

## Original papers

## On-site ion monitoring system for precision hydroponic nutrient management

Woo-Jae Cho<sup>a</sup>, Hak-Jin Kim<sup>a,b,\*</sup>, Dae-Hyun Jung<sup>a</sup>, Dong-Wook Kim<sup>a</sup>, Tae In Ahn<sup>c</sup>, Jung-Eek Son<sup>c</sup><sup>a</sup> Department of Biosystems and Biomaterial Engineering, College of Agriculture and Life Sciences, Seoul National University, Seoul, Republic of Korea<sup>b</sup> Research Institute of Agriculture and Life Sciences, Seoul National University, Seoul, Republic of Korea<sup>c</sup> Department of Plant Science, College of Agriculture and Life Sciences, Seoul National University, Seoul, Republic of Korea

## ARTICLE INFO

## Keywords:

Closed system  
Hydroponics  
Ion-selective electrode (ISE)  
Automatic system

## ABSTRACT

Hydroponic solutions used in greenhouses or plant factories are usually evaluated based on their electrical conductivity (EC) and pH. However, EC and pH cannot provide sufficient information about ion imbalances in hydroponic solutions, and this may result in wastage of nutrients or poor yields. This paper reports on the development of an on-site ion monitoring system based on ion-selective electrodes (ISEs) that can automatically calibrate sensors and measure the concentrations of individual ions ( $\text{NO}_3^-$ ,  $\text{K}^+$ , and  $\text{Ca}^{2+}$ ) in hydroponic solutions. This enables farmers to effectively manage nutrients in reused solutions by rapidly identifying any imbalances that appear in the nutrient ratios. The measurement performance of the developed system was evaluated using hydroponic solutions prepared for growing paprika crops in greenhouses. An application test was conducted to investigate the feasibility of using the developed on-site ion monitoring system for the automated measurement of three macronutrients ( $\text{NO}_3^-$ ,  $\text{K}^+$ , and  $\text{Ca}^{2+}$ ) in a real greenhouse. The results showed that the developed system was able to measure  $\text{NO}_3^-$  concentrations, showing an almost 1:1 relationship with the results of a standard instrument, i.e., ion chromatography (slope of 0.99 and  $R^2$  of 0.99). Although the developed system overestimated and underestimated the  $\text{K}^+$  and  $\text{Ca}^{2+}$  concentrations with slopes of 1.17 and 0.75, respectively, the high coefficients of determination of 0.99 and 0.97 made it possible to use calibration factors to compensate for differences in estimation. In fact, relatively low RMSEs of  $< 20 \text{ mg L}^{-1}$  over the range of  $40\text{--}1200 \text{ mg L}^{-1}$  were obtained from a comparison of the ISE method and standard analysis when tested in hydroponic samples taken on different days during the period of paprika growing. This indicates that ISEs could be applicable to measurements where there is a strong linear relationship between the ISE method and standard analysis. In the application tests, the system could monitor the temporal changes in ionic concentrations in hydroponic solutions effectively, showing sensitive responses to changes in the concentrations of the three ions with an acceptable level of performance.

## 1. Introduction

Recently, there has been an increasing interest in recirculating and reusing nutrient solutions in closed growing systems as a means of reducing the cost and minimizing the environmental impact of hydroponic systems, such as soil and water pollution induced by the used nutrient solutions (Jung et al., 2015; Rius-Ruiz et al., 2014). The pH and electrical conductivity (EC) of the solutions are usually monitored to evaluate the nutrient status of recirculating hydroponic solutions used in greenhouse plant production (Bamsey et al., 2012; Domingues et al., 2012; Katsoulas et al., 2015). However, such approach cannot provide sufficient information about ion imbalances induced by

nutrient uptake in plants and the drainage ratio in plant growing beds because EC is an indiscriminate measure that only indicates the total composition of nutrient ions (Ahn et al., 2010; Bailey et al., 1988; Savvas and Gizas, 2002; Zekki et al., 1996). Moreover, the uptake ratios of the individual ions should be varied according to the crop species (Trejo-Téllez and Gómez-Merino, 2012).

