

# CORRELATION ANALYSIS BETWEEN INDICES OF TREE LEAF SPECTRAL REFLECTANCE AND CHLOROPHYLL CONTENT

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### ABSTRACT:

This study was conducted to investigate variations of leaf chlorophyll content and surface spectral reflectance of different tree species (*Daphniphyllum glaucescens*, *Michelia formosana*, *Illicium dunnianum* and *Machilus kusanoi*) across contrasting terrain in the Nanjenshan Reserve of Kenting National Park, Southern Taiwan. The results showed that there were significant differences ( $P < 0.01$ ) among the REP (Red Edge Position) with total chlorophyll concentration ( $R^2=0.508$ , *Daphniphyllum glaucescens*;  $R^2=0.667$ , *Michelia compressa*;  $R^2=0.503$ , *Illicium dunnianum*;  $R^2=0.774$ , *Machilus kusanoi*). The vegetation index from hyperspectral measured positively correlated with total chlorophyll concentration in all species SR705 ( $R^2=0.236$ ,  $P<0.000$ ); mSR705 ( $R^2=0.5283$ ,  $P<0.000$ ); ND705 ( $R^2=0.265$ ,  $P<0.000$ ) and mND705 ( $R^2=0.573$ ,  $P<0.000$ ). The results suggest that the REP could be used to estimate the chlorophyll content in tree leaves. The index mNDVI705 seemed more sensitive to detecting chlorophyll content in a wide range of tree species across a terrain. Results obtained in this paper discuss using hyperspectral data to estimate the actual leaf chlorophyll content by using low costing and time-saving procedures.

## 1. INTRODUCTION

Green plants all have unique spectral features, mainly because of the chlorophyll and carotenoid and other pigments and water content can together constitute the spectral feature of a plant (Philip and Shirly, 1978). Traditionally, the predominant method for measuring chlorophyll content is using the spectrophotometer; with this method plant tissues are used, which costs more time and sustain some damage to the plants. Therefore, a portable hyperspectral instrument for testing is an alternative method that can be carried out without hindering chlorophyll measurements through reflection, transmittivity and absorption (Chappelle et al., 1992). This method showed the unique application of hyperspectral technology in estimating chlorophyll content of vegetation. The application of hyperspectral can help us get much information, and the information can not be acquired from traditional wide wavelength spectra or ratio parameters. Therefore using high analytical spectrum instrument (e.g., AVIRIS, CASI, LI-1800, GER1500) allows us to directly decide the red edge reflection value (the reflection value on the first derivative peak). In addition, a linear method or a polynomial method may be adopted to estimate the chlorophyll content of plants. The chief method adopted by many predecessors, when using hyperspectral remote sensed data to assess vegetation, is regression method, which is used to decide the wavelengths that are related with the content of chlorophyll. Regression analysis (or the structure of wavelengths, including vegetation index and differential spectra) is then conducted between these wavelengths and chlorophyll content to establish some

regression models. Researchers have also used the above theoretical basis to estimate the chlorophyll contents, nitrogen nutrition condition, growing trend, effective radiation in photosynthesis, and biomass of plants (Dalezios et al., 2001; Thenkabail et al., 2000) and on the aspect of ecological system there are studies on the vertical layers of forests (Blackburn, 1998). The spectral reflection feature of a leaf is usually directly related with the surface characteristic, leaf structure, water content and chlorophyll content (Gausman, 1982). In order to compare the spectral difference among leaves of different species with different shapes of leaf, in this research, mNDVI given by Sims and Gamon (2002) was taken as NDVI for comparison. Most studies related with (REP) are limited in the areas of the growth of agriculture products and the estimation of their yields. However, since few studies are concerned with forests, the focus of this study is on the relationship between hyperspectral data such as vegetation index, and REP optical coefficient, and chlorophyll content based on 4 tree species taken from 3 topographical areas such as windward, valley, and leeward. This data can provide more reliable information on the application of hyperspectral data in the study of forest vegetations' indices.

## 2. MATERIALS AND METHODS

### 2.1 Study Area

The leaf samples of four species used in this study were collected from Nanjenshan Nature Reserve of Kenting National

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Park, Southern Taiwan. The annual mean temperature at the study area was 22.9°C and annual rainfall was 2,592.4 mm during 1997-2005. In Nanjenshan Nature Reserve, forest vegetation distribution is influenced by three major terrains; windward, valley and leeward (Hsieh and Hsieh, 1990). In this area the winter precipitation and the intensity of northeast winds were found to correlate with the differentiation of forest types. Those in the northeast district are evergreen since the wind is rather moist. The thorny scrubs and deciduous scrubs appear in the southwest district due to severe dry winds. The high species diversity of Kenting National Park is largely attributed to the heterogeneous environment (Su and Su, 1988).

