Remote Sensing of Growing Conditions of Rice Plants by Landsat MSS Data and Color IR Aerial Photograph

By KAZUYA MIYAMA* and HIROSHI SATO

Agricultural Physics Division, Hokkaido National Agricultural Experiment Station
(Hitsujigaoka, Toyohira, Sapporo, 061-01 Japan)

Introduction

Remote sensing is the technique of deriving information about an object or a phenomenon on the ground without actually coming in contact with it. The quantity measured in remote sensing systems is the electromagnetic energy which is reflected or radiated from the object of interest. Therefore, the remote sensing data are usually collected by the remote-senser on board the airplane or the satellite. This technique is very useful for the measurement or investigation of earth surface conditions, for example, in the field of agriculture, geology, environment, etc., and the practical application of this technique is expected.

The authors have been carrying out a study on the application of remote sensing technique to investigate the agricultural land.[6] For instance, a distribution map of ash-fall caused by Mt. Usu eruption was made by analizing the aircraft MSS (multispectral scanner) data.[2,3,11] It was clarified that the remote sensing data are very useful for making distribution maps of soil moisture content or of water surface temperature.[4] In addition, a survey technique using Landsat MSS data for geographical distribution of damaged rice crop caused by cold summer weather was established.[5,7]

Present address:
* Agriculture, Forestry and Fisheries Research Council Secretariat, Ministry of Agriculture, Forestry and Fisheries
(Kasumigaseki, Chiyoda, Tokyo, 100 Japan)

In this report, the spectral reflectance of paddy fields with rice canopy will be mentioned at first. It is the basis for analysis of remote sensing data to clarify the characteristics of spectral reflectance on the various ground surface. Secondly, the process of making distribution maps of plant height or Leaf Area Index of rice in paddy fields will be mentioned. In this analysis, color infrared (IR) aerial photographs and Landsat MSS data were used. Landsat is the Earth resources satellite launched by the National Aeronautics and Space Administration (NASA) of U.S.A..

Spectral reflectance of rice plants

1) *Temporal changes in spectral reflectance of paddy fields*

The reflectance of plants is characterized by low reflectance at approximately 0.45 and 0.65 μm and by high reflectance in the near-infrared region. These characteristics of spectral reflectance are due to chlorophyll and internal cell structure of plant leaves.[10] Fig. 1 shows spectral reflectance curves of rice in a paddy field. The shape of reflectance curve changes remarkably as the rice season proceeds, in other words, as rice plants grow or as ratio of covering soil surface by rice canopy increases.

The reflectances shown in Fig. 1 were measured by a handy spectrometer (Kimoto, PM-12A) which was set at a height of 3 m above the paddy field. The reflectance is expressed in terms of relative values to the reflection

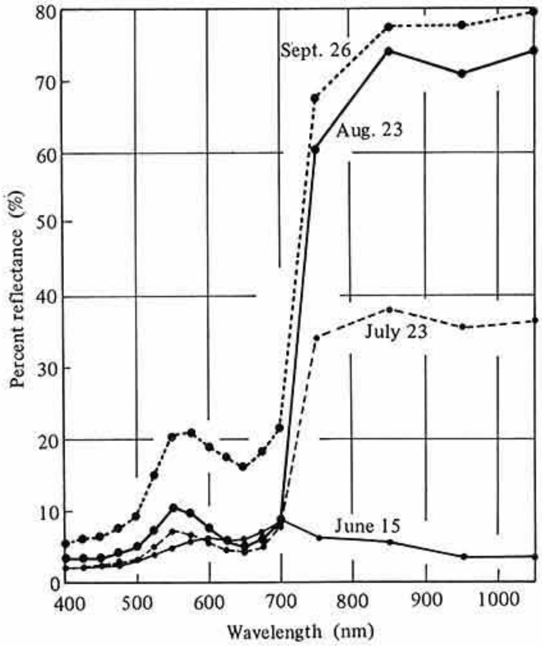


Fig. 1. Characteristic of spectral reflectance in paddy field during the growth period of rice (Hitsujigaoka, Sapporo, 1983)

from the standard white board set aside the target. The data measured by the handy spectrometer are given as follows:

$$V_\lambda=\log \int_{\lambda_1}^{\lambda_2} I_\lambda \cdot T_\lambda \cdot R_\lambda \cdot S_\lambda \cdot d\lambda + C \quad \cdots\cdots\cdots\cdots(1)$$

where V_λ = measured data by handy spectrometer at λ wavelength

I_λ = electromagnetic energy from the sun

T_λ = transmittance of filter

R_λ = spectral reflectance of object

S_λ = spectral sensitivity of photocell

C = constant specific to the equipment used

Supposing that spectral reflectance of the standard white board is equal to 1.0 and the region from λ_1 to λ_2 is very narrow, we can deduce the equality of Eq. (2) with Eq. (1).

