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A Spectroradiometer for Field Use

VI. Radiometric estimation for chlorophyll index of rice canopy*

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In rice cultivation in Japan, nitrogen fertilizer applied as basal and top dressings is the most effective and easiest method for controlling plant growth after transplanting. However, it is often difficult to determine the amount of nitrogen and/or its application time in actual cultivations. Estimating the nitrogen level in the plant body at a given growth stage might help to solve this problem, but chemical analysis procedures are apt to be time and labor consuming.

The nitrogen content of plant body, however, seems to have a close relationship with the chlorophyll content of leaf blades (CHL : chlorophyll a+b mg/dm^2). Consequently, CHL is considered to be one of the key characteristics for judging the crop condition, and, as a result, some nondestructive methods for measuring the CHL have been proposed[8,19]. As for the methods for surveying a whole canopy field, MATSUSHIMA et al.[13] and MATSUZAKI et al.[14] developed a "color chart" to standardize the greenness of lowland rice canopy which was observed by the naked eye. However, an applicable machine has not yet been developed for surveying the chlorophyll level in a certain area of a paddy field. Spectral reflectance measurement for crop canopy seems to be one of promising methods because it is a nondestructive way to take information from a wide canopy area in a short time. We reported possibilities of radiometrical remote sensing for biomass and grain yield of rice canopies under field conditions[16,17] by using a computerized spectroradiometer for field use[15]. Canopy reflectance in the visible (VIS) to nearinfrared (NIR) region seems to be affected by both the phytomass and the chlorophyll content in the field of view (FOV) of the sensor. Chlorophyll index (CI) is an agronomic index defined as the total amount of chlorophyll per unit land area (g/m^2 ground) and it was utilized and discussed by OKUBO et al. in a study on grassland productivity[10].

A portable spectrophotometer was newly devised to take spectrum easily from various crop fields[18].

The objectives of this study were 1) to examine the validity of the hypothesis that some popular indices of the VIS and NIR bands (VI : Vegetation Index) are more closely related to CI than to LAI or CHL, and 2) to point out a better VI for estimating CI of paddy rice fields using the portable spectrophotometer.

Materials and Methods

Fourteen cultivars of rice plant (*Oryza sativa* L.) were grown in the two paddy fields (Fields A and B) located in Tsukuba in 1983. The cultivars included Japonica type, Indica type, and crossbreds of the two types. The cultivars used in Fields A and B are listed in Table 1. In the Field A, the plot size was 10 m×3.2 m, and each plot was divided into a narrowspacing plot (20 cm×21 cm) and a wide-spacing plot (40 cm×42 cm). The transplanting date was June 6 and the basal dressing was 7.8 g nitrogen/m^2 to each plot. In the Field B, three levels of top dressing (0, 4, and 8 g nitrogen/m^2) were made in addition to the basal dressing of 4 g nitrogen/m^2. The plot size was 2 m×10 m. The tansplanting date was May 20 and the plant spacing was 18 cm×25 cm. A compound N-P-K fertilizer was used for both

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Table 1. Rice cultivars used in this study.

Indica type :	H-2871, TORO, Razza-77, Alborio, Nanking-11
Japonica type :	Sugaippon, Asahi, Koshihikari, Minehikari, Nipponbare, LT-18
Indica/Japonica crossbred :	Milyang-23, Suwon-258, Akenohoshi

fields. The heading date was from August 13 to September 9 in Field A and from August 7 to 22 in Field B.

Spectral reflectance measurements were made on July 29, August 3, 30, October 1, 7, and 18, all of which were clear and calm days.

The design of the photometer used was described in a previous papar[18]. The FOV was 9.4°×1.1° and the wavelength range scanned was from 400 to 1,200 nm at 10 nm intervals.

The photometer, looking vertically and 2 to 3 m away from the canopy surface, was attached to the mount at the top of a crane boom which was mounted on a motorized cart[18]. Spectral reflectance values were calculated as the ratio of canopy radiance to the radiance of a reflectance standard which was an aluminium plate sprayed with Kodak White Reflectance Coating. The averages of three measurement readings were used in the analysis.

The reflectance data from the logged plots were not used in the calculations.

