RESEARCH ON DETECTION OF RICE ECOTYPES BY CANOPY SPECTRAL REFLECTANCE

Mitsuo KAMBAYASHI[1)*], Koki HOMMA[1)], Masayasu Maki[2)], Yoshihiro HIROOKA[1)], Tatsuhiko SHIRAIWA[1)]

[1)] Graduate School of Agriculture, Kyoto University (Public organization),
Kitashirakawa-Oiwake, Sakyo, Kyoto 6906-8502, Japan
Tel: +81 (0)75-753-6042; Fax. +81 (0)75-753-6065
*E-mail: cancanbayashi@yahoo.co.jp
[2)] Graduate School of Engineering, Kyoto University (Public organization),
Katsura, Nishikyo, Kyoto 615-8540, Japan

KEY WORDS: Canopy Spectral Reflectance, Rice Ecotypes, Detection, TIPS, NDVI

Abstract:
From the view point of food security, observation of crop growth and estimation of crop production is eagerly required. Although satellite observations based on remote sensing have already been conducted, improvement on estimation accuracy is still necessary. One of the possible ways is combination of remote sensing with crop growth simulation model. However, simulating results quite varied by parameters which were mostly determined by cultivar ecotypes. Accordingly, detection of rice ecotypes is probably quite informative and improves the estimating accuracy. This study preliminarily conducted research on detection of cultivar ecotypes by canopy spectral reflectance on the ground level for rice which is the major crop in Asia.
We conducted field experiments in Kyoto in 2011 and 2012, with 8 cultivars (3 japonica and 5 indica cultivars) including traditional and improved types, and indica and japonica types. Canopy multispectral reflectance of rice canopies was measured once a week by MS-720 (Eko Instruments) from 1m above canopy.
Cluster analysis showed that canopy multispectral reflectance was significantly different between cultivars. The difference depends on a form of plants and height and the result may enable us to distinct rice cultivars in plant communities.
Our previous study proposed a new indicator (TIPS: Time-series change Index of Plant Structure) for leaf area index (Hashimoto et al., 2009). Common vegetation indices such as NDVI are thought to indicate canopy coverage, suggesting that the difference between TIPS and vegetation index contributes to detect cultivar ecotypes in rice.

INTRODUCTION

Recent frequent disasters often caused steep increase of grain prices, which menaces food security. In order to improve food security, it is necessary to observe not only weather but also its impact on food production. Although global observations based on satellite based remote sensing have already been conducted (Peng et al., 2011, Aboelghar et al., 2011, Inoue et al., 2012), improvement on estimation accuracy for food production is still necessary. On the other hand, crop growth simulation models has also been utilized to estimate weather impact on food production (Yoshida et al., 2010), the estimation is substantially based on a point, but not on an area. Accordingly, simulation model combined with remote sensing has been developed (Homma et al., 2012).
Rice, one of the major staple foods, has been cultivated on broad area in Asia from the ancient. The cultivation differentiates rice into subspecies: indica and japonica. The modern breeding improved rice to increase productivity potential dramatically as known as green revolution. The improvement also differentiates rice into traditional and improved types. Growth and productivity is quite varied with these differentiations (ecotypes).
Although the rice growth simulation model commonly needs crop parameters which are different among cultivars, it is usually difficult to obtain cultivar information for each farmer's field. Accordingly, obtainment of the information by remote sensing may be one of the critical techniques to operate a simulation model combined with remote sensing.
Substantially distinction of cultivars is necessary for the rice growth simulation model, but it is always quite difficult even by human observations. Since rice growth and productivity is quite different among ecotypes as described in the above, this study aimed to distinguish rice ecotypes by remotely sensed canopy spectral reflectance on the ground.