## 2.2 Plant Materials

Measurement of leaf spectral reflectance was obtained by randomly harvesting leaves from 4 species from the three types of terrain. From each terrain type, 1 sampling site from the leeward area and 2 sampling sites from the windward and valley areas, respectively, were selected. Fifty sample leaves taken from the top of the canopies of each species and was carried out in late April of 2005. Leaf samples were stored in plastic bags and kept cool for further analysis.

## 2.3 Measurement of Leaf Chlorophyll Content and Spectral Reflectance

In this research, the biochemical analysis of chlorophyll followed the method of Yang *et al.* (1998). Leaf spectra were obtained from all the sampling leaves of 4 species which are in same ages and same size of the same tree species. Leaf specimens were collected from 3 different terrains pots per treatment randomly. We obtained a sample size *Daphniphyllum glaucescens* of n=35. This was *Michelia formosana* samples short of an expected n=34, *Illicium dunnianum* that is n=32 and *Machilus kusanoi* n=26 for the different species and terrains, respectively. Leaf spectral measurement was conducted using a GER1500 (Spectra Vista Corporation, NY, USA). Measurements were taken between 09:30 AM and 14:30 PM. Conditions varied from cloud-free to overcast skies but care was taken to avoid measurement when clouds were passing overhead or darkened.

## 2.4 Data Analysis

All statistical analyses were conducted using the STATISTICA statistical software (Version 6.1, StatSoft Inc. Tulsa, Oklahoma, USA, 2002). Coefficients of determination ( $R^2$ ) were calculated for relationships between various chlorophyll content from the result of biochemical analysis treated as independent variables and vegetation indices and REP were collected from GER1500 treated as dependent variable. To test and verify the relationship of chlorophyll content between vegetation indices and REP, regression analyses were used in the first data analysis step. The vegetation indices NDVI (Eqn. 1) and simple ratio (SR) (Eqn. 2) were used to calculate the vegetative indices obtained from spectral reflectance measurements:

$$NDVI_{705} = \frac{R_{750} - R_{705}}{R_{750} + R_{705}} \quad (1)$$

$$SR_{705} = \frac{R_{750}}{R_{705}} \quad (2)$$

where the wavelengths for NDVI and SR were 705 and 750 nm, respectively, and are based on the chlorophyll index developed by Gitelson and Merzlyak (1994).  $R_{705}$  and  $R_{750}$  are the leaf sample spectral reflectance from the GER1500. Based on the results of Sims and Gamon (2002), they modified these two indices which tend to increase reflectance across the whole visible spectrum of a wide range of species. They chose  $R_{445}$  as a measure of surface reflectance and indicated that  $R_{445}$  is a good reference for all but the lowest chlorophyll content leaves. The modified indices of NDVI and SR are as follows (Eqs. 3 and 4):

$$mND_{705} = \frac{R_{750} - R_{705}}{R_{750} + R_{705} - 2R_{445}} \quad (3)$$

$$mSR_{705} = \frac{R_{750} - R_{445}}{R_{705} - R_{445}} \quad (4)$$

The derivative analysis of spectra reflectance was used primarily to locate the position and height of the inflection point of the red edge. The first derivative was calculated using a first-difference transformation of the reflectance spectrum obtained from the polynomial fit. In this case, the red-edge peak in the derivative spectra was composed of a peak maximum usually between 680 and 750 nm and calculated by the Peakfit curves statistical software (Version 4.12, Systat Software Inc. San Jose, USA). The first derivative was calculated using a first-difference transformation of the reflectance spectrum (Dawson and Curran, 1998) as follows (Eqs. 5):

$$FDR_{(\lambda i)} = (R_{\lambda(j+1)} - R_{\lambda(j)}) / \Delta\lambda \quad (5)$$

where FDR is the first derivative reflectance at a wavelength  $i$ , midpoint between wavebands  $j$  and  $j+1$ ,  $R_{\lambda(j)}$  is the reflectance at the  $j$  waveband,  $R_{\lambda(j+1)}$  is the reflectance at the  $j+1$  waveband, and  $\Delta\lambda$  is the difference in wavelengths between  $j$  and  $j+1$ .

## 3. RESULT AND DISCUSSION

Results of the data collection and analyses of chlorophyll content and leaf reflectance measurements are described here, showing the relationships found between derivative reflectance spectra (REP), vegetation indices and chlorophyll content measurements.

