applied sciences

MDPI

Article

Independent or Combinational Application of Sheep Manure and Litter from Indigenous Field Vegetation of *Quercus* sp. Influences Nutrient Uptake, Photosynthesis, Intrinsic Water Use Efficiency, and Foliar Sugar Concentrations in Olive Plants (*Olea europaea* L., cv. "Koroneiki")

Theocharis Chatzistathis [1,*], Christos Chatzissavvidis [2], Athanasios Papaioannou [3] and Ioannis E. Papadakis [4]

[1] Institute of Soil and Water Resources, Hellenic Agricultural Organization (ELGO) DIMITRA, 57001 Thessaloniki, Greece
[2] Department of Agricultural Development, Democritus University of Thrace, 68200 Orestiada, Greece
[3] Department of Forestry and Natural Environment, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece
[4] Laboratory of Pomology, Department of Crop Science, Agricultural University of Athens, Iera Odos 75, 11855 Athens, Greece
* Correspondence: chchatzista@gmail.com or t.chatzistathis@swri.gr

Abstract: The recent energy crisis has increased the cost of fertilization for olive growers. This is why alternative nutrient sources, such as manures and other organic materials, could be used to sustain olive production within the framework of sustainable agriculture, by decreasing chemical fertilization inputs. A greenhouse pot experiment was established with a marl soil substrate that was modified with three amendments (sheep manure, or SM; litter from evergreen broadleaf species, or EBLS, such as *Quercus* sp.; their combination, i.e., SM + EBLS) and a control soil (no application of amendments) to investigate their influence on the nutrition, physiology, and leaf sugar concentrations of olive plants. Plant growth was not significantly affected by the amendments, while the lowest leaf N, K, and Zn concentrations were determined in the control soil. Significantly higher photosynthetic rate was determined in the SM + EBLS, compared to SM. Significantly higher intercellular CO_2 was found in the EBLS and SM + EBLS, while significantly higher intrinsic water use efficiency (WUEi) was found in the SM + EBLS and the control. Significantly higher translocated sugar content was recorded in the SM + EBLS compared to the control. Overall, it was concluded that the optimum treatment was SM + EBLS, i.e., the combinational application of SM and EBLS. However, multi-year research under field conditions is necessary to draw more stable conclusions about the beneficial role of organic amendments on the nutrition and physiology of olive trees.

Keywords: organic fertilization; sheep manure; organic amendments; sustainable agriculture; plant nutrition; soil fertility; *Olea europaea* L.

check for updates

Citation: Chatzistathis, T.; Chatzissavvidis, C.; Papaioannou, A.; Papadakis, I.E. Independent or Combinational Application of Sheep Manure and Litter from Indigenous Field Vegetation of *Quercus* sp. Influences Nutrient Uptake, Photosynthesis, Intrinsic Water Use Efficiency, and Foliar Sugar Concentrations in Olive Plants (*Olea europaea* L., cv. "Koroneiki"). *Appl. Sci.* **2023**, *13*, 1127. https://doi.org/10.3390/app13021127

Academic Editor: Gerhard Soja

Received: 4 November 2022
Revised: 28 December 2022
Accepted: 12 January 2023
Published: 14 January 2023

Copyright: © 2023 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

Organic fertilization is an alternative approach to supplying the critical quantities of nutrients for crops in the framework of organic and sustainable agriculture without negatively influencing crop yields or the environment [1]. In many cases, the overuse of inorganic fertilizers has led to the following: (i) soil quality deterioration; (ii) surface and groundwater pollution; (iii) increased greenhouse gas emissions [2]. Thus, as a result of the recent energy crisis, which has increased the prices of inorganic fertilizers and the cost of production for farmers, it is expected that organic fertilization will play a crucial role in the near future in decreasing inorganic fertilization inputs and improving farmer incomes. There is a strong interest in organic fertilization [3]. Apart from the beneficial impact of

organic fertilizers at reducing production costs, other beneficial roles of organic fertilizers are as follows: (i) increasing soil organic C and matter [4–6]; (ii) enhancing soil microbial activities and improving soil quality [7,8]; (iii) boosting yields [8–10]; (iv) ameliorating fruit quality [8,11]; (v) increasing root production [12]. Different kinds of organic materials and agricultural/food industry bio-products (e.g., olive mill waste composts and pomace, other kinds of composts, municipal wastes, and recycled pruning materials) are used as soil amendments and bio-fertilizers for crops [13–18]. In other cases, in order to support organic farming and ecosystem services, decrease fertilizer inputs, and enhance the sustainable management of agricultural ecosystems, the integration of laying hens with orchards and the use of cover crops were suggested [15,19].

Animal manures are included among the commonest, cheapest, and easily used organic fertilizers in tree orchards. Manures from different animal origins (e.g., cow, goat, sheep, horse, poultry, and pig) may be used as soil amendments to improve organic C, enhance nutrient uptake, and support plant growth [5]. According to Therios (1996) [20], animal manures differ in nutrient content. These differences in nutrient content may be owed either to the kind of animal, animal feeding, or manure preservation [20]. Chatzistathis et al. (2020) [5] realized a comparative study among cow and goat manure supplies and the inorganic fertilization of olive plants and showed the beneficial role of both manures to improve organic C, soil fertility, and influence plants' nutrition and physiology (including WUEi and translocated sugars). These beneficial effects of manure applications depend not only on the kind of animal but also on the rate at which the manure is applied. According to El Gammal and Salama (2016) [21], both the rate of sheep manure application and the application method had a significant impact on the growth, fruit setting, and fruit qualitative characteristics of guava (cv. "Balady") trees. According to our knowledge, no further investigations were realized on the effects of sheep manure on the nutrition and physiological performance of olive trees, while no studies at all were realized on the influence of well-decomposed litter from indigenous field vegetation of evergreen broadleaf species (such as that of *Quercus* sp.) on the soil's nutrient availability and nutrient absorption by crops. Based on the above published information, our study was based on the premise that SM and EBLS could influence the nutrient uptake, photosynthetic rate, and WUEi of olive plants.

The aim of our study was to investigate the influence of the following: (i) sheep manure and (ii) well-decomposed litter from indigenous field *Quercus* sp. vegetation (as well as their combinational application) on the growth, nutrition, photosynthetic rate, and leaf sugar concentrations in potted olives (*Olea europaea* L., cv. "Koroneiki"). "Koroneiki" was selected for the investigation since it is the most well-known Greek olive cultivar producing high-quality oil (rich in oleuropein).

2. Materials and Methods

2.1. Plant Materials and Treatments

Two-month-old rooted olive cuttings (approximately 20–25 cm in height) of the cultivar "Koroneiki" obtained from a commercial nursery were transplanted into 3-L black plastic bags, each containing 3.3 kg of soil substrate (either as pure native soil of the parent material marl or as soil mixed with SM or EBLS). The olive plants were grown for 168 days (from the end of January to the middle of July) inside a greenhouse at the Department of Forestry and Natural Environment at the Aristotle University of Thessaloniki, Macedonia, Northern Greece. After all of the plants were randomized, they were categorized into 4 similar groups (coinciding with each of the 4 soil substrate treatments). The following 4 treatments were applied: (i) control soil (no application of organic amendments); (ii) soil amended in mixture with sheep manure (SM); (iii) soil amended in mixture with well-decomposed litter from evergreen broadleaf species, or EBLS (leaves of well-decomposed litter from *Quercus* sp., received from indigenous olive groves' vegetation with a C/N of approximately 27–28); (iv) soil amended in mixture with a combinational application of SM and EBLS. The sheep manure was approximately one-year-old and well-digested, while the litter received from

the field indigenous *Quercus* sp. vegetation was well-decomposed. The nutrient contents of the two organic amendments (SM and EBLS) are shown in Table 1. In each of the 4 treatments, 6 plant replicates were included.

Table 1. Nutrient contents of the two organic amendments applied to the control soil.

Organic Material	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu
	% D.W.					mg kg^{-1} D.W.			
SM	2.63	0.16	2.99	1.25	1.32	3142	283	81	18
EBLS	1.25	0.08	0.31	1.11	0.36	4122	1205	90	16

SM = sheep manure; EBLS = litter from evergreen broadleaf species, i.e., from *Quercus* sp.

The mixtures between the native marl soil and the SM or EBLS were in a ratio of 95:5 (i.e., 95% *w*/*v* of soil and 5% *w*/*v* of SM or EBLS). In the SM + EBLS treatment, the ratio was 95:2.5:2.5 (i.e., 95% *w*/*v* of soil, 2.5% *w*/*v* of SM, and 2.5% *w*/*v* of EBLS). All of these mixtures were prepared before planting, and afterwards, the plants were established and grown inside an experimental greenhouse. During the entire experimental period, the minimum, average, and maximum temperatures were 8, 22, and 32 °C, respectively, while the relative humidity ranged from 52% to 87%. Finally, from the beginning of the experiment to the end of April, the plants were irrigated using an automated spray system with 200 mL of high-quality water two times per week, while from early May to the end of the experiment, they were irrigated with the same amount of water every second day.

