Automation of pesticide-free cilantro aeroponic crops

Automatización de cultivos aeropónicos de cilantro libres de pesticidas

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Abstract

Introduction− Aeroponics allows the possibility to grow plants in places where conventional open-field agriculture is difficult. The use of technology improves the efficiency of the process although some energy control and irrigation system solutions must be improved.

Objective− Implement an autonomous power supply and an irrigation control system for pesticide-free food production.

Methodology− The autonomous system was designed using *MATLAB-Simulink-MPLAB* tool to perform the control model and to be applied to the crop. A *dsPIC* was programmed for the irrigation cycle control algorithms using *MATLAB-Simulink* blocks.

Results− The results show that the irrigation cycle and power supply of the aeroponic system help maintain uniformity of plant growth during the tests period, which allows a better development of the aeroponic crop.

Conclusions− Cultivation by aeroponics reduces the use of pesticides, growing space, water consumption, and nutrients consumption. Automation in irrigation and power supply systems allows good growth in coriander, which can be evidenced by increases in the weight and volume of the test plants.

Keywords− Pesticide-free food; aeroponics; autonomous irrigation system; clean production; autonomous electric power supply.

Resumen

Introducción− La aeroponía permite la posibilidad de cultivar plantas, en lugares donde la agricultura convencional de campo abierto es difícil. El uso de la tecnología permite mejorar la eficiencia de los procesos, aunque se requiere incorporar algunas mejoras y soluciones en los sistemas de suministro energético y control del riego.

Objetivo− Implementar una fuente autónoma de suministro energético y un sistema de control del riego para la producción de alimentos libres de pesticidas.

Metodología− El sistema autónomo se diseñó utilizando la herramienta *Matlab-Simulink-MPLAB*, para desarrollar el modelo de control y aplicarlo al cultivo. Además, se programó un *dsPIC* para los algoritmos de control del ciclo de riego utilizando bloques *Matlab-Simulink*.

Resultados− Los resultados muestran que el ciclo de riego y el suministro de energía, ayudan a mantener plantas uniformes en el cultivo durante el periodo de las pruebas, lo que permite a su vez incorporar mejoras en el desarrollo de los cultivos aeropónicos.

Conclusiones− Cultivar de manera aeropónica reduce el uso de pesticidas, espacio, agua y nutrientes. La automatización en los sistemas de irrigación y de suministro de potencia, permite lograr un buen crecimiento en el cilantro, lo cual se puede evidenciar mediante el incremento en los niveles de peso y volumen, registrados en las mediciones de las plantas de prueba.

Palabras clave− Alimentos libres de pesticidas; aeroponía; sistemas de irrigación autónoma; producción limpia; fuente de potencia eléctrica autónoma.

I. Introduction

As the human population continues to grow, the volume of food production must also increase; thus, a viable, productive model is required for future agriculture. For example. Although the high production of food in Latin America, some countries still need to increase the exportation of agricultural products with respect to the current importation to improve their balances [1]. The food demands of society cannot rely only on the current production model: new alternatives to produce food must be implemented.

Plant factories with aeroponic food production are an alternative that can optimize space and water resources [2], and reduce costs by automating operations and reducing the resources used to control phytosanitary problems. This concept is of great importance for agriculture, because it allows large-scale food production, occupies less space, and consumes less water and nutrients [3]–[6].

Aeroponics can produce a higher yield of pesticide-free food, optimize the production space, provide a cleaner growing environment, and reduce serious environmental impacts that affect the climate, promote biodiversity, and improve the quality of life required by rural and urban inhabitants [7]–[10]. Currently, aeroponics is used in agriculture around the world [11], [12]. However, new intelligent technologies are still required to prepare soil and nutrients for plants, improve the electric power supply, and monitor plant growth [13]–[15].

Interest in this topic has increased since studies were performed in companies and universities of Japan, where the number of aeroponic plant factories has expanded from 50 in 2009 to 153 by March 2013 [16]. Some aeroponic technologies have been introduced in "open" plant factories that use natural sunlight. "Closed" aeroponic plant factories, which use artificial light to produce crops in a highly efficient manner, have appeared more recently. These plant factories can provide optimum growing conditions for plants by controlling the internal environment. However, the high initial costs of the construction of a factory and the costs of electricity for air conditioning and lighting are still very high [17].

