Optimum Band and Band Combination for Retrieving Total Nitrogen, Water, Fiber Content in Tealeaves Through Remote Sensing Based on Regressive Analysis

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***Abstract*—Optimum band and band combination for retrieving total nitrogen, water and fiber content in tealeaves with remote sensing data is investigated based on regressive analysis. Based on actual measured data of total nitrogen, fiber and water content in tealeaves as well as remotely sensed visible to near infrared reflectance data with 5nm of wavelength steps and ASTER/VNIR onboard Terra satellite, regressive analysis is conducted. As the results, it is found that 1045nm is the best wavelength for retrieving total nitrogen content while 945nm is the best wavelength for fiber content retrieval. Also it is found that 545nm is the best wavelength for water content. On the other hand, it is found that 350 and 750nm wavelength combination is the best for estimation of total nitrogen content while 535 and 720 wavelength combination is the best for fiber content estimation. It also found that 545 and 760nm wavelength combination is the best for water content retrieval.**

Keywords—regressive analysis; total nitrogen content; tealeaves; fiber content;; water content

I. INTRODUCTION

It is highly desired to monitor vitality of crops in agricultural areas automatically with appropriate measuring instruments in order to manage agricultural area in an efficient manner. It is also required to monitor not only quality but also quantity of vegetations in the farmlands. Vegetation monitoring is attempted with red and photographic cameras [1]. Grow rate monitoring is also attempted with spectral observation [2].

This paper deals with automatic monitoring of a quality of tealeaves with earth observation satellite, network cameras together with a method that allows estimation of total nitrogen and fiber contents in tealeaves as an example. Also this paper describes a method and system for estimation of quantity of crop products by using not only Vegetation Cover: VC and Normalized Difference Vegetation Index: NDVI but also Bi-directional Reflectance Distribution Function: BRDF because the VC and NDVI represent vegetated area while BRDF represents vegetation mass, or layered leaves.

Total nitrogen content corresponds to amid acid which is highly correlated to Theanine: 2-Amino-4-(ethylcarbamoyl) butyric acid for tealeaves so that total nitrogen is highly correlated to tea taste. Meanwhile fiber content in tealeaves has a negative correlation to tea taste. Near Infrared: NIR camera data shows a good correlation to total nitrogen and fiber contents in tealeaves so that tealeaves quality can be monitored with network NIR cameras. It is also possible to estimate total nitrogen and fiber contents in leaves with remote sensing satellite data, in particular, Visible and near infrared: VNIR radiometer data. Moreover, VC, NDVI, BRDF of tealeaves have a good correlation to grow index of tealeaves so that it is possible to monitor expected harvest amount and quality of tealeaves with network cameras together with remote sensing satellite data. BRDF monitoring is well known as a method for vegetation growth [3],[4]. On the other hand, degree of polarization of vegetation is attempted to use for vegetation monitoring [5], in particular, Leaf Area Index: LAI together with new tealeaves growth monitoring with BRDF measurements [6].

It is not well known that the most preferable wavelength bands for observation of vegetation. Vitality of vegetation can be expressed with nitrogen, fiber and water contents in the leaves. Therefore, it is better to determine appropriate wavelength for retrieving theses parameters. In order to determine appropriate wavelength bands for estimation of total nitrogen, fiber and water contents in tealeaves, regressive analysis is conducted. Through regressive analysis, it is clarified that appropriate single wavelength and double wavelength for the retrievals with respect to the actual truth data sets of the parameters and hyperspectral data of reflective radiance from the tealeaves.

In the following section, research background is described followed by method for determination of appropriate single and double wavelength for retrievals. The regressive analysis results are summarized followed by conclusion and some discussions.

II. RESEARCH BACKGROUND

A. Vegetation Area Monitoring and Agricultural, in Paticular, Tea Farm Area Monitoring System

The proposed tea estate monitoring system is illustrated in Figure 1. Visible and NIR network cameras are equipped on the pole in order to look down with 10-80 degrees of incident angle (these angles allow BRDF measurements). The pole is used for avoid frosty damage to the tealeaves using fan mounted on the pole (for convection of boundary layer air). With these network cameras, reflectance in the wavelength region of 550nm (red color) and 870nm (NIR) are measured together with BRDF assuming that vegetated areas are homogeneous and flat. BRDF is used for estimation of Grow Index (GI) and BRDF correction from the measured reflectance of the tealeaves.

