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ESTIMATION OF THE AREA AND THE YIELD OF A RICE PADDY BY LANDSAT-5/TM

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ABSTRACT

Identification of rice paddy fields and estimation of their areas from the images taken by LANDSAT-5/TM were attempted. The results were verified by aerial photographs and also by ground observations. Changes of the spectral characteristics of rice plants were measured with a portable spectroradiometer during the growth period. Analyzing these characteristics, an index was developed for evaluating the growth and the yield of rice. Applying the index to the data observed by LANDSAT-5/TM on Sep. 26, 1986, Oct. 20, 1989 and Sep. 21, 1990, it was confirmed that the estimates derived from the index agreed with actual values. The results well demonstrates its feasibility for evaluating the yield of rice by a satellite like LANDSAT-5/TM.

Key Word : Remote sensing, Area estimation, Yield estimation, Paddy, Rice

INTRODUCTION

Since the geographical complexity of farm lands and intricate cropping systems cause the various difficulties in the practical use of a satellite, the spaceborne observation of crops has not widely used in Japan. But in the world, a satellite has become one of the important tools for the identification of crop species and the estimation of their cultivated areas.

Tucker *et al.* (1978), Walburg *et al.* (1982), Chaeles *et al.* (1984), Ishiyama *et al.* (1984) and Chalmers et al. (1987) analyzed and defined the spectral characteristics of crop canopies. On rice paddies, radiometric studies have been also tried by Paul *et al.* (1983), Patel *et al.* (1983), Miller *et al.* (1983), Martin *et al.* (1986), McCloy(1987), McCloy *et al.* (1987) and Ishiguro *et al.* (1993), the wavelength or bands used in their studies were, however, restricted to LANDSAT/MSS. For monitoring crop growth, Dusek *et al.* (1985) and Gardner *et al.* (1985) developed the indices of VIS and MIR for winter wheat and corn, respectively. But no dependable indices for paddy rice have been obtained, yet. The objective of this research was, therefore, to develop a reliable method of assessing the growth and yield of rice crop cultivated in Japan using a satellite.

MATERIALS AND METHODS

The procedure consisted of the estimation of the area of a paddy and the evaluation of the growth of rice plants grown there. Hishikari town in Kagoshima, Japan was selected as a model area since it located in the middle of a typical rice growing region in the Prefecture. There are horticultural farms, rice paddies, small hills and mountains. Urban centers are also spotted. The paddy fields vary in size and most of them are around 30m by 100m.

LANDSAT-5/TM data are composed of seven channels of sensors that receive reflectances of ground objects from visible to infrared regions. Since clouds on an observation point intercept the reflectance the data should be collected on fine days. Therefore, among LANDSAT-5/TM data sets of this area (the path-row No.112-38) surveyed during the harvest season of rice, those with less than 50% cloud coverage were selected. Considering cost and other factors, geometrically and radiometrically corrected data of them were obtained from the Remote Sensing Technology Center, Tokyo, Japan on floppy disks for three different dates (September 26, 1986, October 20, 1989 and September 21, 1990).

A few ground truths were made during the harvest season for the years 1988 to 1991. Ground maps on a scale of 1:250,000 were used for verification of the images as well as identification of the sampled areas or training areas for a series of digital analyses. Color aerial photographs of November 7 and 8, 1988 were obtained from Hishikari town office to compare with the results. First, five categories, namely urban area, rice paddy, upland field, woods and river, were defined. Then, the training areas were chosen by comparing the map prepared by a field survey and aerial photographs. CCT values of each training area were statistically evaluated and the properties of the areas were analyzed by relating with spectral characteristics of each band. Subsequently, categorical classification was performed by a color image processor, SPICCA (Avio Ltd.). In the end, the total area of paddy fields estimated by image processing and that reported by the local government was compared.

Changes of the spectral characteristics of rice plants were measured with a portable spectroradiometer (Abe-sekkei Ltd.) during these growing periods. Analyzing these characteristics, an index was developed for evaluating the growth condition and the yield of rice and was applied to LANDSAT-5/TM data.

