BASIC TESTS OF PH AND EC PROBES FOR AUTOMATIC REAL TIME NUTRIENT CONTROL IN PROTECTED CROP PRODUCTION

Yun-Kun Huh, Soo-Yong Jang, Youn-Kug Choo, Sun-Ok Chung, Yong-Joo Kim

Dept. of Biosystems Machinery Engineering
Chungnam National University
Daejeon, Republic of Korea

Ki-Yuol Jung

Coarse Cereal Crop Research Division, Department of Functional Crop
National Institute of Crop Science, RDA.
Miryang-si, Gyeongsangnam-do, Republic of Korea

ABSTRACT

Research on greenhouse and plant factory has been actively conducting to provide a stable growth environment. In plant factory, EC concentration (EC) and acidity (pH) of nutrient have a significant impact on physiological and morphological of plant. Therefore, EC and pH are important element for automatic control of nutrient solution. In this study, performance pH and EC sensors was evaluated for the responsiveness, accuracy and displacement. This study includes development of environmental monitoring system using pH and EC sensors which connected with computer and the pH and EC data was displayed in computer screen. PH buffer solutions were used in the experiments of seven kinds such as 4, 5, 6, 7, 8, 9, 10 res. EC of each standard solution in distilled water (0 µS / cm) were used in the experiments of seven kinds such as 100, 1000, 2070, 2764, 3900, 5000 µs / cm respectively. The experimental environment was kept in 25℃ and 50% humidity to control error. For evaluating the performance, measurement program was designed by control and instrumentation program (Labview 2010, National instrument Inc., Texas, USA) and data processing program carry out on data operation, storage, and display. Data was saved every 10 seconds. To evaluate the performance of the sensor, 1second interval and 10second intervals were used for 5minutes and 60minutes respectively for measuring accuracy. Also, for investigating whether nutrient or performance changes, cleaning sensors were compared to non-cleaning sensors. The error ranges were showed that pH was less than 2% and EC was 0 and 0.1 dS/m. From this study, these sensors are confirmed the appropriate sensors to measure the pH and EC of nutrient solution. For proposing sensor calibration and cleaning time, compared two statuses during 14 days in difference frequency for sensors correction and cleaning. One sensor was always in the nutrient and another one was corrected and cleaned in every 24 hours. Result showed the error of pH sensor was more than 5% after 6 days. Correction and cleaning of sensors are required within 6 days.

Keywords: Protected horticulture, Growth environment, Plant nutrient, Real time control, Electrical conductivity (EC), Acidity (pH)

INTRODUCTION

Stable and sustainable agricultural and food production is expected to be difficult due to increased population, global warming, and climate change. In addition, safe and good quality crop and food production is becoming an important issue for better life. Protected facilities such as plant factory and greenhouse have advantages of year-round cultivation and controllable environment, and crop growth and quality. Growth environment of protected facilities can be divided into ambient and root-zone parts. Ambient environmental variables include temperature, humidity, light intensity, gas concentrations, and root-zone variables include water content, nutrient and gas concentrations. These factors considerably affect crop growth and quality. Proper temperature should be considered depend on the crop growth period and humidity control can prevent from diseases. Also, concentration of CO_2 make increases crop growth and yield by promoting photosynthetic rate. Choi et al. (2003) studied effect of temperature on tipburn incidence of butterhead and leaf lettuce. In order to prevent tipburn incidence, optimum day temperature for butterhead and leaf lettuces was 22 to 26 °C in initial and middle growth stages and 20 to 24 °C in the later growth stage. Optimum night temperature was 15 to 20 °C. Jin et al. (2000) researched CO2 concentration and nutrient concentration on growth of butterhead lettuce. Growth of butterhead lettuce was high when CO2 concentration was 1000 to 2000 ppm in middle growth stages. Also, optimum concentration of culture medium was confirmed as 1.2 to 1.8 mS/cm. For automatic control of these environmental variables requires real-time sensing technologies.

In order to control greenhouse environment more precisely and conveniently, real-time monitoring and automatic control technology have been developed. Gao et al. (2011) developed greenhouse monitoring system using TinyOS and temperature, humidity, light could be monitored. Control application program was designed with Visual Basic, which realizes the remote control between the PC and the monitoring system. It also enhances the efficiency, accuracy, reliability and has higher value of applications. Morimoto et al. (1995) applied to control of physiological processes of plants using optimal regulators and an intelligent control technique using genetic algorithms. These control techniques were useful for the optimal control of the physiological processes of plants.

