Detecting biophysical and geometrical characteristics of the canopy of three olive cultivars in hedgerow planting systems using an UAV and VIS-NIR cameras

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Abstract

The success of olive *(Olea europaea)* orchards depends on the interaction between genotype, planting system and orchard management. Research efforts often collide with the lack of high-throughput monitoring technologies for effective and rapid evaluation of expressed phenotypes under field conditions. Rapid phenotyping technologies allow to acquire a large number of information in a relatively short period, optimizing efforts and labour. In an experiment carried out in Sicily, an unmanned aerial vehicle (UAV) equipped with NIR-VIS cameras was used to monitor canopy characteristics of three olive cultivars ('Koroneiki', 'Biancolilla' and 'Calatina'), planted at three different planting distances (PD) (4 x 4 m, 4 x 3 m and 4 x 2 m). Vegetative indices and canopy geometrical characteristics were calculated by means of the map algebra technique and structure from motion technique, respectively. Significant differences in the Normalized Differential Vegetation Index (NDVI) and Green Normalized Differential Vegetation Index (GNDVI) values were measured for the different combinations of cultivars and PD. In particular, the highest and lowest values of NDVI and GNDVI indices were measured in Koroneiki (4 x 4 m) and 'Calatina' (4 x 3 m) plots, respectively. There was a linear relation between NDVI and prunings removed, expressed on both mass and volume per tree, for all cultivar x PD combinations. Tree canopy volume, estimated by the UAV-VIS camera technique, was higher in Koroneiki than in 'Calatina', with intermediate values measured in 'Biancolilla'. The more spaced trees (4 x 4 m) had bigger canopies (6.4 m^3) than those planted at 4 x 2 m (5.7 m^3), but when the volume was expressed as m^3 of canopy per m^2 of soil the opposite trend was observed. The higher canopy volume per square meter was related to a higher fraction of intercepted PAR measured at noon. Our results indicate potential application of the UAV-NIR-VIS technique to determine canopy characteristics of different planting systems and cultivars of olive.

Keywords: Canopy volume, GNDVI, NDVI, *Olea europaea* L., planting density, pruning.

INTRODUCTION

Modern olive growing relies on the interaction between genotype, planting system and orchard management. Research efforts collide with the lack of high-throughput monitoring technologies for effective and rapid evaluation of expressed phenotypes under field conditions. Field phenotyping is a critical component of crop improvement because it represents the expression of the interactions between genetic and environmental factors, and

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their effects on important production traits such as fruit yield and tolerance to abiotic and biotic stresses. Plant architecture is especially important in fruit breeding programs. One of the goals of breeding programs for olive trees is to develop cultivars suitable either for discontinuous canopy (open vase configuration) or continuous canopy (hedgerow) configurations to promote the mechanization of modern orchards (Marino et al., 2019; Díaz-Varela et al., 2015).

Similarly, pruning modifies canopy architecture which, in turn, can markedly affect tree physiology and fruit quantity and quality (Caruso et al., 2017, Cherbiy-Hoffmann et al., 2013). Investigations on canopy architecture and pruning strategies usually involve the characterization of tree architecture by manually measuring several geometric features of the crown and the manual sampling of the pruning material to be weighed. These tasks are labor-intensive and time-consuming and can generate inconsistent results due to the irregular geometry of the tree crown. New methodologies based on remote sensing techniques through unmanned aerial vehicle (UAV) have been developed allowing a more accurate and rapid acquisition of biophysical parameters in fruit trees and vines (Caruso et al., 2019; Matese et al., 2017; Zarco-Tejada et al., 2012).

The aim of this work was to assess the ability of UAV and VIS-NIR cameras techniques in estimating critical parameters of tree canopies of different olive cultivars planted at different tree distances.