In the human diet, the family Brassicaceae has been present since ancient times. This family includes species such as broccoli (Brassica oleracea italica), radish (Raphanus sativus), mustard (Sinapis alba), arugula (Eruca vesicaria L. Cav), among others. The latter is of great interest not only at a nutritional level but also by the pharmaceutical industry, due to its high content of secondary metabolites with interesting medical properties [18]–[22].

The use of intelligent systems, modern technologies applied to agriculture, renewable energy systems adapted to crops, and controlled irrigation systems for aeroponic food processes are necessary topics to improve food production efficiency and achieve sustainable markets. Power supply reliability and efficient irrigation systems are current topics. Intelligent irrigation systems offer energy savings by automating the delivery of nutrients to plants based on changes in environmental variables and in order to optimize food production in terms of biomass. The development of systems that reduce the high initial investment, as well as being more efficient in terms of energy consumption in response to the abundant processes or energy-demanding functions in the system, are still required.

This paper presents the application of an autonomous electric power system for the clean production of pesticide-free aeroponically produced food. The system comprises the following: a greenhouse; cultivation beds; an irrigation system; water pumps; nutrient dispensers; power grid supply, hardware to control the intelligent algorithms integrated into the system; process optimization algorithms; and connection to the electrical network and alternative energy sources. The results show how this automatic system improves pesticide-free food growth. This paper is organized as follows. Section 2, presents the methodology used in this research and a description of the electronic circuits implemented for the tests. Section 3 presents the results and analysis, and Section 4 presents the conclusions.

II. Materials and methods

This section presents the materials and methods used for the development of a continuous power supply and irrigation control system. The methods consisted of implementing a greenhouse for the tests, developing power supply and irrigation control circuits, aeroponic cultivation, and crop testing procedures.

A. Greenhouse implementation

Two aeroponic greenhouses were installed at San Antonio de Prado and Universidad Nacional de Colombia, Medellín, at altitudes of 1,900 and 1,479 meters above sea level, respectively. These zones have a subtropical climate that remains constant throughout the year and they are located in mountainous areas with mild winds.

The greenhouse of San Antonio de Prado comprised thirty beds for aeroponic cultivation, each measuring 30 m by 1.2 m. Each bed was prepared with 30 Styrofoam supports of dimension 1 m by 1.2 m and each was used to accommodate 56 vessels in which five seeds were placed. The greenhouse of Universidad Nacional de Colombia comprised nine beds for aeroponic cultivation, each measuring 6 m by 1.2 m. Each bed was prepared with 6 Styrofoam supports of dimension 1 m by 1.2 m, and each was used to accommodate 56 vessels in which five seeds were placed.

The greenhouses were completely covered with plastic to protect the plants from direct sunlight, wind, and rain, and to enable better control over external environmental factors that would affect the experiments. The vessels nestled in Styrofoam allowed the plants to be grown in small containers, which are arranged to perform parallel tests in different beds. The beds were connected to an irrigation system with valves controlled independently by a *dsPIC*. The system in San Antonio de Prado comprised two 3 hp pumps with a pressure of 60 psi and two valves to irrigate each bed with water and nutrients via micro sprinklers. The system in Universidad Nacional de Colombia comprised one 1 hp pumps with a pressure of 50 psi and two valves to irrigate each bed with water and nutrients via micro sprinklers.

B. Plants for the test

Coriandrum sativum, commonly known as “cilantro,” was used as the test plant species due to its rapid growth (approximately 90 days on land and approximately 56 days in aeroponic systems). These plants grow to approximately 40–60 cm in height and are common in tropical and mountainous zones. The lack of moisture and nutrients in few hours leads to partial root death and loss of mass. Five cilantro plants were grown in each vessel, with 56 vessels for each Styrofoam support.

C. Aeroponic food production system

Fig. 1, diagrams and displays the overall pesticide-free food production system implemented in this research. The entire system is controlled automatically by a *dsPIC30F4011* from Microchip Technology Inc., AZ, USA. The electronic system performs two control functions. The first implements the continuous power supply for the irrigation system. For this purpose, the dsPIC30F4011 detects the electrical energy in the network with a sensor and later, with the AC digital output or a battery selector, the power supply switches between the power grid and the batteries. The second function controls the watering cycle and the delivery of nutrients to the plants through a digital output water pump.