### 3.1 Spectral Reflectance of Four Species

In order to estimate chlorophyll content of tree leaves using spectral reflectance, hyperspectral remote sensing provided new approach for measuring chlorophyll content of plants because of its hyperspectral analytical rate, variety of wavelengths, continuance of wavelengths, and abundance of data. On the aspect of original spectral reflectance, most studies have proven that there is some correlation between spectral variants and pigment content. In addition, some predecessors have discovered that when plants are in different conditions in terms of nitrogen supply, nutrition level or hereditary factors, the leaves' contents of chlorophyll and carotenoid are different, and the pigments' contents of different leaves is also closely related with the environment in which the plant grows. In Fig. 1 we found that using the first derivatives spectra curve to find REP

is more efficient than the traditional method of using original spectra reflectance to explore the change of reflection curve. The relationship between REP and chlorophyll content will be studied further in the following section.

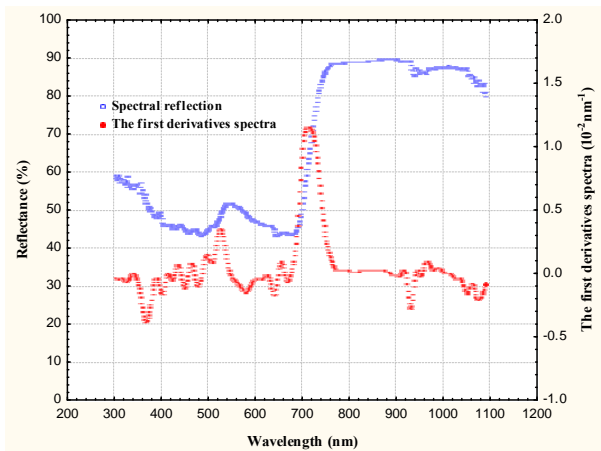


Figure 1. The reflectance spectrum and derivative reflectance spectrum of all species mean spectrum reflectation

### 3.2 Relationship Between REP and Chlorophyll Content

In this study, in order to explore the capability of using REP to estimate the chlorophyll content of leaves, the correlation coefficient related with red edge inflection point, REP and chlorophyll, and carotenoid of each species was analyzed as shown in Table 1.

Table 1. Regression equations relating the parameters of red edge of leaves to their pigment contents for *Daphniphyllum glaucescen*, *Michelia compressa*, *Illicium dunnianum* and *Machilus kusanoi*

Trees	Regression equations	R <sup>2</sup>
<i>Daphniphyllum glaucescen</i>	Chl = 98.584λ <sub>red</sub> - 66761.259	0.508**
	Car = 42.565λ <sub>red</sub> - 28546.904	0.696**
<i>Michelia compressa</i>	Chl = 215.619λ <sub>red</sub> - 149796.414	0.666**
	Car = 74.906λ <sub>red</sub> - 51566.680	0.617**
<i>Illicium dunnianum</i>	Chl = 147.675λ <sub>red</sub> - 102017.431	0.503**
	Car = 66.055λ <sub>red</sub> - 45729.653	0.669**
<i>Machilus kusanoi</i>	Chl = 113.183λ <sub>red</sub> - 77126.258	0.774**
	Car = 42.886λ <sub>red</sub> - 29021.724	0.770**
All species	Chl = 133.989λ <sub>red</sub> - 91865.439	0.577**
	Car = 49.718λ <sub>red</sub> - 33753.059	0.541**

\*\* ,p < 0.01

From Table 1, there is a good correlation between the red edge parameter and the total contents of chlorophyll and carotenoid, and have reached at 0.01 significant level; while on the aspect of the correlation between REP and the total chlorophyll content, *Michelia formosana* and *Illicium dunnianum* reached a great level.

From the above results we understand that the average REP always moved towards longer wavelength with the increase of chlorophyll content, which is called “red shift”; the REPs of all species were in the range of 698 nm-723.2 nm; from the view angle of plant’s physiological condition, when the leaves are senescing or when they are under adverse environmental conditions, their chlorophyll contents may fall gradually, and the location of the red edge tent to move towards shorter wavelength, which is called “blue shift”. This result shows that

the location of red edge comparatively near longer wavelengths range is an index that shows healthy growing.

