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Review

Effects of Pruning Mulch on Nutrient Concentration of Avocado (*Persea americana* Mill.) Fruit under Subtropical Conditions

Antonio Aguirre-Arcos [1], Minerva García-Carmona [2], Marino Pedro Reyes-Martín [1], Layla M. San-Emeterio [3], Emilia Fernández-Ondoño [1,*] and Irene Ortiz-Bernad [1]

1 Department of Soil Science and Agricultural Chemistry, University of Granada, Av. de Fuente Nueva s/n, 18071 Granada, Spain
2 Department of Agrochemistry and Environment, Miguel Hernández University, Av. de la Universidad s/n, 03202 Elche, Spain
3 Department of Biogeochemistry and Plant and Microbial Ecology, Institute of Natural Resources and Agrobiology (IRNAS), Av. Reina Mercedes 10, 41012 Seville, Spain
* Correspondence: efernand@ugr.es

Abstract: In this study, avocados of the Hass variety cultivated in Almuñécar (Granada, Spain) are analyzed after soil mulching with pruning debris. The mulch treatment assay was composed of pruning wastes from subtropical crops (avocado, cherimoya, and mango) and garden wastes from the surrounding areas. The aim of this work is to analyze the nutrient content in avocado fruit and the effect of pruning-waste mulching on fruit development over four years. Avocado fruits collected in 2013, 2016, and 2017 were weighed, their volume and their sugar content were calculated, and macro- and micronutrients were analyzed in the peel, pulp, and stone (endocarp and seed). The pulp contained the highest concentration of nutrients, especially Cu, Zn, P, Na, and Ca. The peel presented high concentrations of Mn, K, and N, while the stone recorded the lowest values in nutrients, with the greatest decreases in years with the lowest precipitations registered. Over the study period, a decline was detected in the nutrient concentrations related to the alternation of high and low yields, typical of this crop, due to environmental factors. In the years 2016 and 2017, avocados accumulated higher amounts of micronutrients and P, presumably because of greater water availability in the soil. During the study period, the application of pruning wastes did not affect the nutrient concentration of fruits except for the garden pruning waste in certain elements in the pulp during the last study year.

Keywords: crop; endocarp; macronutrients; micronutrients; mulching; peel; pruning waste; pulp; stone

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1. Introduction

The Hass variety of avocado (*Persea americana* Mill. var. Hass) constitutes one of the most ubiquitous orchards in South and Central America. Mexico alone accounts for 38% of world production, whereas Spain represents approximately 1.4% of global production, ranking 17th in the world [1]. This subtropical orchard crop has spread throughout the world [2], and, currently, avocado is grown with other tropical and subtropical species in the Iberian Peninsula, such as cherimoya (*Annona cherimola* Mill.), mango (*Mangifera indica* L.), and papaya (*Carica papaya* L.). The Spanish production has especially relied on the southern Spanish subtropical coast, comprising the provinces of Granada and Malaga [3]. Given the steep topography, orchards are grown mainly on terraces, a practice that reduces the planting density and the average yield to approximately 30 kg tree^{-1}, which leads to an average fresh fruit yield of 8 t ha^{-1} in the most frequent densities [4].

Among the factors that may determine fruit development, the availability of nutrients in the soil can significantly affect the distribution of nutrients in the different fruit parts: peel, pulp, and stone [5]. Additionally, climatic conditions such as temperature can have an impact on sugar content [6]. This is particularly relevant for the southern coast of Spain, where temperatures can reach critical values for avocado orchards during the summer season (above 40 °C in the months of July and August [7]). Silber et al. [5] indicated that the processes of alternate bearing and fruit abscission are related to nutrient availability and climatic stress periods, whereby yield can vary from 40 to 10 t ha^{-1} [8,9].

Subtropical orchards produce great amounts of organic waste every year. Since the avocado is consumed fresh, the peel and stone are discarded and would be difficult to reuse; this is also true for its crop pruning wastes [10,11]. This may represent a major environmental concern in areas where the orchards are gathered, making proper management necessary as the waste is not always entirely recycled.

However, these unused parts have been found to be commonly used for oil and other products, especially in countries that are major producers, such as Mexico. In these farms, these bioresources could be used. The feasible uses of parts of the fruit include thermal energy [12], and multiple applications in the pharmaceutical, chemical, and cosmetic industries [13], thanks to their richness in different bioactive compounds [14]. Several authors have highlighted the suitability of using these fruit parts as a source of enriched phenolic extracts with high antioxidant properties [15] or as a useful source of inexpensive natural components [16,17], providing proteins (3–9 wt%), carbohydrates (43–85 wt%), lipids (2–9 wt%), and minerals (2–6 wt%) [13]. Alternatively, avocado seeds can serve as additives in the food industry [2] and the peel as a substitute for activated carbon in the restoration of polluted water [18]. Lastly, the potential of avocado by-products has also been acknowledged by other avocado-producing countries, such as Chile, according to a review about their bioactive compounds and health benefits that was recently published [19].

