Article

Use of Agri-Food Composts in Almond Organic Production: Effects on Soil and Fruit Quality

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Abstract: The objective of this work was to study the agronomic effects of the application of agri-food composts in almond trees (*Prunus dulcis* L.) cultivated in two different areas with different almond varieties (cv. *Guara* and cv. *Ferraduel*), with both in organic farming conditions throughout two cropping cycles. To reach this objective, almond production and quality issues (seed production, kernel yield, nutrient contents and kernel quality), as well as several physico-chemical and biological properties of the amended soils at the beginning and at the end of each campaign were studied. The four composts used (C1, C2, C3 and C4) were elaborated mainly using exhausted grape marc (EGM) and other wastes (waste from orange juice production, OW; waste from tomato soup production, TW; cattle manure, CM; and sheep manure, SM). Two treatments were used as control treatments, one based on sheep manure and another without any amendment. The composts used produced similar results in kernel yield and production compared to the traditional treatment (sheep manure). However, the thickness of the kernel was higher in the treatments using composts with exhausted grape marc and sheep manure or tomato soup waste. In relation to the almond quality, few differences related to the effect of treatments were observed, except for the content of proteins, sucrose, some fatty acids and vegetal sterols.

Keywords: organic farming; compost; fertilization; almond; fruit quality

1. Introduction

The extensive management of typically Mediterranean crops such as olives, almonds or grapevines under organic farming conditions (OFC) demands specific sources of organic fertilizers and amendments, which must be validated by specific regulations in an agronomic scenario with a very significant scarcity of traditional manures. Spanish almond production constitutes 84% of the European production and 5% of the worldwide production, with around 330,000 tons in 2018 (more than 77,000 Ha under OFC, representing 15% of the total area) [1]. The almond tree is a fairly rustic crop that easily adapts to multiple edaphoclimatic zones, with almond cropping in OFC being an added value solution for marginal areas and arid conditions. However, organic almonds have enjoyed premium prices compared to conventional ones, and the premium has decreased as organic production has increased [2].

Composting using wastes from agro-industrial activities can be used in OFC, considering the origin and composition requirements set by the legislation [3]. Co-composting strategies based on the combination of agri-food derived wastes, such as exhausted grape marc, waste from citric and horticultural processing, as well as livestock wastes in semi-intensive farms, allows for the obtention of balanced composts with added-value properties

for OFC. In this sense, there is an increasing scientific literature that highlights the high quality of the composts prepared with this type of agri-food waste and particularly with wastes from winery activities [4,5]. However, the study of the agronomic behavior of this type of compost in pluriannual field trials and in different management conditions is required. Bustamante et al. [6] observed a mineralization rate in laboratory incubation trials between 11% and the 20% of the added carbon using agri-food composts, with this contribution being highly dependent on the stability of the organic matter and on the mineralogical composition of the amended soil. The contribution of compost amendment in these OFC almond systems can include not only a restoration of the soil organic fertility, but also an improvement of the crop quality. Sanchez-Bel et al. [7] reported better results in organic fertilization compared to a mineral equivalent in almond cultivation using the *Guara* variety.

For this reason, a two-year experiment using two landraces and hydric conditions was developed in order to compare the application of agri-food composts with the traditional management based on sheep manure amendments, studying production and fruit quality parameters, as well as several physical, chemical and biological properties in the amended soils.

2. Materials and Methods

2.1. Experimental Design

The field experiments were carried out during two consecutive seasons (2008 and 2009) in two different areas in Alicante (Spain) under OFC controlled by the Valencian Organic Farming Committee; one in Pinoso (38°23′ 13.90″ N 1° 05′ 02.74″ W elevation 634 m, 3.9% slope) with *Prunus dulcis* cv. *Guara* almond trees and located irrigation, and another one in Fontanars (38°44′38.15″ N, 0°52′19.36″ W, elevation 605, slope 4.6%) with *Prunus dulcis* cv. *Ferraduel* almond trees, grown in extensive conditions. The climates in these areas are semi-arid for Pinoso (Köppen BSk) and Mediterranean for the Fontanars area (Köppen: Csa). The climatic data at the experimental sites over the study period showed a cumulative rainfall of 314 and 388 mm and a mean temperature of 15.1 °C and 14.7 °C for the field areas of Pinoso and Fontanars, respectively. The temperature and rainfall patterns observed in the years corresponding to the study were typical of the areas studied. Weather data were obtained from two meteorological stations belonging to the IVIA-GVA (Valencian Community) located at the experimental sites. Soils in both areas were calcareous, sandy loam textured, with an alkaline pH and low fertility (Table 1).

