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Review Article

Aeroponics Soilless Cultivation System for Vegetable Crops

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Abstract

Aeroponics is the soilless cultivation and it is a process of growing crops suspended in the air or in a mist without using soil. 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: Aeroponics, Vegetables, Soilless culture, Growing system

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Introduction

By the year 2050, the population of Earth is expected to rise by 3 billion people. It was found that approximately 109 hectares of additional traditional farmland will be needed to feed them. Only 80% of the Earth's arable land suitable for farming now. Roughly 15% of this land has been rendered unusable for farming due to poor management and climate change has claimed even more. Populations in the northeast buy produce for at least 6 months out of the year from farms over 3,000 miles away, according to multiple produce vendors in the area. This produce has been engineered to survive the long trip and extend shelf life in local stores. Good quality and tasty produce of limited quantity is available for a few months in a year, and hence farming in off season has no significant. Another issue is that crop yields are highly dependent on weather. A single poor growing season can cause thousands to starve in many areas of the world.

In addition to the prior problem described, and due to the absence of adequate planning, another critical problem comes into the picture: the deficiency in human nourishment, caused mostly by the growing population. A greater quantity of hectares is needed every day for agriculture thus a major quantity of water to care for them is needed. In order to have enough soil to farm in, an immense quantity of forest is cut down every day which causes a great amount of water, which would lie on the ground before, to be reduced considerably. This chain of high priority problems requires an improvement in the administration of the use of liquid resource so that human consumption has the priority in its use, and not the other activities, like agriculture. To solve the problems mentioned, new farming methods have been searched, one of them being aeroponics. With this technique, the plants are held by certain structures that maintain it fixed in a way that the roots are sustained up in the air [42].

Controlled Environment High-Rise Farm (CEHRF) is an integrated solution of all technologies available which is based on an aeroponic growing system, chosen for its 90% reduction in water use, 60% reduction in nutrient use, stimulated crop growth, and higher density capabilities as compared to traditional farming. The growing regimen is designed to provide a year-round continual harvest by offsetting planting times, so that a steady and reliable crop yield can be achieved while providing full-time year round employment in a safe environment with benefits. These farms can be placed near the populations they are intended to serve, keeping money in local economies.

Aeroponic literally means "growing in air." An aeroponic system is medium-less in that the roots of the plant are free hanging inside an open root-zone atmosphere. The vegetation zone is separated by the supports used to hold the plants in the top of the unit. Nutrients are mixed in with water in a reservoir basin; this is then filtered and pumped into a pressurized holding tank that is intermittently misted onto the root system. The water droplet size must be big enough to carry the nutrients to the roots in sufficient quantity, but small enough to not immediately precipitate out of the root mass. Unused solution drips down into the base of the unit and is strained, filtered, and pumped back into the reservoir. By doing some lateral thinking, we concluded aeroponics provided the ideal approach to investigating mineral uptake by processing vegetables when supplied with optimum levels of water, nutrients and air [11].

Aeroponics

Aeroponics is the process of growing plants in an air or mist environment without use of soil or an aggregate media. The word aeroponic is derived from the Latin word ‘aero’ (air) and ‘ponic’ means labour (work) [15]. This is an alternative method of soil-less culture in growth-controlled environments. Aeroponic culture differs from both conventional hydroponics, aquaponics, and *in-vitro* (plant tissue culture) growing. Nowadays, aeroponics is being applied successfully in South America [32] and attempts are made to introduce this technology also in some African countries [38]. In modern horticulture, different soil-less production techniques such as aeroponics [41] and Nutrient Film Techniques [45] have been developed. Earlier works has shown good results with NFT for potato tuber production [52, 54]. However, tuber initiation was poorer in nutrient solution without solid media than in porous media (e.g. perlite or vermiculite). The tuberization inhibitions of stolons immersed in a solution could be the consequences of the lack of mechanical resistance [51]. The utilization of aeroponic systems for potato seed production is very recent in Europe. Until 10 year ago, the use of these technologies was limited almost everywhere in the world and only some countries such as China or Korea were using them for the commercial production of potato quality seeds [25].

