

Original Research

PROPERTIES OF PLANT AND SOIL SHAPING FRUIT AND OIL TRAITS IN
DIFFERENT CULTIVARS OF *Olea europaea* L.

DOI: 10.5937/EcoTER26374N

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Abstract

Geographical and climatic conditions influence plant–soil interactions, shaping fruit characteristics and olive oil quality, particularly within the Mediterranean basin. In Italy, *Olea europaea* cultivars exhibit different responses to local pedoclimatic conditions resulting in extra virgin olive oils (EVOO) with diverse properties. This study investigated five Italian cultivars grown in two contrasting regions: Pisciotana (PIS), Ravece (RAV), and Ortice (ORT) in Campania, and Frantoio (FRA) and Moraiolo (MOR) in Umbria. Soil properties analyzed included pH, cation exchange capacity (CEC), soil organic matter (SOM), nitrogen (N), C/N ratio, microbial carbon (C_{mic}), and endogenous mineralization coefficient (CEM). Plant traits assessed were specific leaf area (SLA) and maximum photochemical efficiency (F_v/F_m), while fruit and oil characteristics included dry matter (DM), free acidity, total polyphenol content (TPC), and peroxide value. Soils in Umbria were predominantly alkaline, with lower CEC and SOM, that promoted conservative plant strategies with reduced SLA. Campania soils showed higher nutrient availability, favoring more acquisitive strategies with increased SLA and vegetative growth. High N in PIS and RAV promoted vegetative growth over fruit biomass leading to TPC reduction. ORT cultivar showed high microbial activity but lower SLA and F_v/F_m. Our results highlight how soil properties regulate plant performance and oil quality through fine soil–plant feedback mechanisms.

Keywords: soil quality, soil nutrients, leaf traits, fruit and oil production, geographical and climatic conditions.

INTRODUCTION

The Mediterranean basin is the main olive-growing area in the world, with over 97%, and Italy ranks second among the olive-oil producers [1]. Here, *Olea europaea* L. is very rich in

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variety due to both the environmental and geographic variability that substantially characterizes the entire Italian territory. Bartolini *et al.* [2] reported that the Italian olive germplasm includes 600 cultivars, corresponding to the half of the world total which is around 1200. The growth environment plays a key role in the development and characterization of the different varieties of *O. europaea*. Soil may affect the plant individual response, influencing with its physical-chemical and biological properties (including pH, organic matter quality, nutrients, water availability, and pedoclimatic characteristics) photosynthesis and thus primary productivity. The specific geographic and ecological peculiarities determine different fruit and oil characteristics generating ecotypes with distinct eco-physiological traits. Consequently, extra virgin olive oil (EVOO), a key component of the Mediterranean diet, shows variability in its composition depending on factors such as cultivar, climate, soil conditions, harvesting methods, and processing techniques. These variables shape oil chemical profile, particularly its fatty acid composition, phenolic compounds, and antioxidant content, thereby influencing taste, stability, and nutritional properties. Each cultivar is generally associated with specific soil physical, chemical, and biological properties, and presents distinct leaf functional traits that reflect its ability to utilize the available resources within the environment. Different cultivars may experience varying levels of stress in the proper habitats, showing different degrees of tolerance or sensitivity to environmental conditions and management practices during fruit development and ripening.

Environmental conditions significantly influence both yield and oil quality: however, the interactions between soil factors and productivity in olive trees are still not fully understood. This study aims to explore how soil properties drive plant response through leaf functional traits, and how these interactions shape fruit characteristics and ultimately oil quality. The analysis focuses on five Italian *Olea europaea* L. cultivars (Pisciottana, Ravece, Ortime, Frantoio, Moraiolo) cultivated across two contrasting regions of Italy.

MATERIALS AND METHODS

Study area

The experiment was carried out in five olive orchards composed each by a specific cultivar of *O. europaea* located in the Italian regions of Campania and Umbria. Campania region is in southern Italy where the summers are dry and winters are rainy. Three orchards were chosen: Pisciotta (P, Salerno Province, 40°7'0''N, 15°14'0''E) with cv. Pisciottana (PIS), Luogosano (Avellino Province, 40°59'18''N, 14°59'30''E) with cv. Ravece (RAV), Molinara (Benevento Province, 41°18'00''N, 14°55'00''E) with cv. Ortime (ORT). Umbria region is in central Italy, where climate is more continental. The Umbrian orchards were two, both located in Perugia (Perugia Province, 43°08'28''N, 12°27'46''E), one covered by cv. Frantoio (FRA), the other by cv. Moraiolo (MO), respectively. The cultivars were selected based on their specific production areas, while the study sites were chosen for their uniform conditions including weeds control practices, absence of pesticide use, long-term cultivation of the same cultivar, similar management regimes, and rainfed systems.

