Original Scientific paper
10.7251/AGRENG2002029S
UDC 663.951:54(520)

MONITORING THE GROWTH AND QUALITY OF JAPANESE GREEN TEA BY UAV IMAGERY

Ayako SEKIYAMA[1]*, Kiyohisa SATO[2], Sawahiko SHIMADA[1], Tomonori FUJIKAWA[3]

[1]Faculty of Regional Environment Science, Tokyo University of Agriculture, Tokyo, Japan
[2]Nileworks Inc., Tokyo, Japan
[3]Faculty of Regional Regeneration Science, Tokyo University of Agriculture, Tokyo, Japan
*Corresponding author: a3sekiya@nodai.ac.jp

ABSTRACT

The optimal harvest season of Japanese green tea in Japan is judged by individual farmers based on their experiences. To confirm that optimal season, it requires a lot of efforts such as sampling of tea flushes by plucking, chemical component measuring by near-infrared spectroscopic analysis. Thus, an efficient method to determine the optimal season which can cover a wide area at once is considered highly helpful for farmers. This research measured normalized difference vegetation index (NDVI) of tea flushes by a multi-spectrum sensor mounted on an unmanned aerial vehicle. At the same time, chemical component of tea flushes was measured to compare with the result of NDVI. The result showed that the value of NDVI for the optimal harvest season of tea-leaf is 0.6 to 0.7. The result of chemical component measuring showed the increase of total free amino acids and reduction of total free sugars while tea-leaf ripens. Therefore, there was a positive relation between the value of NDVI, and total free amino acids and total free sugars. It indicates a high possibility to predict the optimal harvest season of tea flushes by NDVI.

Keywords: *Chemical components*, *NDVI, Remote sensing, Structure from Motion, Tea leaves.*

INTRODUCTION

The amount of exports of Japanese tea increased approximately five times in the last ten years because of global health trends and the popularity of Japanese foods in the recent years. Japanese green tea has brand power and the amount of its exports is expected to keep increasing. However, the output of green tea in Japan has been gradually decreasing last ten years due to aging and decrease of the farming population (MAFF). In Shizuoka prefecture where is located in the middle part of Japan with a temperate climate, the production of green tea is very active and occupies about 40 % (32,200 tons in dried tea leaves in 2013) of the total share in Japan (Shizuoka prefecture, 2015). The harvest season of green tea in Japan, occurs two times of late April to early May for the first picking and middle June for the second picking which is grown after the first one was picked. The first picked is grown in March to April when it is cold. The leaves try to store lots nutrition in themselves thus the grade and selling price are higher than the second one. Since the sprout of the leaves is hardened while growing and blooming, the latter the harvest timing is, the more the output gets but the lower the quality gets. Therefore, it is very important to consider the optimal balance between quality and output because of the trade-off relation between them. Currently, the decision of the harvest timing is dependent on farmers' experience and visual observation. As an objective way, there is a method called "quadrate plucking" which plucks a certain amount of buds by hands within unit area, to measure its growth condition and quality. This enables to measure chemical component of the tea leaves and the weights of the buds to confirm the optimal harvest timing. However, most of the tea plantation is located in slope area, and it requires a hard word to conduct visual observation or quadrate plucking. For these reasons, it is expected that application of remote sensing can contribute to lowering the burden of farmers to find out the optimal harvest timing by observing in a wide area at once without direct site observation or sampling and analyzing in multiple time series.

Kim et al. (2010) found a positive correlation between Normalized Difference Vegetation Index (NDVI), and the weights of buds and fiber level, and a negative correlation between the entire quantity of nitrogen and amino acids by analyzing images obtained from a near infrared camera to monitor green tea leaves. Ishikawa et al. (2012) took the same measure and proposed establishing the quality estimate index based on green and red wavelength regions to estimate a proper harvest timing. Recently, the number of research which apply Unmanned Aerial Vehicle (UAV) has been increasing because of its high portability and the increasing popularity due to the lowering price. UAV enables us to create images with higher resolution and obtain images more frequently compared to satellite images. Thus, it is useful to observe the growing crops frequently. The use of UAV in the agricultural field is growing. For example, Hama et al. (2018) applied UAV to take images of rice from the period of the emergence of ears till the period of maturity, to estimate the amount of harvest. Sato et al. (2016) investigated the effective wavelength region to measure the growth level of tea leaves by filtering the camera equipped with UAV. However, the quantitative method to clarify the optimal harvest timing for the first picking has not been established. Therefore, this research attempts to propose a monitoring method for the tea leaves by applying aerial images taken by a multi-spectrum camera equipped with UAV. Concretely, it discusses the possibility to estimate the growing condition and quality of the first picking by analyzing the relation between chemical components of the tea flushes taken by the quadrate plucking and spectral characteristics of the tea flushes.