METHODS AND EQUATION

Field experiment

Field experiments were conducted in Kyoto University (Kyoto Prefecture, 35° 02' N, 135° 47' E) in 2011 and 2012. The experiments used 8 cultivars divided into 3 japonica and 5 indica cultivars and into 5 improved and 3 traditional cultivars (Table 1). We also divided cultivars on the basis of leaf appearances: 3 vertical, 3 intermediate and 2 horizontal type cultivars. We conducted 3 kinds of fertilizer treatments (No, Less and Standard) were conducted under pesticide application. The No treatment was conducted without fertilizer, whereas the Less and Standard treatments included the application of chemical fertilizer at a rate of N-P_2O_5-K_2O = 5-5-5 g m^{-2} as basal, and the Standard treatment was top-dressed with fertilizer on the July 21th and 28th in 2011 and July 26th and August 3rd in 2012. The rate of each top-dress application was N-P_2O_5-K_2O = 2.5-2.5-2.5 g m^{-2}. Thus, the total application rate for the Standard treatment was N-P_2O_5-K_2O = 10-10-10 g m^{-2}. The Less treatment was designed to starve nutrients around the heading period. Sowing was May 9th in 2011and May 10th, and transplanting was Jun 2nd in2011 and Jun 7th in 2012. Plants density is 30cm×15cm (22.2 plants m^{-2}) for all cultivars, and EP is also planted at double density (15cm×15cm (44.4 plants m^{-2})).
For measuring spectral reflectance of rice canopies, we used a spectroradiometer MS-720 (EKO INSTRUMENTS, Japan). MS-720 can measure radiation from 350nm to1050nm by 3nm. The data is interpolated by 1 nm. We measured the sky radiation with a FOV 180°attachment and the plant radiation with a FOV 45°attachment 1m above rice canopies once about a week from transplanting to maturing. We calculate reflectance dividing plant radiation by the sky radiation. To reduce the value errors by change of the sky radiation caused by cloud, we measured on perfect sunny days Measuring LAI by LAI-2000(LI-COR, USA) in 2011 and LAI-2200(LI-COR, USA) in 2012 was taken one or two times a week from three weeks after transplanting to maturing. LAI-2000/LAI-2200 measurements were acquired at sunset or overcast days with a single sensor mode and a sequence of two above, four below within each plot. In order to reduce the influence of the adjacent plots and the operator, a 45° view-cap was applied on the optics.

Table 1: Cultivar information used in this study.

Cultivar	Abbreviation	Origin	Subspecies	Breeding	Appearance	Maturation (Heading date)
Shinnou265*	EP	China	Japonica	Improved	Vertical	Early (8/5)
Shinnou265* (Double density)	WEP	〃	〃	〃	〃	〃
Koshihikari	Kos	Japan	Japonica	Improved	Intermediate	Early (8/8)
Kasalath	Kas	India	Indica	Traditional	Horizontal	Early (8/11)
Takanari	Tak	Japan	Indica	Improved	Vertical	Intermediate(8/14)
Nipponbare	Nip	Japan	Japonica	Improved	Vertical	Intermediate(8/20)
B6144F-MR-6-0-0	B6144	Indonesia	Indica	Improved	Intermediate	Late(8/26)
Beniasahi	Beni	Japan	Japonica	Traditional	Intermediate	Late(8/30)
Bei Khe	Bei	Cambodia	Indica	Traditional	Horizontal	Late(9/6)

*Shinnou265 is categorized in Erect Panicle, which is recently popular in North China.

Time-series change index of plant structure

TIPS is a new index showing time-series change of plant structure by using spectral reflectance (Hashimoto et al., 2009). TIPS is calculated by plant canopy reflectance and can estimate LAI more exactly than other vegetation indices such as NDVI, SAVI and EVI. For calculation of TIPS, at first we need reference spectra which are the spectrum when LAI is max value used for optimization. After similarity in visible band and visible to near infrared band is calculated between reference and objective spectra by improved matched filter method (Oki et al., 2002), TIPS is obtained by equation (1) and (2).

$L_{difference} = a'_{vis} - a'_{vis+nir}$ ･･･(1)

$TIPS = 1 - (L_{difference} / L_{difference\text{-}max})$ ･･･(2)

$L_{difference}$: Index of difference of LAI between object and reference
a'_{vis} : Similarity in visible band
$a'_{vis+nir}$: Similarity in visible plus near infrared band
$L_{difference\text{-}max}$: $L_{difference}$ when LAI is max (heading period)

RESULTS AND DISCUSSION

Figure1 shows the time-series change of rice canopy spectral reflectance by using Nipponbare which is a standard rice cultivar. The value of reflectance is lower than the general one because we measured radiation with an attachment in this study. But it appears to be no problem when we detect rice cultivars because the value is only compressed to about a one-tenth. As plants grow, reflectance of shorter wavelength than red edge is getting smaller except for green band around 550nm. On the other hand, reflectance of longer wavelength than red edge is getting bigger until ripening stage.

