HYPERSPECTRAL REMOTE SENSING OF RIPARIAN VEGETATION AND LEAF CHEMISTRY CONTENTS

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ABSTRACT: An experiment was carried out to determine whether lignin, cellulose and nitrogen contents of leaves could be estimated from near infrared (NIR) reflectance spectra for riparian fallen leaves from 2 bamboos, 7 herbaceous plants, 8 deciduous and 3 evergreen trees. In laboratory, NIR spectra were obtained for each 38 samples of nondestructive accumulated leaves and dry powder, after grinding them. The nondestructive leaves were in various form depending on the plant species. Reflectance spectra were recorded as log(1/R) and transformed to the first and second derivative of log(1/R). Lignin and cellulose were measured using wet chemistry separation technique. Nitrogen was measured using CHN elemental analyzer. Leaf chemistry contents show significant differences in figure types of plants. In order to estimate chemical contents, stepwise multiple linear regression was performed with log(1/R), the first derivative of log(1/R) and the second derivative of log(1/R) in datasets of nondestructive leaves and dry powdered leaves. The best estimation for lignin and cellulose of nondestructive cumulated leaves appeared with the first derivative of log(1/R). For nitrogen, the best prediction was found in the second derivative of log(1/R) and the first derivative of log(1/R) was also around the same value. Stepwise multiple linear regressions show squared multiple correlation coefficient values (R^2) of 0.89 for lignin, 0.94 for cellulose and 0.80 for nitrogen. On the other hand, the best estimation for lignin, cellulose and nitrogen of dry leaf powder appeared with the first derivative of log(1/R). Stepwise multiple linear regressions show R^2 of 0.89 for lignin, 0.93 for cellulose and 0.93 for nitrogen. In cases of dry powder which ground leaves show higher R^2 value than nondestructive leaves. As for R^2 value, the regression produced suitable results for estimating lignin, cellulose and nitrogen. These results suggest that hyperspectral remote sensing for riparian vegetation may be useful for estimating chemistry contents of leaves.

1. INTRODUCTION

Wetland is the most productive ecosystem on earth. The production of organic substances by riparian vegetation is an important factor in the riparian ecosystem. Much of them become detritus or plant litter and get mixed into water and soil. Aquatic plants, algae, micro-organisms and benthic-organisms assimilate nutrients released by detritus and plant litter. Measurement of these parameters are essential to understand the mechanism of the riparian ecosystem and to assess the carbon or nitrogen cycle in regional and global scale. It was not, however, easy to observe spatial distribution of bio-chemical parameters.

Therefore, estimation of leaf chemistry contents using hyperspectral remote sensing could allow predictions of these processes, such as productivity, decomposition, and nutrient turnover. The relationship leaf or canopy spectra in the near infrared region and contents of lignin, cellulose and nitrogen contained in protein or chlorophyll has been examined. These organic compound show absorption in near infrared region caused by harmonics or overtones of the fundamental stretching frequencies or deformations of C-H, N-H and O-H bonds. Lignin and cellulose are the main biochemical compounds which compose the cell wall of plants. Lignin is a polymer of phenylpropanoid and the absorptions appear at 1120, 1200, 1420, 1450, 1690, and 1940 nm. Cellulose is a D-glucose polymer and the absorptions appear at 1200, 1490, 1780, 1820, 1940, 2100, 2270, 2280, 2340 and 2350 nm. Nitrogen,

contained in protein or chlorophyll shows absorptions at 910, 1020, 1510, 1690, 1940, 1980, 2060, 2180, 2240, 2300 and 2350 nm.
This study investigated a hyperspectral observation method to monitor the riparian ecosystem and to measure bio-chemical parameters. The lignin, cellulose and nitrogen contents of fallen leaves from sites in Tamagawa-river were measured using the method of wet chemical procedures and CHN analyzer. Near infrared reflectance spectroscopy was evaluated for estimating lignin, cellulose and nitrogen contents. The datasets with nondestructive fallen leaves and dry powder of fallen leaves were made and compared using stepwise linear regression statistical method. Stepwise regression was used to generate equations of chemical contents from Reflectance spectra and derivative of Reflectance spectra in selected wavelengths. This is the fundamental research for hyperspectral remote sensing studies that deal with the mechanism of the riparian ecosystem.

