# IMPLEMENTATION OF AN AEROPONIC GROWING CHAMBER TO CULTIVATE LETTUCE IN A GREENHOUSE

**[1]CORAL MARTÍNEZ-NOLASCO, [2]JOSÉ A. PADILLA-MEDINA, [3]MAURO SANTOYO-MORA, [4]SANDOR E. DOMÍNGUEZ- VELAZCO, [5]JUAN PRADO-OLIVAREZ, [6]CRISTAL Y. MORENO-AGUILERA**

[1,3]Division of postgraduate studies and research, Tecnológico Nacional de México en Celaya, México
[2,4,5]Department of electronics Engineering, Tecnológico Nacional de México en Celaya, México
[6]Department of mechatronics Engineering, Tecnológico Nacional de México en Celaya, México
E-mail: [1]coral.martinez@itcelaya.edu.mx, [2]alfredo.padilla@itcelaya.edu.mx, [3]mauro.santoyo@itcelaya.edu.mx, [4]sandordv2017@gmail.com, [5]juan.prado@itcelaya.edu.mx, [6]16030338@itcelaya.edu.mx

**Abstract -** The aim of this work is to implement an aeroponic growing chamber in a greenhouse that allows to inspect the growth process of a lettuce plant with a non-invasive technique. This inspection is focused on the examination of the foliar and radicular systems that integrate the lettuce. It is defined a 30-day period for the inspection, which begins at the end of the germination (thirtieth day) and culminates on the sixtieth day in the growing cycle of the plant.
One of the main characteristics in the presented aeroponic system is that the nutrient solution tank is independent from the structure that contains the plants. With this proposal the roots grow freely suspended and are exposed to an environment with high levels of oxygenation and low levels of relative humidity. Under these conditions, it was noticed a peculiar architecture developed by the radicular system. The aeroponic chamber was tested for three growing cycles to analyze its performance. This analysis considered the fresh mass of the lettuce and the length of its primary root. The results indicate that the proposed system can repeat successful growing cycles and accomplishes with the attributes of an aeroponic system, which are to be ecological and to have low water consumption.

**Keywords** - Aeroponics, Atomizer, Fertigation, Nebulization, Radicular system, Nutrient solution.

## I. INTRODUCTION

One of the consequences from the climate change in the world is the higher risk of droughts. Consequently, the agriculture is challenged with an inevitably phase of changing to prevent an impact over the food production. Moreover, the worldwide population growth demands not only the production of high-quality food but also its production in a short period of time. As a result, the agriculture requires a production beyond conventional methods by the creation of novel techniques as the so-called "soilless cultivation". This technique is widely related to aeroponics and hydroponics (Lakhiar, Gao, Syed, Chandio, & Buttar, 2018). The soilless culture represents a new key point in the agriculture through the possibility of reducing the consumption of both water and fertilizer by implementing an efficient fertigation. In fact, the soilless culture is also being adopted as part of the urban agriculture (Fernández-Bregón, Valera, & Urrestarazu, 2013). Aeroponic culture is a new technology of soilless culture which integrates plant nutriology, plant physiology, ecological environment, agricultural automation, horticultural crop cultivation and other disciplines (LIU, et al., 2018).

The first objective of this work is to model and to implement an aeroponic growing chamber in a greenhouse to grow *Iceberg* and *Italian* types of lettuce. Second, to define the experimental variables implicated in the soilless cultivation of lettuce as the type of seeds, the correct timings for fertigation, and the nutrient solution characteristics expressed by its electric conductivity (EC) and pH level.

The presented aeroponic system demonstrates to have the advantages of an easy implementation in reduced spaces, a functional automated fertigation system, the direct access to the radicular system of the lettuce crops and the possibility to have more than six complete growing cycles for lettuce in a year.