Based on these preceding results, the samples of the 4 species were comprehensively studied for the relationship between REP and chlorophyll content and carotenoid, and are illustrated in Fig. 2. From Fig. 2, correlation between some indices was obvious not only in the analysis of a single species, but also in the mixed samples of 4 species. From the above results a conclusion may be drawn that whether an analysis is conducted on a single species or a group of tree species, chlorophyll and carotenoid content can be calculated with their linear relationship with REP; REP can faithfully reflect the thickness of pigment in plants’ leaves. These results agree with the studies of most reports, although many researches were about crops (Dalezios *et al.*, 2001; Pattey *et al.*, 2001; Thenkabail *et al.*, 2000).

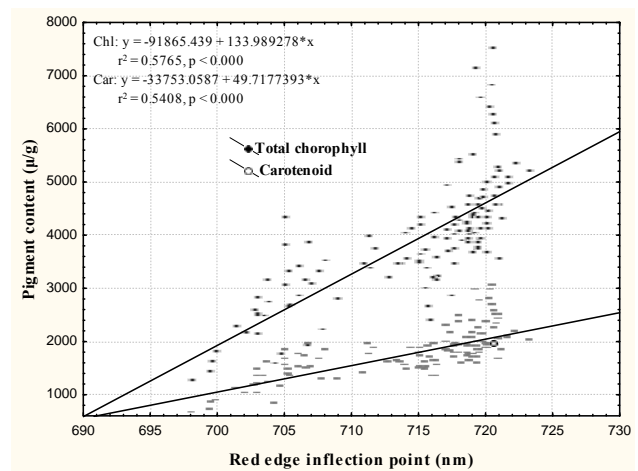


Figure 2. Relationship between leaf red edge inflection point, chlorophyll content and carotenoid content of mixed species.

Pigments extracted with acetone from *Daphniphyllum glaucescen*, *Michelia compressa*, *Illicium dunnianum* and *Machilus kusanoi*

The REP shift to shorter wavelengths due to pigment degradation, as expected and previously reported (Horler *et al.*, 1983; Vogelmann *et al.*, 1993). Despite these described may change in the canopy scale (due to the canopy structural change), it can be seen that the REP indicator of pigment content could be detected from the experiment of REP value in leaf scale. And there were many suitable simulate models for broad leaf canopies to link leaf optical properties with canopy structural characteristics through radiative transfer modeling (e.g., PROSPECT model, SAIL model, LIBERTY model, BOREAS model). The next section describes the results obtained that the relationship between several vegetation indices calculated from the leaf spectral reflectance and leaf pigment content measurements in different terrains.

### 3.3 Vegetation Index and Chlorophyll Content

This study analyzed the relationship between pigment content and NDVI, mNDVI, SR, and mSR; the results of a single tree species are in Fig. 3. From the results we understand that the correlation between 2 modified indices such as mNDVI and mSR and chlorophyll content were much better than the ordinary vegetation indices i.e. NDVI and SR. After the factor of different leaf structures is taken into calculation according to the calculation principle for modified vegetation indices, the

discrepancy caused by different leaf structure is eliminated. This result also shows that using the modified indices can also raise the correlation as mentioned above even in the calculation of spectra reflectance for a single species of tree leaves (the results of mixed species will describe in the following section).

There was an obvious correlation between chlorophyll content and mSR and mNDVI (Fig. 3), which showed that these two indices can be used to effectively estimate the change of

pigment content of a single species. From this result and on the basis of the correlation coefficient for the same species, mNDVI was always higher than NDVI, and there was a huge difference between these two sets of indices. From the analysis of the relationship between the pigment content and SR and mSR, we found that SR was in a relatively random and irregular relationship with the change of pigment contents; their correlation was different for variance species.