LAI of each plot at each radiometric experiment was determined from the leaf area of four hills sampled after the spectral measurement. An area meter (model AAM-7, Hayashidenkoh, Tokyo) was used for measuring the leaf area. CHL was estimated with a chlorophyllo-meter (model GM-1, Fuji Film Corp., Tokyo) and a calibration curve[18]. The calibration was made by a preliminary experiment in which the chlorophyll contents of leaf discs (3 mm in diameter) from the fourteen cultivars were analysed with the 80% acetone extracts according to the MACKINNEY's equation[12]. The calibration curves (Fig. 1) were decided by means of the "intersecting straight line model" method using a FORTRAN program coded by OTSUKA and YOSHIHARA[11].

The following simple regression model was used to evaluate the experimental data.

$$Y=\beta_0\times\beta_1X \quad (1)$$

β_0 and β_1 are the intercept and the slope, respectively. X in the equation (1) is the

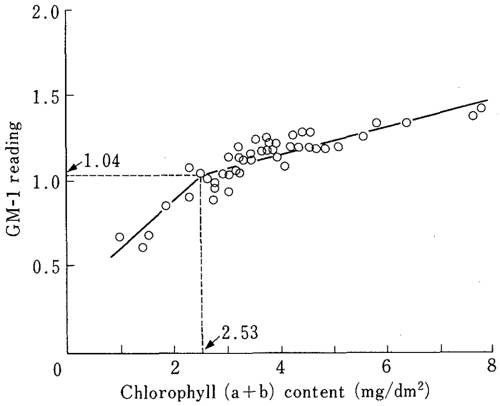

Fig. 1. Calibration chart used to estimate the chlorophyll content per unit leaf area of a rice leaf blade from the reading of chlorophyllo-meter (GM-1).

agronomic variables measured directly at the rice canopy, such as LAI, CHL, and CI. CI was estimated by means of the following equation,

$$CI(g/m^2)=0.1\times CHL(mg/dm^2)\times LAI \quad (2)$$

Y in the equation (1) is a single band reflectance or VIs such as biband ratio (BR) or normalized difference (ND)[6].

Reflectances at 560 nm (G: Green), 680 nm (R: Red), and an average value of 800 to 900 nm (NIR: Near-Infrared) were transformed into VIs such as BR and ND by means of the following equations:

$$BR_R=NIR/R \quad (3)$$

$$BR_G=NIR/G \quad (4)$$

$$ND_R=(NIR-R)/(NIR+R) \quad (5)$$

$$ND_G=(NIR-G)/(NIR+G) \quad (6)$$

Results

Table 2 shows the correlation coefficients (r) between the agronomic variables and the band reflectances or VIs. Agronomic variables examined were LAI, CHL, and CI. The radiometric variables tested were G, R, NIR, BR_R, BR_G, ND_R, and ND_G.

G and R showed negative correlations to LAI, CHL and CI, while NIR correlated positively to LAI and CI. NIR and CHL showed no significant correlation. It is to be noted that the single band reflectance G gave the highest correlation coefficient to CHL (−0.714), and that the single band NIR did not neccessarily give a high correlation to LAI. Among the four VIs examined, BR_R was expected to be a relatively good index for estimating LAI (r=0.778). The r value, however, raised slightly up to 0.791 when the CI was used as the independent variable instead of LAI. Except in the case of ND_R, the r value for CI was higher than that for LAI or CHL, which were regressed to the VIs. Among them, BR_G showed the best fit and r was 0.816 for 127 observations. BR_G gave a better correlation than BR_R to both CI and CHL.

Fig. 2, a scattergram of G versus CHL, shows that the G decreased as the CHL increased, but that it tended to plateau at high CHL region over 4 mg/dm^2. Fig. 3 shows a scattergram of BR_G versus CI that represents the best fit among all of the combination examined in this study. The summary of the simple regression analyses, r values of which are relatively high in Table 2, is presented in Table 3.

Table 2. Correlation coefficients between three agronomic variables and spectral reflectances taken from fourteen cultivars of paddy rice plants under field conditions.

VI	Agronomic variable LAI	CHL	CI
G	−0.449*	−0.714*	−0.640*
R	−0.589*	−0.644*	−0.521*
NIR	0.535*	0.161	0.400*
BR_R	0.778*	0.625*	0.791*
BR_G	0.690*	0.709*	0.816*
ND_R	0.682*	0.633*	0.671*
ND_G	0.691*	0.713*	0.774*

BR_R=NIR/R, BR_G=NIR/G,
ND_R=(NIR-R)/(NIR+R),
ND_G=(NIR-G)/(NIR+G).
*Significant at 0.1% level.
The observation number is 127.