$$V_{\lambda R}-V_{\lambda W}=\log R_\lambda \quad \cdots\cdots\cdots\cdots(2)$$

where $V_{\lambda R}$ = measured data of object by spectrometer

$V_{\lambda W}$ = measured data of standard white board by spectrometer

Then, the following equation can be obtained from Eq. (2).

$$R_\lambda=10^{(V_{\lambda R}-V_{\lambda W})} \quad \cdots\cdots\cdots\cdots(3)$$

The reflectances shown in Fig. 1 were calculated by Eq. (3) and expressed as percentage.

2) *Change of Vegetation Index with growth of rice plants*

The ratio technique is widely used for normalization of remote sensing data or for emphasis on the spectral characteristics of object.[1] For the analysis of plants, it is well known that the ratioing parameter called Vegetation Index such as RVI or DVI is very effective.[8]

$$RVI=IR/R \quad \cdots\cdots\cdots\cdots(4)$$

$$DVI=(IR-R)/(IR+R) \quad \cdots\cdots\cdots\cdots(5)$$

where IR = reflectance in near-infrared region

R = reflectance at red wavelength

The plant height (H), Leaf Area Index (LAI) and biomass (Biomass) of rice were measured at the same time of measuring the spectral reflectance of paddy fields. Temporal changes in H, LAI, Biomass and RVI, DVI are shown in Fig. 2. RVI and DVI shown in Fig. 2 are calculated by Eq. (4) and (5). In this case, IR and R are given by

$$IR=(R_{850}+R_{950}+R_{1050})/3 \quad \cdots\cdots\cdots\cdots(6)$$

$$R=(R_{625}+R_{650}+R_{675})/3 \quad \cdots\cdots\cdots\cdots(7)$$

where R_N is spectral reflectance at N nm wave length by the handy spectrometer. Measured rice plants were transplanted on May 31, 1983, and harvested on October 20. Heading date was August 19 (individual heading time ranged from August 14 to 24). In 1983, cold summer delayed the growth of rice by about 2 weeks in Ishikari Plain, Hokkaido, Japan.

Fig. 2 shows that the value of Vegetation Index before heading time (August 13 or 23) increases in proportion to H, LAI, or Biomass. Especially, it is clear from Fig. 2 that there is a linear correlation between RVI and H, LAI or Biomass. The coefficient of correlation between RVI and LAI was the highest, showing a correlation model given in Eq. (8).