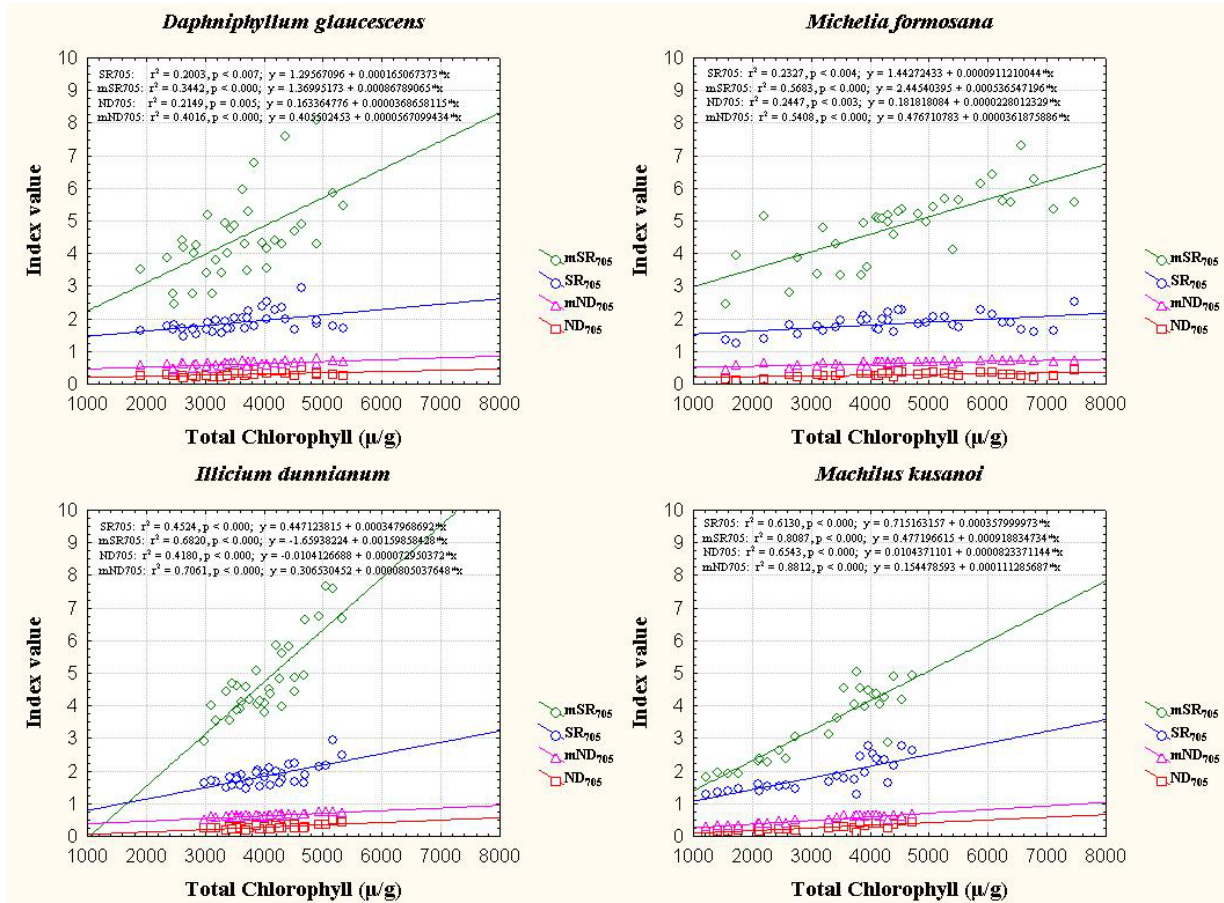


Figure 3. The correlation between chlorophyll content and NDVI, mNDVI, SR, mSR in 4 species

We also analyzed the correlation of the vegetation indices and chlorophyll content of the samples taken from 4 different species of trees and the results are shown in Fig. 4 where the modified indices were in a better correlation with each other for different species. Sims and Gamon (2002) also demonstrated that modified spectral indices can be applied across species with widely varying leaf structure without the necessity for extensive calibration for each species. The results for the most useful in ecological remote sensing studies, the above relationships could be generalized across most species and different leaf ages. Modified indices could be used for the leaf structural variability was simply to understand that the indices can remove the difference only by one major wavelengths 445 nm. Many studies indicated that light reflected directly from the leaf surface never enters the leaf cells and thus is not influenced by pigment and water content. Surface reflection can be greatly enhanced by leaf epidermis (e.g., leaf hairs, surface waxes, cuticle thickness, et cetera), and wavelengths 445 nm can detect the variation (Reicosky and

Hanover, 1978; Slaton *et al.*, 2001). They also demonstrated that modified spectral indices can be applied across species with widely varying leaf structure without the necessity for extensive calibration for each species. From the above results we concluded that for the correlation of mNDVI and mSR with the change of pigment contents of a single species, mNDVI was in a better correlation, and there was a huge difference between mNDVI and mSR in this respect. Following the results, the modified indices were added as a constant to all reflectance values reduces both on SR index and ND index even when there was no change in the leaf absorptance of tissues below the epidermis or in the same tree species.