Table 1. Main soil properties of 0–30 cm soil layer at the experimental sites.

Parameter	Soil 1	Soil 2
pH	8.82 ± 0.01	8.56 ± 0.01
EC (dS m^{-1})	0.11 ± 0.00	0.21 ± 0.01
Total carbonate equivalent (%)	62.5 ± 0.5	22.8 ± 0.1
Soil texture		
Thick elements (%)	13.2 ± 0.1	32.6 ± 0.1
Sand (%)	75.3 ± 0.1	70.5 ± 0.0
Silt (%)	16.6 ± 0.1	15.5 ± 0.1
Clay (%)	8.2 ± 0.1	14.0 ± 0.1
Oxidizable organic C (g kg^{-1})	5.10 ± 0.03	5.22 ± 0.37
Total Kjeldahl N (g kg^{-1})	0.70 ± 0.00	0.70 ± 0.00
NO_3^--N (mg kg^{-1})	17.3 ± 0.0	21.8 ± 0.8

Soil 1: soil from the experimental site located in Pinoso; Soil 2: soil from the experimental site located in Fontanars. EC: electrical conductivity. Data values are reported as mean value (n = 3) ± standard error.

Four different organic amendments based on agri-food compost were applied as a single application at the beginning of the experiment in each experimental area (Pinoso and Fontanars) using two reference treatments to confirm the efficiency and the agronomic behavior of these composts—one based on sheep manure with ferrous sulphate as an

additive, the amendment traditionally employed in trial areas, and a control treatment, in which no organic amendment was used. The amendment application rate complied in all cases with Ecologic Agriculture regulations for manures [3], which allow 170 kg N ha^{-1}. Each treatment was applied once in four subplots covering 15 trees each, with a row spacing of 7×7 m^2 (row $\times$ almond tree), equivalent to 205 almond tree ha^{-1}. Treated and non-treated plots were arranged in a completely randomized block design. The border effect was eliminated by guard rows at the edge of each block.

In Table 2 the main characteristics of the organic materials used are shown. The composts used were prepared mainly using exhausted grape marc (EGM) from a distillery, mixed with other residual materials (orange juice waste, OW; tomato soup waste, TW; sheep manure, SM; cattle manure, CM), with all these wastes having origin and composition requirements within those established by the legislation to be fit for their use in organic farming [3]. The proportions of these components in the composting mixtures were as follows (on a dry-weight basis):

- C1: 60% EGM + 40% OW
- C2: 60% EGM + 40% TW
- C3: 60% EGM + 40% CM
- C4: 60% EGM + 40% SM

Table 2. Characteristics of the organic materials used in the experiment.