Watering cycle periods considered a cycle of 20 s ON and 160 s OFF. Water and nutrient delivery are performed by valves #1 and #2, which control the micro sprinklers. Two valves are needed in order to increase the pressure and achieve very small droplets of water mist, which is necessary for the proper functioning of aeroponic systems. The photos in Fig. 1, show the plants that were grown with this process.

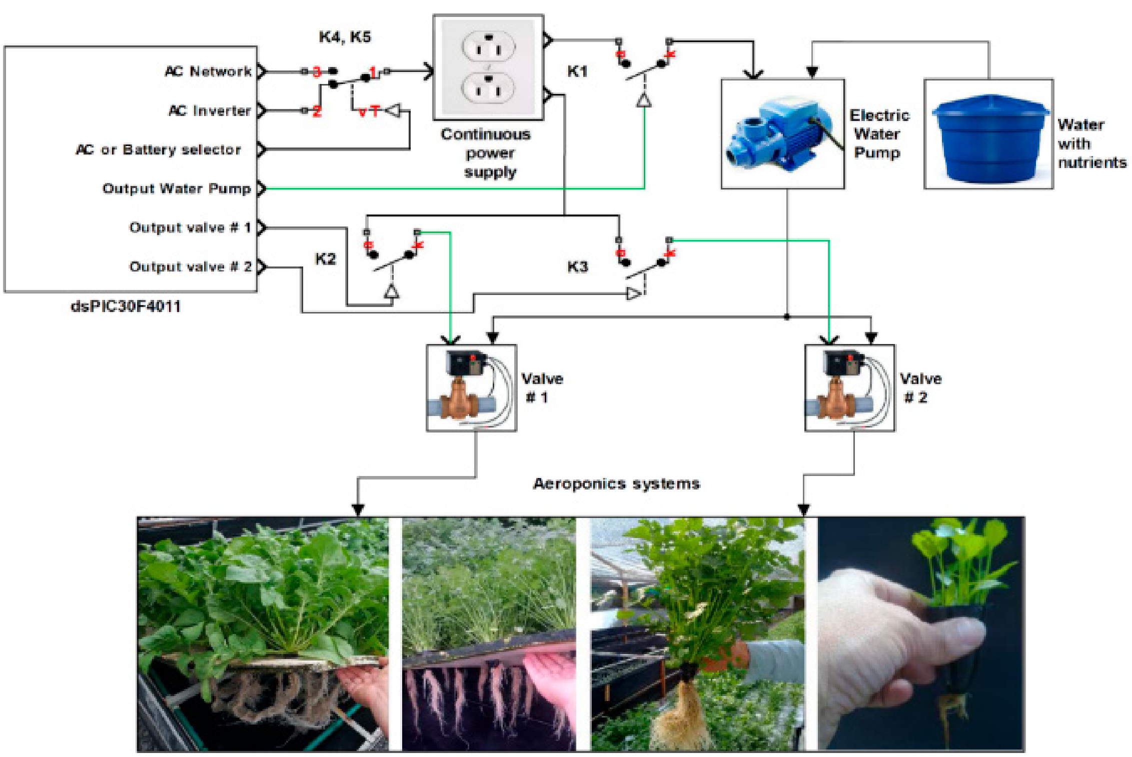

Fig. 1. System for growing pesticide-free aeroponic food. (Top) Diagram of the overall system. (Bottom) Photos showing plants grown in their containers.
Source: Authors.

D. Automatic irrigation system

Fig. 2, shows the sequence blocks implemented in the *MATLAB-Simulink* software for programming the irrigation cycles of the aeroponic system. Using a block pulse generator electric water pump, a PWM signal is generated for ON for 20 seconds and OFF for 160 seconds. The water pump is controlled by the digital output B0 output electric water pump. Using the block pulse generator valve #1, a PWM signal is generated to control valve #1; this allows that the valve is ON for 10 seconds to irrigate and then OFF for 170 seconds. Valve #2 is controlled by the block pulse generator valve #2, which must be OFF for the first 10 seconds; then, the water pump works for the next 10 seconds (ON) and then OFF for 160 seconds to complete the watering cycle.