The aeroponic culture technique is an optional device of soil-less culture in growth-controlled environments such as greenhouses. This method consists of enclosing the root system in a dark chamber and supplying a nutrient solution of mist device. This was widely used in horticultural species including tomato [5], lettuce [10, 17, 18], cucumber [40] and ornamental plants such as chrysanthemum [34] or poinsettia [44]. Aeroponic systems for seed production have been established following increased demand for more efficient high quality seed production methods [24]. Aeroponic system has been applied successfully in Korea for potato seed tuber production [24, 25]. Therefore, aeroponics or aero hydoponics have displaced traditional hydroponic systems for mini tuber production [9]. Despite increasing interest in soil less culture methods in commercial horticultural production, little information is available for potatoes. Aeroponic systems are more water resource efficient than hydroponic system. Another remarkable advantage of the aeroponics is the minimal contact between the support structure and plant, due to which the unconstrained growth of the plant is possible. The aeroponics systems are widely used for NASA space research programs.

History

Techniques of growing plants without soil were first developed in 1920s by botanists who used primitive aeroponics to study plant root structure; aeroponics has long been used as a research tool in root physiology (Barker, 1922 [4]). Soilless culture is considered as a modern day practice, but growing plants in containers above ground has been tried at various times throughout the ages. Wall paintings found in the temple of Deirel Bahari appear to be the first documented case of container-grown plants [35]. In the early 1940s, the technology was largely used as a research tool rather than an economically feasible method of crop production. It was W. Carter in 1942 who first researched air culture growing and described a method of growing plants in water vapor to facilitate examination of roots. In 1944, L.J. Klotz was the first to discover vapor misted citrus plants in a facilitated research of his studies of diseases of citrus and avocado roots. In 1952, G.F. Trowel grew apple trees in a spray culture. Fifteen years after the study of Carter (1942) [7] and Went (1957) [53] named the air-growing process in spray culture as “aeroponics”. The first commercial aeroponics setup was the Genesis Rooting System, commonly called the Genesis Machine, by GTi in 1983. The device was controlled by a microchip and simply connected to an electrical outlet and a water faucet. Aeroponics has been used successfully in production of several horticultural and ornamental crops [5]. Aeroponic system has been applied successfully in Korea for potato seed tuber production [24, 25]. As of 2006, aeroponics is used in agriculture around the globe. Farran and Mingo (2006) [15] reported a minituber yield of 800 tubers/m^2 at a plant density of 60 plants/m^2 over a five months period with weekly harvests. This translates into a multiplication rate of 1:13. They also found the field performance of aeroponically produced tubers to be similar to minitubers produced from the pots. At the International Potato Centre (CIP) in Peru, yields of over 100 tuberlets /plant were obtained [38].

Importance of Aeroponics in Vegetable crops

Aeroponics is an improvement in artificial life support for non-damaging plant support, seed germination, environmental control, and drip irrigation techniques that have been used for decades by traditional agriculturalists. Excellent aeration is the main advantage of Aeroponics [27]. These techniques have been given special attention from NASA; since a mist is easier to handle than a liquid in a zero gravity environment. One of the main disadvantage was expensive [7].

Growing in soil is no longer a sustainable way to grow food for the 7 billion people on the planet. Increase crop yields by 45% to 75%. Outcomes of using aeroponics system over their counter parts are more efficient use of water. Almost 99 percent of the water is used. Since pesticides and soil compatible fertilizers are not used, fruits and vegetables obtained are pure and doesn't need to be washed before use. Delivers nutrients directly to the plant roots, which results in a faster growth of crops. Fruits and vegetables obtained from an aeroponics-based greenhouse are healthy, nutritious, pure, rich, fresh and tasteful. Uniform growth among all crops was also observed [33].

Aeroponic bio-pharming is used to grow pharmaceutical medicine inside the plants. The technology allows for completed containment of remain inside a closed-loop facility. Reports show that the system is ten times more successful than conventional techniques, tissue culture and hydroponics, which take longer and are also more labour intensive. The system has the ability to conserve water and energy. Aeroponics system uses nutrient solution recirculation hence, a limited amount of water is used. It comparatively offers lower water and energy inputs per unit growing area [15, 43]. Using aeroponics for cloning improves root growth, survival rate, growth rate and maturation time [46]. Studies have shown that, the mean tuber yield under aeroponics is better than when the same material is left to produce tuber under conventional means [39, 50]. Such results clearly show that, aeroponics system can be effectively used for potato propagation [14, 16, 43]. The aeroponics system optimizes root aeration. This is true because the plant is totally suspended in air, giving the plant stem and root systems access to 100% of the available oxygen in the air which promotes root growth. Such environment also gives plants 100% access to the carbon dioxide concentrations ranging from 450 to 780 ppm for photosynthesis hence, plants in an aeroponics environment grow faster and absorb more nutrients than regular hydroponics plants [43]. This is in line with Sun *et al.* (2004) [48] who reported that, the aeroponics system increased stomatal conductance of leaf, intercellular CO_2 concentration, net photosynthetic rate and photochemical efficiency of leaf.

