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Mineralization of bagged pruning waste in agrosystem on the subtropical coast of Andalusia (Spain)

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Abstract

Spreading of pruning waste over the soil surface may increase soil organic carbon, thus improving soil physical properties and serving as a source of nutrients and energy for microbial populations. The aim of this study was to test the effect of the environmental conditions and the biochemical composition of pruning waste from avocado, cherimoya, mango and gardens on their decomposition process in a Mediterranean subtropical climate. Bagged pruning and garden waste were placed on the ground at a distance of 1 m around the trunk of the three trees from each crop. The concentrations in C, N, lignin, cellulose, hemicellulose, other extracts and ash were determined at the beginning of the experiment (T0), after six (T6) and 24 (T24) months in the field. Initially, significant differences were detected for all types of waste, especially in lignin, hemicellulose, cellulose and other extracts. No significant differences were found in the N content and the C content in mango pruning waste was significantly lower than that in avocado. The greatest weight loss recorded at T24 (63.2%) was related to the lower content in lignin, cellulose and other extracts. Weight losses and C concentrations showed negative correlations with lignin content. Despite the intense decomposition of all the waste, between 55 and 36.8% of the original weights were recorded at the end of the experiment. Recalcitrant C could be the result of the lignin concentrating in the case of the garden waste applied to the different crops.

Introduction

The 21st Conference of the Parties to the United Nations Framework Convention on Climate Change in Paris (cop21/unfccc, 2015) launched the '4 per 1000' initiative, presented by the French delegation and supported by the majority of the formed assembly. This initiative aimed to mitigate climate change, which among other measures, proposes to implement practical sustainable techniques in agricultural soils in order to increase soil organic carbon sequestration accompanied by a significant reduction of CO_2 concentration in the atmosphere.

The increase of soil organic carbon depends on diverse factors, firstly the addition of organic matter. One of the most suitable types are those from the crop itself, e.g. pruning waste (Coppens *et al*., 2007). Pruning waste has traditionally been burned, resulting in greater carbon emissions to the atmosphere as CO_2. Besides, this practice has been linked with nutrients leaching from soil, removing macronutrients and micronutrients from the environment. Following the proper management of pruning waste from tree crops, we can contribute to climate-change mitigation and carbon sequestration, besides eliminating large amounts of organic waste (López *et al*., 2014).

Smith (2008) estimated that the carbon sequestration potential for agricultural activities in European soils ranged between 0.3 and 0.8 t C/ha/year. However, climate conditions within Mediterranean area increase carbon sequestration potential in this zone (Vleeshouwers and Verhagen, 2002), as higher precipitation periods coincide with the coldest periods. This can decrease the activity of soil microorganisms, reducing mineralization processes. De Santo *et al*. (1993) pointed out that in the dry Mediterranean climate the limiting effect of low water contents in the litter and soil can be expected to be more pronounced than that in more moist north-European climates. Moreover, many exceptions arise as small climate variations, e.g. subtropical Mediterranean climate from southern Europe coastal zones (Granada, Málaga and Almería) promote the growth of subtropical orchards with singular characteristics. Subtropical crops within this area (avocado, cherimoya and mango) produce large amounts of pruning waste, approximately 40 kg per tree and year in avocado, 25 kg per tree and year in cherimoya, and 10 kg per tree and year in mango, which can favour the emission of CO_2

including their burning. Being shredded and applied in the soil surface, these pruning waste can improve soil quality and have a great impact on C storage, and therefore on the internationally recognized '4 per mil' Initiative concerning climate-change mitigation.

Garden areas are widely common from residential and/or tourist zones along the southern Spanish coastal zone, and as described elsewhere, pruning waste from forest or garden areas contributes to these large amounts of organic/vegetable waste, emphasizing the environmental problems described above (Torres *et al.*, 2015). Also, these prunings can contribute to the global target of carbon storage in soils (Benito *et al.*, 2006). Recently, allotment gardens have been recognized as important assets for ecological and societal goals such as local climate mitigation, water regulation and provision of biodiversity as well as recreation, health and social cohesion in cities (Cabral *et al.*, 2017). The fresh organic matter present in organic waste stimulates the development and activity of the soil microbial community and can also incorporate exogenous microbes into the soil environment. Moreover, organic matter improves the physical structure of the soil and contributes to carbon sequestration (Foley and Cooperband, 2002). Nevertheless, the biostimulant capacity of organic amendments depends on their chemical composition (Ajwa and Tabatabai, 1994).

For the proper application of prunings and other organic waste, these should meet certain quality standards, so that farmers can use them. These standards require: the large amount of prunings as homogenous as possible without involving an extra economic expense to the farmer and to contain zero content in heavy metals and pathogens (especially from those coming from other fields/sites) (Benito *et al.*, 2006). Such waste can contribute to the reduction of C emissions by minimizing the transport of waste to other areas and using it for the same crop (Verdonck, 1988). Some authors studied composting processes involving pruning waste before application (Benito *et al.*, 2005). This prior step can improve the quality of the mulching and reduce pest risk. However, it can increase the cost in the overall process and make this practice less feasible for the farmer.

Soil organic matter is partly transformed due to mineralization. This process releases CO_2 to the atmosphere and other nutrients to the soil so that it can provide other organic structures (Parton *et al.*, 2007; Castellano *et al.*, 2015). Other parts of soil organic matter can be transformed also but preserving their organic compounds in order to make up the majority of soil hummus owing to the interaction with the mineral matrix and the formation of clay-humic compounds (Six *et al.*, 2002). Mineralization and humification of prunings depend on their characteristics (branch size and composition), climate and soil biotic conditions (Paul and van Veen, 1978; Sariyildiz and Anderson, 2003). Climate conditions can result in a good long-term (23 up to 31 months) indicator of weight loss while the soil decomposer community can represent it as well over the same time range (Keiser and Bradford, 2017).