Discussion

Canopy reflectance consists of the reflectance from leaf blades, stems, panicles, dead parts, and soil surface etc. in the field of view (FOV) of the sensor. Canopy reflectance may possibly be affected by both the phytomass and the chlorophyll content of each leaf blade. It was assumed that the spectral reflectances from a crop canopy gave information on the total amount of chlorophyll in the FOV of the sensor instead of simply on CHL alone, or LAI alone. Chlorophyll index (CI) is an agronomic index defined as the total amount of chlorophyll per unit land area (g/m^2 ground). AOKI and WAN measured reflectances from a model canopy under electric bulbs and pointed out that the amount of chlorophyll per unit land area was well predicted by NIR/far red (FR) reflectance ratio[1].

INADA[9] found that biband ratio of NIR (800 nm) and green (550 nm) was a fairly good index for estimating chlorophyll content of a single leaf blade when the spectrum were measured by using a laboratory-settled photometer with an integrating sphere accessary. AOKI et al.[2] also suggested the effectiveness of NIR/G and NIR/FR ratios from the result of an experiment in which they used a portable spectral photometer looking remotely at a small area on a leaf under an electric light. These methods, mentioned above, were concerned with the chlorophyll

Table 3. Summary of simple regression analyses for the relations between three agronomic variables and vegetation indices.

Model	Coeff. (S.E.) b_0	b_1	S.E.E.	r^2
$G=\beta_0+\beta_1 CHL$	10.38 (0.36)	−0.97 (0.085)	1.84	0.51
$BR_R=\beta_0+\beta_1 LAI$	− 1.66 (1.39)	4.46 (0.32)	6.53	0.61
$BR_R=\beta_0+\beta_1 CI$	5.71 (0.90)	6.29 (0.44)	6.36	0.63
$BR_G=\beta_0+\beta_1 CI$	3.51 (0.24)	1.86 (0.12)	1.73	0.67

b_0 : intercept of regression line. b_1 : regression coefficient.
S.E.E. : standard error of estimate. r^2 : contribution ratio due to regression.

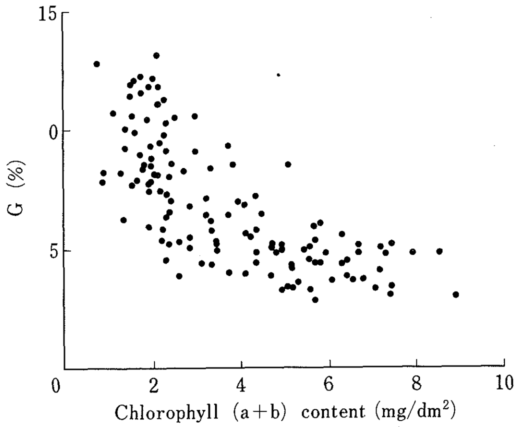

Fig. 2. Scattergram of green band reflectance versus chlorophyll content (a+b mg/dm² leaf).

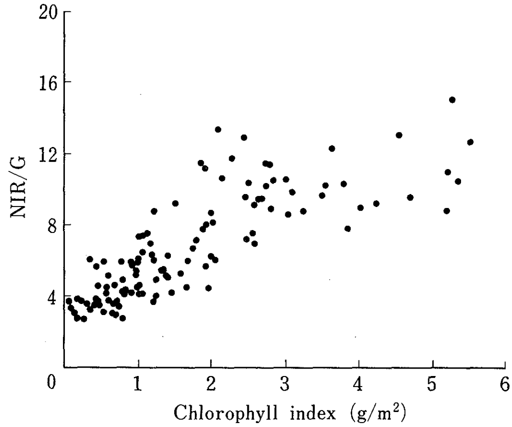

Fig. 3. Scattergram of near-infrared/green ratio of reflectance versus chlorophyll index (CI : a+b g/m² ground).

content (mg/dm²) of a single leaf blade, although the information on a certain area of crop field was also requested.