Aeroponics method of propagation is one of the most rapid methods of seed multiplication. An individual potato plant can produce over 100 minitubers in a single row [39], as opposed to conventional method that create approximately 8 daughter tubers only in the course of a year while only 5 to 6 tubers per plant are produced using soil in the greenhouse in 90 days [20]. Another advantage of aeroponics system is that of easy monitoring of nutrients and pH. Aeroponics system provides precise plant nutrient requirements for the crop, thereby, reducing fertilizer requirement and minimizing risk of excessive fertilizer residues moving into the subterranean water table [36].

Aeroponics system also allows the measurement of nutrient uptake over time under varying conditions. Barak *et al.*, (1996) [3] used an aeroponic system for non-destructive measurement of water and ion uptake rates for cranberries. All these results clearly show that, aeroponics is a research tool for nutrient uptake and opens up possibilities for the monitoring of plant health and optimization of crops grown in closed environment. Aeroponics production system is very space efficient, with plants taking up minimal room.

In contrast with other techniques such as hydroponics and conventional system, aeroponics exploits better vertical space for root and tuber development [46]. The environment under aeroponics is kept free from pests and diseases since plant to- plant contact is reduced hence; plants grow healthier and quicker than plants grown in a medium. In addition, if a plant becomes diseased, it is quickly removed from the plant support structure without disrupting or infecting the other plants.

As a result, many plants can grow at higher density (plants per unit area) than in the traditional forms of cultivation such as hydroponic and soil [46]. The system clones plants in less time and reduce numerous labour steps associated with the other techniques such as tissue culture techniques [47]. In addition, the air-rooted plants are cloned and transplanted directly in the field without a fear of a seedling being prone to wilting and leaf loss, due to transplant shock.

Difference between aeroponics and hydroponics [19, 25, 43]

Aeroponics	Hydroponics
Roots: Suspended in air or in an enclosed environment, Thus, the plants are able to absorb the nutrient-rich water solution and is able to remain oxygenated	Roots: Immersed in a nutrient-rich medium such as water or soil or may be supported by inert media such as gravel or perlite, Thus, the plants are able to absorb the dissolved nutrient in the medium
Solution: Sprayed onto the fine mist of mineral nutrients	Solution: Dissolved in the medium
Crop Yield: Harvest better quality and more food due to better aeration available to roots	Crop Yield: Harvest poorer quality and less food due to a limited amount of air and nutrient
Exposure to CO_2: Greater and Larger exposure	Exposure to CO_2: Smaller and Less exposure
Spread of Diseases: Reduced	Spread of Diseases: Possible
Water: Required in minimal amount	Water: Required twice the amount of water by aeroponics

Nutrients used in aeroponics system

An indoor aeroponics system uses less water and nutrients because the plant roots are sprayed in intervals using a precise drop size that can be utilized most efficiently by osmosis to nourish the plant. Little excess nutrient solution is lost to evaporation or runoff. Plant disease is minimized because the roots are left open to air, avoiding soaking is a stagnant moist medium. Aeroponics creates possibilities to cultivate plants without soil or substrate, obtaining the optimal yield, saving water and nutrient solutions and do not contaminate the environment [26]. Carbon, oxygen and hydrogen are present in air and water. Water may contain a variety of elements with primary nutrients such as nitrogen, phosphorus, potassium and secondary nutrients viz., calcium, magnesium, and sulphur, micro-nutrients are iron, zinc molybdenum, manganese, boron, copper, cobalt and chlorine. Roots use nutrients as ions in water positively charged cations, or negatively charged anions. An example of a cation is ammonium, NH^{4+}, and an anion nitrate, NO^{3-}, both important nitrogen sources for plants [1, 3, 13, 15, 23, 28, 49]. As plants use the ions, the pH of the solution can change, meaning it can lean too far positive or too far negative. The optimal pH for plant growth is between 5.8 and 6.3. In aeroponic system where water and nutrients are recycled, it is important to measure the acid/base or pH measurement to allow plants to absorb nutrients. Aeroponic using spray to nourish roots use much less liquid resulting in easier management of nutrient concentration with greater pH stability.

