Electric Supply and Autonomous System for a Cleaner Production of Pesticide-Free Aeroponic Food Products

HOYOS, F. E.[a*], CANDELO, J. E.[a], CHAVARRIA H. J.[b]

a. Universidad Nacional de Colombia, Sede Medellín

b. Colombian Aeroponics Company, Medellín, Colombia

**Corresponding author, fehoyosve@unal.edu.co*

Abstract

Aeroponics allows a more efficient agriculture because the possibility to grow plants in places where conventional open-field agriculture is difficult. The use of technology allows to improve efficiency of the processes, although some energy control and irrigation system solutions must be improved. This paper presents the application of an autonomous power supply and an irrigation control system for the pesticide-free aeroponic food production. The system was designed using Matlab-Simulink-MPLAB tool to perform the control model and to be applied to the crop. Besides, a dsPIC was programmed for the irrigation cycle control algorithms using Matlab-Simulink blocks. The results show that the irrigation cycle and power supply help to maintain uniform plants in the crop, which allows a better development of the aeroponics.

Keywords: *pesticide-free food, aeroponics, autonomous irrigation system, cleaner production, electric power*

1. Introduction

As population continues growing, the volume of food production must increase to supply the needs and a viable productive model is required for agriculture. For example, although the high production of food in countries such as Colombia there are failures in the model as the importation of agricultural products increased by 107% between 2000 al 2015, compared to the increase in exportation easing of 4.8%. The food demands of society cannot rely only on the current production model and new alternatives to provide food must be implemented.

Plant factories with aeroponic food production is an alternative to optimize space and water resources (Lakkireddy et al., 2012), because it reduces costs by automating operations and reducing the resources used to control phytosanitary problems. This concept is of great importance for agriculture as this allow to produce a great amount of food with low inversion, and also achieve a saving of space, water, and nutrients (Odegard and Van der Voet, 2014).

Aeroponics allows a higher production of pesticide-free food, optimizing the production space (Runia, 1995), allowing a cleaner production of food, reducing serious environmental impacts that affect the climate, promoting biodiversity, and giving quality of life of rural and urban inhabitants, today aeroponics is used in agriculture around the globe (Hoehn, 1998), also excellent aeration is the main advantage of aeroponics (Carter,1942). However, new application of technologies to prepare soil and nutrients, to improve electric power supply, monitoring plants growth through the use of intelligent technology are still required (Bisgrove, 2010; Mei-Yu Wu et al., 2011; Sugano, 2015).

The interest on this topic has been growing with studies performed in companies and universities of Japan, where the applications increased from 50 in 2009 to 127 to march 2012. Besides, some technologies have also been introduced in open plant factories, which use natural sunlight. In recent years, some close plant factories use artificial light to produce crops in a highly efficient manner. These plant factories can provide optimum growing conditions for plants without influence of the external environment. However, the high initial costs of the construction of a factory and the costs of electricity for air conditioning and lighting must be reduced (Sugano, 2015).

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 efficiency for the food production and to achieve sustainable markets. Power supply reliability and efficient irrigation system are topic of current matter around the world, as irrigation systems has not adapted to intelligent efficient energy savings, by automating the delivery of nutrients to plants based on changes in environmental variables and which optimizes the food production and biomass. The development of system that reduces 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 an application of an electric power autonomous system for a clean production of pesticide-free aeroponic food products. The system consists of the greenhouse, the cultivation, the irrigation systems, the water pumps, the nutrient dispensers, the power grid supply, the hardware for the control, the intelligent algorithms integrated into the system, the process optimization algorithms for achieve efficiency, and the connection to the electric network and alternative energy sources. The results presented show how this automatic systems allow to improve the processes for obtaining best pesticide-free food, by controlling the irrigation systems and achieving an efficient supply system. Therefore, the document has been organized as follows: Section 2 presents the methodology used in this research with the description of the electronic circuits implemented for the tests; Section 3 presents the results and the analysis; and Section 4 presents the conclusions.

2. 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, the development of a power supply circuit and the irrigation control circuit and the aeroponic cultivation and performing the different tests.

1.1 Greenhouse implemented

An aeroponic greenhouse was installed in the Universidad Nacional de Colombia, where the city of Medellín is at 1,479 meters above the sea level. This city has a subtropical climate that remains constant throughout the year. The absolute temperature of the city varies between 8° and 33.2° Celsius, with a maximum average temperature of 27.6° Celsius and the minimum average temperature of 16.9° Celsius. The city is located in a mountainous zones and has mild winds.