Additionally, the recycling of organic pruning wastes [20,21], as well as unusable fruit parts [22], may constitute a sustainable agricultural practice that can help reduce CO_2 emissions and improve soil quality. Recycling can also be extended to other organic residues, for example, those from garden maintenance, as a solution to the progressive loss of soil nutrients. Several authors have analyzed litter mineralization and nutrient release in various climates: tropical and subtropical [23–25], semi-arid [26], and Mediterranean [20,27,28]. In olive groves, Sofo et al. [29] indicated the fundamental role of pruning wastes in carbon sequestration; moreover, Nieto et al. [30] reported an significant increase in organic carbon content in the first 30 cm of soils after 6 to 10 years of continuous application of organic mulch.

Although it has been widely reported that the spreading of pruning wastes can result in a higher concentration of nutrients in soils, data are lacking on how the application of organic residues composed of pruning wastes from subtropical crops (avocado, cherimoya, and mango, in addition to garden wastes) ultimately affects the avocado fruit nutritionally in the short to medium term. In order to understand how the nutrients are distributed in avocado fruit and the suitability of the agricultural practice of mulching in avocado crops, the aim of this study is to analyze the effect that the mulching of pruning wastes has over time (four years of study) on the development of avocado fruit. The monitoring of avocados was in terms of their physical properties (weight, volume), sugar content, and the macro- and micronutrient contents within the different fruit parts: peel, pulp, and stone (seed plus endocarp). Given the marked differences in the pruning waste composition, we hypothesize that the nutrient content of different parts of the fruit improves when a sustainable agricultural practice such as mulching, comprising diverse organic wastes, is applied under subtropical climates. This work offers an evaluation of the properties of the fruit grown on the southern Spanish subtropical coast both for human consumption, as well as the possible use of the disposable parts for the food industry and as a soil amendment.

2. Materials and Methods

2.1. Study Area Location

The study was conducted on the experimental farm "El Zahor" (36°45′54.2″ N, 3°39′55.0″ W, 235 m a.s.l.), about 7 km away from the municipality of Almuñécar, on the subtropical coast of Granada (southern Spain). The experiment was made on avocado trees (*Persea americana* Mill.) of the Hass variety, growing in soil developed on weathered schists of low carbonation, classified as Eutric Escalic Anthrosol [31] with variable slopes (30–60%). The soil is characterized by 1% of organic carbon and 0.1% of N content in the first 5 cm of soil depth, pH around 8, and a loam soil texture with 9.8%, 39.8%, and 50.4% of clay, silt, and sand, respectively.

The subtropical Mediterranean microclimate in the area registered an average temperature during the study period (2013 to July 2017) of 17.6 °C, average relative humidity of 73.5% (73.3% in summer and 69.3% in winter), and accumulated rainfall of 1290.6 mm (484.6 mm in 2012–2013, 451.8 mm in 2015–2016, and 354.2 mm in 2016–2017), although the evapotranspiration for the same period was 3289.2 mm. During the study period, the average monthly temperature did not exceed 30.5 °C or reach freezing (minimum temperature 6.9 °C). Data for the weather during fruit development over the study period is presented in Figure 1 (climatic data collected from the Almuñécar meteorological station of the IFAPA Research Field Station, located on the experimental farm).