$$LAI=0.268 \cdot RVI+0.0262 \quad r=0.988 \quad \cdots(8)$$

As mentioned above, it is clear that

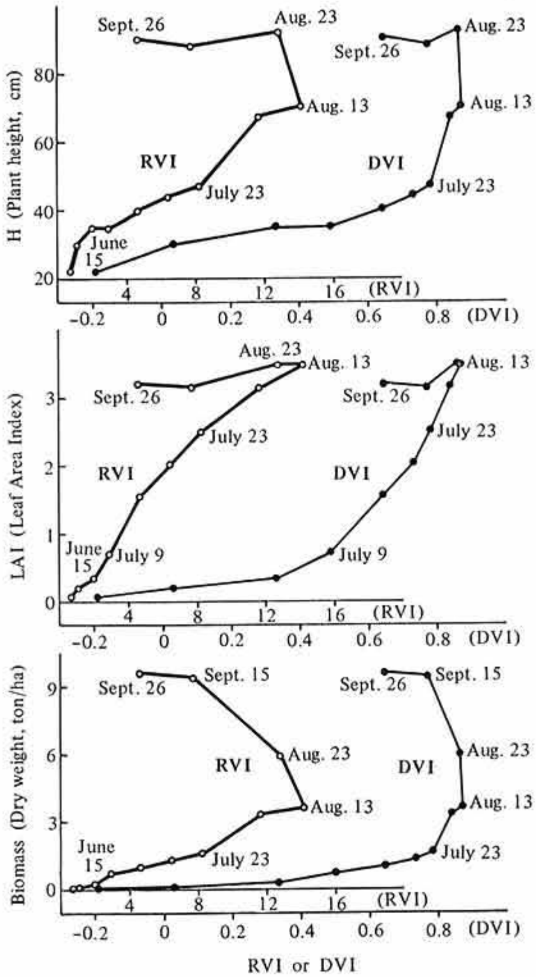


Fig. 2. Temporal changes in rice plant height (H), Leaf Area Index (LAI), biomass (Biomass) and Vegetation Index (RVI, DVI) (Hitsujigaoka, Sapporo, 1983)

Vegetation Index is useful for estimating the amount of rice growth before heading time. In the period after heading time, it is possible to consider from Fig. 2 that there is negative correlation between Vegetation Index and Biomass.[5]

Investigation on plant height of rice

It was possible to make the distribution map of rice plant height in paddy fields by using

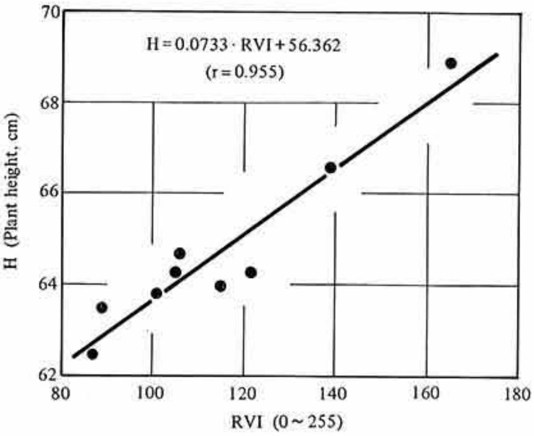


Fig. 3. Correlation between rice plant height (ground truth data) and RVI (by the color IR aerial photograph) (Kurisawa, Hokkaido, August 4, 1983)

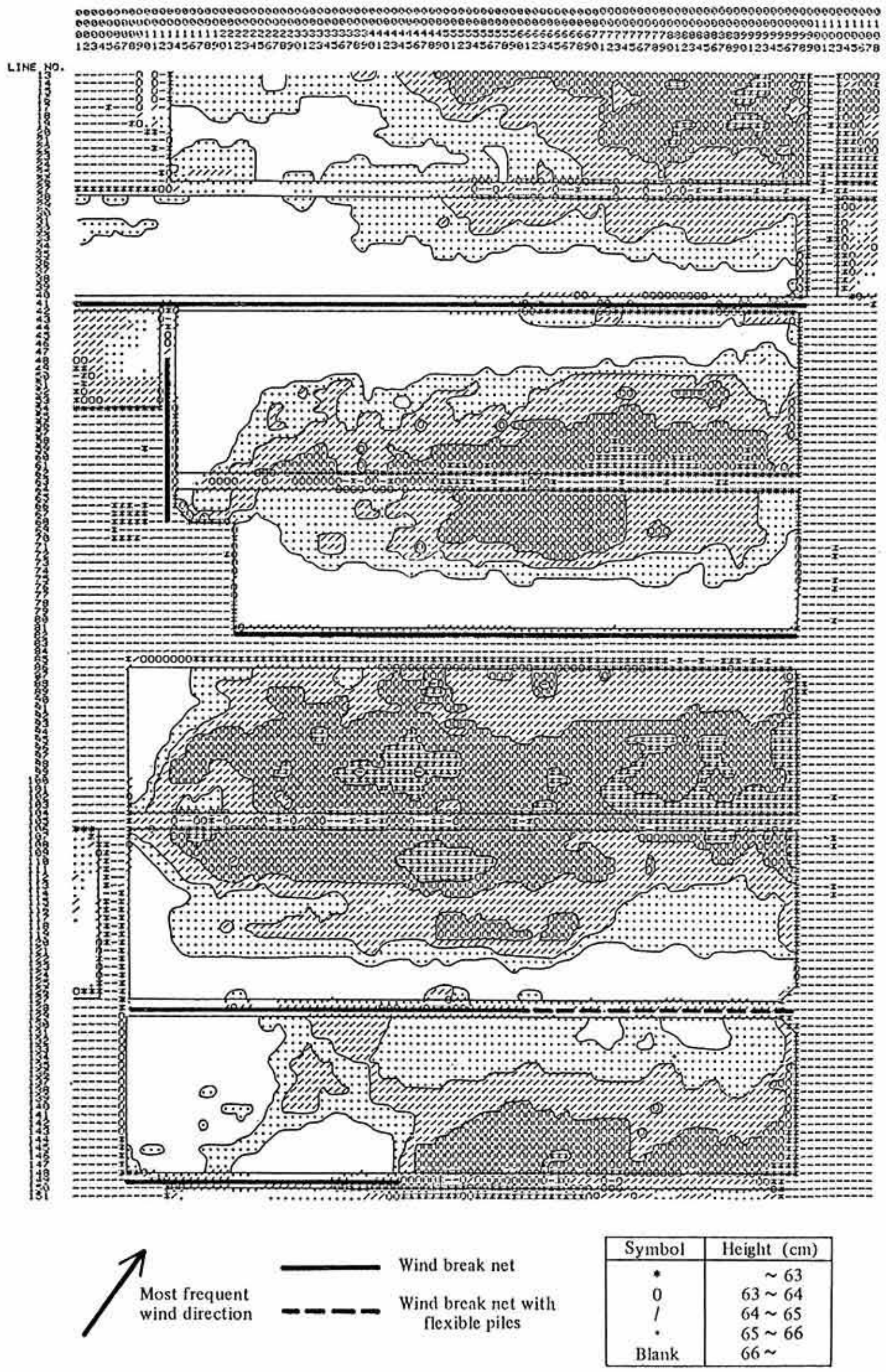
color IR aerial photograph.[7] The photograph used (false color image) is:

Covering area : Kurisawa Town, Hokkaido
Flying date : August 4, 1983
Scale : 1/8000
Flying height : 1720 m

Digitization of this film image density was carried out by the drum-scanner system. Through this process, the digital image which consisted of green, red and near-infrared channels was made from the film image. And the digital image analysis was carried out by using a computer system named HIPS. HIPS is the name of Hokkaido National Agricultural Experiment Station Image Processing System which was developed by the authors.

It is apparent from Fig. 2 that there is a linear correlation between the rice plant height and RVI. Therefore, by using the observation data of the rice plant height in the paddy fields and RVI values at the ground truth points where the plant height was observed, the regression model given in Eq. (9) or shown in Fig. 3 was obtained for the estimation of rice plant height.

$$H(\text{cm}) = 0.0733 \cdot RVI + 56.362 \qquad r = 0.955 \quad \cdots\cdots (9)$$



Symbol	Height (cm)
*	~ 63
0	63 ~ 64
/	64 ~ 65
·	65 ~ 66
Blank	66 ~

Fig. 4. Distribution map of rice plant height
The map was made from the color IR photograph. The pixel size of this map is 1.6 m.
(Kurisawa, Hokkaido, August 4, 1983)

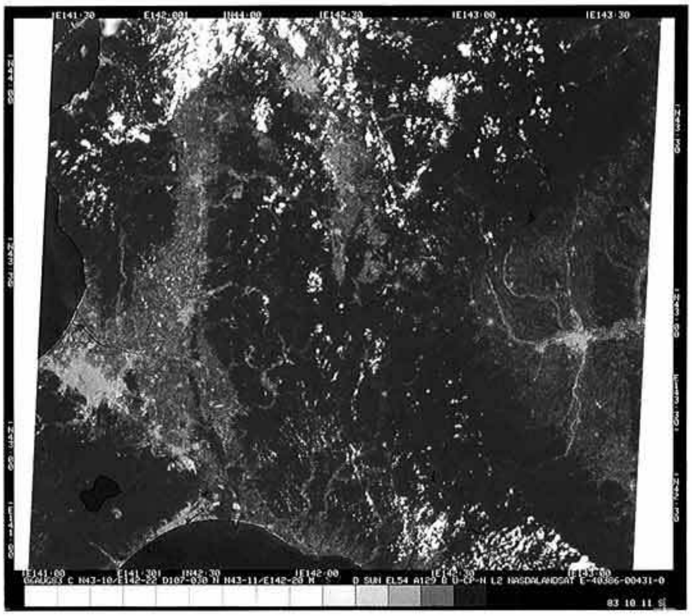


Plate 1. Landsat MSS data (False color image), 107-30, Aug. 6, 1983

Plate 2. Distribution map of Leaf Area Index in paddy fields (by Landsat MSS data, August 6, 1983)