Castellano *et al.* (2015) considered the quality of the pruning waste essential to describe humification and/or mineralization processes, especially when determining the N content, C : N ratio and phenol/lignin concentrations. Cellulose and lignin contents were demonstrated to increase the content of recalcitrant soil carbon, in which only a light fraction can be taken up by soil organisms (Torres *et al.*, 2014). Gleixner *et al.* (2001) pointed out that lignin is the main component of terrestrial ecosystems, represents a major part of the input of the plant to the soil and, together with other compounds of plant remains, are severely modified by the action of microorganisms. Stevenson (1994) and Thevenot *et al.* (2010) pointed out that the stability and low degradability of lignin in the soil is overestimated and its contribution to humus is exaggerated. Due to its structural complexity only some organisms can degrade lignin (Thevenot *et al.*, 2010), and some studies suggest that the oxidation of lignin occurs through anaerobic or even abiotic processes (Otto *et al.*, 2005). Similarly, in numerous studies, the lignin : N ratio has been tested as an indicator of the quality of the plant waste and their capacity to release N (Seneviratne, 2000).

One of the most popular techniques for assessing mineralization and humification processes of pruning waste under partially-controlled field conditions is bagging (Kurz-Besson *et al.*, 2005). Bags with a mesh size equal to 2 mm are commonly used due to the average size of soil macrofauna (body size ≥2 mm) (Frouz *et al.*, 2015) and minimizing pruning waste losses. In addition, this allows bag placement following a short-distance pattern/experimental design where soil micro- and macrofauna can find their influence zone. The different initial composition of C, N and fibres is expected to influence the intensity of the mineralization. Hence, pruning waste with a higher cellulose and lower lignin content are expected to lose more weight.

The goal of this study was to assess the effect that the chemical and biochemical composition of the pruning waste from three subtropical crops located in southern Spain, avocado, cherimoya and mango, has on the decomposition process. In addition, garden waste were used to test how micro environmental conditions (mainly caused by agricultural practices) in each crop affect their breakdown. Specific objectives included the analysis of carbon, nitrogen, cellulose, hemicellulose, lignin and other extracts content of the pruning waste of subtropical species and garden waste throughout their decomposition during the study period.

Materials and methods

Study area location

The study plots were located in the Experimental Farm 'El Zahorí' (36°45′N, 3°39′W, 235 m a.s.l.), in the municipality of Almuñécar (Granada province, S Spain). The experiment was conducted using bagged pruning waste under the canopies of avocado trees (*Persea americana* Mill.), cherimoya trees (*Annona cherimola* Mill.), and mango trees (*Mangifera indica* L.) growing in soils classified as Eutric Escalic Anthrosols (IUSS Working Group WRB, 2015).

The climate is subtropical Mediterranean and the weather station (located on the experimental farm) showed an average temperature during the study period (July 2014 to July 2016) of 17.8°C, average relative humidity of 75.1%, and accumulated rainfall of 787.4 mm, although the evapotranspiration (ETo) for the same period was 2279.1 mm. During the study period the average monthly temperature did not exceed 25.6°C or reach freezing (minimum temperature: 10.8°C). In general, the relative humidity of the study area was high (>70%) except for three months (Fig. 1).

The orchards were located in a ravine facing the sea, although the three crops had different orientations: the avocado stand was oriented to the north, the cherimoya to the south-west and the mango to the south. The agricultural practices in each crop are different. Thus, cherimoya crop receives a large annual pruning that eliminates almost all its branches; avocado trees are the largest and avocado crop is the one that is watered the most.

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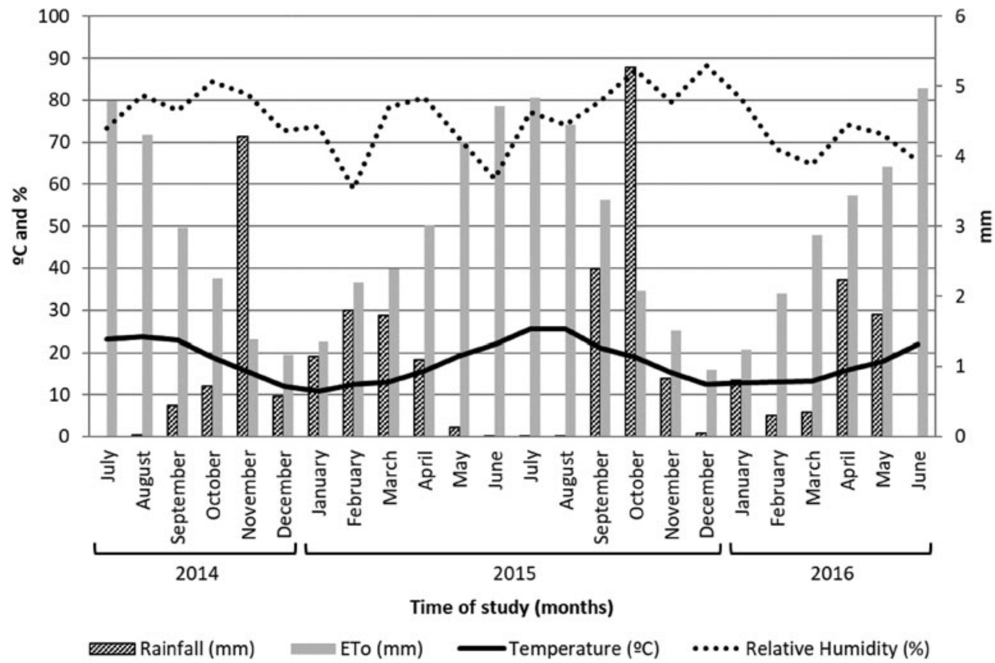

Fig. 1. Temperature, rainfall, reference ETo and relative humidity averages per month during the study period.