Root-zone environmental variables such as pH and EC affect nutrient absorption and solubility. Recent increase of nutrient solution culture causes demand of real-time monitoring of the pH and EC status. Biernbaum et al. (1999) conducted 50 experiments for 10 years for real- time monitoring and automatic control of pH and proposed model about nutritional status of crop and chemical characteristics of pH. Sample solution of pH, EC, NO_3^--N and K^+ were measured with Cardy flat electrode meters. Averaged over crops, solution pH was similar for SLT and SME (after extraction) at each N concentration. SME and SLT solution of EC and K^+ concentrations were similar for samples collected from the 50 and 100 mg · liter^{-1} N treatments. Also, Cavins et al. (2000) carried out PourThru sample test to supply proper nutrient solution. As the result, nutrient solution program was developed to determine the amount of pH and EC and range of pH and EC was proposed for hydroponics.

For automatic control design, predictable problems must be solved such as maintain proper irrigation ratio and sensors. Researches have been conducted about irrigation control model which can keep proper irrigation ratio depend on growth stages. Bilderback (2001) reviewed the procedure and update growers on the Virginia Tech Extraction Method (VTEM), also called the PourThru extraction procedure. As the result, EC can build up in the irrigation water. The EC may be chlorides and sulfates, not essential nutrients. Lack of Ca, Mg and minor nutrients may cause a noticeable drop in pH. As nutrients are washed out or used, the medium has less buffering capacity and may reflect the pH of the irrigation water, which is often around pH 7.0. Futagawa (2012) confirmed crosstalk of pH, EC and temperature sensors. As the result, each sensor can be measured at the same time without impact of crosstalk. To confirm the absence of crosstalk between the sensors, we made simultaneous measurements of pH, EC, and temperature of a pH buffer solution in a plant bed. When the solution was diluted with hot or cold water, the real time measurements showed changes to the EC and temperature, but no change in pH. Sensor was capable of simultaneous in situ measurements in rock wool without being affected by crosstalk.

In order to apply previous studies in real-time monitoring and automatic control technology, responsibility and accuracy of sensors should be confirmed. Raoufi et al. (2014) studied about optical sensor for pH monitoring using a layer-by-layer deposition technique emphasizing enhanced stability and re-usability. The aim of this study has been to prepare a number of such sensors and compare the performance of three different stabilization approaches used for the development of an effective wavelength-dependent pH-sensitive optical sensor. An improvement in performance and in shelf-life, stability and re-usability of the sensor was achieved by the addition of two bilayers of APTMS/SiO_2 in the work carried out. Zeng et al. (2008) improved dual-sensor horizontal penetrometer by incorporating an EC sensor. In order to overcome the cross-modulation of signals from water content and EC sensors, two filters with specific pass-bands were connected in each circuitry. Experimental results showed that the improved technique could provide more informative data to interpret soil physical conditions at field-scale.

For real-time monitoring and automatic control system, performance and cleaning / calibration time of sensors should be checked in Root-zone environment. This study is the basic research for development of real-time monitoring and automatic control of nutrient solution to obtain data about sensor performance and replacement time. The specific purposes are 1) evaluation of pH and EC sensors performance by measuring responsiveness and accuracy 2) suggestion of cleaning and calibration time of the sensors.

MATERIALS AND METHODS

Experimental material

The condition of real-time automatic control system of nutrient solution is confirming the performance of sensors and suggesting replacement and cleaning time of sensors to prevent error of measured value from inflow foreign. Park, et al. (1999) studied for effect of pH level and EC on growth. The optimum pH of the nutrient solution for lettuce production was pH 5.0 to 7.0 and optimum ionic strength of the solution was EC 1.2 to 1.6 mS/cm. In this experiment, nutrient solution concentration was confirmed and range of concentration was defined that pH is 4 to 10 and EC is 0 to 5 dS/m. while sensors selection, measurement range, price and generality were considered.

Control and instrumentation program (Labview 2010, National instrument Inc., Texas, USA) was used for designing the operating program. pH and EC data transmitted from the sensor output as mV value and passed to DAQ. After the correction, data was converted into the value of pH and EC through the formula in the program. Finally, values were displayed in text boxes and graphs. Storage period of data was controlled and saved every 10 second. Storage format was saved as 'year, month, day, hour, minute, second ".