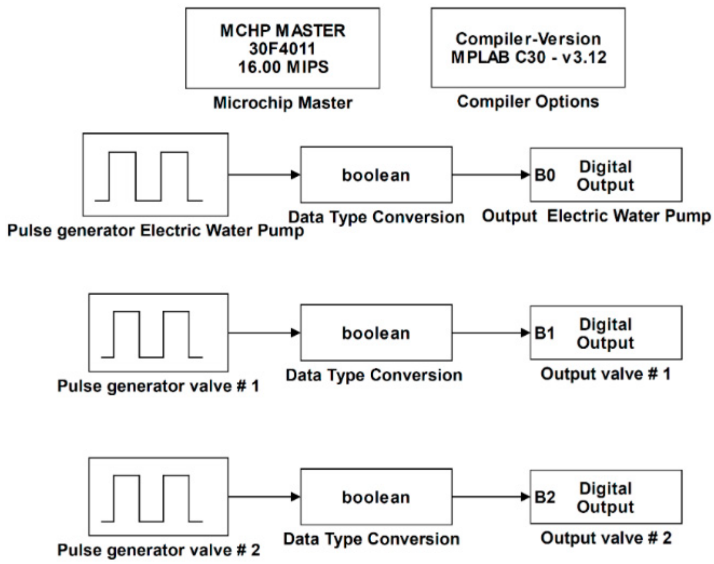

Fig. 2. Irrigation cycle programming in MATLAB-Simulink.
Source: Authors.

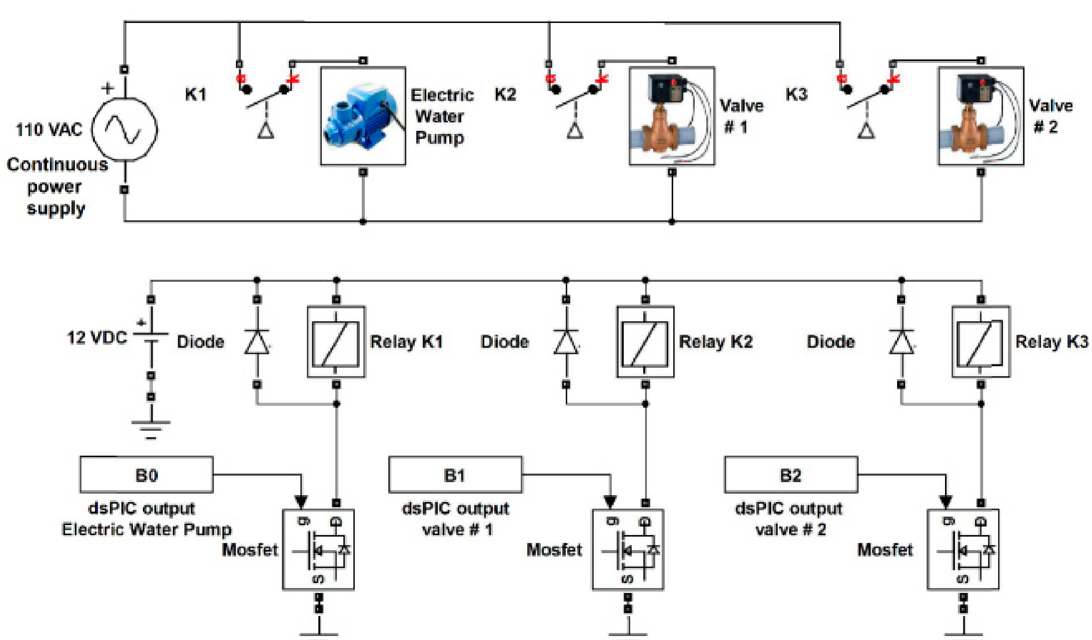

Fig. 3. Diagram of the electric circuit supplying water and nutrients to the plants.
Source: Authors.

E. Electrical system for the nutrient cycles

Fig. 3, shows the electric system and the required connections to supply the nutrients to the plants using micro sprinklers and the respective irrigation cycles. The digital input B0 controls the relay K1 with a MOSFET IRFZ44N and starts the electric water pump for 20 seconds, which delivers water and nutrients to the plants. The digital input B1 controls relay K2 to open valve #1 for 10 seconds and input B2 controls relay K3 to open valve #2 for 10 seconds to deliver the nutrients to the bed.

Fig. 4, shows the developed circuit with the elements and connectors with current capacities up to 10 Amps that connect to the water pump of 1 kW.

