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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