AGRO PRODUCTIVIDAD

Colegio de Postgraduados

Forest inventory using proximal remote sensors, in a plantation of *Cedrela odorata* L. and *Hevea brasiliensis* Müll. Arg.

Hernández-Moreno, José A.[1]; Ordóñez-Prado, Casimiro[2]; Hernández-Ramos, Adrián[3*]; Cortés-Sánchez, Bossuet G.[4]; Buendía-Rodríguez, Enrique[5]; Martínez-Márquez, Carlos A.[1]

[1] Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP), El Palmar Experimental Field, Tezonapa-El Palmar Grande Highway, Km 16.5. El Palmar, Tezonapa, Veracruz. Postal Code 95080.
[2] INIFAP, Gulf Central Regional Research Center, San Martinito Experimental Field. Mexico-Puebla Federal Highway, km 56.5. San Martinito, Tlahuapan, Puebla, Mexico. Postal Code 74100.
[3] INIFAP, Northeast Regional Research Center, Saltillo Experimental Field. Saltillo-Zacatecas Highway, km 342 + 119. Hacienda de Buenavista, Saltillo, Coahuila, Mexico. Postal Code 25315.
[4] INIFAP, Regional Research Center, Tlaxcala Experimental Site. Santa Ana-Tlaxcala Federal Highway, km 2.5. Santa Ana Chiautempan, Tlaxcala, Mexico. Postal Code 90802.
[5] INIFAP, Regional Research Center, Valley of Mexico Experimental Field. Los Reyes-Texcoco Highway, km 13.5. Coatlinchán, Texcoco, Estado de Mexico, Mexico. Postal Code 56250.
* Correspondence: hernandez.adrian@inifap.gob.mx

Citation: Hernández-Moreno, J. A., Ordóñez-Prado, C., Hernández-Ramos, A., Cortés-Sánchez, B. G., Buendía-Rodríguez, E., & Martínez-Márquez, C. A. (2026). Forest inventory using proximal remote sensors, in a plantation of *Cedrela odorata* L. and *Hevea brasiliensis* Müll. Arg. *Agro Productividad*. https://doi.org/10.32854/0xrkbj79

Academic Editor: Jorge Cadena Iñiguez
Associate Editor: Lucero del Mar Ruiz Posadas
Guest Editor: Daniel Alejandro Cadena Zamudio

Received: January 5, 2026.
Accepted: April 19, 2026.
Published on-line: June XX, 2026.

Agro Productividad, 19(5). May. 2026. pp: 3-14.

ABSTRACT

Objective: To evaluate the accuracy of the iPhone 15 Pro® LiDAR sensor for measuring diameter at breast height (DBH) and photogrammetry with unmanned aerial vehicle (UAV) for estimating tree height.

Methodology: The research was conducted in a 17-year-old mixed plantation. DBH was measured with a diameter tape, and tree height with a clinometer. These measurements were compared with data from the LiDAR sensor and UAV photogrammetry. Agreement was assessed using linear regression (R^2, RMSE) and the intraclass correlation coefficient (ICC).

Results: High agreement was observed between traditional methods and remote sensing. For DBH, the comparison yielded R^2=0.95, RMSE=1.47 cm, and ICC=0.964. For height, the results showed R^2=0.96, RMSE=0.64 m, and ICC=0.981.

Study limitations/implications: The study was conducted in a plantation with regular spacing. The results should be validated under different conditions (species and stand structures). The slight systematic underestimation of DBH using LiDAR, attributed to the sensor's resolution, justifies its operational use.

Findings/conclusions: Remote sensors provided accuracy comparable to that of traditional techniques, with superior operational efficiency. iPhone LiDAR is viable for DBH measurement, and UAV photogrammetry is suitable for height estimation in commercial inventories. Their integration allows for automated, georeferenced digital databases for advanced spatial analysis.

Keywords: Forest parameters, Augmented reality, Free software, Mobile LiDAR sensor.

INTRODUCTION

Forest inventories describe the quantity, size, and quality of trees in a forest, as well as other characteristics of the area where they grow and develop (Liang *et al.*, 2016).

They also serve as a basis for planning the sustainable management of forest resources, estimating timber volume, biomass, carbon, and biodiversity, and evaluating the dynamics of forest ecosystems and identifying changes over time with the greatest possible accuracy (Hernández-Moreno *et al.*, 2024).

Traditionally, data and information for forest inventories are obtained using manual equipment, tools, or devices, the most common being diameter measuring tapes or calipers for diameter at breast height (DBH), or clinometers for total height (TH). In practice, this is time-consuming, labor-intensive, costly, and prone to multiple measurement errors (Liang *et al.*, 2016; Hernández-Moreno *et al.*, 2025). The above requires alternative methods, such as the use of remote sensing devices to obtain tree parameters (Liang *et al.*, 2016; Hernández-Moreno *et al.*, 2025). Currently, the availability of devices and the combination of remote sensors offer innovative alternatives for this purpose.

Terrestrial LiDAR (Light Detection and Ranging) and digital photogrammetry using unmanned aerial vehicles (UAVs) have demonstrated potential for the accurate estimation of structural parameters of forest ecosystems (Liang *et al.*, 2016). However, their operational adoption at small, medium, and large scales has been limited by the high cost and technical complexity of professional equipment (Mokroš *et al.*, 2018). This difference has driven the development and evaluation of low-cost proximal remote sensing technologies, such as LiDAR sensors on mobile devices or low-cost UAVs with high-resolution RGB cameras. These technologies have multiple applications and will provide an unprecedented amount of tree/local-level information on ecosystem-specific physical and biological processes and their dynamics (Pierrat *et al.*, 2025).