To manage the imbalances in nutrient ratios in EC-based systems, periodical adjustment of recycled nutrient solutions was introduced, and adequate intervals were investigated (Ko et al., 2013; Ko et al., 2014; Savvas, 2002). However, the use of periodical adjustments to manage nutrient ratios has several limitations. For example, periodical adjustments cannot help farmers to respond rapidly to unexpected

\* Corresponding author at: Department of Biosystems and Biomaterial Engineering, College of Agriculture and Life Sciences, Seoul National University, Seoul, Republic of Korea.  
E-mail addresses: [er8er@snu.ac.kr](mailto:er8er@snu.ac.kr) (W.-J. Cho), [kimhj69@snu.ac.kr](mailto:kimhj69@snu.ac.kr) (H.-J. Kim), [jeogus@snu.ac.kr](mailto:jeogus@snu.ac.kr) (D.-H. Jung), [dwk8033@snu.ac.kr](mailto:dwk8033@snu.ac.kr) (D.-W. Kim), [genisleaf@snu.ac.kr](mailto:genisleaf@snu.ac.kr) (T.I. Ahn), [sjeenv@snu.ac.kr](mailto:sjeenv@snu.ac.kr) (J.-E. Son).

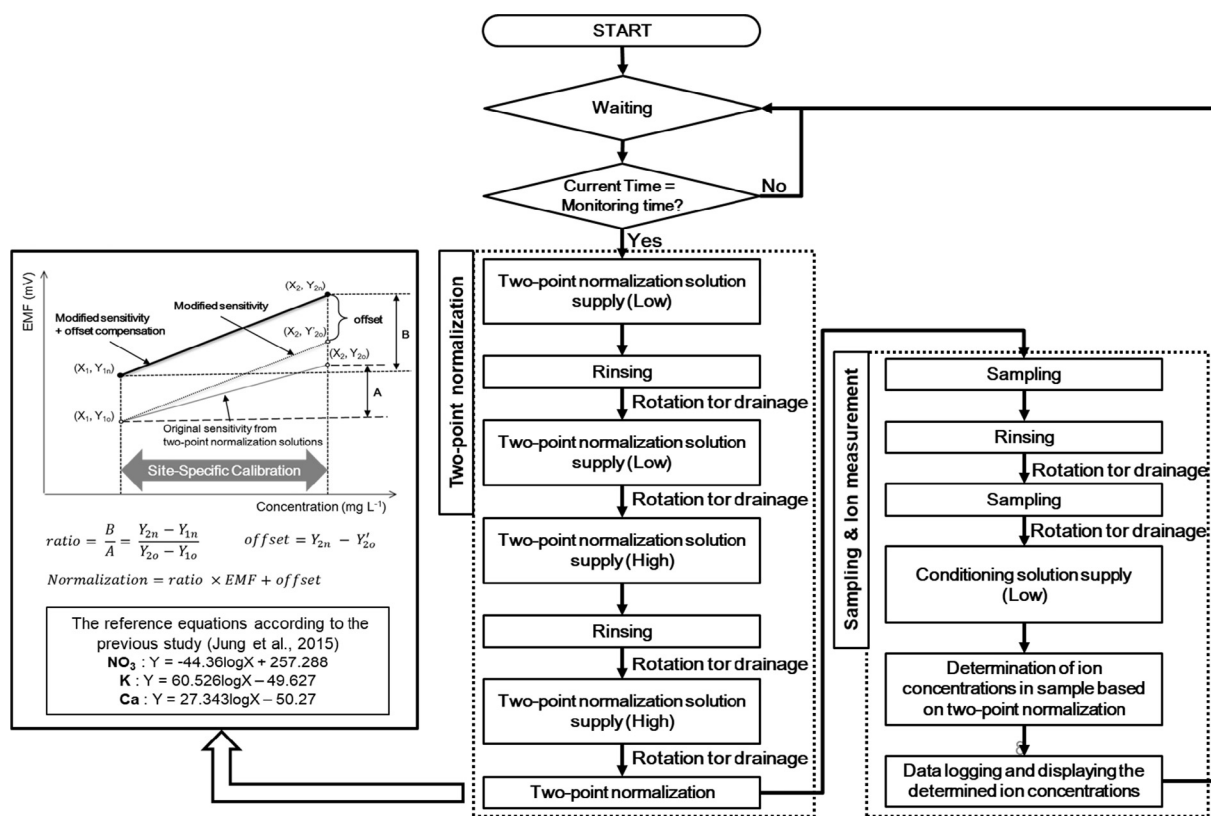


Fig. 1. Flow of operations implemented in the on-site ion monitoring system.

changes in nutrient ratios in hydroponic solutions. In addition, the intervals of adjustment vary depending on the plant species and climates.

