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Automated system developed to control pH and concentration of nutrient solution evaluated in hydroponic lettuce production

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ABSTRACT

Lettuce is one of the most widely consumed leaf vegetables. In hydroponic the growth depends upon the composition of nutrient solution. Due to its nutrient absorption, the conductivity and pH suffer continuous variations. This paper describes the development of a system completely managed by a lab-made software. It monitors the conductivity and pH throughout 24 h during the whole cycle of production. Also, allows adjust automatically any variation, through solenoid valves which dispense solutions of acid/base or nutrient. The efficiency of the proposed instrumentation was evaluated by simultaneously cultivation of same kind of lettuce (Vanda) in two different ways, hydroponics in greenhouse controlled with the developed devices, and grown conventionally in soil, adopted as referential. Agronomic and chemical parameters of commercial interest were analyzed for both crop, attesting the precocity in harvest (64 against 71 days) with reduced labor, better control and higher productivity, especially in fresh and dry matter of aerial parts, presenting 267.56 and 13.33 g plant^{-1} respectively, using the developed system. The data sequence regarding the concentration of nutrients for the automated hydroponic system was similar to those obtained by the mentioned researchers, as follows: K > N > Ca > P > Mg > S > Fe > Zn > Mn > Cu. This similarity highlights the efficiency of controlling the parameters of conductivity and pH in the instrumental system applied to hydroponics, offering the producer an effective and viable alternative in the production of lettuce.

1. Introduction

According to Ryder and Whitaker (1976), the lettuce (*Lactuca sativa* L.) has probably originated from Southern Europe and Western Asia. After being disseminated throughout Europe, it was introduced to the Americas, becoming one of the largest cultivated vegetable in the world (Medina et al., 1982). World production of lettuce for the year 2009 was approximately 24 million metric tons, with a cultivation area of 1 million hectares (USDA, 2011). In Brazil this area is around 35,000 ha (Sala and Costa, 2005).

The major milestone in the development of economic and commercial hydroponics was the *NFT* concept, which stands for Nutrient Film Technique, developed by Allen Cooper in 1965 (Jones Júnior, 1983). According to Bernardes (1997), the *NFT* system is a water cultivation technique in which plants grow with their roots within a channel (impermeable walls) through which a nutrient solution (water and nutrients) circulates. Most hydroponic crops are unsuccessful, mainly due to the lack of nutritional aspects in this production system, which requires adequate preparation and management of the nutrient solutions.

Hydroponics has several advantages, such as: possibility of using areas unsuitable for conventional farming, such as arid and degraded soils (Teixeira, 1996); independence of the crop to weather conditions, such as Indian summer, frost, hailstorms, wind, flooding, and weather seasons, allowing cultivation throughout the year (Faquin et al., 1996); reduction in the use of labor-intensive activities such as weeding and soil preparation. Moreover, activities in hydroponics can also be considered more gentle (Castellane and Araújo, 1994). Furthermore, there is the anticipation of harvest due to the shortening of the plant cycle; showing fast economic return (Faquin et al., 1996), dispensing crop rotation (Teixeira, 1996), including optimal efficiency in the use of water and nutrients, with high environmental benefit (Vernieri et al., 2005). In addition, hydroponic cultivation has been reported not only to be associated to higher production yields but also to allow better control and standardization of the cultivation process, thus reducing overall production costs (Nicola et al., 2005; Fallovo et al., 2009).

On the other hand, there are some disadvantages such as the high cost of installing the systems (Faquin et al., 1996); the need

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for continuous monitoring of the operation of the system, especially the supply of electrical power and control of nutrient solution (Faquin et al., 1996; Castellane and Araújo, 1994); the need of specialized manpower and technical assistance (Sanchez, 1996); as well as new products and appropriate techniques to control pests and diseases, because conventional pesticide may decrease the biological quality of the product (Teixeira, 1996). It is therefore essential to consult technical experts to design the projects, be them from universities and/or experienced consultants, considering the cost and complexity of the project (Sanchez, 1996).

One of the basic principles for vegetable production, both in soil and in hydroponic systems, is to provide all the nutrients the plant needs. Several chemical elements are essential for growth and production of plants, in a total of sixteen elements: carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, sulphur, calcium, magnesium, manganese, iron, zinc, boron, copper, molybdenum and chlorine. Among the elements mentioned above, there is a division according to their origin: organic, C, H, O and minerals; broken down into macronutrients, N, P, K, Ca, Mg, S, and micronutrients, Mn, Fe, B, Zn, Cu, Mo, Ni, Cl (Malavolta, 2006).

This division between macro and micro takes into consideration the amount each nutrient is required by the plant for its cycle. Plants have, in their constitution, around 90–95% of their weight in C, H, O. But these organic elements do not cause any problems since they come from the air and water, which are abundant in our system. Therefore, greater emphasis should be given to the mineral elements, which are the ones that will make up the nutrient solution.

In hydroponic crops, absorption is usually proportional to the concentration of nutrients in the solution near the roots, being much influenced by environmental factors such as salinity, oxygenation, temperature, pH and conductivity of nutrient solution, light intensity, photoperiod and air humidity (Furlani et al., 1999). Each of the macro and micronutrients have at least one function within the plant and its excess or deficiency leads to symptoms of characteristic deficiency or toxicity.

Nutrients play a key role in the quality and productivity of lettuce. Thus, the balanced application of nutrients is vital in determining the quality of the product (Abou-Hadid et al., 1996). According to Goto et al. (2001), lettuce crops absorb relatively small amounts of nutrients when compared to other cultures. However, it can be seen as demanding in nutrients, especially in the final phase of its cycle.