MATERIALS AND METHODS

In this study, carried out in Sicily, an unmanned aerial vehicle (UAV) equipped with NIR-VIS cameras was used to monitor canopy characteristics of three olive cultivars, ('Biancolilla', 'Calatina' and 'Koroneiki'), planted at three different planting distances (PD) (4 x 2, 4 x 3 and 4 x 4 m) in 2012. Fruits from each tree were harvested by hand between October ('Biancolilla') and November ('Koroneiki') 2018. Trees were pruned on 27 February 2019 and pruned material was weighed. Flights were performed using a S1000 UAV octocopter (DJI, Shenzhen, China) equipped with a consumer RGB photo-camera (Coolpix P7700, Nikon, Shinjuku, Japan) and a multispectral (NIR-RG) camera (ADC-lite, Tetracam, Inc., Gainesville, FL, USA) mounted on a 2-axis stabilized gimbal. Images were acquired before (27 February 2019) and after (28 February 2019) pruning at noon under clear sky conditions, the flight altitude was 50 m above ground level (AGL) flying at 2.5 m s^{-1} speed. Vegetative indices and canopy geometrical characteristics were calculated by means of the map algebra technique and the structure from motion technique, respectively (Caruso et al., 2017; Caruso et al., 2019). The multispectral images were first mosaicked using Autopano Giga 3.5 Software (Kolor SARL, Challes-les-Eaux, France), then georeferenced and orthorectified using the ground referenced points (ArcGIS software®, ESRI, Redlands, CA, USA). The three-dimensional tree canopy volume was reconstructed starting from the digital surface model (DSM) obtained through automatic aerial triangulation, bundle block adjustment and camera calibration methods using Agisoft Photo-Scan® (Agisoft LLC) as in Caruso et al. (2019). The volume of the pruned material, placed in the middle of the inter-row, was estimated using the same approach used for the canopy volume estimation. Light interception was measured on 27 February 2019 at noon using a LI-COR Line Quantum Sensor (LI-191 SB; Licor, Lincoln, NE, USA). In particular, Photosynthetic Active Radiation (PAR) was measured above and below (at ground level) the canopy and in order to estimate the fraction of PAR intercepted by tree canopies. Two measurements were taken in each 1x1 m square of a grid beneath the four central trees. The experimental design was a split-plot where cultivar was considered as the main plot and planting distance as the sub-plot. Each treatment consisting of 9 plants. Means were separated by least significant differences (LSD) at P > 0.05 after analysis of variance (ANOVA).

RESULTS

Significant differences in the Normalized Differential Vegetation Index (NDVI) and Green Normalized Differential Vegetation Index (GNDVI) values were measured among the different cultivars but not PD or CV x PD (Fig. 1). 'Calatina', described as a low vigour cultivar, showed values of both NDVI and GNDVI, significantly lower than those measured for cvs 'Koroneiki' and 'Biancolilla'. NDVI allowed detection of differences between high, medium and low vigor cultivars better than GNDVI. GNDVI values were similar for cvs. 'Koroneiki' and 'Biancolilla'. The highest and lowest values of both NDVI and GNDVI indices were measured in 'Koroneiki' (4 x 4 m) and 'Calatina' (4 x 3 m), respectively.

There was a linear relationship between NDVI and pruned material, expressed on either as mass or volume per tree, for all cultivar-PD combinations (R^2 = 0.93 and R^2 = 0.78, respectively) (Fig. 2). Similar relationship, but with lower regression coefficients, were observed when pruning material was plotted against GNDVI (R^2 = 0.72 and R^2 = 0.46, for pruning mass and pruning volume, respectively).

Tree canopy volume, estimated by the UAV-VIS camera technique, was higher in 'Koroneiki' and 'Biancolilla' (6.9 and 6.7 m^3, respectively) than in 'Calatina' (5.1 m^3). The more widely spaced trees (4 x 4 m) had bigger canopies (6.4 m^3) than those planted at 4 x 2 m (5.7 m^3), but when the volume was expressed as m^3 of canopy per m^2 of soil surface the opposite trend was observed (Fig. 3, ''Koroneiki'' given as example). In particular, canopy volume/m^2 in 'Koroneiki' trees ranged between 0.65 (4 x 2 m) and 0.32 (4 x 4 m) m^3 m^{-2}. The higher canopy volume per square meter was related to a higher fraction of intercepted PAR measured at solar noon (12:20 AM) (Figs. 3 and Fig. 4). The highest and lowest values of fraction of intercepted PAR were measured in 4 x 2 m (48%) and 4 x 4 m (35%) planting distances, respectively.