On the other hand, ASRAR et al.[5] reported that the LAI of wheat fields could be predicted by BR_R taken by a hand-held radiometer. GALLO et al.[7] related the absorbed photosynthetically active radiation (APAR) to the ND_R. These two groups of investigators measured the reflectance factor from the crop canopy instead of a single leaf blade with a view toward applying the results for crop growth modeling study.

Recently, AOKI et al.[3] and AOKI and TOTSUKA[4] showed that NIR/FR ratio taken from a model canopy in indoor was hopeful for predicting the total amount of chrolophyll per unit area.

The result of our field experiment indicated that the VIs such as BR_R and BR_G were more closely related to CI (g/m² ground) than LAI alone or CHL (mg/dm² leaf) alone. Our results also seem to support the effectiveness of NIR/G ratio, even when the radiometric data acquisition was made for a canopy in outdoors.

No noticeably deviated data points due to the difference of cultivar were found in this study. And the 3 types of cultivar used (Indica, Japonica and I/J crossbreds types) also showed no significant differences in their spectral sensitivity to CI. However, it might be possible to consider that the extent of errors in the spectral and agronomic measurements exceeded and masked that of the plant type or cultivar characteristics in this study. That is, individual agronomic variations were larger than spectral specificity of each cultivar. Therefore, it must be clarified further that there remains relatively large deviation of the measured data from the regression model. The fact that the FOV of the photometer was too small in comparison with the altitude of measurement may possibly be one of the causes.

From the present study we concluded as follows : (1) CI gave a better fit than LAI or CHL alone in regression to some popular VIs such as BR_R and ND_R, (2) BR_G represented the best model in combination with CI. CHL was not easily estimated from radiometric data ; and (3) CI is defined as a product of CHL and LAI, so that the results of this study may provide an interesting method for predicting plant biomass or productivity by means of radiometrical remote sensing technique.

Summary

Field spectral reflectance measurements were made for some rice cultivars during the maximum tillage number stage to the maturing stage. Leaf area index, average chlorophyll content of leaf blade (chlorophyll a+b mg/dm² leaf), and chlorophyll index (chlorophyll a+b g/m² ground) which is a product of the former two variables, were examined in simple linear regressions to each of the green, red and near-infrared band reflectances, and some vegetation indices. It was indicated that most of the vegetation indices examined showed a

better fit when they were regressed by the chlorophyll index than by LAI or chlorophyll content. Among some vegetation indices, near infrared/green biband ratio gave the highest r^2 value in an equation of which the independent variable was the chlorophyll index.

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* In Japanese with English summary.
** In Japanese, the title was tentatively translated by the present authors.

〔和 文 摘 要〕

作物群落用反射スペクトル解析装置の開発

第6報 野外分光反射測定による水稲のクロロフィルインデックスの推定

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可搬型で野外で容易に扱える分光反射係数計測システム（既報）を用いて，最高分けつ期から登熟期における水稲個体群の反射スペクトルを波長域400～1,200 nm で測定した．小型クレーン車を利用することにより，圃場での垂直下向き観測を実施した．供試した材料は，日本型，インド型及び日印交雑種を含む14の水稲品種である（第1表）．

分光反射係数の測定後，葉緑素計（富士フィルム）により各区の葉身クロロフィル含量（CHL : mg/dm²）を測り（較正図を第1図に示す），また，抜き取りによって葉面積指数（LAI）を推定した．クロロフィルインデックス（CI : g/m² 土地面積ベース）は CHL 及び LAI の積として求めた．

スペクトルデータから緑（G : 560 nm），赤（R : 680 nm）並びに近赤外（NIR : 800～900 nm）の各反射率を使い，上記の三種の作物情報との相関関係を調べ，次の結果を得た（第2，3表）．

1. CHL と単独で最も相関の高かったのは G 反射係数で，相関関係（r）は－0.714であった（第2図）．

2. NIR/R（バイバンド）比と CI との相関関係は，NIR/R 比と LAI との相関関係よりも強い傾向を示した．

3. CI と最も高い相関係数を示したのは，NIR /G（バイバンド）比であった（r=0.816）（第3図）．

以上の結果から，野外の分光反射係数，特に可視～近赤外域の情報では，LAI ないし CHL を推定するよりも両者の積の CI（単位土地面積当たりクロロフィル量）を推定する方が，精度が良くなることが示唆された．また，CI を推定するパラメータとしては NIR/G 及び NIR/R が良好だったが、NIR/G の方が若干有利であると思われた．