomization is to break up liquid molecules into fine droplets (Avvaru *et al*. 2006). Using basic sprinkler-type garden nozzles, the most common aeroponics system uses pressurized water that is sprayed onto the roots. Various atomizers, together with specific spray patterns and orifices, are developed in several disciplines to provide tiny droplets of liquid down to 1 micron. The atomizers are classified as atomizations of a high, medium, and low frequencies (Rajan and Pandit 2001; Lu *et al*. 2009).

Small orifice atomization nozzles may create problems such as nozzle clogging, and cause water supply to stop. Thus stop clogging the nozzle orifice; the mesh filters are used to prevent clogging of the nozzle. While the larger nozzles with a larger orifice reduce nozzle blockage chances but require high pressure to operate. Selecting the right atomization nozzles is essential for producing the required droplet size. The droplet size ranged from sub-microns to thousands of microns and was characterized in a different rating.

The optimal droplet size range for most plant species within the aeroponics system is between 30 and 100 microns. The smaller droplets saturate the air within this range, maintaining humidity levels inside the growth chamber. The selection of nozzles for atomization should be based on growers' requirements. Ultrasonic foggers, whose working frequencies range from 1 to 3 MHz, are expensive and hard to maintain. The foggers require special electrical circuits to power them, so they have very complex structures. Besides, they also influence the nutrient solution's chemical properties. The foggers are suitable for planting indoors. It is more convenient to use the low-pressure nozzles than foggers. These nozzles are cheap and easy to keep, but their quantities of atomization are small.

EC & pH of nutrient solution

In the aeroponics method, where regular recycling of water and nutrient solution. For good plant growth, it is, therefore, important to periodically measure the pH and EC value of the nutrient solution. If the readings are not at the appropriate level, then the grower must change them. For each plant, the optimal pH and EC range depend on the appropriate environmental conditions. Though the prepared nutrient solution pH and EC values could not exceed 7 and 2.5ds m^{-1}. The ideal EC and pH values of aeroponics nutrient solutions vary from 1.5 to 2.5 ds m^{-1} to 5.5 to 6.5 and 5.0 (Resh 2004; Chadirin *et al*. 2007).

The electrical conductivity (EC) of the nutrient solution affects the uptake of nutrients by plants, their vegetative growth, the yield and quality of minitubers in potato (Chang *et al*., 2011). The optimal nutrient solution depends on the concentration of nutrients, the environmental conditions, species, and cultivars (Furlani *et al*., 1999). Suh and Park (1997) experimented to determine the optimal EC for sweet, opal, and bush basil grew hydroponically and found that fresh mass per plant increased with decreasing EC. Most of the concentration of the nutrients increased with increasing EC except Mg and Ca, which decreased. Nitrogen concentrations in sweet basil increased by 0.6% to 0.7% as EC increased from 0.5 to 4.0 dS/m.(Walters and Currey, 2015). Spraying growing season & highest EC (4 $mScm^{-1}$) treatment resulted in the greatest production of leaf and fresh root mass in lettuce cultivars. (William *et al*., 2018).

Increasing EC levels caused greater production of flavonoid and phenolic compounds (Kim *et al*., 2008). The pH of this water can be adjusted and held at the preferred range of 5.5 to 6.0, which allows maximum availability of nutrients to plant roots. Anderson *et al*., (2017) indicated that even slight increases of pH to levels of 7.0 could significantly reduce lettuce fresh matter and dry matter.

Plant growth responses, photosynthetic rate, stomatal conductance, and transpiration rate were also found to be affected by EC levels. Also, antioxidant defense enzymes such as catalase (CAT), ascorbate peroxidase (APX), peroxidase (POD), glutathione reductase (GR) and monodehydroascorbate reductase (MDHAR) significantly elevated in the leaves and roots of plantlets at higher EC levels. This increase could reflect a defence response to the cellular damage provoked by higher EC levels in the nutrient solution (Dewir *et al*., 2005).