RESULTS AND DISCUSSION

Identification of Paddy Fields

Though each object has its own reflectance characteristics, the combined analysis of responses of several spectra intensifies the differences among objects. In remote sensing, enhanced images by mathematical combinations of some spectral bands will make the classification of objects on the ground easy. This kind of treatment also reduces the fluctuation caused by the dimension of analysis and/or atmospheric effects such as different solar radiation and sun elevation.

Tucker(1978) and Ishiguro *et al.* (1993) reported that the images processed by subtracting Band-5 from Band-4 identified rice paddies most accurately. But the result of this method depends on the period of observation by LANDSAT. Therefore, the Band Ratio Method (BRM) was adopted in this study. The optimal band combination was found to be of Band-2 and Band-1 and the results are demonstrated in Fig. 1. Paddy fields around the Sendai river and in the mountainous areas are easily recognizable in this figure, showing the effectiveness of this method.

Area Estimation

The estimated areas of rice fields are shown and compared with statistics based on ground surveys reported by the town office in Table 1 for three years. Since one pixel of LANDSAT-5/TM data corresponds to 30m by 30m on the ground, the unit of estimates depends on the resolution.

The Multi Level Slice (MLS) method extremely overestimated or underestimated the areas. Though the confidence level of 95% was adopted, the result was, however, overestimated by 25% for the data of Sep.21, 1990. It is not clear why this misleading result occurred.

On the other hand, BRM fairly well estimated the actual values, deviating less than 15%. This method overrated the data of September in both 1986 and 1990. This may due to some confusing objects with rice plants of this growth stage on the ground.

Overall results suggest that BRM is the most reliable one to estimate the areas of paddy fields from the LANDSAT-5/TM data. Though this method proved its own excellent potential to be applied in a land use survey, it needs to be more refinement. It is expected that further study will eventually fruit reliable indices to show not only the cultivated area of the crop but also crop growth parameters and yield.

Characteristics of Spectral Reflectance

Fig. 2 shows the changes in spectral response of a rice plant in the vegetative stage. The reflectance seemed to depend on the growth stage of a plant. In the vegetative period, the reflectance in the visible region, 400nm to 700nm, showed low values. In the infrared region it presented high readings and increased with maturing. On the other hand, the reflectance in the reproductive stage increased in the visible region and decreased in the infrared region.

Construction of Index

Let IR is the mean reflectance obtained for the spectra from 760nm to 900nm, representing Band-4 for LANDSAT-5/TM, and R is for 630nm to 690nm corresponding with Band-3. In the period from July 6 to August 30, as shown in Fig. 2, the values of IR increased rapidly while the values of R decreased slightly. This suggested the linear relation between IR and R for the vegetative period of rice. By the same token, for the reproductive stage IR was considered to relate linearly with R. Kuth *et al.* (1977) and Dusek *et al.* (1985) obtained the similar results for wheat, where IR and R were 850nm and 675nm, respectively.

The measurements collected by a satellite depend on the date of observation, because of the difference of the atmospheric conditions. Each day has its own unique atmospheric property and the energy required to penetrate the atmosphere differs from one day to another for any wave lengths. To avoid the drift of the measurements, the following correction formulae were proposed. Both IR and R are non-dimensional.

$$IR' = IR / (IR + R). \quad (1)$$

$$R' = R / (IR + R). \quad (2)$$

As shown the scatter diagram in Fig. 3, IR' relates linearly with R' for the reflectance of rice plants. The value of IR' was 0.8 at the beginning of observation, July 6 and increased as time went by during the vegetative stage of rice. On the other hand, it decreased in the reproductive stage. This relation suggested its effectiveness in analyzing the growth of rice crop.

When the variances of IR' and R' became large, the linear combination of IR' and R' as Eq.(3) worked well.

$$Z = \cos(\phi)IR' + \cos(\phi)R', \quad (3)$$

where ϕ is the angle between the axis of R' and Z.