LAI in paddy fields				
Red	:	0	~	2.73
Pink	:	2.74	~	2.85
Yellow	:	2.86	~	2.97
Green	:	More than		2.98

Landcover		
Light blue	:	City, town
White	:	Forest
Blue	:	Water
Black	:	Others

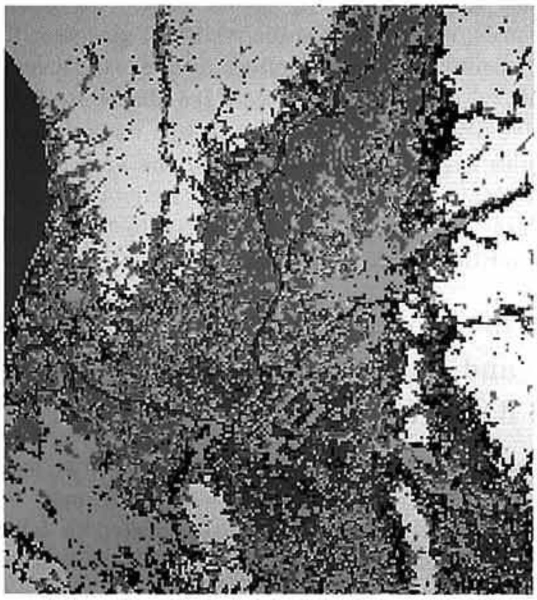


Plate 3. Distribution map of rice damage caused by cold summer (by Landsat MSS data, September 19, 1980)

Rice yield (kg/10a)				
Red	:	0	~	300
Pink	:	300	~	350
Yellow	:	350	~	400
Green	:	More than		400

Landcover		
Light blue	:	City, town
White	:	Forest
Blue	:	Water
Black	:	Others

where RVI = ch.3/ch.2
ch.2 = CCT value of digital image at 500～600 nm wavelength
ch.3 = CCT value of digital image at 700～900 nm wavelength
(These values were stretched to 0～255.)

Using Eq. (9) and the digital image converted from the color IR aerial photograph, the distribution map of rice plant height (Fig. 4) was made. Fig. 4 is a gray-map printed by lineprinter, and the size of the study area is about 173 × 222 m (108 columns × 139 lines). The negative sign shown in Fig. 4 as one of gray-map symbols indicates the land cover type except rice plant which was classified by unsupervised classification.[10] The right side area symbolized by negative sign in Fig. 4 is mainly dry field and the left side area is mainly farmhouse.

Fig. 4 shows the detailed distribution of rice plant height in paddy fields. In other words, we can see the inequality of rice growth in paddy field or the effect of the wind break net. Furthermore, we can see that the effective area of the wind break net with flexible piles spread more widely than the area of the ordinary net. In this way, remote sensing data are very useful to investigate the actual condition of rice growth.

Investigation on LAI of rice plants and characteristics of cold summer damage

Using the Landsat MSS data, it was possible to make the LAI distribution map of rice plants in paddy field area located in Ishikari Plain, Hokkaido. The LAI distribution map showed the area of damaged rice crop caused by cold summer in 1983.[7] Used Landsat MSS data (Plate 1) are:

Path-Row : 107–30
Date : August 6, 1983
Satellite : Landsat-4
Senser : MSS

The spectral bands used in the Landsat MSS are:

Band 4 : 500～600 nm
Band 5 : 600～700 nm
Band 6 : 700～800 nm
Band 7 : 800～1100 nm

1) Land cover classification using Landsat MSS data

The study area was chosen from the Landsat MSS data mentioned above. The size of study area is about 54 × 91 km (950 columns × 1600 lines) and this area almost covers Ishikari Plain. Using the Landsat MSS data in the study area, land cover classification was conducted to find out the paddy fields where rice crop was planted. The study area was classified into 25 sub-classes according to their spectral reflectance by supervised classification method using the maximum-likelihood decision rule.[10] Then these sub-classes were combined into 8 classes of land cover type: paddy field (rice plant), dry field or grassland, forest, strip ground, town, water, cloud and shadow of cloud. The classification performance in the training fields was more than 95% in every class and 98.3% on average of 8 classes.