The main nutrients used in aeroponics are

Nutrient	Concentration (g/L)
$N\text{-}NH_4$	0.54
$N\text{-}NO_3$	0.35
P	0.40
K	0.35
Ca	0.17
Mg	0.08
Na	0.04
Fe	0.09
Zn	0.03
B	0.03
Cu	0.04

Aeroponics growing system

The principles of aeroponics are based on the possibility of cultivating vegetables whose roots are not inserted in a substratum (the case with hydroponics) or soil, but in a container filled with flowing plant nutrition. In these containers root can be find the best condition regarding the best oxygenation and moisture. These conditions allow for the better plant nutrition assimilation in a more balanced way, with consequential faster development of the cultivated plant.

Plant containers can be mounted on top of one another and because they are light and handy, they can be easily moved according to agricultural needs. Numerous plants are mounted in vertical columns within a greenhouse or shade house space. Nutrients are allowed to trickle down through the growth columns. Most agricultural plants need a direct exposure to the sun during the first vegetative development. Afterwards this direct exposure is no longer relevant. Based on this observation, plant containers are periodically displaced. Young plants are placed at the highest level of the growth column. Afterwards they are progressively lowered utilizing a rotational mechanical system. With the rotation periodically repeated, this permits constant production without any interruption. The Aeroponic system is agriculture with a non-stop production cycle [1, 26, 37].

Plant nutrition is supplied into a closed circuit. Consumption is consequently limited to only the quantities absorbed by the plants, allowing for substantial water savings. For example: to produce a kilogram of tomatoes using traditional land cultivation requires 200 to 400 liters of water, hydroponics requires about 70 liters, aeroponics utilizes only about 20 liters. Because the aeroponic system is a continuous-cycle in an enclosed space it reduces the agricultural labor into a series of mechanical routine operational tasks which are carried out daily and throughout the year. This enables workers to acquire considerable skill within a short period of time a few months. In traditional agriculture commercial production is obtained only with skilled workers qualified by many years of experience.

The aeroponic equipment is sheltered within greenhouses or anti hail-storm coverings according to the latitude. Climate controls within the greenhouse ensure optimal growing conditions, assuring high yields.

Components of aeroponics system

Spray misters

Atomization is achieved by pumping water through nozzles at high pressure. Nozzels come in different spray patterns and orifices. Larger nozzles and orifices reduce the chance of clogging but need pressure to operate and have high flow rates. Selecting nozzles that produce the droplet size needed will provide adequate coverage at the intended rate and pressure.

Droplet size in a given spray may vary from sub microns to thousands of microns. These droplets are categorized different classifications. For HPA the classification is fine atomization fine mist of 10 to 100 um. Use a fine mesh filter prior to misting nozzles to prevent clogging. Hydro atomize water and nutrient solution to 5 – 50 micron droplet spray range. Jet nozzles with 0.025 inch orifice operating at 80 to 100 psi deliver droplets of 5 – 50 microns per second. Spray jet with 0.016 orifice operating at 80 to 100 psi deliver droplets of 5- 25 microns per second.

Droplet size

The ideal droplet size range for most plant species is 20 - 100 microns. Within this range the smaller droplets saturate the air, maintaining humidity levels within the growth chamber. The larger droplets 30 - 100 microns make the most contact with the roots. Spray droplets less than 30 microns tend to remain in the air as a fog. While any droplets over 100 microns tend to fall out of the air before containing any roots. Too large of a water droplet means less oxygen is available to the root system.

High pressure water pump

High pressure aeroponics requires a pump that can produce enough to pressurize the water to produce the ideal droplet size of 20 to 50 microns. These pumps are generally diaphragm pumps or reverse osmosis booster pumps. The pump must produce a steady 80 PSI with required nutrient flow.

pH meter

The optimal pH for plant growth is between 5.8 and 6.5. In aeroponics systems, where water and nutrients are recycled, it is important to measure the pH to allow plants to absorb nutrients. The nitrogen (N) absorbs better at pH 6.0, while the phosphorous (P) and potassium (K) are better at 6.25 and up. The pH scale is a way to measure the Acid or Basic (alkaline) in nutrient solution. The official definition of pH is: a unit of measure that describes the degree of acidity or alkalinity of a liquid solution. It is measured on a scale of 0 to 14. Acids are in a range from 0 to 7, with lower numbers being a stronger acid. Alkaline is in the range from 7 to 14, with the higher numbers being a stronger base.