DISCUSSION

The vegetative indices tested in this study allowed to discriminate between the two cultivars with the highest ('Koroneiki') and lowest ('Calatina') vigor, but not across planting distances . Avola et al. (2019) tested different vegetation indices and a multivariate approach to discriminate field-grown olive cultivars in an experimental field with different scion/rootstock combinations. They reported that it was possible to discriminate two cultivars (Frantoio and Leccino) based on seven (NDVI, SR, GNDVI, GRNDVI, GRVI, NGRDI, and RVI) out of 15 VIs. The ability of vegetative indices in discriminating different olive cultivars could efficiently support the certification activities applied to olive oil authentication or, considering plant protection, could highlight differences in cultivar susceptibility to diseases.

NDVI and GNDVI were also well correlated to the material removed from olive trees by pruning, regardless of planting distances and olive cultivar. Although further investigations are needed to confirm these results, a potential application of these relationships could be to estimate the required pruning intensity depending on tree vigour, canopy dimension and tree spacing. Similar results were observed in field-grown grapevines for which the correlation coefficient of the relationship between pruning weight and NDVI increased from the first (May) to the last (August) date of flight (Caruso et al., 2017). Monitoring the pruned material is important because, given a standardized pruning strategy, it provides an estimate of tree vigor. The possibility to estimate the volume of pruning material through the UAV-VIS technique assessed in this study implies positive effects in terms of time and labour saving for plant phenotyping. Jimenez-Brenes et al. (2017) used RGB imagery acquired by an UAV to estimate tree crown geometry of olive trees subjected to three different kinds of pruning techniques, concluding that the UAV-VIS technique was able to discriminate different pruning intensity.

Tree canopy volumes obtained through the UAV-VIS camera technique were consistent with the fraction of the intercepted PAR, highlighting the importance of the characterization of the canopy geometry in understanding the light interception and distribution within the olive orchard. In a previous study, Guillen-Climent et al. (2012) generated intercepted radiation maps in row-structured tree orchards using a miniaturized multispectral camera mounted on an UAV. The reliability of this technique was confirmed by a RMSE comprised between 0.09 and 0.10 when remote sensed data were compared with ground measurements. Our results indicate potential application of the UAV-NIR-VIS technique to determine canopy characteristics of different planting systems and cultivars of *Olea europaea*.

	Significance		
VI	C	PD	C x PD
NDVI	***	n.s.	n.s.
GNDVI	***	n.s.	n.s.

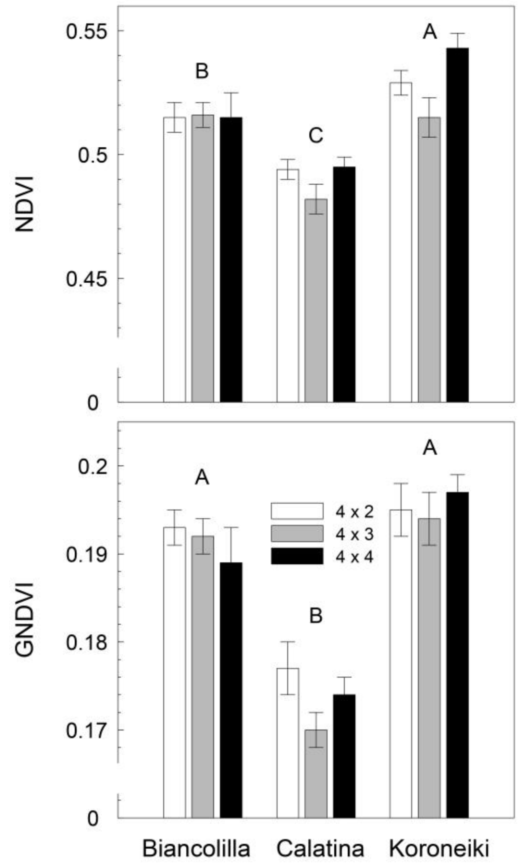

Fig. 1 Normalized Differential Vegetation Index (NDVI) and Green Normalized Differential Vegetation Index (GNDVI) measured on 27 February 2019 on olive trees (cvs. 'Biancolilla', 'Calatina' and 'Koroneiki') planted at 4 x 2, 4 x 3 and 4 x 4 m. Histograms are mean ± standard error of 9 trees for each combination of cultivar-planting distance. Different letters indicate significant differences between cultivars after ANOVA ($p \geq 0.05$). Legend: VI, vegetative index; C, cultivar; PD, planting distance; n.s., not significant.