All the soils were classified as Cambisols for their early horizon differentiation in the subsoil, with medium and fine textured material derived from parent material [3].

The samplings of leaves and soils were conducted for two consecutive years, before the olive harvest simultaneously. Soil was collected in three subareas of each orchard, under at least five olive trees, at 0–40 cm of depth. For the assessment of leaf traits and chemical analyses, only healthy leaves were sampled around the canopy of trees, with no visible vegetative abnormalities or signs of viral infection. From each subarea, a standardized sampling procedure was carried out appropriately selecting ten fully expanded leaves around the entire canopy of the trees, at least 1.5 m from the soil. In addition, olives were harvested in the same subareas in different ways: hand picking, combing, gleaning, beating, and mechanical harvesting. Subsequently, oil was extracted in laboratory using an Abencor mill.

Soil analyses

Prior to measurements, the collected soil was sieved at <2 mm and two aliquots were obtained: one for chemical analysis, airdried at room temperature, while the other for biological features, stored immediately at 4°C and processed within one week since sampling. The following properties were measured: pH, cation exchange capacity (CEC), soil organic matter (SOM), total nitrogen (N), Carbon-to-Nitrogen ratio (C/N), microbial carbon (C_{mic}) and endogenous mineralization coefficient (CEM). Shortly, soil pH was measured potentiometrically, CEC via cation extraction with BaCl₂ at pH 8.2 and titration with EDTA [4]. Organic carbon (C) and N were obtained by CNS analyser (Thermo Finnigan, EA 112 series), in samples previously treated with HCl (10%) to remove carbonates, and C/N was calculated. SOM was derived multiplying C by 1.724 [5]. C_{mic} and CEM were measured according to Memoli *et al.* [6]. Briefly, C_{mic} was evaluated through the substrate-induced respiration method SIR after the addition of glucose (75 mM) as an easily mineralizable substrate. After the incubation of five days in the dark at 25°C, the CO₂ evolved was titrated with HCl 0.05 N and converted into C incorporated in the microbial biomass. CEM was obtained as ratio between the soil respiration monitored over ten days (determined similarly to C_{mic} but with the addition of distilled water, and monitored for ten days) and C.

Plant, olive and oil measurements

Specific leaf area (SLA) and maximal photochemical efficiency of PSII (F_v/F_m) were determined as eco-physiological markers. SLA was calculated as the ratio between leaf area and leaf dry mass. F_v/F_m was measured with a fluorometer FluorPen FP100 (Photon System Instrument spol. s.r.o., Drásov, Czech Republic) and calculated as: $(F_m - F_0)/F_m$, where F_0 represents the background fluorescence signal and F_m is the maximal fluorescence in the dark-adapted state (F_m). F_0 was induced by a weak measuring light of 0.5 $\mu\text{mol photons m}^{-2} \text{s}^{-1}$ on 30 min dark-adapted leaves, while F_m was obtained by applying a 1 s saturating light pulse (3,000 $\mu\text{mol photons m}^{-2} \text{s}^{-1}$). For olives, dry matter (DM) and total polyphenol content (TPC) were assessed. Briefly, DM was obtained after olive drying at 75°C for 48 h in the oven whereas TPC was quantified with Folin-Ciocalteu and sodium carbonate, and the absorbance was measured after 90 min in the dark at 725 nm [7]. For oil, free acidity (FA), peroxide value (PV) and TPC were evaluated. FA was determined by mixing oil with ether and ethanol (1:1=v:v) and titration with KOH 0.1 M [8]. For PV, oil was mixed with acetic acid and chloroform (3:1=v:v), and potassium iodide, then titrated with sodium thiosulfate (Reg. CE 1989/03). Oil TPC was evaluated similarly to olive, but differed for absorbance measurement, occurring at 760 nm [9].