Regarding the replacement of nutrients in the nutrient solution, several methods are described for use in hydroponics. However, there is little detailed information about the performance of these methods during the development of plants. The control of nutrients in the nutrient solution through an automated system was proposed by Nielsen (1984) with the adjustment of water level, concentration of nutrients and pH. At a constant water level, the decrease in salt concentration is related to a decrease in electrical conductivity (EC), which can be used for monitoring the nutrient levels in the solution (Junior et al., 2008).

The electrical conductivity is proportional to the total content of ions, thus a decrease in EC is accompanied by a proportional fall in the total amount of ions available for absorption by the roots. However, different salts have different electrical conductivity. Therefore, for each formulation there will be a linear function relating EC and total dissolved ions (Filgueiras et al., 2002).

It is known that humans are subject to errors due to tiredness or distraction during the development of certain activity and that they act differently from one another. The automatic mechanism used in production control in various areas of knowledge, on the other hand, suffers no such influence and therefore is not harmful to the homogeneity of production (Costa, 2001).

The rapid evolution of electronics, coupled with the increasing expansion of the market, has enabled access to state-of-the-art technology and tools that before were only available in well-equipped laboratories and research centers. Agricultural engineering, in general, has benefited from this technological advance, be it from the development of new equipment, or in adapting those already available to other sectors of production, to be used in agriculture (Queiroz, 2007).

Greenhouse engineering and hydroponics are two very rapidly developing sectors of agriculture and are strongly linked with each other. Computational intelligence, mainly in the form of automatic monitoring and control, is a major tool of this development. Highly developed instrumentation and 'intelligent' control in hydroponics provides an opportunity for maximizing both quality and quantity of production through the advanced management of all involved processes. The production systems are continuously monitored and precisely controlled. An important issue in these highly computerized and automated systems is the quality of information provided by the sensors, as well as the quality of decisions passed to the actuators. The quality of information received from or passed to the system is not checked in the vast majority of automated greenhouse or hydroponic facilities (Ferentinos and Albright, 2003).

The application of automation in greenhouses can provide advantages to production development in the following aspects: better control, being more accurate and safe; reduction of manpower, since an automated greenhouse will need fewer people working, decreasing the flow, discouraging the entry of diseases; optimization in electricity consumption, since the market is increasingly competitive, it is necessary to use alternatives to reduce energy consumption; improved product quality, as a completely controlled greenhouse will produce a better quality crop; and provision of a record, which can be analyzed and, if necessary, steps can be taken for future productions (Costa, 2001).

According to Bliska and Honörio (1996), the advance of information technology provided farmers an economy in the various handling operations involved in the greenhouse. The automation in nutrient solution supply, ventilation, temperature control, artificial shading, in moving the curtains controlled by microcomputer ensures maximum exploitation of the protected environment potential, as well as increasing the efficiency of crop performance.

This paper aims to describe the development of an automated system, capable to control online via software and webcam, pH and conductivity, even with the great variation of the temperature in greenhouse along 24 h, during whole cycle of lettuce cultivation. Also, intends to explain, how system automatically fixes the pH and concentration of nutrients of solution that irrigates the hydroponic lettuce, by opening and closing of solenoid valves, by delivering solutions acids, basics and nutrients. To evaluate the efficiency of proposed system, agronomic characteristics such as: quantities of fresh and dry matter in the aerial part, dry matter in the root, total number of leaves, and number of leaves larger than ten centimeters, as well as, chemical parameters, like levels of macro and micronutrients, were analyzed to attest the nutritional quality of lettuce produced, compared with the conventionally grown in soil, considered as referential.

2. Materials and methods

The experiment was realized in greenhouse located in the Centre of Agricultural Sciences, State University of Londrina – UEL; latitude, 23°23′ S; longitude, 51°11′ W and altitude of 566 m.

The composition of the prepared nutrient solution initially presented the following nutrient concentrations in mg L^{-1} (ppm): N – 147; P – 21.7; K – 163.8; Ca – 140; Mg – 33.6; S – 43.4; Fe – 3.5; Mn

– 0.35; Cu – 0.014; Zn – 0.035; B – 0.35; Mo – 0.007; at initial pH 5.8 and electrical conductivity at 1.5 mS cm^{-1}.

Daily measurements were made of pH (pHmeter, pH-100, pHTEK®) and EC (portable conductivity meter, dist3 HANNA INSTRUMENTS®) in the nutrient solution tank, in order to compare manual data, with values obtained by the automated system. For correction of electrical conductivity the nutrient solution prepared was used. For pH control, hydrochloric acid and sodium hydroxide 0.5 N solutions were used.

The choice for this study of the cultivar Vanda (Sakata Seed Sudamerica Ltd.) was made randomly by the availability of seedling. The selection of only one kind of lettuce was done, just aiming to minimize and avoid variance coming from the cultivar, allowing that observed differences could be attributed only to the distinct methods of cultivation.

Initially three experimental crops were conducted simultaneously. The cultivations were done in parallel, in order to compare data obtained using the proposed system with two other systems, in similar environmental conditions of growth. The first cultivation was made inside of the greenhouse on the left, using NFT hydroponics, controlled by the new fully automated system projected. The second experiment, on the right side inside the same greenhouse, uses current widely used system of hydroponic growth, that after removal of aliquots, pH and conductivity are analyzed on laboratory, and the nutrient solution concentration is adjusted manually. And the third, cultivation in the ground, made in a more conventional way. Unfortunately, during a holiday, the lack of technical care caused the loss of the entire production crop, manually controlled. Therefore, just 2 systems became available for the comparison. So soil crop were taken as reference of quality.

