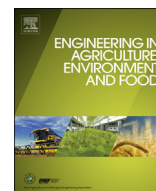




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Research paper

Design and testing of a nutrient mixing machine for greenhouse fertigation

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ABSTRACT

To improve the efficiency and accuracy of water-nutrient mixing, a multi-channel fertigation machine was designed; the hardware includes a programmable logic controller (PLC), a touch system and multi-channel sensors. A sectional forecast control algorithm based on the nutrient dilution model was proposed to control the fertigation machine. When the 100-fold concentrated nutrient solution was diluted by a factor of 20–200, the results showed that the standard deviations of the electrical conductivity (Ec) and the pH for four repeat measurements were 0–0.4 mS cm⁻¹ and 0.057–0.12, respectively; therefore, the performance of the nutrient solution was stable. When the target Ec values were 1.0, 1.5, 2.0, 2.5, 3.0 and 4.0 mS cm⁻¹, the variation coefficients relative to the target Ec values for three repeat measurements were 2%, 0.94%, 0.87%, 0.63%, 2.37% and 1.8%, respectively. The multi-channel water-nutrient mix resulting from the sectional forecast control algorithm was precise; the error of the Ec was less than 0.05 mS cm⁻¹, which satisfies the requirements of fertigation for soilless cultivation in greenhouses.

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1. Introduction

Although facility horticulture occupies a small portion of global agricultural land, this practice has expanded considerably in recent decades (Sonneveld and Voogt, 2009). Protected horticulture contributes substantially to local agricultural development (i.e., in Ragusa, Italy) and national economies (i.e., in the Netherlands) (EFSA, 2010). Traditional horticulture is generally concentrated in small areas and may contribute to environmental degradation because of waste discharges and a high consumption of water, fertilisers and agrochemicals (Gallardo et al., 2009). The pollution associated with intensive agriculture forces horticulturalists to adopt more environmentally friendly cultivation methods, such as closed soilless culture, hydroponic systems and biological control of pests and diseases (Vox et al., 2010).

Improvements to the systems supplying water and nutrients to horticulture crops is crucial to improving quality and production while consuming less water and fertiliser. Protected horticulture

operations using fertigation systems are considered superior to field production systems in terms of water and nutrient use efficiencies (Bradley and Marulanda, 2000; Sheikh, 2006). A greenhouse cucumber crop in Florida (USA) required one-third the amount of water, 28% less nitrogen and 23% less potassium per kilogram of fruit compared with a field-grown cucumber crop (Jovicich et al., 2007). However, the efficiency of the fertigation system in protected horticulture depends on the design and management of the water and nutrient application systems (Valenzano et al., 2008). Fertigation systems are ideal for precisely controlling water-nutrient ratios and recycling water and nutrients because the drainage can be easily captured for reuse. Such systems can reduce pollution and lower the consumption of water and fertiliser (Carmassi et al., 2005). Fertigation machines are less frequently studied in Asia, and most such systems have remained in the experimental phase (Zhang, 2009; Yang et al., 2005). By contrast, numerous studies have been performed investigating crop fertigation machines (Dougherty et al., 2007). Presently, the Netherlands, Israel and the Australia, have developed end-market products such as the NutriFlex, the NutriFit and the Nutrijet irrigation machines (Priva Company, Netherlands); the Elgal-Agro system and automatic fertigation machine (Fertiga, Israel) (Zhang,

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2009); and the MICO-MASTER series products (Australia) (Ma, 2005).

However, these fertigation machines are expensive and are therefore not suitable for popularization and application. This paper introduces a design for a multi-channel fertigation machine with the advantage of low cost, which uses a programmable logic controller (PLC) and touch control system. To minimise the long time lag and increase the uniformity in the water-nutrient mix, a forecast closed-loop control algorithm with subsection optimization was applied. This algorithm was based on several mathematical models of nutrient solution dilution. Using this system, a precise, efficient water-nutrient mix was obtained. The statistical analysis showed that the water-nutrient mix resulting from the fertigation machine was stable and uniform.