Statistical analysis

The statistical analysis was performed using OriginPro 2025 (OriginLab Corporation, Northampton, MA, USA) for soil, plant, olive and oil of the studied cultivars. The normality of the data distribution was assessed by the Shapiro-Wilk test and equal variance test was performed. Comparisons were tested by One-Way ANOVA followed by the Tukey test ($p < 0.05$). Spearman Rank Order Correlation was tested to evaluate the relationships between soil properties and plant traits ($p < 0.05$).

RESULTS AND DISCUSSION

The results for soil chemical and biological properties under different cultivars (PIS, RAV, ORT, FRA, MOR) of *O. europaea* are reported in the Table 1 and Figure 1, respectively.

Soils of the Umbria region, under FRA and MOR, were more alkaline than those from Campania (PIS, RAV, ORT), with pH values ranging from 8.4 to 8.5. FRA and MOR also showed lower CEC compared to others, as possibly related to the parent material, basically made of limestone, rich in carbonates. The high values of pH with low CEC could be related also to the scarce presence of clay particles and low SOM [10]. Indeed, in the Umbrian soils, SOM as well as N is less abundant compared to the other cultivars but, interestingly, MOR showed the highest C/N. The diverse ability of microorganisms in exploiting organic resources could be a possible reason [11]. Notably, CEM is the highest while Cmic is the lowest (Figure 1). In this context, the mineralization occurs rapidly due to low soil nutrients, potentially leaving a complex residue likely linked to a specific composition of the microbial community [12]. This explanation is also supported by the negative correlations between CEM and SOM and N (correlation coefficient: -0.620, $p < 0.001$ and -0.481, $p = 0.001$).

FRA also followed this trend as the similarity between the Umbrian soils is strictly related to similar lithology, edaphic properties and plant ecotypes. Conversely, among Campania cultivar, PIS and RAV were more similar to each other compared to ORT. In detail, this latter differed for SOM, N and CEM (Table 1). However, also ORT soils showed good CEC but a more intense activity of microorganisms, despite their quantity, indicating a better nutritional condition for olive plants and a faster organic matter turnover (Table 1, Figure 1).

Table 1 Chemical properties of soils under different cultivars of *O. europaea* (Pisciottana-PIS, Ravece-RAV, Ortice-ORT, Frantoio-FRA, Moraiolo-MOR) displayed as mean $\pm$ standard error: pH, Cationic Exchange Capacity (CEC, $\text{cmol}_+ \text{kg}^{-1}$), Soil Organic Matter (SOM, % dw), Nitrogen (N, % dw), Carbon-to-Nitrogen ratio (C/N). Different letters indicate statistically significant differences (One Way-ANOVA at $p < 0.05$)

	pH	CEC	SOM	N	C/N
PIS	8.0 $\pm$ 0.1 B	13.9 $\pm$ 1.3 AB	7.00 $\pm$ 0.39 A	0.30 $\pm$ 0.01 A	10.50 $\pm$ 1.30 B
RAV	7.9 $\pm$ 0.1 B	19.1 $\pm$ 0.7 A	6.10 $\pm$ 0.30 A	0.32 $\pm$ 0.02 A	9.99 $\pm$ 0.78 AB
ORT	8.0 $\pm$ 0.1 B	13.3 $\pm$ 1.9 AB	3.31 $\pm$ 0.13 B	0.22 $\pm$ 0.02 B	14.92 $\pm$ 1.72 AB
FRA	8.4 $\pm$ 0.0 A	9.4 $\pm$ 1.4 B	3.48 $\pm$ 0.42 B	0.14 $\pm$ 0.02 B	18.20 $\pm$ 4.35 AB
MOR	8.5 $\pm$ 0.1 A	9.3 $\pm$ 0.8 B	3.91 $\pm$ 0.34 B	0.16 $\pm$ 0.01 B	27.29 $\pm$ 6.53 A