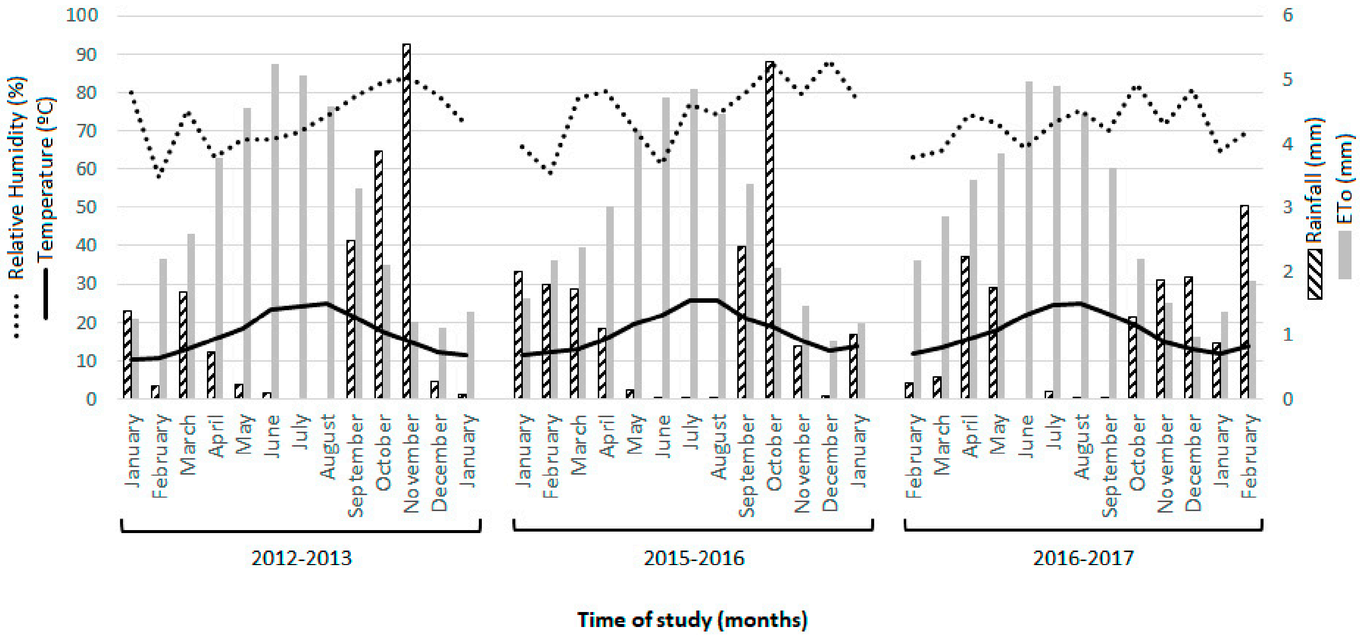

Figure 1. Relative humidity, temperature (left *Y*-axis), and rainfall reference evapotranspiration (eTo) (right *Y*-axis) averages per month during the study periods.

Avocado orchards were cultivated on terraces roughly 160–170 × 2–3 m with a northern orientation. The trees were 3–5 m high, planted at a density of approximately 300 trees ha^{-1}. Drip irrigation was applied to each tree daily during summer and autumn and every other day in winter and spring. Monthly irrigation doses applied per tree were 960 L per month from December to May, increasing to 2240 L between June and November. Nutrients were applied by fertigation in March, June, and September: N, P, and K, ammonium phosphate (for blossoms in February), potassium nitrate, ammonium, and chelated Fe, Zn, and B. Weeds were controlled using a string trimmer, and soils were not tilled. According to data from the Andalusian Regional Government [32], during the study period, avocado production was 6.5, 7.3, 7.6, and 8.3 t ha^{-1} in 2013, 2014, 2015, and 2016, respectively.

2.2. Sampling Design

Five terraces with avocado trees were selected for the experiment. Treatments consisting of pruning remains (branches and leaves) from the annual maintenance pruning of three subtropical orchards (avocado, cherimoya, and mango) in the same area were spread as mulch in each plot, according to the treatment, together with organic waste from surrounding garden areas, for a total of four treatments. Garden waste was mainly composed of the ornamental species palm (*Washingtonia robusta*), rubber plant (*Ficus elastica*), and lantana (*Lantana camara*). The concentration of nutrients on the mulch material is depicted in Table S1. Moreover, a more detailed characterization of the pruning is detailed in [20].

Each type of pruning waste was shredded and mixed into a homogeneous composition. The resulting particle size was between roughly 2 and 30 mm. Each type of pruning debris was separately applied every year in four replicates along the different terraces, following the scheme shown in Figure 2. Each replicate comprised the spread of mulch under two pairs of trees (leaving one tree without treatment in between), for a total of 8 trees for each type of pruning waste (avocado, cherimoya, mango, and garden). In addition, another 8 trees were used as a control without any pruning applied, making a total of 40 avocado trees. For each pair of trees, the avocado, cherimoya, mango, and garden mulch treatments contained approximately 24 kg of avocado pruning waste, 12 kg of cherimoya pruning waste, 6 kg of mango pruning waste, and 12 kg of garden waste, respectively. All pruning wastes were spread as a mulch over the soil surface under the tree canopy, covering a total soil surface of 4 × 8 m in a homogeneous cover. A factorial design was used as the sampling design.