Sowing took place on April 07th, in PLANTMAX® substrate, and irrigated with water until the complete emergence of seedlings. When seedlings presented four definite leaves, on May 06th, they were transplanted to the definite benches. In the hydroponic system there was a bench with three channels, and approximately thirty plants were transplanted to each channel. For conventional tillage in soil there was no regular monitoring, although the seedlings were transplanted in the same period as the hydroponic cultivation and were subsequently acquired from the producer in time of harvest, 64 days for the automated system and 71 days for soil. There was no need to apply pesticides (insecticides and fungicides) during the conduct of the experiment in any of the treatments.

The study used a completely randomized design with two treatments - automated hydroponics cultivation and conventional tillage in soil - with four repetitions. The useful parcel is one lettuce plant. Each lettuce plant harvested was characterized as one repetition.

2.1. Instrumental system in hydroponics

The system developed is simple, has autonomy, is versatile and makes decisions automatically. It requires no sophisticated equipment. Someone can even take advantage of existing instruments in many laboratories that are easily attached.

The instrumental system used in this paper was built according to the outlined in Fig. 1 and comprises: a Compaq Presario 5620 Desktop PC (Pentium II 400 MHz 512 kB cache L2, 256 MB PC100 with memory RAM, network interface card Intel 21143/2 based 10/100 Mbps Ethernet Controller – *on board*, hard disk 20 GB, video card ATI Rage LT Pro 8 MB SDR AGP 2×), equipped with an ADC/DAC interface & "lab-made" Controller INTPC-12, running on a Microsoft Windows XP Professional 32-bit operational system; software developed by PhD Professor Carlos Alberto Paulinetti da Camara from Group DIA/UEL called *ControlHidro*; an external "lab-made" circuit switching; a pH meter model TEC-2 – TECNAL; a conductivity meter model 35 – YSI; a "lab-made" temperature control circuit, two stabilized fonts of 12 VDC 3.5 A – HAYONIC; a submerged pump model SB-1000 – SARLOBETTER; a flow system with a "lab-made" LM35 temperature sensor, a conductivity cell – YSI 3400 series $K = 1.0$ cm^{-1} and a combined electrode of pH – MICRONAL; three 2-way 12 volt low pressure solenoid valves – INDEBRAS; a USB 480 K webcam – BRIGHT; and a USB Network Adapter Instant Wireless – LINKSYS.

The instrumental system developed and used showed in Fig. 1, is entirely managed by software, via microcomputer and interface, which receives data from the experiment and from the webcam, continuously records and transmits wirelessly. Measures of temperature, conductivity and pH, done through sensors and electrodes, which are submerged in nutrient solution that irrigates lettuce, were done via an external circuit switching. When, there is any change in the predetermined values, immediately valves triggers to control the acidity of the medium or replenishing the nutrients consumed by lettuce.

Monitor the temperature of the nutrient solution is sorely needed since the results of the conductivity and pH are directly influenced by this parameter. The developed system can measure and automatically compensates variations in temperature by mathematical models.

The corrections are essential, since the oscillations inside the greenhouse are large, in temperature and relative humidity, solar radiation, concentration of CO_2 and ventilation. These parameters influence the process of plant production, providing the proper development, when the limits established are maintained, or resulting in death, if the recommendations are not met (Teruel, 2010).

The correction, almost immediate of the nutrient solution, leads to a more balanced culture, creating healthier and more homogeneous leafs. Conventionally hydroponic crops with manual correction, usually takes the plants to suffer stress. Normally this occurs due to the delay in adjusting the concentration of nutrient solution, with either deficit or excess of macro and micro nutrients, whose absorption also depends on the acidity of the medium.

Our study in this article, merely reproduces the conditions of hydroponic cultivation conventional that uses manual correction, does just the automation of the cultivation. The fact that practically, no articles has been found, describing automated systems in scientific journals accessible, except the article of Suhardiyanto et al. (2001), which describes the system just for pH control, with similar principle, it made difficult to compare with the literature. And for this, the cultivation of soil was used here, to verify the performance of the designed system, comparing some chemical/agronomic parameters.

A commercial system is available in market, capable to do correction in pH and conductivity, marketed by Hanna – model HI 9913-2. It is equipment dedicated, specific and is not operated by computer. However, the fact that the system developed, allow the storage of data throughout the entire cycle of cultivation, opens a range of options for its use in researches by specialists and producers, different from instrument commercialized. Enables studies leading to better understanding of absorption of nutrients and its consumption, recording the amounts consumed in different stages of plant growth.

Can also make crops under different experimental conditions established and controlled. So, enable to vary the type of nutrient added and the acidity, allowing correlating with the changes occurred in the vegetable, which remain as an historical record. The acquisition and control else allows to have a feedback able to changing the experimental condition.

With an eight-channel probe, allows the connection of more five measuring instruments, which could be selective electrodes, in case of monitoring a specific nutrient like potassium, the next