The greenhouse has 9 beds for the aeroponic cultivation with measures of 30 meters of length by 1.2 meters of width. Each bed is conditioned with 30 styrofoams of 1 meter of length by 1.2 meters width to accommodate 56 vessels where 5 seeds are placed. The greenhouse is completely covered with plastic to protect the plant from the direct sun radiation, wind and rain, allowing to have a control on the experiments because it has a suitable environment to avoid external factors. The vessels allow to accommodate plants to grow in a small containers. The disposition of the plants in the vessels, styrofoams and best allow to control samples for experiments and parallel tests can be performed in different beds. The beds have an irrigation system with valves controlled independently by dsPIC. The system has 1 pumps of 1 hp to 110 VAC with a pressure of 50 psi, with two valves to irrigate water and nutrients to 1 bed.

1.2 Global system for cleaner production

Figure 1 shows the global system designed for the cleaner production of pesticide-free food products implemented in this research. The entire system is controlled automatically by a dsPIC30F4011 of Microchip Technology Inc. The electronic system performs control over two stages: the first consists of the implementation of a continuous power supply needed to power plants with the irrigation which should never be missing. To perform this task the dsPIC30F4011 detects the electrical energy in the network with a sensor, later with the AC digital output or a battery selector the power supply switches between power grid and batteries. The second stage consists of the control of watering cycles and the delivery of nutrients to the plants through a digital output water pump, which switch ON and OFF the electric water pump.

The periods of the watering cycles were previously studied and this test considered 20 seconds to switch ON and 160 seconds to switch OFF the electric water pump. The digital output valve # 1 switches ON and OFF the valve # 1, which delivers the nutrients to the plants by switching the half of the micro sprinklers. With the digital output valve # 2 switches ON and OFF the valve # 2, which delivers the nutrients to the plants by switching the other half of the micro sprinklers. Two valves are needed in order to increase the pressure and achieve a very small drops of water mist, which is necessary for a proper functioning of aeroponic systems. At the bottom of the figure, the aeroponics systems is shown with the air-fired plants obtained with this process.

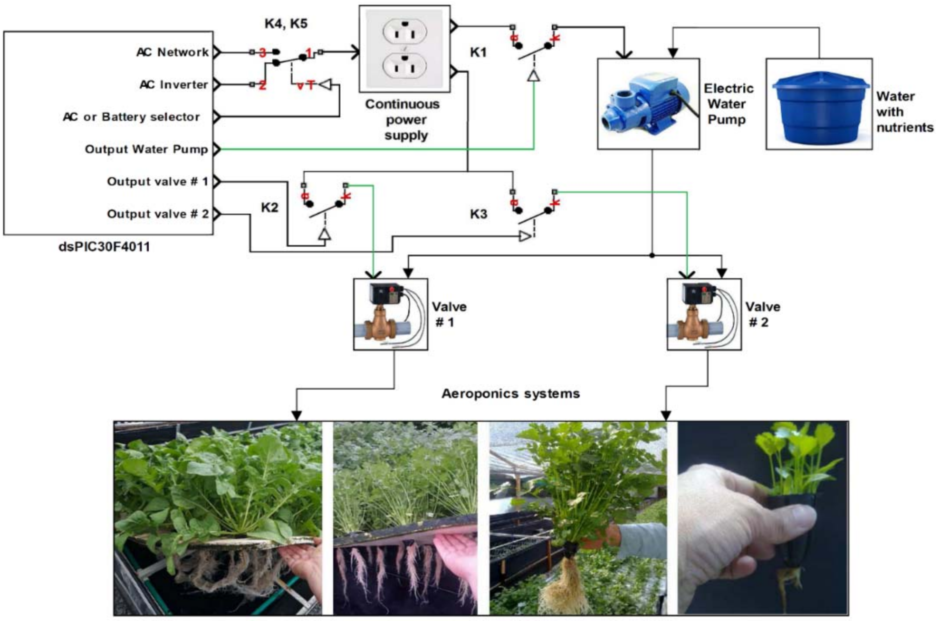


Fig. 1. Global system for the cleaner production of pesticide-free aeroponic food products.

