Prediction of Grain Quality and Yield of Winter Wheat Using Ground-based Spectroradiometer Data

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abstract: Winter wheat (*Triticum aestivum* L.) is one of the main crops of Japan and widely cultivated in dried paddy field as rotate cultivation crop following the policy of reducing rice acreage. Grain protein concentration, however, is low and the quality varies largely. The objective of this study is to predict the grain protein concentration and yield in the field before harvest using remotely sensed data in order to harvest separately according to the grain quality. In this study, ground-based spectral reflectance measurement using FieldSpec (handheld) was carried out for wheat canopy scale, under 7 different nitrogen applications at different growth stages. The specific reflectance ratio that related with leaf biomass, standing nitrogen and nitrogen concentration were selected and applied to estimate yield and grain protein concentration. Reflectance ratio (R_{510}/R_{630}) is correlated with yield ($r^2 = 0.428^{***}$) and (R_{425}/R_{630}) is correlated with grain protein concentration ($r^2 = 0.365^{***}$) at anthesis growth stage. No relationships were found in the low productive plots and strong correlation was found high productive plots ($r^2 = 0.459^{***}$).
keywords: Grain protein concentration, Leaf nitrogen status, Spectral ratio, Winter wheat, Yield

1. Introduction

Winter wheat (*Triticum aestivum* L.) is one of the main crops of Japan and widely cultivated in dried paddy field as rotate cultivation crop following the policy of reducing rice acreage in Japan. However, winter wheat cultivated in dried paddy field is known as low quality and the quality varies largely. Grain protein concentration (GPC) is an important quality index. The formation of grain protein is physically depended on plant nitrogen accumulation and its translocation to grain in the grain filling stage [1]. Thus, leaf nitrogen concentration was strongly correlated GPC at antesis and SPAD readings were used for GPC prediction [2, 3]. Continuously, using reflectance ratio, Zhao et al. reported the availability of reflectance ratio in red edge on sorghum for estimation for nitrogen status [4]. In recent decades, the relationship between nitrogen concentration of plant and Vegetation Index obtained by aerial and satellite sensor has been reported [1, 5, 6]. In the case of wheat that cultivated in dried paddy field, however, it is still difficult to estimate nitrogen status or GPC with high accuracy.

In Gifu prefecture, central Japan, winter wheat were harvested all at once and brought together to mill although better to harvest separately depending on GPC level, but no way has established as of the moment. However, if it could be predict the GPC using remotely sensed data before harvest, it is possible to harvest separately depending on GPC level.

2. Materials and methods

1) Experiment site

The field experiment was conducted at paddy field (approximately 0.18 ha) of Gifu Prefectural Research Institute for Agricultural Sciences located in the southern part of Gifu prefecture, central Japan. The mean annual temperature was 17.7ºC and annual precipitation was 1903 mm in 2004.

Because of over production of rice in Japan in recent years, the rotate cultivation is recommended; the wheat is cultivated in a dried paddy field after paddy rice harvested in this experiment site, and 7 levels of different nitrogen were applied in this study. Agronomy calendar and field measurements are shown in Fig. 1. Winter wheat Norin 61 variety was sown 30 cm of ridge width and 8Kg $10a^{-1}$ of seeding rate.

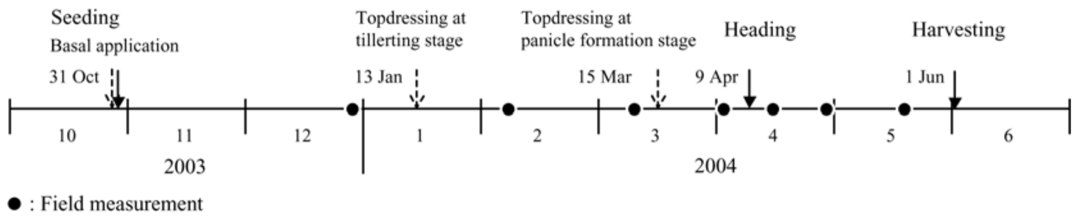

Fig. 1. Agronomy calendar and field measurements during Oct 2003 to Jun 2004.

2) Measurement

The field measurements were carried out 7 times during Dec 2003 to May 2004 (see Fig.1). Canopy spectral reflectance at fixed observation points (4 points × 8 blocks) and sampling points (3 points × 8 blocks) was recorded using ASD FieldSpec Handheld (Analytical Spectral Devices INC, Boulder, CO, USA) with spectral range from 325 to 1075 nm. Biomass samplings were also carried out in each growth stages. Other measurements (SPAD, plant height, soil water content) were also carried out for each plot. However, these data were not analyzed in this study.