2. MATERIALS AND METHODS

2.1 Study site

Ground leaves for this study were collected from a riparian site that located in about 52km from the mouth of Tamagawa-river. The native plants peculiar to a dry river bed were growing on the site sparsely in the middle reaches of Tamagawa-river. However, as a result of flux's being stable by upstream dam construction and river repair, most of them were covered by vegetation and riparian ecosystem was changed its nature. Since invader plants, such as *Robinia pseudoacacia*, had expanded the distribution especially, native plants, such as *Aster kantoensis* becoming endangered.

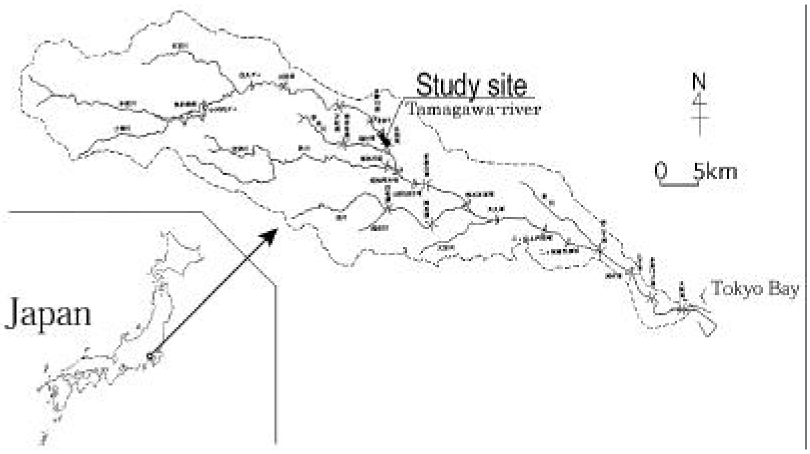


Fig. 1. Study site in the midstream of the Tamagawa-river.

2.2 Leaves collection

In all 20 Species, 2 bamboos, 7 herbaceous plants, 8 deciduous and 3 evergreen trees were selected from riparian plant communities at Tamagawa-river. Collection of leaves were done in such a day that no rainfall occurred before the day of collection. A part of samples were separated for chemical analysis. After blowing away the dirt which adhered to the surface of leaves with the airbrush, leaves were placed in a drying oven at 70°C for 24 hr. And the dry leaves were ground with the blender, mortar and pestle. The other samples for spectral measurements were placed in the laboratory without destroying. They were dried automatically.

Table 1. List of the plant species from riparian site of Tamagawa-river.

Scientific name	Family	Figure	Number of samples
Miscanthus sacchariflorus	*POACEAE*	herbaceous plant	1
Miscanthus sinensis	*POACEAE*	herbaceous plant	2
Imperata cylindrica	*POACEAE*	herbaceous plant	2
Zoysia japonica	*POACEAE*	herbaceous plant	2
Phragmites japonica	*POACEAE*	herbaceous plant	2
Phragmites communis	*POACEAE*	herbaceous plant	2
Pueraria lobata	*LEGUMINOSAE*	herbaceous plant	2
Pinus densiflora	*PINACEAE*	woody plant	2
Cryptomeria japonica	*TAXODIACEAE*	woody plant	3
Juglans mandshurica var. sachalinensis	*JUGLANDACEAE*	woody plant	3
Salix subfragilis	*SALICACEAE*	woody plant	2
Salix integra	*SALICACEAE*	woody plant	1
Quercus acutissima	*FAGACEAE*	woody plant	3
Quercus serrata	*FAGACEAE*	woody plant	1
Quercus glauca	*FAGACEAE*	woody plant	2
Celtis sinensis var. japonica	*ULMACCEAE*	woody plant	1
Zelkova serrata	*ULMACCEAE*	woody plant	1
Robinia pseudoacacia	*LEGUMINOSAE*	woody plant	2
Pleioblastus chino	*POACEAE*	bamboo	3
Phyllostachys bambusoides	*POACEAE*	bamboo	1