2.2. Soil Sampling and Laboratory Analyses

The soil samples were collected from the upper 60-cm layer (where the main part of the olive trees' root system exists and nutrients are mainly taken up) [22] of a native marl soil from typical mature olive groves in an agricultural region around the city of Thessaloniki, Central Macedonia. After 5 soil samples were randomly collected, they were carefully mixed to homogenize them. Then, the homogenized soil samples were transferred to the experimental greenhouse to prepare the soil mixtures with the organic amendments (as described above in Section 2.1), fill the black plastic bags where the plants were grown, and establish the experiment. After all of the mixtures of the native marl soil and the organic amendments were prepared, in order to determine their initial fertility (before the beginning of the experiment), approximately 1.5 kg of each soil mixture (i.e., soil + SM, soil + EBLS, and soil + SM + EBLS) was transferred to a laboratory for chemical analyses.

The soil mixtures and the control soil were dried at room temperature, their stones were removed, and then they were sieved through a 10-mesh screen before the analyses. The laboratory analyses included the following: determination of pH; particle size analysis; organic matter; Kjeldahl N; Olsen P; exchangeable cations (Ca, Mg, and K); DTPA-extractable micronutrients (Fe, Mn, Zn, and Cu). These parameters were determined as follows: pH in the soil: distilled water paste 1:1 [23]; particle size analysis according to the Bouyoucos method [24]; organic matter with the potassium dichromate method [25]; Kjeldahl N according to the method described by Bremner and Mulvaney (1982) [26]; Olsen P according to the method of Olsen and Sommers (1982) [27]. The exchangeable cations (Ca, Mg, and K) were calculated based on the method of ammonium acetate [28], while the DTPA-extractable micronutrients (Fe, Mn, Zn, and Cu) were determined after the extraction of 10 g of soil with DTPA at pH 7.3 [29]. The concentrations of the exchangeable cations and extractable micronutrients (i.e., those of Ca, Mg, K, Fe, Mn, Zn, and Cu) were measured by ICP (OPTIMA 2100 DV, optical emission spectrometer, Perkin Elmer, Waltham, MA, USA) [30].

2.3. Plant Growth

At the end of the experiment, the main shoot length and the total plant biomass were determined. The plant biomass was determined as follows: After all of the experimental plants were harvested, each one was divided into two equal parts for the shoot (i.e., basal and apical shoots). Afterwards, the leaves were separated from the shoots and the root system from the other plant parts; thus, the fresh weights of the apical and basal plant tissues (leaves and stems) were determined. After the plant tissues were washed and dried at 75 °C for 48 h, the dry weights of all plant parts were determined. By adding the fresh and dry weights of all the plant parts, the total plant fresh and dry weight (total biomass) was calculated.

2.4. Leaf Nutrient Concentrations and Total Plant Nutrient Content

At the end of the experiment, after the plants had been harvested and the leaves separated from the other plant parts, washed, and dried, they were ground to a fine powder to pass through a 30-mesh screen. Afterwards, a portion of 0.5 g of the fine powder of each sample was dry-ashed in a muffle furnace at 515 °C for 5 h. Then, the ash was dissolved in 3 mL of 6N HCl and diluted with double-distilled water up to 50 mL. The plant tissues' P, K, Ca, Mg, Fe, Mn, Zn, and Cu concentrations were determined by ICP (OPTIMA 2100 DV optical emission spectrometer, Perkin Elmer, Waltham, MA, USA) [30]. The nitrogen was determined by the Kjeldahl method [31]. The macronutrient concentrations were expressed in % D.W., while those of the micronutrients, i.e., Fe, Mn, Zn, and Cu, were expressed in mg kg^{-1} D.W. By multiplying the concentration of each nutrient in each plant tissue by the corresponding D.W., the absolute quantity (content) of each nutrient in each plant part (apical and basal stems and leaves, root) was calculated. Then, by adding up the nutrient contents per plant part, the total plant nutrient content was calculated.

2.5. Gas Exchange Measurements and Intrinsic Water Use Efficiency (WUEi)

In order to determine the gas exchange measurements (i.e., the measurements of photosynthetic rate, stomatal conductance, and intercellular CO_2 concentration), the LC PRO portable gas exchange measuring system (ADC Bioscientific Ltd., Hoddesdon, UK) was used. These measurements were performed on the youngest, mature, and fully expanded leaves during a time period from 10:00 to 12:00 a.m. at full natural light intensity. Finally, the intrinsic water use efficiency (WUEi) was determined as the net photosynthetic rate per stomatal conductance.

2.6. Sugar Fractionation

An aliquot of 40 mg of freeze-dried leaf tissues was added to HPLC-grade water (Carlo Erba Reagents S.A.S, Val-de-Reuil, France) and vortexed. Then, an extraction of the water-soluble carbohydrates was performed in a microwave oven. After centrifugation (4400× *g* for 10 min at 4 °C), the supernatant was removed, and the process was repeated twice. The two supernatants were pooled together and filtered using syringe filters. The HPLC analyses were conducted using an HPLC pump (model 510 Waters, Milford, MA, USA) equipped with an HP refractive index-RI (HP 1047A, HP, Palo Alto, CA, USA). The mobile phase consisted of HPLC-grade water. An aliquot (20 µL) of the extract was injected into an Agilent Hi-Plex Ca column (Agilent, Santa Clara, CA, USA). The processing of the chromatograms was performed by means of the Peak Simple Chromatography Data System, which consisted of hardware (Model 302, SRI Instruments, Bad Honnef, Germany) and the Peak Simple 4.51 chromatography acquisition and integration software for Windows (SRI Instruments, Bad Honnef, Germany). The leaf concentrations of sucrose, glucose, fructose, and mannitol were determined by fitting data to reference curves created using HPLC pure-grade standards [32].

2.7. Statistical Analysis

The experimental design consisted of 4 fertilization treatments. In each treatment, 6 replicates were included; thus, the total number of experimental plants was 24. The data were statistically analyzed by the SPSS statistical program (one-way ANOVA). Particularly, Duncan's multiple range test for $p \leq 0.05$ was used for the comparison of the mean values among the treatments.

3. Results

3.1. Nutrient Content of the Two Organic Amendments and Properties of the Soil Mixtures (Substrates)

Sheep manure (SM) was the better organic amendment (based on its macronutrient content) compared to the EBLS. More specifically, approximately two times higher N and P, 3.5 times higher Mg, and 9.5 times higher K concentrations were found in the SM. In contrast, the EBLS had a higher micronutrient content based on its Fe and Mn concentrations, which were approximately 1.3 and 4.3 times higher, respectively, compared to the SM (Table 1). After the application of the two organic amendments, the pH was not significantly modified, while the organic matter increased from approximately 1.5% to approximately 3.5% in the SM and more than 5% in the SM + EBLS treatment (Table 2). Similarly, the Kjeldahl N increased from 0.17% to approximately 0.24–0.25% in the SM and SM + EBLS treatments. After the SM application, the Olsen P increased by approximately 4.3 times (from 0.74 mg/100 g of soil in the control to 3.20 mg/100 g of soil in the SM treatment) (Table 2). The exchangeable K concentration was approximately two times higher in the SM and SM + EBLS treatments compared to the EBLS and the control (Table 2). Finally, the Zn concentrations were approximately two and three times higher in the EBLS and SM + EBLS compared to the control, while those of Mn were 1.3–1.5 times higher, respectively (Table 2).

Table 2. Properties of the four soil mixtures (substrates) after the application of organic amendments (sheep manure, or SM, and litter from evergreen broadleaf species, or EBLS).

Treatments	pH	Organic Matter	Kjeldahl N	C/N	Olsen P (mg/100 g Soil)	Ca	Mg	K	Fe	Mn	Zn
		% soil				cmol kg^{-1} soil			mg kg^{-1} soil		
Soil + SM	7.63	3.58	0.24	8.65	3.20	34.68	2.73	1.16	2.38	2.52	0.66
Soil + EBLS	7.67	2.95	0.20	8.56	1.88	48.89	3.20	0.62	3.08	3.30	0.92
Soil + SM + EBLS	7.67	5.12	0.25	11.88	2.00	55.63	3.90	1.18	2.86	3.80	1.25
CONTROL soil	7.68	1.55	0.17	5.29	0.74	60.95	3.35	0.53	2.70	2.48	0.45

The numbers represent the means of six replicates (N = 6). SM = sheep manure; EBLS = litter from evergreen broadleaf species, i.e., from *Quercus* sp.

3.2. Plant Growth

The total plant biomass was not significantly influenced by the treatment (Table 3). Some significant differences were recorded in the apical leaves' weight and in the apical and basal stems' weights. In addition, a significantly lower value of the shoot/root ratio was recorded in the SM compared to the EBLS treatment and the control (Table 3).

Table 3. Growth parameters of the olive plants among the treatments.

