The potential of UAV multispectral imagery to estimate chlorophyll content of vine leaves

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Abstract

As is known, chlorophyll is an important biophysical parameter used to monitor the overall physiological status of plants. The aim of this research was to study the potential of UAV multispectral images for estimating the contents of leaf chlorophyll in vineyards. For this purpose, a UAV flight was conducted (eBee SQ with Parrot Sequoia multispectral camera) and simultaneously in-situ measurements of leaf chlorophyll content of vine were performed using MC-100 Chlorophyll Meter. A total of 51 samples were collected: each sample representing the average of 5 measurements from the top of a single plant. Pearson correlation analysis was applied to test the relationships between spectral reflectance, Normalized Difference Vegetation Index (NDVI), Normalized Difference RedEdge Index (NDRE) and in-situ measured leaf chlorophyll content. A Partial Least Squares Regression (PLSR) model was also applied to predict chlorophyll content using 6 predictor variables: NDVI, NDRE and green, red, red edge, near infrared bands. The results showed that among spectral reflectance, the red band was most sensitive to chlorophyll variations (r = -0.46). Positive correlation between chlorophyll content and NDVI/NDRE also was found (r = 0.67 and r = 0.57, respectively). Promising results were obtained for the PLSR model (R^2_{Val} = 0.49, $RMSE_{Val}$ = 43.68), which proves the high potential of multispectral UAV imagery for chlorophyll monitoring in vineyards.

Keywords: Vineyards, UAV, Chlorophyll content, PLSR, Remote Sensing

1. Introduction

The chlorophyll concentration is a crucial biophysical parameter sensitive to the environmental stress (water and nutrient deficiency, pathogens, temperature extremes, etc.) on plants and a perfect indicator of the plants overall physiological status, health, yield prediction etc. (Cabello-Pasini and Macías-Carranza, 2011; Elarab et al., 2015; Singhal et al., 2019). The chlorophyll content in plants can be measured by visible and near infrared (NIR) parts of the electromagnetic spectrum, widely available through remote sensing (RS) data (Carter and Knapp, 2001; Singhal et al., 2019). Satellite RS images have been widely used for chlorophyll content estimation across large areas (Morley et al., 2020). However, the spatial resolution of satellite images results in mixed pixels (averaging the spectral response of all the objects within a single pixel) causing misestimation of chlorophyll contents (Carter and Knapp, 2001; Morley et al., 2020). This problem is more pronounced in the case of vineyards, because of discontinuous structure. To overcome this problem the use of Unmanned Aerial Vehicles (UAV) has been widely adopted, which can provide ultra-high spatial resolution (a few centimeters) multispectral images for wide areas (Singhal et al., 2019; Vanbrabant et al., 2019).

The aim of this research was to study the potential of ultra-high spatial resolution images obtained from the Parrot Sequoia multispectral sensor mounted on senseFly eBee SQ UAV for the estimation of leaf chlorophyll content in vineyards.

2. Materials and methods

2.1. Study site and in situ measurements

The study area (≈ 4.4 ha) was "Trinity Canyon Vineyards" located in the Vayots Dzor region of Armenia, in the close vicinity of the world oldest known wine producing site (about 6100 years old) (Fig. 1-a). Established in 2009 "Trinity Canyon Vineyards" adopted the practice of organic viticulture and is the first in Armenia producing certified organic wine("Trinity Canyon Vineyards," 2014). The vineyard is located on a dry steppe landscape zone and is characterized by light brown soils and the prevalence of bright sunny days (340-350 days) in the year, which conditions the high quality of crops and grape in particular (Vardanyan and Valesyan, 2007).

The chlorophyll content in grape leaves was measured simultaneously with UAV survey during the 19th of September 2019 and by using a portable MC-100 Chlorophyll Concentration Meter (Apogee Instruments, Inc.) (Fig. 1-e). MC-100 measures chlorophyll concentration through the ratio of optical transmittance at red (653 nm) and NIR (931 nm) regions. Overall, 51 measurements were taken from the entire study area. Each measurement represents the average of 5 sub-measurements from the top of a single plant (one specimen with one root). The coordinate of each measured point was recorded using a Garmin Oregon 650 GPS receiver. The accuracy of the GPS receiver is ±3m, thus, in order to precisely locate measurement points on the UAV image sheets of white paper were attached to the top of the plant next to the measured ones before the UAV flight (Fig. 1-b).

2.2. UAV survey and image processing

The UAV survey was done with fixed wing senseFly eBee SQ mounted with Parrot Sequoia multispectral sensor (Fig. 1-c). The ultra-high resolution multispectral (green: 550 nm, red: 660 nm, red edge: 735 nm, NIR: 790nm), as well as RGB images for the study area were acquired. For a precise radiometric correction of multispectral images reflectance panel data was used (Fig. 1-d). The orthomosaic (pixel size 3.5x3.5 cm) was generated using Agisoft Metashape Professional. Then Normalized Difference Vegetation Index (NDVI) and Normalized Difference Red Edge Index (NDRE) were calculated (Raeva et al., 2019):

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)}$$

$$NDRE = \frac{(NIR - Red\ Edge)}{(NIR + Red\ Edge)}$$

For each in-situ measurement point the average values of spectral reflectance, as well as NDVI and NDRE from 3x3 pure pixels were extracted to be used in a subsequent statistical analysis.