2.3 Spectral measurements

Spectral measurements in the 800-2,500nm range of nondestructive leaves and dry powder of ground leaves were conducted with FieldSpec Pro FR(Analytical Spectral Devices, Inc.). The resolution of the wavelength of this instrument is around 2nm, and can perform the sampling of a spectrum at intervals of 1nm. The halogen lamp was used for the light source. It was installed in the angle upper part of 45 degrees to the sample. The tip of the bare optical fiber of 25 view angles is installed in the perpendicular upper part of a sample. Reflectance was measured by using Spectralon(Labsphere, Inc.) as a standard white board.
The undestroyed leaves were accumulated on the turntable so that a background might not be in sight. The nondestructive leaves were various in form depending on the plant species. In order to mitigate the problem of the non-Lambertian properties, the turntable was went into a 360 degree roll and eight spectra were acquired. The dry powder which ground leaves were flattened out with a medicine spoon and the thickness of about 1mm were covered with it. Like the nondestructive leaves, the turntable was rotated and eight spectra of ground powder leaves were acquired.
In order to reduce a noise, reflectance spectra was smoothed using Savitzky-Golay filtering. The reflectance spectra was converted to log(1/R) because of approximately linear relation between the concentration and log(1/R) value at the wavelength absorbed. Additionally, log(1/R) were transformed to the first and second derivative of log(1/R) for statistical analysis.

2.4 Chemical analysis

The dry powder of leaves were used for chemical analysis. Lignin and cellulose were measured using wet chemistry separation technique(Van Soest and Wine, 1968). Cell wall components, such as lignin and cellulose were separated by use of detergent with which cetyl trimethyl ammonium bromide contains.
Nitrogen was measured using CHN elemental analyzer 2400(PerkinElmer, Inc.). This instrument performs elemental analysis of substances and determines contents of carbon, hydrogen and nitrogen through combustion.

3. RESULTS

3.1 Leaf chemistry contents

Lignin, cellulose and nitrogen contents of 2 bamboos, 7 herbaceous plants, 11 trees are shown as percentages of dry weight in Table 2. The mean value of cellulose was little higher than lignin, and the variance lignin was lager than cellulose. Kruskal-Wallis test was performed for three groups of herbaceous plant, bamboo and woody plant. The significant difference ($p< 0.01$) were recognized in lignin and cellulose. This statistical method does not show the significant deference about all combination. However, the lignin content in woody plants were higher than herbaceous plants and bamboos. Herbaceous plants of cellulose was the highest, the next was bamboos, and the minimum was woody plants. Thus, leaf chemistry contents show differences in figure types of plants.

Table 2. Result of chemical analysis which shows percentages of dry weight.

	n	Range (%)		Mean	Variance
		min	max		
Lignin	38	5.5	43.1	20.5	143.9
Cellulose	38	14.2	40.1	24.4	43.8
Nitrogen	38	0.4	2.8	1.3	0.3

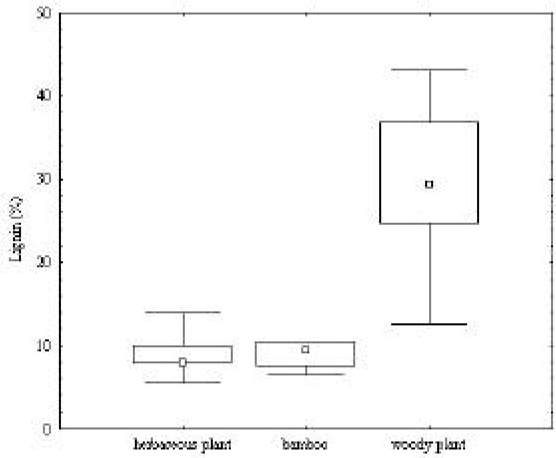


Fig. 2. The difference of lignin content among plant figure, such as herbaceous plant, bamboo, and woody plant.

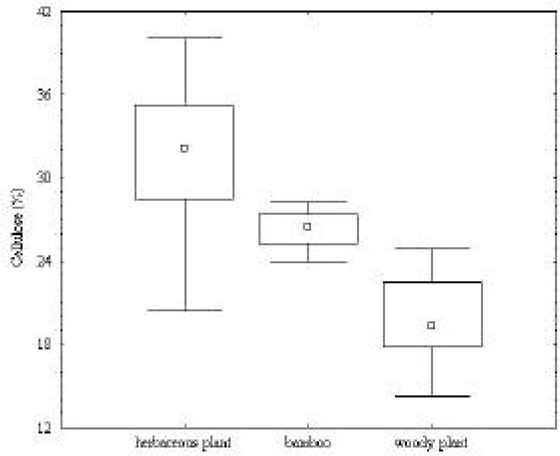


Fig. 3. The difference of cellulose content among plant figure, such as herbaceous plant, bamboo, and woody plant.