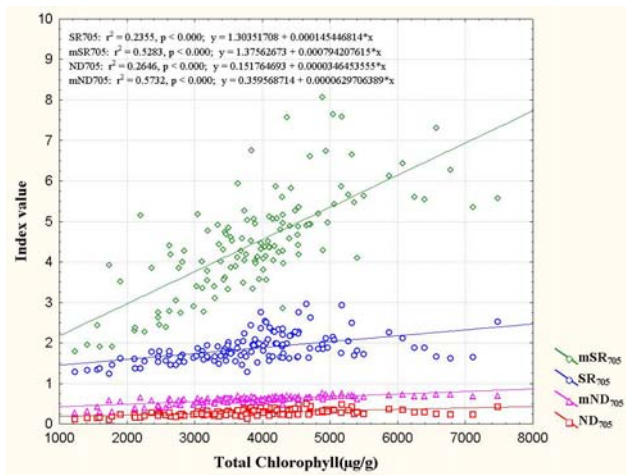


Figure 4. The correlation between chlorophyll contents and NDVI, mNDVI, SR, mSR across all tree samples

### 3.4 Terrain Effects

In order to decide whether topographic differences influence the physiological condition of plants and investigate the differences in physiological conditions by the method of spectra reflectance measurement, we conducted a Scheffe test for total chlorophyll, carotenoid, and REP of all the species sampled in 3 terrains. The sampled of 4 species were compared with 3 topographic features respectively; the comparison between chlorophyll content and REP and are shown in Table 2. From the above results and based on the correlation of REP ( $\lambda_{red}$ ) and first derivatives point of the red edge ( $D\lambda_{red}$ ) with the contents of chlorophyll and carotenoid, the REP of *Illicium dunnianum* and *Machilus kusanoi* in leeward terrains had no obvious correlation with chlorophyll change only because the sample size were too few. The REP of all the other species all showed good correlation with the chlorophyll change, while the first derivatives point of the red edge ( $D\lambda_{red}$ ) appeared to have less correlation. These results further testified that REP has a better application on the calculation of chlorophyll content, and showed more constant correlation in the study for a single species in 3 kinds of terrains.

Terrain	Species	Parameters of red edges	Total Chlorophyll	Carotenoid
Windward	<i>Daphniphyllum glaucescens</i>	$\lambda_{red}$	0.634* <sup>1)</sup>	0.626
		$D\lambda_{red}$	-0.109	-0.221
	<i>Michelia compressa</i>	$\lambda_{red}$	0.907**	0.897**
		$D\lambda_{red}$	0.579*	0.538
	<i>Illicium dunnianum</i>	$\lambda_{red}$	0.790**	0.736**
		$D\lambda_{red}$	0.371	0.204
	<i>Machilus kusanoi</i>	$\lambda_{red}$	0.761**	0.562*
		$D\lambda_{red}$	0.720**	0.515
Leeward	<i>Daphniphyllum glaucescens</i>	$\lambda_{red}$	0.877**	0.882**
		$D\lambda_{red}$	-0.339	-0.361
	<i>Michelia compressa</i>	$\lambda_{red}$	0.919**	0.931**
		$D\lambda_{red}$	0.706**	0.703**
	<i>Illicium dunnianum</i>	$\lambda_{red}$	0.945	0.955*
		$D\lambda_{red}$	0.554	0.461
	<i>Machilus kusanoi</i>	$\lambda_{red}$	0.856	0.882
		$D\lambda_{red}$	-0.392	-0.443
Valley	<i>Daphniphyllum glaucescens</i>	$\lambda_{red}$	0.963**	0.953**
		$D\lambda_{red}$	-0.035	-0.035
	<i>Michelia compressa</i>	$\lambda_{red}$	0.887**	0.834*
		$D\lambda_{red}$	-0.709*	-0.709*
	<i>Illicium dunnianum</i>	$\lambda_{red}$	0.785**	0.796**
		$D\lambda_{red}$	-0.023	-0.129
	<i>Machilus kusanoi</i>	$\lambda_{red}$	0.927**	0.933**
		$D\lambda_{red}$	-0.703*	-0.709*

<sup>1)</sup> \*, \*\*, \*\*\* significance at the 0.05, 0.01, 0.001 probability level, respectively.

