Carbon stock assessment in Macaúba (*Acrocomia aculeata*) plantations based on aerial digital images

Sousa P. A. M., Souza, J. C., de Albuquerque B. C., Galvan V. A., Pimentel L. D., Corrêdo L. P.

Agronomy Department, Federal University of Viçosa, Brazil

A paper from the Proceedings of the
17th International Conference on Precision Agriculture and 11th Brazilian Congress on Precision and Digital Agriculture
13-15 July 2026
Porto Alegre, Brazil

Abstract.
The macaúba or macaw palm (Acrocomia aculeata) is a palm tree native to Brazil with significant productive, bioenergetic, and environmental potential, particularly due to its carbon sequestration capacity and its use in systems linked to carbon credits. However, quantifying carbon in large-scale plantations still relies on manual measurements, which are time-consuming and lack scalability. This study aimed to evaluate semi-automated protocols based on drone-acquired aerial imagery to estimate the individual height of macaúba plants and, subsequently, their carbon stocks. Fifty-four methods were evaluated, combining capture modes, flight altitudes, buffer sizes, and height extraction metrics within Canopy Height Models (CHM). These methods were tested across three spacing configurations: single row, double row, and 5 x 5 m. The selected protocols yielded an RMSE between 0.33 and 0.42 m, with a percentage error of less than 5%. Application over the total area estimated 822.9 tons of carbon across 5,010 plants. The results indicate the feasibility of this methodology for large-scale carbon inventories.

Keywords.
Digital Agriculture; Biofuels; Canopy Height Model (CHM).

INTRODUCTION

Macaúba has stood out in the context of climate change due to its capacity to accumulate biomass and carbon, alongside its potential for oil and biofuel production. However, the crop lacks efficient methods to monitor extensive plantations and estimate biometric variables with lower operational costs. Plant height is a variable that can be used in allometric equations to estimate accumulated carbon in macaúba (Moreira et al., 2025). Currently, techniques and tools such as telescopic poles and clinometers are used, which have limitations for large areas. Thus, drones, orthomosaics, and canopy height models can assist in the semi-automated and individualized acquisition of heights and carbon stock. Therefore, the objective of this study was to evaluate and

The authors are solely responsible for the content of this paper, which is not a refereed publication. Citation of this work should state that it is from the Proceedings of the 17th International Conference on Precision Agriculture and 11th Brazilian Congress on Precision and Digital Agriculture. EXAMPLE: Last Name, A. B. & Coauthor, C. D. (2026). Title of paper. In Proceedings of the 17th International Conference on Precision Agriculture and 11th Brazilian Congress on Precision and Digital Agriculture (unpaginated, online). Monticello, IL: International Society of Precision Agriculture and Brazilian Congress on Precision and Digital Agriculture.

select protocols based on aerial imagery to measure the individual height of macaúba plants across different spacings and to assess their application in estimating carbon stock.

METHODOLOGY:

The study was conducted at an experimental site owned by the Federal University of Viçosa, located in the municipality of Araponga-MG, in areas cultivated with macaúba under three spacings: single row (7 x 3.5 m), double row [8 x (4 x 4) m], and 5 x 5 m. A total of 88 plants were measured, comprising 30 in the 5 x 5 m spacing, 29 in the double row, and 29 in the single row. The reference measurements were obtained in the field using a graduated telescopic pole, considering the curvature of the highest expanded leaf (Moreira et al., 2025).

The images were acquired using a DJI Mavic 3M drone with RTK positioning correction. The drone performed orthogonal and mixed flights at altitudes of 60, 80, and 100 m (Fig 1). The acquired images were processed and, as results, orthomosaics, digital surface models (DSM), digital terrain models (DTM), and canopy height models (CHM) were obtained. Using orthomosaics as a basemaps, centroid points were manually marked on each of the plants, from which buffers with 1.2, 1.5, and 2.0 m radii were generated and used for cropping the CHM rasters into circular areas, one for each plant. The canopy height data for each of the clipped areas were extracted by three different height extraction metrics: mean, median, and third quartile.

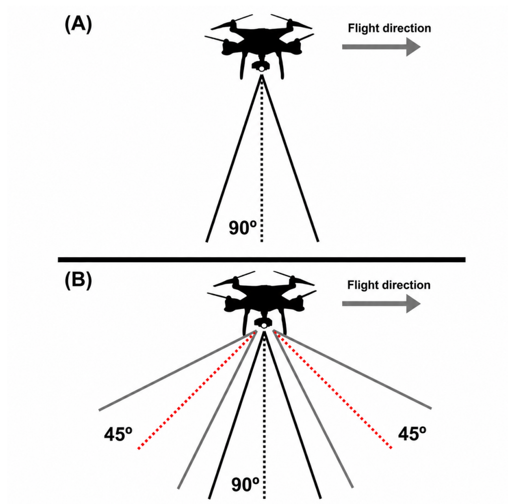

Fig 1. Flight directions and camera angles: orthogonal (A) and mixed (B)

The combinations of capture mode, flight altitude, buffer, and metric resulted in 54 methods. The methods were evaluated for height extraction accuracy using MAE, and for precision using the standard deviation of the errors. Protocol selection was performed using the multiplicative ranking method (Tofallis, 2014). The highest-ranked method was chosen for each of the different spacings (Fig. 2). MAE%, RMSE, and Bias were used as secondary metrics. Carbon stock was estimated using a height based allometric equation, according to Moreira et al. (2025).