Table 1. Total cumulative irrigation doses applied per tree (litre) to the three crops during the study period

	Drip irrigation applied (litre)		
Sampling period	Avocado	Cherimoya	Mango
T6 (July 2014 to January 2014)	12 160	9758	7296
T24 (July 2014 to July 2016)	38 400	30 720	23 040

Surface drip irrigation was applied at different rates for the three different crops (Table 1).

Sampling design

The pruning waste from each crop was collected from the maintenance prunings of each crop in 2014. These pruned branches were passed through a chipper-shredder and the plant waste was mixed intensively to a homogeneous composition. The shredded pruning waste had an approximate particle size between 2 and 30 mm. Subsequently, the pruning waste was packed into a PVC mesh bag ($26 \times 26\ cm^2$) with a pore diameter of 2 mm. Each bag contained 100 g of crushed pruning waste dried at room temperature (25°C). On 1st July 2014 (T0), these bags were placed on the ground at a distance of 1 m around the trunk of the tree (all bags being equidistant from the surface drip irrigation) after removing the dead-leaf layer naturally present. Bagged pruning waste from each crop (avocado, cherimoya and mango) were placed on the soil surface under their corresponding trees, simulating the simplest operation for farmers, i.e. *in situ* shredding the pruning waste of each crop. Thus, bagged avocado pruning waste was placed under the canopies of three different avocado trees from the avocado crop (AA), bagged cherimoya pruning waste was placed under the canopies of three different cherimoya trees from the cherimoya crop (CC) and bagged mango pruning waste was placed under the canopies of three different mango trees from the mango crop (MM). The garden waste came from different species, but mainly palm (*Washingtonia robusta*), ficus (*Ficus elastica*) and lantana (*Lantana camara*). The bagged garden waste underwent the same treatment, but placed under the canopies of three different trees from each crop: avocado (GA), cherimoya (GC) and mango (GM). Thus, a total of four bags were placed under the canopy of each of the three trees of each crop: two bags of pruning waste from the same tree species and two bags of garden pruning waste (Fig. 2). After 6 months (January 2015, T6), a bag of pruning waste of the crop species and one of the garden pruning waste were collected from each tree, repeating the same steps after 24 months (July 2016, T24).

Characterization of the waste

After each sampling period, in the laboratory, the pruning waste was removed from the bags and the soil particles adhered to the pruning waste brushed away, and pruning waste were later weighed (Table 2). The samples were then dried for 72 h in a forced-air oven at 65°C and weighed again. The dry samples were finely ground in a mill (IKA Werke M20) and screened, using a sieve (C.I.S.A. RP-03) to a particle size of 0.25–1 mm. All assessments were made in triplicate.

Total C and N were determined with a CN Gas Analyzer by using an induction furnace and thermal conductivity (LECO TruSpec CN). The macromolecular substances and the cellulose and hemicellulose fractions were determined by the acid detergent (ADF) and neutral detergent (NDF) fibre content following the method of Van Soest and Wine (1967). Lignin was calculated from the insoluble fraction in 72% H_2SO_4 (Technical Association of Pulp and Paper Industry, TAPPI, T 222 om-02, 2002*a*). The difference between NDF and ADF gives the hemicellulose percentage contained in the initial waste. The cellulose

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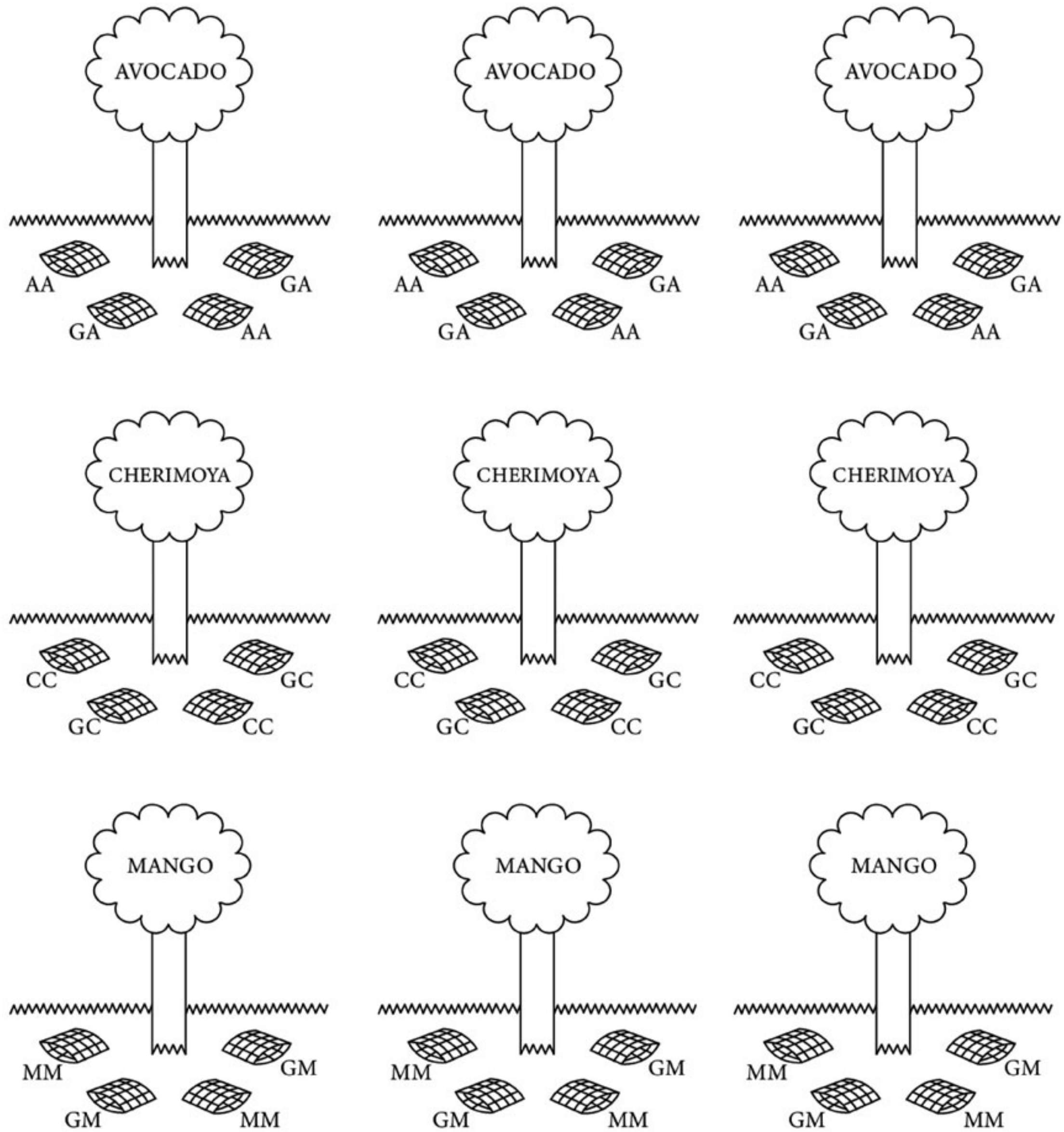