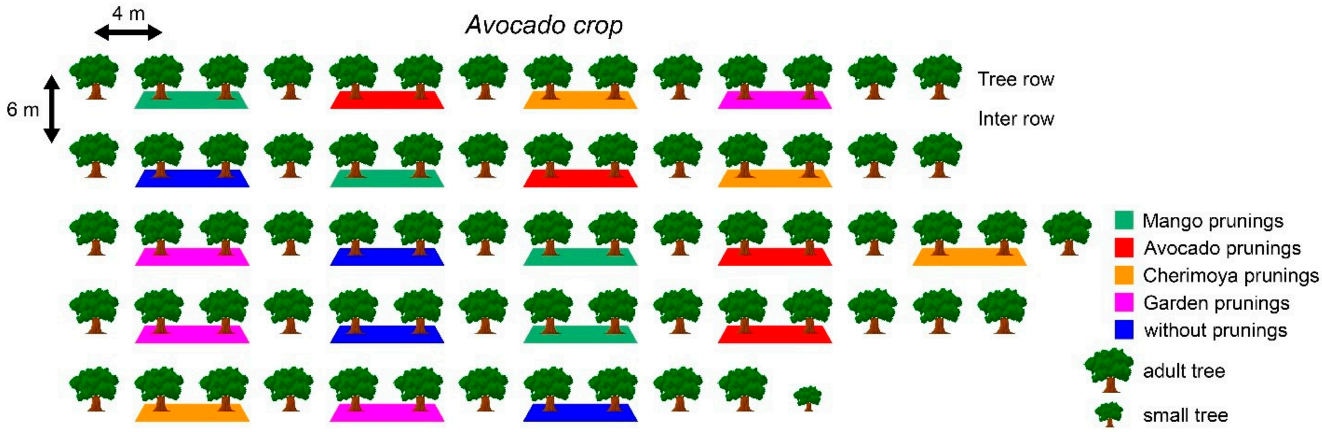

Figure 2. Distribution scheme of the pruning and garden waste in the avocado crop.

The experiment started in July 2012 with the first application of mulch; this was conducted every year during the study period (4.5 years). Fruit sampling was conducted at three different times: in January 2013, January 2016, and February 2017. A total of two fruits were randomly collected from each tree from the same treatment, making a total of 16 fruits per treatment, for a total of 80 fruits per year, 240 in total at the end of the experimental study. The average annual avocado fruit production during the experiment was between 100 and 120 kg tree^{-1}.

2.3. Sample Preparation and Analysis

All fruits collected were weighed, and their volume and size were measured. Afterwards, each fruit was separated into the peel, pulp, and stone (seed plus endocarp). Soluble solid content was determined from the pulp using the refractometric method, the most common measure of sweetness in fruits [33], and a digital refractometer (Atago Co., PR-1 Brix-Meter, Tokyo, Japan), hereafter referred to as "sugar content" in fruits, expressed in percentage. Each fruit part was dried at 65 °C for 48 h in a hot-air oven (Digitronic-TFT, Selecta, Barcelona, Spain), and the weights before and after drying were compared to calculate the water content.

After being dried, fruit parts were milled (IKA Werke M20) and then mineralized by acid digestion in a microwave (Model XP150 Plus Mars) in a solution of HNO_3 and H_2O_2 in a 1:1 proportion (5 mL). Products from acid digestion were filtered. Macro- and micronutrients (K, Na, Ca, Mg, Fe, Cu, Mn, Zn) were analyzed using an atomic absorption spectrometer (SpectrAA 220 FS Varian) for an aliquot of the acid digestion. The P content was determined according to Olsen et al. [34] and determined by a UV/visible spectrophotometer (Thermo Helios Alpha UV/Vis Spectrophotometer, Thermo Fisher Scientific, Waltham, MA, USA). The total contents of N and C were determined by dry combustion using a TruSpec LECO carbon analyzer (LECO Corporation, St. Joseph, MI, USA).

2.4. Statistical Analysis

All statistical analyses were performed in rStudio v.3.6.2 [35] using the packages "agricolae" and "FactoMineR" [36,37]. Normality and homoscedasticity were checked prior to all the analyses using the Kolmogorov–Smirnov test and Levene's test, respectively. For cases not meeting the normality or homogeneity requirements, the data were transformed to assume statistical parametric assumptions. In order to study the effects on fruit parameters and the nutrient content of the mulching treatments applied to soils (pruning wastes from avocado, cherimoya, mango, garden, and control without application) and the distribution of the different parts of the fruit (peel, pulp, and stone), two-way ANOVA was performed. Significant differences among the parts (peel, pulp, and stone) in each year of the study (2013, 2016, 2017) were estimated with ANOVA, followed by multiple comparisons with Tukey's test ($p < 0.05$); the same tests were applied to study the differences between the years of the study for each part of the fruit. To test the relationship between nutrients in relation to the different study years, principal component analysis (PCA) was applied.

3. Results

The results for the variables (weight, volume, and sugar content) analyzed in the avocado fruits indicated remarkable changes over the years (Figure 3). Both the weight and volume of the fruits followed the same trend, with significantly higher values in the fruits of 2016. On the contrary, sugar content showed the opposite trend, with lower content in 2016 (9.3 ± 2.7%) and the highest content during the first year of study (14.3 ± 2.7%). No significant effect due to the mulching treatment was detected in any of the variables measured in the avocado fruits ($p > 0.05$).