	C1	C2	C3	C4	Sheep Manure
pH	7.28 ± 0.01	7.25 ± 0.06	7.88 ± 0.02	7.61 ± 0.03	7.46 ± 0.02
EC (dS m^{-1})	2.75 ± 0.06	2.62 ± 0.01	6.15 ± 0.12	5.64 ± 0.04	6.99 ± 0.10
TOM (%)	83.4 ± 1.65	86.2 ± 0.74	74.2 ± 0.06	61.3 ± 0.78	34.9 ± 0.21
TOC (%)	47.5 ± 0.49	49.5 ± 0.21	42.2 ± 1.63	33.9 ± 0.71	17.9 ± 0.18
TN (%)	2.86 ± 0.13	2.95 ± 0.02	2.92 ± 0.13	2.34 ± 0.05	1.73 ± 0.01
C:N ratio	16.6 ± 0.76	16.8 ± 0.04	14.5 ± 0.08	14.5 ± 0.59	10.3 ± 0.11
P (g kg^{-1})	3.09 ± 0.42	4.85 ± 0.13	6.46 ± 0.20	5.12 ± 0.28	2.53 ± 0.31
Ca (g kg^{-1})	26.4 ± 1.2	21.0 ± 3.8	34.5 ± 1.1	72.4 ± 0.8	64.3 ± 1.5
Mg (g kg^{-1})	1.97 ± 0.11	1.89 ± 0.12	5.91 ± 0.40	5.84 ± 0.51	4.79 ± 0.40
K (g kg^{-1})	10.2 ± 1.1	14.0 ± 0.5	18.6 ± 0.2	15.3 ± 1.5	8.11 ± 0.15
Na (mg kg^{-1})	641 ± 2	537 ± 6	6712 ± 121	3678 ± 24	1380 ± 33
Fe (mg kg^{-1})	717 ± 43	746 ± 55	1907 ± 2	3704 ± 77	7000 ± 81
Cu (mg kg^{-1})	14.0 ± 0.2	16.1 ± 0.6	25.1 ± 0.6	16.7 ± 2.5	7.60 ± 0.12
Mn (mg kg^{-1})	23.3 ± 2.0	31.0 ± 1.4	98.7 ± 1.4	114 ± 6	135 ± 3
Zn (mg kg^{-1})	274 ± 1	179 ± 3	137 ± 4	93 ± 7	50 ± 6

C1: 60% EGM + 40% OW; C2: 60% EGM + 40% TW; C3: 60% EGM + 40% CM; C4: 60% EGM + 40% SM. EGM: exhausted grape marc; OW: orange juice waste; TW: tomato soup waste; CM: cattle manure; SM: sheep manure. EC: electrical conductivity; TOM: total organic matter; TOC: total organic carbon; TN: total nitrogen. Data values are reported as mean value ($n = 3$) ± standard error.

These composts showed similar pH values, between 7.25 and 7.88. The electrical conductivity was moderate (EC < 3 dS m^{-1}); except in sheep manure and in composts C3 and C4, for which the electrical conductivity values were higher, possibly (in the case of the composts) due to the use of manures in their elaboration [8]. The N content exceeded 2% in all composts. On the other hand, the C/N ratio showed suitable values according to reference values [9], indicating a good degree of maturity. The use of cattle manure increased the phosphorus content in composts. Composts C3 and C4 also showed higher potassium content than the rest of the organic materials, as well as higher sodium content due to the incorporation of mineral salts in the diet of ruminant cattle. The micronutrient contents were adequate, and in the case of Cu and Zn, fulfilled the Spanish legislation [10].

2.2. Analytical and Statistical Methods

Both the determinations made in the soil and the organic amendments were analyzed according to the methods used by Bustamante et al. [6,9,11]. In the case of vegetable matter, almond production, seed yield and kernel dimensions (length, width and thickness) were

studied. Kernel macronutrients (P, K, Ca and Mg) and kernel micronutrients (Fe, Cu, Mn and Zn) were detected in the nitric-perchloric digestion extract through Inductively Coupled Plasma-Mass Spectrometry (ICP-MS). C and N content was determined in a C/N macro elemental analyzer, whereas P content was determined colorimetrically [12]. Finally, different kernel quality parameters (humidity, fiber, proteins, fat, sucrose, global sucrose, palmitic C16, stearic C 18, oleic C 18 1, linoleic C18 2, cholesterol, campesterol, estigmasterol, β-sitosterol and total sterols) were determined by Near-Infrared Spectroscopy NIRS analysis using the equipment and calibrations from the Regulatory Council of Appellation of Origin Turron de Jijona.

In order to assess the overall effects of the organic amendments on soil characteristics and almond quality and production, different statistical analyses were conducted. The model used for analysis of variance of the data concerning soil parameters was the two-way repeated measures ANOVA test, considering the type of treatment and time. In the case of almond yield and production parameters and nutrient contents of kernels, the mean average values of each parameter considering both crops and areas were tested using one-way analysis of variance (ANOVA). The general linear model (GLM) was used to study the effects of the factors studied (fertilizing treatment, crop variety and type of area) on the morphological quality, organoleptic and nutritional quality of the kernel. In all cases, the Tukey-*b* post-hoc test was used to evaluate the differences between specific averages ($p < 0.05$). Data analysis was carried out using the SPSS v. 18.0 statistical software package.