Fig. 2. General scheme of the placement of bagged pruning waste in the sample design.

fraction (% by weight) was calculated by the difference between the percentages of ADF and lignin. For the low-molecular-weight substances, the ash content was determined by weighing the samples after burning them on a muffle furnace at 575°C, by applying the TAPPI T 211 om-12 standard (TAPPI T 211 om-12, 2002*b*).

Finally, a fraction called 'other extracts' (OE) was considered, these including the components not quantified in the macromolecular substances, nor in the ashes and that we determined by difference up to 100% of the initial weight. This fraction included both soluble lignin and extractive substances composed of diverse minority components, substances that can be extracted in water or organic solvent (Fan *et al.*, 1982).

Statistical analysis

Normality and homoscedasticity were checked prior to all the analyses using the Shapiro–Wilk test and the Levene test, respectively. For the determination of the differences between the time course of the different pruning waste, the non-parametric Kruskal–Wallis test was performed, recommended for unbalanced designs and with few cases of replication. As a method of multiple comparisons, the Tukey test was applied at a confidence level of 95%. Bivariate correlations were performed according to the Pearson method. The information of multiple dimensions was visualized and interpreted with non-metric multidimensional scaling, or NMDS. All computations were made using SPSS and R.

Results

During the 2 year study, ETo was consistently higher than precipitation, except in November 2014 and October 2015 (Fig. 1). The crop was irrigated mainly because of the lack of rainfall and water requirements. As the avocado tree requires great irrigation and a moderately high temperature as optimum conditions, this crop was planted with a northern orientation and received the highest applied irrigation rates (Table 1). In addition, these trees have a

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Table 2. Mean values ± standard deviation for the attributes weight (*W*), C and N concentrations, C : N ratio, lignin (L), cellulose (CL), hemicellulose (H), other extracts (OE) and ash in crops in each sampling period (time)

Soil under pruning	Time	*W* (g)	C (g/kg)	N (g/kg)	C/N	L (%)	H (%)	CL (%)	OE (%)	Ash (%)
AA	T0	100 ± 0aA	474.5 ± 0.7aA	0.5 ± 0.1aA	90.2 ± 9.8aA	30.9 ± 1.5aA	10.7 ± 1.6aA	29.7 ± 1.2aA	24.3 ± 1.7aA	4.3 ± 0.8aA
	T6	72.13 ± 7.1bAB	433.1 ± 6.7bA	0.8 ± 0.0bA	54.8 ± 3.0bA	51.0 ± 2.7bA	0 ± 0bA	19.1 ± 0.9bA	5.5 ± 3.2bA	24.4 ± 1.8bA
	T24	55.00 ± 6.0cA	400.5 ± 14.8cA	1.3 ± 0.0cA	31.8 ± 0.8cA	49.5 ± 5.5bA	0 ± 0bA	24.7 ± 4.9bA	16.9 ± 4.0aA	8.9 ± 2.8aA
CC	T0	100 ± 0aA	473.8 ± 1.7aA	0.7 ± 0.1aA	70.3 ± 8.9aB	21.1 ± 1.8aB	20.1 ± 2.7aB	37.0 ± 2.1aB	17.8 ± 2.2aB	4.0 ± 1.8aA
	T6	66.57 ± 2.9bA	363.0 ± 80.8abA	1.4 ± 0.2bB	26.0 ± 4.1bB	38.3 ± 1.4bB	10.3 ± 0.3bB	31.1 ± 3.6aB	7.3 ± 5.1aA	13.0 ± 4.3bB
	T24	36.82 ± 8.3cB	324.6 ± 8.4bB	1.3 ± 0.1bA	25.4 ± 1.8bB	39.9 ± 6.3bAB	7.4 ± 0.7bB	28.3 ± 4.5aA	13.1 ± 6.8aA	11.3 ± 1.6bA
MM	T0	100 ± 0aA	456.7 ± 1.3aB	0.6 ± 0.0aA	73.5 ± 0.9aAB	27.5 ± 1.5aA	2.3 ± 0.4aC	23.9 ± 1.2aC	38.1 ± 0.7aC	8.3 ± 0.3aB
	T6	81.70 ± 4.0bB	385.2 ± 17.4bA	0.6 ± 0.1aA	62.5 ± 9.4abA	37.9 ± 1.2bB	0 ± 0bA	29.8 ± 1.3abB	15.7 ± 5.7bA	16.7 ± 4.0bB
	T24	41.38 ± 5.2cAB	388.2 ± 13.3bA	0.7 ± 0.0aB	54.8 ± 1.6bC	36.1 ± 2.9bB	0 ± 0bA	32.8 ± 4.1bA	22.2 ± 4.1bA	9.0 ± 0.7aA