1.3 Automatic irrigation system

Figure 2 shows the sequence blocks that have been implemented in the Matlab-Simulink software for programming the irrigation cycles of the aeroponic system. With the block *pulse generator electric water pump* a PWM signal is generated with ON for 20 seconds and OFF for 160 seconds. The water pump is controlled by the digital output *B0 output electric water pump*. With the block *pulse generator valve # 1* a PWM signal is generated to control the valve # 1; this allows that the valve is ON for 10 seconds to irrigate water and later the valve is OFF for 170 seconds. The valve # 2 is controlled with the block pulse generator valve # 2, this must be OFF the first 10 seconds; then the next 10 seconds working ON with the water pump; later the valve must be OFF for 160 seconds to complete the watering cycle.

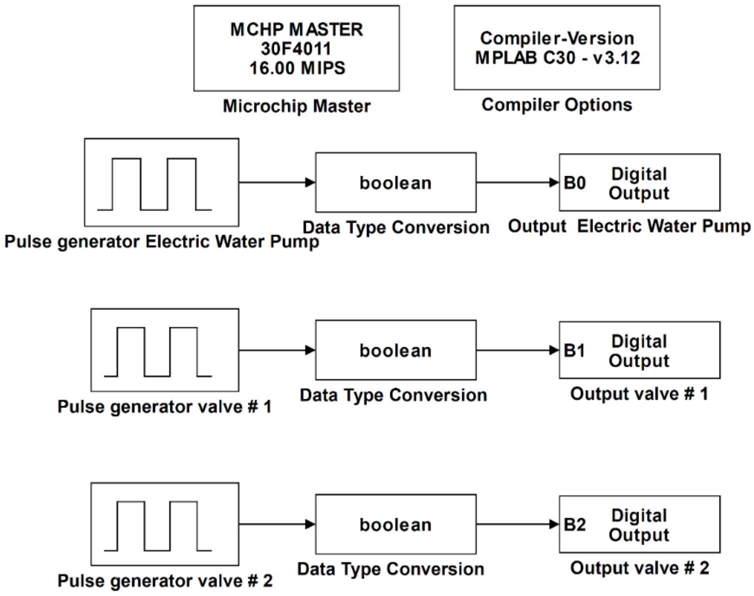


Fig. 2. Irrigation cycle programming in Matlab-Simulink.

1.4 Electrical system for the nutrient cycles

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

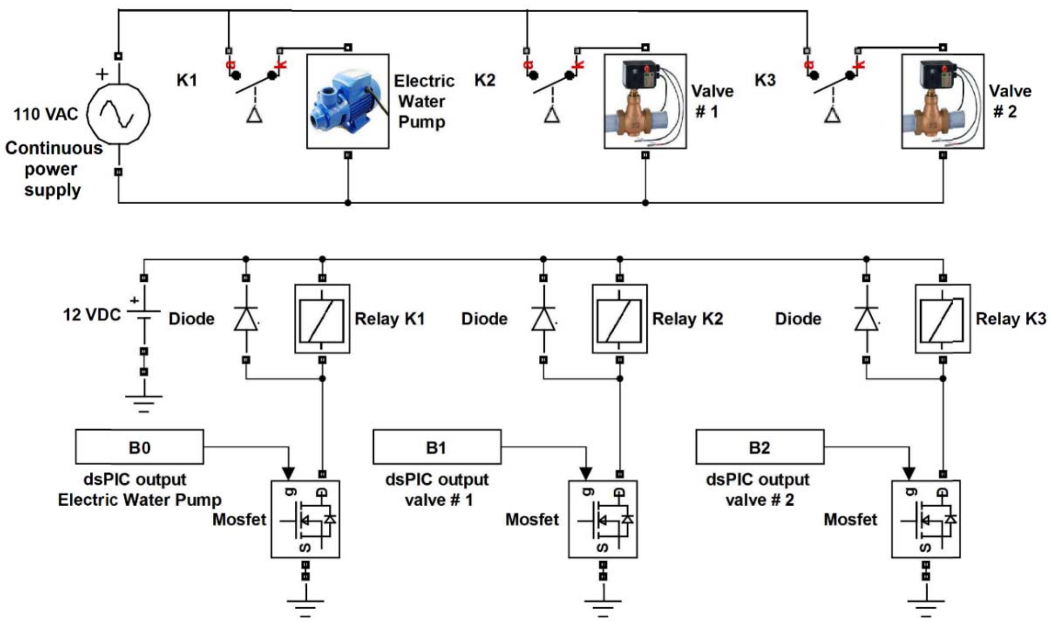


Fig. 3. Diagram of the electric circuit required to supply the nutrients to the plants.

