Doctoral Dissertation

Toward the Efficient Grazing Management with Hyperspectral Remote Sensing

(Summary)

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March 2016

Current pasture nutrient managements need more site specific precise grazing management means to improve productivity and profitability as well as mitigating environmental impacts. To know current status of the target area is a critical step to establish optimal management strategies. Remote sensing technologies have been widely applied as a tool for real-time monitoring in various vegetation environments with large scale based on spaceborne or airborne instruments. However, there are some limitations in the such conventional remote sensing technologies for the agriculture use due to its operational inflexibility and lower spatial and spectral resolution, particularity in the grazing paddock, where shows high heterogeneity by animal activities. Low-altitude platforms, including ground-based sensing, can provide such information with higher spectral and spatial resolution with increased temporal frequency and lower cost than spaceborne or airborne instruments. During recent decades, optical sensing ranges (400–2500 nm) have been expanded from panchromatic or multispectral use to imaging spectrometer and hyperspectral sensor system, which have the spectral resolution less than 10 nm bandwidth. Moreover, recent advances in hyperspectral remote sensing, detectable narrow absorption features, have been allowed to more accurate quantification from its abundance spectral information for not only biophysical characteristics of natural and cultivated species but also other information which were difficult to retrieve using conventional broad-band sensors such as nutrient deficiency, pests, plant stress and vegetation composition. For the practical application of hyperspectral remote sensing in agriculture or precision grazing management sector, it is required to refine the predictive accuracy for estimation of the status of growth or nutrient by more sophisticate data analysis. Also, ground-based remote sensing systems need to establish the efficient way for spatial interpolation of proximally sensed acquired data from the target surfaces.

The study explored the use of ground-based sensor system as a means of providing the information for making a precision grazing management strategy. The objectives of the study were (1) to investigate the use of cloud-free ground-based bi-directional multispectral sensor for quantifying herbage mass in an Italian ryegrass (*Lolium multiflorum* Lam.) (chapter 2), (2) to investigate hyperspectral field spectroscopy as a tool for estimating herbage mass and quality (chapter 3) and potentially soil nutrient (chapter 4) using *in situ* canopy spectral information in a mono-cultural meadow field or mixed sown pasture, and (3) to map a spatial variability of forage mass (chapter 5) and quality status (chapter 6) using remotely sensed canopy spectral information of multispectral or hyperspectral by geostatistical approaches in a mono-cultural meadow field of Italian ryegrass.

In chapter 2, the author investigated the use of cloud-free hand-held crop measuring device (Ebara Corporation, Tokyo, Japan) of multispectral sensor as a tool for crop growth assessment. The investigation involved the prediction of aboveground biomass (ABM), leaf area index (LAI) and available standing crude protein contents (CP_{mass}) in a dry matter (DM) of forage. Widely used vegetation indices were calculated from sensed data using the device and univariate regression analysis, simple linear regression, is conducted to find the relationship with the parameters of interest. Normalized difference vegetation index (NDVI) showed best performance to estimate ABM (R^2_{cv} = 0.76) and LAI (R^2_{cv} = 0.80) and soil-adjusted vegetation index (MSAVI) as best for CP_{mass} (R^2_{cv} = 0.78) even under unstable weather conditions, with logarithmic transformation of plant parameters, whereas relatively poor ability in the estimation of CP concentration (CP_{con}). These findings clarified both the feasibility of the device as a real-time monitoring for crop growth and the limitation of the device due to its lower spectral resolution (multispectral broad band sensor system), for accurate assessment of forage status particularly the quality as a forage. Chapter 3 investigated hyperspectral proximal sensing as tool for forage quality status as well as biophysical parameters (ABM and LAI) using a portable spectrometer (MS-720; Eko Instruments Co., Tokyo, Japan), which measures reflectance in the 350–1050 nm wavelength region. Partial least squares (PLS) regression, which is known for adequate way of handling to multicollinear data set, was performed to find the relationship between spectral data and forage properties. To improve prediction ability of the PLS models, waveband selection was carried out using genetic algorithm prior to the PLS regressions (GA-PLS). Wide ranges of 15 forage parameters, which were including ABM, LAI and contents of total digestible nutrients (TDN), neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL), neutral detergent insoluble crude protein (NDICP), ether extract (EE), crude protein (CP), non-fiber carbohydrate (NFC), Ash, phosphorus (P), potassium (K), magnesium (Mg) and calcium (Ca), were tested to investigate the potential of practical use of field spectroscopy instead of direct destructive chemical assessment or laboratory near infrared spectroscopy (NIRS). The approach using GA-PLS to estimate forage parameters from *in situ* canopy hyperspectral reflectance was improved the predictive accuracy in most of the presumed parameters (R^2_{cv} = 0.45–0.88, RPD = 1.35–2.87) to the PLS model using full spectrum (FS-PLS) (R^2_{cv} = 0.31–0.82, RPD = 1.18–2.36).

Chapter 4 also investigated the use of ground-based hyperspectral remote sensing in the grasslands environment. In this chapter the investigation focused on the estimation of plant P in grass-legume mixed sown pasture and soil P fertility using *in situ* canopy spectral information in New Zealand pasture. This experiment employed active sensor system for the Spectro-Canopy Pasture Probe (CAPP) based on ASD Field Spec Pro radiometer (Analytical Spectral Devices Inc. [ASD], Boulder, CO, USA) which measures from 350 nm to 2500 nm. To handle thousands of spectral information and avoid over-fitting of the regression model, wavelength region selection was performed with backward interval PLS (bi-PLS). GA-PLS is employed to refine redundant wavelength in the selected wave region in the previous procedure for the quantification of P in pasture and soil. It was demonstrated that refining wavelength region permit accurate prediction of ABM (R^2_{cv} = 0.91) and P_{mass} (R^2_{cv} = 0.89) only using less than 10% of waveband information in full spectrum of 2001 bands.

In chapters 5 and 6, the scale of investigations was extended from the canopy level to field level. Spatial interpolation was conducted using estimated forage status from the remotely sensed canopy spectral reflectance to understand the entire field status. Using geostatistical approaches, spatial dependencies were investigated to generate the distribution map of forage crop growth or nutrient status. In chapter 5, the maps of ABM, LAI and CP_{mass} were generated based on NDVI values by the regression models acquired in chapter 2. However, though the good prediction performance in early to mid-growing season, it was difficult to recognize the spatial and temporal difference when it reached high-biomass stages because of the saturation of NDVI values as previously known limitation.

In chapter 6, thus, hyperspectral canopy reflectance data and GA-PLS regression models of chapter 3 were employed for estimating ABM, NDF, TDN and CP. Compared to chapter 5, more accurate spatial distribution maps were generated for not only biophysical property but also biochemical properties from the beginning of the growing season to harvest. Improved prediction ability of the estimation model of GA-PLS allowed differentiating biomass and nutrient status within field scale and between individually managed sub plots.

Finally, chapter 7 summarized the findings of this study, and discussed the contribution and future perspectives of the use hyperspectral remote sensing in the future study for efficient and precise livestock management.