Note: Comparing the pruning waste of the three tree species, avocado pruning waste (AA), cherimoya pruning waste (CC) and mango pruning waste (MM): upper-case letters compare with respect to the treatment factor (pruning waste), and lower-case letters compare with respect to the time factor (sampling period).
Values that do not share at least one letter are significantly different. The Tukey-test was applied ($P < 0.05$).

large crown and are not deciduous, which decreases ETo and moderates soil temperature (data not shown). The cherimoya crop received an irrigation rate intermediate between that of the avocado and the mango (Table 1) and was pruned to total defoliation at the beginning of winter so that the crown volume was the smallest of the three types of trees. In addition, the south-western orientation of the orchard presumably gave it the highest insolation, implying a higher ETo. Finally, the mango crop was located on a south-facing slope and had the lowest irrigation rate. However, this crop not being deciduous has a lower ETo and greater water economy than does the cherimoya.

Evolution of weight of the pruning waste and garden waste over time

The time course of the weight of the waste from the different species with respect to garden waste was similar, except for MM and GM (Tables 2 and 3). Significant differences in weight were noted in each sampled period for the same type of pruning waste. The weight changes were greater at T6 than at T24 for AA and CC. However, MM showed a higher significant weight change at T24 than at T6. CC underwent the greatest weight loss with respect to initial weight in both T6 and T24, but without significantly differing from AA at T6 or from MM at T24. The weight changes for CG and GM were greater at T6 than at T24, both being significantly different from GA. However, GM at T24 had the least weight loss, but differing significantly only regarding to GC (Table 3).

C and N concentrations

C and N concentrations in each sampling time point are presented in Tables 2 and 3. The time course of the C concentration was similar for MM, GM and GC, and also similar between AA and GA. The statistical analysis of C content in AA and MM revealed significant differences between T6 and T0, decreasing in both cases by 41.4 and 71.5 g/kg, respectively (Table 2). Similarly, the AA significantly differed in the concentration of C between T6 and T24. Regarding the C content in MM, no significant differences were detected between T6 and T24. On the other hand, CC fell significantly only in the comparison of T0 with respect to T24.

The N concentration over the time course between AA and GA, and between CC and GC, were similar, but not between MM and GM. AA and CC registered a significant increase in the N content at T6 with respect to T0, specifically of 0.2 and 0.7 g/kg, respectively (Table 3). AA increased in N content again at 24 months. However, MM did not vary significantly in N concentration over time.

The C : N ratio decreased after each sampling and at T24 it significantly differed among the pruning waste of the three species. The C : N ratio of AA declined significantly after each sampling, and in CC it also fell significantly at T6, but did not change at T24, whereas in MM a significant decrease was found only from T0 to T24 (Table 2).

As expected, the C : N ratio was lower in the garden waste than in the prunings from the subtropical species and at T6 decreasing 30.3 g/kg in GA and more than 41 g/kg in GC and GM. The C concentration lowered significantly at T6 for all pruning waste except for CC. The N concentration more than doubled, going from 0.8 to 1.8 and 0.8 to 1.9 g/kg in GC and GM, respectively, and increasing from 0.8 to 1.3 g/kg in GA at T6. Decrease in C

Table 3. Mean values ± standard deviation for the attributes weight (*W*), C, N, C : N ratio, lignin (L), cellulose (CL), hemicellulose (H), other extracts (OE) and ash in garden waste in each sampling period (time)

Soil under pruning	Time	*W* (g)	C (g/kg)	N (g/kg)	C/N	L (%)	H (%)	CL (%)	OE (%)	Ash (%)
GA	T0	100 ± 0aA	455.6 ± 1.4aA	0.8 ± 0.1aA	59.1 ± 4.6aA	33.1 ± 1.8aA	0.7 ± 0aA	34.5 ± 1.4aA	21.3 ± 1.6aA	10.4 ± 1.5aA
	T6	70.87 ± 6.8bA	386.9 ± 32.0bA	1.3 ± 0.1bA	28.9 ± 1.6bA	38.9 ± 1.4bA	0 ± 0bA	34.5 ± 0.6aA	20.2 ± 0.8aA	6.4 ± 1.2aA
	T24	43.19 ± 8.6cAB	291.4 ± 21.5cA	1.5 ± 0.1bA	20.1 ± 0.4cA	46.3 ± 0.3cA	0 ± 0bA	25.4 ± 1.7bA	4.0 ± 5.2bA	24.5 ± 6.4bA
GC	T0	100 ± 0aA	455.6 ± 1.4aA	0.8 ± 0.1aA	59.1 ± 4.6aA	33.1 ± 1.8aA	0.7 ± 0aA	34.5 ± 1.4aA	21.3 ± 1.6aA	10.4 ± 1.5aA
	T6	53.37 ± 3.0bB	328.1 ± 36.9bA	1.9 ± 0.1bB	17.6 ± 2.3bB	52.2 ± 0.9bB	0 ± 0bA	21.4 ± 1.0bB	0.9 ± 1.5bB	29.3 ± 5.9bB
	T24	38.76 ± 4.9cA	359.6 ± 20.0bB	1.5 ± 0.2cA	23.6 ± 1.7bB	42.8 ± 0.5cA	0 ± 0bA	23.3 ± 0.8bA	21.3 ± 4.2aB	12.7 ± 3.6aA
GM	T0	100 ± 0aA	455.6 ± 1.4aA	0.8 ± 0.1aA	59.1 ± 4.6aA	33.1 ± 1.8aA	0.7 ± 0aA	34.5 ± 1.4aA	21.3 ± 1.6aA	10.4 ± 1.5aA
	T6	59.17 ± 3.2bB	360.5 ± 21.0bA	1.8 ± 0.1bB	20.1 ± 0.8bB	48.9 ± 0.9bB	0 ± 0bA	17.6 ± 1.0bB	9.7 ± 2.4bC	23.8 ± 0.5bB
	T24	53.83 ± 0.6cB	373.9 ± 8.8bB	1.8 ± 0.1bA	21.4 ± 0.7bAB	47.3 ± 0.5bA	0 ± 0bA	22.6 ± 0.9cA	13.7 ± 2.7bAB	16.5 ± 3.7cA