## II. MATERIALS AND METHODS

### AEROPONIC GROWING CHAMBER CONSTRUCTION

As first step, the aeroponic chamber was modeled with the aid of SolidWorks. The complete model built for the aeroponic chamber is shown in Fig. 1. This design was considered to have a capacity for 30 lettuces, where each plant counts with its own nozzle for irrigation. The main structure of the chamber includes an inspection window on one side for either examine or capture images from the radicular system; the purpose of this window is to have an easy access to the radicular system and protect it from a continuous light exposition. As can be seen in Fig. 1, the chamber has an independent tank from the main structure which stores the nutrient solution. The separation of the tank facilitates the preparing of the nutrient solution and the measuring of its EC and pH levels. The aeroponic chamber also includes a recirculation system located

at the bottom of the main structure. All the recollected nutrient solution by this system is returned to the independent tank after a fertigation cycle.

The structure of the aeroponic chamber has a size of 2.53×1×1.4 m and is built with a structural square tubing of 1 in with a 3 mm wall thickness. These dimensions of the structure consider an equal distribution for 30 lettuces along three rows and reserve the recommended space for a full-growth lettuce. Namely, a full-growth lettuce measures approximately 0.3 m of length by 0.3 m of width and has a root with a length of 0.25 m. With the purpose of maintaining the lettuce roots suspended, the system counts with a tray built in Styrofoam with perforated circular plant holders to allocate 2 in hydroponic pots.

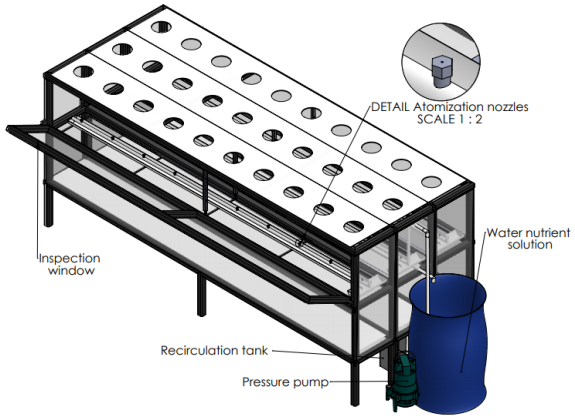



**Fig. 1 Aeroponic growing chamber model**

The fertigation system includes a set of 30 hybrid nozzles connected to 1 in PVC pipes and a pressure regulating valve. A 1/3 hp submergible pumping unit is used to pump the nutrient solution in the system. On the initial tests of this system, the plants experienced some stress because of the type of nebulizers selected for the first design. With this initial configuration, the system was operating with 0.5 in nebulizers that produced a direct strike over the roots in the form of large drops at high pressure, provoking the stress. As result of this observation, the design adopted a 0.25 in fog spray nozzle on the nebulizers with a flow rate of 2-2.5 L/hr., a pressure of 220-280 kPa and a spraying diameter of 1.2-1.8 m. This nozzle also includes a knob to regulate the size of the droplets and the spraying area.

In aeroponics, the fertigation timing is crucial because the crops rely on an adequate obtention of both nutrients and water to have an optimal development. Therefore, the aeroponic chamber includes an automated system to switch the on/off cycles of the pumping unit by using an asymmetric timer of the trademark CARLO GAVAZZI. To find the optimal timing, the fertigation system was tested with an initial configuration of 18 s for the fertigation either every 30 min during the day or every 60 min during the night. Despite the good appearance in the foliar system of the lettuce with this configuration, the radicular system presented black tips which indicated a nutritional deficiency in the crop. Based on this observation, the fertigation system required an adjustment on the proposed initial timings. Thus, it was found that the adequate fertigation timing corresponds to a 24 s spraying period every 24 min all day long. After setting the automated fertigation system with these times, it was possible to obtain three favorable harvests and a consumption rate of nutrient solution from 7 to 10 liters per day.