MATERIALS AND METHODS

The project site is a tea filed in Kikugawa City, Shizuoka Prefecture where located in the middle part of Japan (Fig. 1a). The targeted breed is Yabukita (*Camellia sinensisis (L.) O Kuntze cv. 'Yabukita'*), grown in a moderate slope area. The onsite investigation took four days (29 April, 1, 3 and 10 May 2017) in total during the growing period of the first picking.

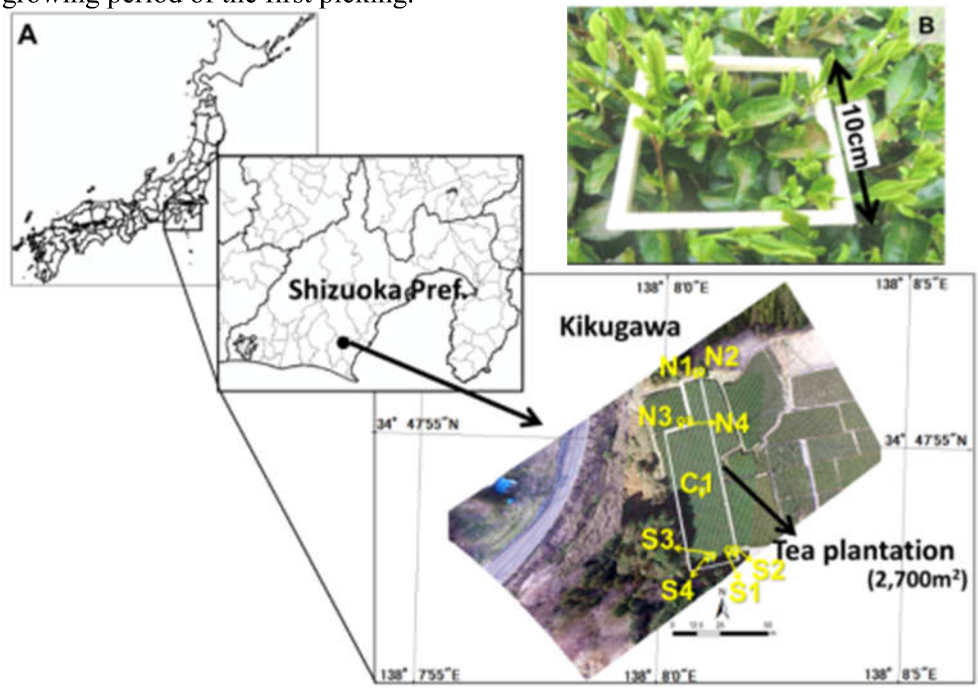

Figure.1 Location of tea plantation field and sampling points of tea leaves (a). Frame of quadrate plucking for tea leaves (b).

Aerial images were taken by UAV and quadrate sampling was conducted in nine points (four points in northern part, four points in Southern part, and one point in the middle part of the field) for analysis of the chemical components. Thus, the total was thirty-six samples. In analysis of the chemical components, the buds within a wooden frame of ten centimeters square were plucked, frozen by liquid nitrogen and then analyzed by a gas chromatography-mass spectrometer (QP2010 Plus by Shimadzu Corporation). Through this analysis, totally twenty chemical components such as aspartic acid, theanine and caffeine were measured (Table 1).

Table 1. Measured chemical components

Pyruvic acid	Serine	Glutamic acid	Galacturonic acid
Alanine	Threonine	Glutamine	Inositol
Oxalic acid	Malic acid	Fructose	Sucrose
Succinic acid	Aspartic acid	Citric acid	Caffeine
Glycine	GABA	Glucose	Theanine

To make aerial images taken by UAV ortho-rectified photo mosaic or orthomosaic, the latitude, longitude and altitude of ground control point (GCP) which was set up in the target field based on the measure by RTK-GNSS, were measured.
For aerial photograph, a UAV, Inspire 1 by SZ DJI Technology Co., Ltd. and a multispectral sensor, Sequoia by Parrot Drones SAS, were applied. Sequoia can obtain spectral data of four separate bands (Green: 530 to 570 nm, Red: 640 to 680 nm, Red Edge: 725 to 745 nm, Near infrared: 770 to 810 nm). The flight altitude was set at 30 m and images were captured by automatic pilot using a free drone flight application, Pix4Dcapture by Pix4D S.A. The taken images were processed orthomosaic by a Structure from Motion (SfM) software, Pix4Dmapper. The pixel resolution of all the images was 3 cm. NDVI images were created from each orthomosaic images.
The value of NDVI responding to each sample of tea flushes were identified after calculating the average value in each pixel of NDVI images which corresponds to the sampled points. Since the resolution of pixel is 3 cm, about nine pixels are measured which cover the 10 cm square sampled by quadrate plucking.