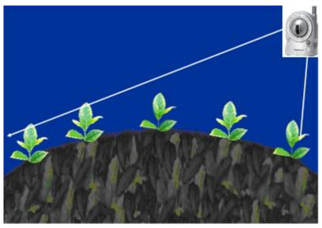
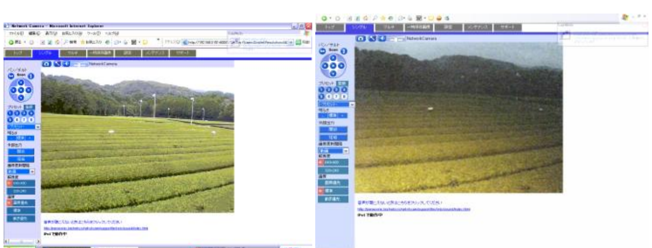


Fig. 1. Illustrative view of the proposed vegetation monitoring system with two network cameras, visible and NIR

These are controlled through Internet terminals. Visible Pan-Tilt-Zoom: PTZ network camera and NIR filter (IR840) attached network camera is equipped on the pole. PTZ cameras are controlled by mobile phone as well with “mobile2PC” or Internet terminal with “LogMeIn” of VNC services [7] through wireless LAN connected to Internet. Acquired camera data are used for estimation of total nitrogen and fiber contents as well as BRDF for monitoring grow index. An example of visible camera image acquired in daytime is shown in Figure 2 (a) while that for NIR camera image acquired in nighttime is shown in Figure 2 (b).

The cameras are connected to the Internet through the network card of W05K that is provided by AU/KDDI. Through http://119.107.81.166:8080, the acquired image data are accessible so that it is easy to access the data from Internet terminals. Panasonic BB-HCM371 cameras are used for the experiments. Solar panel of G-500 (12V, 500mA, 8.5W) with battery of SG-1000 is used together with Xpower75 (60W) of inverter.



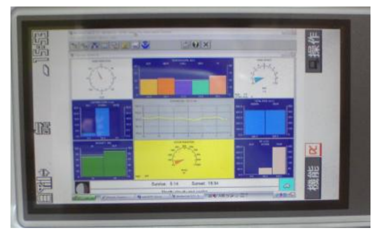
(a)Daytime (b) Nighttime

Fig. 2. Examples of farmland monitored visible camera images.

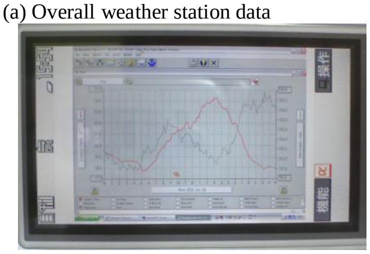
On the other hand, weather station data can be accessible from the URL of http://katy.jp/mapstation/ of data server provider through wireless LAN connection from the weather station to the Internet terminal. Figure 3 shows examples of the images displayed onto mobile phone. Not only camera imagery data, but also weather station data can be monitored with mobile phone. Figure 4 (a) and (b) shows overall weather station data of atmospheric pressure, solar direct and diffuse irradiance, leaf wetness, soil moisture, etc. and time duration of air-temperature and relative humidity of the tea estate while Figure 4 (c) shows web camera imagery data.

(a) New tealeaves appears partially (b) New tealeaves covers all over the surface

Fig. 3. Typical photos of new tealeaves grow process taken with network camera at tea estate of the prefectural tea research institute of Saga in the begging of April (a) and the late of April (b).



(a) Overall weather station data



(b) Air-temperature and relative humidity

(c) Camera image data

Fig. 4. Data displayed onto mobile phone

B. Tea Farm Area Monitoring with HyperSpectrometer

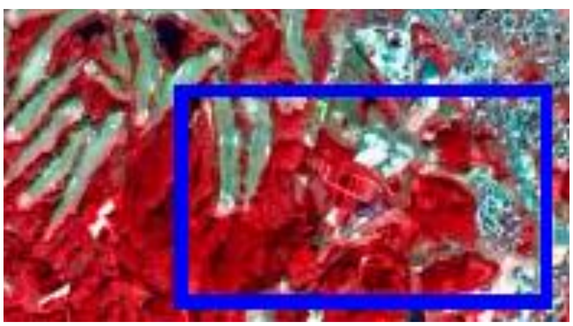
Other than these, hyper-spectral sensor can be equipped at the tea farm areas. Due to the fact that two bands of visible and near infrared cameras are not good enough in terms of estimation accuracy of nitrogen, fiber and water contents of tealeaves. Therefore, single and double wavelength bands for getting better accuracy of nitrogen, fiber and water contents have to be determined.