Note: Comparing the garden waste on avocado crop (GA), garden waste on cherimoya crop (GC) and garden waste on mango crop (GM): upper-case letters compare with respect to the treatment factor (pruning waste), and lower-case letters compare with respect to the time factor (sampling period).
Values that do not share at least one letter are significantly different. The Tukey-test was applied ($P < 0.05$).

of the garden waste was similar in time to those in CC and MM, but much higher than in AA, especially at T24. The time course of the N content was similar only between CC and GC. The greatest differences in the N concentration were found between MM and GM.

C and N pools

The time course of the pool of total C and N (concentration by weight in each period) is plotted in Fig. 3. The C declined at the end of the study period (T24), losing between 23.9 and 35.5 g regarding the initial pool. No changes were detected in the N pool of AA, whereas in CC, N increased by 0.24 g at T6 and later significantly decreased at T24. MM did not change in the N pool from T0 to T6 but decreased significantly at T24 (Fig. 3).

The C losses were greater in the avocado orchard but with significant differences only with respect to the garden waste in the mango orchard. GM had the same C pool at T6 and T24 (Fig. 3). The total N content increased in all wastes except for MM at T6 and decreased only in GC at T24.

Lignin, hemicellulose, cellulose, other extracts and ash concentration

The results for the fibre-concentration analysis are shown in Tables 3 and 4. At first, the CC had the lowest lignin content, registering significant differences with respect to the other types of pruning waste. The lignin concentration augmented progressively at T6 and T24. The AA showed the highest concentrations in all the samples, registering significant differences regarding the other pruning waste except with the CC at T24.

The initial concentrations of hemicellulose, cellulose and other extracts were significantly different among the three subtropical species. The highest hemicellulose and cellulose concentrations, and the lowest lignin concentration were found in CC. Table 2 indicates that hemicellulose concentrations dipped significantly at T6 in the pruning waste of the three trees, reaching almost 50% in CC and disappearing in AA and MM. In CC, no significant changes were observed from T6 to T24.

The cellulose concentration in AA declined significantly (35.8%) from T0 to T6. Subsequently, it increased at T24, although without differences. In CC, no significant differences were found in cellulose concentration in any of the samples. MM showed its cellulose concentration increased over time because it degraded at a lower rate than other pools, with a significant difference between T0 and T24. The other extracts significantly decreased at T6 in AA and MM, but there were no differences in CC.

In the garden waste, GC and GM at T6 lost all the hemicellulose, a large part of other extracts and more than half of the cellulose. GC also lost lignin, while in GA, all of the hemicellulose disappeared, but a lower percentage of other extracts and cellulose was lost. At T24, GC lost mainly lignin, GA lost cellulose and lignin, while GM registered no differences in fibre content in T6 (Table 3).

Fibre pool

As can be seen in Fig. 4 in T6, much of the hemicellulose was lost in CC (the pruning waste with the highest hemicellulose content) and all the hemicellulose disappeared in AA and MM. AA and CC also showed approximately the same decrease in cellulose.