RESULTS AND DISCUSSION

Images taken in each investigation day are shown in Fig. 2. In all these dates, the NDVI values are higher in the southern part of the field than the northern part. It is considered the long sunlight length compared with the northern part. The NDVI value in the entire field increased throughout the period from 29 April to 10 May.

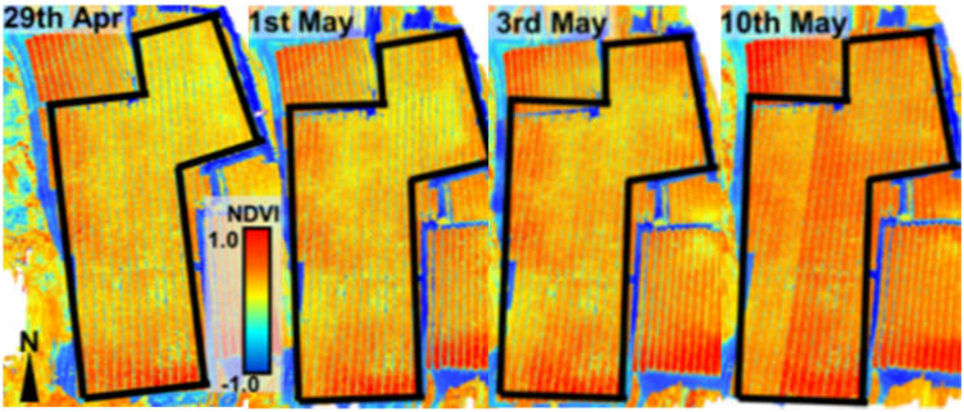

Figure.2 Change of NDVI distribution at tea plantation field

The NDVI values that correspond to each sampling point by quadrate plucking for each investigation day are shown in Fig. 3. The N3, N4, S3 and S4 are not included in this analysis because these were cultivated before 10 May. Every sampling point showed the increased of NDVI values throughout the survey period. In addition, the NDVI values are lower in the northern part than the southern part throughout the time. On the first day, the difference of the NDVI value is twice as much between the northern and southern parts. However that difference became smaller by 10 May, a day before the harvest and the number of error in standard deviation also decreased. Therefore, it is assumed that the maturity within the field is uniformized as the harvest period comes close. The lowest NDVI value was 0.6 at the sample point, C1, the highest were 0.67 in S1 and S2 on 10 May. Thus, it is expected that the NDVI value for the harvest for the first picking is approximately between 0.6 and 0.7. From these reasons, it shows that when NDVI values reach around these values, it is the time for harvest of the tea flushes.

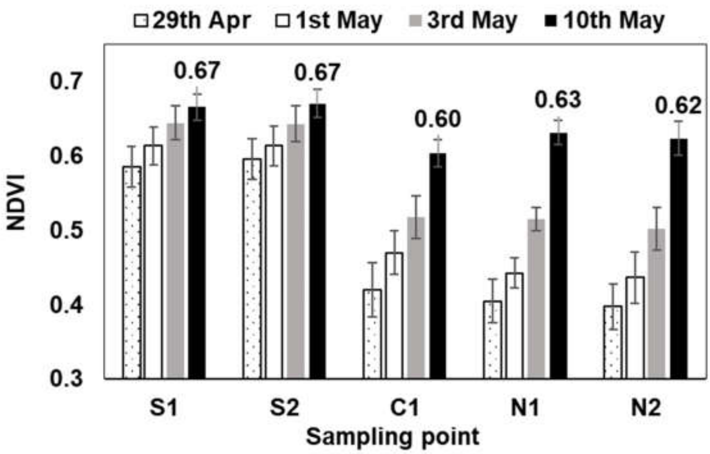

Figure. 3 Change of NDVI each sampling point (Bars represent Standard Deviation)