## CROP AND EXPERIMENTAL DESIGN

The harvest periods defined to evaluate the performance of the aeroponic chamber started on the summer of 2019 and concluded on the beginning of 2020. The first and second harvests occurred in 2019 over the periods of August-October and October-December respectively, while the last harvest period corresponded to January-February in 2020. These experiments were developed in a greenhouse property of the Tecnológico Nacional de México en Celaya, which is located at the city of Celaya in the state of Guanajuato, Mexico. Each of the first two experiments employed 30 *Iceberg* lettuce seedlings. On the other hand, the third experiment employed 30 *Italian* lettuce seedlings. It is worth noting that the seedlings from all the experiments were transplanted to the aeroponic chamber on the morning of the thirtieth day of germination. The lettuce crops were fertigated for a 30-day period with a Steiner nutrient solution for hydroponics (Lakhiar, Gao, Syed, Chandio, & Buttar, 2018). To prepare this nutrient solution, it is required water with a pH level of 6. Since the raw water in the region of Celaya has a pH level of 7.8, it was necessary to level down the pH by adding 0.5 ml of nitric acid per liter of water. To guarantee the quality of the nutrient solution, every third day were verified the pH level, the total dissolved solids (TDS), and the EC from the solution. As described before, the pH level must be of 6, meanwhile the TDS and EC levels must be in a range of 1726-1880 ppm and 3128-3290 µS/cm, respectively. All the measurements made on the nutrient solution were performed with a pocket tester from UMEXUS.

During all the experiments the room temperature and relative humidity of the greenhouse was monitored. The highest value of room temperature reported 39 °C at 14:00 hr. and was registered on the first harvest period. This value of temperature occurred as effect of the summer season in the region and the plastic-wall closed structure of the greenhouse. The Fig. 2 shows the behavior for the mean room temperature and the relative humidity in the greenhouse observed on the first harvest period.

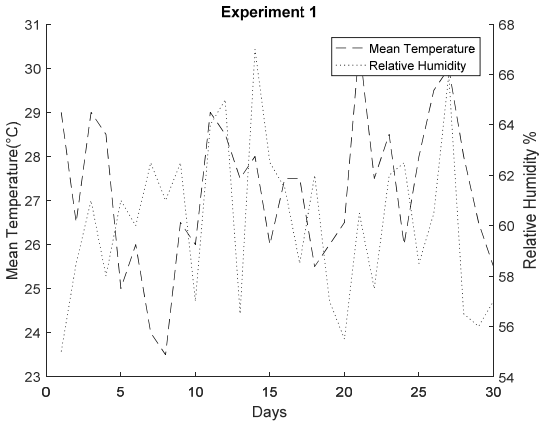



**Fig. 2 Mean room temperature and relative humidity for experiment 1**

On hot days is common that at least one lettuce suffers with abiotic stress due to high levels of temperature and low levels in the relative humidity. When a lettuce crop is under this type of stress it is noticeable with a loss of turgency on the leaves. This same effect is characteristic of the hydric stress when a root has not been fertigation adequately, for example when a nozzle is not working properly. A key point to mention is that the lettuce plant uses the night period to recover from the stress suffered all day long.

The Fig. 3 shows a photograph with the side view of the aeroponic chamber. As can be seen in the photograph, each lettuce crop has a nozzle pointing directly at the base of the radicular system to be fertigated with nutrient solution.



**Fig. 3 Crop of Iceberg lettuce on the aeroponic growing chamber**

## III. RESULTS

After testing the aeroponic chamber during some growing cycles, it was possible to define the optimal timings to be implemented in the automated fertigation system. These timings were not only determined by the design of the aeroponic chamber, but also by the local weather conditions. Under the conditions of the local weather, it was necessary to adjust the fertigation timings for longer periods on hot days (e.g. like the days during the first harvest period which daily mean temperature is shown in Fig. 2).

The harvest of the lettuce crops was made on the morning at the sixtieth day of the growing cycle. Before removing a lettuce crop from its holder, the primary root growth was measured with the aid of a conventional instrument. In order to appreciate the length distribution of the primary roots, the measured values were grouped in a histogram for each experiment. According to the histograms presented in the Fig. 4, the distributions for each experiment tend to a normal distribution.

