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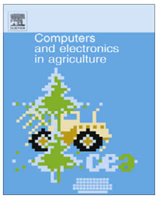

Development and evaluation of an automated system for fertigation control in soilless tomato production

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ABSTRACT

An automatic control system was developed for real time preparation and application of nutrient solution for soilless tomato production. The control strategy was based on transpiration estimates by the Penman–Monteith model and on leachate concentration by measurements of electrical conductivity. The performance of the fertigation system was evaluated during tomato cultivation in sand substrate under greenhouse conditions. The commercial crop yield was 4.74 kg m^{-2} and the average total soluble solids of tomato fruits was 4.50 °Brix. Water use efficiency for tomato crop cultivated with the developed control system was 17.94 kg m^{-3}. To produce 1 kg of tomato fruits, 44.42 L of nutrient solution were necessary. The proposed system was efficient in adjusting the frequency of fertigation cycles and controlling the prepared nutrient solution concentration, minimizing environmental problems related to effluent disposal and contributing to economy of fertilizer and water resources.

1. Introduction

The need of large amounts and high quality vegetable products to meet the growing demand of world population justifies the development of technologies which synchronize the nutrient solution demand and supply to greenhouse plants in order to achieve crop yield optimization. The knowledge about water and nutrient uptake by plants is crucial for developing control strategies which make possible to supply the required amounts of water and nutrients for maximum crop growth and development (Kläring, 2001).

The majority of the root water uptake is lost by plant transpiration, which accounts for approximately 90% under greenhouse conditions (Li et al., 2001). Thus, irrigation frequency control, based on measurements or estimates of transpiration rates, provides a sophisticated method of supplying the real plant water demand.

According to Zolnier et al. (2004), there is much interest in automatic systems for plant production. Irrigation scheduling in greenhouses can be optimized using growth models that simulate the leaf area expansion with evapotranspiration models that are capable of simulating water consumption during the whole crop development stages.

Automatic control systems have been applied in almost all engineering fields with great success. In the field of automatic irrigation, measurements of soil, plant and atmosphere variables related to the plant water status can provide the information of the consequences of previous actions to calculate the irrigation frequency and duration (Romero et al., 2012).

Due to low cost and practical reasons, the most common technique used to control the nutrient solution concentration is based on measurements of electrical conductivity, which indirectly quantifies the total amount of dissolved ions in the solution. On the other hand, the nutrient solution concentration can be monitored and controlled by measuring each nutrient present in the solution with ion-specific sensors, such as the ion selective electrode (ISE) and the ion selective field effect transistor (ISFET) sensor. However, a number of practical difficulties related to ISE and ISFET sensors still need to be resolved, in particular, stability and robustness of the measuring systems, life expectation of the sensors and their high costs (Gieling et al., 2005b).

In the last 25 years, the development of control systems capable of automating operations of preparation and management of nutrient solution for hydroponic and soilless cultivation has been intensified (Glass et al., 1987; Papadopoulos and Liburdi, 1989; Kläring et al., 1997; Savvas and Adamidis, 1999; Urrestarazu and García, 2000; Blair and Taylor, 2004; Gieling et al., 2005a; Van Straten et al., 2006; Steidle Neto, 2007; Domingues et al., 2012). In these studies, the control strategies are generally based on mathematical models and/or on monitoring of the electrical conductivity, ion individual concentration, pH and/or climatic variables of the crop environment.

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The present work was carried out to develop a fertigation automatic control system and to evaluate its performance for a tomato crop grown in sand substrate under greenhouse conditions. The control strategy was based on crop transpiration estimated by the Penman–Monteith model and on leachate concentration measured by electrical conductivity cells. Results provided by the developed control system regarding accumulated volumes (fertigation and leachate), commercial crop yield, fruit quality and water use efficiency were evaluated.

2. Materials and methods

2.1. Fertigation automatic control system

The core of the Fertigation Automatic Control System (FACS) is based on estimates of crop transpiration and on leachate concentration, which was indirectly measured by the electrical conductivity of the drained nutrient solution. The proposed system is a closed loop controller, which is meant to receive feedback from the estimated and measured variables. FACS was developed to be commanded by a computer with minimal hardware requirements and is managed by a software (Hidro-Control), specifically written in C++ language for this purpose (Steidle Neto, 2007). Besides the computer, this control system consisted of reservoirs, dosage and fertigation pumps, electronic circuits and sensors.