Figure 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.

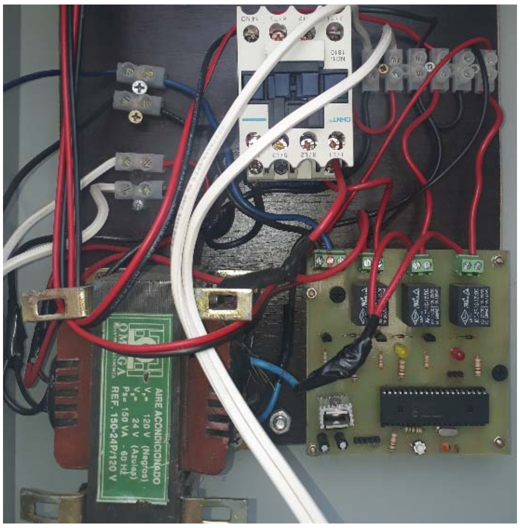


Fig. 4. Electric circuit implemented for the control of irrigation cycles.

1.5 Construction of a reliable power supply

The aeroponic systems dedicated to the food production are strictly dependent on the electrical energy (NASA, 2006), this gives power to the water pumps to deliver the nutrients to plants by means of micro sprinklers. In several occasions, the power grid has presented some external disconnections up to 5 hours and the plants enter immediately to a prolonged water stress process, because of lack of water and nutrients. When the time without electricity is prolonged, the lack of supplying water and nutrients reduces the growth and efficient production, and also produces plant deaths. Therefore, an auxiliary system of 3000 watts has been implemented, which is low cost solution to protect the aeroponic system for approximately 24 hours with the energy stored in batteries.

Figure 5 shows the diagram with the blocks designed to supply electricity continually for the aeroponic system, which was 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 in ON or short-circuits can be presented in the circuit. Finally, the block UART 2 is placed to visualize the real time signal of the voltage sensor.

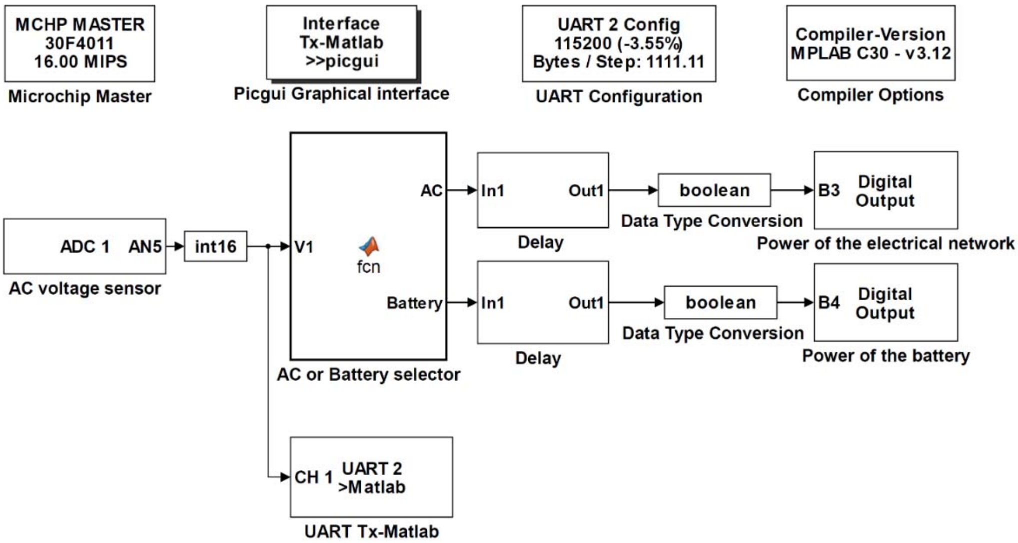


Fig. 5. Block in Matlab-Simulink designed for a continuous power supply to the aeroponic system.

Figure 6 shows the electrical circuit of the system developed to deliver power for the aeroponic system. The B3 input controls the K4 relay which is responsible for giving power from the electrical grid to the aeroponic system. When no power from the electrical network is available, the B4 input controls the relay K5 to give continuity to the electricity service by means of the energy stored in the batteries.