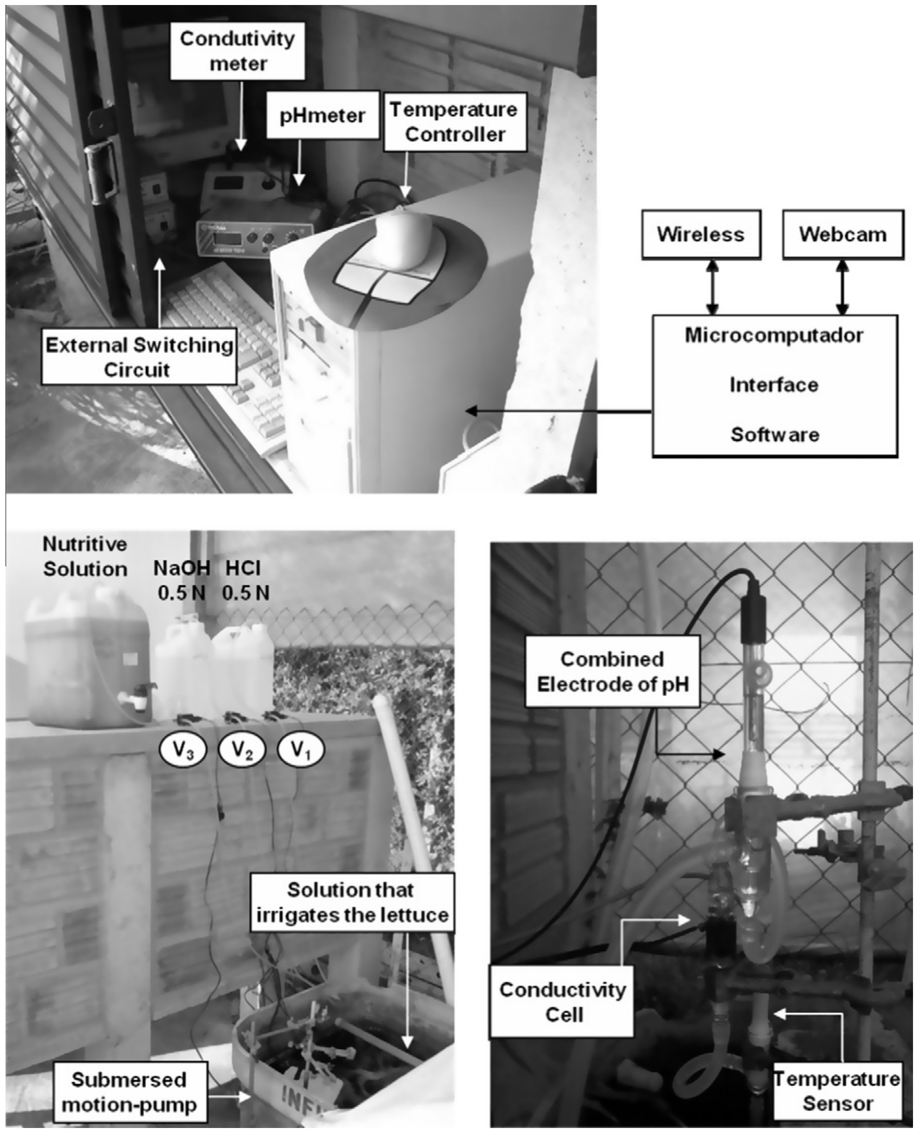

Fig. 1. Flowchart of instrumental system developed by DIA/UEL Group, utilized in monitoring and control of hydroponic lettuce. V_1, V_2 and V_3 are solenoid valves.

step proposed by the research. In principle, any other parameter could come to be measured and controlled by the system designed.

In the nutrient solution tank, the submerged pump was placed to work as a circulation pump in a continuous flow system. In this system, a commercial thin layer conductimetric flow cell was attached, where the solution runs over the platinum-platinized electrode surface, as well as a temperature sensor and a pH combined electrode, fitted in a "lab-made" wall-jet flow cell, in which the solution falls perpendicular to its surface. Because the pH electrode has high impedance, the pH meter is extremely sensitive to external noise (power supply, cables, engines, solutions, etc.). These noises are amplified along with the pH signal, making the readings fluctuate. Despite the good grounding of all instrumentation, it has been opted to working with sensors in a continuous flow system in order to minimize the effect of the electric noise from the nutrient solution, especially in the pH reading.

To construct the temperature sensor, a commercial electronic component LM35 (National Semiconductor) was used, in which the output voltage is directly proportional to the temperature in degrees Celsius, ranging between −55 and 150 °C. This sensor has an output with low impedance, precise linear tension and inherent calibration, making the reading interface particularly simple, allowing the low cost of the entire system. A resistor of 2.2 kΩ and a 1.0 MΩ resistor were used. The circuit layout was designed in the P-CAD 2002 software, being made of copper plate and left in corrosion process in a solution of 2.5 mol L^{-1} ferric perchlorate for approximately forty minutes. To encapsulate the sensor, a thermo retractable polyethylene film was used, as well as a colorless epoxy adhesive – Araldite® for the finishing.

The external switching circuit – ESC was developed by Professor Luiz Henrique Mazo, in the laboratory of the Electrochemical Materials and Electroanalytical Methods Group (GMEME) from the Institute of Chemistry in Sao Carlos of University of Sao Paulo (USP). This circuit consisted of 12 VDC relay, triggered via computer by the program *ControlHidro* through circuit 8255 (2) in the INPC-12 interface, having an independent power supply of 12 VDC 3.5 A. The developed system, with 24 access routes, allows for the execution of electrochemical techniques, multiple data acquisition and the control of high and low pressure valves.

2.2. Software ControlHidro

The software *ControlHidro* is responsible for monitoring and correcting the pH and conductivity in the nutrient solution that irrigates the hydroponic lettuce. It was developed using Microsoft Visual Basic 6.0, running in multitasking environment Windows 9x/Me/XP – 32 bits. The command libraries to act on the conversion stages ADC/DAC of the INTPC-12 interface, as well as in the controls in TTL level, were written in C and Assembly languages. These libraries have been compiled and converted to a DLL *(Dynamic Link Library)* in Microsoft Visual C++ 6.0 (Camara, 1999).