Currently, benchtop or portable analyzers equipped with ion-selective electrodes (ISEs) are used to measure the concentrations of individual ions in hydroponic solutions. However, for on-site nutrient monitoring, which requires frequent immersions of the ISEs in solutions, the accuracy of the determination of nutrient concentrations is strongly affected by the signal drift and reduced sensitivity over time, which could be caused by manual calibrations, sampling, and the maintenance involved in the operation of ISEs (Caceres et al., 2017; Kim et al., 2017; Rius-Ruiz et al., 2014; Vardar et al., 2015). In this regard, a computer-based measurement system that performs automatic solution sampling and electrode calibration makes it possible to improve the nutrient concentration measurements (Dorneanu et al., 2005). Ideally, an automated sensing system for hydroponic nutrients would be able to periodically calibrate the electrodes and continuously measure the nutrients in a hydroponic solution, while automatically performing calibration and introducing sample solutions (Jung et al., 2015).

In previous studies, automatic measurement systems were developed in conjunction with a two-point normalization method to quantify NO<sub>3</sub><sup>-</sup>, K<sup>+</sup>, and Ca<sup>2+</sup> ions in hydroponic solutions with an acceptable level of accuracy (Cho et al., 2017; Jung et al., 2015; Kim et al., 2013). It was reported that the use of a two-point normalization, consisting of a sensitivity compensation followed by an offset adjustment, was effective in standardizing the responses of multiple electrodes for each ion. However, the predictive capability of the developed systems was only validated in a polycarbonate chamber growing lettuce or in a laboratory using paprika hydroponic solutions obtained from a greenhouse.

To enhance the practical use of the previously developed ion measurement systems (Jung et al., 2015; Kim et al., 2013) for hydroponic solutions in real greenhouses, the ultimate goal of this study was to develop an on-site ion monitoring system with robustness and an easy-to-use user interface that could automatically measure the

concentrations of three macronutrient ions (NO<sub>3</sub><sup>-</sup>, K<sup>+</sup>, and Ca<sup>2+</sup>) in recirculating hydroponic solutions, as these are closely related to the yield and nutritive quality of plants (Flores et al., 2004). The specific objectives were to (1) revise the system developed by Kim et al. (2013) for use in real greenhouses to perform real-time and direct measurements of the three ions based on automatic sampling and electrode rinsing and (2) investigate the performance of the developed system to quantify the temporal variability in the concentrations of the three ions during the period of paprika growth in real greenhouses.

## 2. Materials and methods

### 2.1. Preparation of NO<sub>3</sub><sup>-</sup>-K<sup>+</sup>-Ca<sup>2+</sup> ISEs

Two different polyvinyl chloride (PVC)-based ion-selective membranes were prepared based on the chemical compositions reported by Jung et al. (2015) for sensing nitrate (NO<sub>3</sub><sup>-</sup>) and potassium (K<sup>+</sup>). The electrodes were fabricated according to the procedures described in previous studies (Cho et al., 2016; Jung et al., 2015; Kim et al., 2013). Specifically, PVC-membrane disks with a diameter of 2.5 mm were attached to the ends of PVC bodies of 44 mm length using tetrahydrofuran solvent. The NO<sub>3</sub><sup>-</sup> ISEs were then filled with an internal solution of 0.01 M NaNO<sub>3</sub> and 0.01 M NaCl, while the K<sup>+</sup> ISEs were filled with 0.01 M KCl. A Ag/AgCl electrode immersed in the PVC body was prepared by coating a silver wire (model 265,594, Sigma Aldrich, MO, USA) having a diameter of 1 mm with Ag/AgCl ink (model 01164, ALS, Tokyo, Japan). To sense calcium (Ca<sup>2+</sup>), a commercially available Ca<sup>2+</sup> ISE (Orion 9320BN, Thermo Fisher, MA, USA) was used with a double-junction electrode (Orion 900200, Thermo Fisher, MA, USA) as the reference electrode to simultaneously collect individual signals of electromotive force (EMF) between each ISE and the reference electrode. For simplicity in describing the electrodes and experiments, NO<sub>3</sub><sup>-</sup>, K<sup>+</sup>, and Ca<sup>2+</sup> will hereafter be written without the charges, i.e., NO<sub>3</sub>, K, and Ca.

Download English Version:

<https://daneshyari.com/en/article/6539671>

Download Persian Version:

<https://daneshyari.com/article/6539671>

[Daneshyari.com](https://daneshyari.com)