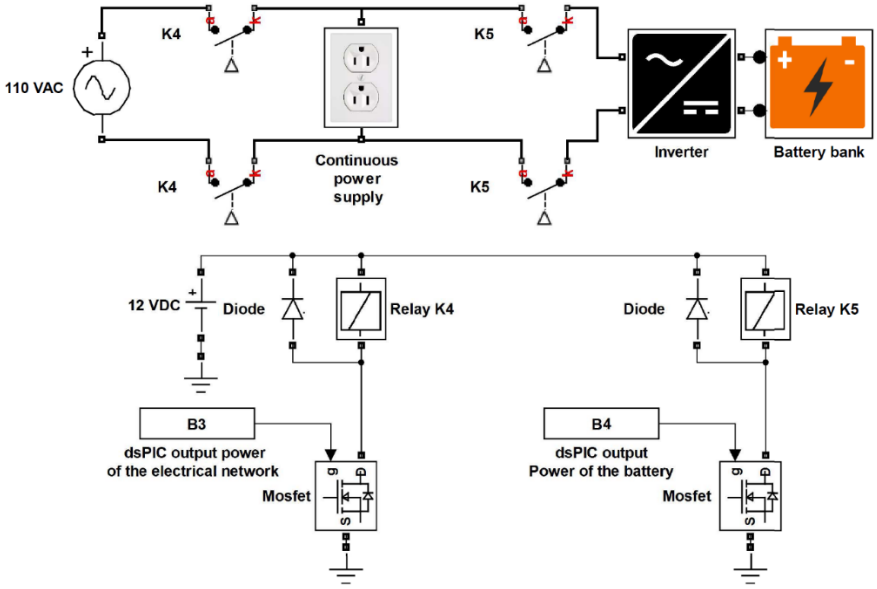


Fig. 6. Diagram of the electrical circuit necessary to develop the continuous power supply.

Figure 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 case of increasing the use of more beds in the aeroponic system.

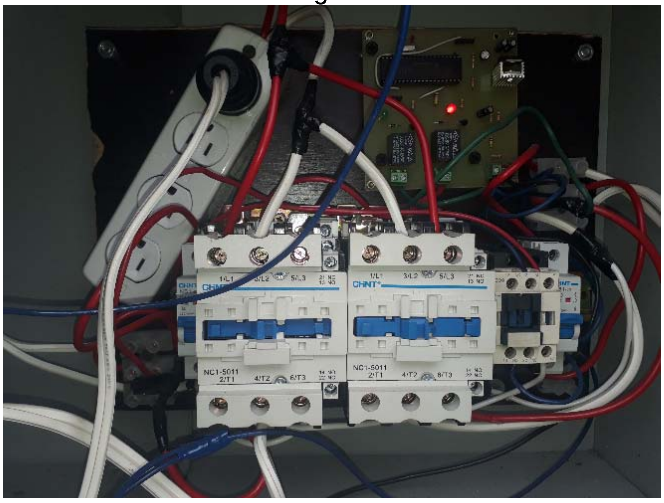


Fig. 7. Circuit implemented for supplying a continuous power to the aeroponic system.

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

3. Results and Analysis

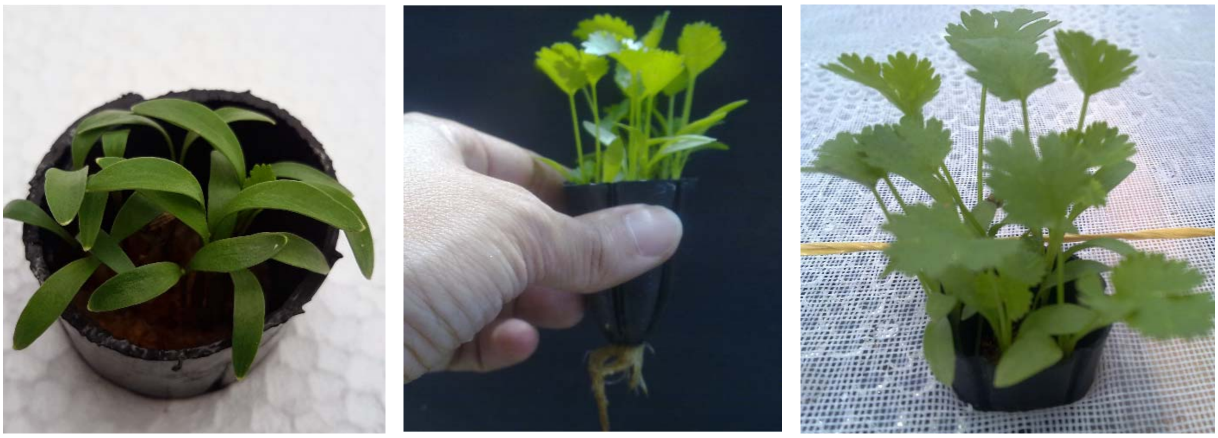
For the test, the *Coriandrum sativum* or commonly known as *cilantro* was used, because this plant grows in approximately 90 days on land and approximately 56 days in aeroponic systems. This type of plant measures approximately from 40 to 60 cm in height. This plant grows commonly in tropical zone and mountainous zones. The lack of moisture and nutrients in few hours leads to partial root death and loss of mass. Five plants of cilantro were located in each vessel with 56 vessels for each styrofoam.