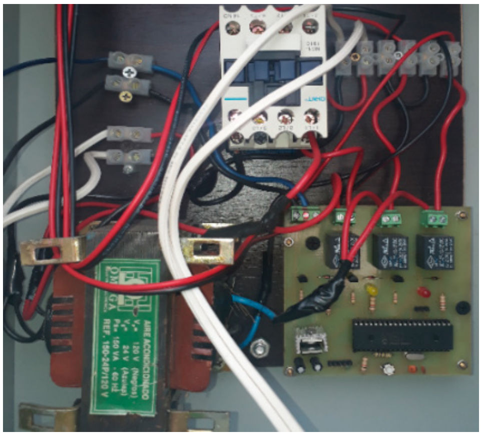

Fig. 4. Electric circuit implemented for the control of irrigation cycles.
Source: Authors.

F. Construction of a reliable power supply

Aeroponic systems for plant production are wholly dependent on a continuous power supply [11] to power the pumps used to deliver water and nutrients by means of micro sprinklers. As the power grid could experience outages of up to five hours, the plants could suffer from prolonged water stress. If the lack of water and nutrients is prolonged, then efficiency in plant growth and even plant death can occur. Therefore, an auxiliary 3 kW system with battery storage was installed as a low-cost solution in the event of outages of up to 24 hours.

Fig. 5, shows the diagram with the blocks designed to supply continuous power for the aeroponic system. These were programmed in *MATLAB-Simulink* and implemented in a *dsPIC30F4011*. The input AC voltage sensor consists of a sensor that detects the absence of electricity in the power grid. The block AC or battery selector activates the output B3 for the power grid or the output B4 for the batteries. The function delay provides a time in milliseconds to avoid that the two outputs B3 and B4 are ON, thereby preventing a short-circuit in the system. Finally, the block UART 2 is placed to visualize the real-time signal of the voltage sensor.

Fig. 6, shows the electrical circuit of the system developed to deliver power for the aeroponic system. The B3 input controls the K4 relay that is responsible for delivering power from the electrical grid to the aeroponic system. When no power is available from the electrical network, the B4 input controls relay K5 to provide electricity continuously by using energy stored in the batteries.

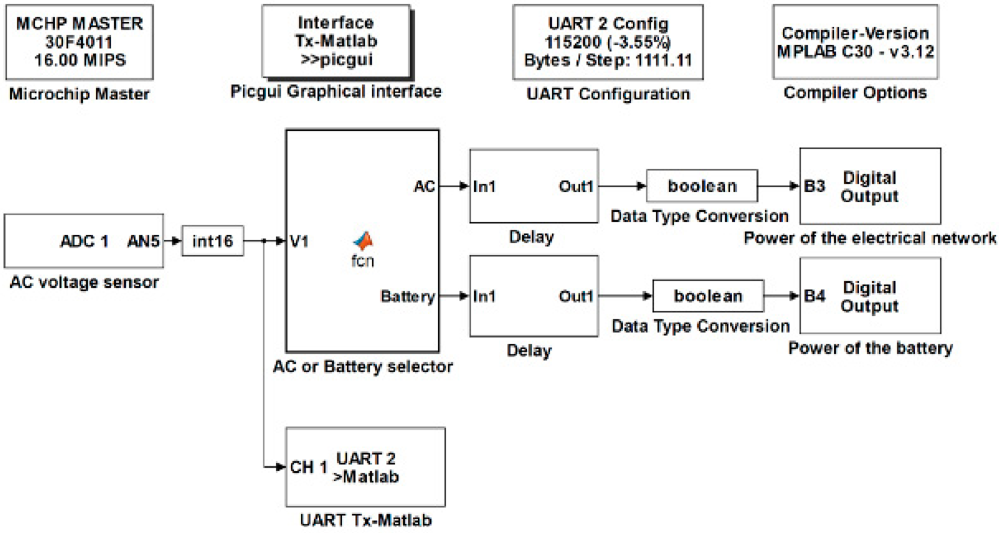

Fig. 5. Block in MATLAB-Simulink designed for a continuous power supply to the aeroponic system.
Source: Authors.