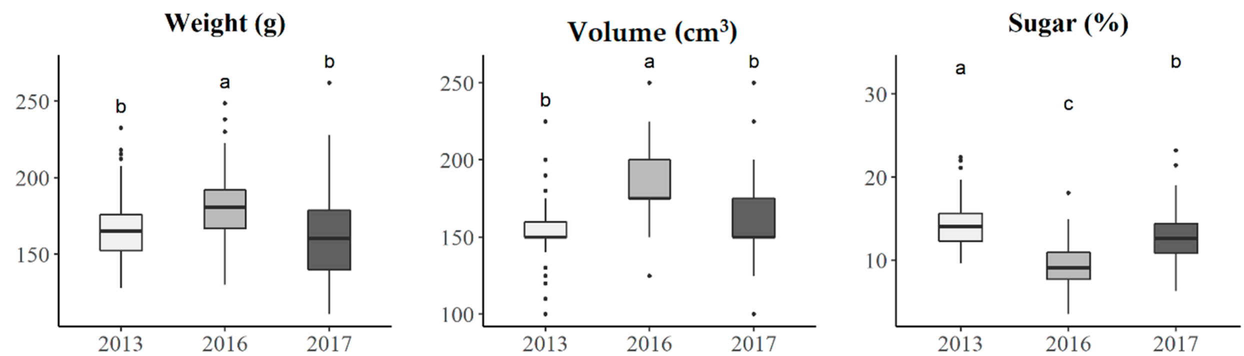

Figure 3. Fruit parameters (weight, volume, and sugar content) measured in the three study years (2013, 2016, and 2017). All treatments are considered. Lowercase letters represent significant differences among the study years (Tukey's test $p < 0.05$).

Regarding the nutrient content in the fruits, a significant effect of the year of study was found in the distribution of all nutrients analyzed in each part of the avocado fruit (peel, pulp, and stone; Table 1). The most abundant element was K in all three parts of the fruit. Nutrient pools of K, Na, Ca, Mg, Zn, and N (in mg per 100 g^{-1}) decreased significantly in the three parts of the fruit over time during the experiment. The micronutrients under study (Fe, Cu, Mn, and Zn) followed a trend similar to that of the macronutrients, except in certain cases. Fe in the pulp decreased in 2016 but increased in 2017, reaching values similar to those in 2013. Cu reached the highest values in 2016 for the three parts of the fruit and then declined in 2017 to values similar to those in the peel in 2013 but was still higher than the values in the pulp and stone in 2013. In the stone, Mn decreased during the experiment, while the content in the peel and pulp slightly increased in 2017 compared to 2016, although the values were still lower than in 2013.

Table 1. Distribution of the nutrient content (mean values and standard deviation) in mg per 100 g of fruit (DM, dry matter) and in g per 100 g for C and N (DM) in each of the three sampling years (2013, 2016, and 2017) for the three parts of the avocado fruit (peel, pulp, and stone). Lowercase letters indicate for each nutrient individually the differences among the fruit parts (peel vs. pulp vs. stone) per each year separately, and uppercase letters indicate for each nutrient the significant differences among the years of study (2013 vs. 2016 vs. 2017) for the same part of the fruit separately (post-hoc Tukey's test $p < 0.05$). Two-way ANOVA p-values for the part of the fruit and the treatments applied are shown at * $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$; n.s. means not significant at $p < 0.05$.