When measuring the pH you want to mix your nutrients with the water completely first to ensure a true reading. If the reading is not at the proper level you need to adjust it using pH adjusters called "pH up" and "pH down," Depending on weather your reading is to high or to low. If it's too high use the pH down, and if it's too low use the pH up. pH for some vegetable crops in aeroponics [1, 2, 15, 21].

Crops	pH
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
Carrots	5.8-6.4

EC (Electrical conductivity)

There are different methods to measure the dissolved nutrients in the solution or concentration. The most common way is to measure the electrical conductivity, or EC with a meter. For example, lettuce grows best with an EC of about 1.6. Remember this is the concentration of minerals in the water, whether good or bad stuff. Let’s say the EC of your tap water before adding any nutrients is 0.3. So if you make up a nutrient solution for your aeroponic system to an EC of 1.6, nearly 19% of the things dissolved in the water is things the plant does not want. The EC of solution is a measure of all of the salts dissolved in water, including those added in the fertilizer.EC is measured in mS/cm (milliSiemens per centimeter).

EC vary by crop but are often in the range of 1.0 to 2.0 mS/cm. A low EC indicates that not enough fertilizer is being supplied to meet plant needs. A recommendation is to avoid EC greater than 4.0 mS/cm. At higher EC the plant will die. As with closed systems, the EC will usually rise through the system to prevent this increase the proportion of run-off by increasing the volume and/or frequency of irrigation. The following were listed for some of the crops [1, 2, 25].

Crops	EC (mS/cm)
Cucumber	1.7-2.2
Lettuce	0.8-1.2
Onions	1.4-1.8
Potato	2.0-2.5
Spinach	1.8-2.3
Tomato	2.0-5.0
Carrots	1.6-2.0

Light and Temperature

Replacement for Sun light is very essential. It can be replaced by fluorescent tubes of required Intensity.15000-20000 lux – for vegetative growth.35000-40000 lux –for flowering and fruiting. The optimum temperature for all plants is 15°C – 25°C [38]. But this condition can be offered by air conditioning exhaust fan and ventilation. According to the requirement of the plant the suitable method can be chosen. By heating or cooling the nutrient before it is misted into the root zone, the temperature inside the growing chamber (which needs to be insulated) can be precisely controlled. Depending on how extreme the aerial environment, it is possible to grow crops with nutrient solution warming or cooling only in aeroponics, something which is more difficult to achieve in other hydroponic systems where the solution rapidly cools/heats as it flows through the system. In Singapore, by cooling the aeroponic solution by 10 - 15^0C below the ambient air temperature, cool season crops can be grown within modifying the temperature of the aerial environment.

Misting Frequency and Nutrient Reservoir

Aeroponic systems may mist the root system continuously, or intermittently and both methods work well, since water logging and oxygen starvation are not a problem in aeroponics. The major advantage of intermittent aeroponics systems is the saving in running cost, since the pump is only on for a short period of time, but the roots are still contained within the nutrient, moisture and oxygen rich environment between mistings. And since aeroponics systems do require larger pumps with greater energy requirements than other hydroponic systems, this saving is an important feature. Always look for systems that either link light levels to misting frequency or have the ability to program in a large number of misting cycles per 24 hours. As a general rule, a misting cycle of 1 -2 minutes of misting followed by 5 minutes off will ensure the root system does not dry out under most conditions. Farran and Mingo (2006) [15] used systems that mist for 10 seconds at 20 min intervals.

Aeroponics systems are further divided into those which have a separate nutrient reservoir and pump the nutrient up into the root chambers and those with an all in one contained chamber and nutrient tank. The simpler aeroponic systems spray the nutrient up from the reservoir in the bottom of the root chamber, where it drips back down after misting the root system. By the time the plants are mature, the root system has often grown down into the nutrient solution stored in the base of the chamber and blockages can occur. Larger aeroponic systems return the nutrient after misting to a separate nutrient reservoir.

Aeroponics Working Method

In aeroponic system the young plants can be either raised as seedlings using especially designed lattice pots or cuttings can be placed directly into the aeroponic 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 nutrient. There is a high success rate with plant cuttings which are rooted in aeroponics - in fact this method has been extensively used as a research tool into root development on many difficult to propagate plant species. The base of the cutting is supplied with high levels of oxygen and moisture in a humid environment which prevents desiccation and accelerates root formation.