On the other hand, principal component analysis (PCA) was conducted to investigate how the chemical components change over the investigation time and whether its change depends on a kind of chemical component (Fig. 4). Especially, this research focused on changes in total free amino acid such as theanine, glutamic acid, aspartic acid and serine, and total free sugar such as sucrose, glucose and fructose. Thus, it is considered that the result of PCA shows that the first principal component is the factor for total free amino acid and the second principal component is for total free sugar. Furthermore, the score of both total free amino acid and total free sugar showed the inverse relationship for each principal component, and there is a trade-off relationship such as that as total free amino acid increases, total free sugar decreases. From these results, it is presumed that the amount of amino acids and sugar changes as the tea leaves matures. In addition, scatter diagrams were created for each investigation day based on the principal component scores obtained from the result of PCA (see Fig. 5). Although there was not much difference in chemical components between 29 April and 3 May, the second principal component which is total free sugar, significantly increased by 10 May, the day before harvesting. As it is known that the sweetness of green tea is contributed by sugar, it is presumed that its sweetness increases as the tea leaves matures. It is also known that as the growth of the tea leaves accelerates, the consumption amount of amino acid for the growth of buds lowers than the amount of translation from the roots to buds (Hakamada and Maehara, 1978). The results of this research can validate it. Single regression analysis was conducted for the NDVI images created based on all the chemical components and aerial images taken by UAV. The result showed the strong negative correlation (R=0.72**, $P < 0.001$) between aspartic acid and the NDVI value. Considering that the ideal NDVI value for the harvest time is between 0.6 and 0.7, the ideal aspartic acid amount for harvest time is between 0.5 to 1.5µmol/100g. There was no any other chemical component which showed a strong correlation with several vegetation indices including NDVI. As seen from the result of PCA, there is a difficulty of approximation by regression equation since the chemical components contained in the tea leaves do not change gradually in accordance with its growth but suddenly changes immediately before the time of harvest.

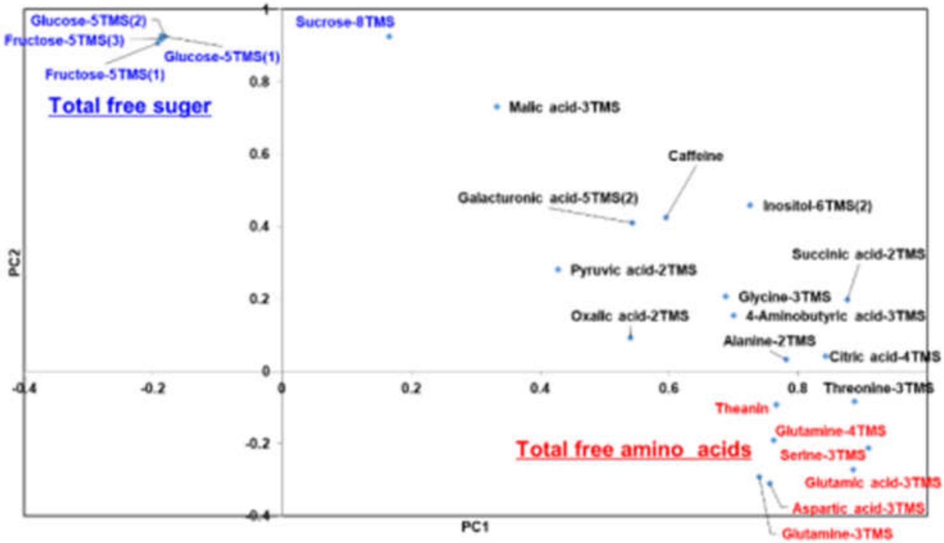

Figure. 4 Principle component analysis using chemical components at tea plantation

