Integrating geographic information system and remote sensing in predicting rice grain protein

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Abstract

Application of remote sensing and GIS has great potential in crop monitoring and retrospectively can set the strategies and management practices as to maximize yield and grain quality. In this study, UAV remote sensing data were utilized to predict grain protein content. Total images were differentiated into two groups as cloud free and cloud shadowed. On one hand for the cloud free samples, the vegetation index, NDVI derived from the canopy spectral reflectance was significantly correlated to the final grain protein content (R2=0.553, RMSE=0.210%, n=14). On the other hand, for cloud shadowed samples, the result demonstrated that vegetation index, NDVI was significantly correlated to the final grain protein content (R2=0.479, RMSE=0.225%, n=35). Different layers and files were created to manage, store and mapping grain protein using ArcGIS. All test fields at first and then, the NDVI image of each test field was also converted to shape file. Henceforth, the information of each field was displayed using overlap function. Therefore, protein content of rice in each field can be mapping by GIS and possibly forecasted using canopy or images spectral reflectance at grain filling stage.

Introduction

Rice (Oryza sativa L.) is considered as commercially important crop and world's most widely grown cereals that plays a critical role in food security especially in South and East Asia. In addition, nearly half of the world's population consume rice as the major staple food, and is more particularly important in Asia, where approximately 90% of world's rice is produced and consumed (Zeigler and Barclay, 2008; Khush, 2004). Rice serves as an important source of dietary protein for half the world population, contributing approximately 29.1% of protein for human consumption in developing countries (Sautter et al., 2006). As laboratory method is time consuming and costly, remote sensing could provide spatial and temporal measurements of surface properties and was recognized as a reliable method for the estimation of various variables related to physiology and biochemistry (Hinzman et al. 1986; Diker and Bausch 2003). Due to its fast, non-destructive and relatively cheap characterization of crop status (Bouman, 1995) and potential of extension to regional level (Ishiguro et al., 1993), remote sensing has attracted a great deal of attention in terms of application for crop monitoring and yield prediction so far (Cassanova et al., 1998). Many studies described the capability of remote sensing technology to rapidly measure many crop nitrogen content (Rondeaux et al., 1996). Nevertheless, only few studies conducted to predict rice grain protein content prior to harvesting (Ryu et al., 2011).

Geographic information system (GIS) is widely applied in the field of natural resource management, regional distribution map for heavy metal, scheduling and monitoring of irrigation water supply to the rice field (Iverson and Risser, 1987; Facchinelli et al., 2001; Rowshon et al., 2003). In the field of agriculture, use of GIS is being accelerated in pace over time. The key management factors (timing and period of midseason drainage, timing of fertilizer application and timing of harvest) variation among fields causing disparity of protein content over the large fields have been established (Ryu et al., 2011). Therefore, intervention of GIS in rice agriculture is very important for better management and monitoring its quality.

The objective of the study was to establish a prediction model of grain protein content of rice using remote sensing data and to make a GIS database and combine the RS with GIS for better management and grain quality monitoring.

Materials and methods

Test field

Study site was located in Pyeongteak, South Korea (latitude: 370 1' 34.4" N, longitude: 1260 49' 45.2" E). A total 54 fields, each area between 0.3 and 0.5 ha were selected under the study. Koshikari was the variety transplanted in all fields and usual farmland management was adopted. Sampling was done synchronously at the time of image acquisition at the geo-referenced points and GPS locations were recorded one week before harvesting. Protein content of milled rice was measured by near-infrared spectroscopy NIR (FOSS, InfratechTM 1241 Analyzer, Hoganas, Sweden).

Image acquisition

Three imaging sensors in RGB, NIR and RE camera (WX, S110, CMOS, Canon, Japan) were mounted with fixed-wing UAV (eBee, Sensefly, Switzerland) to acquire the images. The UAV was operated by an Autopilot associated with autonomous flight (eBee Ag, Sensefly, Switzerland) based on differential GPS (DGPS), 3-axis accelerometer, gyros and a 3-axis magnetometer and flew at a height around 150 m. The ground resolution was around 4 cm during flight. The flight plan software (Emotion, Sensefly, Switzerland) on ground and the UAV were connected through a radio link where position, altitude and status data were transmitted at 2.4 GHz frequency within 3 km range. The images were acquired in midday to reduce the influence of incident light angle and dew on the leaf surface.

All images acquired from each flight were combined with Gyro and GPS information by using flightplan software, then mosaicked the image by UAV mapping software (Pix4D mapper pro, Pix4D, Switzerland) considering each band and finally tagged image file format (TIFF) of 8 bit/pixel was produced. The sampling points identified in the georeferenced images through quadratic equation with UAV mapping software using GCPs.

For GIS database, several thematic layers and files were created by ArcGIS software (Esri, New York Street, Readlands, California, USA).

Results

The table 1 shows the precision and accuracy of different vegetation indices (VIs) calculated from different algorithms using different visible and near infra-red bands of the electromagnetic spectrum. The VIs calculated from RGB and RE images showed no correlation with final grain protein contents while the NDVI derived from NIR image showed small correlation but, better than any other indices (R2=0.210, RMSE=0.327%) with final grain protein content followed by RVI (R2=0.194, RMSE=0.329%) and GNDVI (R2=0.133, RMSE=0.342%) considering all 54 samples.

