An Evaluation of UAV-Derived Aerial Imagery for Estimating the Fresh ABG Biomass of Cassava

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Abstract. *The objective of this study to estimate the above-ground biomass of cassava using aerial imagery-derived UAV. The cassava plantation aerial imagery by UAV with a 20M pixel camera was acquired by flying at an altitude of 30 meters and 90 meters to compare the ability to estimate the fresh ABG biomass of cassava. The data processing of UAV images was carried out using modern computer vision algorithms for estimating the geometric parameters of cassava to calculate the fresh above-ground biomass of cassava from the allometric equation derived from the measurement of height (H) and the fresh biomass above the ground of the cassava from the cassava plantation. The results showed that the flying altitudes of 30 meters and 90 meters of the accuracy achievement had RMSE values of 0.65 and 0.98 respectively. This study can be used as a guideline for estimating the fresh above ground biomass of cassava plantation with UAV photogrammetry.*

Keywords: Biomass, UAV, Cassava, Allometric Equation, Digital surface model.

1. Introduction

Cassava is one of the most important crops in the world. In 2022, the global production of cassava root was 277 million tones[1]. Cassava is the drought-tolerant crops that can be successfully grown on marginal land, has little potential for-profit ; often has poor soil ; and gives reasonable yields where many other crops do not grow well [2]. Cassava is a major biomass energy plant [3, 4] and It is an excellent raw material for the production of tapioca flour and ethanol [2, 5]. Thailand was a major grower cassava plantation that provides jobs and economic development in Thailand [5].

Traditional methods to estimate biomass are both labor-intensive and time-consuming are moreover difficult to apply to the very large spatial extent of the study area [6].

UAV-generated Digital Surface Models (DSMs) play a crucial role in precision agriculture by providing detailed terrain and vegetation information. Plant height, accurately measured through UAV-derived DSMs, serves as a key indicator for estimating biomass. This technology, highlighted in studies such as Borra-Serrano et al. [7], Li et al. [8], and Bunruang and Siwa [9], enables precise biomass estimation, optimizing crop management, and fostering informed decision-making for sustainable agriculture.

UAV remote sensing-based biomass estimation model developed by combining the field and UAV-derived aerial imagery data had been examined by several researches [8, 10-15]. For example, Li et al. [8] successfully estimated above-ground biomass and predicted yields in potatoes using UAV-based RGB and hyperspectral imaging. Random Forest regression models demonstrated high prediction accuracy for both fresh and dry above-ground biomass, achieving a coefficient of determination (r^2) greater than 0.90. Crop yield was predicted using four narrow-band vegetation indices and crop height ($r^2 = 0.63$), based on imagery data obtained 90 days after planting. Akbarian et al. [15] conducted an investigation on the best-fit models for sugarcane biomass estimation using linear mixed-effect modeling on unmanned aerial vehicle-based multispectral images. The proposed model outperformed Multiple Linear Regression (MLR), Generalized Linear Model (GLM), and Generalized Additive Model (GAM) for both wet and dry sugarcane biomass, achieving coefficients of determination (R2) of 0.93 and 0.97, and Root Mean Square Error (RMSE) values of 12.78 and 2.57 t/ha, respectively. Selvaraj et al. [13] conducted a study on machine learning for high-throughput field phenotyping. Their research in image processing provides insights into the associations between above-ground in cassava, which were successfully examined with high accuracy and consistently correlated strongly ($r = 0.65$ to 0.84) with above-ground biomass (AGB). However, it is surprising that there are not many studies on the application of UAV remote sensing for estimating above-ground biomass (ABG) of cassava. Very little has been done, and there remains a poor understanding of the underlying mechanisms. Consequently, this study is a pioneering effort to investigate whether UAV-derived aerial imagery can be used for estimating fresh ABG biomass in regard to cassava plantations. UAV-derived aerial imagery data of the cassava plantations in Kumphawapi District, Udon Thani Province, Thailand was chosen for the investigation. The objective of this work to report simple linear correlations between fresh ABG biomass of cassava derived from UAV-derived aerial imagery data and the fresh ABG biomass values collected in the field by flying at an altitude of 30 meters and 90 meters to compare the ability to estimate the fresh ABG biomass of cassava. The results of the correlation models are to be compared against independent testing data so as to reveal the root mean square errors of the models. The outcome of this study is expected to be of use as the basis for further fine-tuning of the statistical parameters in the near future.