After market survey, a G-R (glass-reference) combination glass electrode in pH sensor (Model: SH-100PHS, SHINHAN A-TEC Co. Ltd., Changwon, Republic of Korea) was selected. Measurement range, maximum available pressure, and sampling rate of the sensor unit were 0~14, 8 kg/cm, and 1 kHz, respectively. Operating temperature and output voltage ranges of the pH converter (Model: SH-100PHC, SHINHAN A-TEC Co. Ltd., Changwon, Republic of Korea) were -5~45 °C and DC 1~5 V, respectively. A screw type EC sensor (Model: SH-100ECS, SHINHAN A-TEC Co. Ltd., Changwon, Republic of Korea) and EC converter (Model: SH-100ECC, SHINHAN A-TEC Co. Ltd., Changwon, Republic of Korea) were also selected. Specifications and photo of the sensors and convertors are shown in Table 1.

Table 1. Specifications of the sensors and convertors.

Item(Device)				
Model	SH-100PHC	SH-100ECS	SH-100PHCC	SH-100ECCC
Range	pH 0~14.0	0.0~5.0 mS/cm	pH 0~14.0	0.0~5.0 mS/cm
Error	±3 %	±3 %	±3 %	±3 %
Operation temp.	-5 ~ 45 °C	-5 ~ 45 °C	-5 ~ 45 °C	-5 ~ 45 °C
Photo				

Measured mV values were sent to PC using NI USB 6009 and saved, data was analyzed and compared with standard solutions values. Finally, performance of sensors was evaluated by calculating error of measured values.

Table 2. Specifications of the NI USB-6009.

Photo	Item	Specifications
	Manufacturing	NI instrument
	Model	USB-6009
	Analog resolution	12 bit
	Digital resolution	52 bit
	Analog Sampling rate	10 KS/s
	Analog output	10 V

Standard solutions were chosen considering crop growth environment. Seven pH solutions (pH 4, 5, 6, 7, 8, 9, 10 buffer solution; DUKSAN Co. Ltd., Ansan, Republic of Korea) and seven EC solutions (EC 0, 100, 1000, 2070, 2764, 3900, 5000 μS/cm buffer solution; SECHANG INSTRUMENT Co. Ltd., Seoul, Republic of Korea) were used.

Analytical methods

Sensors were placed in nutrient solution and value was measured. Seven kinds of pH and EC standard solutions were measured for precision and accuracy of the sensor. External environment was composed in small room of the plant factory (Precision Agriculture Laboratory, Chungnam National University, Deajoen, Republic of Korea) and temperature and humidity was maintained at 25°C and 50 %. The data was measured 1second intervals for 5 minutes, 10 second intervals for 60minutes.

In this study, cabbages most common plants for plant factory vegetables were chosen. Nutrient solutions were prepared at pH 6.5 and EC 1.2 dS/m because those concentrations of values are used in hydroponic. Nutrient solution was made by mixing the stock solution with water and Nitric acid (HNO_3). pH and EC sensor was measured for 14 days to compare cleaning sensor (Experimental sensor) and non-cleaning sensor (Reference sensor). Measuring vessel was sealed to protect from foreign inflow. Reference sensor was placed into nutrient solution for 14 days. Experimental sensor was washed and calibrated every 24 hour under the same condition as sensor1.

Deficiency of trace elements such as Iron (Fe), Manganese (Mn), Zinc (Zn) interferes in growth of leafy vegetables. When difference of sensor 1 and sensor 2 was more than 5%, sensor calibration and cleaning time were proposed within range of pH 7.0.

RESULTS AND DISSCUSION

pH and EC sensor accuracy evaluation

When EC standard solution was measured, output value of EC 0 (distilled water) average was 0.0657 and standard deviation was 0.0423. Distilled output value should be 0V. However, output value was higher than 0 V because of inflow of fine salt through sensor, measuring vessel and environment. When grow crops, average output value of sensor requires higher concentration of EC than output of EC 0. Therefore, errors exceeding

EC 0 do not have to be considered. Figure 1 and 2 shows that 7 kinds of standard solutions were measured for 5 minutes of every 1 second using pH and EC sensors. In the experiment for 5 minutes measured, all of the sensors output values had high reliability except EC 0 because of a relatively short period of time to flow debris and change concentration of standard solution.