Fig. 2 shows a screenshot of the software *ControlHidro* obtained by remote connection, using the *software* Real VNC (Virtual Network Computing). The microcomputer that monitors the hydroponic system accepts a remote connection with other computers on the UEL network and also on the Internet, sharing the desktop with them, allowing any of the researchers to view and interact in real time with the software anywhere on campus or from their homes, and also allowing for the shutdown of the experiment if necessary. It should be noted that the webcam used in this work allows following the development of hydroponic lettuce and even diagnosing diseases by the appearance of the leaves, as well as functioning as a security camera.

Using digitized images captured by the webcam can make diagnoses of lack or excess of nutrients, keeping the information in databases, for the next experiment.

The *ControlHidro* software displays a dialogue box named *Control Module.* This dialogue box contains six tabs, which are: main, temperature in degrees celsius, pH, conductivity, valves and data/files. The tabs temperature in degrees celsius, pH, conductivity and valves in the *Control Module* are responsible for calibrating the pH meter and conductivity, pH data correction and conductivity with temperature and activation of valves containing acidic, basic and nutrient solutions when necessary, so that the pH in the nutrient solution was maintained between 5.8 and 6.2, and conductivity between 1.5 and 1.7 mS cm^{-1} at 25 °C.

The Main tab presents data on temperature, pH and specific conductivity at 25 °C for the nutrient solution in real time. On this tab, it is also possible to change the frequency of data acquisition – pre-programmed for 3 min – and check the control and calibration of equipment, i.e., date and time the equipment was calibrated, and the name of the responsible operator. On the Data/Files tab, data on temperature, pH and conductivity obtained by the *software* are displayed in tables. Data are always accompanied by the time they were collected and also on the activation time for each of the three valves used in this project. The data contained in these tables are saved in text files (ASCII) with the following names: DD MM YY *temp.dat*, DD MM YY *pot.dat* and DD MM YY *cond.dat*. It has been decided to set the date (DD – day, MM – month, YY – year) in the filename, to avoid the risk of losing all experimental data in case of problems while obtaining them. This option, as well as providing smaller files and minimizing the effect of lost data, facilitates their processing per day. *ControlHidro* was programmed to save data every 15 min. It should be emphasized that in all the days were made up of data files via a remote link.

It should be noted that for better visualization of monitoring temperature, pH and conductivity of the hydroponic solution, a graphic module was added with a mobile time scale, programmed to change every hour, as shown in Fig. 2.

2.3. Features evaluated

Plants from the automated hydroponic crop were harvested 64 days after sowing, showing precocity compared to those in conventional cultivation on soil were harvested at 71 days, time they had reached maximum vegetative growth, before beginning the bolting process.

Four plants were randomly collected from each treatment, where the following characteristics were noted:

2.3.1. Fresh weight of aerial part, dry weight of aerial part and roots, total number of leaves and number of leaves longer than ten centimeters

The aerial part from each plant was separated from its roots and weighed on digital scales. Therefore, the leaves and stems were considered as fresh matter, as it is usually sold in the market. Only the outer leaves were removed in the senescence process.

The mass for dry matter was obtained by weighing the aerial parts and roots, after drying in greenhouse with forced air circulation at 60 °C for 72 h.

The total number of leaves was obtained by counting the number of leaves in each plant.

The number of leaves longer than ten centimeters was obtained by counting these leaves from the total. This entire methodology has been described in Sanchez (2007).

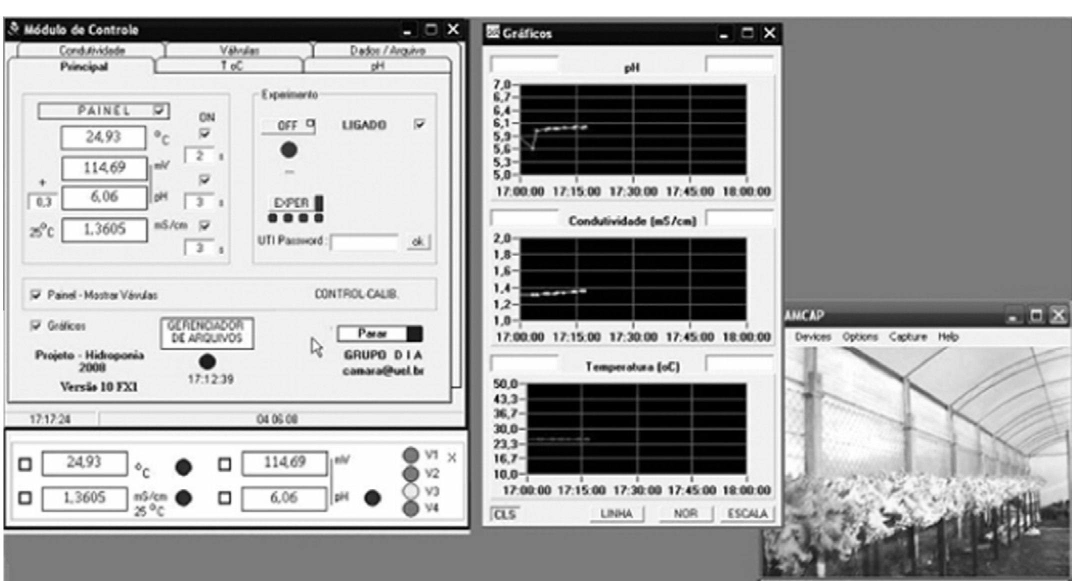

Fig. 2. Digitized screen of software *ControlHidro* and image of automated hydroponic cultivation obtained through a webcam by remote connection.