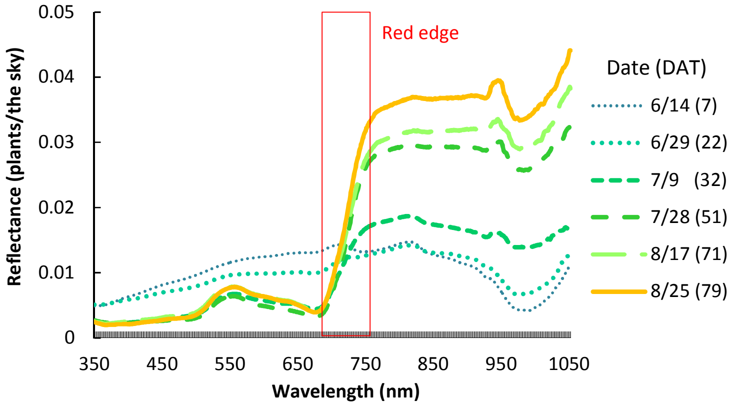


Figure 1: Time-series change of rice canopy spectral reflectance (Nipponbare)

We selected reflectance factors at 20 or 40-nm intervals at heading for each cultivar and each fertilizer treatment and conducted principal component analysis. Referring to the band of MODIS, we set 20-nm intervals around blue band (459-479), green band (545-565), red band (620-670) and NIR band (841-876) (Table 2).

Table 2: The eigen vectors of each reflectance factors in the first 3 principal components (PC)

Wavelength (nm)	PC1	PC2	PC3
350	-0.0028	0.0047	-0.0102
390	-0.0037	0.0042	-0.0062
430	-0.0029	0.0051	-0.0032
450	-0.0031	0.0079	-0.0029
470	-0.0034	0.0105	-0.0029
490	-0.0036	0.0134	-0.0029
530	0.0187	0.0660	0.0024
550	0.0262	0.0820	0.0035
570	0.0173	0.0767	0.0019
590	0.0068	0.0644	0.0001
610	0.0027	0.0580	-0.0005
630	-0.0017	0.0502	-0.0017
650	-0.0066	0.0390	-0.0022
670	-0.0092	0.0233	-0.0035
690	-0.0034	0.0455	-0.0028
730	0.2396	0.1555	0.0201
770	0.5832	-0.0027	0.0320
810	0.6099	-0.0134	0.0336
830	0.6161	-0.0141	0.0281
850	0.6209	-0.0156	0.0279
870	0.6262	-0.0178	0.0256
890	0.6279	-0.0178	0.0216
930	0.6302	-0.0041	-0.0070
970	0.5825	0.0101	-0.0331
1010	0.6081	0.0029	-0.0371
1050	0.6661	0.0055	-0.0935
Contribution rate	0.9809	0.0136	0.0038
Total contribution rate	0.9809	0.9945	0.9983

The scatter diagram against PC1 and PC2 indicated that reflectance factors did not show any obvious trend for each cultivar (Fig. 2A). The fact that PC1 scores were different among fertilizer treatment (Fig. 2B) suggested that effect of leaf quantity was larger than that of leaf appearance (Fig. 2C). Cluster analysis also indicated that reflectance factors were similar among fertilizer treatment but not among cultivars (Fig. 3). These results indicate that distinction of slight difference among leaf appearance as shown in Fig. 2C is necessary at least to distinguish rice ecotypes.