3. Results and Discussion

3.1. Effect of the Treatments on Soil Properties

Different effects were observed regarding the edaphic properties, depending on the degree of stability of the amendments and, to a lesser extent, on the typology of the composts used (Table 3). The use of the organic treatments did not imply a significant variation in soil pH, except for manure, which produced a slight acidification, together with C1 compost, probably due to the limestone nature of these soils, which involves a buffer effect that avoids sudden changes in the pH with the addition of organic matter [13]. All amendments produced a significant increase in conductivity due to the incorporation of water-soluble salts, with manure standing out, with initial growth rates of up to five times, decreasing over time in all cases, although maintaining values that almost doubled those in the control treatments. In addition, soil organic amendments caused sustained increases in oxidizable organic-carbon content (from 2 to 3 g C kg soil^{-1}) and nitrogen associated with organic matter compared to the control.

The content of nitrates in the soil was also significantly increased, especially in manure, with this effect being sustained over time, possibly due to the faster mineralization of the organic matter present in this waste, being a non-stabilized material [11]. The P fraction available was higher in all the fertilized scenarios after the application compared to the unfertilized controls, with this effect being importantly attenuated over time, probably due to the extraction and reduction of bioavailability as a result of the nature of limestone and soil pH. All amendments proved to be excellent available K sources, as their levels increased at least two-fold compared to the control, and this increase was also significant for manure. Although the development of the experiment seemed to show a general decrease in the content of this macroelement, the fertilizing effect at a potassium level should be highlighted. This nutrient is usually considered very movable in the cultivable layer but it maintained significantly higher average values in the soil than the controls in both areas, which was probably associated with the design of balanced composts with waste derived from specific plant parts (fruit) that are naturally rich in K. However, the sodification effect of the amendments was low compared to the control, when compared to the potassium increase, although it was maintained at least until the end of the second crop cycle.

As shown in Table 3, the amendments affected soil biotic activity. Regarding microbial biomass C level and edaphic respiration, we also observed initially that amendments generated generalized and significant increases in these parameters with respect to the

control, as other authors observed when adding organic amendments to the soil [6,14,15]. Manure was not the most efficient treatment when activating the soil, since although it provided the maximum relative initial water-soluble C, it did not generate the highest levels of microbial biomass. Sustained effects are important, although the different composts seemed to behave similarly, perhaps highlighting C3 and C4 composts, in terms of biomass C and water-soluble C values, as the most balanced composts, considering their effect on soil biotic activity. In any case, the capacity of the composts to provide a good and lasting source of nutrients for crop and soil biological activity is, in view of the data obtained, highlighted.

Table 3. Average values of soil parameters during the experiment according to the treatment used, considering both areas.

Treatment	pH	EC (dS m^{-1})	OC (g kg^{-1})	TKN (g kg^{-1})	N-NO$_3^-$ (g kg^{-1})	P (mg kg^{-1})
Control	8.60c	0.11a	5.96a	0.80a	27a	28a
Sheep manure	8.33a	0.36e	8.24b	1.17b	81d	39c
C1	8.40b	0.20c	11.3c	1.69d	32b	45d
C2	8.61c	0.17b	8.13b	1.32c	37c	33b
C3	8.64c	0.24d	7.79b	1.22b	37c	46d
C4	8.65c	0.24d	7.81b	1.31c	29ab	43d
F-ANOVA	122 ***	256 ***	71 ***	87 ***	447 ***	114 ***