A mixing reservoir with capacity of 30 L was used to store the nutrient solution destined to fertigation. Also, two 100 L reservoirs were employed to store the stock solutions (A and B) and one 100 L reservoir was used to store the water for the stock solutions dilution (Fig. 1).

In addition, three pumps of 7.5 W were connected to the lower lateral sides of each stock solution and water reservoirs in order to accurately dose the necessary amounts in the mixing reservoir. After diluting the stock solutions A and B in the mixing reservoir, nutrient solution was applied to the crop by using a 32 W small fertigation pump.

Level control of the nutrient solution inside the mixing reservoir was accomplished by an electronic circuit connected to a contact sensor which was developed to avoid solution overflow during its automatic preparation.

Meteorological variables of the cultivation environment, required for estimating plant transpiration, were real time measured using one minute time intervals. The probes included an integrated air humidity and temperature sensor (model Humitter 50Y, Vaisala Inc., Woburn, USA), placed in an aspirated radiation shield, and a pyranometer for measuring global solar radiation (model CM3, Kipp & Zonen, Delft, Netherlands), both positioned in an adjustable support and maintained 0.5 m above the canopy. Another integrated air humidity and temperature sensor was externally installed in a multi-plate shield located under the greenhouse gutter.

Fig. 1. Perspective view of reservoirs (mixing, stock solutions and water) and computer of the FACS.

The environmental sensors were connected to the analog channels of a data acquisition board and a multiplexing panel (models CYDAS 1602HR and CYEXP 32, CyberResearch Inc., Branford, USA), both installed on the computer mother board (Zolnier et al., 2000). Additionally, an electromechanical relay board (model ERA-01, Keithley Instruments Inc., Cleveland, USA) was connected to the data acquisition board and used to start the dosage and fertigation pumps.

Real time monitoring of the nutrient solution concentration was done by an electronic circuit which was specially developed for measurements of electrical conductivity (EC) ranging from 0.10 to 10.15 dS m^{-1} (Steidle Neto et al., 2005). Due to variations of the nutrient solution temperature, electrical conductivity values were compensated for 25 °C by another electronic circuit which measured nutrient solution temperatures from 10 to 40 °C (Steidle Neto and Zolnier, 2006). Electrical conductivity cells (model EW 19500-20, Cole–Parmer Instrument Company, Chicago, USA), each one consisting of two platinum coated electrodes ($K = 1\ cm^{-1}$) and a 10 kΩ thermistor, were connected to the mentioned electronic circuits and used for measuring the leachate electrical conductivity. Digital signals sent by the temperature and electrical conductivity circuits, as well the signal from the nutrient solution level, were also measured by the data acquisition board.

The pH of the nutrient solution was monitored by a preamplified electrode (model PHE-1304-NB, Omega, Stamford, USA). Due to mutual interference among electrical signals coming from the pH electrode and EC cells when they are immersed in the same solution, the pH was measured on a weekly basis. Thus, the pH of the nutrient solution was adjusted if necessary, always maintained between 5.6 and 6.0 (Resh, 2001). This was done by adding sulfuric acid or potassium hydroxide aiming to reduce or increase the pH, respectively.

2.2. Control strategy

The control strategy of the FACS was implemented in the Hidro-Control algorithm, developed with the purpose of synchronizing nutrient solution demand and supply to the plants. This control strategy was divided into two sub-strategies: the first was based on crop transpiration estimates and used to control the nutrient solution supply; the second was based on leachate electrical conductivity measurements and used to control the prepared nutrient solution concentration.

2.2.1. Nutrient solution supply sub-strategy

The FACS was projected to control the plant nutrient solution supply according to the atmospheric demand of the cultivation environment (greenhouse) by adjusting fertigation frequency.

Crop transpiration is the main variable of the decision process related to fertigation frequency and its estimation was based on the Penman–Monteith model parameterized by FAO (Allen et al., 1998). Crop coefficients were obtained according to the thermal time (accumulated degree-days), by a vegetative growth model obtained from previous transpiration measurements in soilless tomato production under greenhouse conditions (Steidle Neto, 2007). Degree-days were calculated on a base temperature of 10 °C for tomato crop (Wolf et al., 1986).

The substrate surface was covered with a transparent plastic film (mulching) to minimize evaporation so that water loss due to the atmospheric demand was accounted as plant transpiration only.