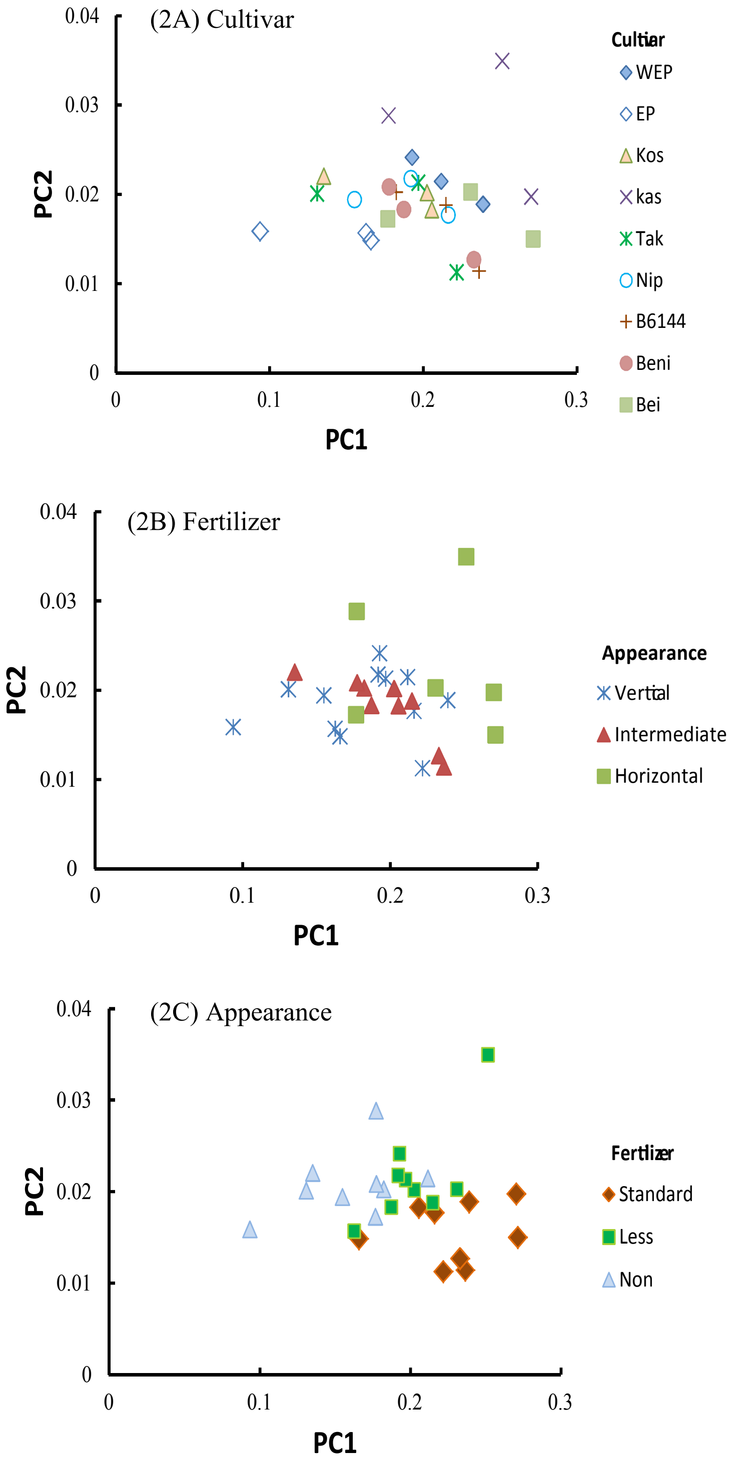


Figure 2: Scatter diagram against principal component 1 and 2. Fig. 2A is a sort of cultivar, Fig. 2B is a sort of fertilizer and fig. 2C is a sort of appearance.