3.2 Correlation between NIR reflectance spectra and chemical contents

Pearson's product moment correlation coefficient was calculated for NIR reflectance spectra and chemical contents. The correlation coefficient can range between -1 to +1. A correlation coefficient of positive value signifies a positive relationship, while negative value shows a negative relationship. If the correlation coefficient is zero, it shows non-correlated. Pearson's correlation coefficient express the degree of linear relationship between NIR reflectance spectra and chemical contents of lignin, cellulose and nitrogen. The correlogram in Fig. 4 shows that there are characteristic wavelengths which correlate with chemical contents and the chemical contents might be estimated from NIR spectra.

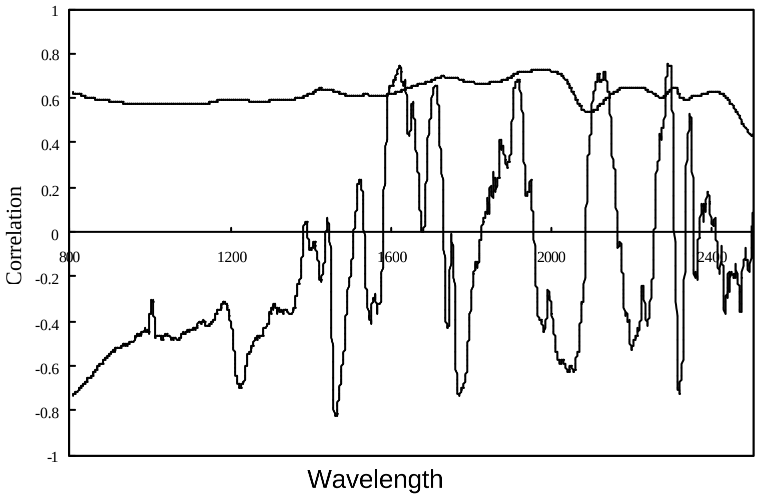
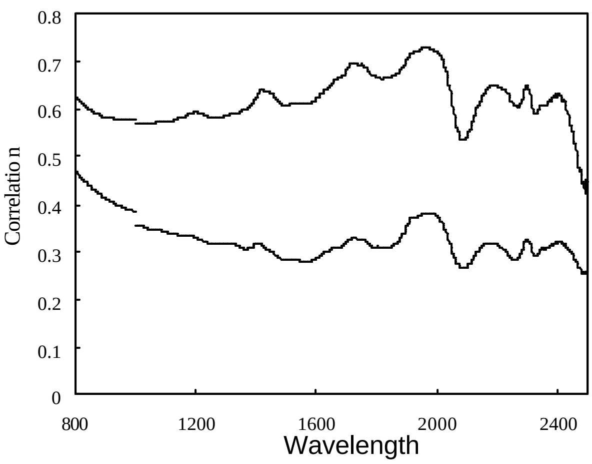


Fig. 4. Correlogram of log(1/R) and the first derivative of log(1/R) reflectance spectra to lignin content. The upper line in slight variation is log(1/R) and the lower varied line is the first derivative of log(1/R).

The correlogram in Fig. 5 plots the log (1/R) spectra of nondestructive accumulated leaves and the log (1/R) spectra of dry powder which ground them. The correlation coefficient of ground leaves is higher than that of nondestructive leaves. However, the correlograms resemble in spectral signature. The correlogram signature shows that the relationship between reflectance spectra and chemical content is not confounded by factors, such as angle of sensor, and leaf angle, light angle. The correlogram in Fig. 6 shows the relationship between the log (1/R) spectra of nondestructive accumulated leaves and the log (1/R) spectra of dry powder. The wavelength with low correlation coefficient values appear at the absorption features for water centered around 1400 and 1900 nm wavelength. The water spectra dominates the reflectance spectra and the signature of spectra is masked (Curran, 1989).



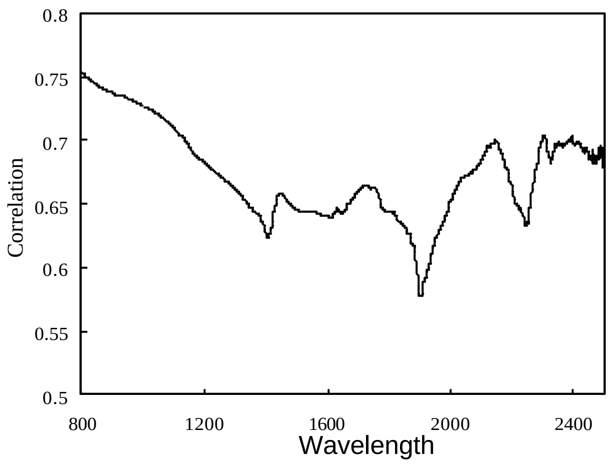


Fig. 5. Correlogram of log(1/R) spectra of nondestructive spectra of leaves and dry powder to lignin content. The upper powder. The low line is dry powder and the lower line is nondestructive around the wevelength of leaves. These correlograms resemble in spectral signature.