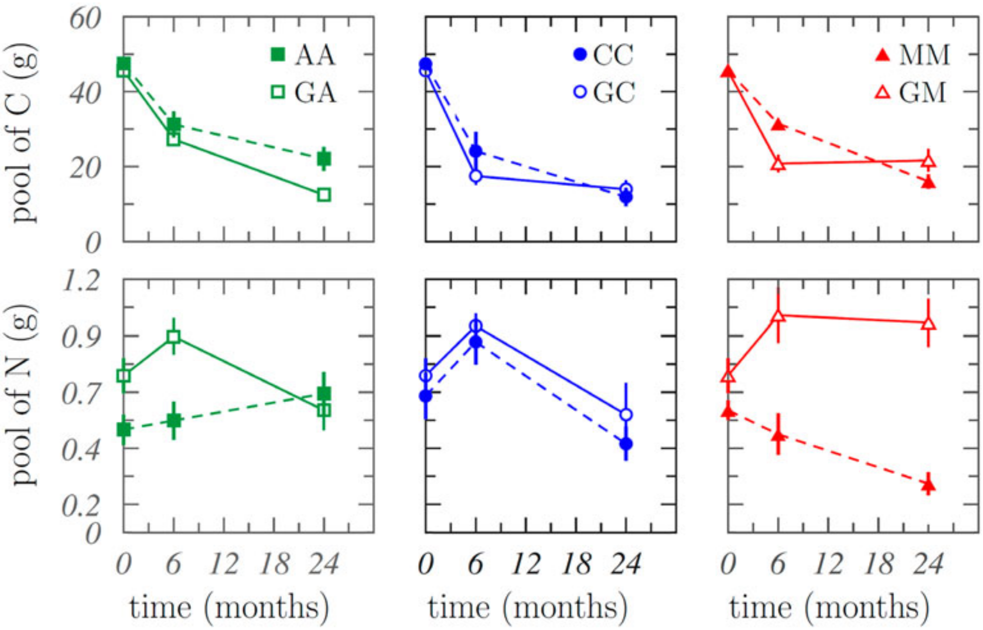

Fig. 3. (Colour online) Pools of carbon (C) and nitrogen (N) in species (avocado pruning waste on avocado crop (AA), cherimoya pruning waste on cherimoya crop (CC) and mango pruning waste on mango crop (MM)) and garden waste (garden waste on avocado crop (GA), garden waste on cherimoya crop (GC) and garden waste on mango crop (GM)) in each sampling period. *Note*: Thin bars represent the standard error of the sample. $P < 0.05$.

Table 4. Pearson bivariate correlations between weight and the studied variables in pruning waste over time

	C	N	C/N	Lignin/N	Lignin	Hemicellulose	Cellulose	Other extracts	Ash	Water
Weight										
AA										
Pearson	**0.979**	**−0.916**	**0.952**	0.557	**−0.838**	**0.890**	0.551	0.472	−0.354	**−0.915**
Sig. (bi)	0.000	0.001	0.000	0.119	0.005	0.001	0.124	0.200	0.350	0.001
CC										
Pearson	**0.803**	**−0.785**	**0.862**	0.007	**−0.887**	**0.921**	**0.760**	0.396	−0.664	**−0.958**
Sig. (bi)	0.009	0.012	0.003	0.986	0.001	0.000	0.018	0.291	0.051	0.000
MM										
Pearson	0.652	−0.657	**0.769**	−0.205	−0.589	**0.719**	**−0.744**	0.459	0.150	**−0.992**
Sig. (bi)	0.057	0.054	0.015	0.596	0.095	0.029	0.021	0.214	0.701	0.000
GA										
Pearson	**0.888**	**−0.930**	**0.923**	**0.691**	**−0.964**	**0.852**	**0.793**	**0.780**	−0.599	**−0.951**
Sig. (bi)	0.001	0.000	0.000	0.039	0.000	0.004	0.011	0.013	0.088	0.000
GC										
Pearson	**0.842**	**−0.830**	**0.918**	**0.873**	**−0.718**	**0.968**	**0.923**	0.266	−0.353	−0.**871**
Sig. (bi)	0.004	0.006	0.000	0.002	0.029	0.000	0.000	0.489	0.351	0.002
GM										
Pearson	**0.950**	**−0.978**	**0.983**	**0.925**	**−0.969**	**0.993**	**0.915**	**0.836**	**−0.733**	**−0.808**
Sig. (bi)	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.005	0.025	0.008

Note: The water variable includes the cumulative sum of rainfall plus irrigation.
There is a significant linear relationship in the cells marked in bold (the critical level of correlation is less than the level of significance 0.05). $n = 9$.

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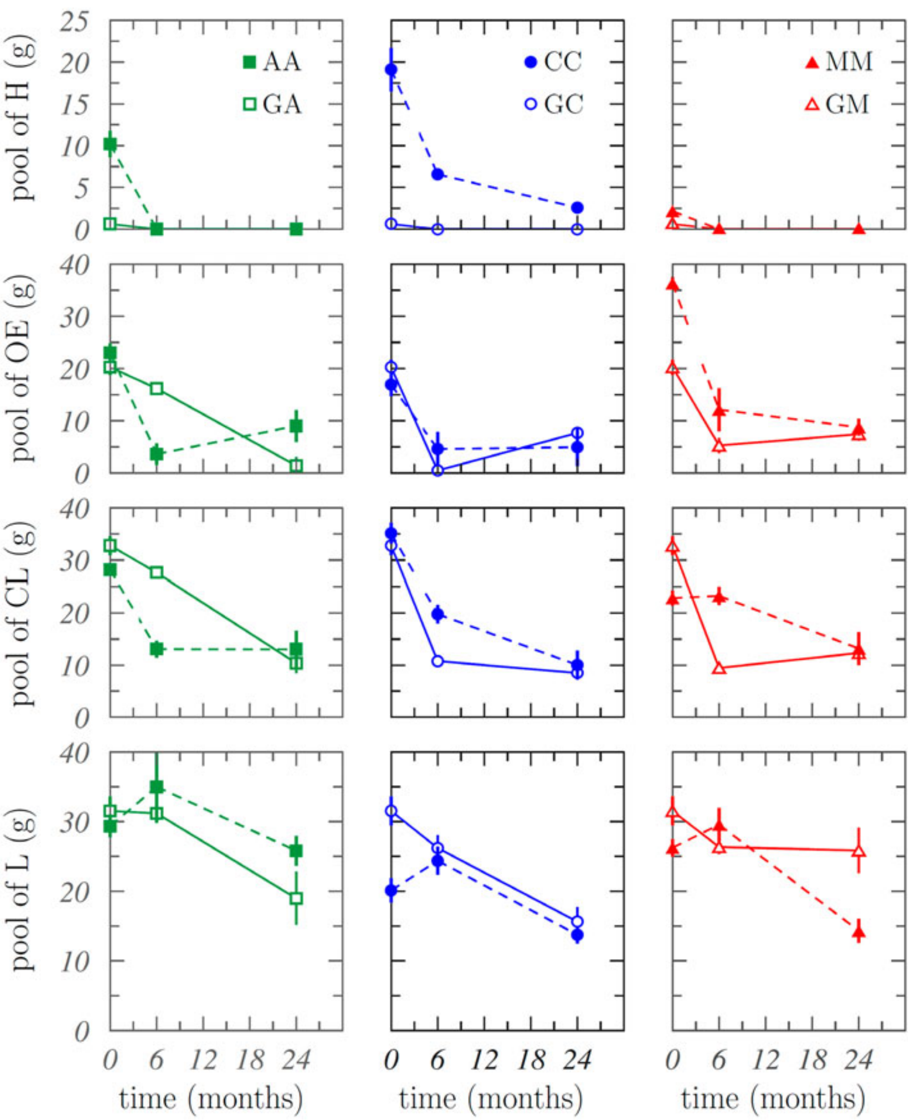