2.3.2. Nutrient concentration in lettuce leaves from automated hydroponic and conventional soil cultivations

After the leaves were dried in greenhouses, they were grounded in order to determine the concentration of macro and micronutrients, using a micro-mill (Marconi). After this, the levels of nutrients were determined through the Kjeldahl technique for nitrogen and ICP-MS spectroscopy for the remaining ones. These tests were performed at EMBRAPA Soybean of Londrina, following the method proposed by Plank (1992), Tucker and Bowling (1984), Silva (1999), Tedesco et al. (1995) and Miyazawa et al. (1992).

3. Results and discussion

3.1. Evaluation of the efficiency in the instrumental system

It is known that the temperature of the nutrient solution that irrigates the lettuce grown in hydroponic systems is directly related to conductivity and pH parameters, since variation in these parameters is influenced by changes in temperature of the solution in the tank. In this study, with the development of the *ControlHidro* software, it was possible to acquire data from the temperature of the nutrient solution throughout the 24 h/day and to correlate these with changes in pH and conductivity values, making the immediate control of these parameters possible. Fig. 3 shows the temperature variation in the solution irrigating the lettuce over a day of cultivation.

Through the graph, it is possible to notice that the nutrient solution reached its lowest temperature close to eight o'clock in the morning, at approximately 14 °C, while its highest temperature was obtained close to four o'clock in the afternoon, with a value of approximately 24 °C.

In this experiment, the range of electrical conductivity predetermined as ideal was 1.5 mS cm^{-1} assuming 1.7 mS cm^{-1} as a maximum limit. As the electrical conductivity decreased when compared to the predetermined ideal level, the valve responsible for dispensing the nutrient solution within the container was immediately open, causing the measure to return to its ideal value (Figs. 2 and 4). By looking at Fig. 4, it can be noticed where the valve was open (point A), programmed via software, responsible for the electrical conductivity parameter, discharging nutrient solution when recognizing a different value from what has been predetermined in its configuration. The time spent in this recovery was of approximately 2 min.

It is known that the pH value for the nutrient solution should be between 5.5 and 6.5, since this is the range where the plants will have greater availability of nutrients. In the present study, the limit between 5.8 and 6.2 was established as the control for this parameter. It could be observed that while the software acquires different data from which has been pre-programed, one of the valves responsible for controlling the pH is triggered, dispensing acidic or basic solution in the nutrient solution reservoir, causing the pH of the solution go back to the pre-established value. Observing Fig. 5 it can be noticed that in (A) no valve responsible for pH parameter is open, because the value acquired by the software is within the range limit. However, in (B) the valve responsible for dispensing acidic solution is open for a specific amount of time, since the system detected a pH value above the pre-established maximum value, making this parameter return to its limit range. In (C) the opening of the valve that contains basic solution can be noticed because the software reported a pH value below the pre-established limit, so that the pH value returns to the limit range. In (D) here is also the opening of the valve that contains acidic solution, which stayed on for enough time so that the solution reached a pH value within the expected level. And finally in (E) it can be observed that by being within range, there was no need to

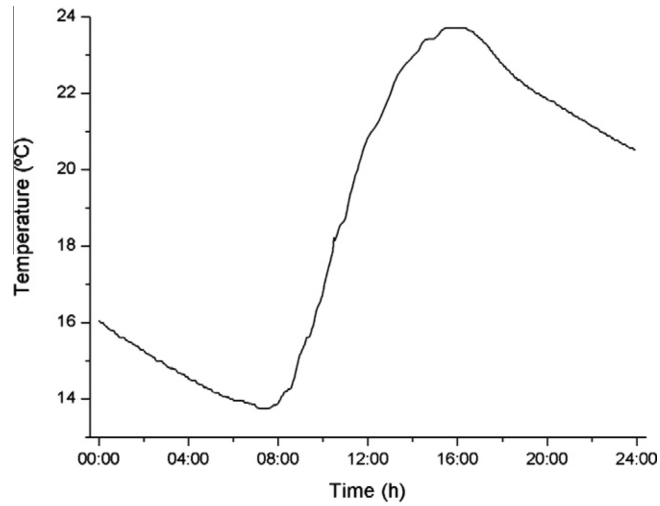

Fig. 3. Variation of temperature of the nutritive solution in function of time, during a day of lettuce cultivation in automated hydroponic system.

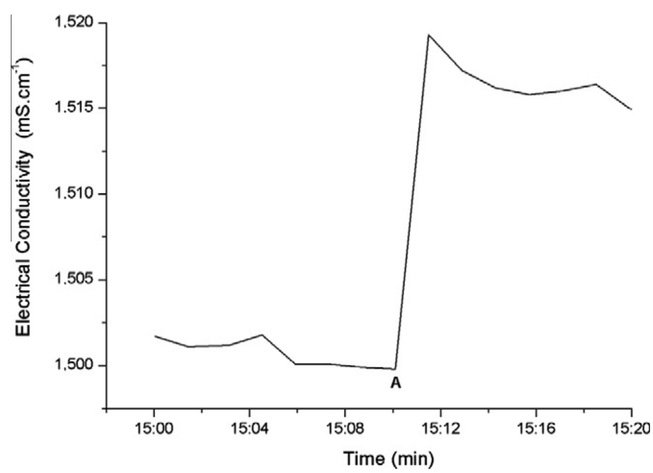

Fig. 4. Variation of electrical conductivity in function of time. In (A) occurs the activation of the valve responsible to dispense nutrient solution inside the reservoir in automated hydroponic system.