Table 1. The coefficient of determination and root mean square error between VIs and PC at grain filling stage

Vegetation Index	R^2	RMSE (%)	Model
NIR (n=54)			
NDVI	0.210	0.327	y=3.103x+4.230
GNDVI	0.133	0.342	y=-0.825x+8.122
RVI	0.194	0.329	y=0.404x+4.551

As the brightness level of all test fields in the images were not same, therefore, the total images were divided into two groups as cloud free and cloud shadowed (Ryu et al. 2011). Fig. 1 shows the relationship between protein content and NDVI of cloud free sample. By using the estimation model, the R2 and the RMSE values were 0.553 and 0.210% respectively. Therefore, prediction of rice protein content with lower RMSE is possible by using the reflectance of the near infrared.

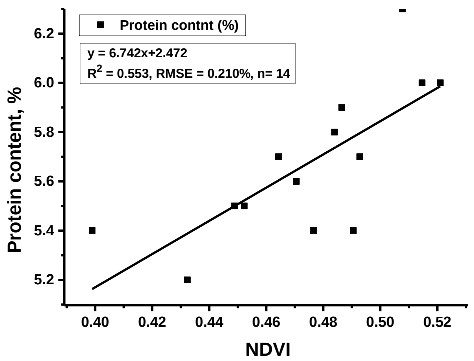

Figure: 1 Relation between NDVI and grain protein content at grain filling stage for cloud free samples

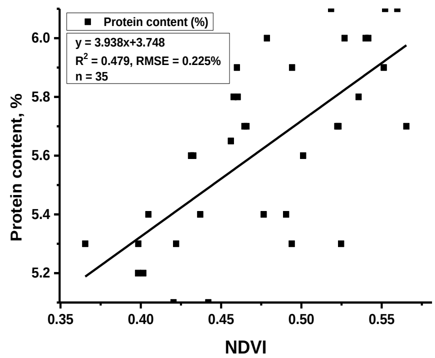

Figure: 3 Relation between NDVI and grain protein content at grain filling stage for cloud shadowed samples

Fig. 2 shows the relationship between protein content and NDVI of cloud shadowed sample. From the regression model it was observed that five data points were showed different trend and fallen distant to the fitted regression line, thereby, the estimation model performed weak with lower R2 = 0.222 and comparatively higher RMSE = 0.320%. Therefore, five data points were dropped out from the model as outlier. The established model using 35 samples performed better than the model considering 40 samples, yielded higher R2 and lower RMSE of 0.479 and 0.225% respectively.

Different layers and files were created to manage, store and mapping grain protein using ArcGIS software. Each shape file of test fields was made based on polygon and the NDVI image of each test field was converted to shape file using vectorizing function. Hence, the information of each field was displayed one by one using the function of overlap. Protein content of rice in each field can be mapping by GIS and possibly forecasted using canopy or images spectral reflectance at grain filling stage.

Discussion

A moderate correlation was found from the established models based on Normalized Difference Vegetation Index (NDVI) for predicting rice protein content before harvest performed a little different while the whole samples divided into two groups as cloud free (R2 = 0.553) and cloud shadowed (R2 = 0.479). Cloud free model performed better than cloud shadowed models and this result is roughly better than the result of R2 = 0.401 for cloud free, R2 = 0.250 for cloud shadow and a general purpose model with R2 = 0.392 (Ryu et al., 2011) might be because of different ground resolutions for the two studies. The spectral reflectance value calculated at the sampling points of the test fields not showed consistent and uniform trend with the final grain protein content causing low performance of the models might be because of improper vegetation cover and field condition. Generally, healthy vegetation will absorb most of the visible light that falls on it, and reflects a large portion of the near-infrared light, unhealthy or sparse vegetation reflects more visible light and less near-infrared light, bare soils reflect moderately in both the red and infrared portion of the electromagnetic spectrum (Holme et al., 1987). The growth conditions of all fields were not similar; some fields were greener with standing water while some other fields yellowish in color and less vigorous as relatively dry condition caused early leaf senescence. Furthermore, good numbers of field crops lodged at the time of sampling. Though, similar field management adopted for all the test fields, however, there was variation in final grain protein contents might be the reasons of fertility level of soil and land topography which was not measured initially.

Multispectral camera can be used to further improve the prediction model. Reducing the shadow effect in image can also be improved the model performance. It is also necessary to investigate the reflectance of different growth stages with the final grain protein content to predict the quality before harvesting. Moreover, the relation between leaf nitrogen concentration, grain protein content, leaf chlorophyll concentration, Leaf Area Index (LAI) and VIs need to be studied further.

Conclusion

Grain protein content of rice can be possibly forecasted using the canopy or image spectral reflectance at grain filling stage prior to harvest using UAV remote sensing that can operate medium to higher altitude. In the rice grain protein contents' estimation, the visible and red-edge wavebands were not useful for the analysis where the near infrared waveband was essential for the estimation of the result of the simple linear regression analysis. Using the near infrared and red waveband information the root mean square error of protein content was 0.210% for cloud free and 0.225% for cloud shadowed samples respectively. Moreover, remote sensing can provide site-specific properties of crop with near real-time data and large scale coverage at relative economical cost. Protein content of rice in each field over an area can be mapping by GIS and possibly forecasted using canopy or images spectral reflectance at grain filling stage.

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