2. Materials and Methods

2.1 Study Area

The study site (Fig. 1) is located within Kumphawapi District, Udontani Province, Thailand (17o04’53.30”N, 103o02’11.40”E), at an average elevation of 186 m MSL. The study area has a warm temperate semi-humid continental monsoon climate. The average annual temperature is 34.5 °C. The mean annual rainfall of Udontani Province is 1,270 mm. The rainy season, which sets in during 2nd week of May and continues till the 2nd week of October, has a mean seasonal rainfall of 1,050 mm.

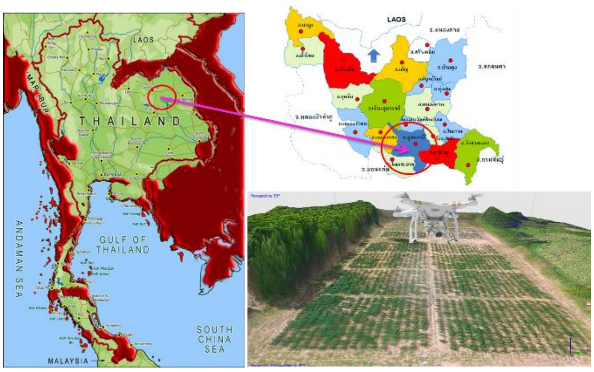


Fig. 1 The location of the cassava plantation in Kumphawapi District, Udon tani Province

2.2 Field Data Collection

The research was designed to monitor cassava growth in the tuber initiation stage. The cassava variety used in the research is Rayong 86-13. Random Collect 50 samples designated for Destructive biomass measurements, all conducted on June 23, 2021. To ensure accurate geographical references (Fig. 2), five ground control points (GCPs) evenly distributed within the field were located with centimeter accuracy using Real-Time Kinematic (RTK). The biomass measured in the field was based on the weight of the fresh cassava trees.

2.3 Unmanned aerial vehicle and camera setup

The digital imagery was collected over three flights with the DJI Phantom 4 Advanced. Digital imagery was collected by using a 20-megapixel camera, which captures three discrete spectral bands: blue (wavelength = 450 nm), green (wavelength = 550 nm), and red (660 nm). Flight paths over the trial area were designed by PIX4D Capture. The forward overlap was 80% and the lateral overlap was 60%. The flight speed was fixed at 6 m/s. ISO and shutter speed were fixed at 160 and 1/2000, respectively. The flight altitude above ground level (AGL) was 30 and 90 m.

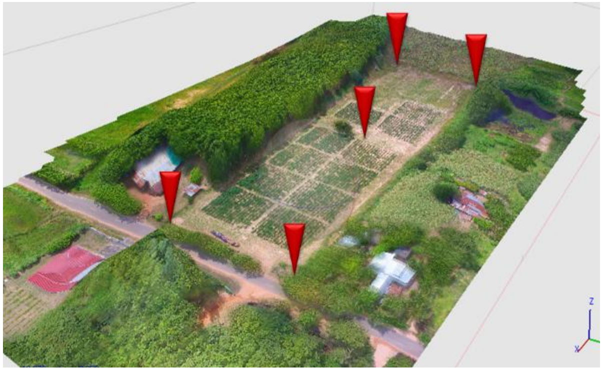


Fig. 2 The location of five ground control points

2.4 Image processing and data extraction

Agisoft PhotoScan 1.4.5 was used to produce digital surface models (DSMs) and generate orthomosaics. In the Agisoft PhotoScan project, five ground control points were employed to georeference the study area and enhance accuracy.