2) LAI distribution map

The rice plant height in the training field A, B or C was observed on August 6, 1983. Using these data and observed relation between the rice plant height and LAI, as shown in Fig. 5, the LAI value in the training field A, B or C can be estimated. Besides, RVI in the training field A, B or C can be calculated from the Landsat data. So that, we can obtain a LAI estimation model such as Eq. (10) from the data of LAI and RVI in the training field A, B and C, because it can be considered that there is a linear correlation between LAI and RVI as shown in Fig. 2 or Eq. (8). This process is shown in Fig. 5.

$$LAI = 0.0106 \cdot RVI + 1.854 \quad \cdots\cdots\cdots\cdots (10)$$

where RVI = Band 7/Band 5
Band 5 = CCT value of Band 5 in Landsat MSS data

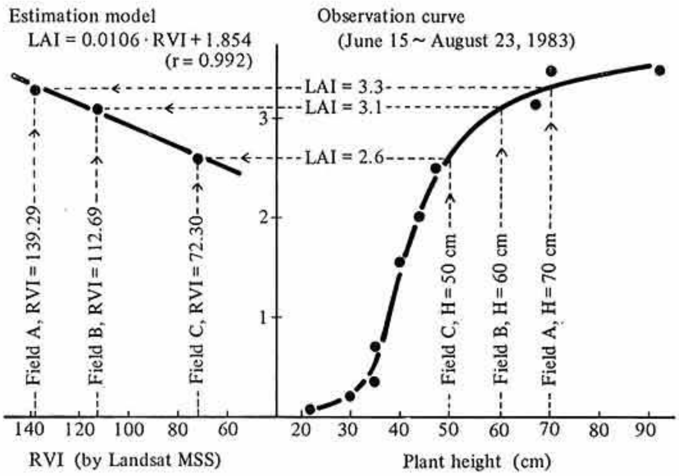


Fig. 5. Process for making the LAI estimation model of rice plant
The purpose of this model is to estimate the LAI value from the Landsat MSS data.

Band 7 = CCT value of Band 7 in Landsat MSS data
(These values were stretched to 0~255.)

LAI in a paddy field area was calculated by Eq. (10) and the Landsat MSS data. In other words, by applying the LAI estimation model (Eq. (10)) to all pixels which were classified into paddy field by the land cover classification of the study area, the LAI distribution map of the study area was obtained. Plate 2 is one of color-coded LAI distribution maps made from the Landsat MSS data. Plate 2 shows a 54 × 57 km area which is the central part of the study area, and this image is one of grid-cell images made from pixel image of LAI. The grid-cell size is 285 m square (5 columns × 5 lines) and the color-code of grid-cell shows the average LAI of paddy field pixels in a grid-cell.

3) The distribution of cold summer damage

In 1983, the rice crop in Ishikari Plain was hit by cold summer damage due to delayed growth. Especially, the low temperature delayed the growth of rice through late May to early August.[9] Therefore, the LAI of rice in early August will reflect the extent of rice damage. For this reason, it can be considered that the LAI distribution map made from the Landsat MSS data (August 6, 1983) is the distribution map of damaged rice crop caused by cold summer. In other words, Plate 2 shows the damaged rice distribution as expressed in terms of LAI.

It is apparent from Plate 2 that the whole area in Ishikari Plain was hit by cold summer damage in 1983, whereas Plate 3 shows that the south-eastern part of the plain was mainly hit by cold summer damage in 1980 because a cold eastern wind blew along that part. Plate 3 is the damaged rice distribution map made from the Landsat data in September 19, 1980.[5] The information, derived from the Landsat MSS data, agreed with the ground truth data (yield and yield estimate index of rice in corresponding administrative districts, reported by the Ministry of Agriculture, Forestry and Fisheries).