RMSE (Root Mean Square Error) values showed that maximum and minimum values were 0.13 and 0.015, respectively in seven kind (pH 4~10) of Nutrient solutions. As the result, RMSE values had high confidence and pH concentration was increased more. RMSE values showed higher reliability progressively, except RMSE value of pH 5. Maximum and minimum measurement errors were ±1.4 % and ±0.41 %, respectively at same experimental conditions. These results were more accurate than official sensor error range (±3 %).

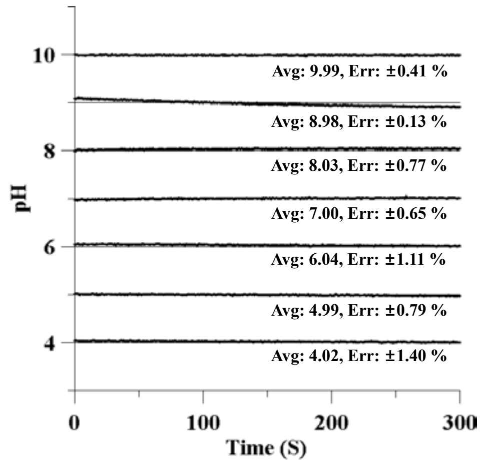

Figure 1. Graph of pH for 5 minutes.

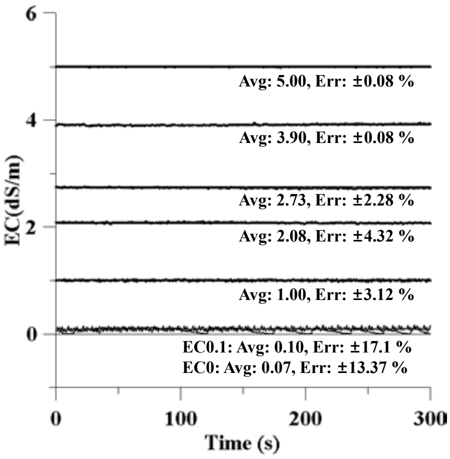

Figure 2. Graph of EC for 5 minutes.

When considering range (pH 4~7, EC 2~5) of leafy vegetables growing, pH and EC sensors were determined by suitable sensor for real-time monitoring of nutrient solution.

Figure 3 and 4 shows that 7 kind of standard solutions were measured for 60 minutes every 10 second using pH and EC sensors. When pH standard solution was measured in this experiment, error range was maximum ± 1.55 % and minimum ± 0.51 %. RMSE values were 0.008 ~ 0.022 about pH concentration. Therefore, this experiment error could be confirmed that similar to measuring for five minutes every 1 second. In EC standard solution measurement results, result was similar to 5 minutes experiment. Error range was within ± 5 % except EC 0 and 0.1. Also, RMSE values were 0.009 to 0.013. Therefore, suitability of sensors was confirmed.

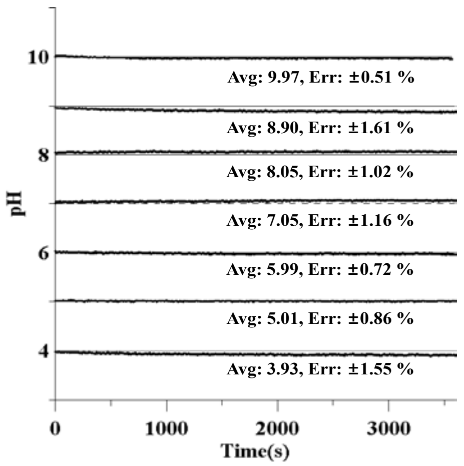

Figure 3. Graph of pH for 60 minutes.

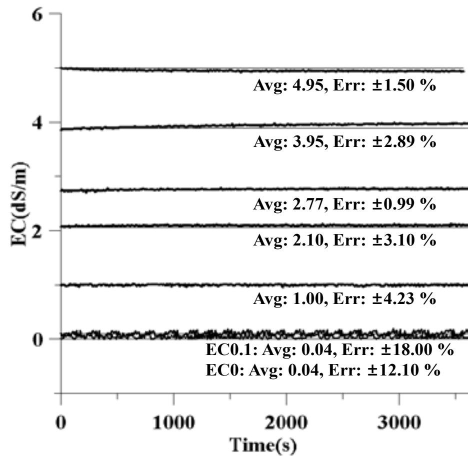

Figure 4. Graph of EC for 60 minutes.