Fig. 8. Complete electrical system implemented for the experimental test.

Figure 9 show the growing process of the plant through different days up to 56 days by using the automatic irrigation system and the continuous power supply. Figure 9a shows the plants with 10 days, Figure 9b shows the plants with 16 days, Figure 9c shows the plants with 20 days, Figure 9d shows the plants with 48 days, Figure 9d shows the plants with 56 days, and Figure 9f shows the plants with 56 days of growing. The last three figures show that the roots and leaves maintain with the proper colour indicating that the plants are not water stress and the system has maintained continually water and nutrients.

All plants that are subject to the same environmental, irrigation, and nutrient supply conditions must have similar growing process, size, mass, and weight. In the case of a continuous power supply the plants must not present difficulties with the growth.

Figure 10 shows the beds for different sizes of the cilantro. Figure 10a shows the cilantro in 24 days, Figure 10b shows the cilantro in 30 days, Figure 10c shows the cilantro in 44 days and Figure 10d shows cilantro in 56 days. In addition Figure 10 shows the status of the root and the cilantro leaves, which are in very good condition.



a) 10 days b) 16 days c) 20 days

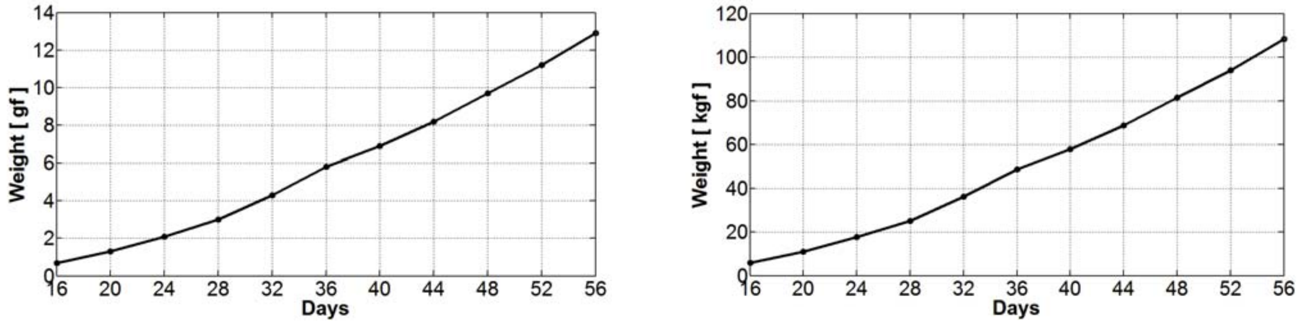
d) 48 days e) 56 days f) 56 days

Fig. 9. Growing process of the cilantro plant over the days.

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

Fig. 10. Cilantro growth in bed over the course of days.

Figure 11 presents the weight measures of a plant and a bed for the same period. Figure 11a shows the weight of a plant obtained during the process and Figure 11b shows the weight of the bed for the same period. Figure 11 shows that the growing behaviour is linear increasing, where the mass is maintained in the time maintaining a reliable and continuous irrigation process and electricity supply.



a) Weight vs days of a plant b) Weight vs days of a bed

Fig. 11. Weight of the biomasa in the growing period.

Figure 12 presents the volume of water spent for the growing process of a bed for the same (Figure 11) growing period. Figure 12 shows that the amount of water spent during the process is linear increasing with growth of plants, where an irrigation system maintains the same flow of water with nutrients to maintain the production of plants.