In particular, LiDAR sensors integrated into mobile devices, along with low-cost unmanned aerial vehicle (UAV) platforms, represent a promising and affordable alternative for generalizing the use of precision forestry technologies, making them more accessible and cost-effective for foresters, technicians, academics, students, and researchers (Mokroš *et al.*, 2018; Fassnacht *et al.*, 2024). Currently, forest inventories need reliable measurement alternatives using low-cost devices or sensors that increase efficiency, accuracy, and the quality of field data. Devices such as smartphones or tablets with low-cost LiDAR and UAVs, originally designed for other sectors, are being adapted for forestry applications, offering an alternative to improve traditional methods in the face of satellite remote sensing technologies (Fassnacht *et al.*, 2024; Zhou *et al.*, 2025; Pierrat *et al.*, 2025).

In this context, the objectives of this research were: 1) To evaluate the accuracy and efficiency of the LiDAR sensor in an iPhone 15 Pro® for measuring diameter at breast height (DBH), and 2) To determine the reliability of UAV photogrammetry for estimating the heights of individual trees, compared to traditional methods, in a mixed tropical forest plantation.

MATERIALS AND METHODS

Area of study and experimental design

The research was conducted in a 0.87-hectare mixed forest plantation of *Cedrela odorata* L. and *Hevea brasiliensis* Müll. Arg., established 17 years ago, located between coordinates 18° 31' 5.98" N and 96° 45' 36.20" W, in the "El Palmar" Experimental Field of the Instituto Nacional de Investigaciones Forestales, Agricolas y Pecuarias (INIFAP), in Tezonapa, Veracruz (Figure 1). The plantation has a systematic design with a spacing of 3×4 m (density of 833 trees/ha), and a composition of 60% *C. odorata* and 40% *H. brasiliensis*.

Acquisition of field data and data using remote sensors

The experimental unit consisted of 70 individuals, 44 *C. odorata* trees and 26 *H. brasiliensis* trees, with DBH≥15 cm, which were selected by stratified random sampling to ensure the representativeness of the population, with respect to the heterogeneity of the mixed commercial forest plantation.

Reference measurements were performed using traditional methods. DBH was measured with a diameter tape, and total height (TH) was determined using a Suunto® clinometer, taking two reciprocal readings per tree (north-south), averaging them to minimize errors.

Subsequently, the iPhone 15 Pro® LiDAR sensor was used with the Polycam® application (Polycam, Inc., 2025) to generate point clouds and 3D models of each tree in ".las" format. The app utilizes the device's three cameras as well as the LiDAR sensor (Mokroš *et al.*, 2018; Hernández-Moreno *et al.*, 2024). Each tree was scanned from multiple angles at a distance of 3-5 m, circling the tree in a 360° scan to ensure the quality of the point cloud. It should also be noted that the maximum range of the LiDAR sensor is 5 m (Mokroš *et al.*, 2018; Hernández-Moreno *et al.*, 2024); therefore, a 2 m pole

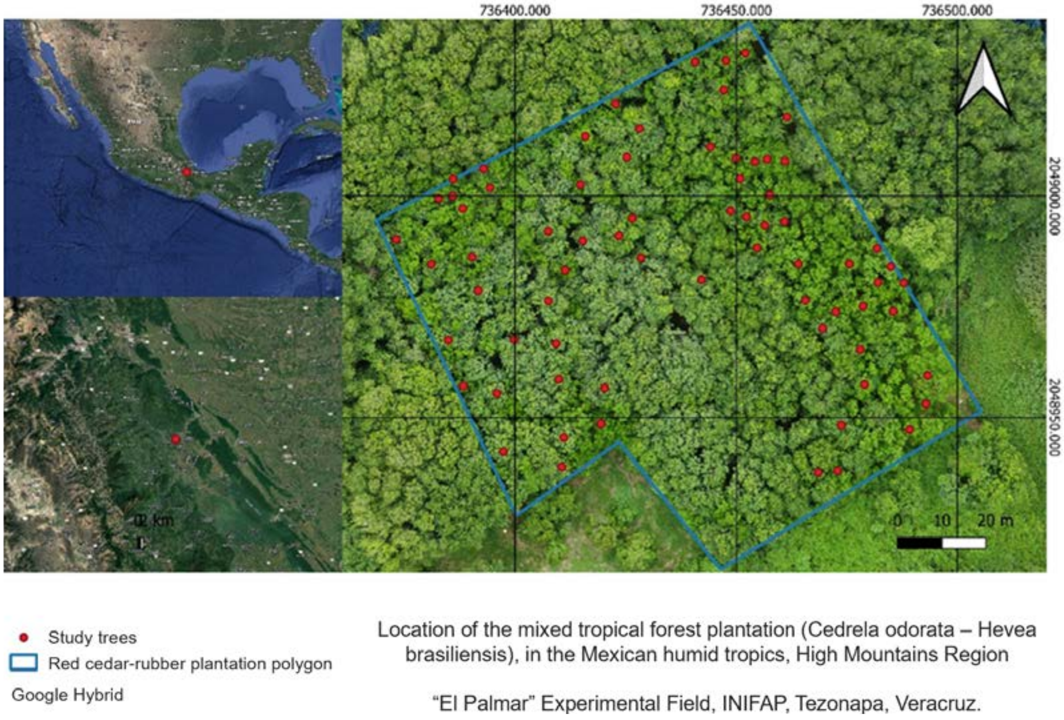

Figure 1. Location map of the study area, INIFAP, E. F. El Palmar, Tezonapa, Veracruz, Mexico.

was also used to ensure greater scanning range towards the upper parts of the trunk. The device was mounted on a DJI Osmo Mobile 7® stabilizer to ensure more stable and higher-quality point cloud scans (Figure 2).