	Main Shoot Length (cm)	Total Biomass (g)		Apical Leaves' Weight (g)		Basal Leaves' Weight (g)		Apical Stems' Weight (g)		Basal Stems' Weight (g)		Root Weight (g)		Shoot/Root
		F.W.	D.W.	F.W.	D.W.	F.W.	D.W.	F.W.	D.W.	F.W.	D.W.	F.W.	D.W.	D.W.
SM	121.33 a	54.08 a	17.84 a	8.91 b	2.99 b	11.25 a	4.18 a	5.03 b	1.79 b	11.00 a	4.60 b	17.89 a	4.28 a	3.09 b
EBLS	114.83 a	60.55 a	21.37 a	13.84 a	5.21 a	9.58 a	3.77 a	6.78 a	2.75 a	11.37 a	5.12 ab	18.98 a	4.51 a	3.96 a
SM + EBLS	116.58 a	58.57 a	20.27 a	12.61 a	5.17 a	10.22 a	3.86 a	6.49 a	2.48 ab	11.52 a	4.97 b	17.73 a	4.44 a	3.50 ab
CONTROL	113.50 a	60.57 a	21.33 a	10.29 ab	4.53 a	10.16 a	4.06 a	6.61 a	2.98 a	12.87 a	6.68 a	21.03 a	5.07 a	3.67 a

The numbers represent the means of six replicates (N = 6). The different letters in the same column symbolize statistically significant differences among the treatments, according to Duncan's multiple range test for $p \leq 0.05$. SM = sheep manure; EBLS = litter from evergreen broadleaf species, i.e., from *Quercus* sp.

3.3. Foliar Nutrient Concentrations and Total Plant Nutrient Content

Significantly lower leaf N concentrations were determined for both the basal and apical leaves in the EBLS and the control compared to the SM + EBLS (Table 4). With regard to K, significantly lower leaf K concentrations were recorded in the control compared only to the SM treatment. Similarly, insignificant differences among the four treatments were determined for both Ca and Mg (Table 4). Concerning the micronutrients, a significantly lower leaf Fe concentration was determined for the basal leaves in the SM + EBLS. Similarly, for Zn, a significantly lower foliar Zn was found in the SM + EBLS and the control (Table 5).

Table 4. Leaf macronutrient concentrations of the olive plants among the treatments.

	N		P		K		Ca		Mg	
	% D.W.									
	Basal leaves	Apical leaves	Basal leaves	Apical leaves	Basal leaves	Apical leaves	Basal leaves	Apical leaves	Basal leaves	Apical leaves
SM	2.23 ab	2.31 ab	0.16 a	0.15 a	1.64 a	1.89 a	1.33 a	0.87 a	0.18 a	0.15 a
EBLS	1.86 b	1.87 b	0.15 a	0.13 a	1.31 ab	1.42 ab	1.24 a	0.84 a	0.15 a	0.13 a
SM + EBLS	2.50 a	2.55 a	0.18 a	0.17 a	1.53 ab	1.63 ab	1.38 a	0.88 a	0.17 a	0.14 a
CONTROL	1.88 b	1.81 b	0.17 a	0.16 a	1.19 b	1.23 b	1.10 a	0.77 a	0.14 a	0.13 a

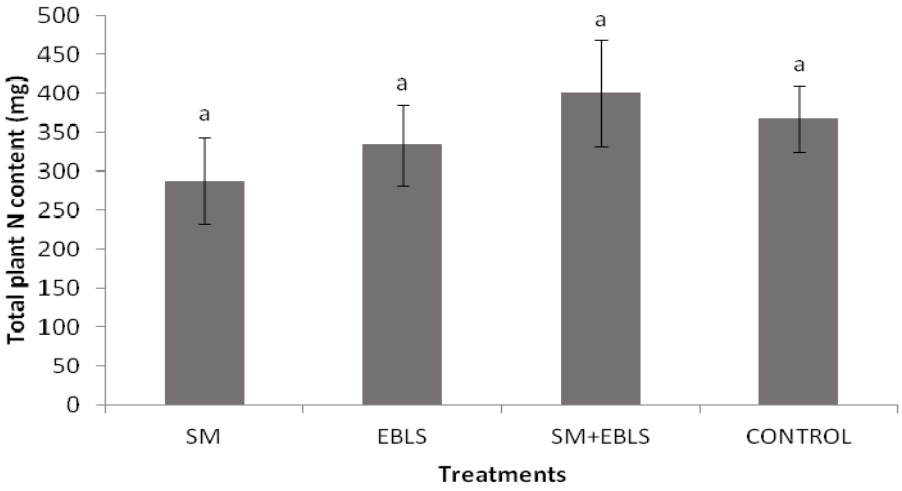
The numbers represent the means of six replicates (N = 6). The different letters in the same column symbolize statistically significant differences among the treatments, according to Duncan's multiple range test for $p \leq 0.05$. SM = sheep manure; EBLS = litter from evergreen broadleaf species, i.e., from *Quercus* sp.

Table 5. Leaf micronutrient concentrations of the olive plants among the treatments.

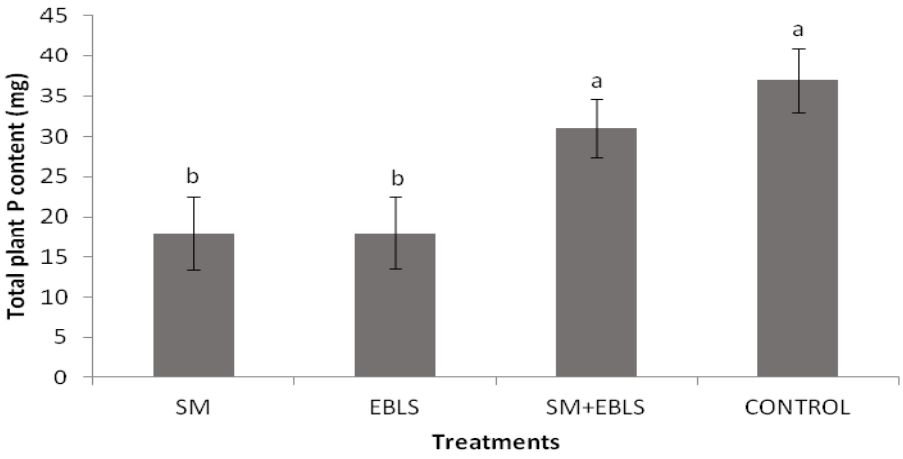
	Fe		Mn		Zn		Cu	
	mg kg^{-1} D.W.							
	Basal leaves	Apical leaves	Basal leaves	Apical leaves	Basal leaves	Apical leaves	Basal leaves	Apical leaves
SM	104 a	59 a	55 a	57 a	39 a	42 a	2.6 b	3.0 ab
EBLS	79 ab	68 a	66 a	61 a	35 a	41 a	2.0 b	2.5 b
SM + EBLS	48 b	70 a	65 a	53 a	24 b	23 b	2.8 ab	3.4 a
CONTROL	104 a	59 a	70 a	60 a	21 b	23 b	3.8 a	3.7 a

The numbers represent the means of six replicates (N = 6). The different letters in the same column symbolize statistically significant differences among the treatments, according to Duncan's multiple range test for $p \leq 0.05$. SM = sheep manure; EBLS = litter from evergreen broadleaf species, i.e., from *Quercus* sp.

The total plant content for the macronutrients did not significantly differ among the treatments, with the exception of P, where significantly lower contents were determined in the SM and EBLS (Figure 1). Concerning the micronutrients, a significantly higher Mn content was found in the EBLS compared to the SM and SM + EBLS. Similarly, for Zn, a significantly higher total content was determined in the EBLS compared to the SM + EBLS and the control (Figure 2).

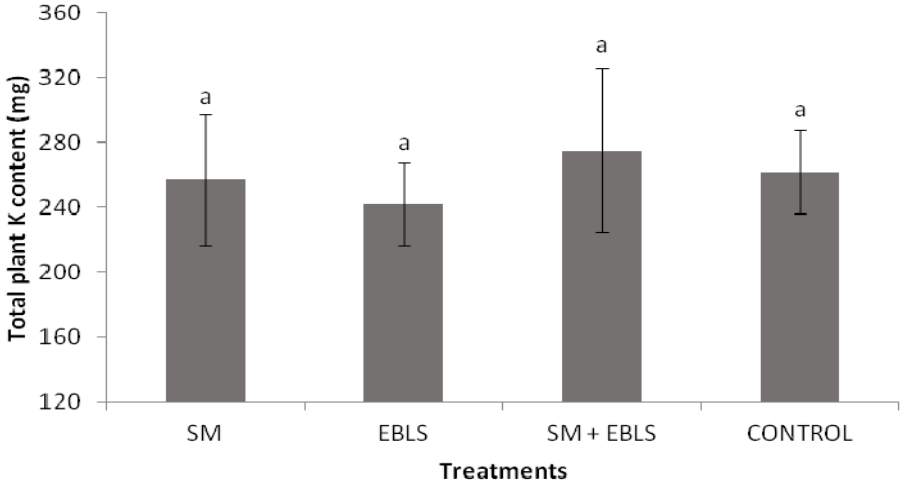


(**A**)