Light and temperature

The temperature of both air and nutrient solutions should be controlled in the aeroponics system for rapid plant maturation. When temperatures rise, the chemical processes start at faster rates, and the enzyme activities deteriorate. For all plants, the optimal temperature range is 15–25°C. Nevertheless, growth chamber temperatures should not be higher than 30°C and less than 4°C (Otazú 2014). The LED could be seen as the best light producer in the aeroponics system for plant growth. It provides in a controlled condition with multiple light qualities and effects of light on plant growth. The light LED has a smaller volume and mass, good life, energy-saving, single wave length, and narrow bandwidth (Bula *et al*. 1991; Brown *et al*. 1995).

Humidity and dissolved oxygen concentration

Humidity is the principal component required for successful plant growth and development in the aeroponics system. Nevertheless, the growth of plants is greatly affected by the rise and decrease in relative humidity (Ford and Thorne, 1974; Schussler 1992). The aeroponics system provides plant growth with the best oxygenation environment. It allows plant roots to grow with an abundant supply of oxygen in the air. Therefore no further mechanism is required.

Misting Frequency and nutrient reservoir

The nutrient reservoir is designated in the aeroponics system as separate or external, and within or within the growth chamber. The nutrient reservoir purpose is to store solution. The atomization nozzles are attached to the distribution line in the separate or external reservoir by means of a pressure pump to supply the solution to the growth chamber. In order to recycle excess solution, the drain line is given in the growth chamber. Though the atomization nozzles in the inner reservoir directly get the nutrient supply from the bottom of the growth chamber, where it drips back down after misting on the root system.

Table 1. Spray time interval for horticultural crops

Plants	Spray interval	Author
Tomatoes	60-sec on and 5-min off	Osvald *et al*. (2001)
Cucumber	7-sec on and 10-min off	Peterson and Krueger (1988)
Lettuce	1.5-min on and 5-min off	Kacjan-Marsic and Osvald 2002
Saffron	1-min on and 1-min off	Souret and Weathers 2000
Burdocks	30-sec on and 60-sec off	Pagliarulo and Hayden 2000
Anthurium	15sec on and 15 mints off	Fascella and Zizzo 2007
Acacia	40-sec on and 30-sec off	Weber *et al*. 2007
Peas	3-sec on and 10-mins off	Rao *et al*. 1995
Onion	7-sec on and 90-sec off	Jarstfer *et al*. 1998
C. speciosa	2-sec on and 2-min off	Kumari *et al*. 2016

Technical setup of aeroponics

A typical aeroponics unit consists of a closed styrofoam chamber in which plant shoots are inoculated in holes made on styrofoam sheet, and emerging roots remain dangled in the air. The chamber might be lined with a black sheet in order to assist in the maintenance of optimum humidity and darkness in the chamber. Plants cuttings in aeroponics are misted through the nozzles, which are evenly spaced and fixed into PVC pipes for the supply of nutrient solution. The pipeline is connected to the motor which pumps the nutrient solution at high pressure. To regulate the nutrient spraying for a set time interval, a digital timer is connected to the pump. Space between nozzles and their pressure, the spacing of styrofoam holes, pumping capacity of the motor, duration of nutrient spraying, and the time gap between two subsequent sprays may vary according to the scale of aeroponics unit setup and cultivated plants. Nutrient solution dribbling from the suspended roots in the tank is pumped back to the water tank and recycled (Udit Sharma *et al*., 2018)

Crops in an aeroponic platform are subjected to multiple climates that influenced stress situations. In traditional agriculture, these stress situations are considered uncontrollable, and crop productivity achieved only to such extend, the climate permits it. That is why crop production is correlated to seasonal dynamics. Each and every such stress point consumes energy, which otherwise would have been diverted to metabolism. For example, the above optimum temperature would induce more transpiration of water resulting in reduced mineral absorption into plant tissues and thus reducing multiple enzymatic activities. So, for an aeroponic system to support crop growth to the maximum genetic potential, it has to function under a climate-controlled environment.