To obtain the photogrammetric data, a protocol of three consecutive flights was executed using the commercial DJI Mini 3 Pro® UAV equipped with a 48 MP RGB camera. The flight design was based on validated methodologies for high-precision forest inventories (Luppichini *et al.*, 2025; Ordóñez-Prado *et al.*, 2025) and configured to optimize canopy cover and detail. Each flight consisted of a double grid trajectory (Figure 2), with three different flight heights (45 m, 55 m and 65 m) and with three different camera tilts (90° and oblique at 80° and 65°) between missions, obtaining 371 images for subsequent processing.

This multimodal strategy combines vertical geometry for the accurate generation of elevation models with oblique angles that better capture the lateral structure of the trunk and crown (Luppichini *et al.*, 2025; Ordóñez-Prado *et al.*, 2025). All flights were scheduled with a minimum overlap of 80% frontal and 70% lateral to ensure the construction of a dense point cloud. For high-precision georeferencing, six ground control points (GCPs) were distributed and taken on stable features in the study area using an EFIX 7® dual-frequency differential GNSS receiver, achieving horizontal and vertical accuracies with a ground resolution ≥2 cm/pixel.

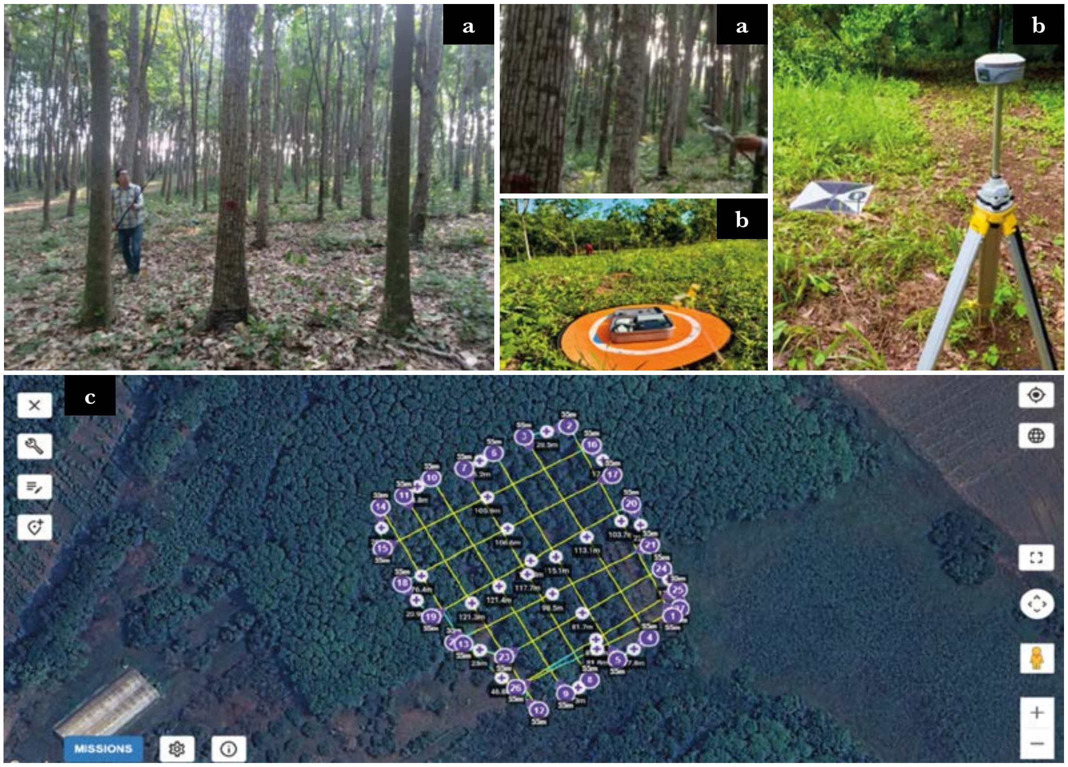

Figure 2. Data acquisition process: a) LiDAR scanning with mobile device, b) UAV flight for photogrammetry with PCT, c) Example of flight mission.

Data processing and statistical analysis

Estimation of DBH

Once the point clouds, individual 3D models of the basal section of the trunk of between 6-7m, of each tree were obtained by scanning with the LiDAR sensor of the iPhone 15 Pro® (Figure 3), the processing was automated by means of a script developed in the R programming environment (R Core Team, 2025).

The algorithm implemented with the lidR (Roussel *et al.*, 2020) and conicfit (Gama & Chernov, 2015) packages executed the following steps for each ".las" file, which represents each of the 70 trees:

- *Filtering of the DBH slice*: Each point cloud was filtered to isolate points between 1.2 and 1.4 meters above ground level, thus defining the slice corresponding to the diameter at breast height (1.3 m). This step discards noise from branches, leaves, or understory vegetation (Figure 4).
- *Geometric fit and diameter calculation*: A least-squares circle fitting algorithm was applied to the filtered point cloud to find the cylinder that best fits the spatial distribution of the points, using Pratt's method (Gama & Chernov, 2015). The diameter of the fitted circle (multiplied by 100 to convert to centimeters) was recorded as the LiDAR-estimated diameter at point (DBH_LiDAR). Metrics for the quality of the fit were calculated, including the number of points used from the cloud, the center, the radius, and the root mean square error (RMSE) of the points to the fitted circle (Figure 4).
- *Quality control and visualization*: The script incorporated visualization functions that generated, for each tree, a 2D graphic showing the distribution of points in the slice and the adjusted geometric circle, along with a 3D graphic of the point cloud (Figure 4). This visual output allowed for immediate verification of the scan quality and the fit, facilitating the identification of errors caused by slices with too few points or atypical trunk geometry.