From Fig. 3, ϕ is found to be 135. Substituting the value,135, for ϕ, the Eq.(3) becomes as Eq.(4),

$$\begin{aligned} Z &= \cos(135)IR' + \cos(135)R' \\ &= 0.70IR' - 0.70R'. \end{aligned} \quad (4)$$

From Eqs. (1) and (2),

$$Z = 0.70(IR - R) / (IR + R). \quad (5)$$

Normalized Difference Vegetation Index (NDVI), one of the vegetation indices for wheat and corn, proposed by Dusek *et al.*(1985) was

$$NDVI = (IR - R) / (IR + R). \quad (6)$$

Comparing the Eqs. (5) and (6), the following equation was derived,

$$Z = 0.70NDVI. \quad (7)$$

This index, Z, for rice happens to be basically same as the index for wheat and corn and is proportional to NDVI.

Evaluation of the yield of rice paddy

Fig. 4 illustrates the image based on NDVI in Hishikari Town. The brightness of the legend presented at the left side in this figure corresponds to the calculated NDVI value. The brighter the shade, the higher the value. White means the largest NDVI value in the data. After analyzing the characteristics of the image of the identified area, it was found that the difference of the shade signified the difference of the growth stage of rice plants.

The image of Kagoshima Prefecture created by NDVI is presented in Fig.5. At first the image for each town in the prefecture was obtained, then the composite image was made. Since both the maximum and the minimum of NDVI in Fig. 5 are different from those in Fig. 4, the brightness of the legend of Fig.5 does not agree with that of Fig. 4.

Fig. 6 displays the relationship between the average value of NDVI for each town and the reported value of yield/1,000m^2 in the statistics published by the town office. The correlation coefficient between them was 0.95. This result confirmed that the degree of the shade related to the yield. The field having greater yield produces the greater value of NDVI, resulting in brighter shade in the processed image.

CONCLUSIONS

Identification of rice paddies and estimation of their areas were attempted and the results were verified by video recorded aerial photographs and by grand observations. Among several methods, Band Ratio Method was superior to other methods and yielded better figures close to the statistics published by the local town offices on the area estimate.

The growth index obtained from the spectral reflectance of rice plants well indicated the growth stage. The image processed by this growth index showed the possibility of monitoring the growth of rice by a satellite. The relatively high correlation coefficeinet, r=0.95, between NDVI and yield/1000m^2 suggested the plausibility of evaluation of the yield of rice by NDVI calculated from satellite data. Hopefully, this method will take place the conventional method that strictly based on manual random sampling by officials sent by local governments.

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Table 1. Comparison of the officially reported figures of rice growing area and the estimates by three methods

Date of Observation	Estimated area (ha) Single	MLS	BSM	BRM	Reported area (ha)
Sep. 26, 1986	1604.0 (131.1%)*	747.5 (61.2)	1099.6 (89.1)	1400.0 (114.7)	1220
Oct. 20, 1989	1502.8 (161.2)	563.4 (60.6)	735.0 (80.2)	815.0 (87.7)	930
Sep. 21, 1990	4102.1 (256.4)	1024.9 (125.0)	1164.1 (125.2)	889.4 (108.4)	820

* Percentage of the estimate against the reported value.

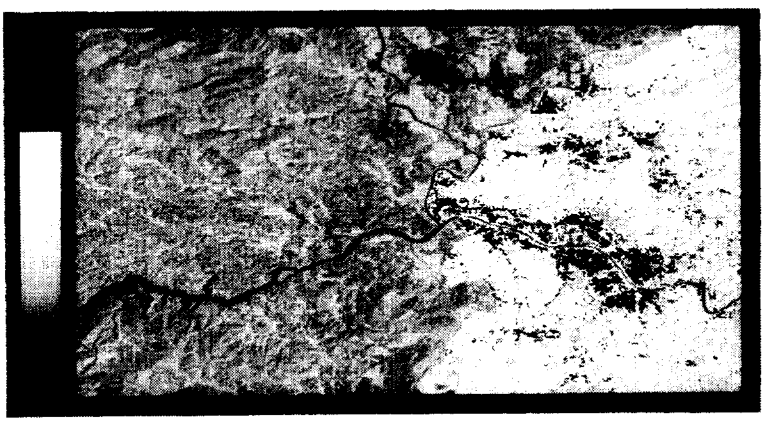

Fig. 1. Image processed by Band Ratio Method (Band-2 / Band-1) to identify rice paddy fields in Hishikari Town (L-5/TM; 1990).