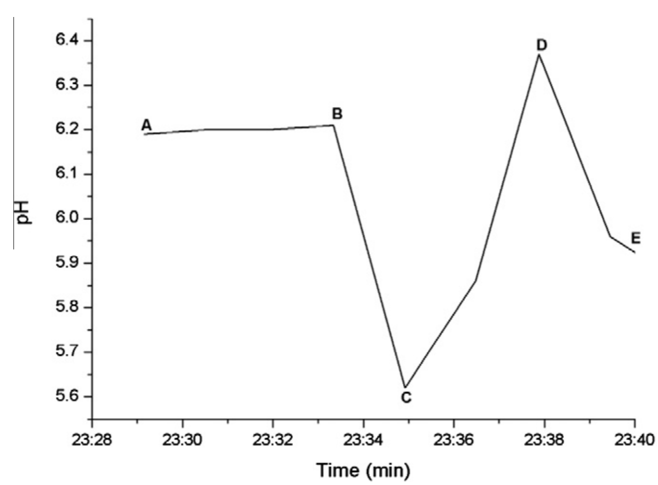

Fig. 5. Variation of pH in function of time. In (A) valves are switched off; in (B) occurs the opening of the valve dispensing acid solution; in (C) occurs the opening of the valve having basic solution; in (D) occurs again the activation of the valve with acid solution; in (E) valves are deactivated.

Table 1
Average of fresh and dry mass of aerial part (FMAP and DMAP), dry root mass (DRM), total number of leaves and leaves higher than ten centimeters (NTF and NF10) obtained by automated hydroponic system and conventional soil cultivation, of hydroponic lettuce cultivations found in literature.

	Experimental data cultivation (g plant^{-1})		Hydroponic cultivations (g plant^{-1}) of literature	
	Automatized hydroponic	Soil	Sanchez (2007)	Blat et al. (2011)
FMAP	267.56[a]	307.90[a]	118.72	179.20
DMAP	13.33[a]	14.77[a]	6.41	8.30
DRM	1.82[a]	1.55[a]	1.36	1.80
NTF	22.50[a]	24.50[a]	23.79	30.20
NF10	18.50[a]	21.00[a]	9.72	16.40

[a] Average do not differ between themselves by t Test at level of 5% probability.

open any of the valves responsible for controlling the pH, since the value acquired by the software was within the present range limit.

The sensitivity of the system in recognizing values different from those predetermined allows the correction of pH and conductivity parameters with speed, precision and efficiency. Thus, it is unnecessary the manual work of collecting and correction, based on titrations of small aliquots withdrawn from the nutrient solution, made in laboratory, with later corrections in the tank. Once that, by opening and closing of valves, the correction is made instantly through automated correction, the system allows the producer to have better control over the parameters, that influence plant growth by continuous monitoring of data, allowing an appropriate development, leading to reduce of the time spending and manpower, with precocity of harvest, higher productivity and best quality.

3.2. Analysis of agronomic characteristics of the plant

It can be observed in Table 1 that the mean fresh and dry mass of aerial part (FMAP and DMAP) and dry root mass (DRM) did not differ by Test t for the automated hydroponic and conventional cultivation in soil. For the total number of leaves (NTF) and leaves higher than ten centimeters (NF10), it can be noticed that there have been no significant differences between the types of cultivation, with an average of 23 and 19 leaves, respectively. The exaggerated size of leaves is often undesirable due to the difficulty in packing them without damaging the leaves.

The difference between the values of fresh and dry weight of aerial part, between cultures, can be explained by the fact that in conventional cultivation in soil, the plant is exposed directly to a higher incidence of solar radiation, and consequently suffers a greater variation in temperature throughout the day, while in automated hydroponics, the incidence of light is minimized through screens placed in the greenhouse, and therefore the temperature variation is not so drastic. This variation may have led to greater plant transpiration in conventional cultivation in soil than in automated hydroponics, generating a higher rate of photosynthesis and consequently higher biomass production. It also must be considered that soil lettuce was collected 7 days after hydroponics.

Establishing a comparison between the automated hydroponic experiments with other crops reported in literature (Table 1), it can be observed that while differing among themselves, the cultivation of this study showed values that are relevant in fresh and dry weight of shoots, indicating a production within commercial standards for the species. For dry root mass, no significant differences were observed that varied from the results reported in literature.

Regarding the total number of leaves, it can be noticed that the values obtained in this study are consistent with those found in literature. However, for the amount of leaves greater than ten centimeters, the results of this project were better when compared with values obtained by the mentioned authors, showing that through automated hydroponics it is possible to obtain a good yield, with plants presenting appropriate leaf size for consumption.

Table 2
Average content of macronutrients in lettuce aerial part grown in automated hydroponic system and conventional soil cultivation.

Cultivations	Macronutrients (g kg^{-1})					
	N	P	K	Ca	Mg	S
Hydroponic automated	33.10[b]	8.04[b]	77.49[a]	9.28[a]	3.46[a]	2.72[a]
Soil	39.58[a]	13.56[a]	82.40[a]	7.40[a]	3.00[b]	3.07[a]

Averages followed by the same letter in the column don't differ between them by *t* Test at a level of 5% probability.

Table 3
Average content of micronutrients in lettuce aerial part grown in automated hydroponic system and conventional soil cultivation.

Cultivations	Micronutrients (mg kg^{-1})			
	Fe	Cu	Mn	Zn
Automated hydroponic	214.77[b]	9.10[a]	50.56[a]	51.54[b]
Soil	532.85[a]	7.00[a]	30.55[b]	32.14[a]

Averages followed by the same letter in the column don't differ between them by *t* Test at a level of 5% probability.

3.3. Analysis of nutrient concentrations in hydroponic and soil cultivations

After analyzing the data obtained from the experiments, it could be observed that the cultivation carried out conventionally differed from automated hydroponic cultivation only in the levels of macronutrients nitrogen, phosphorus and magnesium, and the concentrations of micronutrients iron, manganese and zinc. Data regarding concentrations in shoots of crisphead lettuce from both experiments are described in Tables 2 and 3 for macro and micronutrients, respectively.