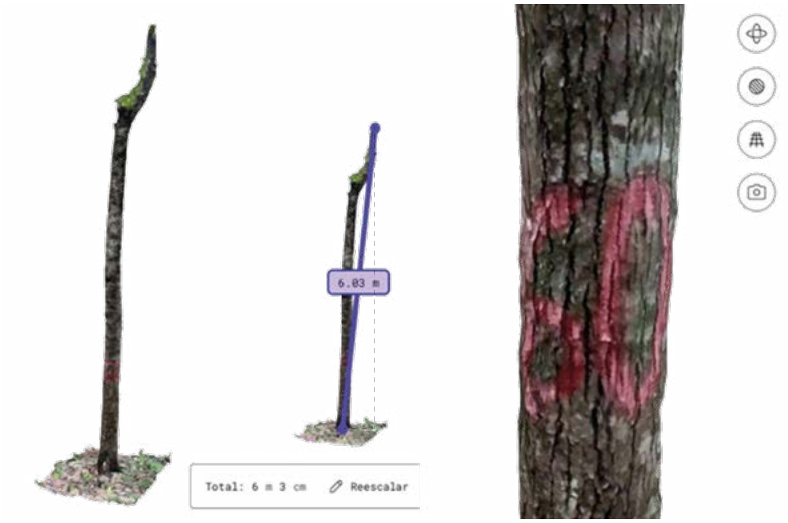

Figure 3. Example of individual ".las" point cloud (3D model) of the basal section of the trunk of a *C. odorata* tree (View in the Polycam app).

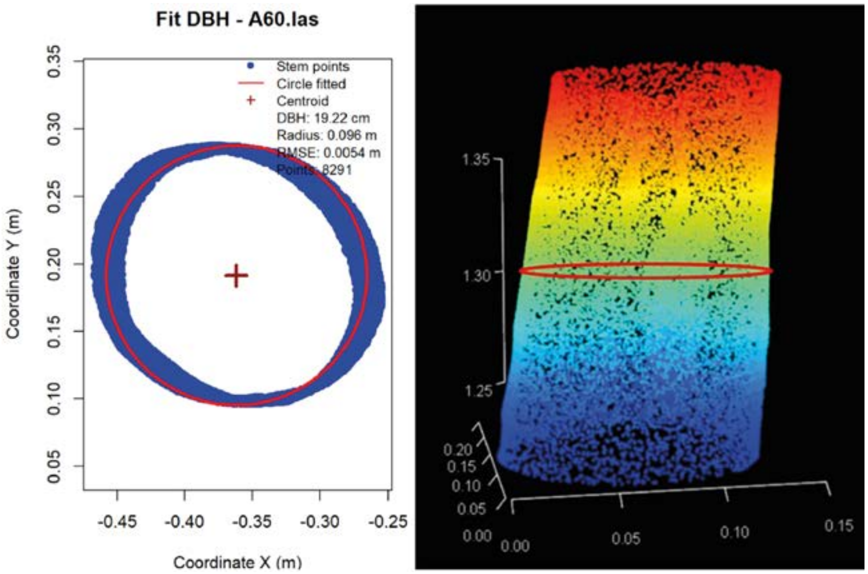

Figure 4. Example of graphical output in R, of the LiDAR processing script for a tree (A60), showing: Left) Plan view (2D) of the points of the trunk slice and the geometric circle adjusted to estimate the DBH. Right) 3D view of the point cloud filtered between 1.2 and 1.4 m in height., for the DBH adjustment.

The quantitative results (DBH_LiDAR, adjustment error, center coordinates) were automatically compiled into a digital table for further statistical analysis.

Photogrammetry with UAV

Photogrammetric processing was performed using Agisoft Metashape® software (v. 2.0), following the standard workflow with PCT, to generate a dense point cloud, a high-resolution digital terrain model (DTM), and finally an orthomosaic with a resolution of 1.8 cm/pixel (Luppichini *et al.*, 2025).

The total heights of the 70 trees studied were estimated from the following products: digital terrain model (DTM) and dense point cloud, generated by photogrammetry with UAVs (Figure 5). For this purpose, an automated processing workflow was implemented in R, using the lidR package (Roussel *et al.*, 2020).

First, the point cloud was normalized to remove terrain topography using an irregular triangulation (TIN) algorithm based on points classified as ground, using the CSF filter (Zhang *et al.*, 2016). This normalization allowed us to obtain the heights above ground (Z_b) for all points, *i.e.*, the base of all trees (Figure 6). Subsequently, a canopy height model (CHM) was generated with a spatial resolution of 0.3 m, using the pixel-to-maximum-value method (Zhang *et al.*, 2016). The precise location of each tree within the CHM was determined using the known coordinates of the 70 sampled individuals. For each location, the maximum height from the normalized point cloud (Z_crown) was extracted within a defined search radius (buffer=2 m), corresponding to the total height estimated by the UAV (TH_VANT). This procedure ensured that the Z_crown measurement would align with the Z_b measurement, for each of the 70 trees, ensuring that both measurements were made on the correct tree (Figure 6).

