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## **Unlocking canopy dynamics: UAV-LiDAR-based biomass estimation in *Ocimum basilicum***

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### **ABSTRACT**

UAV-LiDAR offers a high-throughput route to phenotyping and biomass estimation in basil (*Ocimum basilicum* L.). Over three crops seasons (2021–2023), we evaluated three commercial varieties across 96 plots under different irrigation regimes and sowing densities. Multi-temporal LiDAR acquisitions quantified canopy height, LAI and volume and were validated against ground truth. Canopy volume strongly predicted fresh biomass ( $R^2 = 0.93$ ; mean error < 8%). Across years, fresh biomass per single cut ranged from 0.2 to 2.0 kg m<sup>-2</sup> depending on variety, contrasting weather conditions and management. Results demonstrate that a non-invasive UAV-LiDAR workflow can deliver accurate, plot-scale fresh biomass estimates, enabling frequent monitoring of crop performance and supporting data-driven agronomic decisions in high-value aromatic crops.

**Keywords:** UAV-LiDAR, precision agriculture, phenotyping, biomass estimation, basil.

### **INTRODUCTION**

Basil (*Ocimum basilicum* L.) is a high-value aromatic crop also central to pesto production and increasingly cultivated in open fields with multiple harvests to meet industrial quality requirements. Accurate, timely biomass assessment is pivotal for phenotyping, management, and supply-chain planning, yet destructive sampling is labor-intensive and poorly scalable. Remote sensing with UAVs enables high-throughput monitoring, but passive optical indices saturate at high canopy density and are confounded by illumination and canopy architecture (Bånkestad & Wik, 2016). By contrast, LiDAR can robustly capture canopy structure and improves biomass inference, yet UAV-LiDAR is underused in leafy horticulture (Rivera et al., 2023). We evaluate a UAV-LiDAR workflow for basil fresh-biomass across varieties and managements, using multi-temporal structural metrics validated against ground truth to support decisions in industrial supply chains.

### **MATERIALS AND METHODS**

Field trials (2021–2023) comprised 96 plots (32/40/24 plots per year, respectively) with Garibaldi and Prospera in 2021; Garibaldi, Prospera, Italiko in 2022–2023, under drip

and sprinkler irrigation and variable sowing densities (see La Placa et al., 2024 for 2021–2022; while a sowing single density adopted in 2023). UAV surveys at 20 m AGL (Matrice 300 RTK + Zenmuse L1, LiDAR/RGB) were flown pre and post-harvest at each of four cuts per season, enabling multi-temporal canopy characterization. LiDAR point clouds were denoised, field-cropped, and ground-classified to derive a 0.1 m DEM; heights were normalized, and canopy metrics were extracted (height; voxel-based volume before and after each cut). LAI maps were computed from normalized point clouds via gap-fraction/voxelization (1 m window; 0.05 m voxels). Ground references included plot-level fresh biomass (on-combine electronic weighing), quadrat biomass checks, plant height, and LAI (LI-COR LAI-2200C). Analyses were performed using LiDAR360 and MATLAB.

## RESULTS & DISCUSSION

Across three seasons, single plot cut fresh biomass ranged 0.2–2.0 kg m<sup>-2</sup>. Due to heat, drought and elevated pressure of *Peronospora belbahrii*, year means differed sharply: in 2021 1.30, in 2022 0.64 and in 2023 0.95 kg m<sup>-2</sup>. Variety ranks shifted: 2021 Prospera > Garibaldi; 2022 Garibaldi  $\geq$  Prospera with Italiko lowest; 2023 Garibaldi dominant (Prospera -23%, Italiko -20%). LAI alone explained ~50% of variance ( $R^2=0.50$ , positive correlation), while height was weak ( $R^2=0.27$ ) and often inverted at the first cut (negative association,  $R^2=0.37$ ). In contrast, LiDAR-derived canopy volume removed (pre–post cut) correlated tightly with plot-level fresh biomass ( $R^2=0.93$ ), capturing variety and management effects, consistently with evidence that height alone is insufficient and that structural metrics, and their fusion with LAI, improve biomass prediction (Li et al., 2016; Ballesteros et al., 2018).

## CONCLUSIONS

UAV-LiDAR canopy volume accurately estimates fresh basil biomass, outperforming LAI or height alone and enabling non-destructive, operational monitoring across varieties, seasons, and irrigation regimes. Future work should fuse structural metrics with spectral features to enhance *Peronospora belbahrii* damage assessment and early warning.

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