Fig.6. Correlogram of log(1/R) nondestructive leaves to dry correlation values appear water absorption.

3.3 Estimation of leaf chemistry contents by statistics

In order to estimate chemical contents, stepwise multiple linear regression was performed with log(1/R), the first derivative of log(1/R) and the second derivative of log(1/R) in datasets of nondestructive leaves and dry powder of leaves. The regression tested the effects of a maximum of 4 predictor variables to avoid the overfitting problem.

The best estimation for lignin and cellulose of nondestructive cumulated leaves appeared with the first derivative of log(1/R). For nitrogen, the best prediction appeared with the second derivative of log(1/R) and the first derivative of log(1/R) was also about the same value. Stepwise multiple linear regressions showed squared multiple correlation coefficient values (R^2) of 0.89 for lignin, 0.94 for cellulose and 0.80 for nitrogen.

	Lignin (n=38)			Cellulose (n=38)			Nitrogen (n=38)		
	Selected Wavelength	R^2	*SEP*	*Selected Wavelength*	R^2	*SEP*	*Selected Wavelength*	R^2	*SEP*
log(1/R)	802	0.23	10.80	802	0.23	5.96			
	811	0.47	9.13	812	0.55	4.64			
1st Derivative	2487	0.67	7.08	2064	0.68	3.85	2199	0.42	0.45
	1921	0.77	6.04	1671	0.86	2.59	822	0.57	0.39
	1388	0.83	5.17	1139	0.90	2.19	1941	0.68	0.34
	1895	0.89	4.33	2072	0.94	1.73	1993	0.80	0.28
2nd Derivative	1863	0.38	9.69	856	0.47	4.96	1025	0.40	0.46
	1841	0.64	7.52	1231	0.66	4.03	2135	0.60	0.38
	968	0.72	6.67	2106	0.74	3.55	2190	0.73	0.32
	934	0.80	5.78	1869	0.82	3.01	1935	0.80	0.28

Transition of R^2

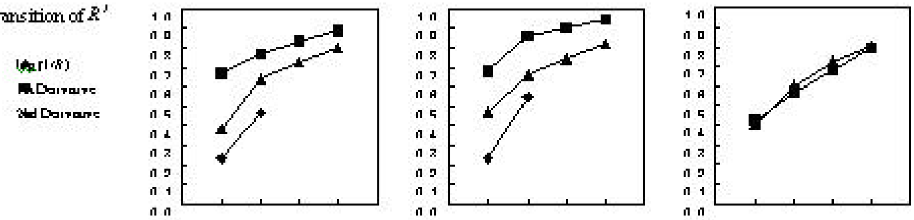


Fig. 7 Result of stepwise multiple linear regression for the dataset of nondestructive leaves. The selected wavelengths and the transition of R^2.

On the other hand, the best estimation for lignin, cellulose and nitrogen of dry leaf powder appeared with the first derivative of log(1/R). Stepwise multiple linear regressions show R^2 of 0.89 for lignin , 0.93 for cellulose and 0.93 for nitrogen.

	Lignin (n=38)			Cellulose (n=38)			Nitrogen (n=38)		
	Selected Wavelength	R^2	*SEP*	*Selected Wavelength*	R^2	*SEP*	*Selected Wavelength*	R^2	*SEP*
log(1/R)	1963	0.53	8.45	1989	0.48	4.91	800	0.16	0.54
	2067	0.59	8.05	1894	0.68	3.88	2496	0.31	0.50
	2372	0.69	7.08	2072	0.81	3.08	2454	0.50	0.43
	2354	0.80	5.76	2162	0.89	2.31			
1st Derivative	1456	0.72	6.47	1613	0.82	2.91	2067	0.74	0.30
	1820	0.80	5.61	2285	0.87	2.46	1722	0.82	0.25
	2310	0.85	4.86	2135	0.91	2.13	1490	0.89	0.20
	1878	0.89	4.28	2421	0.93	1.82	2086	0.93	0.17
2nd Derivative	1662	0.43	9.29	1428	0.57	4.45	1516	0.44	0.44
	1759	0.70	6.89	1450	0.79	3.13	1503	0.59	0.39
	2180	0.77	6.03	1414	0.87	2.49	2019	0.70	0.33
	1683	0.84	5.10				2009	0.79	0.29