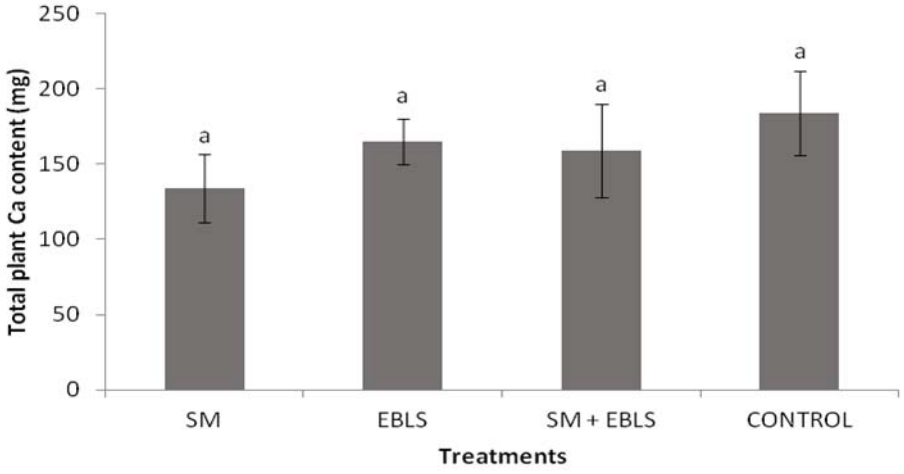


(**B**)

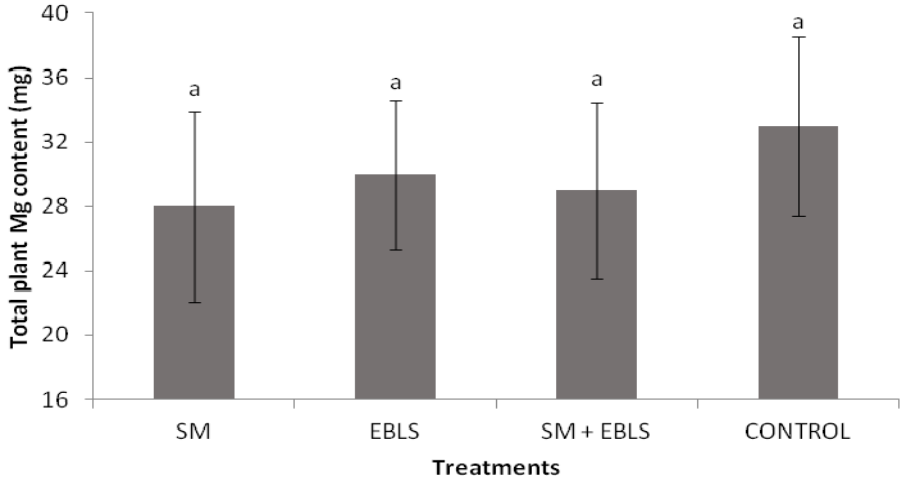
Figure 1. *Cont.*



(**C**)

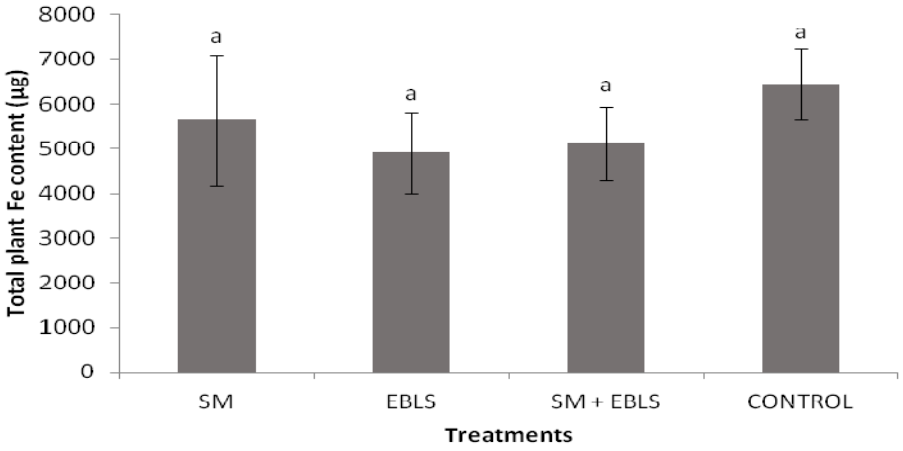


(**D**)

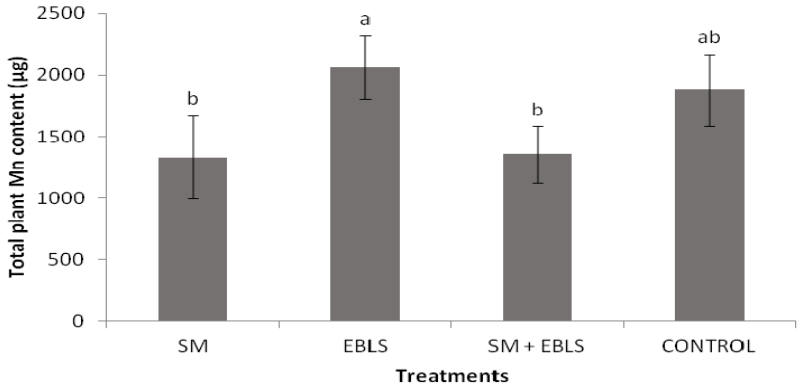


(**E**)

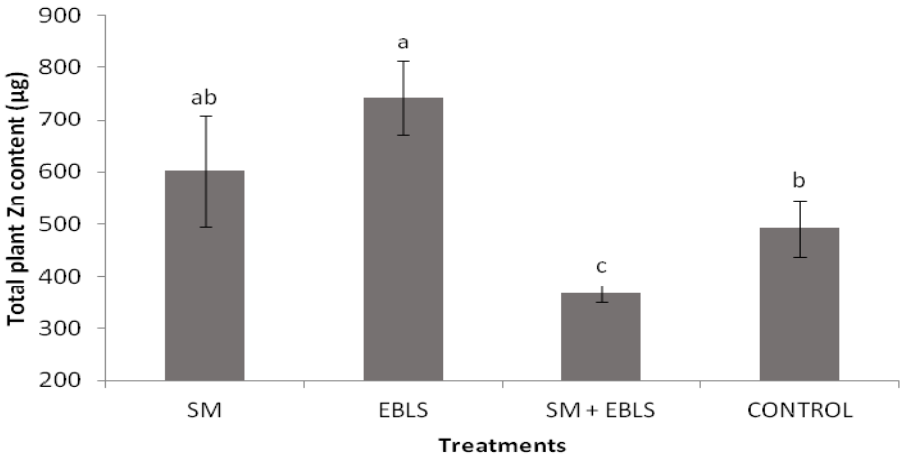
Figure 1. Total plant N (**A**), P (**B**), K (**C**), Ca (**D**), and Mg (**E**) content among the treatments. The different letters on the bars symbolize statistically significant differences among the treatments, according to Duncan's multiple range test for $p \leq 0.05$. SM = sheep manure; EBLS = organic material (litter) from evergreen broadleaf species, i.e., from *Quercus* sp.



(**A**)

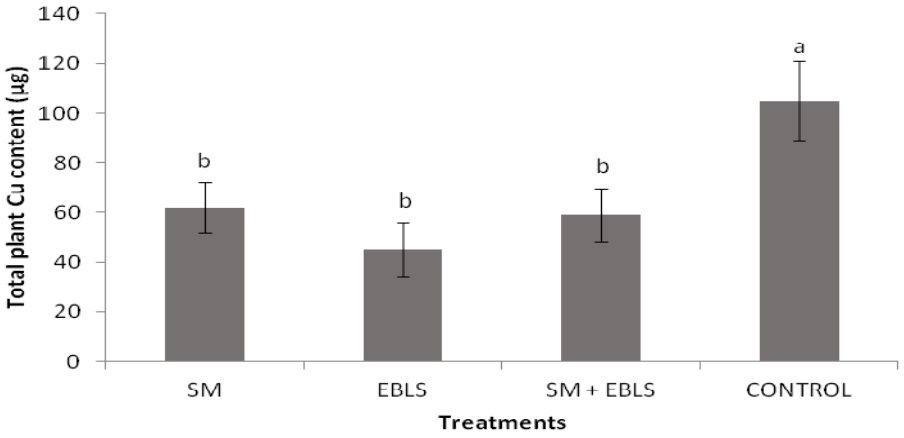


(**B**)



(**C**)

Figure 2. *Cont*.