Treatment	K (g kg^{-1})	Na (g kg^{-1})	MBC (mg kg^{-1})	Soil Respiration (mg CO$_2$ kg^{-1} day^{-1})	WSC (mg kg^{-1})	qCO$_2$ (mg C-CO$_2$ g^{-1} MBC day^{-1})
Control	0.19a	0.53a	121a	113a	117a	263bc
Sheep manure	0.51b	0.61b	197b	133b	189c	252b
C1	0.87e	0.51a	275d	175d	105a	296d
C2	0.51b	0.54a	210b	148c	161b	255b
C3	0.58c	0.65b	248c	129b	176bc	176a
C4	0.66d	0.63b	242c	145c	173bc	282cd
F-ANOVA	194 ***	20 ***	78 ***	84 ***	30 ***	48 ***

C1: 60% EGM + 40% OW; C2: 60% EGM + 40% TW; C3: 60% EGM + 40% CM; C4: 60% EGM + 40% SM. EGM: exhausted wine grape marc; OW: orange juice waste; TW: tomato soup waste; CM: cattle manure; SM: sheep manure. EC: electrical conductivity; OC: oxidizable organic carbon; TKN: Total Kjeldahl nitrogen; MBC: microbial biomass carbon; WSC: water-soluble carbon; qCO$_2$: metabolic quotient or specific respiration rate. Linear mutivariate analysis of repeated measures (time-series). Signification: ns: not significant; ***: $p < 0.001$. Average values in a column followed by the same letter are not significantly different at $p < 0.05$ (Tukey-*b* test).

3.2. Effect of Treatments on Almond Yield

In the experimental design presented, two types of areas were considered because of their variety and their different agronomic management practices, in order to be able to extrapolate general effects associated with the fertilizing treatments. However, despite this, it is difficult to conclude that amendments improved production with regard to unfertilized control treatments (Table 4), showing in this case that organically managed soils presented a quite significant damping effect. This fact was as well observed by Valverde et al. [16] in an almond crop experiment in different water regimes and types of fertilization. The lack of a conventional control managed inorganically failed to allow the comparison of both types of management. In any case, it appears that the composts C2 to C4 showed comparable effects to manure regarding crop and yield, with these effects being non-significant compared to the control treatment. On the contrary, the compost made from exhausted grape marc and orange juice waste (C1) led to lower yield and production levels, probably due to this compost inducing the maximum values of nitrogen and potassium in the soil. Different studied have reported the importance of nitrogen and potassium for almond crops, since these macronutrients are required in large amounts by this crop. Thus, Muhammad et al. [17] found a decrease in the individual fruit weight and yield with increasing N application, an effect observed by other authors in other tree species, such as pistachio [18] and apple [19]. Concerning the effect of potassium, different studies [20,21]

have reported no significant influence of K fertilizers on almond fruit weight and yields, although the studies have also shown that this effect could be site-specific.

Table 4. Yield and production average values considering both areas and crops.

Treatment	Weight Almond (kg Tree^{-1})	Weight Kernel (kg Tree^{-1})	Yield [1] (%)	Average Weight Kernel (g)
Control	5.6ab	1.6ab	25.1ab	1.74ab
Manure	6.1ab	1.8ab	25.8ab	1.81ab
C1	2.8a	0.6a	22.0a	1.50a
C2	6.2ab	1.9ab	26.1b	1.99b
C3	7.5b	2.2b	25.8ab	1.94b
C4	5.6ab	1.6ab	26.1b	1.68ab
F-ANOVA	11.8 ***	3.3 *	2.8 *	4.1 *

[1] Relationship between kernel weight and full almond. C1: 60% EGM + 40% OW; C2: 60% EGM + 40% TW; C3: 60% EGM + 40% CM; C4: 60% EGM + 40% SM. EGM: exhausted wine grape marc; OW: orange juice waste; TW: tomato soup waste; CM: cattle manure; SM: sheep manure. Signification: ns: not significant; *: $p < 0.05$; ***: $p < 0.001$. Average values in a column followed by the same letter are not significantly different at $p < 0.05$ (Tukey-*b* test).