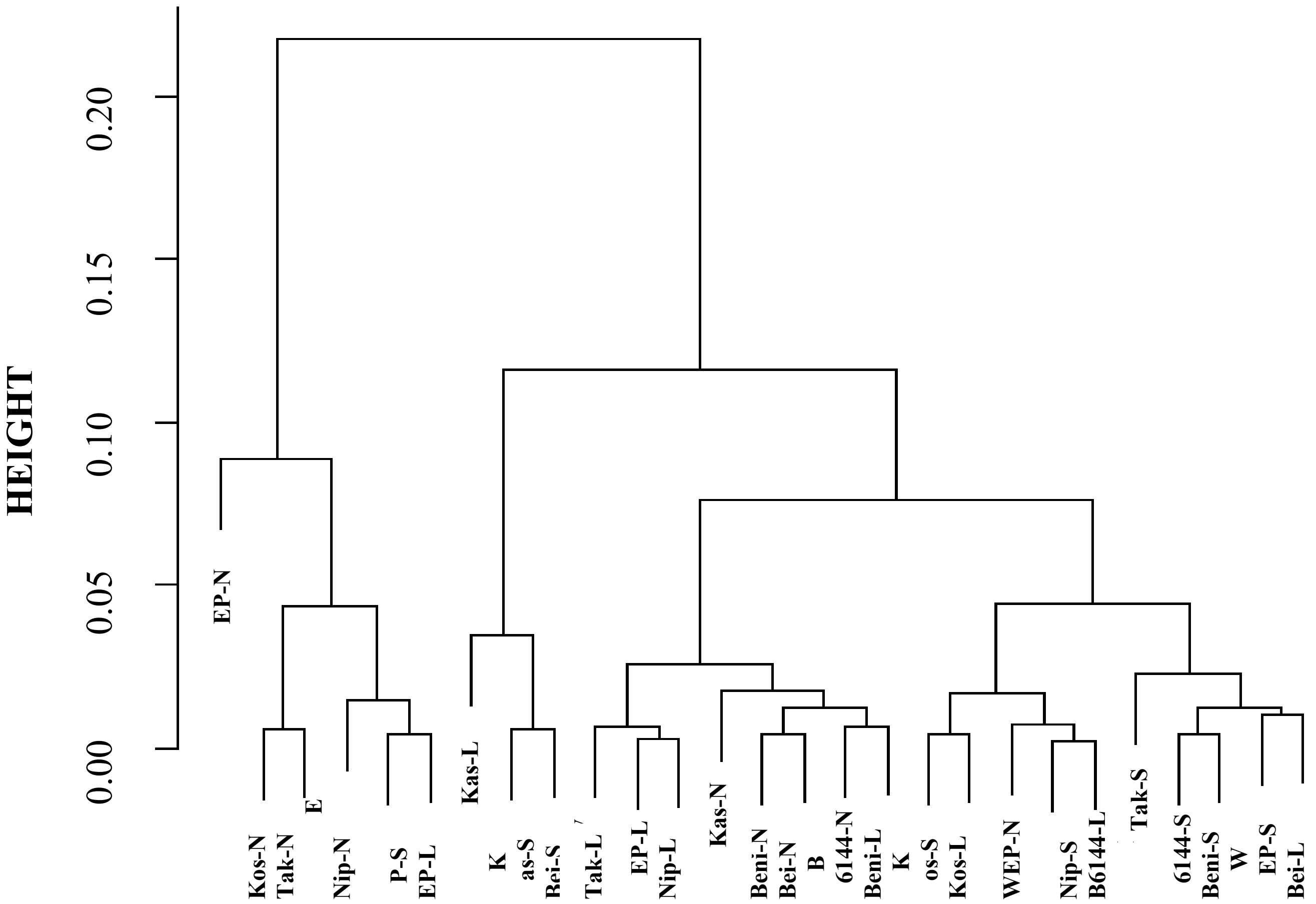
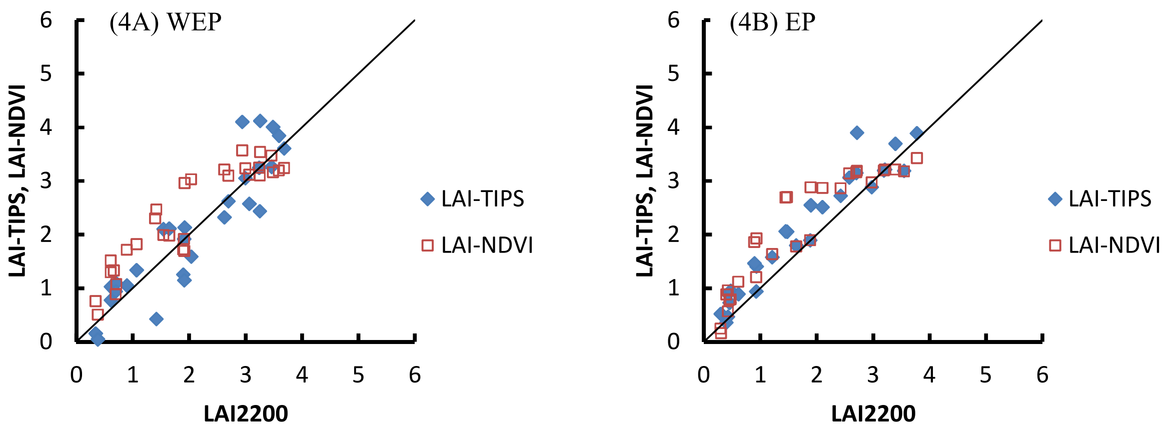