Furthermore, the LAI histogram shown in Fig. 6 was obtained from the LAI data of all pixels which had been classified into paddy field in the study area. It may be regarded

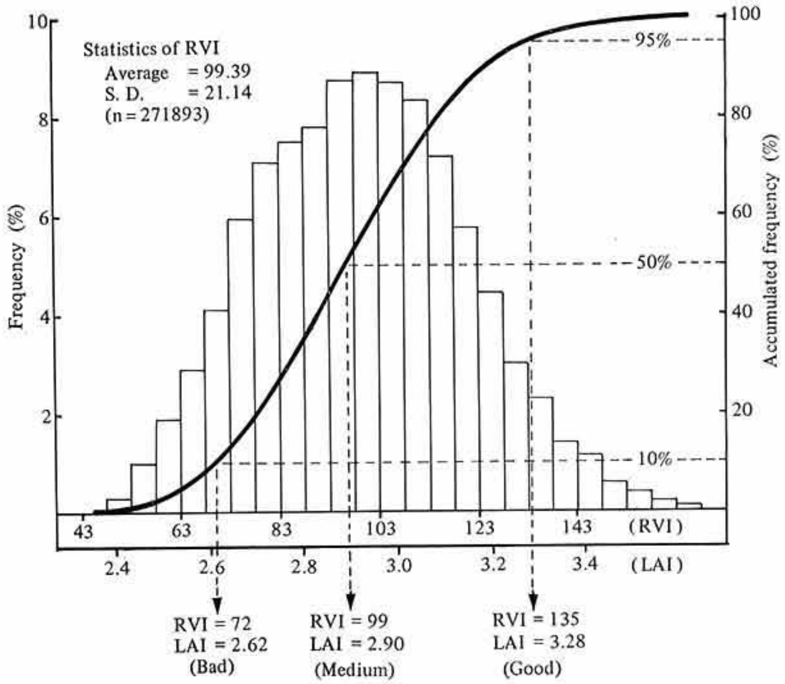


Fig. 6. Histogram of LAI of rice in the study area and the process for estimating the LAI value of good, medium and bad growing rice (August 6, 1983)

that the point of 95% on accumulated curve of LAI shown in Fig. 6 indicates the LAI value for good growth of rice in the study area. In the same manner as above, the 50% and 10% point may be regarded as the LAI value for medium and poor growth of rice, respectively. Based on this idea, the LAI of rice crop showing good, medium and poor growth was 3.28, 2.90 and 2.62, respectively. By substituting these LAI values into the temporal curve of LAI shown in Fig. 7, it became clear that the growth delay in the rice crop showing medium and poor growth was by about 11 days and 15 days, respectively, as compared with the crop of good growth. The growth delay expressed by these numbers of days was regarded as caused by the cold summer damage, by taking the crop of good growth as normally growing rice. Ground truth data showed that the days of growth delay in Ishikari Plain was 11–16 days on August 1 and 8–15 days on the August 15, 1983.[9] It is obvious that the days of growth delay of the rice crop interpreted from the Landsat data well agrees with the results by ground truth.

Thus, the Landsat MSS data can be used effectively to interpret rice growing conditions or to analyze characteristics of rice damage such as cold summer damage.

Conclusion

The spectral reflectance of paddy fields with rice canopy was observed by the handy spectrometer. As a result of investigating these data, it became clear that Vegetation Index such as RVI or DVI which had been calculated from the spectral reflectance was useful for detecting the plant height, LAI or biomass of rice.

The distribution map of rice plant height in the paddy fields was made by digital image analysis of the color IR aerial photograph. This map showed the inequality of rice growth in the paddy field or the effect of the wind break net.