Year		Peel	Pulp	Stone	Two-Way ANOVA (*p*-Values)		
					Part	Treatment	Part:Treat.
2013							
	Fe	5.92 Cc ± 0.67	5.24 Bb ± 0.57	3.68 Ba ± 0.35	<0.001 ***	n.s.	n.s.
	Cu	0.56 Aa ± 0.06	0.97 Bb ± 0.11	0.54 Aa ± 0.07	<0.001 ***	n.s.	n.s.
	Mn	0.86 Bc ± 0.10	0.70 Ba ± 0.10	0.79 Cb ± 0.10	<0.001 ***	n.s.	n.s.
	Zn	0.95 Ba ± 0.11	1.40 Bc ± 0.23	1.03 Cb ± 0.11	<0.001 ***	0.048 *	n.s.
	P	236 Cb ± 62	269 Bc ± 62	204 Ba ± 60	<0.001 ***	n.s.	n.s.
	K	4136 Cc ± 398	3318 Cb ± 412	1957 Ca ± 258	<0.001 ***	n.s.	n.s.
	Na	157 Ca ± 21	198 Cb ± 21	162 Ca ± 16	<0.001 ***	n.s.	n.s.
	Ca	197 Cb ± 23	185 Cb ± 20	180 Ca ± 24	<0.001 ***	n.s.	n.s.
	Mg	200 Bb ± 18	235 Cc ± 27	187 Ca ± 20	<0.001 ***	n.s.	n.s.
	C	5.07 Bb ± 0.20	6.58 Bc ± 0.35	4.58 Ca ± 0.16	<0.001 ***	n.s.	n.s.
	N	0.11 Bc ± 0.01	0.09 Cb ± 0.02	0.07 Ca ± 0.01	<0.001 ***	0.026 *	n.s.
2016							
	Fe	3.60 Ab ± 1.55	2.78 Aa ± 1.92	4.06 Bb ± 1.55	<0.001 ***	n.s.	n.s.
	Cu	0.78 Ca ± 0.23	1.40 Cb ± 0.45	0.83 Ca ± 0.26	<0.001 ***	0.014 *	n.s.
	Mn	0.6 Aa ± 0.17	0.5 Aa ± 0.21	0.60 Ba ± 0.29	n.s.	n.s.	n.s.
	Zn	1.23 Cb ± 0.53	1.43 Bc ± 0.48	0.76 Ba ± 0.29	<0.001 ***	n.s.	n.s.
	P	179 Bb ± 47	240 Ac ± 40	151 Aa ± 32	<0.001 ***	n.s.	n.s.
	K	1610 Bb ± 364	1667 Bb ± 313	905 Ba ± 201	<0.001 ***	n.s.	n.s.
	Na	58.92 Bab ± 43.24	72.08 Bb ± 51.75	47.52 Ba ± 44.66	0.005 **	n.s.	n.s.
	Ca	106 Ba ± 29	126 Bb ± 32	105 Ba ± 40	<0.001 ***	n.s.	n.s.
	Mg	93.25 Ab ± 14.59	102 Bc ± 12	82.45 Ba ± 18.35	<0.001 ***	n.s.	n.s.
	C	5.25 Cb ± 0.11	6.42 Ac ± 0.14	4.40 Ba ± 0.16	<0.001 ***	n.s.	n.s.
	N	0.07 Ab ± 0.01	0.07 Bb ± 0.01	0.04 Ba ± 0.01	<0.001 ***	n.s.	n.s.
2017							
	Fe	4.42 Bb ± 2.34	6.18 Cc ± 3.42	2.67 Aa ± 0.88	<0.001 ***	0.046 *	0.013 *
	Cu	0.63 Ba ± 0.21	0.77 Ab ± 0.24	0.71 Bb ± 0.19	<0.001 ***	0.047 *	n.s.
	Mn	0.81 Bc ± 0.26	0.66 aBb ± 0.28	0.47 Aa ± 0.19	<0.001 ***	0.013 *	n.s.
	Zn	0.78 Ab ± 0.26	0.87 Ab ± 0.40	0.49 Aa ± 0.11	<0.001 ***	n.s.	n.s.
	P	135 Aa ± 22	252 Bab ± 42	141 Aa ± 16	<0.001 ***	n.s.	n.s.
	K	1327 Ab ± 301	1399 Ab ± 472	710 Aa ± 117	<0.001 ***	n.s.	n.s.
	Na	15.35 Aa ± 11.97	51.78 Ab ± 26.98	20.75 Aa ± 7.18	<0.001 ***	n.s.	n.s.
	Ca	64.01 Ab ± 27.29	97.67 Ac ± 22.78	38.81 Aa ± 15.50	<0.001 ***	0.040 *	n.s.
	Mg	93.76 Ab ± 17.66	67.57 Aa ± 14.40	67.47 Aa ± 15.75	<0.001 ***	n.s.	n.s.
	C	4.90 Ab ± 0.08	6.67 Bc ± 0.26	4.25 Aa ± 0.11	<0.001 ***	n.s.	n.s.
	N	0.06 Ac ± 0.01	0.06 Ab ± 0.01	0.03 Aa ± 0.01	<0.001 ***	n.s.	n.s.

The pruning-waste treatments had a negligible effect on the nutrient distribution in the different parts of the avocado fruits (Table 1). A significant effect related to the treatments was found for Zn and N in 2013, for Cu in 2016, and for the micronutrients Fe, Cu, Mn, and Ca in 2017. However, a subsequent analysis comparing the different treatments with the controls (without mulching) demonstrated no effects on the nutrient content due to the treatment (Table S1). The only exception was the Mn content in 2017, when the garden waste resulted in a higher content of this element in the pulp (increasing from 6 to 8.4 mg kg $^{-1}$; for more information, see Supporting Materials, Table S2).

The PCA performed on all the nutrients analyzed in the three parts of the avocado fruits showed marked differences between the nutrients in avocados from 2013 compared to those from 2016 and 2017, the latter two forming a cluster (Figure 4). The explanatory variables of the fruits in 2013 (N, Ca, K, Mg, and Na) differed from those of 2017 fruits and were related to the content of C, P, and micronutrients. The same trend was observed when the data from the peel, pulp, and stone were studied separately, the peel and pulp being the parts where most nutrients accumulated (see Supporting Materials, Figure S1).