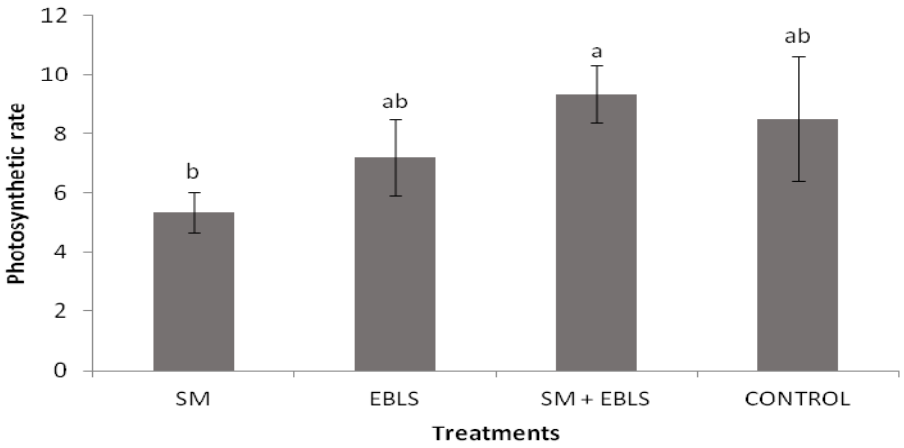


(**D**)

Figure 2. Total plant Fe (**A**), Mn (**B**), Zn (**C**), and Cu (**D**) content among the treatments. The different letters on the bars symbolize statistically significant differences among the treatments, according to Duncan's multiple range test for $p \leq 0.05$. SM = sheep manure; EBLS = organic material (litter) from evergreen broadleaf species, i.e., from *Quercus* sp.

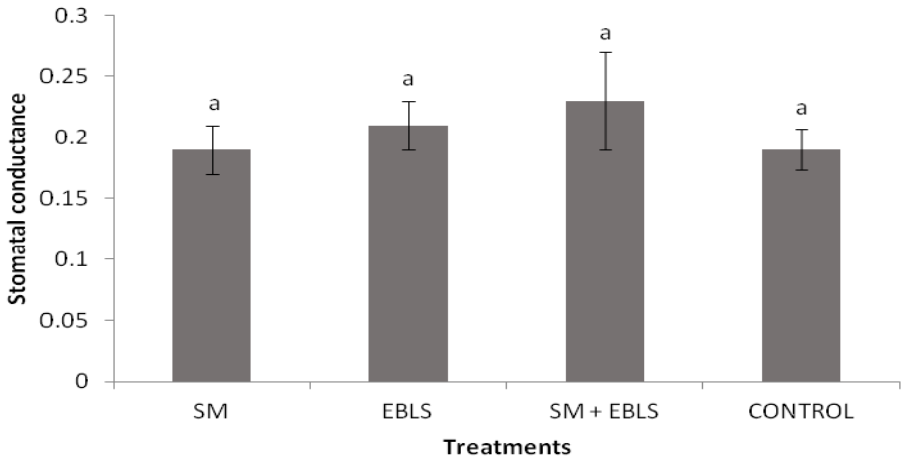
3.4. Gas Exchange Measurements and Intrinsic Water Use Efficiency (WUEi)

The photosynthetic rate of the olive plants was significantly higher in the SM + EBLS compared to the SM. Insignificant differences in the photosynthetic rates were recorded among the other treatments (Figure 3A). Similar results were also obtained for the intercellular CO_2 concentration, where a significantly higher CO_2 concentration was recorded in the SM + EBLS and the EBLS compared to the SM and the control (Figure 3C). A similar tendency was determined among the treatments for stomata opening, although the differences were not significant (Figure 3B). Finally, the WUEi was significantly lower in the SM and the EBLS compared to the SM + EBLS and the control (Figure 3D).

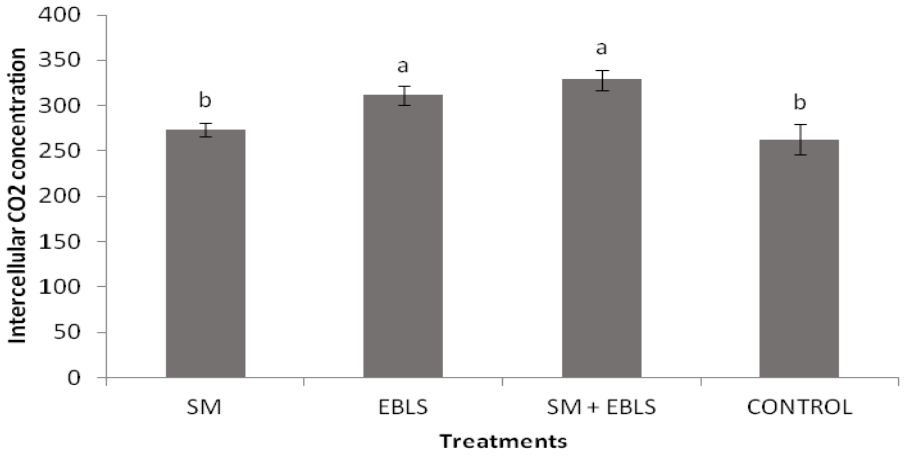


(**A**)

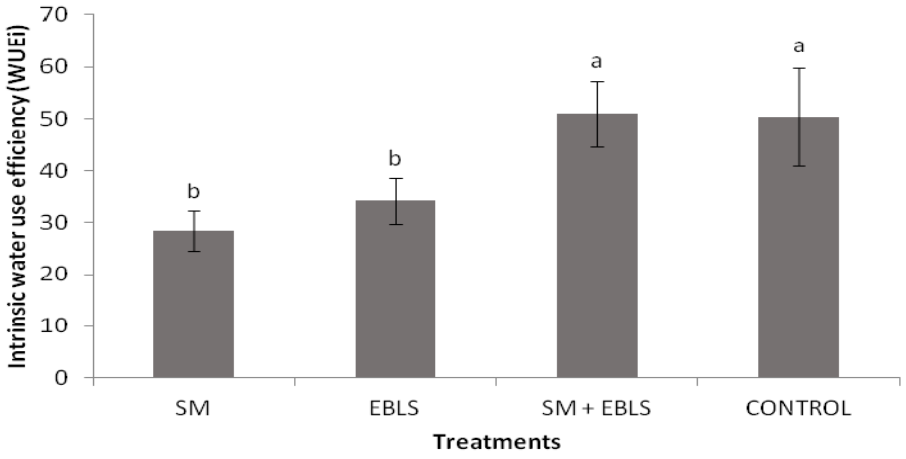
Figure 3. *Cont.*



(**B**)



(**C**)



(**D**)

Figure 3. Photosynthetic rate (μmol CO_2 m^{-2} s^{-1}) (**A**), stomatal conductance (mol m^{-2} s^{-1}) (**B**), intercellular CO_2 concentration (μmol CO_2 mol air^{-1}) (**C**), and intrinsic water use efficiency (μmol CO_2 mol H_2O^{-1}) (**D**) of the olive plants among the treatments at the end of the experiment. The different letters on the bars symbolize statistically significant differences among the treatments, according to Duncan's multiple range test for $p \leq 0.05$. SM = sheep manure; EBLS = organic material (litter) from evergreen broadleaf species, i.e., from *Quercus* sp.

3.5. Leaf Sugar Concentrations

The sucrose concentration was significantly lower in the control plants, while those of glucose and fructose were lower in either the SM + EBLS treatment or in both the SM + EBLS and SM treatments (Table 6). Thus, the total translocated sugars (sucrose and mannitol) were significantly lower in the control compared to the SM + EBLS, while the total non-translocated sugars (fructose and glucose) were significantly lower in the SM + EBLS compared to the control (Table 6). The ratio of translocated/non-translocated sugars was significantly lower in the control compared to the SM + EBLS. Since the translocated sugars were lower in the control and the non-translocated sugars were lower in the SM + EBLS, the total sugar content did not significantly differ among the treatments (Table 6).

Table 6. Leaf sugar concentrations of the olive plants among the treatments.

Treatments	Suc.	Glu.	Fru.	Man.	Suc./Fru. + Glu.	Non-Translocated Sugars (Fru. + Glu.)	Translocated Sugars (Suc. + Man.)	Translocated/Total Sugars	Translocated/Non-Translocated Sugars	Total Sugars
						% D.W.				
SM	1.74 a	2.59 b	0.60 ab	1.87 b	0.48 a	3.19 b	3.62 ab	0.38 a	1.11 ab	9.70 a
EBLS	1.45 a	3.01 ab	0.84 a	2.13 b	0.38 a	3.85 ab	3.58 ab	0.38 a	0.93 ab	10.07 a
SM + EBLS	1.53 a	2.91 b	0.59 b	2.94 a	0.44 a	3.50 b	4.47 a	0.45 a	1.28 a	10.47 a
CONTROL	0.97 b	3.63 a	0.78 a	2.44 ab	0.22 b	4.41 a	3.40 b	0.34 a	0.77 b	10.50 a

The numbers represent the means of six replicates (N = 6). The different letters in the same column symbolize statistically significant differences among the treatments, according to Duncan's multiple range test for $p \leq 0.05$. Suc = sucrose; Glu = glucose; Man = mannitol; SM = sheep manure; EBLS = organic material (litter) from evergreen broadleaf species, i.e., from *Quercus* sp.