Table 2. Correlation coefficient between the parameters of red edge of leaves spectra and chlorophyll and carotenoid for windward, leeward and valley

When all samples of the 4 species were comprehensively analyzed, we divided them into groups of different terrains to analyze the relationship between REP and the contents of chlorophyll and carotenoid. The regression equation results are summarized in Table 3. These results show that REP had a good correlation with pigment contents for all the terrains, but the correlation coefficients were different according to different terrains, among which the coefficient of the trees

growing closest to valleys on leeward is the lowest, the reason of which may be that trees growing in windward terrains are more varied in chlorophyll contents for the influence of wind-caused adverse environment, while those growing on leeward or valleys are not influenced by it. Some studies have reported that the leaf physiological structure of the windward species with relatively higher leaf mass per area seemed to be able to reduce physical damage produced by the monsoon winds, and



physiologically enhance dehydration tolerance (Su, 1993). The influence of topographic features, particularly slope aspect, on vegetation pattern was commonly related to prevailing winds, such as the monsoon effects in Nanjenshan Nature Reserve. When vegetations are exposed to mechanical stimuli, such as wind, touching or rubbing, they typically produce shorter and thicker stems, more roots, and increased flexural rigidity of stems and roots (Niklas, 1998; Henry and Thomas, 2002; Anten *et al.*, 2006). These responses increase the resistance of plants to mechanical failure (Niklas, 1998). The leaf characteristics change may play important roles in the ability of windward species to cope with windward environmental conditions in Nanjenshan Forest (Kuo and Lee, 2003).

Table 3. Regression equations relating the parameters of red edge and total chlorophyll for windward, leeward and valley

Terrain	Regression equations	R <sup>2</sup>	F-value
Windward	Chl = 247.126λred - 173055.841	0.459** <sup>1)</sup>	39.803
	Car = 67.106λred - 46201.797	0.307**	20.803
Leeward	Chl = 134.521λred - 92363.222	0.830**	156.174
	Car = 56.143λred - 38387.925	0.833**	160.670
Valley	Chl = 97.596λred - 65933.989	0.681**	89.769
	Car = 26.458λred - 24318.309	0.471**	37.326

<sup>1)</sup> \*\*, P<0.01.

For the analysis of the correlation coefficients for NDVI, mNDVI, SR, and mSR with chlorophyll content for each species in 3 terrains, the results showed that the four vegetation indices have different correlations with chlorophyll according to different species; except that *Illicium dunnianum* and *Machilus kusanoi* in leeward terrains showed no obvious correlation with chlorophyll change because their samples were too few; all the other species showed good correlation. Besides, after comparing the modified indices and the unmodified ones of some species, the correlation between the modified index and chlorophyll content is much better than before the modification. This result also showed that using the modified indices can also raise the accuracy in estimating the contents of chlorophyll for the same species.

According to the theories for mNDVI and mSR, these two indices have the capability of making up the structural differences of leaves of different species. The changes of the four indices in 3 kinds of terrains are shown in Table 4.

Table 4. Correlation coefficient between the total chlorophyll of all leaf samples and their spectra in three terrains

Terrain	Vegetation Index			
	SR <sub>705</sub>	mSR <sub>705</sub>	NDVI <sub>705</sub>	mNDVI <sub>705</sub>
Windward	0.274	0.638***	0.301*	0.706***
Leeward	0.647*** <sup>1)</sup>	0.766***	0.675***	0.827***
Valley	0.560***	0.798***	0.594***	0.887***
All	0.485***	0.727***	0.514***	0.757***

<sup>1)</sup> \*, \*\*\*, significance at the 0.05, 0.001 probability level, respectively.

The results showed that the correlation between the modified indices (mNDVI, mSR) and chlorophyll content is much obvious for the 3 kinds of terrains. More importantly, the correlation relationship in windward was increased using the modified indices when compared with the ordinary indices. This could be explained by the leaf structural variability in windward was much different, and the modified indices made the variability less apparent. It has already been established that the community of Nanjenshan Nature Reserve is organized by different topographic plant associations. In additionally, the correlation between the modified indices and chlorophyll content for all the species are much better than ordinary vegetation indices, and mNDVI shows a better correlation than mSR. These results are in accordance with Sims and Gamon (2002), who indicated that using the modified indices can also raise the accuracy in estimating the contents of chlorophyll for different species. According to understanding the different terrains effects the physiology change in the same species and finding the most sensitivity indices. We analysed all the vegetation indices and REP of 4 species in 3 terrains by Scheffe

test. The results shown in Table 5.