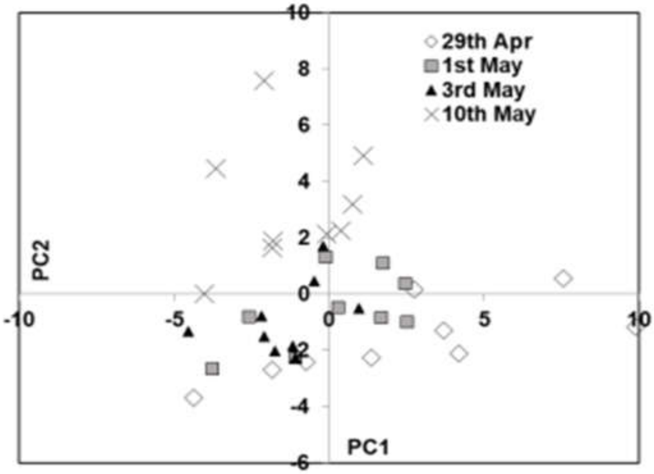

Figure. 5 Distribution of principle component score each day

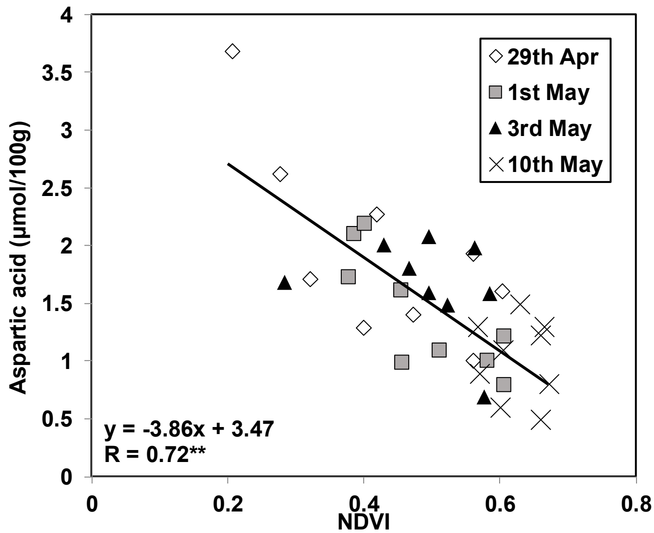

Figure. 6 Relationship between NDVI and Aspartic acid

CONCLUSION

This research discussed if it is possible to determine the optimal harvest time for the first picking of green-tea leaves by using UAV images rather than depending on experiences by farmers. In addition, the UAV images and the samples of the tea leaves were taken at the same time and the relation of vegetation index gained from the UAV images and chemical components gained from the sampling was analyzed. As the results, the following findings were shown:

- The NDVI value all over the tea plantation field at the time immediately before harvesting was between 0.6 and 0.7. It assumed that around these values imply the optimal harvest time for the first picking.

- The relation between total free amino acids and sugar is tradeoff as the tea leaves grow, based on the investigation into changes of chemical components of the tea leaves.
- There is a correlation between the NDVI values and aspartic acid. There is possibility to predict the amount of aspartic acid based on the NDVI values.

REFERENCES

Shizuoka Prefecture, Japan. (2015). White paper of Japanese green tea.

Jong-Hwan KIM, Byungdug JUN, Kazuichi SUGIYAMA, Kenji TORAO, Yoshihiko, HORIUCHI, Hitoshi IRYOU and Masahiko ARAI. (2010). A Method of Yield and Quality Estimation for Tea-plant Using On-site Remote Sensing. *Journal of the Japanese Agricultural Systems Society*. **26(1)**, pp.1-8.

Daitaro ISHIKAWA, Ayaka NSHIWAKI, Takuto NISHIMOTO, Naoya CHISHAKI, and Etsuji ISHIGURO. (2011). Study on Nondestructive Estimation Method for Growth and Quality in Tea Leaves Using Proximal Remote Sensing Method -Development of Estimation Method of Optimum Harvesting Period for Fresh Leaves using Spectral Image and Application to Fertilization. *Journal of the Japanese Society of Agricultural Technology Management*. **18(3)**: pp.115-122.

Akira HAMA, Kei TANAKA, Atsushi MOCHIZUKI, Hiroyuki ARAI, Toshiyuki HIRATA, Ryuya YAWATA, Yasuo TSURUOKA and Akihiko KONDOH (2018). Estimating Paddy Rice Plant Height and Yield Using UAV Remote Sensing and Solar Radiation. *J. Japan Soc. Hydrol. and Water Resour.* **31(2)**: pp.68-82.

Satoh KIYOHISA, Sawahiko SHIMADA, Ayako SEKIYAMA, Hiromichi TOYODA, Tamon YANAI and Nobuhiro HORI (2016). Extraction of Near-infrared Information from Aerial Photography Using UAV with Supergel Color Filter Aiming for In-situ Tea growing Monitoring. *Journal of The Remote Sensing Society of Japan,* **36(2)**, pp.131-135.

Katsuhiro HAKAMATA and Mitoshi MAEHARA (1978). Changes in Total Nitrogen, Free-Amino Acids, Caffein and Tannin of Tea Leaves with Special Reference to the development of New Shoots. *Tea Research Journal*. **48**. pp.57-63.

MAFF: Ministry of Agriculture, Forestry and Fisheries, Japan (2009-2018). Census of agriculture and forestry.URL:https://www.maff.go.jp/j/tokei/kouhyou/sakumotu/sakkyou_kome/index.html#r. Accessed 09.01.2020.