As the calibration error was occurred at the both ends of spectral range, the spectral ranges from 350 to 975 nm were used in this study. Canopy spectral data at the early growth stage, reflectance from soil was dominative than that from plant leaves, so data before 1 April were omitted.

After measurements, samples of wheat plant were divided into 4 materials (green leaf, stem, panicle and yellow leaf). After separating, each material was dried at 80ºC for 48h, and then weighed and leaf nitrogen concentration (%) on a dry matter basis was determined using gas chromatography (C-R6A, SHIMAZU Co, JAPAN). The standing N (nitrogen) was calculated as the dry weight of the leaf biomass multiplied the % nitrogen of leaf biomass in this study.

3) Yield and grain protein concentration

The wheat was harvested on 1 June 2004. After harvest, weighed each material and the yield was determined. Grain nitrogen concentration was determined using gas chromatography and then, grain protein concentration was converted from grain nitrogen concentration using eq. (1).

$$GPC = 5.7 \times GNC \qquad (1)$$

where, GPC is grain protein concentration (%), GNC is grain nitrogen concentration (%) and 5.7 is conversion factor for wheat.

3. Results and discussion

1) Estimating the leaf biomass and leaf nitrogen status

Coefficient of determination between leaf green biomass (mg m^{-2}), leaf standing N (mg m^{-2}), leaf nitrogen concentration (%) and canopy reflectance at single wavelength are shown in Fig. 2. Reflectance at 520, near 630, and 695 nm wavelengths are strongly related with each crop variables. From this reason, reflectance ratios (R_λ/R_{520}, R_{630} and R_{695}) were calculated. 3 spectral ratios (R_{510}/R_{630} for leaf biomass, R_{460}/R_{630} for leaf standing N and R_{460}/R_{630} for leaf nitrogen concentration) were selected in this study. The relationships between leaf biomass and R_{510}/R_{630} (A), standing N and R_{460}/R_{630} (B) and nitrogen concentration and R_{425}/R_{630} (C) are shown in Fig.3. Each regression lines of reflectance ratio are fitted better than that of single reflectance in this study.

