UAV-derived canopy volume predicts leaf biomass in pollarded forage trees

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Highlights

- UAV RGB imagery was used to estimate leaf biomass of forage trees.
- A high-resolution digital surface model (5 mm) was generated by photogrammetry.
- Tree canopy volume and species identity were key predictors of leaf biomass.

Introduction

European livestock systems are increasingly affected by climate change, particularly summer droughts and heatwaves. Integrating trees into pastures can mitigate these effects by providing shade and an additional forage resource. Tree leaves are generally less affected by summer weather extremes than herbaceous vegetation, have comparable nutritive value, and decline more slowly in quality, offering greater feeding flexibility (Mesbahi et al., 2025). However, knowledge on leaf biomass production in forage trees remains limited and highly variable among species and pruning practices (Larsen et al., 2025). Moreover, no standardized method exists to assess this biomass, as most approaches were developed for wood production. Destructive sampling is time-consuming, while allometric equations are often species-specific and difficult to generalize (Galland et al., 2025). Unmanned aerial vehicles (UAVs, or drones) are increasingly used to estimate tree height or crown area (Bossoukpe et al., 2021). Here, we evaluated whether UAV-derived metrics can estimate leaf biomass in four forage tree species.

Material and Methods

The study site was in Lusignan, France (46°25'19.6"N, 0°07'18.2"E). The 2-ha agroforestry plot consisted of 168 forage trees distributed in four rows: *Alnus cordata*, *Fraxinus excelsior*, *Morus alba*, and *Ulmus* ‘Nanguen’. Trees were planted in 2014 at a spacing of 3 m within rows and 20 m between rows, and pollarded in 2020 at 50–80 cm above ground. Since 2021, they have been browsed by dairy cows in summer for two weeks and pruned in winter to maintain their pollard structure.

Drone flights were conducted in early July 2021, 2022, and 2023 using a UAV equipped with an RGB camera. The drone flew at 20 m above ground level and captured images every three seconds, ensuring 85% front and 80% side overlap between photographs. Images were processed in Agisoft Metashape to generate a digital surface model (DSM) with a spatial resolution of 5×5 mm. Using QGIS, a buffer was delineated around each tree to define the local ground level. Tree height and canopy volume were extracted from the DSM using the Volume Calculation Tool plugin.

Within one week after each drone flight, tree height was measured manually and leaves (including petioles) were harvested from 3–6 trees per species each year (N = 49 trees). Dry biomass was measured and modelled in R using the glmmTMB package. Candidate models included tree height or canopy volume as predictors, either alone or interacting with species, with year included as a random effect. All hierarchical submodels, including additive and null models, were considered. Model selection was performed using Akaike weights with the MuMIn package.

Results and discussion

Tree height derived from UAV imagery closely matched manual measurements ($r = 0.95$, $R^2 = 0.91$, Figure 1A), confirming the reliability of drone-based structural measurements. The best model predicting leaf biomass included the interaction between canopy volume and species, with year as a random effect, indicating that canopy volume is a better predictor of leaf biomass than tree height alone (Figure 1B). The results also highlight the importance of species-specific equations for biomass prediction, as reported for herbaceous vegetation and shrubs (McCann et al., 2022). Additional studies will therefore be required to extend this approach to a wider range of forage tree species.

Because the method relies on a two-dimensional DSM, the empty volume between canopy and ground cannot be fully captured. In our study, trees were pollarded at 50–80 cm and branches developed close to the ground, which limited this issue. However, higher pollarding heights or high-stem trees may reduce prediction accuracy. In such cases, full 3D canopy reconstruction rather than a DSM-based approach could improve biomass estimation, although it requires more processing time.

Using the selected model, total leaf biomass available was estimated at 70 kg DM.ha^{-1} in 2021, 73 kg DM.ha^{-1} in 2022, and 89 kg DM.ha^{-1} in 2023. Considering that a dairy cow consumes around 20 kg DM per day, the 168 fodder trees in this plot provide a complementary forage resource rather than a primary feed source, but trees can compete with low-producing grasslands (Galland et al., 2025).

These results demonstrate that UAV photogrammetry provides an accurate, non-destructive, and potentially rapid method for estimating leaf biomass in pollarded forage trees.

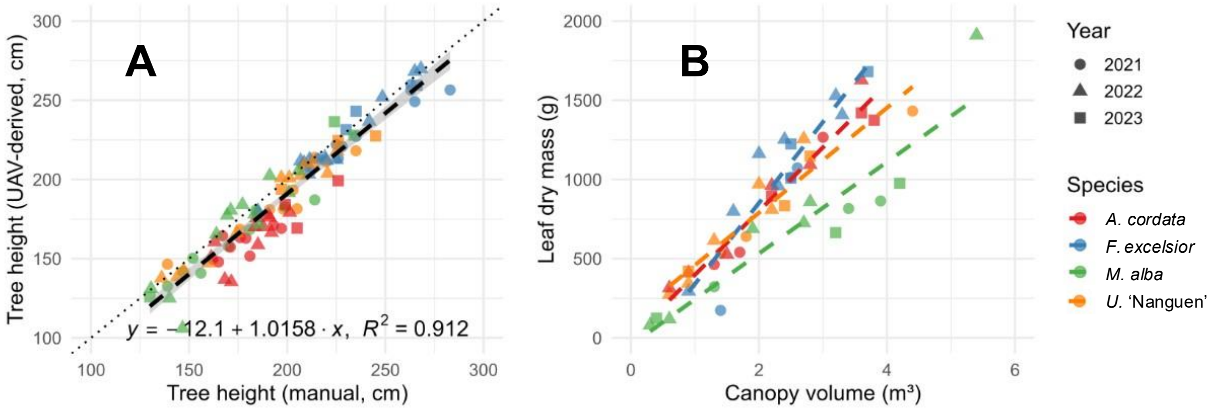

Figure: Relationship between manually measured and UAV-derived tree height (A), and between leaf dry mass and UAV-derived canopy volume (B).

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Keywords

Biomass modelling, Digital surface model, Drone, Fodder trees, Photogrammetry

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