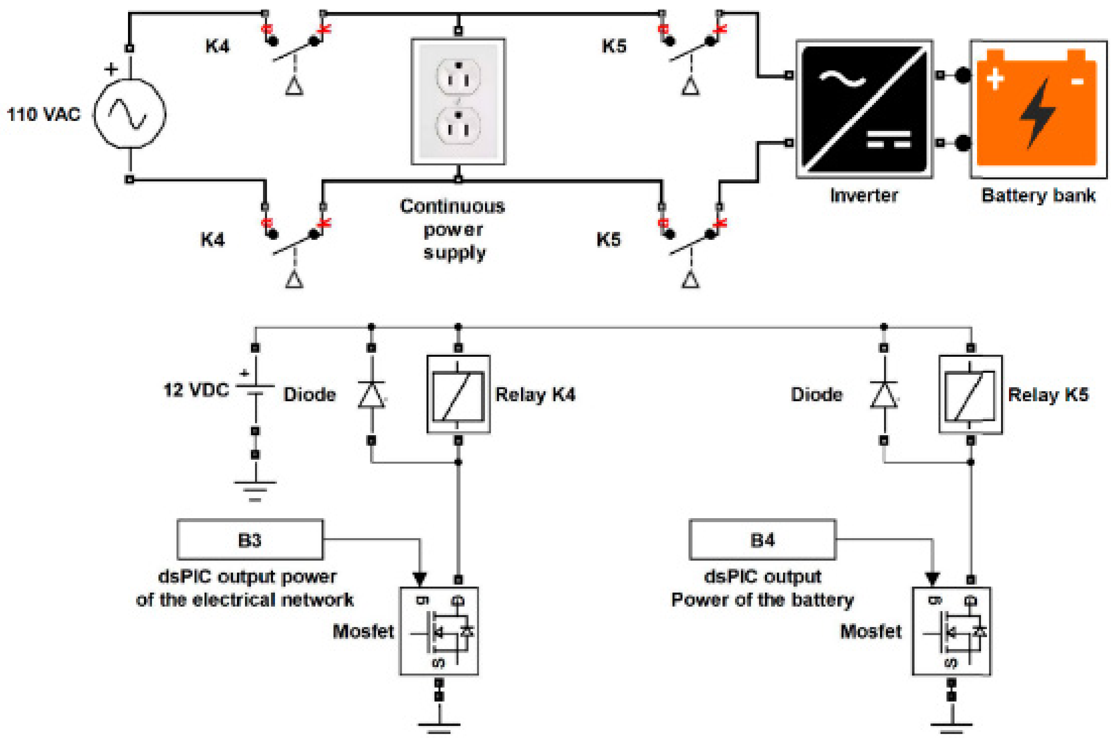

Fig. 6. Diagram of the electrical circuit necessary to develop the continuous power supply.
Source: Authors.

Fig. 7, shows the circuit developed for the test with two 110 AC relays and 75 Amps for the purpose of handling more electrical power in the case of increasing the number of beds in the aeroponic system.

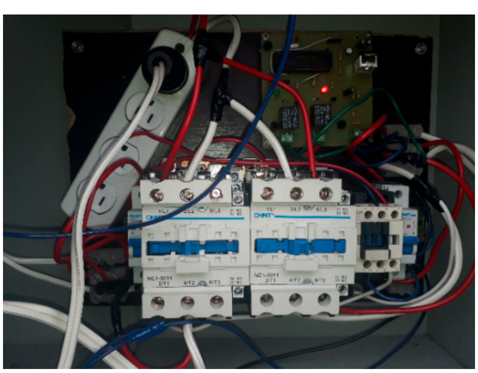

Fig. 7. Circuit implemented for supplying continuous power to the aeroponic system.
Source: Authors.

Fig. 8, shows the complete electrical system developed for the experimental test. The upper part of the figure shows the electronic system used to control the irrigation cycles. The middle part of the figure presents the system with the control for continuous power and the lower part of the figure displays the batteries.

Fig. 8. Complete electrical system implemented for the experimental test.
Source: Authors.

III. Results and analysis

Fig. 9, shows the growing process of the plants from day 10 to day 56 while using the automatic irrigation system and the continuous power supply. Figs. 9a–9e show plant growth at days 10, 16, 20, 48, and 56, respectively. Fig. 9e also shows plant growth on day 56. The last two figures show that the roots and leaves maintain a normal color, indicating that the plants are not water stressed and the system has maintained continually water and nutrients. All plants are subjected to the same environmental, irrigation, and nutrient supply conditions.

Fig. 10, shows the cilantro beds at different growth stages. Figs. 10a–10d, show plant growth at days 24, 30, 44, and 56, respectively. Fig. 10 also shows the status of the cilantro roots and leaves, which are in very good condition.

a) 10 days

b) 16 days

c) 20 days

d) 48 days

e) 56 days

Fig. 9. Growing process of the cilantro plant from days 10 to 56.
Source: Authors.

a) 24 days b) 30 days c) 44 days d) 56 days

Fig. 10. Cilantro growth in beds from days 24 to 56.
Source: Authors.