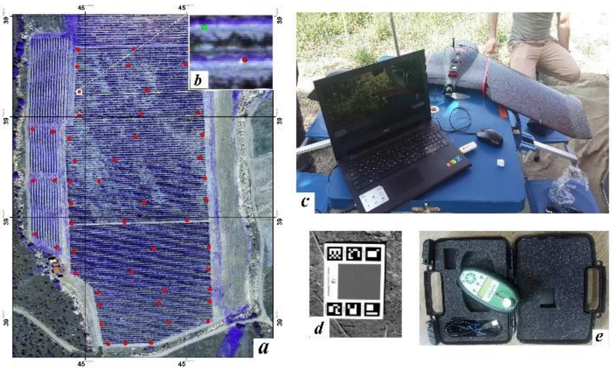

Figure 1. a) Study area, b) Measurement point recorded by GPS (green) and measurement point corrected using a sheet of white paper (red), c) SenseFly eBee SQ UAV d) Reflectance panel, e) MC-100 Chlorophyll Concentration Meter

2.3. Statistical analysis

In order to detect potential outliers among measured chlorophyll data the boxplot technique was used: the values outside *(Quartile 1 – 1.5 * Interquartile range)* and *(Quartile 3 + 1.5 * Interquartile range)* were treated as outliers. To study the relationships between leaf chlorophyll content and UAV data, a Pearson correlation analysis was performed. All statistical analyses were done using the Python programming language. To model chlorophyll content in vine leaves from UAV data (NDVI, NDRE and green, red, red edge and NIR bands) Partial Least Squares Regression (PLSR) was implemented using the open source Python "scikit-learn" library (Pedregosa et al., 2011). The input dataset for the PLSR model was randomly split into training (80%) and testing (20%) sets. The training set was used for the model calibration and selection of the optimal number of PLSR components via Leave-One-Out (LOO) cross validation, while the testing set for the final validation of the model on unseen data. For the model evaluation Root Mean Square Errors (RMSE) and coefficients of determination (R^2) were calculated, both for cross-validation and testing.

3. Results and discussions

3.1. Correlation between leaf chlorophyll content and UAV data

As a result, no outliers were found in chlorophyll data. The highest significant ($p < 0.01$) positive correlation was established between the chlorophyll content in vine leaves and NDVI ($r = 0.67$), followed by NDRE ($r = 0.57$). Similar results for both NDVI and NDRE, with a slightly low correlation coefficient ($r \approx 0.5$), were established by (Kopačková-Strnadová et al., 2021), where UAV images acquired via Parrot Sequoia multispectral sensor were used to estimate the chlorophyll content in spruce monocultures. A negative significant correlation ($r = -0.46$, p=?) was identified between the chlorophyll content and the red band, which was expected, as chlorophyll absorbs light in the red region. The result is in line with the study of Singhal et al. (2019), where maximum correlation in red band acquired by Parrot Sequoia with chlorophyll content in maize was registered. Moreover, the Parrot Sequoia multispectral sensor used record red band in 660 nm, which is close to the spectral regions (680-690 nm) used for estimating the chlorophyll content in previous studies (Singhal et al., 2019). No significant correlations were found between chlorophyll contents and green ($r = 0.04$), red edge ($r = -0.12$) and NIR ($r = 0.11$) bands. However, it was shown earlier that particularly, red edge reflectance is strongly correlated with leaf chlorophyll (Carter and Knapp, 2001; Elarab et al., 2015).

3.2. Estimation of leaf chlorophyll content

The results of the PLSR model are shown in Fig. 2. Based on the lowest RMSE of LOO cross-validation the optimal number of PLSR components was found to be 2. As it can be seen, the PLSR model provides satisfactory results both for calibration ($R^2_{Cal} = 0.41$, $RMSEC_{Cal} = 52.80$) and validation ($R^2_{Val} = 0.49$, $RMSE_{Val} = 43.68$).

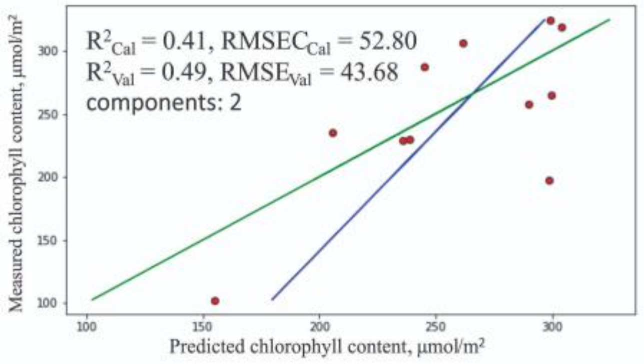

Figure 2. Scatter plot of predicted vs. measured chlorophyll contents when validating the PLSR model

The results are quite optimistic and could be improved by increasing the number of sampling points and introducing machine learning algorithms. For instance, recent studies have shown that Kernel-Ridge regression (Singhal et al., 2019), Random Forest, Subtractive clustering etc. (Vanbrabant et al., 2019) could be successfully used to estimate the chlorophyll content in vegetation from multispectral UAV images.

Conclusion

This study was designed to investigate the potential of UAV multispectral imagery for the estimation of chlorophyll content in vine leaves. The experimental site was the “Trinity Canyon Vineyards” located in the Vayots Dzor region of Armenia. The correlation of the in-situ measured chlorophyll contents with NDVI, NDRE and spectral reflectance was studied and a PLSR model was developed and tested for modelling chlorophyll content.

The results showed that among spectral reflectance, the red band was most sensitive to chlorophyll variations. A positive correlation between chlorophyll content and NDVI/NDRE was also established.

Promising results were obtained for the PLSR model, which proves that multispectral UAV imagery have a big potential for chlorophyll monitoring in vineyards. The follow-up research should be focused on the use of the advanced machine learning algorithms and chlorophyll measurements from various stages of leaf senescence.

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