Once the young plant has been established into the aeroponics system, the root system rapidly develops in the chamber or channel. What is important at this stage is that the optimum size of the droplets is maintained within the system for maximum efficiency. There is a huge range of aeroponic nozzles so selection of a droplet size range which best suits the plant and system used is fairly easy. Spray droplets less 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. Within this range the smaller droplets saturate the air, maintaining humidity levels within the growth chamber, the larger droplets 30 - 100 microns make the most contact with the roots, while any droplets over 100 microns tend to fall out of the air before containing any roots.

The principles of aeroponics are based on the possibility of cultivating vegetables whose roots are not inserted in a substratum or soil, hanging in a containers filled with flowing plant nutrition. In these containers root can be find the best condition regarding the best oxygenation and moisture. These conditions allow for the better plant nutrition assimilation in a more balanced way, with consequential faster development of the cultivated plant. Plant nutrition is supplied into a closed circuit. Consumption is consequently limited to only the quantities absorbed by the plants, allowing for water savings. For example: to produce a kilogram of tomatoes using traditional land cultivation requires 200 to 400 liters of water, hydroponics requires about 70 liters, aeroponics utilizes only about 20 liters.

Crop Production

Like hydroponic systems, aeroponics is also likely to be profitable producing high value crops.

Potato

C.B. Christie and M.A. Nichols., 2004 [11] have used aeroponics to mass produce high healthy seed potatoes and also to produce gourmet early (new) potatoes. When the early growth and development of potatoes in hydroponics is examined it soon become clear that the root system developed well ahead of the stolons that are to produce the tubers. The key to tuber production in aeroponics is in controlling the initiation of the tubers. This can be achieved using an intermittent irrigation system, or by temporary stressing the plant. One of the advantages of the system is that synchronized tuber production is possible allowing a very large number of relatively uniform tubers to be produced at a single time.

In mitigating the problem of shortage of good quality seeds, strategies to rapidly multiply the seed tubers such as tissue culture in conjunction with hydroponic and aeroponic systems have been tried by Irman *et al*., 2012 [21]. Chang et al., 2012[9] found that an interruption of nutrient supply at stolon growth stage significantly increases root activity, restricts stolon growth, and finally induces tuber initiation. Therefore, non-tuberizing conditions such as hot temperatures and late season cultivars favor use of this nutrient interruption technique, particularly for seed potato production in hydroponics. Aeroponics could be an appropriate system for producing potato minitubers. In our system, up to 800 minitubers/m^2 could be obtained, using only 60 plants/mt square with repeated harvests every week. Minitubers thus produced were healthy, free of infections, and their physiological behavior in field conditions was similar to those obtained by hydroponics [15]. The International Potato Center (CIP) has recently developed and promoted mini-tuber production based on a novel, rustic and publically available aeroponics system. Results showed that the aeroponics system is a viable technological alternative for the potato mini-tuber production component within a potato tuber seed system producing more number of tubers, high tuber yield tuber weight [32]. Plants once cleaned through meristem culture and induction of tuberization under aeroponics system, produce high quality potato seed tubers rapidly that are free from contamination of pathogens and multiplication of potato tubers was easy and were directly planted in the main field. Thus aeroponic system, has potential to increase income and reduce cost of production of quality seed, thereby, making it more accessible to growers in developing countries where potato production is heavily constrained by the use of poor quality seed tubers.

Yams

The aeroponics technology should be considered as an effective yam propagation method. Genotypes of both *D. rotundata* and *D. alata* were successfully propagated in it using both pre-rooted and fresh vine cuttings. Results of these studies revealed that vines cutting from five months old plants rooted successfully (95%) within 14 days in aeroponics. An average of 83% (range of 68% - 98%) rooting of vine cutting was registered for the five genotypes used. Genotypes performed differently in aeroponics technology for mini-tuber production. Yam mini-tubers harvested from aeroponics varied from 0.2g to 110g depending on the genotype, the age of harvest and the composition of the nutrient solution. However, this system is sensitive to excessive heat and care must be taken to regulate the temperature [31].

