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TOWARDS *IN SITU* MONITORING OF ROOT GROWTH TRAITS: COMBINING SPECTRAL IMAGING WITH TRANSPARENT BED HYDROPONICS

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ABSTRACT

We developed a novel method that enables non-laboratory monitoring of the growth characteristics of crop root systems by combining spectral imaging with a transparent bed hydroponics. Root systems of spinach grown were observed through the transparent bottom plate using a hyperspectral camera daily. An optimal index for the classification of root ages (days after emergence) was determined as the ratio of reflectance at 498 and 601 nm. Additionally, the distribution of root age was visualized over the entire cultivation period, showing the daily dynamics of root growth and aging. This method enables comprehensive analysis of both root growth dynamics and age distribution patterns within the entire root system. Furthermore, we also evaluated the feasibility of using a multispectral camera to enhance practicality and broaden the applicability of the method. Results showed comparable performance in estimating root growth and age dynamics while offering improved accessibility, reduced instrument costs, shorter measurement times, and lower computational costs.

Keywords: hyperspectral camera, multispectral camera, root growth, root age, spinach

INTRODUCTION

Roots play essential roles in nutrient and water uptake, and in storage and reuse of photosynthetic products in plant eco-physiological viewpoints. Therefore, analytical monitoring of root growth traits (e.g. growth status and age) is critical especially for effective crop production such as smart / precision agriculture. However, existing methods for monitoring root traits are often limited by their inability to observe the entire root systems and/or labor-intensive under agricultural conditions. To address these limitations, spectral imaging may be a labor-saving approach to analyze plant eco-physiological information nondestructively, and replacing cultivation beds with transparent materials in hydroponics may offer a novel approach for in situ nondestructive observation of the entire root system.

In this study, we combined spectral imaging with transparent hydroponics for monitoring of the spatial and temporal distributions of root growth and root age in spinach cultivation.

MATERIALS AND METHODS

Spinach (*Spinacia oleracea*, cv. 'Wase Kurone') was cultivated in the transparent hydroponic bed at Kyushu University and imaged daily from 6 November – 16 December, 2022. Images were taken by a hyperspectral camera (Specim IQ, Specim Ltd., Finland). Root segments were tracked and root age was defined as days after emergence. Daily spectral information (420-950 nm) was extracted, and an optimal ratio for classification of root age was determined based on the Spearman correlation coefficients between reflectance ratios and root age. Roots were classified into four age classes and area percentages quantified on daily basis. Furthermore, to reduce analysis costs, the same procedure was conducted using a multispectral camera equipped with a CMOS sensor (IMX454LXR- C, Sony Semiconductor Solutions, Japan).

RESULTS & DISCUSSION

Tracking root growth and spectral changes revealed that the reflectance ratio showing the highest correlation with root age was the ratio of reflectance at 498 nm and 601 nm (R_{601}/R_{498}) with a Spearman correlation coefficient of $|\rho|$=0.82. Using this ratio, roots were classified into four age classes, and false color images visualizing root age were created at 10, 20, 30, 40, and 50 days after sowing (Fig. 1; Jin et al. 2025a). Root age progressed from the plant base toward the surrounding area, and age distribution dynamics were observed according to the balance of emergence rates between new and old roots. When using a multispectral camera, the accuracy of age estimation slightly decreased ($|\rho|$=0.71), but visualization of root age distribution dynamics was confirmed to be feasible (Jin et al. 2025b).

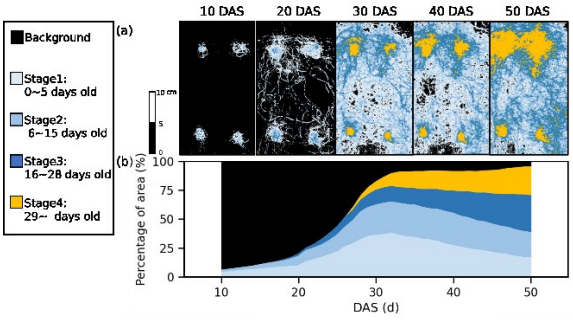

Fig.1 False color images of roots obtained by the hyperspectral camera at various stages: 10, 20, 30, 40, and 50 days after sowing (DAS) (A) and the daily change in the percentage of the area occupied by each growth stage of the root system within region 2 from 10 to 50 DAS (B).

CONCLUSIONS

Dynamics of root growth and age distribution of leafy vegetables can be visualized by combining spectral imaging with transparent hydroponic bed. This provides an efficient, nondestructive technique for evaluating root vitality and developmental patterns in agriculture.

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