4. Discussion

The SM was a better source of macronutrients (especially N, P, and K) compared to the EBLS (Table 1), which is why higher Kjeldahl N, Olsen P, and exchangeable K concentrations were recorded in the SM-treated soil compared to the control and to the EBLS-treated soil (Table 2). In contrast, higher micronutrient concentrations were determined in the EBLS compared to the SM (Table 1), and this also influenced the soil DTPA-extractable concentrations of Fe, Mn, and Zn, which were higher in the EBLS-treated soil compared to the SM-treated soil (Table 2). According to Therios (1996) [20], the different organic byproducts of vegetal origin (e.g., leaves of different annual or perennial plant species) significantly differ in their N, P, and K contents. It was found that the N content varied from 0.25% (in the leaves of *Lactuca sativa* L.) to 2.45% (in the leaves of *Medicago sativa* L.), while the P content fluctuated from 0.05% (in the leaves of *Pisum sativum* var. saccharatum L.) to 0.50% (in the leaves of *Medicago sativa* L.) and the K content varied from 0.30% (in the leaves of *Avena sativa* L.) to 2.10% (in the leaves of *Medicago sativa* L.) [20]. Based on these ranges of nutrient concentrations from materials from other plant species, EBLS is a relatively moderate source of N (containing 1.31% of N) for crops, a poor source of P (containing 0.08% of P), and a very poor source of K (containing only 0.31% of K) (Table 1). Especially for fruit crops (such as *Olea europaea* L.), in which high K demands exist (particularly in "on-years" with high crop loads, where high quantities of K are removed after fruit collections), EBLS as an organic fertilizer seems to be of limited importance to satisfying the necessary macronutrient needs (especially for K and, afterwards, for P and N). In contrast, SM seems to be a good source of macronutrients (especially of K and N, containing 2.99% and 2.63%, respectively) and a moderate source of P (containing 0.16%) (Table 1). Therios (1996) [20] supports the idea that the different kinds of animal manures (from chickens, cows, horses, sheep, pigs, and goats) differ significantly in their nutrient content. It was found that the highest N content was determined in goat manure (2.77%) and the lowest in pig and cow manures (approximately 0.50–0.55%). Chatzistathis et al. (2020) [5] found that goat manure's N, P, and K contents were 2.80%, 0.13%, and 2.54%, respectively, i.e., they were similar to those determined in our study for SM (2.63% for

N, 0.16% for P, and 2.99% for K). Thus, it can be concluded that SM is of approximately equal importance for macronutrient supply as goat manure. In contrast to our data, it was supported that SM is of lower importance as an N, P, and K supplier compared to goat manure [20]. The difference between our data and those of Therios (1996) for SM may be attributed to different feed rations between sheep and/or to different conditions of manure fermentation and preservation [20].

The micronutrient (Fe, Mn, Zn, and Cu) content of SM (3142, 283, 81, and 18 mg kg^{-1}, respectively) (Table 1) was of similar importance to that determined for goat manure in another study [5]. Therios (1996) [20] states that the different kinds of animal manures contain Fe, Mn, Zn, and Cu in amounts of 40–460, 5–90, 15–90, and 5–15 mg kg^{-1}, respectively. Based on these values, it is clear that the SM used in our experiment contained approximately seven times higher Fe concentrations and three times higher Mn concentrations compared to the relevant maximum values quoted by Therios (1996). These differences in the Fe and Zn concentrations between our data and the values quoted by Therios (1996) could be attributed to the different animal origins, as well as to the different feed rations and/or to different conditions of manure fermentation and preservation [20]. The zinc and copper concentrations in SM (Table 1) were, however, very close to the maximum values quoted by Therios (1996). In a previous study with cow and goat manure applications in olive plants, it was found that the Fe, Mn, Zn, and Cu concentrations were approximately 2000–3000, 300–370, 78–80, and 15–17 mg kg^{-1}, respectively [5], i.e., they were all close to the micronutrient concentrations determined in the present study for SM.

With regard to the influence of SM and EBLS applications on other soil properties, the clear influence of organic materials on organic matter (OM) boosting and the increase in Kjeldahl N should be distinguished. The most beneficial treatment was the combinational application of SM with EBLS, where the OM content was 5.12% (Table 2). Other researchers also found that manure applications boosted soil organic matter contents [33,34]. Apart from the positive influence of organic amendments on soil organic matter, SM and EBLS applications also positively influenced Kjeldahl N, Olsen P, and exchangeable K (Table 2). These data are in agreement with those found by other researchers [35–37].

The main shoot length, total plant biomass, and shoot/root values were not significantly influenced by the treatments (Table 3). These data are partially in agreement with a previous comparative study between the impact of inorganic and organic fertilizations on potted olive plants, showing that among the different organic treatments, insignificant differences in plant growth were recorded. Significantly higher shoot/root and total plant biomass values were found when the olive plants were supplied with an inorganic controlled-release fertilizer [5]. In contrast, Mazeh et al. (2021) [38], who also realized a comparative study between an organic and an inorganic fertilizer application on the growth of young potted and field-grown olive trees, found that the organic fertilizer promoted the growth of both potted and field olive trees (an increment of 22–29% of the trunk cross-sectional area), showing its biostimulant action. In the potted trees, a rapid elongation of the stem (an increment of +30% of the tree height compared to the inorganically fertilized trees) and a higher number of leaves occurred [38]. In the study of Perez-Murcia et al. (2021) [37], where agri-food composts were used in organically managed almond trees, it was found that sheep manure applications showed similar results with agri-food composts on yields. Finally, it was found that a significantly higher tree height was recorded in apple trees fertilized with cow manure and compost compared to cases when they were grown on other organic mulches (barley straw, chipped pine bark, forest humus, commercial peat moss, and commercial mycorrhizal substrate) [10]. Although no direct comparison of our data with those of Kiczorowski et al. (2018) [10] can be performed due to the different experimental conditions (a pot experiment vs. a field study, respectively), it cannot be neglected that these results are partially in disagreement with our data.

The leaf N and K concentrations were significantly higher either in the SM or in the SM + EBLS treatments compared to the control (Table 4), which shows the beneficial effect of these organic amendments on enhancing the N and K uptakes by olive plants.

Perez-Murcia et al. (2021) [37] found that the N content of kernels in almond trees did not significantly differ among the organic treatments (composts elaborated from different kinds of waste, such as sheep manure) and the control, while the K content was significantly lower in the control compared to three out of the four composts used as biofertilizers. This partially agrees with our data for the K uptake, although the experimental conditions were different (a field experiment in the study of Perez-Murcia et al. (2021) and a pot experiment in our case). Similarly, for Zn, the SM and EBLS applications positively influenced the Zn uptake by the olive plants, as indicated by the data shown in Table 5, which also agrees with the results of Perez-Murcia et al. (2021) for the Zn kernel content among the organic treatments and the control trees. In the study of Kiczorowski et al. (2018) [10], it was found that cow manure, compost, and forest humus applications had similar beneficial effects on the foliar nutrient contents of apple trees [10]. With regard to the total plant nutrient contents, significant differences among the treatments were recorded only in the cases for the P, Mn, Zn, and Cu contents (Figures 1 and 2). These differences may be explained as follows: (i) differences in the dry weight of the plant tissues (Table 3); (ii) differences in the nutrient uptake (Tables 4 and 5) among the treatments; or (iii) differences in both of them.

Although non-significant differences in the stomata opening were determined among the treatments, the photosynthetic rate was significantly lower in the SM compared to the SM + EBLS (Figure 3A,B). This could probably be attributed to the significantly lower intercellular CO_2 concentration determined in the SM (Figure 3C). Despite the fact that the differences in the stomatal conductance were not significant among the four treatments (Figure 3B), the similar tendency in the stomata opening and intercellular CO_2 concentration (i.e., in the SM and the control, slightly lower stomatal conductance values were determined) (Figure 3B,C) may explain the differences recorded in the intercellular CO_2 between the following treatments: (i) SM and control and (ii) EBLS and SM + EBLS (Figure 3C). Cow manure supplies significantly influenced the stomata opening, intercellular CO_2 concentration, and photosynthetic rates of apple trees compared to the control [39], which partially confirms our data (only for CO_2 concentration, but not for stomata opening or photosynthetic rate, where the differences were insignificant). In our case, the most beneficial strategy to boost the stomata opening, intercellular CO_2 concentration, and photosynthetic rate of olive plants was the combinational supply of SM and EBLS (Figure 3A–C). Finally, a study on cow manure (CM) and goat manure (GM) applications found that the optimum strategy to boost the photosynthetic rate of olive plants was GM application, while the most beneficial effect for the increase in stomata opening derived from the combinational supply of CM and GM [5], which means that CM failed to increase stomatal conductance. These data partially confirm our results since, in our case, the CO_2 concentration and photosynthetic rate in the SM treatment were significantly lower and the stomata opening was slightly lower compared to the combinational application of SM + EBLS (Figure 3A–C).