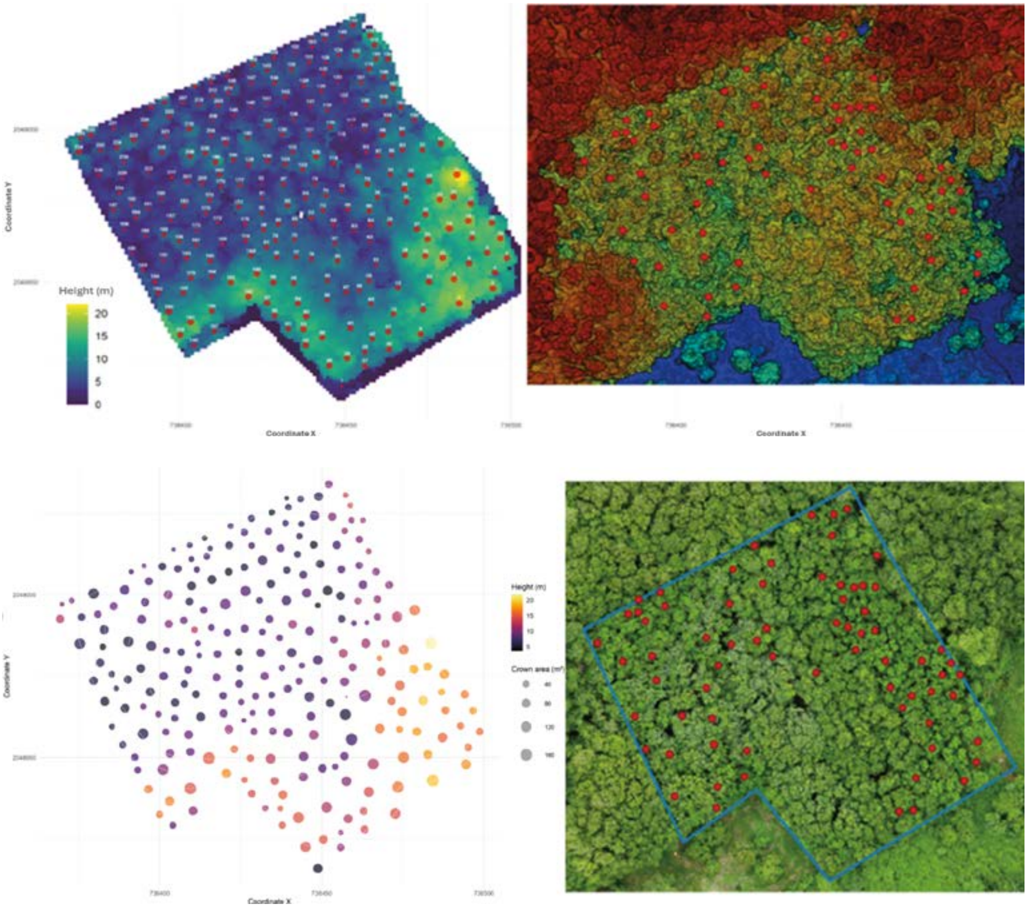

Figure 5. Left) Location and total heights of all trees in the plantation. Right) DTM and point cloud, showing the location of the 70 trees studied.

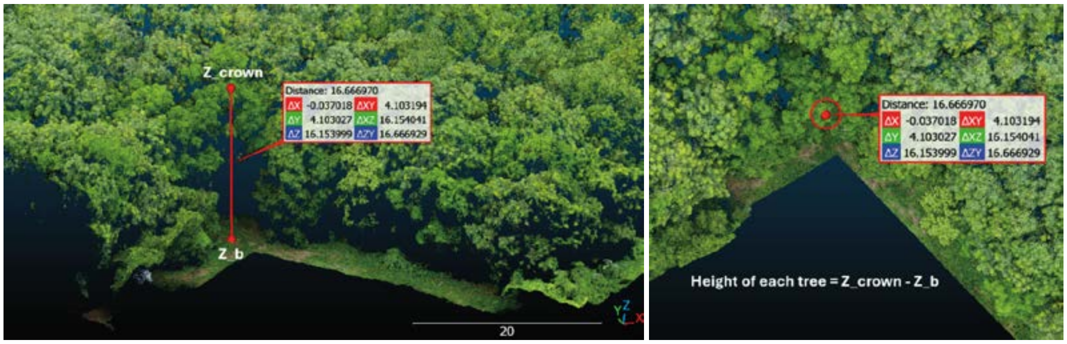

Figure 6. Obtaining the heights of the crown (Z_crown) and the base of the tree (Z_b), using point cloud and DTM.

For quality control, advanced visualizations were generated (3D graphs, 2D maps, histograms) and all data were exported to standard formats (.csv, shapefile) for further analysis in GIS.

Statistical analysis

To determine the agreement between traditional methods (tape measure, clinometer) and proximal remote sensors (mobile LiDAR, UAV), a simple linear regression model was used. The coefficient of determination (R^2) and the root mean square error (RMSE) were calculated, the latter being a primary measure of accuracy (White *et al.*, 2016). Additionally, the intraclass correlation coefficient (ICC) was calculated using a two-way model and absolute agreement to measure the reliability and absolute agreement between the methods; values greater than 0.90 indicate high reliability (White *et al.*, 2016).