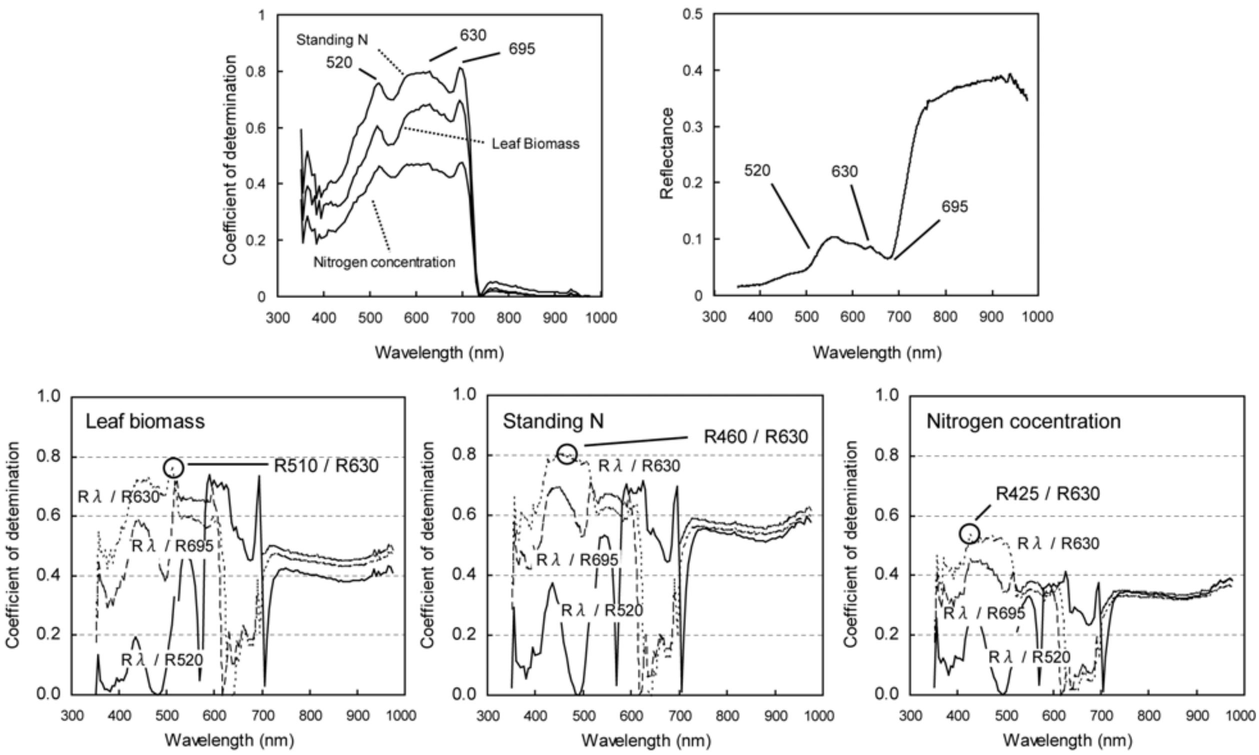

Fig. 2. Coefficient of determinations vs. wavelength for the relationships between leaf biomass and canopy reflectance (upper stand) and coefficient of determinations vs. wavelength for the relationships between leaf biomass, standing N, nitrogen concentration and reflectance ratio of R_λ/R_{520}, R_λ/R_{630}, R_λ/R_{695} (lower stand).

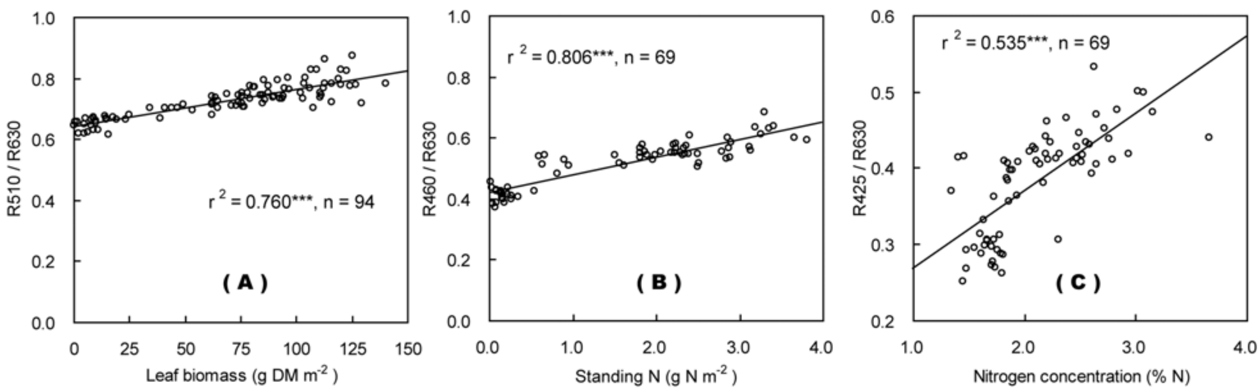

Fig. 3. The relationships between leaf biomass and R_{510}/R_{630} (A), standing N and R_{460}/R_{630} (B), nitrogen concentration and R_{425}/R_{630} (C).

2) Predicting of yield at anthesis or milk grain stages

The relationships between yield and R_{510}/R_{630} at anthesis or milk grain stage (29 April 2004) were shown in Fig. 4 (A). In order to compare with R_{510}/R_{630}, NDVI $_{(R895-R675)/(R895+R675)}$ and NDVI $_{(R750-R705)/(R750+R705)}$, the relation ships between yield and NDVI $_{(R895-R675)/(R895+R675)}$ and NDVI $_{(R750-R705)/(R750+R705)}$ are shown in Fig. 4 (B) and (C). There are significant positive correlation between yield and R_{510}/R_{630} (r^2 = 0.428, P < 0.001), however, NDVI $_{(R895-R675)/(R895+R675)}$ and NDVI $_{(R750-R705)/(R750+R705)}$ showed much higher relation with yield. In this case, only no nitrogen applied plot was responded and other plots varied widely despite of nitrogen application. Excepting the no nitrogen applied plots, no relationships are found between yield and each Indexes.