In regular agricultural practice, toxic formulations like organophosphates are used to kill pest and disease incursions. Water, air, and soil are the three conduits for pathogens and insect pests to enter the growing area. All three conduits are sterilized repeatedly with non-toxic oxidizing agents whenever biological oxygen demand is sensed more than the set threshold. Harvesting in aeroponics is convenient, clean and allows a greater size control by sequential harvesting (Ritter *et al*., 2001)

Plants cultivated aeroponically had a higher biomass yield and total phenolics and flavonoid content and antioxidant properties compared to plants grown in soil (Chandra *et al*., 2014). Under aeroponic growth conditions, the good aeration of the roots is the most critical factor for the growth of plants. In aeroponics, plants are totally suspended in the air, giving their root system access to 100% of the available air oxygen, promoting root metabolism and plant growth (Chiipanthenga *et al*., 2012).

Aeroponics system has a special advantage in countries with tropical conditions, such as Brazil e.g. production of high-quality seeds free for viruses (Alex *et al*., 2018). Roots in the aeroponics system are suspended in the air inside a chamber without light, where they are periodically nebulized with nutrient solution (Buckseth *et al*., 2016). The main advantage of this system include less water waste, high sanitary quality, higher multiplication rate, and stepped harvest. (Ritter *et al*., 2001; Buckseth *et al*., 2016). Information about nutrient solutions for different cultivars, suitable plant densities, and the interaction between these factors is needed (Rolot and Seutin 1999; Ritter *et al*., 2001; Farran and Mingo- Castel, 2006). Irman Idris and Muhammad (2012) monitored the chamber's parameters such as temperature and humidity, and the control system was used to manage actuators in delivering water and nutrients.

Vegetable production

Aeroponics has been utilized for the production of various vegetable crops, i.e., *Cucumis sativus* (Park *et al*., 1997), *Lactuca sativa* (Demsar *et al*., 2004), *Solanum lycopersicum*, (Kim *et al*., 1999) and leafy vegetables (Bohme & Pinker, 2004). Large scale production of potato seed tubers (Muthani *et al*., 2011) and yam tuber production was also successfully achieved using this technique. An aeroponic system for seed potato production was also successfully established in Korea (Kang *et al*., 1996) under tropical and subtropical conditions. Although results reported the inhibition of tuberization in immersed organs or subjected to continuous mist culture (Wan *et al*., 1994), tuberization under three procedures could be promoted under certain stress conditions such as N deficiency (Krauss and Marschner, 1982) and short term reductions in solution pH (Wan *et al*., 1994). Recently, Ritter *et al*. (2001) showed that aeroponics for producing potato minitubers under temperate weather conditions substantially improved minituber production.

Yield and nutrient status was found to be maximum in tomato (*Lycopersicon esculentum* Mill.) grown in aeroponic culture by the application of different nutrient solutions with Rockwool (Andrzej Komosa *et al.,* 2014). The multiplication rate of potato micro tubers of national cultivars in aeroponics while maintaining weekly intervals between harvests. The number of mini tubers were two to three times greater in the case of aeroponic production than by the traditional method. A full economic analysis is necessary to prove that this production technique can be put into practice (Rykaczewska, 2016).

