学 位 論 文 内 容 の 要 旨

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学 位 論 文 題 名

Development of a Real-time Optical Sensor for Detecting Wheat Growth Status
小麦生育診断のためのリアルタイム光学センサに関する研究

I　Introduction

Precision farming (site-specific management, prescription farming, and variable rate application technology) is an information and technology-based agricultural management system to identify, analyze, and manage site-soil spatial and temporal variability within fields for optimum profitability, sustainability, and protection of the environment. Precision agriculture requires reliable technology to acquire accurate information on crop conditions. Based on this information, the amount of fertilizers and pesticides for the site-specific crop management can be optimized. A ground-based optical sensor and instrumentation system was developed to measure real-time crop conditions.

II　Materials and methods

A winter wheat field of 40m × 120m in size was cultivated in three consecutive years in the experimental field of Hokkaido University, Japan. The field was divided into 8 areas, and four levels of fertilizer (ammonium nitrate), 0, 30, 60 and 90 kg ha^{-1} with two repetitions were applied to create a range of crop growth variations. Field in-season measurements including SPAD value, canopy reflectance using an active N-sensor embedded on the tractor as a ground-based platform with an RTK-GPS and solar sensor, spectral reflectance data using a portable spectroradiometer, height of the crop, nitrogen content of leaves, protein content of grain and grain yield were done after the stem elongation and anthesis stages.

III　Performance evaluation of a plant nutrition sensor

The performance of a ground-based remote sensing system, for measuring wheat growth parameters was evaluated. The results showed that a commercialized plant nutrition sensor (CropSpec, TOPCON CORPORATION) has the potential to estimate growth status in winter wheat. We observed linear relationships of CropSpec values with SPAD value, height of the crop, nitrogen content, and protein content of grain. The results indicated that CropSpec can be used to determine crop health status and make an appropriate topdressing decision. CropSpec allowed better relationships for SPAD, nitrogen, and protein at the GS 39 growth stage. This suggests that the optimum time to take S1 value readings in Sapporo may be the GS 39 to GS 45 growth stages. Green NDVI had the best correlations with INSE S1 value and other measured parameters, indicating that use of other optimal wavelengths may improve the capability of CropSpec for prediction of crop conditions rather than the present wavelengths.

IV Wavelength selection by multivariate analysis

A correlation coefficient spectrum, partial least squares regression (PLSR), and stepwise multi-linear regression (SMLR) procedures were used to determine important wavelengths. Both SMLR and PLS regression procedures yielded good results. Three ranges of wavelengths were selected by considering the PLS B-coefficient and VIP plotted with spectral measurements in each crop variable (SPAD value, grain yield and protein content). The accuracy of PLSR performance (R^2) was improved from 0.77 to 0.84, 0.76 to 0.87 and 0.76 to 0.8 in SPAD, grain yield and protein content, respectively, in the validation results. Some wavelengths [(435, 550, 665, 705, 730, 1315 and 1325 nm), (410, 520, 535, 1025, 1080, 1125, 1130, 1235, 1265 and 1305 nm) and (445, 505, 640, 665, 670, 700, 760, 890 and 930 nm)] were identified by both PLSR and SMLR as significant individual wavelengths for SPAD value, grain yield and protein content, respectively, which have already been recognized in two steps of modeling and validation PLSR.

V Optimal vegetation indices for monitoring winter wheat growth status

The optimum number of hyper-spectral bands, centers, and widths in the visible (VIS), near infrared (NIR), moisture-sensitive near infrared (MS-NIR) and shortwave infrared (SWIR) spectra for establishing relationships with agricultural crop physiological characteristics (winter wheat) were determined. A remarkably strong relationship with crop variables is located in specific narrow bands in the shorter wavelength portion of the red and red edge, 650 nm to 750 nm, with secondary concentrations in the longer wavelength portion of the MS-NIR, 1030 nm to 1130 nm, in one particular section of the SWIR, 1315 nm to 1330nm, and in the blue and green ranges at 405 nm to 530 nm. The difference vegetation index 1 (VDI) with two wavelengths and plant senescence reflectance index 5 (PSRI) with three wavelengths were appropriate for estimating SPAD value up to R^2 =0.764 and R^2 =0.832, respectively. The root difference vegetation index (RDVI) as a two-band vegetation index showed a high linear fit for early prediction of both grain yield (R^2 =0.717) and protein content (R^2 =0.792). Index 7 (SR) as a three-wavelength combination had a strong relationship (R^2 =0.725) with grain yield, while index 6 (MSRI) worked very well to estimate protein content (R^2 =0.786) with three wavelengths.

VI Conclusion

Field experiments were conducted to evaluate and improve the performance and accuracy of an active plant nutrition sensor. The results indicated good potential for estimating growth status in winter wheat by CropSpec. However, spectral reflectance data were used to determine specific individual wavelengths and optimal vegetation indices. Multivariate regression analysis was applied as a step-by-step statistics method to reduce and discriminate highly correlated spectral data wavebands. All possible combinations of two-wavelength and three-wavelength vegetation indices were calculated, and their performance for prediction of crop physiological variables was evaluated.