Trees	Variable	Terrains		
		Windward- Leeward	Windward- Valley	Leeward -Valley
<i>Daphniphyllum glaucescens</i>	Chl	0.023* <sup>1)</sup>	0.015*	0.0857
	Car	0.054	0.0430*	0.675
	SR705	0.0894	0.075	0.332
	mSR705	0.041*	0.064	0.115
	NDVI705	0.062	0.058	0.487
	mNDVI705	0.046*	0.047*	0.126
	REP	0.043*	0.045*	0.149
<i>Michelia formosana</i>	Chl	0.026*	0.021*	0.178
	Car	0.004**	0.046*	0.292
	SR705	0.054	0.062	0.072
	mSR705	0.032*	0.028**	0.093
	NDVI705	0.042*	0.035*	0.112
	mNDVI705	0.031*	0.003**	0.150
	REP	0.036*	0.076	0.176
<i>Illicium dunnianum</i>	Chl	0.031*	0.042*	0.225
	Car	0.044*	0.004**	0.398
	SR705	0.063	0.069	0.102
	mSR705	0.040*	0.028*	0.114
	NDVI705	0.054	0.021*	0.158
	mNDVI705	0.032*	0.037*	0.126
	REP	0.018*	0.038*	0.056
<i>Machilus kusanoi</i>	Chl	0.044*	0.043*	0.203
	Car	0.000***	0.000***	0.250
	SR705	0.042*	0.053	0.361
	mSR705	0.001**	0.001**	0.143
	NDVI705	0.032*	0.029	0.127
	mNDVI705	0.000***	0.000***	0.148
	REP	0.050*	0.046*	0.228

<sup>1)</sup> \*, \*\*, \*\*\* significance at the 0.05, 0.01, 0.001 difference level, respectively.

Table 5. The Scheffe test of vegetation indices and different terrains in 4 species

The results points to the obvious influence of different terrains on the same species of tree, indirectly testifying the obvious

difference in vegetations' physiological and ecological features in 3 different topographical areas in Nanjenshan Reserve. It

was quite obvious that the modified indices were all had better sensitivity than ordinary vegetation indices. This experiment were very succeed in using modified vegetation indices across different terrains. When vegetations are exposed to mechanical stimuli, such as wind, touching or rubbing, they typically produce shorter and thicker stems, more roots, and increased flexural rigidity of stems and roots.

#### 4. CONCLUSIONS

This study proved that there was an obvious correlation between REP and chlorophyll content; the  $R^2$  is 0.508 ( $P<0.000$ ), 0.667 ( $P<0.000$ ), 0.503 ( $P<0.000$ ) and 0.774 ( $P<0.000$ ) for *Daphniphyllum glaucescen*, *Michelia compressa*, *Illicium dunnianum* and *Machilus kusanoi*, respectively, which have all shown obvious correlation. The results confirms Horler et al. (1983) theory on the correlation between REP and chlorophyll content, proving that hyperspectral data can be used to estimate the chlorophyll content of plants' leaves. Moreover, the correlation  $R^2$  between the vegetation index and chlorophyll content were as follows: 0.236 ( $P<0.000$ ), 0.5283 ( $P<0.000$ ), 0.265 ( $P<0.000$ ), and 0.573 ( $P<0.000$ ) for  $SR_{705}$ ,  $mSR_{705}$ ,  $NDVI_{705}$  and  $mNDVI_{705}$ , respectively. In addition, this study also found that the conclusions arrived at the relationship between topographical features and the indices such as chlorophyll contents and some spectral variants are very consistent. These points to the obvious influence of different topographic features on the same species of tree, indirectly testifying the obvious difference in vegetations' physiological and ecological features in 3 different topographical areas in Nanjenshan Nature Reserve.

Two methods were adopted in this study to apply hyperspectral analytical remotely collected data to estimate chlorophyll contents of vegetations; one method analyzed the relationship between the vegetation index and chlorophyll contents, and the other method analyzed the relationship between REP and chlorophyll contents of vegetations. The result compared with traditional wide wavelength remote sensed the feature of hyperspectral remote sensed data was suitable for calculating chlorophyll contents, and in this study the sensitive wavelength range for testing chlorophyll content was also concluded. But from the view angle of physical factors of remote sensing, there were many factors that affected the spectral reflectance. Apart from the difference in signal-to-noise of different spectral instruments, deciding the physical variants of the vegetation itself was difficult, e.g., the difference in leaf structure of wide species can lead to changes in spectral reflectance. In addition, the models set up in the research were still influenced by many factors such as the type of vegetations, species, growth stage, growing condition and testing environment, et cetera. Therefore, a regression analysis for particular vegetation was necessary. The present hyperspectral materials, which were collected from satellites, generally belong to the category of wide wavelength spectra sensing, except some aerial hyperspectral instruments such as AVIRIS, CASI, Hyperion, et cetera. The traditional satellite remote sensing instruments on wide wavelength were limited to red, near infrared, and middle infrared. In the future, if more hyperspectral satellite instruments can be applied, they would be very important for conducting, easily and without damage, rapid chlorophyll and health condition assessments of vegetation cover.

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