Figure 3: Cluster analysis against PC1and PC2

Hashimoto et al. (2009) developed new index (TIPS: Time-series change Index of Plant Structure) to express seasonal change of plant canopy structure. They also indicate that TIPS is less sensitive to leaf angle distribution and more sensitive to leaf area index (LAI) than NDVI. Based on the context, NDVI can be considered as the index of canopy coverage. Accordingly, the difference between TIPS and NDVI may show the difference between LAI and canopy coverage, of which difference are ordinary used to distinguish rice ecotypes.
Figure 4 shows the difference in LAI estimated by TIPS and NDVI against measured by canopy analyzer (LAI 2200). Estimations of LAI for EP by TIPS and NDVI were similar and closely correlated with that by LAI 2200 (Fig. 4B), being caused by vertical leaf appearance. On the contrary, the estimation for Kasalath and Beniasahi were not so accurate and the estimation by NDVI was relatively larger than that by TIPS, being caused by horizontal leaf appearance. The estimation accuracy for B6144 was also not so good, may suggest that leaf appearance is similar with Kasalath and Beniasahi. The result may recommend quantification of leaf appearance.



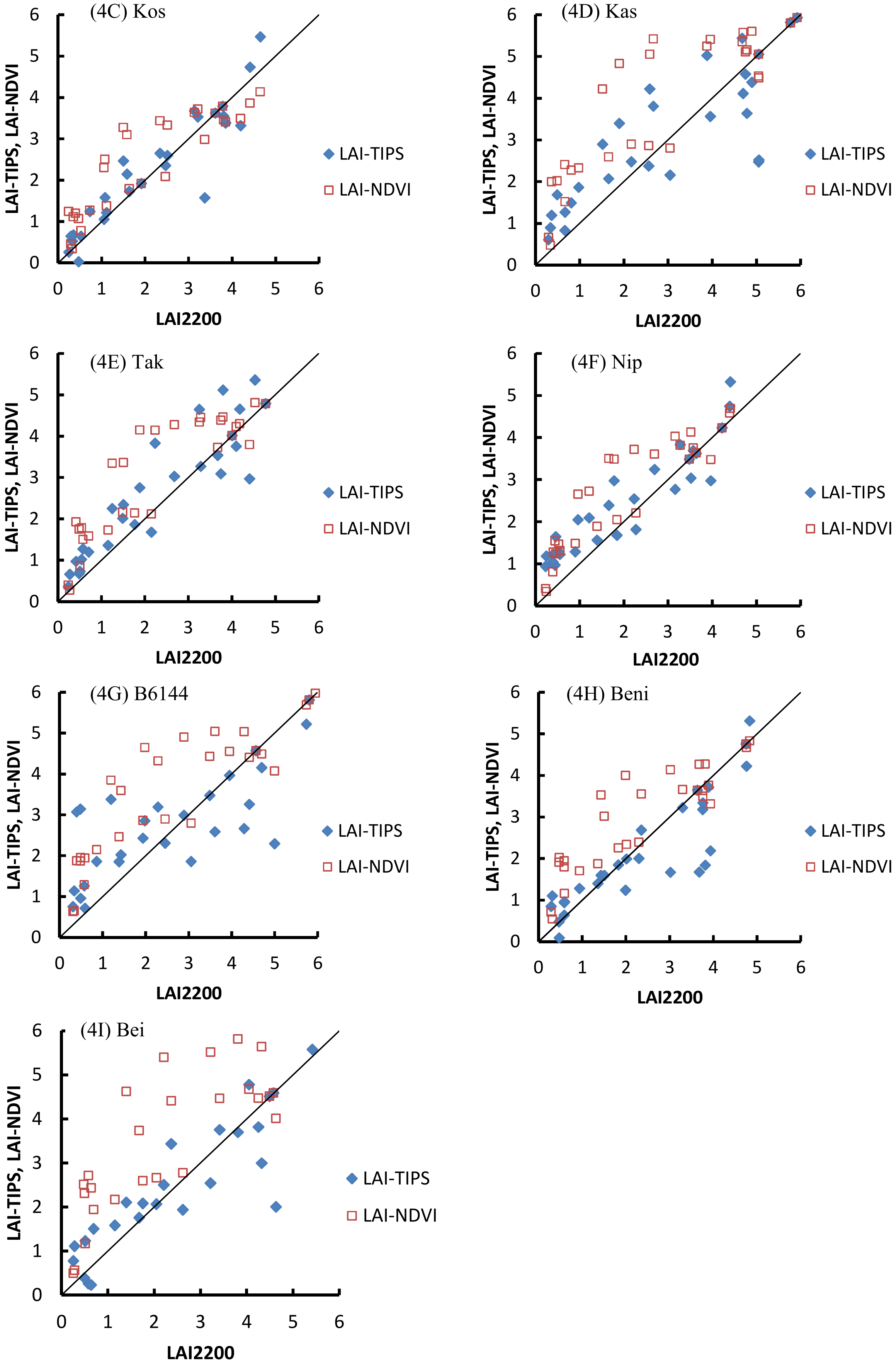


Figure 4: Estimations of LAI by TIPS and NDVI.

The comparison between estimated LAI by TIPS and NDVI clearly shows the responsiveness of two indices of which responsiveness are different among leaf appearance (Fig. 5). Scatter points distribute on y=x line for EP but convexly-upward for Kasalath. In order to make the responsiveness to index, the average slope of regression line of LAI estimated by NDVI against that by TIPS at LAI 2200 value from 0 to 3.5 were calculated for each cultivar (Table 3). The order of slopes seems to be relatively consistent with leaf appearance. However, WEP, dabble-dense-cultivated EP, has larger slope, suggests that this slope may be still affected by density of leaves.