WUEi provides information on how efficiently water is used by plants (high internal utilization in terms of CO_2 assimilation and low losses by transpiration since it is defined as the ratio between photosynthetic rate and stomatal conductance). Our data showed that a significantly higher WUEi value was found in the SM + EBLS and the control compared to the SM- and EBLS-treated plants (Figure 3D). Chatzistathis et al. (2020) [5] found that the type of organic fertilization (cow or goat manure applications) influenced the WUEi in olive plants. Other researchers quoted that WUEi was affected by the K supply [40,41], N fertilization, and AMF inoculation [42]. Thus, in our study, it seems possible that the differences in the nutrient availability and uptake by plants among the treatments (Tables 2, 4 and 5) could be responsible for the differences in the photosynthetic rates of the plants, which afterwards influenced the WUEi. The differences in the K uptake among the treatments (Table 4) did not significantly influence the stomata opening (Figure 3B), as it happened in other studies [5,41]. Thus, the significant differences in the WUEi values should be mainly attributed to the differences in the photosynthetic rates (Figure 3A).

The main leaf translocated sugars were sucrose and mannitol, while the main non-translocated sugars were fructose and glucose. Overall, the translocated sugars were significantly lower in the control compared to the SM + EBLS-treated plants, while the opposite tendency was observed for the non-translocated sugars, which were significantly lower in the SM + EBLS treatment compared to the control (Table 6). Diekmann and Fischbeck (2005) [43] concluded that soluble carbohydrates in wheat plants varied in response to the N supply, while in potato plants, low rates of N fertilization led to a lower accumulation of total soluble sugars compared to those that were properly fertilized [44]. In another study [45], the effect of P on carbohydrates was investigated, and it was found that the P nutrition of pepper plants clearly influenced carbohydrate production, while in other cases, it was found that the foliar K nutrition influenced the accumulation of translocated sugars and the ratio of translocated/non-translocated sugars in olive leaves [5]. In our study, significantly lower foliar N levels were determined in the control and EBLS-treated plants compared to those treated with SM + EBLS (Table 4). In addition, the lowest leaf K concentrations, both for the basal and apical leaves, were observed in the control plants (Table 4). These differences in the N and K uptakes by olive plants might have shown their impact on the differences determined as follows: (i) in the accumulation of translocated sugars among the treatments (Table 6) and (ii) in the ratio of translocated/non-translocated sugars, as also explained by other researchers. However, further research on this topic will be needed under field conditions to better clarify the impact of nutrient uptake on the accumulation of translocated and non-translocated sugars.

5. Conclusions and Future Perspectives

Based on all of the data from our study, it was concluded that the optimum treatment for fertilization was SM + EBLS, i.e., the most beneficial strategy to improve soil fertility, enhance N uptake, boost the photosynthetic rate, internal CO_2 concentration, and WUEi, and improve the content of translocated sugars in olive plants was the combinational application of SM and EBLS. Especially due to the recent energy crisis, which has significantly increased the prices of fertilizers, the importance of finding alternative sources of nutrients for crops has become more and more demanding. Sheep manure and well-decomposed litter from indigenous field vegetation of *Quercus* sp. are the two organic amendments that could supply critical amounts of nutrients toward decreasing the high fertilization rates in olive production. Despite the significance of the presented results, it was pointed out that they are only the first step (especially the application of EBLS and the combinational application with SM, i.e., SM + EBLS) in the evaluation of their potential use as biofertilizers, since more trials and experimentation are needed under field conditions (including flowering and fruit setting measurements, yields, and olive oil quality) to draw more stable conclusions. According to our opinion, these preliminary data should be taken seriously into consideration by olive producers since both SM and EBLS are sustainable sources of nutrient supplies that could be used in the context of the circular economy strategy to sustain olive production.

Author Contributions: Conceptualization, T.C.; methodology, T.C., A.P. and I.E.P.; software, C.C.; validation, T.C., C.C. and I.E.P.; formal analysis, T.C. and I.E.P.; investigation, T.C., C.C. and A.P.; resources, T.C. and A.P.; data curation, T.C., C.C., A.P. and I.E.P.; writing—original draft preparation, T.C.; writing—review and editing, T.C.; C.C. and I.E.P.; visualization, T.C.; supervision, T.C.; project administration, T.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by small-scale research projects of the Soil and Water Research Institute (ELGO "DIMITRA").

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Chatzistathis, T.; Papaioannou, A.; Gasparatos, D.; Molassiotis, A. From which soil metal fractions Fe, Mn, Zn and Cu are taken up by olive trees (*Olea europaea* L., cv. 'Chondrolia Chalkidikis') in organic groves? *J. Environ. Manag.* **2017**, *203*, 489–499. [CrossRef] [PubMed]
2. Miao, Y.; Stewart, B.A.; Zhang, F. Long-term experiments for sustainable nutrient management in China. A review. *Agron. Sustain. Dev.* **2011**, *31*, 397–414. [CrossRef]
3. Aguilera, E.; Lassaletta, L.; Sanz-Cobena, A.; Garnier, J.; Vallejo, A. The potential of organic fertilizers and water management to reduce N_2O emissions in Mediterranean climate cropping systems. A review. *Agric. Ecosys. Environ.* **2013**, *164*, 32–52. [CrossRef]
4. Benabderrahim, M.A.; Elfalleh, W.; Belayadi, H.; Haddad, M. Effect of palm waste compost on forage alfalfa growth, yield, seed yield and minerals uptake. *Int. J. Recycl. Org. Waste Agricult.* **2018**, *7*, 1–9. [CrossRef]
5. Chatzistathis, T.; Papadakis, I.E.; Papaioannou, A.; Chatzissavvidis, C.; Giannakoula, A. Comparative study effects between manure application and a controlled release fertilizer on the growth, nutrient uptake, photosystem II activity and photosynthetic rate of *Olea europaea* L. (cv. 'Koroneiki'). *Sci. Hortic.* **2020**, *264*, 109176. [CrossRef]
6. Arrobas, M.; De Almeida, S.F.; Raimundo, S.; Da Silva Domingues, L.; Rodrigues, M.A. Leonardites rich in humic and fulvic acids had little effect on tissue elemental composition and dry matter yield in pot-grown olive cuttings. *Soil Syst.* **2022**, *6*, 7. [CrossRef]
7. Zhang, J.; Pang, H.; Ma, M.; Bu, Y.; Shao, W.; Huang, W.; Ji, Q.; Yao, Y. An apple fruit fermentation (AFF) treatment improves the composition of the rhizosphere microbial community and growth of strawberry (*Fragaria* x *ananassa* Duch 'Benihoppe') seedlings. *PLoS ONE* **2016**, *18*, e0164776. [CrossRef]
8. Liu, Z.; Guo, Q.; Feng, Z.; Liu, Z.; Li, H.; Sun, Y.; Liu, C.; Lai, H. Long-term organic fertilization improves the productivity of kiwifruit (*Actinidia chinensis* Planch.) through increasing rhizosphere microbial diversity and network complexity. *Appl. Soil Ecol.* **2020**, *147*, 103426. [CrossRef]
9. Jindo, K.; Chocano, C.; Melgares de Aguilar, J.; Gonzalez, D.; Hernandez, T.; Garcia, C. Impact of compost application during 5 years on crop production, soil microbial activity, carbon fraction and humification process. *Com. Soil Sci. Plant Anal.* **2016**, *47*, 1907–1919. [CrossRef]
10. Kiczorowski, P.; Kopacki, M.; Kiczorowska, B. The response of Šampion trees growing on different rootstocks to applied organic mulches and mycorrhizal substrate in the orchard. *Sci. Hortic.* **2018**, *241*, 267–274. [CrossRef]
11. Leonel, S.; Tecchio, M.A. Cattle manure fertilization increases fig yield. *Sci. Agric.* **2009**, *66*, 806–811. [CrossRef]
12. Baldi, E.; Toselli, M.; Eissenstat, D.M.; Marangoni, B. Organic fertilization leads to increased peach root production and lifespan. *Tree Physiol.* **2010**, *30*, 1373–1382. [CrossRef] [PubMed]
13. Lopez-Pineiro, A.; Albarran, A.; Rato Nunes, J.M.; Pena, D.; Cabrera, D. Long term impacts of de-oiled two-phase olive mill waste on soil chemical properties, enzyme activities and productivity in an olive grove. *Soil Till. Res.* **2011**, *114*, 175–182. [CrossRef]
14. Garcia-Ruiz, R.; Ochoa, M.V.; Hinojosa, M.B.; Gomez-Munoz, B. Improved soil quality after 16 years of olive mill pomace application in olive oil groves. *Agron. Sustain. Dev.* **2013**, *32*, 803–810. [CrossRef]
15. Zipori, I.; Erel, R.; Yermiyahu, Y.; Ben-Gal, A.; Dag, A. Sustainable management of olive orchard nutrition: A review. *Agriculture* **2020**, *10*, 11. [CrossRef]
16. Rodrigues Prates, A.; Renée Coscione, A.; Carvalho Minhoto Teixeira Filho, M.; Gasparoti Miranda, B.; Arf, O.; Hamilton Abreu-Junior, C.; Carvalho Oliveira, F.; Moreira, A.; Shintate Galindo, F.; Márcia Pereira Sartori, M.; et al. Composted sewage sludge enhances soybean production and agronomic performance in naturally infertile soils (Cerrado region, Brazil). *Agronomy* **2020**, *10*, 1677. [CrossRef]
17. Chatzistathis, T.; Kavvadias, V.; Sotiropoulos, T.; Papadakis, I.E. Organic fertilization and tree orchards. *Agriculture* **2021**, *11*, 692. [CrossRef]
18. Bargougui, L.; Chaieb, M.; Mekki, A. Physiological and growth responses of young plants of three native olive cultivars to olive waste compost. *J. Plant Nutr.* **2022**, *45*, 2478–2498. [CrossRef]
19. Soares, P.R.; Lopes, M.A.R.; Conceicao, M.A.; Santos, D.V.S.; Oliveira, M.A. Sustainable integration of laying hens with crops in organic farming: A review. *Agroecol. Sustain. Food Syst.* **2022**, *46*, 969–1001. [CrossRef]
20. Therios, I. *Mineral Nutrition of Plants*; Dedousi Publications: Thessaloniki, Greece, 1996. (In Greek)
21. El Gammal, O.H.M.; Salama, A.S.M. Effect of Sheep Manure Application Rate and Method on Growth, Fruiting and Fruit Quality of Balady Guava Trees Grown Under Mid-Sinai Conditions. *J. Agric. Vet. Sci.* **2016**, *9*, 59–72.
22. Therios, I. *Olives. Crop Production Science in Horticulture*; C.A.B. International: Wallingford, UK, 2009.
23. McLean, E. Soil pH and lime requirement. In *Methods of Soil Analysis, Part 2: Chemical and Microbiological Properties*; Page, A.L., Miller, R.H., Keeney, D.R., Eds.; Agronomy Monograph; ASA: Madison, WI, USA; SSSA: Madison, WI, USA, 1982; pp. 199–224.
24. Gee, G.; Bauder, J. Particle-Size Analysis. In *Methods of Soil Analysis, Part 1: Physical and Mineralogical Methods*; Klute, A., Ed.; ASA: Madison, WI, USA; SSSA: Madison, WI, USA, 1986; pp. 383–411.
25. Nelson, D.W.; Sommers, L.E. Total Carbon, Organic Carbon and Organic Matter. In *Methods of Soil Analysis, Part 2: Chemical and Microbiological Properties*; Page, A.L., Miller, R.H., Keeney, D.R., Eds.; Agronomy Monograph; ASA: Madison, WI, USA; SSSA: Madison, WI, USA, 1982; pp. 539–547.
26. Bremner, J.M.; Mulvaney, C.S. Total Nitrogen. In *Methods of Soil Analysis, Part 2, Chemical and Microbiological Properties*; Page, A.L., Miller, R.H., Keeney, D.R., Eds.; ASA: Madison, WI, USA; SSSA: Madison, WI, USA, 1982; pp. 595–615.