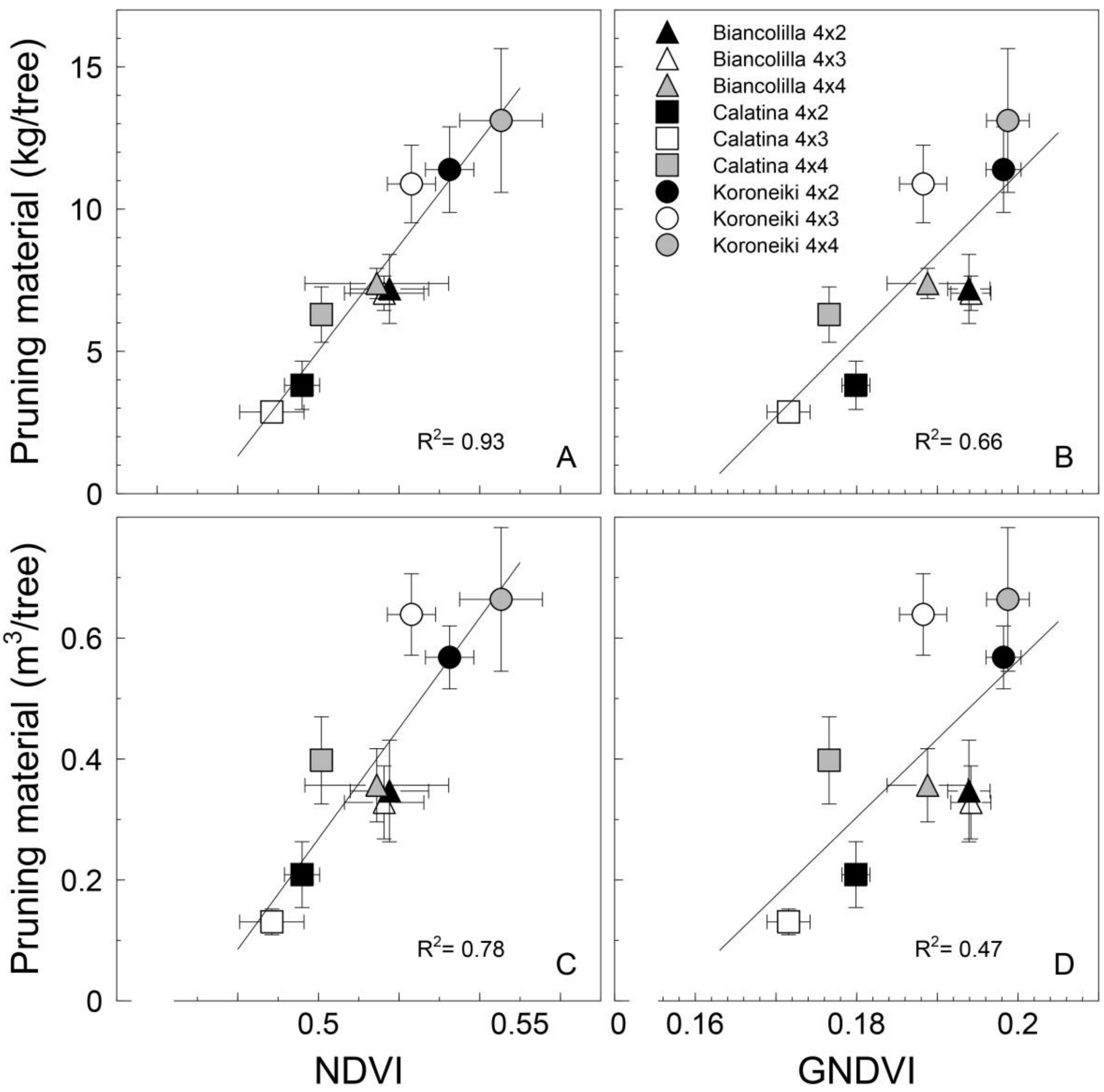

Fig. 2. The relationship between Normalized Differential Vegetation Index (NDVI) and Green Normalized Differential Vegetation Index (GNDVI) of tree canopies and pruning material expressed as either mass (A, B) or volume (C, D) per tree basis. Symbols are means ± standard error of 5 trees for each combination of cultivar-planting distance. Pruning material was weighted immediately after imaging and then removed from orchard.