Transition of R^2

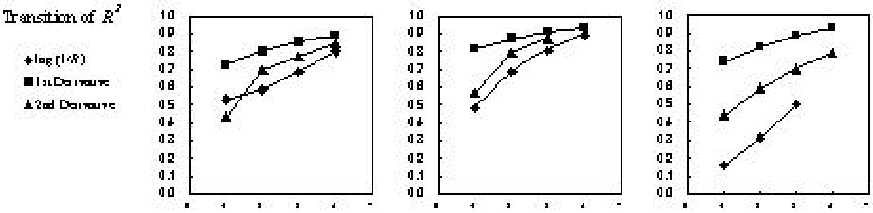


Fig. 8. Result of stepwise multiple linear regression for the dataset of dry powder. The selected wavelengths and the transition of R^2.

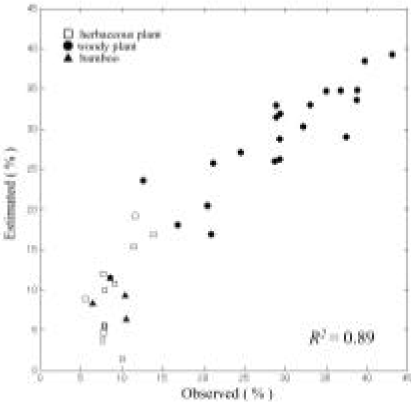


Fig. 9. Relationship between observed lignin contents and estimated contents values.

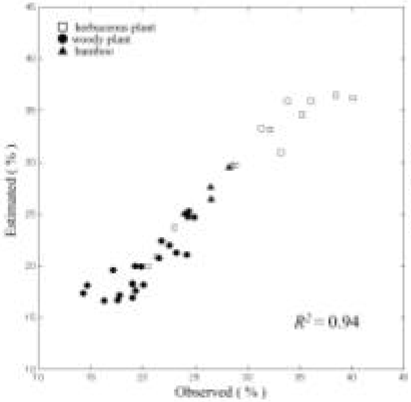


Fig.10. Relationship between observed cellulose contents and estimated contents values.

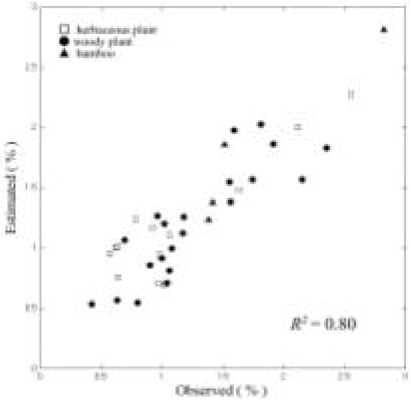


Fig.11. Relationship between observed nitrogen contents and estimated contents values.

In cases of dry powder show higher R^2 value than nondestructive leaves. The selected wavelengths close to the known absorption wavelengths of lignin, cellulose and nitrogen, but were not necessarily related to the known absorption wavelengths. Among nondestructive samples and ground powder samples, the selected wavelengths varied. In the use of stepwise multiple linear regression, wavelength selection does not appear to be based upon the chemical known absorption (Grossmann et al., 1996). However, as for R^2 value, the regression produced suitable results for estimating lignin, cellulose and nitrogen. Relationship between chemistry contents and estimated chemistry contents from multiple regression reflectance are shown in Fig.9, Fig.10 and Fig.11.

5. DISCUSSION AND CONCLUSIONS

The result of stepwise multiple linear regression for estimating lignin, cellulose and nitrogen yielded large correlation coefficient (R^2) values. But there are still several problems remaining such as the accuracy of chemical contents analysis. The relation between selected wavelengths and chemical known wavelengths, or the relation between the selected wavelengths of nondestructive leaves and dry powder should be clarify. Also, the effect of riparian plant species composition on selected wavelengths should be considered. More tests over other datasets using another method of chemical analysis or expanded species and number of samples are required. However the results of this research suggest that hyperspectral remote sensing of riparian vegetation may be useful for estimating leaf chemistry contents. Lignin, cellulose and nitrogen contents of fallen leaves can be estimated using near infrared reflectance spectra with not destroying leaves.

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