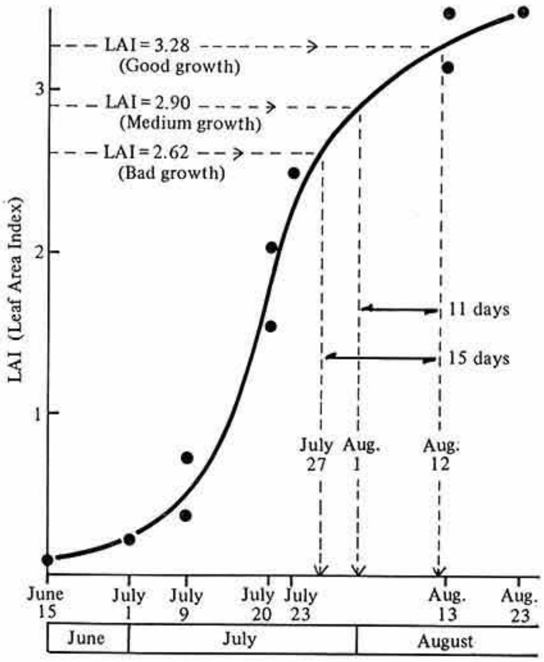


Fig. 7. Temporal change in LAI of rice plants (Hitsujigaoka, Sapporo, 1983) and the process of estimating the extent of growth delay of rice in terms of number of days (Ishikari Plain, 1983)

Using the Landsat MSS data, it was possible to make the LAI distribution map of rice plants in Ishikari Plain. This map was regarded as the distribution map of damaged rice crop caused by cold summer weather.

The remote sensing technique is very useful for collecting various information regarding agricultural land.

Acknowledgments

The authors wish to express their deepest appreciation to Dr. Yasuda, Y. and Dr. Emori, Y., Faculty of Engineering, Chiba University, for valuable advice and the use of equipment. The Landsat MSS data used in this study were supplied from the National Space Development Agency (NASDA) of Japan. The authors are indebted to the staff at NASDA.

References

1) Emori, Y. & Yasuda, Y.: Study on remote sensing of dry fields and image processing system. *In* Research Bulletin of study by subsidy from the Ministry of Agriculture, Forestry and Fisheries, ed. Emori, Y., Faculty of Engineering, Chiba University, Chiba, 73–136 (1979) [In Japanese].
2) Miyama, K. et al.: Studies on the agricultural damage caused by the Mt. Usu eruption using remote sensing. *Res. Bull. Hokkaido Nat. Agr. Exp. Sta.*, **123**, 127–145 (1978) [In Japanese with English summary].
3) Miyama, K., Takahata, S. & Fukuhara, M.: A digital analysis of agricultural damage caused by Mt. Usu eruption using aircraft MSS data *J. Jpn. Soc. Photogrammetry and Remote Sensing*, 18(1), 12–22 (1979) [In Japanese with English summary].
4) Miyama, K.: Remote sensing of paddy field areas using aircraft MSS data. *Jpn. Foundation for Shipbuilding Advancement Remote Sensing Tech. Rep. II 1981*, 181–194 (1981) [In Japanese with English summary].
5) Miyama, K. et al.: An applied study on a remote sensing technique to survey agricultural land. *Transac. Jpn. Soc. Irrig. Draina. and Reclama. Eng.*, **105**, 27–35 (1983) [In Japanese with English summary].
6) Miyama, K.: Survey technique of agricultural infrastructure using remote sensing. *Soil Physical Conditions and Plant Growth*, 47, 15–21 (1983) [In Japanese].
7) Miyama, K., Sato, H. & Fukunaka, H.: An investigation on damaged rice distribution due to cold summer damage using remote sensing technique. *Miscell. Pub. Hokkaido Nat. Agr. Exp. Sta.*, **26**, 41–50 (1984) [In Japanese].
8) Short, N. M.: The Landsat tutoral workbook. NASA, Washington, 159–169 (1982).
9) Otokozawa, R. et al.: The actual condition of damaged rice and its main cause. *In* Report of investigation on agricultural damage caused by abnormal weather in Hokkaido, ed. Miyasaka, A., Hokkaido Nat. Agr. Exp. Sta., Sapporo, 15–36 (1984) [In Japanese].
10) Swain, P. H. & Davis, S. M.: Remote sensing; The quantitative approach. McGraw-Hill, New York, 136–289 (1978).
11) Takahata, S. & Miyama, K.: Study on plant damage caused by Mt. Usu eruption using remote sensing. *In* International Archives of Photogrammetry. **23**, B8 Commission 7, ed. Ackermann, F. The Committee of the 14th International Congress for Photogrammetry Hamburg 1980, Hamburg, 907–915 (1980).

(Received for publication, November 7, 1984)