3.3. Effect of Treatments on the Quality and Nutrient Contents in the Fruit

Table 5 shows the statistical analysis of the morphological qualities of the kernels, in which a wide variability associated with the treatments (amendments, crop, area-variety-management) was observed, and this seemed to have an influence in a significant and complex way on the different scenarios, in relation to length, width and thickness. Valverde et al. [16] observed that the almond's physical properties (thickness, length, mass and width) depended fundamentally on the type of crop system. However, concerning the effect of the treatments regarding thickness as a quality parameter, compost C4 was the only treatment that significantly enhanced this parameter compared with the control treatment, with the rest of fertilizing treatments having a similar effect on thickness to the treatment without fertilization, except for compost C1 (Figure 1). Once again, compost C1 did not improve kernel productive parameters, demonstrating the importance of the validation of each compost specifically in field conditions, since improvements in the soil environment do not always imply the best yields.

Table 5. Multivariate statistical analysis regarding the morphological qualities of the kernels.

Variable	Length *F-ANOVA*	Width *F-ANOVA*	Thickness *F-ANOVA*
Fertilizing treatment	0.602ns	1.807ns	3.714 **
Crop	2.683ns	14.747 ***	405.409 ***
Farm (area-variety)	136.956c	376.819 ***	65.785 ***
Treatment × Crop	2.349 *	1.377ns	1.146ns
Treatment × Farm	3.660 **	4.100 **	0.980ns
Crop × Farm	127.535 ***	7.523 **	0.825ns
Treatment × Crop × Farm	1.038ns	1.796ns	1.539ns

Signification: ns: not significant; *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$.

Table 6 shows the incidence of the design variables (treatment, crop, plot) with respect to composition and nutritional parameters estimated using the NIRS technique in almond kernels. As can be seen, most of the estimated parameters depended more on agronomic aspects such as crop and plot (which includes both almond variety and crop management) than on the fertilizing treatments. However, Sanchez-Bel et al. [7] observed, in the Guara almond variety, a higher content of sugars and organic acids and a better quality of oil in irrigated conditions. In addition, the organic treatments produced almonds with a higher content of sugar, organic acids and fiber and a similar fat content. Askin et al. [22] reported that the content of certain fatty acids, such as palmitic, estearic, oleic and linoleic acids was influenced by the weight of the almond (without shell) and by the thickness of the shell;

therefore, the almond variety could be the factor with the highest influence with respect to the content of fatty acids. Nevertheless, the protein content, as a reflection of the content of provided nitrogen, as well as sucrose and some organic acids and sterols are affected by the existence of organic contributions and their typology. This is a fairly interesting field in ecological agriculture, since most of the added value can be based on this type of properties, determining, for example, the harvesting of other crops of interest such as the olive.
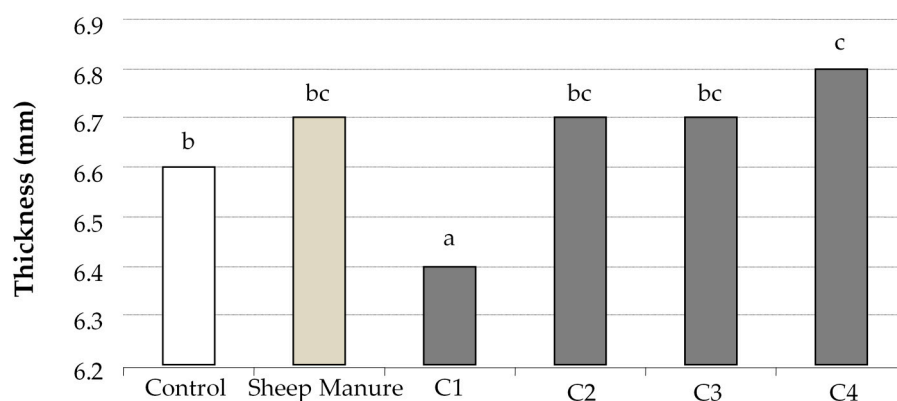
Figure 1. Effects of the treatments on the thickness of the kernel, independently of the species and plot analyzed. Mean values of each treatment followed by the same letter are not significantly different at $p < 0.05$ (Tukey-*b* test).

Table 6. Multivariate statistical analysis regarding organoleptic and nutritional quality of the kernels.