Based on the results of experiments, pH sensor was determined as suitable sensor for real-time monitoring of nutrient solution because error range of pH was less than 2 %. In the case of EC, errors in EC 0 and 0.1 dS/m were larger than others because foreign material might flow into measuring vessel. However, EC 0 and EC 0.1 measured values were small value as first decimal place. It can determine the accuracy limits of sensor performance. Generally, EC of the nutrient solution is about 1.0 ~ 3.0 dS/m for cultivation and all errors were less than 5 %. Therefore, EC sensors can be used as a suitable sensor for measuring electric conductivity.

Suggestion of cleaning / calibration period

In this experiment, pH 6.5 and EC 1.2 dS/m nutrient solutions were made for experiment. Concentration of the nutrient solution was considered suggested concentration in hydroponic cultivation of cabbage. The sensor data was collected on a 3.4-Hz frequency rate. Measurement cycle was considered that error range was less than 5 % in experiment measuring for five minutes and cabbage harvest time was after 2~3 weeks for food. Therefore, Data was saved for 14 days (more than half of the entire cabbage growing period) at 10 minute intervals. Figure 5 shows graph of measured pH value for 14 days. Sensor 1 is placed into nutrient solution for 14 days. Sensor 2 was washed and calibrated every 24 hour under the same condition as sensor 1. As shown in Figure 7, pH change of sensor 2 is less than sensor 1. Also, both of two sensors values increased with time. This cause was determined as ration of the hydrogen ions in the nutrient solution. Therefore, when sensor is washed, composition of an appropriate concentration of the nutrient solution should be carried out.

At initial measurement, difference in error of the two sensors was 0.5 % but over the time, the error was getting higher. There was not regular pattern and after 5 days, error of more than 0.5 % was confirmed. In conclusion, cleaning and calibration time of pH sensor is proposed before 6 days when more than 5 % of error value checked between experimental sensor and reference sensor.

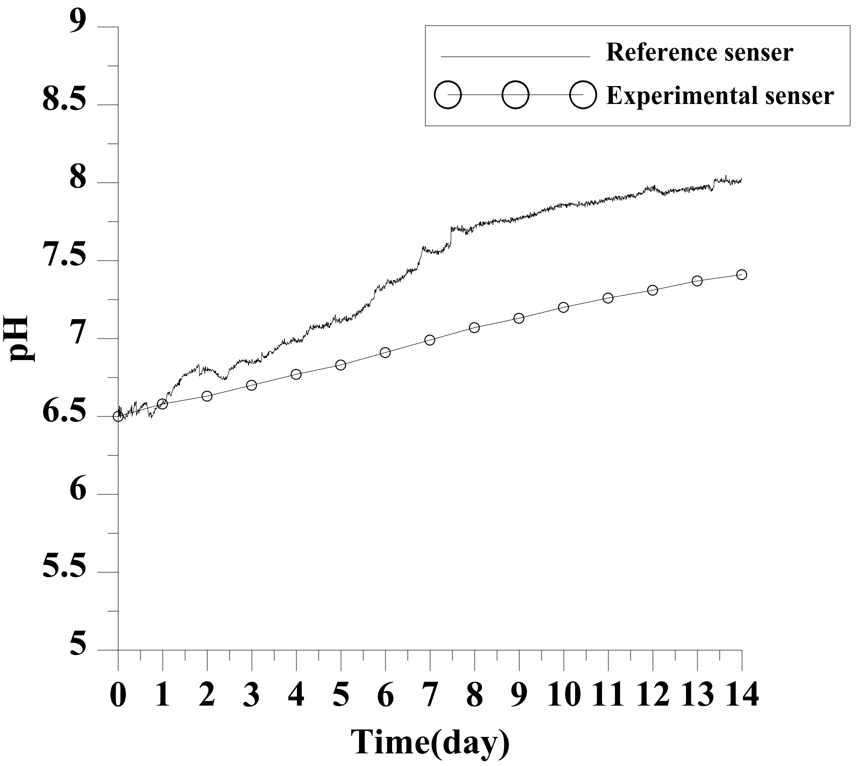

Figure 5. Graph of pH during 14 days.

