Unlocking the Potential of Agricultural Residual Biomass: A methodological framework for the effective use of UAVs

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Introduction

In the agricultural sector, and particularly in viticulture, pruning activities generate substantial quantities of residual biomass each year. This biomass is often underutilized, either left in the field or burned, resulting in adverse environmental and economic impacts (Scarascia - Mugnozza et al., 2015). Amid growing environmental awareness and the pressing need for sustainable resource management, the conversion of vineyard prunings into a usable form presents a promising opportunity. Recent advancements in remote sensing technologies and the deployment of Unmanned Aerial Vehicles (UAVs) have facilitated the accurate estimation and spatial mapping of residual biomass (Zhang & Kovacs, 2012, Bazrafkan et al., 2023), providing the research community a novel method for estimating biomass volume. Environmental monitoring surveys typically focus on biomass estimation at the level of individual plants, rather than assessing biomass volume over entire agricultural areas (McCann et al., 2022). In this context, the present study aimed to develop and implement a UAV-based methodological approach for measuring the volume of woody residual biomass derived from vineyard prunings, and conventional field plant measurements.

Materials and methods

In the present framework, an analytical volume assessment methodology was developedand implemented in the experimental vineyard of the American Farm School (AFS) of Thessaloniki, in Greece. This methodological approach, concerning the monitoring and estimation of woody residual biomass volume is developed in the following stages: 1) Survey Preparation - determination of the research area and the use of the appropriate UAV platform, 2) UAV Flight Planning and UAV–involving the detailed mapping of the AFS's experimental vineyard and the determination of specific flight parameters (height, speed and image overlapping), 3) Data Collection-high-precision georeferenced data collection (RGB images), 4) Data Processing-analysis and determination of image orientation, according to the SFM (Structure from Motion) technique for the generation of a dense 3D point cloud enabling volume estimation, 5) Estimation of the residual Biomass for residual volume estimation where two methods were utilized: a) a UAV-based estimation, by measuring an individual plant volume with the use of dedicated software and b) by classic field measurement and, 6) Results verification-on site stump volume estimation and comparison of the two methods.The above methodological approach is depicted in Figure 1.

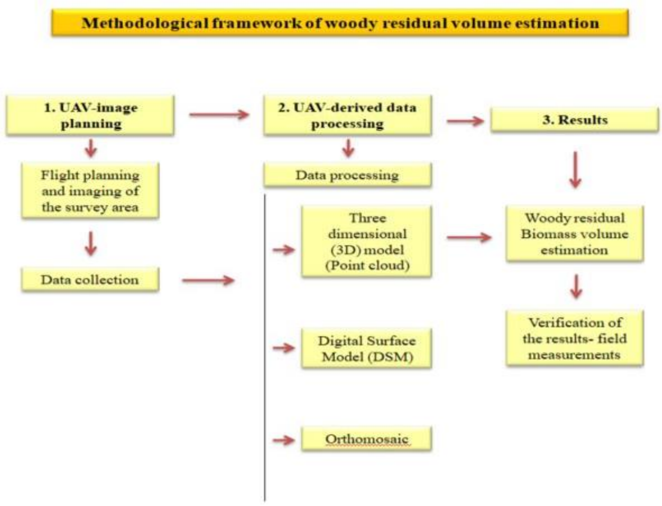
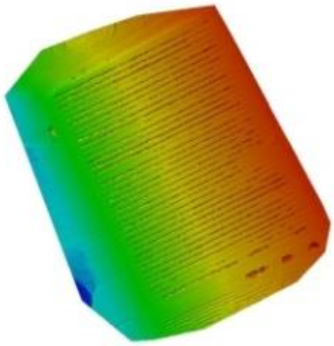


Figure 1. Volume assessment methodology based on UAV-derived data.

Its implementation enabled the generation of the final 3D point cloud, which was then used in order to estimate woody residual biomass volume from the examined vineyard, following specific photogrammetric processing steps (Figure 2). More specifically, through the photogrammetric processing, the generation of the Digital

Surface Model (DSM) (Figure 3) was achieved, enabling vine parameters measurements (height, width), both in 2D and 3D environment.

(a)



(b)

Figure2. (a) UAV-acquired image of the experimental vineyard of the American Farm School in Thessaloniki, (b) DSM of the experimental vineyard.

Results and discussion

To estimate the volume of woody residual biomass, two methodological approaches were employed. First, a representative vine stump was selected based on average diameter and height values. For the purposes of this study, residual biomass was categorized into two distinct types, leafy and woody, to schedule UAV imaging during two separate periods (leaf-on and leaf-off). Following image acquisition, UAV imagery was pre-processed, resulting in the generation of a final 3D point cloud, which formed the basis for volume calculations in this study. Specifically, volume estimation was conducted using the open-access *CloudCompare*™ software (Cloud Compare, 2022), by manually measuring the three dimensions (X, Y, Z) of a vine stump, resulting in a calculated volume of 0,002 m^3. Assuming this volume is representative of all vine stumps across the vineyard, the total woody residual biomass volume was estimated at 3,8 m^3. In addition, on-site measurements and observations were conducted using a conventional (in situ) approach. These field measurements indicated that the average weight of prunings per stump was approximately 1,042 kg.

Conclusions

In the viticulture sector the inclusion and use of UAVs has proved to be a useful tool in vineyard management, as new perspectives in estimation and geospatial mapping of woody residual biomass availability arise, redefining the utilization of prunings, in a short time and at low cost. Based on the average estimated volume data, that was acquired through UAV imaging data processing and the average weight of prunings per stump, that was estimated on site, the specific weight of prunings was estimated to 521kg/m^3, which is within the range reported in the relevant literature (Skoutida et al., 2025). The developed methodology enabled the estimation of a representative stumps volume, utilizing UAV technology, while field measurements demonstrate its effectiveness and the need to obtain a greater, in number and in time series, dataset, which is deemed essential for more accurate outputs.

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