RESULTS AND DISCUSSION

The results demonstrated a high correlation between traditional and alternative methods (Figures 7 and 8). For DBH, the regression showed an $R^2=0.95$ ($p<0.001$), RMSE=1.47 cm, and ICC=0.964, indicating excellent agreement. The calibration equation obtained was: DBH_traditional=1.93+0.963×DBH_LiDAR (Figure 7). For height, $R^2=0.96$ ($p<0.001$), RMSE=0.64 m, and ICC=0.981 were obtained. The relationship was: Height_clinometer=0.09+0.998×TH_VANT (Figure 8). Residual analyses confirmed the linearity and homoscedasticity of the relationships, validating the applicability of the calibration models. The graphical analysis of the comparison in DBH measurement by species revealed greater accuracy in *H. brasiliensis*, compared to *C. odorata*, probably attributable to differences in trunk architecture and presence of buttresses in cedar (Figure 7).

This result, attributed to the trunk architecture, aligns with the findings of Lau *et al.* (2019), who documented that structures such as buttresses in some species can introduce errors in LiDAR measurements. However, in this case, the error was minimal, as the trees belong to a plantation that has undergone consistent maintenance and experienced normal growth. Competition with other trees has resulted in straight trunks with no lower branches (Lau *et al.*, 2019).

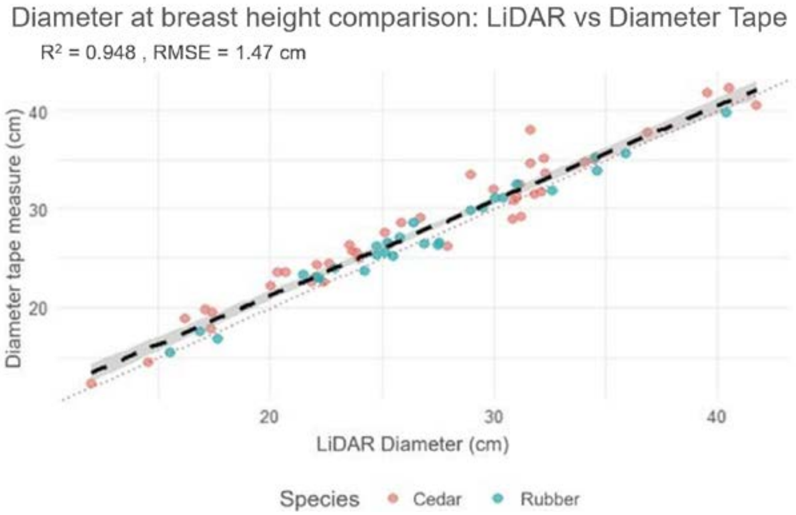

Figure 7. Comparison between DBH measurements taken using remote sensing (LiDAR) and the traditional method (measuring tape).

These results surpass those reported by Wallace *et al.* (2016) in Eucalyptus plantations (R^2=0.83), suggesting that mobile LiDAR technology may be technically viable for operational forestry applications. The slight systematic underestimation of LiDAR (Figure 7) is consistent with the literature, attributable to sensor resolution and processing algorithms (Mokroš *et al.*, 2018; Hernández-Moreno *et al.*, 2024).

Regarding heights, we can observe a slight difference in the accuracy of height estimation between species (Figure 8), with greater accuracy observed in *H. brasiliensis*. This can be attributed to ecophysiological and structural factors (Disney, 2019). First, the crown structure, since *C. odorata* typically develops a dense and stratified crown, even wider than *H. brasiliensis*, especially in plantations with wide spacing like the one studied (3×4 m), where competition is lower (Disney, 2019). This foliage density can limit the effective penetration of photogrammetric techniques, making it difficult for the algorithms to accurately identify the true apex of the tree (Ma *et al.*, 2021). In contrast, *H. brasiliensis* in its productive stage usually maintains a more open crown and a more defined upper canopy, facilitating its detection by photogrammetry (Ma *et al.*, 2021). Secondly, the measurement period (May, prior to the rains) and the phenology could have been a critical factor, since *C. odorata*, a deciduous species, had less foliage, in a state of partial defoliation, while *H. brasiliensis* is a species with more persistent foliage (Neuville *et al.*, 2021). According to Neuville *et al.* (2021), this difference in phenology generates variation in height estimation using photogrammetry, because image correlation algorithms are based on the density, color, and texture of the canopy or foliage. Finally, the composition of the plantation (60% *C. odorata*) presents an irregular and complex canopy. This, according to Neuville *et al.* (2021), increases the overall error in canopy modeling for all species, affecting more noticeably the species or species with a more complex architecture.

Remote sensors proved to be valid and accurate tools, showing high agreement, offering advantages in measurement time (reduction of ∼67%) and data consistency (Table 1), with potential to improve forest inventory in plantations.

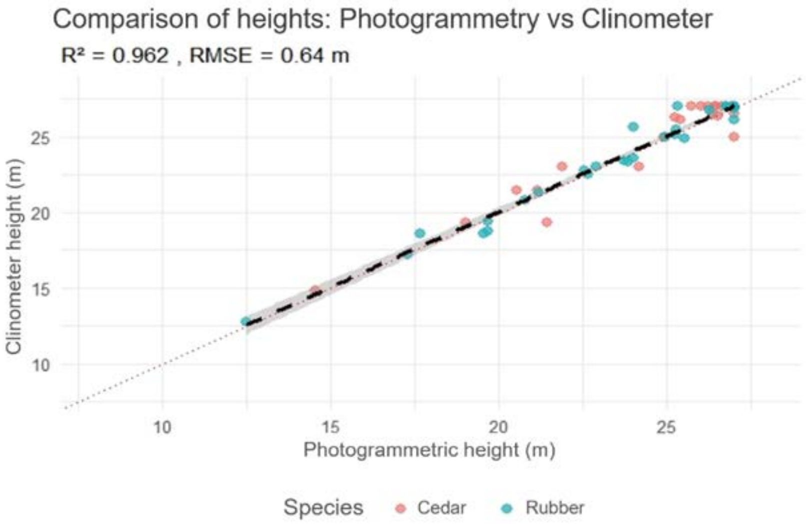

Figure 8. Comparison of total height measurements obtained using a remote sensor (UAV) and the traditional method (clinometer).