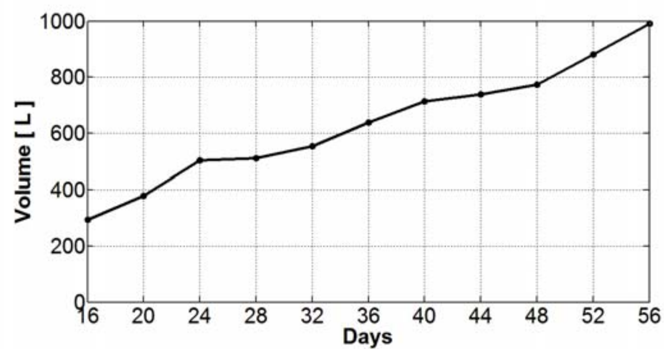


Fig. 12. Spending volume of water consumed per day per bed during a growing period.

Table 1 shows the comparison of cultivating cilantro on land and aeroponic cultivations, this has been designed with the measurements stories of more than 10 years of work in the Colombian Aeroponics Company. As shown in the table aeroponic cultivation has several advantages: greater production is obtained by m^2, this because the density of the number of plants in inverse function with the growth can be increased. It is possible to reduce the harvest losses and agrochemicals and pesticides because with this technology you can control the climatic variables and the phytopathological risk, since it is being cultivated in an enclosed area. It is also possible to reduce the workforce and the quality of life of workers. Additionally, the expense of nutrients is greatly reduced.

Table 1. Comparison of aeroponic cultivation vs 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%

4. Conclusions

This article presented the implementation of an autonomous system for cleaner production of pesticide-free aeroponic food products. The system has an automatic irrigation system and an electric energy storage. Matlab-Simulink-MPLAB tool was used to perform the control model that would apply to the crop. In addition through the programming of a dsPIC helped implement the algorithms of the control of watering cycles. Pumps irrigation cycles programming is developed in Matlab Simulink block. The results show that achieved a good cycle of crop irrigation and backup electrical power for the continued growth of the crop. The application of risk cycles are uniform for the crop, which allows a better development of the aeroponic. This result is useful for the application of irrigation in several crops aeroponic at industrial level. Cultivating in an aeroponics manner has great advantages compared to cultivating on land, among the most important is the reduction of pesticides, the use of space, since it is possible to cultivate on terraces or on roofs of buildings in cities. The consumption of water and nutrients is also greatly deduced.

Acknowledgments

This work was supported by the Universidad Nacional de Colombia, Sede Medellín under the projects HERMES-34671 and HERMES-36911. The authors thank to the School of Physics and the Department of Electrical Energy and Automation for its valuable support to conduct this research.

References

Bisgrove, R., 2010. URBAN HORTICULTURE: FUTURE SCENARIOS. Acta Hortic. 33–46. doi:10.17660/ActaHortic.2010.881.1

Carter W.A. Phytopathology. 1942. 732. pag 623–625.

Hoehn A. Root Wetting Experiments aboard NASA's KC-135 Microgravity Simulator. BioServe Space Technologies. 1998.

Lakkireddy K. K. R., Kasturi K., Sambasiva Rao K. R. S, 2012, Role of Hydroponics and Aeroponics in Soilless Culture in Commercial Food Production. Journal of Agricultural Science & Technology Volume 1, Issue 1, April 2012, Pages 26-35.

Mei-Yu Wu, Ya-Hui Lin, Chih-Kun Ke, 2011. Monitoring management platform for Plant Factory, in: The 16th North-East Asia Symposium on Nano, Information Technology and Reliability. IEEE, pp. 49–52. doi:10.1109/NASNIT.2011.6111120

NASA Spinoff. Progressive Plant Growing Has Business Blooming. Environmental and Agricultural Resources NASA Spinoff 2006, 68–72p.

Odegard, I.Y.R., Van der Voet, E., 2014. The future of food — Scenarios and the effect on natural resource use in agriculture in 2050. Ecol. Econ. 97, 51–59. doi:10.1016/j.ecolecon.2013.10.005

Runia W.T. A Review of Possibilities for Disinfection of Recirculation Water From Soilless Cultures. Glasshouse Crops Res. Sta. Naaldwijk. Holland. 9 p. 1995.

Sugano, M., 2015. Elemental technologies for realizing a fully-controlled artificial light-type plant factory, in: 2015 12th International Conference & Expo on Emerging Technologies for a Smarter World (CEWIT). IEEE, pp. 1–5. doi:10.1109/CEWIT.2015.7338169