27. Olsen, S.; Sommers, L. Phosphorus. In *Methods of Soil Analysis, Part 2: Chemical and Microbiological Properties*; Page, A.L., Miller, R.H., Keeney, D.R., Eds.; Agronomy Monograph; ASA: Madison, WI, USA; SSSA: Madison, WI, USA, 1982; pp. 403–430.
28. Thomas, G.W. Exchangeable Cations Methods of Soil Analysis. In *Methods of Soil Analysis, Part 2: Chemical and Microbiological Properties*; Page, A.L., Miller, R.H., Keeney, D.R., Eds.; Agronomy Monograph; ASA: Madison, WI, USA; SSSA: Madison, WI, USA, 1982; pp. 159–166.
29. Lindsay, W.L.; Norvell, W.A. Development of a DTPA soil test for zinc, iron, manganese, and copper. *Soil Sci. Soc. Am. J.* **1978**, *42*, 421–428. [CrossRef]
30. Hansen, T.H.; De Bang, T.C.; Laursen, K.H.; Pedas, P.; Husted, S.; Schjoerring, J.K. Multielement Plant Tissue Analysis Using ICP Spectrometry. In *Plant Mineral Nutrients. Methods in Molecular Biology (Methods and Protocols)*; Maathuis, F., Ed.; Humana Press: Totowa, NJ, USA, 2013; Volume 953.
31. Chapman, H.D.; Pratt, P.F. *Methods of Analysis for Soils, Plants and Waters*; Division of Agricultural Sciences, University of California: Riverside, CA, USA, 1961; p. 309.
32. Vemmos, S.N. Carbohydrate content of inflorescent buds of defruited and fruiting pistachio (*Pistachia vera* L.) branches in relation to biennial bearing. *J. Hort. Sci. Biotech.* **1999**, *74*, 94–100. [CrossRef]
33. Lin, Y.; Ye, G.; Kuzyakov, Y.; Liu, D.; Fan, J.; Ding, W. Long-term manure application increases soil organic matter and aggregation and alters microbial community structure and keystone taxa. *Soil Biol. Biochem.* **2019**, *134*, 187–196. [CrossRef]
34. Ye, G.; Lin, Y.; Kuzyakov, Y.; Liu, D.; Luo, J.; Lindsey, S.; Wang, W.; Fan, J.; Ding, W. Manure over crop residues increases soil organic matter but decreases microbial necromass relative contribution in upland Ultisols: Results of a 27-year field experiment. *Soil. Biol. Biochem.* **2019**, *134*, 15–24. [CrossRef]
35. Nasini, L.; Gigliotti, G.; Balduccini, M.A.; Federici, E.; Cenci, G.; Proietti, P. Effect of solid olive-mill waste amendment on soil fertility and olive (*Olea europaea* L.) tree activity. *Agric. Ecos. Environ.* **2013**, *164*, 292–297. [CrossRef]
36. Garcia-Orenes, F.; Roldan, A.; Morugan-Coronado, A.; Linares, C.; Cerda, A.; Caravaca, F. Organic fertilization in traditional Mediterranean grapevine orchards mediates changes in soil microbial community structure and enhances soil fertility. *Land Degrad. Develop.* **2016**, *27*, 1622–1628. [CrossRef]
37. Perez-Murcia, M.D.; Bustamante, M.A.; Orden, L.; Rubio, R.; Agullo, E.; Carbonell-Baracchina, A.A.; Moral, R. Use of agri-food composts in almond organic production: Effects on soil and fruit quality. *Agronomy* **2021**, *11*, 536. [CrossRef]
38. Mazeh, M.; Almadi, L.; Paoletti, A.; Cinosi, N.; Daher, E.; Tucci, M.; Lodolini, E.A..; Rosati, A.; Famiani, F. Use of an organic fertilizer also having a biostimulant action to promote the growth of young olive trees. *Agriculture* **2021**, *11*, 593. [CrossRef]
39. Li, Z.; Wang, M.; Yang, Y.; Zhao, S.; Zhang, Y.; Wang, X. Effect of composted manure plus chemical fertilizer application on aridity response and productivity of apple trees on the loess plateau, China. *Arid Land Res. Manag.* **2017**, *31*, 388–403. [CrossRef]
40. Zhu, L.D.; Shao, X.H.; Zhang, Y.C.; Zhang, H.; Hou, M.M. Effects of K fertilizer application on photosynthesis and seedling growth of sweet potato under drought stress. *J. Food Agric. Environ.* **2012**, *10*, 487–491.
41. Saykhul, A.; Chatzistathis, T.; Chatzissavvidis, C.; Koundouras, S.; Therios, I.; Dimassi, K. Potassium utilization efficiency of three olive cultivars grown in a hydroponic system. *Sci. Hortic.* **2013**, *162*, 55–62. [CrossRef]
42. Zhang, B.B.; Zhang, H.; Jing, Q.; Wu, Y.X.; Xiao, S.Z.; Wang, M.M. Effect of mycorrhizal fungi inoculation and nitrogen fertilization on physiological characteristics, growth and nitrogen and phosphorus uptake of wheat under two distinct water regimes. *Agric. Res. Arid Areas* **2019**, *37*, 214–220.
43. Diekmann, F.; Fischbeck, G. Differences in wheat cultivar response to nitrogen supply. II: Differences in N-metabolism-related traits. *J. Agron. Crop Sci.* **2005**, *191*, 362–376.
44. Braun, H.; Rezende Fontes, P.C.; Da Silva, T.P.; Finger, L.F.; Cecon, P.R.; Sato Ferreira, A.P. Carbohydrates concentration in leaves of potato plants affected by nitrogen fertilization rates. *Rev. Ceres Vicosa* **2016**, *63*, 241–248. [CrossRef]
45. Baghour, M.; Sanchez, E.; Ruiz, J.M.; Romero, L. Metabolism and efficiency of phosphorus utilization during senescence in pepper plants: Response to nitrogenous and potassium fertilization. *J. Plant Nutr.* **2001**, *24*, 1731–1743. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.