Parameter	Amendment F-ANOVA	Crop F-ANOVA	Plot F-ANOVA
Humidity	1.53ns	636 ***	18.0 ***
Fiber	1.69ns	0.47ns	567 ***
Proteins	2.53 *	0.48ns	39 ***
Fat	0.87ns	26.6 ***	194 ***
Sucrose	1.34ns	135 ***	173 ***
Global Sucrose	3.18 *	176 ***	11.8 **
C 16 Palmitic	0.84ns	321 ***	37.7 ***
C 18 Estearic	1.78ns	46 ***	21.9 ***
C 18 1 Oleic	1.97ns	1.31ns	2.14ns
C 18 2 Linoleic	2.33 *	6.25 *	8.51 **
Cholesterol	1.60ns	0.499ns	14.5 ***
Campesterol	1.66ns	1.23ns	6.27ns
Estigmasterol	2.74 *	1256 ***	22.1 ***
β-Sitosterol	0.45ns	59 ***	1.59ns
Total sterols	1.42ns	10.5 **	10.4 **

Signification: ns: not significant; *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$.

Table 7 shows the statistical analysis obtained for the organic treatment variable, considering both areas together, with a different type of almond tree variety, as well as management (irrigated and unirrigated) for both crops. It seems clear that the application of the tested organic matter sources did not encourage sustainable changes in the concentrations of C and N in kernels. However, it should be highlighted that phosphorus increased in those with organic fertilization. This fact has been stated as a usual effect in organic management [14]. These contents are probably a demonstration of the increase in available P in the soil, both because of exogenous contributions and because of an improvement in its bioavailability, depending on the forms of P in these composts. Manure is poor in K, regarding the unfertilized control, whereas most of the composts, except for compost C2, sustainably improved the K content in kernels. It is also remarkable that the content of

secondary macronutrients, such as Ca and Mg, in kernels were not affected by treatments compared to the control, probably due to the high basal contents in these soils. Fe contents in kernels were not sustainably affected, whereas other micronutrients such as Cu, Mn and Zn were higher compared to control treatments, with no substantial differences between the different composts and manure. Regarding sodium concentration, the addition of amendments did not generate an Na increase in kernels in spite of its higher concentrations in the soil (data not shown).

Table 7. Nutrient content average values in kernels, considering both areas and crops.

	C (g kg^{-1})	N (g kg^{-1})	P (g kg^{-1})	K (g kg^{-1})	Ca (g kg^{-1})	Mg (g kg^{-1})	Fe (mg kg^{-1})	Cu (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})
Control	642a	40a	5.23a	7.33a	3.4b	2.25a	37ab	13.7a	13.1a	48a
Manure	641a	39a	5.44b	7.28a	3.3ab	2.26a	36a	14.5ab	14.3b	51ab
C1	636a	44a	6.21c	8.32b	3.1a	2.33a	40b	19.3c	13.9ab	54b
C2	643a	40a	5.44b	7.45a	3.5b	2.33a	37ab	16.2b	14.8b	51ab
C3	639a	39a	5.35ab	7.54b	3.5b	2.35a	35a	15.0ab	14.7b	53b
C4	637a	40a	5.47b	7.54b	3.5b	2.37a	36a	14.9ab	14.3b	53b
F-ANOVA	1.2ns	0.48ns	3.43 **	3.30 **	2.20ns	2.69 *	5.6 ***	0.50ns	1.76ns	5.2 ***

Signification: ns: not significant; *: $p< 0.05$; **: $p < 0.01$; ***: $p < 0.001$. Average values in a column followed by the same letter are not significantly different at $p < 0.05$ (Tukey-*b* test).

4. Conclusions

The results obtained from the application of agri-food composts in two almond production areas under organic farming management during two crop seasons have shown that these composts improved the soil characteristics in both areas, increasing the nutrient content and enhancing the biotic activity, with lower increases in soil salinity and nitrate content than the traditional treatment based on sheep manure. In addition, all the composts, except C1 (constituted by exhausted grape marc and orange juice waste), showed similar fruit yields and production average values to those of the traditional treatment (sheep manure). Moreover, the organic treatments produced almonds with a higher content of sugars, organic acids and fiber and a similar fat content, indicating additional positive effects of organic management agricultural practices on the organoleptic characteristics of almonds.

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