Ornamental crops production

The potential of the aeroponic culture system as an effective alternative for growing plants, the degree to which root growth, leaf number of Gerbera, and macro elements uptake in response to N-NH4+/NT ratio, spraying intervals of nutrient solution and light in root media Mojtaba *et al*. (2012). Fascella and Zizzo (2007) cultivated Anthurium in both expanded clay and aeroponic system to solve many problems of potted Anthuriums (plant fall over, crooked stems) and to evaluate the productive and qualitative differences of the two growing systems. The shorter spray interval (3/15 min) resulted in roses with improved growth: length and thickness of flowering stems, length, and thickness of flower buds, and total leaf number enhanced Jowkar *et al*., (2009). Plants of ornamental value such as croton, geranium, philodendron, dracaena, carnation etc. chrysanthemum (Molitor *et al*., 1999) and poinsettia (Scoggins & Mills., 1988) have also studied using this technique. Enhanced growth and root nodulation were observed in *Acacia mangium* through aeroponic culture (Martin *et al*., 1997). Aeroponics is also being utilized for the production of subtropical and temperate region crops in the tropical environment while manipulating their root zone temperature. (He, 2010)

Medicinal crops production

Cultivation of medicinal rhizomes like ginger (*Zingiber officinale*) and high valued root crops like buried rock (*Anemopsis calipmica*) grown well under aeroponics (Hayden, 2006). A new compound, namely 2, 3-Dihydrowithaferin A-3β-O-sulfate was reported in *Withania somnifera* grown aeroponically (Xu *et al*., 2009). Mehandru *et al*., 2014 reported the clonal propagation of three threatened medicinal asclepiads i.e., *Canalluma edulis*, *Leptadenia reticulate* and *Tylophora indica* using aeroponic culture. They observed the higher rooting percentage in stem cuttings grown aeroponically as compared to soil conditions. In a difficult study, Salachas *et al*., 2015 analyzed the effect of available root zone volume and yield as well as the nutritional quality of cultivated holy basil (*Ocimum basilicum*) in an aeroponic system. Medicinal plants grown in an aeroponic culture have also been evaluated for their antibacterial, antiplasmodial as well as cytotoxic properties (Kumari *et al*., 2016). The applicability of aeroponic technology for the cultivation of the traditional field-grown herbaceous medicinal plant *Urtica dioica* (Pagliarulo, 2004). Souret and Weathers (2000) compared the growth of Saffron in aeroponic with soil and hydroponic systems. The growth potential and essential oil production of valerian and lemon verbena in various soilless and soil production system which consisted of floating, aeroponic, growing media, and soil media (Azarmi *et al*., 2012).

SALIENT FEATURES OF AEROPONICS

Very low water consumption

Traditional agriculture is the single largest industry taking up the majority of virtual water consumption. On average, one kilogram of vegetables consumes 150 literres of water, more than 90% of which is lost to the environment through leaching and surface evaporation without passing through the transpiration process. Under Aeroponic condition, the water is sprayed as a mist, and also it is collected and recycled and reused.

Very low mineral consumption

The mineral composition of plant dry matter, is not more than 5% for the majority of crops. But the utilization efficiency in case of traditional agriculture is very low at around just 15%, and in case of coir media-based hydroponics at around 40%, wasting a considerably large amount of costly nutrients in aeroponics the utilization efficiency is at around 80%, and saving a huge amount in operational expenditure.

High plant density

Plant density is a function of root competition for water and minerals, foliage competition for sunlight. With water and mineral availability in the root zone are abundant, only the volumetric space for accommodating roots is the limiting factor of plant density as far root zone is concerned. The root zone chamber is of triangular cross-section, crops like cauliflower, cabbage, lettuce and onion can also be grown. This module can accommodate four times more population than that in the flat surface. For vegetables like tomato, eggplant, and beans can accommodate twice that in flat surfaces.

Multi cropping combination & throughout the year production

Aeroponics system can support all vegetables, both temperate and tropical, severally or individually. The turnaround time for a set of crops like tomato, eggplant, beans, and also for crops like cauliflower, cabbage, lettuce, and onion can be grown in a single unit area.

CONCLUSION

It concluded that aeroponics would in future use effectively in those regions where freshwater and fertile soils are not available. It could, therefore, be the potential application for food production in those regions with vast parts of non-arable land, small area, and large population, as well as in desert areas. It also increases the per capita availability and consumption of fruits and vegetables per person.

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