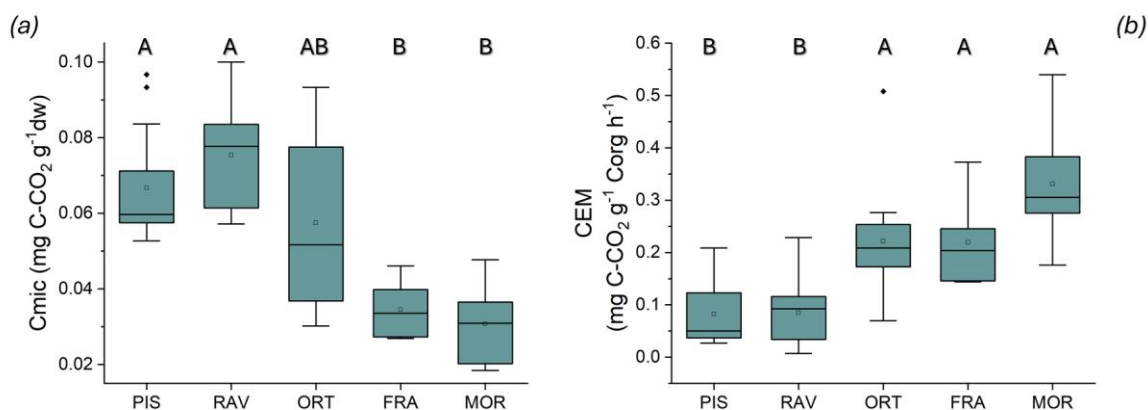


Figure 1 Biological properties of soils under different cultivars of *O. europaea* (Pisciottana-PIS, Ravece-RAV, Ortice-ORT, Frantoio-FRA, Moraiolo-MOR) displayed as box plots representing the interquartile range (IQR) from the 25th to the 75th percentile. The horizontal line and the open square within each box represent the median and the mean, respectively. The whiskers extend to the maximum and minimum values within 1.5 times the IQR for: Microbial Carbon (Cmic, a) and Endogenous Mineralization Coefficient (CEM, b). Different letters indicate statistically significant differences (One Way-ANOVA at $p < 0.05$)

However, among all the soil properties, only CEC is positively correlated with SLA (correlation coefficient: -0.329 , $p = 0.03$), suggesting a balance between leaf resource acquisition and soil organic matter dynamics. As shown in Figure 2, SLA was highest in PIS and RAV and progressively decreased in FRA, MOR and ORT, where it reached the lowest value. This trend suggests that as the mineralization coefficient decreases, in absence of nutrient limitations, leaves tends to adopt a consume strategy. Conversely, in sites with higher mineralization rates but lower CEC and SOM, the soil capacity to retain nutrients may be limited. Under these conditions, plants tend to adopt a more conservative strategy, reflected in lower SLA.

Moreover, although none of the cultivars showed clear physiological stress signals, the F_v/F_m ratio significantly decreased in RAV and ORT compared to PIS and FRA cultivars. Lower values of SLA and F_v/F_m in the ORT cultivar support the relation between specific leaf area and the photosynthetic activity, reflecting the plant's capacity to acquire resources, affecting consequently its growth rate and potential biomass production [13,14].

As soils under PIS and RAV cultivars did not present limitation in the nutritional status, vegetative growth appears to predominate and an increase in fruit dry matter might be expected. However, the high soil N content may have driven the plants to invest more resources in vegetative growth than in fruit biomass accumulation, also reducing polyphenol content in both fruit and oil, which are characterized by more acidity. In fact, fruits of the RAV cultivar showed the lowest dry matter and polyphenol content. In concomitance, both PIS and RAV produced oils with the highest concentration of oleic acid and the lowest polyphenol content (Table 2).