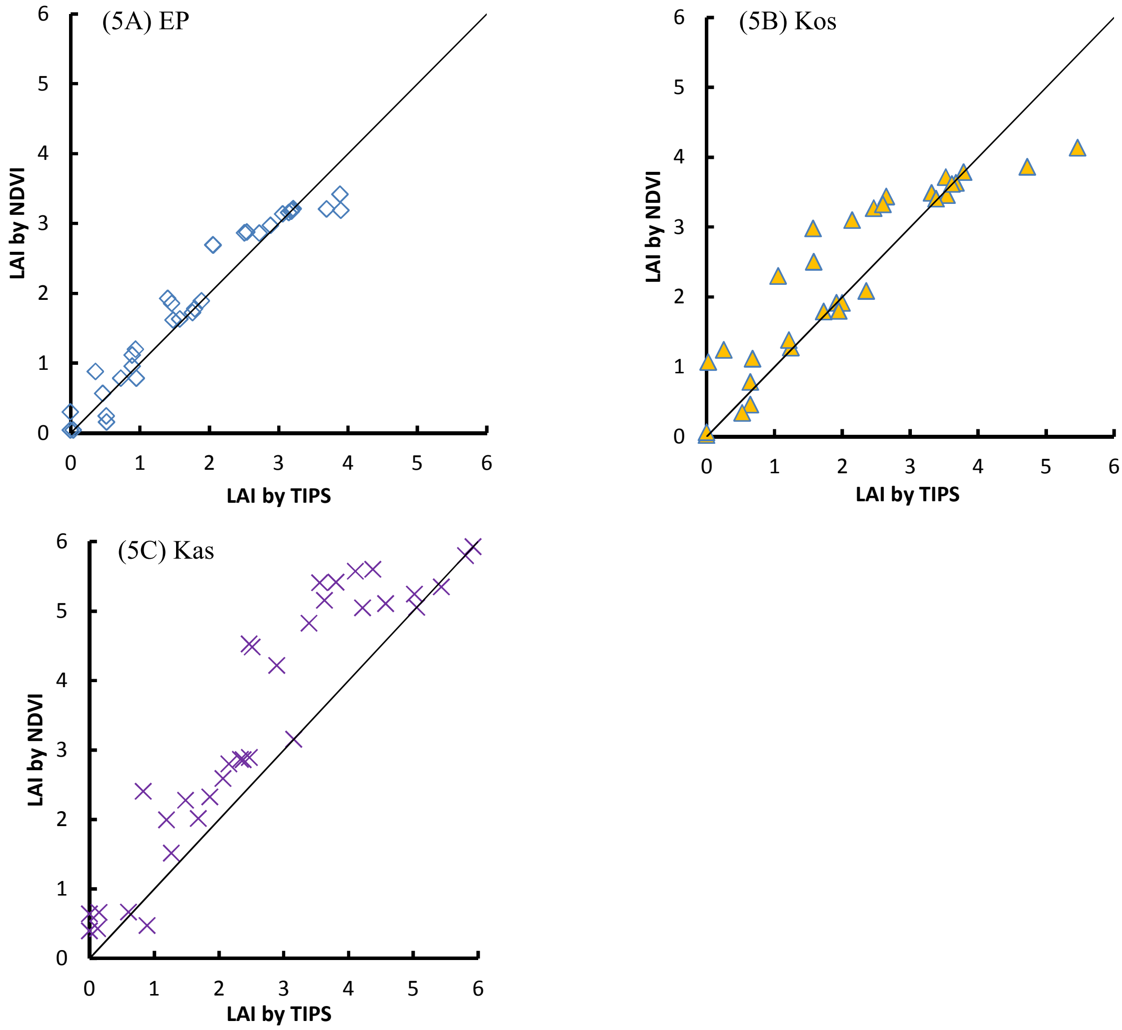


Figure 5: The comparison between estimated LAI by TIPS and NDVI

Table 3: The average slope of regression line of LAI estimated by NDVI against that by TIPS at LAI2200 value from 0 to 3.5

Cultivar	Inclination (NDVI／TIPS)	Appearance
WEP	1.38	Vertical
EP	1.10	Vertical
Kos	1.29	Intermediate
Kas	1.32	Horizontal
Tak	1.27	Vertical
Nip	1.27	Vertical
B6144	1.42	Intermediate
Beni	1.68	Intermediate
Bei	1.68	Horizontal

CONCLUSIONS & RECOMMENDATIONS

Since statistical analysis indicated that reflectance factors are not so different among rice ecotypes, the study analyzed how to distinguish leaf appearances. Based on the report that TIPS is the index for LAI while NDVI is for canopy coverage, we focused on the difference in estimated LAI between by TIPS and by NDVI. The slope of regression line of LAI estimated by NDVI against that by TIPS was corresponded with the leaf appearance: the slope for vertical leaf appearance cultivar tends to be almost 1, but that for horizontal leaf appearance cultivar tends to be more than one. This study only analyzed leaf appearance which one of the characteristics to distinguish rice ecotypes. Therefore distinction of another characteristic, ex. leaf nitrogen concentration, may be necessary to be applied for the purpose.

REFERENCES