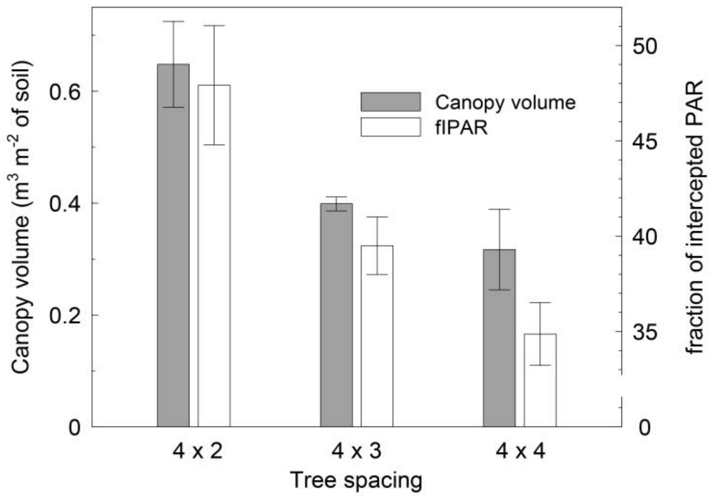

Fig. 3. Fraction of photosynthetic active radiation (PAR) intercepted by the canopy of olive trees (cv. 'Koroneiki') planted at 4 x 4, 4 x 3 and 4 x 2 m. Histograms are means ± standard error (vertical bars) of 6, 5 and 4 values (canopy volume and fraction of intercepted PAR) for 4 x 2, 4 x 3 and 4 x 4 m planting distance, respectively.

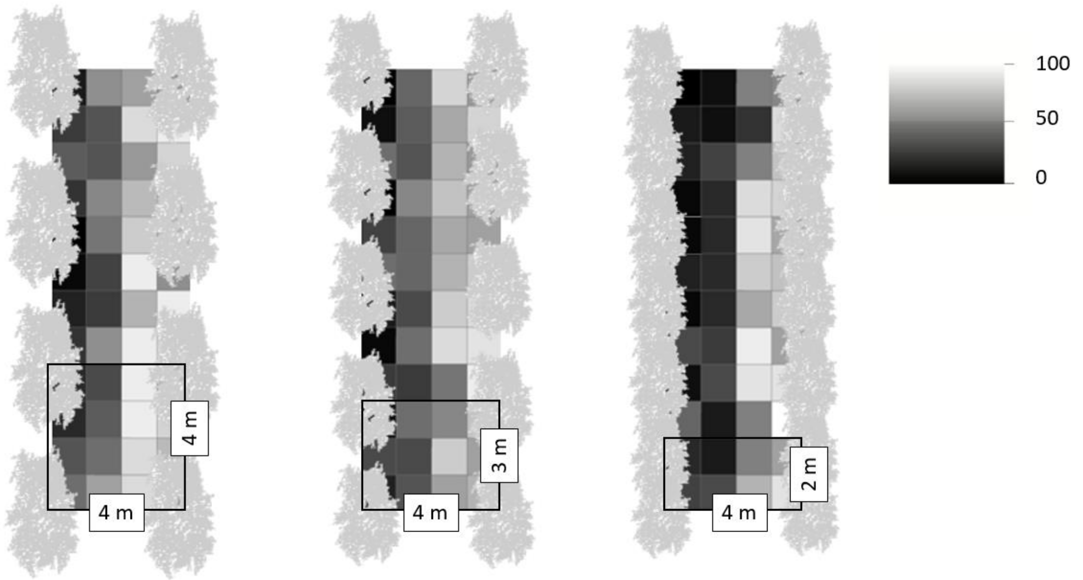

Fig. 4. Photosynthetically active radiation (PAR) measured at noon at ground level, below the canopies of olive trees (cv. 'Koroneiki') planted at 4 x 4, 4 x 3 and 4 x 2m. Each square represents the mean of 2 readings for each 1x1m square. Values are expressed as % of above canopy intercepted radiation.

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