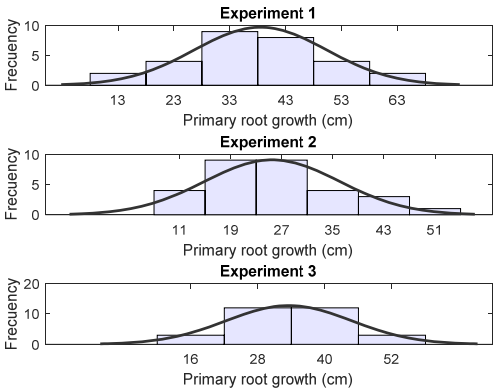



**Fig. 4 Histograms of the radicular systems for the implemented experiments**

The architecture of the radicular system developed by three random specimens can be appreciated in

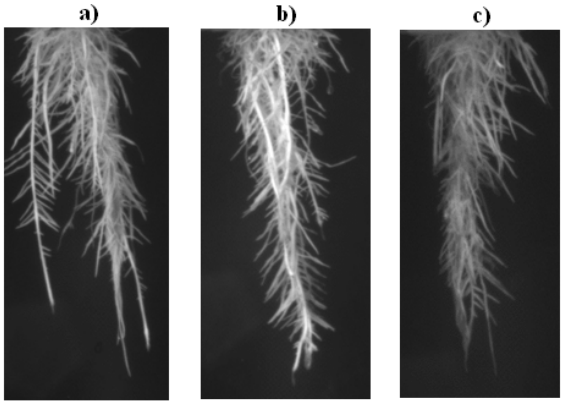



Fig. 5. The showed images were captured at a wavelength of 530 nm with a near-infrared (NIR) camera of model NIR Cool Bigeye G-132B.

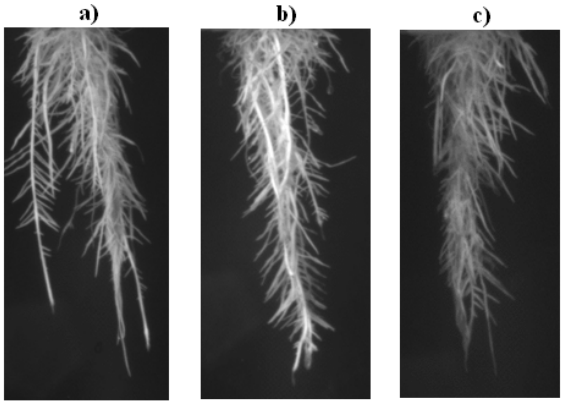


**Fig. 5 Developed radicular system by a) lettuce 10, b) lettuce 17, and c) lettuce 24**

The mass of each lettuce crop was weighted after being harvested from the aeroponic chamber. The calculated mean fresh mass of the harvested lettuces in each experiment are shown in Table I. It follows that the mean fresh mass obtained by the experiments 1 and 3 are similar surpassing the 300 g. On the other side, the resulting fresh mass for the second experiment is lower as consequence of a plague present during the growing cycle in this experiment. Thus, this biotic stress in the crops inhibited their adequate development.

| Parameter | Experiment 1 | Experiment 2 | Experiment 3 |
|---|---|---|---|
| Mean fresh mass (g) | 357.63 | 117.66 | 320.33 |

**Table I Mean of fresh mass for each harvest**

## IV. CONCLUSION

The construction of the presented prototype was not an easy task, since it is difficult to find the balance among the variables involved in growing plants with aeroponics. One of the key aspects in aeroponics to achieve a successful crop growth is the prevention of stress in the radicular system. To that end, it is necessary to have a proper control on the fertigation timing and the sprayed drops must have a small size to prevent stress on the radicular system.

Once there were found the ideal parameters, the next step evaluated the functionality of the aeroponic chamber by testing its performance in three growing cycles for two types of lettuce during different seasons of the year. It is clear to see that these experiments resulted in the completion of the growth cycle producing well-developed lettuce crops. Furthermore, the design of the aeroponic chamber allowed a monitoring in both radicular and foliar systems of the lettuce without either interfering in its growing process or harming the crop in a manual inspection. Finally, with the presented aeroponic system is demonstrated the repeatability of a growing cycle for two types of lettuce during different seasons, in addition to the monitoring and characterizing of the crops during their growing cycle.

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