Aboelghar, M., Arafat, S., Abo Yousef, M., El-Shirbeny, M., Naeem, S., Massoud, A., 2011. Using SPOT data and leaf area index for rice yield estimation in Egyptian Nile delta. The Egyptian journal of remote sensing and space science. 14 (2) pp.81-89.

Hashimoto, N., Maki, M., Tanaka, K., Tamura, M., 2009. Study of method for extracting LAI time-series patterns for the estimation of crop phenology. Journal of the remote sensing society of Japan 29 (2), pp.381-391.

Homma, K., Maki, M., Hirooka, Y. 2012. Toward to develop a simulation model to evaluate geographical distributions of rice growth and yield. Jpn. J. Crop Sci. 81 (Extra issue 1), pp. 410-411.

Inoue, Y., Sakaiya, E., Zhu, Y., Takahashi, W., 2012. Diagnostic mapping of canopy nitrogen content in rice based on hyperspectral measurements. Remote sensing of environment. 126. pp.210-221.

Oki, K., Oguma, H., 2002.Estimation of the canopy coverage in scientific forest using remotely sensed data-estimation of alder trees in the Kushiro Mire-. Journal of the remote sensing society of Japan. 22 (5) pp.510-516.

Peng, D., Huete, R, A., Huang, J., Wang, F., Sun, H., 2011. Detection and estimation of mixed paddy rice cropping patterns with MODIS data. International journal of applied earth observation and geoinformation. 13.pp.13-23.

Yoshida, H., Horie, T., 2010. A model for simulating plant N accumulation, growth and yield of diverse rice genotypes grown under different soil and climate conditions. Field crops research 117. pp.122-130.