2.5 Allometric Equation

Samples of 50 cassava plants were obtained using a destructive method. The height of the cassava plants (H) was measured, and the entire above-ground biomass of the cassava plants was weighed (ABG Biomass). Subsequently, the collected data were utilized to formulate an allometric equation for cassava plants. The results are presented in Equation (1)."

$$\text{ABG Biomass} = 1.4962H^{1.895} \qquad (1)$$

$(R^2=0.891, \text{RMSE}=0.42)$

When ABG Biomass is the above-ground biomass of the cassava tree (kg) and H is the height of the cassava tree (m).

3. Modeling and resampling

The processing of UAV images necessitated the utilization of cutting-edge computer vision algorithms to evaluate the geometric characteristics of cassava. The objective of this process is to calculate the above-ground biomass of cassava trees using allometric equations. This calculation relies on the height of cassava trees obtained from a digital surface model (DSM) derived from UAV photogrammetry.

To evaluate the model for estimating the biomass of cassava plantations, a comparative analysis was conducted at flying altitudes of 30 meters (GSD = 0.82 cm) and 90 meters (GSD = 2.47 cm), resulting in the creation of linear regression models. The coefficient of determination (R^2) and Root Mean Square Error (RMSE) were employed as evaluation metrics to quantify the performance of the regression model. Equations (2)–(3) are used to calculate R^2 and RMSE.:

$$R^2 = 1 - \frac{\sum_{i=1}^{N} (y_i - \hat{y}_i)^2}{\sum_{i=1}^{N} (y_i - \bar{y}_i)^2} \qquad 2)$$

$$\mathrm{RMSE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N} (y_i - \hat{y}_i)^2} \qquad 3)$$

where N is the total sample size, yi is the *i*th measured biomass of the sample, y_bi is the ith predicted value, and y_bi is the *i*th mean measured value.

4. Results and Discussion

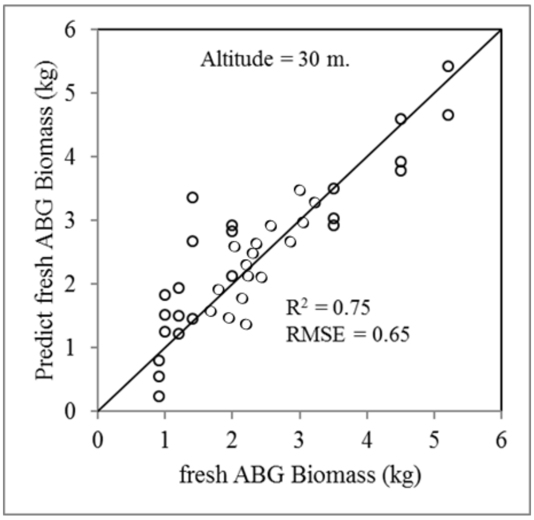
In this study, we use a digital surface model (DSM) derived from UAV photogrammetry processing to estimate fresh canopy biomass in cassava. We employ the DSM value instead of the H value in equation (1). The average field biomass value measured in the field was 2.97 kg (N = 50, SD = 1.42). The R^2 values and RMSE of the linear regression are reported in Table 1. The maximum R^2 and RMSE values belonged to the altitude of 30 m. (R^2=0.75; RMSE=0.65). The plots of all the models are illustrated in Fig. 3. (Biomass maps are shown in Fig. 4) A one-way ANOVA test was also used for testing the similarity between the regression models when two different models were used. It turned out that the two models are statistically not different (i.e., p-value<0.01, N = 50).

The results show a relationship between the field AGB biomass and the linear regression model. Strong statistical correlations of the fresh AGB biomass in cassava models align with prior studies conducted on different types of plants [8, 11, 13, 15].