The values obtained for nitrogen in both crops, while differing significantly among themselves, are considered suitable for lettuce, being within the range of 30.0 to 50.0 g kg^{-1} which is considered appropriate by Trani and Raij (1996); and 30.0 g kg^{-1} recommended by Malavolta et al. (1997).

As for the average contents of phosphorus and potassium, it was found that values in automated hydroponic cultivation and conventional soil were above the range recommended by Trani and Raij (1996) from 4.0 to 7.0 g kg^{-1} and of 50.0 and 80.0 g kg^{-1} respectively. However, Beninni et al. (2005) obtained in a hydroponic cultivation, mean content of phosphorus and potassium, and in conventional cultivation, content for potassium, near those in the present study. As for phosphorus, the level found was much higher than that described by Beninni et al. (2005), showing a possible mineral fertilization with this element in the preparation of the soil where the conventional lettuce acquired in this experiment was grown.

According to Trani and Raij (1996), calcium and magnesium have appropriate recommendation ranges between 15.0 and 25.0 g kg^{-1} and between 4.0 and 6.0 g kg^{-1}. However, the results obtained in this study were lower than those found by those researchers. Even with these values below the recommended range, no abnormality could be found which could have been caused by the deficiency of these elements.

Sulphur has an adequate range between 1.50 and 2.50 g kg^{-1} as mentioned in Trani and Raij (1996) and for Malavolta et al. (1997)

the content of 2.50 g kg^{-1} was considered optimal for growing lettuce. However, the values obtained in this study were slightly above those found by these researchers. Despite finding values above the recommended range, no abnormalities were found for the excessive sulphur, such as light green color on the leaves or generalized chlorosis (Malavolta, 2006).

Regarding micronutrients, it could be observed in this study that iron, copper, manganese and zinc were within the ranges recommended in literature, with no noticeable symptoms of phytotoxicity in lettuce leaves during the conduction of this study.

Although presenting values close to those found by other researchers such as Garcia et al. (1982) with levels between 200.0 and 500.0 mg kg^{-1} and Haag and Minami (1988) with ranges from 300.0 to 1600.0 mg kg^{-1} the levels obtained for iron were different, being higher in conventional tillage in soil than in automated hydroponic. This is due to the type of soil in the Northern region of Parana, classified predominantly as Eutrophic Structured Red Earth and Eutrophic Red Latosoil, all rich in basalt. It should be noted that plants in this test showed no symptoms of excess or deficiency in iron.

For the micronutrients copper and manganese, the results are consistent with those recommended by Trani and Raij (1996) which are between 7.0–20.0 mg kg^{-1} and 30.0 to 150.0 mg kg^{-1}, respectively. The micronutrient zinc presented levels which were statistically different, although within the range recommended by Trani and Raij (1996) with values between 30.0 and 100.0 mg kg^{-1}.

The crops tested obeyed the following decreasing order as for absorption in leaves; for automated hydroponics: K > N > Ca > P > Mg > S > Fe > Zn > Mn > Cu, and conventional soil: K > N > P > Ca > S > Mg > Fe > Zn > Mn > Cu. Data obtained by Furlani et al. (1999) and Cortez (1999), both cultivated hydroponically in a laminar flow, obeyed the following order for the extraction of macronutrients: K > N > Ca > P > Mg, and this is the same sequence which was obtained by Garcia et al. (1982) but in soil conditions. It can be noticed from the data that the sequence for automated hydroponic cultivation is similar to those obtained by the mentioned researchers. However, for the conventional cultivation in soil there is a reversal between calcium and phosphorus, as well as between sulphur and magnesium.

Regarding micronutrients, Verdade et al. (2003) report that the sequence Fe > Zn > Mn > Cu is the most commonly mentioned in literature. In this study, the automated hydroponics and conventional soil presented the same sequence observed by these researchers.

Data found for macro and micronutrients in the present study showed that there were similarity between the crops in automated hydroponic and conventional soil systems in relation to the values obtained by various researchers mentioned here, highlighting the efficiency of the instrumental system in hydroponics for controlling the parameters of conductivity and pH, presenting a viable and efficient production of lettuce.

4. Conclusion

The instrumental system developed proved be efficient in monitoring and fixes pH and conductivity of the nutrient solution of the hydroponic lettuce, which suffers lots of variation during the cultivation. This was attested, by the similarly behavior regarding the agronomic characteristics evaluated, by the comparison of two crops done in parallel, by using automated hydroponic system developed and conventional in soil, taken as reference of quality.

Once that monitoring takes place continuously, corrections can also be done instantly leading to higher productivity, allowing the producer to obtain a plant with leaf of size suitable for consumption and more homogenous. The Vanda cultivar was highlighted, in terms of fresh and dry weight of aerial part, when compared to the result found for other cultivars, considering that the concentrations of nutrients by using the automated hydroponic system were similar to described by literature. This similarity, highlights the efficiency of controlling of conductivity and pH by the automated developed system applied to hydroponics, offering the producer an effective and viable alternative in the production of lettuce.

The condition of mapping of all the stages of cultivation allows the producer to know more about the variations of adsorption of nutrient that occurs during the cycle, which certainly will help to increases quality.

The development of this system also provides a new perspective, with the control of specific macro-and micronutrients such as nitrogen, potassium, calcium and copper, made by the use of selective electrodes in series. It promises an addition of nutrients more “intelligent”, reflecting in better productivity, preserving the nutritional quality of the product and allowing add of value to health.

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