Figure 6 shows the measured EC values for 15 days. Reference sensor was placed into nutrient solution for 15 days. Sensor 2 was calibrated and washed for every 24 hour under the same condition as experimental sensor. EC sensors values were also increased gradually with time because of evaporation of water in the nutrient solution.

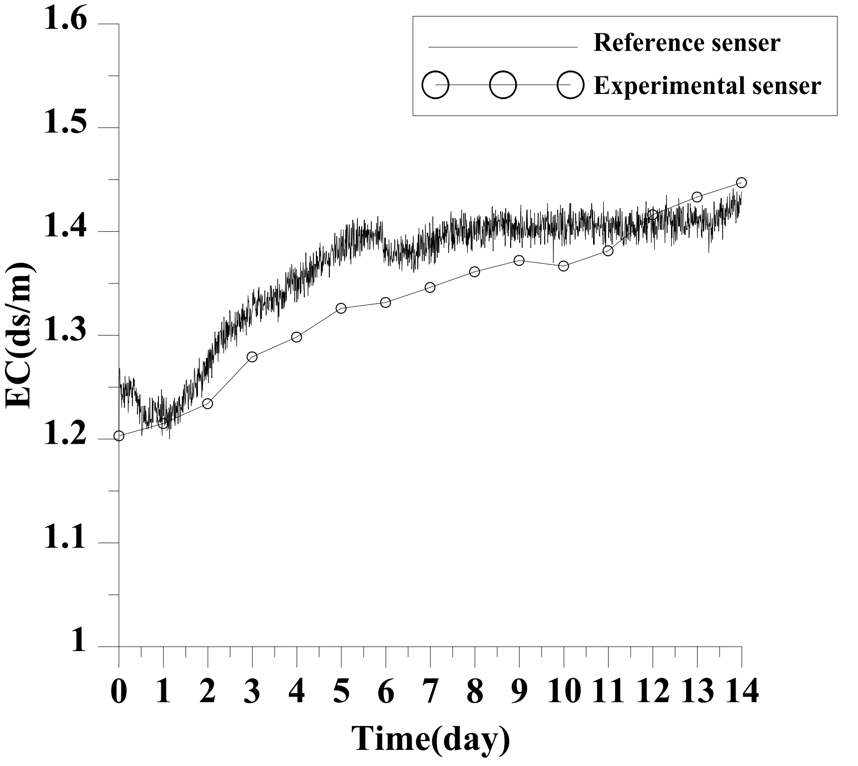

Figure 6. Graph of pH during 14 days.

Differences in errors of the two sensors were measured as 0.42 % at the first time. After 3 days, errors were increased by 3 to 5 %. After 9 days, errors were decreased by 1 to 3 %. Increased or decreased regular pattern was not showed in data analysis. EC errors were measured less than 5 % for 14 days except 5 days. While KCL solution of the pH sensor is a consumable that needs to be replaced after a certain time, EC solution is possible to use semi-permanent. Thus, EC sensor is determined that can measure more reliably. Also, measuring longer than 14 days is not able to expect accurate calibration time due to irregular error change. In this experiment, calibration and cleaning time of sensors was presented considering only change of evaporation water. However, in plant factory, regular check of the sensor is necessary because of foreign such as root and stem pieces in nutrient solution.

CONCLUSION

In This study, basic experiment was conducted to develop real-time monitoring and automatic control system of nutrient solution. Performances of the sensors were evaluated and cleaning and calibration time of sensors were presented depend on pH and EC nutrient solution.

1) To evaluate the performance of the sensor, 1 second interval and 10 second intervals were used for 5 minutes and 60 minutes, respectively for measuring accuracy. Error range of pH in both experiments were less than 2 % and in case of EC, all the errors were less than 5 % except EC 0 and EC 0.1 dS/m. Generally, EC of the nutrient solution is about 1.0 ~ 3.0 dS/m for cultivation and all errors were less than 5 %. Therefore, both sensors were suitable sensor for measuring pH and EC.

2) Reference sensor was placed into nutrient solution for 14 days and experimental sensor was washed and calibrated for every 24 hour under the same condition as sensor 1 for suggesting cleaning and calibration time of sensors. As a result, cleaning and calibration time presented before 5 days. In case of EC, errors were less than 5 % for 14 days. Cleaning and calibration time of EC sensor should be presented considering actual environmental factors in plant factory.

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