Fig. 11, presents the average weight of plants per bed obtained during the growth period. The difference in weight determines the biomass gain by the plants. This result shows the growth to be increasing linearly under continuous irrigation and electricity supply.

Fig. 12, presents the volume of water spent on the growing process of a bed during the growth period. The amount of water used during the process increases linearly along with plant growth (Fig. 11) under continuous power and irrigation.

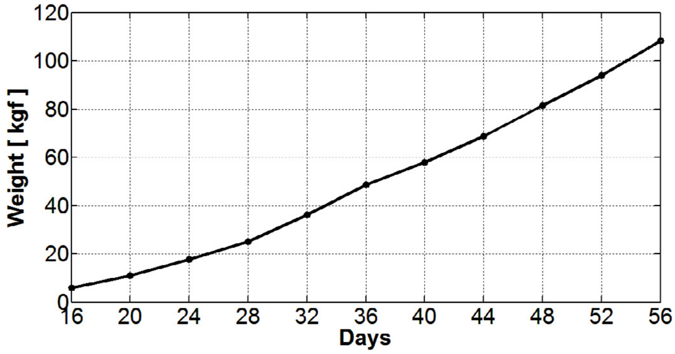

Fig. 11. Average weight of plants per bed during the growth period.
Source: Authors.

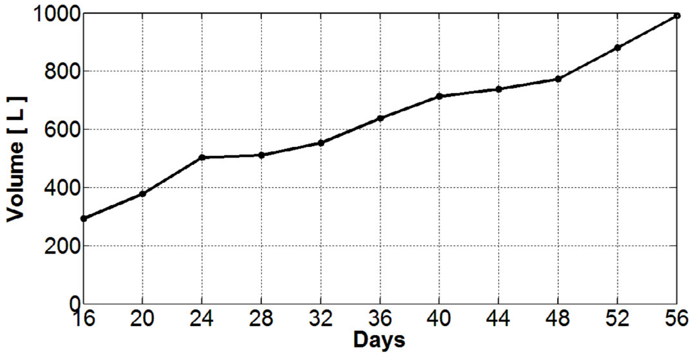

Fig. 12. Volume of water consumed per day per bed during the growth period.
Source: Authors.

Table 1. Comparison of Aeroponic and Land Cultivation

Cilantro cultivation (aeroponics vs land)						
Type of Crop	Harvest Losses (%)	Production (kg/m^2)/year	Agrochemical consumption (%)	Nutrients Price ($) bed/year (%)	Workforce (%)	Degree of Phytopathological risk (%)
Aeroponics	8%	89.5	10%	40%	30%	30%
Land	20%	18	100%	100%	100%	100%

Source: Authors.

Table 1, compares the results of land-based and aeroponics-based cultivation of cilantro (Colombian Aeroponics Company data). These data show the advantage of aeroponic cultivation in terms of production per square meter. As a result of being cultivated in an enclosed area, it is possible to reduce the use of agrochemicals and pesticides to control some phytopathological and other risks (e.g., lack of nutrients). As well as reducing the costs of pesticides, aeroponic cultivation also reduces the number of workers needed and improves their quality of life by growing pesticide-free plants.

IV. Conclusions

This article presented an automated aeroponic cultivation system for the production of pesticide-free cilantro. The system has an irrigation system and electric energy storage capacity. *MATLAB-Simulink-MPLAB* was used to perform the control model. In addition, a programmed *dsPIC* helped implement the algorithms controlling the watering cycles. The pump irrigation cycle programs were developed in *MATLAB-Simulink* block. The implementation achieved a full growth cycle of crop irrigation with backup electrical power. The application of irrigation cycles was uniform for the crop, which allows a better development of the aeroponic. This result is useful for the application of irrigation in several types of aeroponic crops at an industrial level. Cultivating in an aeroponics manner has great advantages compared with cultivating on land; e.g., the reduction of pesticide use and the efficient use of space. The small growing area means that aeroponic cultivation can be done on terraces or on building roofs. The consumption of water and nutrients is also greatly deduced. Future work considers the complete automatization of the aeroponic system such as control of water temperature, air temperature, and lighting; harvest automation; and production of certified seeds; the above topics may open new research lines related to aeroponics and automation.

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