Table 1. Time spent (in hours) and number of people, to measure the inventory parameters of 70 trees using iPhone 15 pro®, UAV, measuring tape and clinometer.

Device	iPhone 15 Pro®	UAV	Total	Measuring tape	Clinometer	Total
Measured parameters	DBH	TH	Both	DBH	TH	Both
Number of people	1*	1*	1	2**	2**	2**
Time used (h)	0.45	3.25	3.70	1.75	4.65	6.40
People per hour	0.45	3.25	3.70	3.50	9.30	12.80

UAV: unmanned aerial vehicle; DBH: diameter at breast height; TH: total height.

Photogrammetric technology presented significant advantages in terms of operational safety and visual documentation capacity, eliminating risks associated with field measurements in rugged terrain. Liang *et al.* (2016) reported similar accuracies (RMSE=0.9−1.4 m) in natural forests, validating the robustness of the method in different forest contexts. Likewise, Hernández-Moreno *et al.* (2024) obtained accuracies of R^2=0.99 and RMSE=0.657 cm for diameter at breast height (DBH); and R^2=0.98 and RMSE=0.369 m for total area (TA). The implementation of remote sensors reduced the measurement time per tree from 8.5 minutes (traditional method) to 3.2 minutes (remote sensors), representing an approximately 67% improvement in time efficiency. This gain translates into a significant reduction in operating costs and the capacity for extensive sampling (Table 1).

The application, adaptation and adoption of the combination of these tools and devices in commercial plantations presents the following advantages (Mokroš *et al.*, 2018; Hernández-Moreno *et al.*, 2024; Zhou *et al.*, 2025):

- *Cost reduction*: A ground-based LiDAR, as well as a high-end UAV, can cost tens of thousands of dollars, not including specialized software and training. In contrast, an iPhone with a LiDAR sensor and a low-cost UAV, plus the use of open-source software, represent an investment of less than a third of that; they have the capacity to generate dense point clouds, which are operationally useful for obtaining reliable measurements, and are also accessible to producers, foresters, technicians, students, academics, and even small and medium-sized businesses.
- *Operational efficiency and scalability*: These low-cost technologies will allow for faster, automated data collection of each tree in the plantation, which can then be stored digitally. For example, a single operator with a UAV can cover tens of hectares in one flight, and a person with an iPhone can measure hundreds of trees per day, compared to traditional methods that require more than one operator (Table 1).
- *Accuracy*: Unlike traditional estimates, these technologies generate a digital, georeferenced, quantifiable, and, depending on the frequency, permanent record of the plantation, which can be used for continuous monitoring. This will allow for more accurate calculations of volume, biomass, and carbon (*e.g.*, applicable to carbon market management).

All of the above will facilitate forest inventories for silvicultural management in tropical forest plantations. However, for the applicability and adoption of these methodologies to be reliable for foresters, technicians, or decision-makers, rigorous validation is necessary, such as that of the present study, which provides statistically sound evidence necessary for decision-makers in commercial plantations to confidently and certainly integrate these low-cost tools.

CONCLUSIONS

The low-cost proximal remote sensors evaluated demonstrated precision and accuracy comparable to traditional methods, with substantial advantages in operational efficiency and data quality. The iPhone 15 Pro® LiDAR sensor is a viable tool for diameter measurement in commercial forest inventories, while photogrammetry with control points provides reliable height estimates. The combination of sensors enabled the automatic generation of georeferenced digital databases, eliminating transcription errors and facilitating advanced spatial analysis. This feature is particularly valuable for long-term monitoring in commercial forest plantations. Validation of these methods under different site conditions and with different tree species is recommended, as well as the application of artificial intelligence techniques for the automated processing of LiDAR and photogrammetric data together.

REFERENCES

Disney, M. (2019). Terrestrial LiDAR: a three-dimensional revolution in how we look at trees. *New Phytologist, 222*(4), 1736-1741. doi:10.1111/nph.15517

Fassnacht, F. E., White, J. C., Wulder, M. A., & Næsset, E. (2024). Remote sensing in forestry: current challenges, considerations and directions. *Forestry: An International Journal of Forest Research, 97*(1), 11-37. doi:10.1093/forestry/cpad024

Gama, J. & Chernov, N. (2015). conicfit: Algorithms for Fitting Circles, Ellipses and Conics Based on the Work by Prof. Nikolai Chernov. R package version 1.0.4. https://CRAN.R-project.org/package=conicfit

Hernández-Moreno, J. A., Pérez-Salicrup, D. R. y Velázquez-Martínez, A. (2024). Medición de parámetros de inventario forestal en bosques plantados, mediante tecnología LiDAR: comparación de métodos. *Revista Mexicana de Ciencias Forestales 16*(87). México, ME:72-99. doi:10.29298/rmcf.v16i87.1488