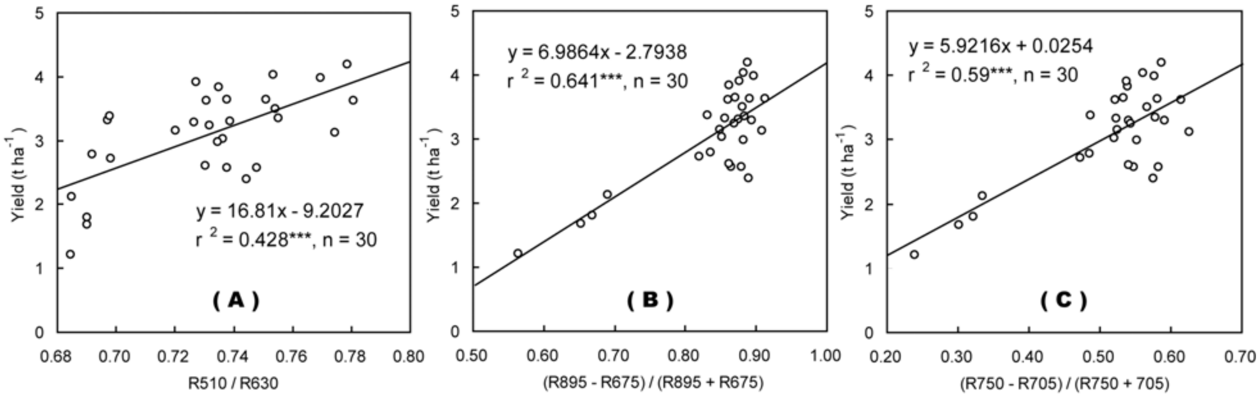

Fig. 4. The relationships between yield and R_{510}/R_{630} (A), (R_{895}-R_{675})/(R_{895}+R_{675}) (B), (R_{750}-R_{705})/(R_{750}+R_{705}) (C).

2) Predicting of grain protein concentration

Positive correlation is found between GPC and R_{425}/R_{630} on 29 Apr (r^2 = 0.3654, P < 0.001, Fig. 4 (A)). No relationships are found in the low productive plots (Fig. 4 (B)) and strong correlation found high productive plots (more than 9 kg of N applied) (r^2 = 0.459, P < 0.001, Fig. 4 (C)). In the low productive plots (less than 5 kg of N applied), GPC is varied largely. It can be thought that GPC was filled because of reduction of panicle and reflectance from soil was still affected because of low plant cover ratio. In order to predict before harvesting with high accuracy, it is important to develop the new index of appraise per biomass or ground cover ratio.

The relationships between GPC and R_{425}/R_{630} at 15 April and 18 May are also analyzed. However, no relationships are found in these growth stages (data not shown here). It is difficult to obtain cloud-free data at anthesis or milk-grain growth stage in Japan [7]. It is necessary to develop the technique that can predict GPC at other growth stages using remotely sensed data in order to use satellite data.

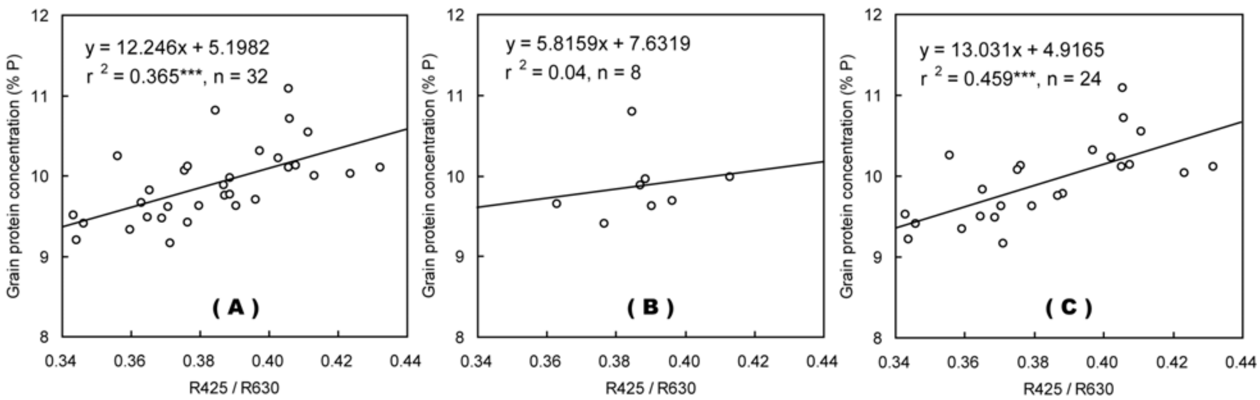

Fig. 5. The relationships between GPC and R_{425}/R_{630} for (A) is all plots,
(B) is low productive plots (less than 5 kg of N applied) and (C) is high productive plots (more than 9kg of N applied).

4. Conclusion

(1) Spectral ratio had strong positive correlation with leaf biomass (R_{510}/R_{630}), leaf nitrogen standing N (R_{460}/R_{630}) and leaf nitrogen concentration (R_{425}/R_{630}).
(2) Yield and grain protein concentration are correlated with selected spectral ratio.
(3) Grain protein concentration can be estimated in the high productive plots applied more than 9 kg of N.

In order to predict grain quality before harvesting with high accuracy, it is important to develop the new index of appraise per biomass or ground cover ratio.

Acknowledgement

This work was partly supported by 21st Century COE program “Establish of Satellite Ecology” under the fund by the Ministry of Education, Culture, Sports, Technology and Science.

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