2. Material and methods

2.1. The fertigation machine

The fertigation machine contains four components: sensors, controllers, actuators and auxiliary equipment (Fig. 1). The sensors include monitoring devices for liquid temperature, liquid level, electrical conductivity (Ec), pH, flow meters and liquid level switches. The controllers consist of a principal computer (WQT-T8048, HMI touch system) and a PLC controller (HW-36MT-4DA). The actuators include electromagnetic valves, diaphragm pumps, boosters, and other parts. The auxiliary equipment includes four concentrated nutrient solution tanks, a dilute nutrient solution tank, a water purifier, drip tapes, five filters, a flow meter, and other parts.

Both the Ec and the irrigation volume of the nutrient solution are set through the HMI touch system, and the controllers then drive the relevant actuators to perform the automatic water-nutrient mixing function based on the dilution algorithm. Additionally, the dilute nutrient solution is transfused into the drip tapes and transported to the soil around the plant root zone. Fig. 2 shows an experimental prototype of the fertigation machine.

The touch system communicates with the PLC controller via the RS232 port to monitor the dilute nutrient solution (Fig. 3). Parameters of the dilute nutrient solution, such as the irrigation volume, Ec, pH and mixed algorithm, can be established via the



Fig. 2. Fertigation experimental prototype.

touch control interface. The operating state of the system and historical data records can be accessed via the touch control interface as well.

Fig. 4 shows the functional sections of the machine. The input terminals of the PLC controller consist of manual control signals and sensor signals. The sensors are attached to the AD0–AD3, which are the A/D ports of the PLC controller. The sensors monitor the liquid temperature, the pH, the Ec, the liquid level and the flow of the dilute nutrient solution. In particular, the flow sensor attached to the X17 port provides a pulse signal. In addition, the output terminals are either connected to the actuators (solenoid valves and diaphragm pumps, 24 VDC) or to the relays to indirectly control the high-voltage equipment (Booster pumps, 220 VAC).

2.2. Preparing the nutrient solution

The fertiliser machinery automatically produces an accurate mixture of water and concentrated nutrient solutions, and the dilution model of the concentrated nutrient solution provides the basis for a precise and efficient water-nutrient mix. Based on a well-

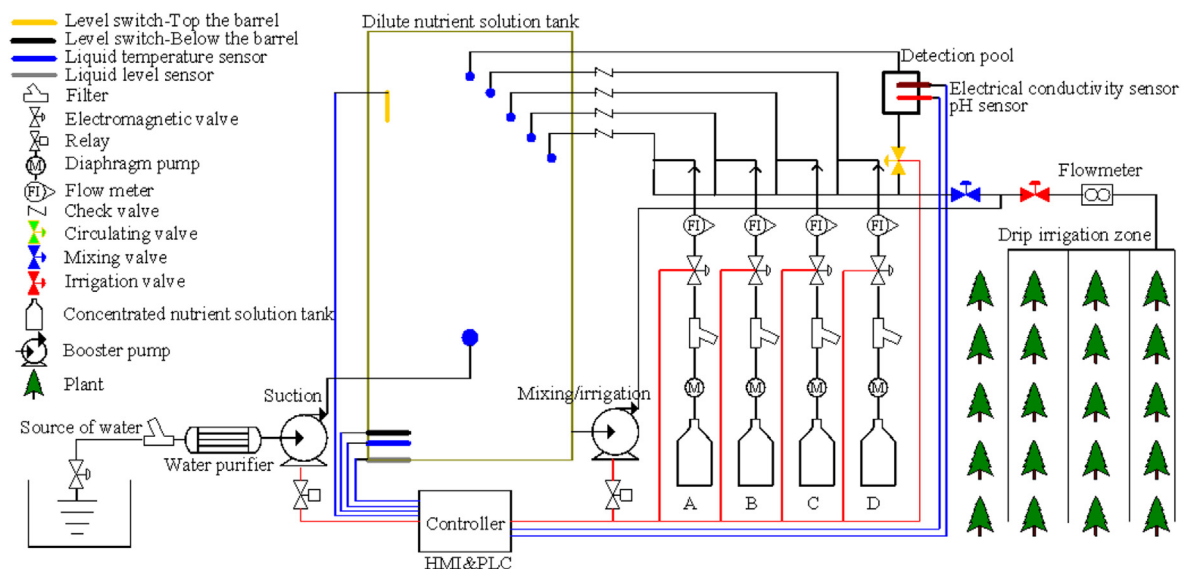


Fig. 1. Schematic of the fertigation machine.

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