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Comparison of Nutrient Analysis Methods (ICP-OES, FIA, Spectrophotometry, and Ion-selective Electrode) in Leachate

Jaebeom Lee[1], Kit Powell[2], Jongyun Kim[1*], William L. Bauerle[2]

[1]Department of Plant Biotechnology, Korea University, Seoul 02841, Korea

[2]Department of Horticulture and Landscape Architecture, Colorado State University, Fort Collins, CO 80523, USA

Leachate analysis provides critical information on root-zone nutrient and water status, enabling precise fertilizer application and improving crop production efficiency. This study evaluated the accuracy and applicability of three ion analysis techniques for leachate samples to support nutrient and water management during crop cultivation. Ninety leachate samples were collected every other day using the pour-through method from two industrial hemp (*Cannabis sativa* L.) cultivars, 'CJ2' and 'First Light' cultivated in a greenhouse at Colorado State University. Elemental concentration were measured using inductively coupled plasma-optical emission spectrometry (ICP-OES; iCAP PRO Duo, Thermo Fisher Scientific) and NO_3^- was quantified by flow injection analyzer (FIA; FIAlyser-2000, FIAlab), while ion concentrations were quantified using spectrophotometry (DR3900, HACH) with ion-specific reagents and ion-selective electrodes (ISE; LAQUAtwin, HORIBA). ICP-OES and FIA served as the reference methods to determine total elemental concentrations corresponding to ten target ions (NO_3^-, PO_4^{3-}, K^+, Ca^{2+}, Mg^{2+}, B, Fe^{2+}, Mn^{2+}, Cu^{2+}, and Zn^{2+}). Spectrophotometric analysis closely matched the reference methods with respect to NO_3^-, PO_4^{3-}, K^+, Ca^{2+}, Mg^{2+}, and Fe^{2+} (r = 0.993-0.999; Lin's Concordance Correlation Coefficient, CCC = 0.989-0.997), demonstrating reliable quantification at substantially lower instrument cost. However, weaker correlations were observed for B, Mn^{2+}, Cu^{2+}, Zn^{2+} (r = 0.255-0.747; CCC = 0.084-0.743), likely due to detection limits and ion interferences. ISE measurements for NO_3^-, K^+, and Ca^{2+} also correlated strongly with the reference methods (r = 0.996-0.999; CCC = 0.996-0.998), indicating that low-cost portable sensors can provide accurate targeted ion analysis. While ICP-OES enables simultaneous multi-element analysis, its high cost and detection limits constrain measurement of ions present at very low concentrations. Spectrophotometry provides precise ion-specific quantification but requires additional time and reagents, whereas ISE offers excellent portability and accuracy for NO_3^-, K^+, and Ca^{2+}, though with limited ion coverage. These findings provide a valuable reference data for developing advanced nutrient and water management models and field-based monitoring technologies in crop production.

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*Corresponding author, E-mail: jongkim@korea.ac.kr