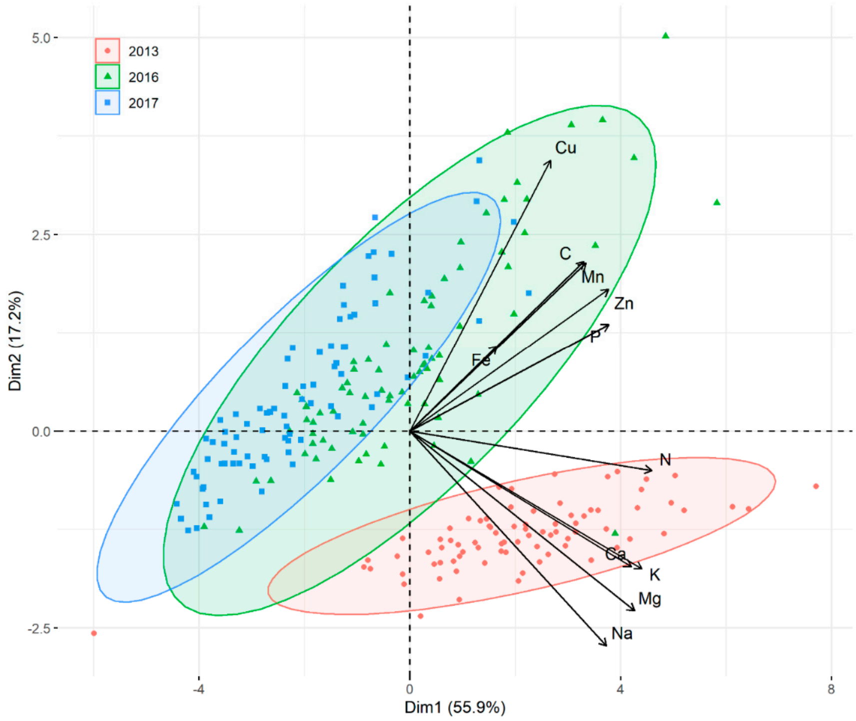

Figure 4. Scores and loadings for PCA performed for the distribution of nutrient contents for the three study years (2013, 2016, and 2017), corresponding to the total element content in the avocado fruit.

4. Discussion

The concentration of nutrients in plants and fruits is sensitive to changes in the cultivation area, water availability, and crop management [38–40]. Additionally, the quality and resistance to bruising of fruit are affected by cultivation practices [41]. The variations in fruit size of avocados over the different study years in subtropical Spain, specifically, the greater weight and volume found in the avocado fruits in 2016, did not appear to be related to the addition of the different pruning mulches but rather to environmental and climatic conditions. These variations could be due to the process of periodic alternation in fruiting abundance expressed by avocado, as predicted in previous studies [8,9,42], together with the increase in soil water content (data not shown) due to higher precipitation and lower eTo in the study area during the period 2015–2016. According to Cowan and Wolstenholme [43], the environmental factors that most affect avocado fruit production are solar radiation, water stress, temperature, and salinity; thus, these were determined in the avocados studied in the present work.

Since the content of sugar has been found to be related to environmental factors as well, the lowest values found in 2016 can be explained by a dilution effect of the sugars compared to the increasing volume and weight of the fruits because of lower water stress. The high solar radiation to which the orchard is exposed has been correlated with greater sweetness of the fruits in cases such as grape and apple [6], and this could also apply to avocado. In citrus, it has been confirmed that greater water stress results in a higher concentration of sugars due to the loss of water in the fruit cells [44]. The greater solar radiation and water loss undergone by our experimental avocados in the periods 2012–2013 and 2016–2017 appear in Figure 1, presenting mean eTo values that are somewhat higher than those of the period 2015–2016, giving rise to fruits of smaller size but with greater sugar content.

In regard to nutrient dynamics, generally, it was found that nutrient concentrations decreased over the years. As mentioned earlier, this may be due to climatic stresses mainly [5]. The peel and the pulp were the fruit parts with the highest accumulation of nutrients, in contrast to findings of Tamayo et al. [45], who reported higher Ca, Mg, N, and micronutrient concentrations in the endocarp of avocado, with P and K accumulating in the pulp. It was also found that the peel and the pulp contained the highest proportion of the macro- and micronutrients except for Fe and Mn in 2016. This discordance could be due primarily to edapho-climatic differences between the studies compared. Moreover, the stone proved to have far lower values than those reported by Tamayo et al. [45] in all the elements, perhaps because these authors separated the endocarp from the seed, whereas we did not, thereby diluting the values by comparison, apart from the conditions mentioned above. Despite its lower proportion of nutrients compared with the other fruit parts, the stone presents a good concentration of nutrients, supporting the foreseen idea of its application as a supplement in the food industry [2] and even as an organic soil amendment, together with the peel, after being treated. This nutrient richness analysis supports the observation by González-Fernández et al. [22], which led to the application of these wastes, combined with bird manure and garden pruning debris, to improve the germination and growth of avocado trees.

The distribution of nutrients by year reflected the differences between 2016 and 2017. Both years showed higher concentrations of the micronutrients Fe, Cu, Mn, and Zn and the same for certain macronutrients, primarily C and P. Meanwhile, in 2013, all the macronutrients were highly accumulated, regardless of the part of the avocado, including K, Na, Mg, Ca, and N. This difference in the nutrient profile may be related to more frequent rainfall events and lower evapotranspiration, especially during 2016, hence the higher soil water availability. This may have favored better availability of micronutrients and P to the plant. Such a scenario is supported by the fact that frequent irrigation provides more availability of the elements that are generally less available in the soil, such as P and micronutrients [8].