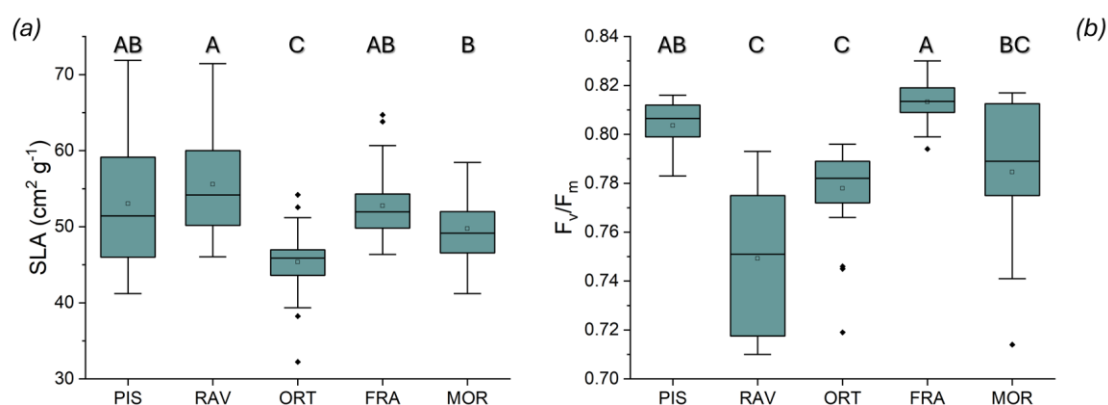


Figure 2 Plant characteristics of different cultivars of *O. europaea* (Pisciottana-PIS, Ravece-RAV, Ortice-ORT, Frantoio-FRA, Moraiolo-MOR) displayed as box plots representing the interquartile range (IQR) from the 25th to the 75th percentile. The horizontal line and the open square within each box represent the median and the mean, respectively. The whiskers extend to the maximum and minimum values within 1.5 times the IQR for: Specific Leaf Area (SLA, a) and Maximum PSII Photochemical Efficiency (F_v/F_m , b). Different letters indicate statistically significant differences (One Way-ANOVA at $p < 0.05$)

Table 2 Chemical properties of fruits and soils of different cultivars of *O. europaea* (Pisciottana-PIS, Ravece-RAV, Ortice-ORT, Frantoio-FRA, Moraiolo-MOR) displayed as mean $\pm$ standard error: fruit Dry Matter (DM, % dw), Total Poliphenol Content (TPC, mg GAE 100 g^{-1} FW), oil Free Acidity (FA, % oleic acid), Peroxide Value (PV, meq $\text{O}_2 \text{kg}^{-1}$ oil) and Total Poliphenols. Different letters indicate statistically significant differences (One Way-ANOVA at $p < 0.05$)

	Fruit		Oil		
	DM	TPC	FA	PV	TPC
PIS	32.52 $\pm$ 0.07 AB	217.87 $\pm$ 6.94 A	0.66 $\pm$ 0.02 A	8.68 $\pm$ 0.09 B	154.96 $\pm$ 1.24 D
RAV	25.89 $\pm$ 5.14 B	151.13 $\pm$ 2.35 C	0.62 $\pm$ 0.03 A	7.50 $\pm$ 0.38 C	136.03 $\pm$ 1.20 E
ORT	37.75 $\pm$ 0.44 A	166.96 $\pm$ 3.11 B	0.42 $\pm$ 0.04 B	10.49 $\pm$ 0.35 A	176.65 $\pm$ 1.92 B
FRA	31.46 $\pm$ 0.84 B	165.25 $\pm$ 1.47 B	0.37 $\pm$ 0.02 B	9.20 $\pm$ 0.49 B	198.27 $\pm$ 1.42 A
MOR	34.68 $\pm$ 1.07 AB	218.33 $\pm$ 3.14 A	0.39 $\pm$ 0.02 B	7.24 $\pm$ 0.20 C	162.35 $\pm$ 1.64 C

CONCLUSION

Our results show a link between soil properties, leaf functional traits, and fruit and oil quality. Cation exchange capacity (CEC) was the only soil variable significantly associated with the specific leaf area (SLA), indicating the significant role of soil nutrient retention in affecting plant resource-use strategies.

Higher SLA and maximal photochemical efficiency of PSII (F_v/F_m) values in PIS and RAV likely indicate a growth strategy in response to favourable soil conditions. Conversely, lower values of these physiological indicators in FRA, MOR, and ORT reflect a transition toward more conservative traits. Despite the absence of visible stress, physiological differences among cultivars were evident.

At the productive level, higher soil nitrogen availability appears to promote vegetative growth despite of fruit production, leading to fruits characterized by lower dry matter and polyphenol content, but higher oleic acid and reduced antioxidants in oils. These results

highlight how soil properties influence both plant physiology and product quality, in terms of fruits and oil, through a close soil–plant interaction.

ACKNOWLEDGEMENT

The authors want to thank: Dr. Farinelli of University of Perugia, Dr. Barbarisi of University of Naples Federico II, Dr. Volpe of ISA-CNR, Avellino, National Park of Cilento and Vallo di Diano (SA), Gentilcore (BN) and La Molara (AV) farms.

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