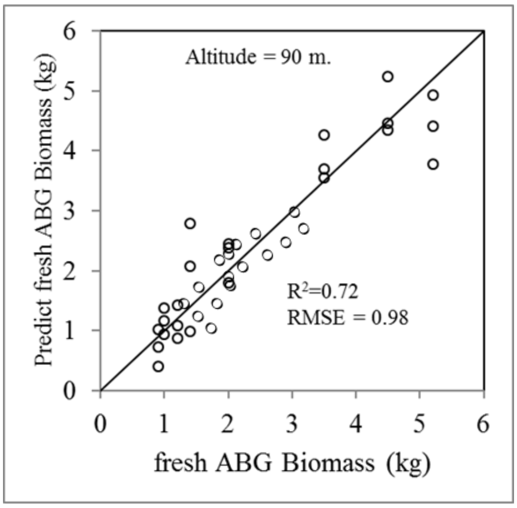
This study employed DSM to estimate the above-ground biomass (AGB) of cassava. The results demonstrate a robust statistical relationship in estimating the fresh AGB biomass in the cassava model, aligning with the findings of Selvaraj et al. [13], despite differences in the study methods. The report specifies the use of vegetation indices (NDRE and GNDVI) for above-ground biomass of cassava (AGB), yielding correlation coefficients (r values) of 0.84 and 0.65, respectively.

Table 1 The R^2 values and the RMSE values of the linear regression model indicating P<0.01

Altitude (m)	Model		Testing	
	R^2	RMSE	R^2	RMSE
30	0.77	0.58	0.75	0.65
90	0.74	0.72	0.72	0.98



(a)



(b)

Fig. 3 The scattering plots with the RMSE values of all models

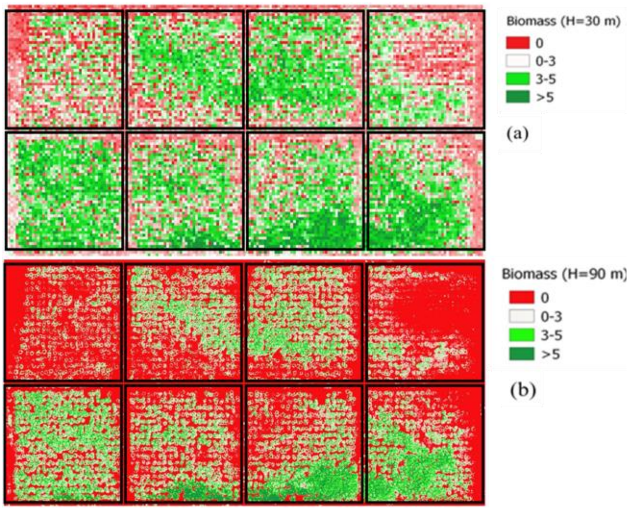


Fig. 4 Shows the cassava fresh above-ground biomass map obtained using the UAV and Allometric Equation. (a) altitude 30 m. and (b) altitude 90 m.

5. Conclusion

Estimating above-ground biomass (AGB) in cassava is a labor-intensive and time-consuming process that involves a multi-step procedure. This method includes sacrificing crops from the field plot, oven-drying them, and subsequently weighing them to assess the fresh and dry biomass of each sample.

The results showed that the ability of UAV-derived aerial imagery data to estimate the fresh above-ground biomass (AGB) of cassava at flying altitudes of 30 meters was better than at 90 meters. In this study, predictor variables used for estimating AGB biomass of cassava were rapidly and non-destructively collected by UAV. The outcome of this study confirms that UAV-derived aerial imagery can be employed to estimate the fresh AGB biomass of cassava. This study represents the initial step in conducting more in-depth studies.

While the aim of this report is not to provide a thorough analysis, the final results may be further improved upon by applying another tool or algorithm [11, 13, 16, 17].

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