C. Dataset for Determination of Approporiate bands for Nitrogen, Fiber and Water Content Estimat5ion

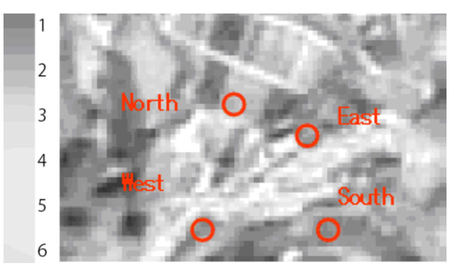
Intensive study area is situated at the Saga Prefectural Tea Institute in Ureshino-city, Saga, Japan. ASTER/VNIR image of the site is shown in Figure 5.

Fig. 5. Terra/ASTER/VNIR images of Saga acquired on May 16 in 2008 (False color representation: Blue Band #1, Green Band #2, Red Band #3).

Figure 6 shows enlarged image of ASTER/VNIR image of Saga Prefectural Tea Institute: SPTI. In particular, nitrogen content in tealeaves is shown in Figure 6 (b). Red circles shows four tea farm areas which are situated in East, West, South and North direction of Saga Prefectural Tea Institute.



(a)Portion of ASTER/VNIR image of Ureshino, Saga



(b)Enlarged image of Saga Prefectural Tea Institute

Fig. 6. Enlarges ASTER/VNIR image and total nitrogen contents in tealeaves at the tea estate (Red circles shows tea estates. Grayscale shows TN% of nitrogen contents in tealeaves derived from equation (1) of TN=22.474 Ref (Band#3)-10.177).

SPTI is situated at (33:07'2.9"N, 129:59'42.5"E,elevation: 130m) at the center location. In terms of species of the tea farm areas, East tea field has Yabukita tea farm area while North tea field has Yabukita tea farm and Okumidori.

Meanwhile, West tea field has Benifuki tea farm while South tea field has Ohiwase tea farm. Just before the harvesting tealeaves, in May 2008, spectral reflectance is measured. Figure 7 shows the reflectance. Meantime, total nitrogen, fiber and water content in the tealeaves are also measured. Thus, correlation can be calculated with these dataset through correlation analysis. Figure 8 shows the calculated correlations

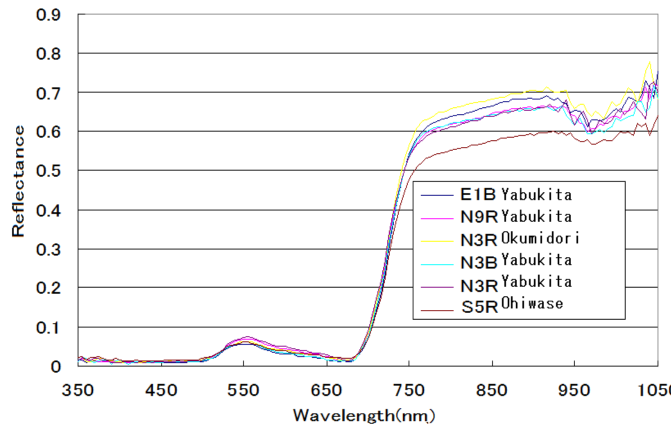


Fig. 7. Spectral reflectance measured at East, North and South tea farm areas situated at SPTI on 5 May 2008.

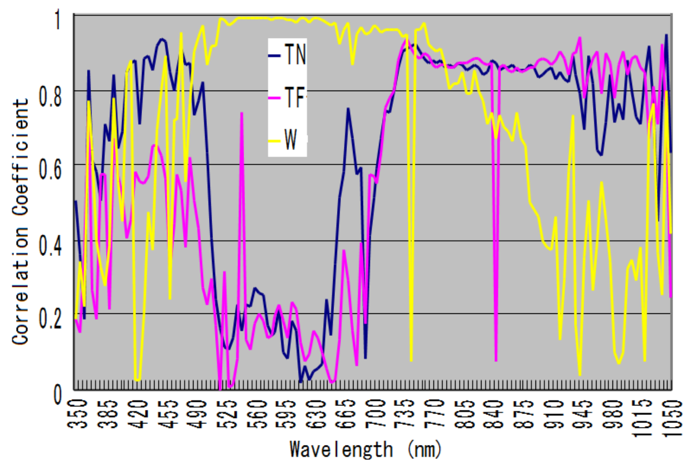


Fig. 8. Correlations between of total nitrogen, fiber and water contents in the tealeaves and the measured spectral reflectance

III. EXPERIEMNTS

A. *Single Spectral Band for Estimation of TN, Fiber, and Water Contentsin TealeavesSlope Effect*

Using the correlations between TN, fiber, and water content in tealeaves and spectral reflectance measured at SPTI, Saga Japan on May 5 2008, just before the harvesting tealeaves, regressive analysis is conducted. Through regressive analysis with single band with 5nm band width, the most appropriate spectral bands for estimation of TN, Fiber, and Water contents in tealeaves are estimated. Table 1, 2, and 3 show the results from the regressive analysis for TN, Fiber, and Water contents in tealeaves, respectively.