Comparing the nutrient concentration in the avocado pulp indicates a greater proportion of nutrients compared to those found in other studies [3,40,46] (Table 2). This could be explained by the expressed units of our data, which are related to dry weight instead of wet weight. Data related to wet weight varied from 55% to 70%, which would explain the greater nutrient content in the dry samples. This was confirmed by comparing our data with those of Tamayo et al. [45], who worked with dry weight. In comparison with this latter study, our avocados presented higher Cu, K, and Ca concentrations and lower Fe, Mn, Zn, P, and Mg. This was presumably due to the differences between the two studies in edapho-climatic conditions, water availability, and crop management [38–40,47].

Finally, the effect of pruning waste on the macro- and micronutrients in the different portions was generally found to be of no significance except in some cases, such as Mn of the garden debris in the pulp of 2017. As stated by Reyes-Martín et al. [20], the garden waste presented lower C:N and lignin:N ratios; hence, its decomposition proved more rapid. This could explain the differences observed in the Mn concentrations, although long-term studies on the release of Mn and other elements are needed to confirm the results. Similar results were found by Reyes-Martín et al. [48] in the same experimental farm, reporting that in the avocado crops, the nutrient release from pruning waste was slow, especially in the micronutrients, and that, in some cases, the concentrations of elements such as N at first increased. The other elements were gradually released in such small amounts that the needs of the trees were not satisfied. In relation to the type of waste applied, Reyes-Martín et al. [48] found higher release rates of nutrients in the garden waste, although the amounts remained insufficient for the crop. Nevertheless, long-term studies could assess these changes in soil properties, as reported by several authors in regard to the application of pruning debris [24,30,49,50].

Table 2. Comparative table of the nutrient concentrations measured in the pulp of the avocado fruits in different studies. Values are expressed in mg 100 g^{-1}, mg kg^{-1}, and % (DW = dry weight, FW = fresh weight, n.d. = no data).

		Fe	Cu	Mn	Zn	P	K	Na	Ca	Mg
Our results (Almuñécar, Spain)	mg kg^{-1} $\%_{(DW)}$	61.80 mg kg^{-1}	7.70 mg kg^{-1}	6.60 mg kg^{-1}	8.70 mg kg^{-1}	0.25%	1.40%	0.52%	0.098%	0.068%
	mg 100 g^{-1} $_{(DW)}$	6.18	0.77	0.66	0.87	252	1399	51.78	97.67	67.57
Granada/Málaga, Spain [3]	mg 100 g^{-1} $_{(FW)}$	n.d.	n.d.	n.d.	n.d.	14	296	3.70	6.80	n.d.
United States [43]	mg 100 g^{-1} $_{(FW)}$	0.61	0.17	0.15	0.68	54	507	8	13	29
Florida, United States [37]	mg 100 g^{-1} $_{(FW)}$	0.17	0.31	0.10	0.40	40	371	2	10	24
Antioquía, Colombia [42]	mg kg^{-1} $\%_{(DW)}$	89.90 mg kg^{-1}	6.60 mg kg^{-1}	16.30 mg kg^{-1}	22.50 mg kg^{-1}	0.29%	1.21%	n.d.	0.048%	0.12%

5. Conclusions

The alternate bearing process and climatic characteristics (precipitation, temperature, and other variables) seem to be driving factors in the change in size and weight of avocado fruit in subtropical avocado crops in southern Spain. Differences in climate conditions, which often have a noticeable effect on the availability of micronutrients and K for plants, affect the overall nutritional composition of different parts of the avocado fruit.

Pruning wastes do not alter the macro- or micronutrient contents of the avocado fruit due to the low decomposition rate and nutrient contribution, conditioned by the microclimatic conditions and biochemical composition of each pruning. The Mn content in pulp was the only parameter that significantly changed its dynamics under garden pruning; however, it cannot be affirmed with certainty that the changes reported were due to the mulching, given the short study period.

The application of pruning wastes could be a feasible, alternative beneficial practice for crops for human consumption, with the positive economic implications that this has for local agriculture.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/horticulturae8090848/s1, Figure S1: Scores and loadings for PCA performed for distribution of nutrient content among the three years of study (2013, 2016, 2017) for the total element content in the avocado fruit in each part of the fruit, peel, pulp and seed.; Table S1: Mean values of the initial nutrient composition in the bagged pruning and garden waste. Data not sharing a common letter are statistically different in nutrient content (Tukey's test, $p < 0.05$). Standard deviation in brackets.; Table S2: Distribution of the nutrient content (mean values and standard deviation, sd) in mg per 100 g of fruit (DM, dry matter), and in g per 100 g for C and N (DM) in each of the three sampling years (2013, 2016, and 2017) and the three parts of the avocado fruits (peel, pulp, and seed) for the dif-ferent treatment of pruning waste application. Lowercase letters represent significant differences among the years of study (Tukey test $p < 0.05$). ANOVA p values results for the effects of treatments application at $p < 0.05$ *, $p < 0.01$ ** and $p < 0.001$ *** n.s. not significant at a $p < 0.05$.

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