Hernández-Moreno, J. A., Velázquez-Martínez, A., Pérez-Salicrup, D. R., Bravo, F., MacFarlane, D. W., & Reyes-Hernández, V. J. (2025). Terrestrial Laser Scanning for Estimating the Volume and Biomass of Coniferous Stems in the Mariposa Monarca Biosphere Reserve, Mexico. *Forests, 16*(2), 334. doi:10.3390/f16020334

Lau, A., Martius, C., Bartholomeus, H., Shenkin, A., Jackson, T., Malhi, Y., ... & Bentley, L. P. (2019). Estimating architecture-based metabolic scaling exponents of tropical trees using terrestrial LiDAR and 3D modelling. *Forest Ecology and Management*, 439, 132-145. doi:10.1016/j.foreco.2019.02.019

Liang, X., Kankare, V., Hyyppä, J., Wang, Y., Kukko, A., Haggrén, H., … Vastaranta, M. (2016). Terrestrial laser scanning in forest inventories. *ISPRS Journal of Photogrammetry and Remote Sensing*, 115, 63-77. doi:10.1016/j.isprsjprs.2016.01.006

Luppichini, M., Paterni, M., Berton, A., Casarosa, N., & Bini, M. (2025). Influences of the ground control point (GCP) configuration on the UAV-derived Structure from Motion (SfM) in the coastal environment. *Earth Science Informatics, 18*(1), 144. doi:10.1007/s12145-024-01677-w

Ma, L., Zheng, G., Eitel, J. U., Magney, T. S., & Moskal, L. M. (2017). Retrieving forest canopy extinction coefficient from terrestrial and airborne LiDAR. *Agricultural and Forest Meteorology*, 236, 1-21. doi:10.1016/j.agrformet.2017.01.004

Mokroš, M., Liang, X., Surový, P., Valent, P., Čerňava, J., Chudý, F., … Merganič, J. (2018). Evaluation of Close-Range Photogrammetry Image Collection Methods for Estimating Tree Diameters. *ISPRS International Journal of Geo-Information, 7*(3), 93. doi:10.3390/ijgi7030093

Neuville, R., Bates, J. S., & Jonard, F. (2021). Estimating Forest Structure from UAV-Mounted LiDAR Point Cloud Using Machine Learning. *Remote Sensing, 13*(3), 352. doi:10.3390/rs13030352

Ordóñez Prado, C., Hernández Ramos, A., Buendía Rodríguez, E., Cortés Sánchez, B. G., Nava Nava, A. & Tamarit Urias, J. C. (2025). Medición de atributos forestales de especies de coníferas mediante fotogrametría digital con drones. *Ecosistemas y Recursos Agropecuarios, 12*(V). doi:10.19136/era.a12nV.4586

Polycam, Inc. (2025). Polycam (Versión 7.0) [Mobile app]. App Store. https://poly.cam/

Pierrat, Z.A., Magney, T.S., Richardson, W.P., Runkle, B.R.K., Diehl, J.L., Yang, X., Woodgate, W., Smith, W.K., Johnston, M.R., Ginting, Y.R.S., Koren, G., Albert, L.P., Kibler, C.L., Morgan, B.E., Barnes, M., Uscanga, A., Devine, C., Javadian, M., Meza, K., Julitta, T., Tagliabue, G., Dannenberg, M.P., Antala, M., Wong, C.Y.S., Santos, A.L.D., Hufkens, K., Marrs, J.K., Stovall, A.E.L., Liu, Y., Fisher, J.B., Gamon, J.A. and Cawse-Nicholson, K. (2025), Proximal remote sensing: an essential tool for bridging the gap between high-resolution ecosystem monitoring and global ecology. *New Phytol*, 246: 419-436. doi:.org/10.1111/nph.20405

Puliti, S., Ene, L. T., Gobakken, T., & Næsset, E. (2017). Use of partial-coverage UAV data in sampling for large scale forest inventories. *Remote sensing of environment*, 194, 115-126. doi:10.1016/j.rse.2017.03.019

R Core Team (2025). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.r-project.org/index.html

Roussel, J. R., Auty, D., Coops, N. C., Tompalski, P., Goodbody, T. R., Meador, A. S. & Achim, A. (2020) lidR: An R package for analysis of Airborne Laser Scanning (ALS) data. *Remote Sensing of Environment* 251: 112061. doi:10.1016/j.rse.2020.112061

Wallace, L., Lucieer, A., Malenovský, Z., Turner, D., & Vopěnka, P. (2016). Assessment of Forest Structure Using Two UAV Techniques: A Comparison of Airborne Laser Scanning and Structure from Motion (SfM) Point Clouds. *Forests, 7*(12), 62. doi:10.3390/f7030062

White, J. C., Coops, N. C., Wulder, M. A., Vastaranta, M., Hilker, T., & Tompalski, P. (2016). Remote sensing technologies for enhancing forest inventories: A review. *Canadian Journal of Remote Sensing, 42*(5), 619-641. doi:10.1080/07038992.2016.1207484

Zhang, W., Qi, J., Wan, P., Wang, H., Xie, D., Wang, X., & Yan, G. (2016). An Easy-to-Use Airborne LiDAR Data Filtering Method Based on Cloth Simulation. *Remote Sensing, 8*(6), 501. doi:10.3390/rs8060501

Zhou, M., Li, C., & Li, Z. (2025). Extraction of individual tree attributes using ultra-high-density point clouds acquired by low-cost UAV-LiDAR in Eucalyptus plantations. *Annals of Forest Science, 82*(1), 20. doi:10.1186/s13595-025-01291-w