TABLE I. RESULT FROM REGRESSION FOR TN CONTENT ESTIMATION WITH SINGLE SPECTRAL BAND WITH 5NM OF BAND WIDTH

Nitrogen	1045nm
R	0.9502
R^2	0.9029
StDev	0.3375
No.	6

TABLE II. RESULT FROM REGRESSION FOR FIBER CONTENT ESTIMATION WITH SINGLE SPECTRAL BAND WITH 5NM OF BAND WIDTH

Fiber	945nm
R	0.9502
R^2	0.9029
StDev	0.3375
No.	6

TABLE III. RESULT FROM REGRESSION FOR WATER CONTENT ESTIMATION WITH SINGLE SPECTRAL BAND WITH 5NM OF BAND WIDTH

Water	545nm
R	0.9999
R^2	0.9997
StDev	0.0004
No.	6

As the results, it is found that the most appropriate spectral bands for estimation of TN, Fiber and Water contents in tealeaves are 1045, 945, and 545 nm. The regressive analysis is conducted based on Pearson's correlation with 95 % of confidence level. The regressive errors of TN, Fiber, and Water contents in tealeaves are shown in Table 4, 5, and 6, respectively.

TABLE IV. REGRESSION ERROR FOR TN CONTENT ESTIMATION WITH SINGLE SPECTRAL BAND WITH 5NM OF BAND WIDTH

Field Name	Species	TN(%)	Est.TN	Reg.Error
E1B	Yabukita	4.7	4.168	0.283
N9R	Yabukita	4.6	4.938	0.114
N3R1	Okumidori	4.9	4.914	0.000197
N3R2	Yabukita	5	4.889	0.0123
N3B	Yabukita	5	5.099	0.00983
S5R	Ohiwase	2.5	2.691	0.0367

TABLE V. REGRESSONE ERROR FOR TN CONTENT ESTIMATION WITH SINGLE SPECTRAL BAND WITH 5NM OF BAND WIDTH

Field Name	Species	Fiber(%)	Est(Fiber)	Reg.Error
E1B	Yabukita	20.4	14.99	29.2681
N9R	Yabukita	17.3	16.66	0.4096
N3R1	Okumidori	1.5	4.98	12.1104
N3R2	Yabukita	19.6	21.66	4.2436
N3B	Yabukita	17.2	16.45	0.5625
S5R	Ohiwase	32.2	33.46	1.5876

TABLE VI. REGRESSION ERROR FOR TN CONTENT ESTIMATION WITH SINGLE SPECTRAL BAND WITH 5NM OF BAND WIDTH

Field Name	Species	Water(%)	Est(Water)	Reg.Error
E1B	Yabukita	0.7623	0.7625	4E-08
N9R	Yabukita	0.7318	0.7314	1.6E-07
N3R2	Yabukita	0.7555	0.7754	0.000396
N3B	Yabukita	0.7271	0.7424	0.000234

As the result, it is found that fiber content in tealeaves is the most difficult followed by TN content and water content There are not available data of water content of truth data for the test sites of N3R1, S5R.

B. Double Spectral Band for Estimation of TN, Fiber, and Water Contents in Tealeaves

The most appropriate two spectral bands with 5 nm of band width for estimation of TN, Fiber, and Water contents in tealeaves are determined through regressive analysis using the aforementioned correlation data between truth data and estimated data. The results from the regressive analysis are shown in Table 7, 8, and 9, respectively.

TABLE VII. REGRESSION RESULT FOR TN CONTENT ESTIMATION WITH SINGLE SPECTRAL BAND WITH 5 NM OF BAND WIDTH

Nitrogen	350&750nm
R	0.9906
R^2	0.9812
StDev	0.1713
No.	6

TABLE VIII. REGRESSION RESULT FOR FIBER CONTENT ESTIMATION WITH SINGLE SPECTRAL BAND WITH 5 NM OF BAND WIDTH

Fiber	535&720nm
R	0.9798
R^2	0.96
StDev	2.538
No.	6

TABLE IX. REGRESSION RESULT ERROR FOR WATER CONTENT ESTIMATION WITH SINGLE SPECTRAL BAND WITH 5 NM OF BAND WIDTH

Water	545&760nm
R	0.9999
R^2	0.9999
StDev	0.0003
No.	6

As the results, it is found that the most appropriate band combination for estimation of TN, Fiber, and Water contents in tealeaves are 350 and 750 nm, 535 and 720 nm, 545 and 760 nm, respectively.