Lettuce

Demsar. J *et al*., 2004 [12] studied the effect of light dependent application of nitrate on the growth and yield of aeroponically grown lettuce. He and Lee, 1998 [18] found that the growth of shoot and root and photosynthetic responses of three cultivars of Lettuce (*Lactuca sativa* L.) confined to different root zone temperatures and growth irradiances under tropical aerial conditions was better to the aeroponically grown crops compared to the control. Luo *et al*., 2009 [30], have developed a very successful method of producing hearted lettuce in the tropics using aeroponics and root cooling. It was also found that the effects of elevated root zone CO2 and air temperature on photosynthetic gas exchange, nitrate uptake and total reduced nitrogen content in aeroponically grown lettuce plants [22].

Leafy vegetables

A comparison of the product yield, total phenolics, total flavonoids, and antioxidant properties was done in different leafy vegetables/herbs (basil, chard, parsley, and red kale) and fruit crops (bell pepper, cherry tomatoes, cucumber, and squash) grown in aeroponic growing systems and in the field. An average increase of about 19%, 8%, 65%, 21%, 53%, 35%, 7%, and 50% in the yield was recorded for basil, chard, red kale, parsley, bell pepper, cherry tomatoes, cucumber, and squash, respectively, when grown in aeroponic systems, compared to that grown in the soil. Antioxidant properties of those crops were evaluated using 2,2-diphenyl-1-picrylhydrazyl (DDPH) and cellular antioxidant (CAA) assays. In general, the study shows that the plants grown in the aeroponic system had a higher yield and comparable phenolics, flavonoids, and antioxidant properties as compared to those grown in the soil [8]. In aeroponics, the biomass production was dependent on the plant densities investigated. The highest yield was obtained for the highest density with 100 plants per m^2. It was proved that the length of the stems and the leaf area were also influenced by plant's density. The vitamin C content was highest in all herbs cultivated in aeroponics whereas the essential content oil was highest in Holy Basil and Perilla cultivated in substrate. The carotene content in water spinach was the highest in substrate culture [6].

Advantages

- Less Fertilizer - Since all the nutrients are contained, they don't end up in groundwater or sinking too deep into the soil to be of any help.
- Less Water - Very important for space travel and those in arid climates. Much of the water lost in traditional gardening is from water evaporating out of the soil. The rest of it just sinks past the roots and the plants never get a chance to drink it.
- More Cost Effective - Since less nutrient solution is needed as compared to hydroponics the costs to operate an aeroponic garden are less than to operate a hydroponic garden. There are also fewer moving parts and complicated systems involved.
- Reduced Disease Damage - Because the plants are seperated from each other and not sharing the same soil, an infection in one plant has a much lower chance of spreading to the rest of your plants.
- Faster and healthier growth since it has enough oxygen (in the root region) Increased harvest rate is 45–70% faster than conventional agricultural techniques.
- Studies has shown that plants grown *via* the aeroponic system have an increase in flavonoids.

Disadvantages

- More expensive for long scale production.
- Ordinary farmers will struggle to manage all these sophisticated instruments.
- Mister spray heads may also have a tendency to clog and not produce mist when needed.
- Many consumers believe that aeroponically grown plants are not as nutritious as other grown plants.
- Maintenance of an aeroponics farm is very expensive.

Conclusion

Aeroponics growing allows plants and crops to grow without the use of pesticide and thus it will be disease free. The crops will grow in a natural healthy manner as the aeroponic system is very similar to nature environmental conditions. Aeroponics is conducted in air combined with micro-droplets of water, almost any plant can grow to maturity in air with a plentiful supply of carbon dioxide, water and nutrients. Aeroponics helps conserve water, land and nutrients, so the aeroponics system is the way of the future, making cultivation of crops easier. Aeroponics appeared to be a highly feasible method for the production of both aerial parts and roots as raw materials for the herbal dietary supplement and phyto pharmaceutical industries.

Future prospects

Aeroponics offers the potential to improve production and reduce costs compared to conventional methods or to the other soilless method of hydroponics (growth in water). Aeroponics effectively exploits the vertical space of the greenhouse and air humidity balance to optimize the development of roots, tubers, and foliage. Commercial production of potato seeds using aeroponic is already progressing in Korea [24, 25]) China and India. In the Central Andean Region of South America, the technology has been used successfully since 2006. At the Huancayo, Peru facility of the International Potato Center, yields of more than100 minitubers/plants have been obtained using relatively simple materials. Aeroponic technology is being tested in several African countries for the production of potato minitubers [29] and current efforts are underway to incorporate aeroponic into potato seed systems of some Sub-Saharan African countries.

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