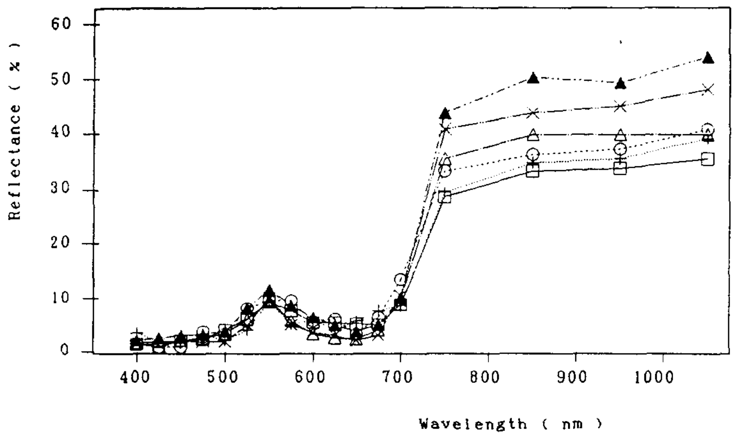

Fig. 2 Changes in spectral response of rice plants (*Oryza sativa* L. var. Minamihikari) in the vegetative stage.

□ : July 6, + : July 11, ○ : July 19,

△ : August 3, × : August 11, ▲ : August 30.

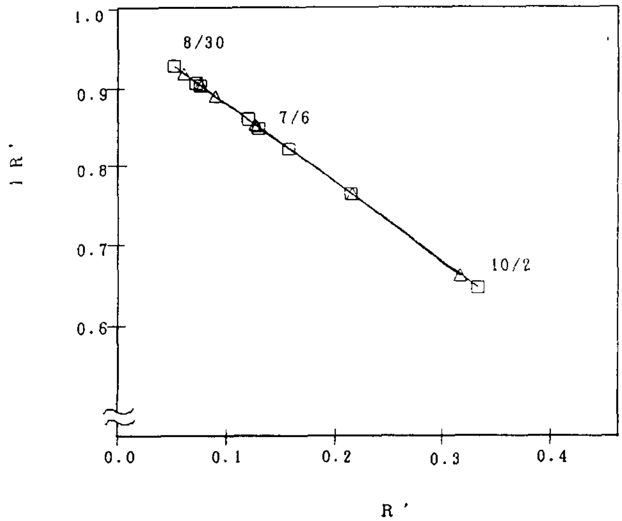

Fig. 3 Scatter diagram of the reflectance of rice plants for IR' and R'.

□ : Hinohikari, △ : Minamihikari

$$IR' = \frac{IR}{(IR + R)} \qquad R' = \frac{R}{(IR + R)}.$$

Fig. 4 Image based on NDVI processed to evaluate the growth stage of rice corp in Hishikari Town (L-5/TM; Sep. 21 , 1990).

Fig. 5 Image based on NDVI processed to evaluate the growth stages of rice crop in towns in Kagoshima Prefecture (L-5/TM; Sep. 21, 1990).

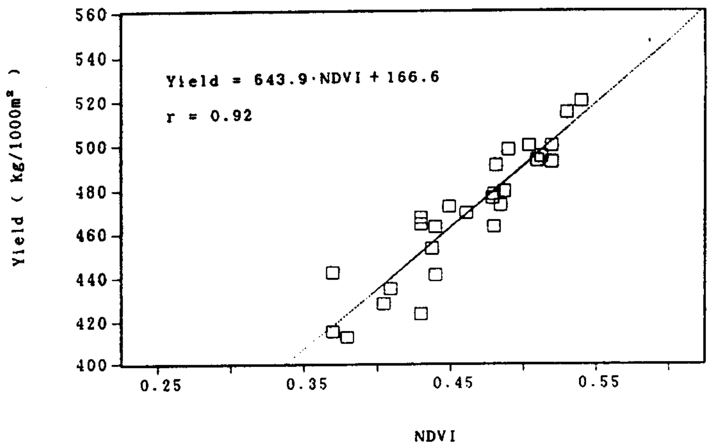

Fig. 6 Relationship between yield/1000m² and NDVI.