C. Comparison of Estimation Accuracy Among Single,Double Spectral Band, and ASTER/VNIR Spectral Bands for Estimation of TN, Fiber, and Water Contents in Tealeaves

Estimation accuracy for TN, Fiber, and Water contents in tealeaves is evaluated with ASTER/VNIR spectral bands and is compared to the aforementioned estimation accuracy with the most appropriate single, and double spectral bands with 5 nm band width. The results from the comparisons are shown in Figure 3, 4, and 5, for TN, Fiber, and Water contents in tealeaves.

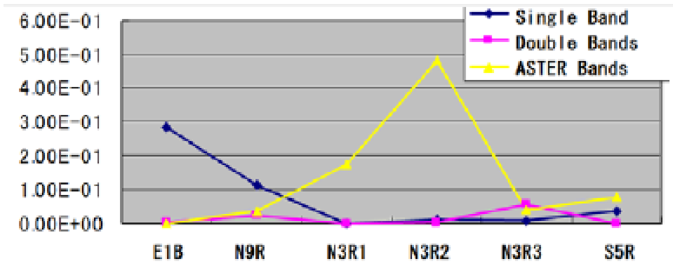


Figure 9 Comparison among single, double, and ASTER/VNIR spectral bands for estimation of TN content in tealeaves

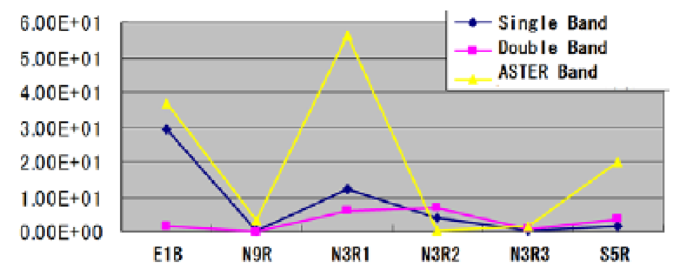


Figure 10 Comparison among single, double, and ASTER/VNIR spectral bands for estimation of Fiber content in tealeaves

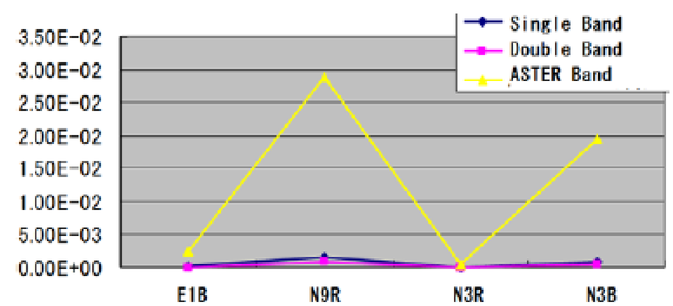


Figure 11 Comparison among single, double, and ASTER/VNIR spectral bands for estimation of water content in tealeaves

The results show that two spectral bands case (double) shows the best estimation accuracy followed by single spectral band, and ASTER/VNIR. Due to the fact that ASTER/VNIR spectral bands are broad in comparison to the single and double spectral bands with 5 nm of band width, ASTER/VNIR spectral bands case shows the worst estimation accuracy. Also it is found that estimation accuracy depends on the tea farm areas of intensive study areas.

IV. CONCLUSION

Optimum band and band combination for retrieving total nitrogen, water and fiber content in tealeaves with remote sensing data is investigated based on regressive analysis. Based on actual measured data of total nitrogen, fiber and water content in tealeaves as well as remotely sensed visible to near infrared reflectance data with 5nm of wavelength steps and ASTER/VNIR onboard Terra satellite, regressive analysis is conducted.

As the results, it is found that 1045nm is the best wavelength for retrieving total nitrogen content while 945nm is the best wavelength for fiber content retrieval. Also it is found that 545nm is the best wavelength for water content. On the other hand, it is found that 350 and 750nm wavelength combination is the best for estimation of total nitrogen content while 535 and 720 wavelength combination is the best for fiber content estimation. It is also found that 545 and 760nm wavelength combination is the best for water content retrieval. The results show that two spectral bands case (double) shows the best estimation accuracy followed by single spectral band, and ASTER/VNIR. Due to the fact that ASTER/VNIR spectral bands are broad in comparison to the single and double spectral bands with 5 nm of band width, ASTER/VNIR spectral bands case shows the worst estimation accuracy. Also it is found that estimation accuracy depends on the tea farm areas of intensive study areas.

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