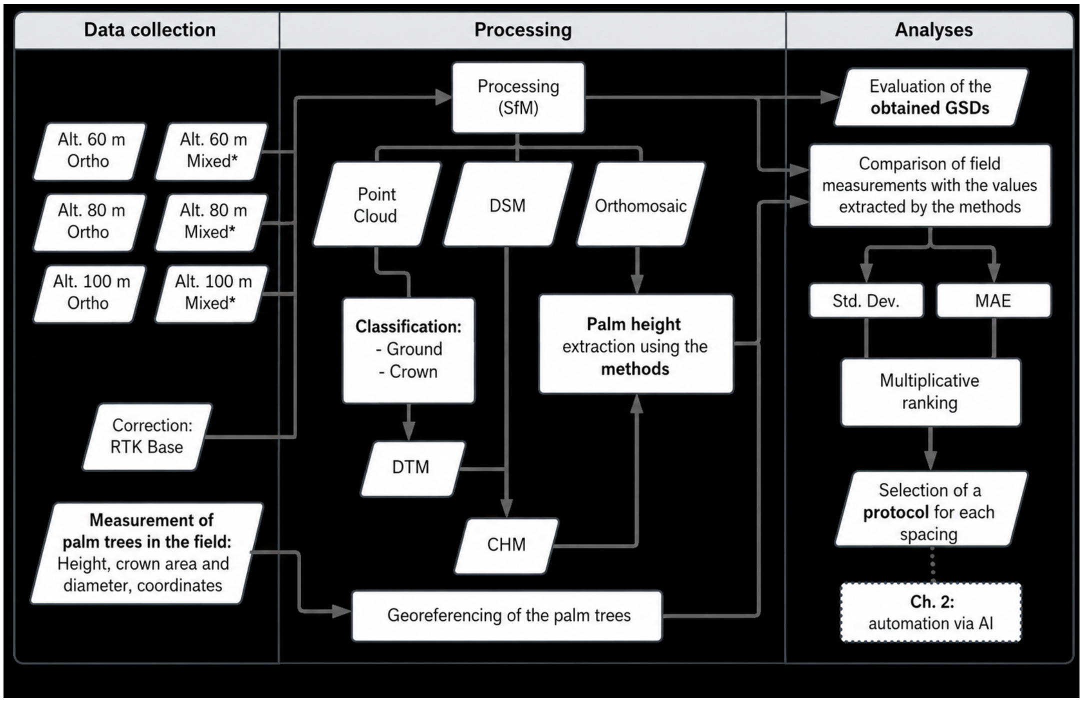

Fig 2. Experimental flowchart

RESULTS:

The selected protocols varied according to the spacing. For the single row, the best method was orthogonal + 80 m + 1.5 m buffer + median. For the double row, orthogonal + 80 m + 1.5 m buffer + third quartile was selected. For the 5 x 5 m spacing, the best protocol was orthogonal + 60 m + 1.2 m buffer + third quartile (Table 1).

Table 1. Results per protocol selected

Spacing	MAE	DPE	MAE%	RMSE	Bias
Double	0,31	0,41	4,04	0,42	-0,13
Single	0,27	0,33	3,15	0,33	-0,06
5 x 5 m	0,3	0,29	3,22	0,36	-0,23

The MAE was 0.31 m in the double row, 0.27 m in the single row, and 0.3 m in the 5 x 5 m spacing. The MAE% was 4.04%, 3.15%, and 3.22%, respectively. The double row presented the highest error, which may be related to the closer proximity between plants and the partial overlapping of the canopies, factors that hinder individualized height extraction. Conversely, the single row and 5 x 5 m spacings showed a better fit, indicating that the planting architecture directly influences the accuracy of the CHM's.

In the carbon stock estimation, errors associated with image-based protocols ranged from 1.52% to 8.22% relative to reference measurements in the comparison between the groups of plants evaluated directly

CONCLUSION:

Drone image-based protocols were efficient in estimating the individual height of macaúba plants. The best methods showed mean errors close to 30 cm and a percentage error of less than 5%, confirming the feasibility of the approach. The protocols resulted in carbon estimation errors of less than 10% relative to the reference values, showing its potential for carbon inventories, environmental audits, and monitoring the large-scale development of macaúba plants.

REFERENCES:

Moreira, S. L. S., Imbuzeiro, H. M. A., dos Santos, R. A. F., Silva, G. C. C., Leite, H. G., Pimentel, L. D., et al. (2025). Carbon accumulation in cultivated macauba trees can be estimated and projected using allometric equations. Industrial Crops & Products, 226, 120682.

Tofallis, C. (2014). Add or multiply? A tutorial on ranking and choosing with multiple criteria. INFORMS Transactions on Education, 14(3), 109-119.