Fig. 4. (Colour online) Fibre pool (lignin (L), cellulose (CL), other extracts (OE) and hemicellulose (H)) in species (avocado pruning waste on avocado crop (AA), cherimoya pruning waste on cherimoya crop (CC) and mango pruning waste on mango crop (MM)) and garden waste (garden waste on avocado crop (GA), garden waste on cherimoya crop (GC) and garden waste on mango crop (GM)) in each sampling period. *Note*: Thin bars represent the standard error of the sample. $P < 0.05$.

The three types of pruning waste lost approximately the same amount of other extracts in T6. At T24, CC continued to lose hemicellulose, cellulose and almost half of the lignin. In AA the cellulose did not diminish but lignin decreased, while MM lost lignin and cellulose. The greater weight loss in mango at T24 was therefore due to the decrease in cellulose and lignin. On the other hand, AA, which had less weight loss, showed no decline in cellulose but only in lignin.

The Pearson bivariate correlations between the weight variations over time and the studied variables in all pruning waste are shown in Table 4. As can be seen, values were positive and significant for C, C : N and hemicellulose but negative for N, lignin, and water input for all types of pruning waste, except for the MM, which did not match in all cases. The correlations between weight and cellulose concentration were positive for all garden waste and those of CC. In MM the correlations were significant and positive only for the weight with C : N and hemicellulose concentration. In contrast to the other types of pruning waste, the correlations were significantly negative between weight and cellulose.

The greatest weight loss occurred in T6 in all types of pruning waste except for MM and was positively related to the C concentration but less related to the other extract concentration (Fig. 5). In contrast, the relation was negative with the N concentration and especially with the water added (accumulated irrigation plus accumulated precipitation). In addition, Fig. 5 shows how CC in T6 and T24 markedly differed with respect to other pruning waste and were related to hemicellulose and cellulose concentrations. Finally, the strong relationship of N concentration with GA, GC, GM and AA at T24 is noteworthy.

Discussion

The mineralization of organic waste is controlled by different factors such as litter composition, weather and soil fauna (Kampichler and Bruckner, 2009). Mason-Jones and Kuzyakov (2017) pointed out that the most important changes take place during the first stages of decomposition. In accordance with this, in our study, the greatest differences in the time course of the composition of the organic waste, both in crops and gardens, occurred during the first months of decomposition (T0 to T6) (Tables 2 and 3). However, Keiser and Bradford (2017) proved that the substantial changes in the composition of the organic waste do not take place during the first months of decomposition,

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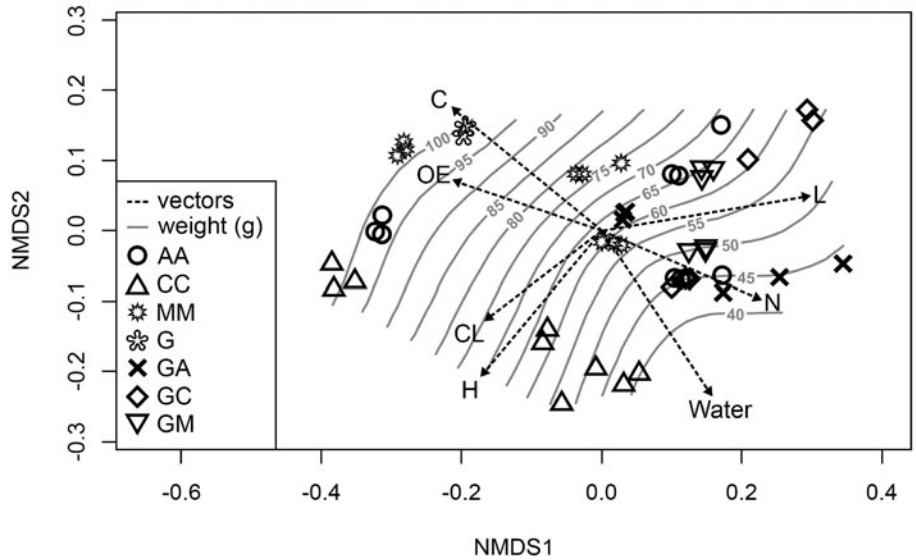

Fig. 5. NMDS plot of all the pruning waste generated, including all the variables (vectors) studied (carbon (C), nitrogen (N), lignin (L), cellulose (CL), hemicellulose (H), other extracts (OE) and water input (water)) and relating them to the weight over time (T0, T6 and T24). *Note*: 'G' garden waste at T0 because the garden waste have the same composition at T0 in all locations (crops), and this composition varies differently over time (T6 and T24) for the different crops. The length of the vector represents the influence of the variable. The direction of the vector (variable) explains the distribution of the data.

but in the long term, between 23 and 31 months. This suggests that the studies that only consider the first stages of decomposition (first months) may find changes in pruning waste weight whereas longer studies (up to 24 months) would be able to reveal notable changes associated with other factors like weather or microbial activity.

Although a more detailed study should be carried out regarding soil moisture, the high moisture produced by the irrigation water, the high relative humidity due to the proximity to the sea and the high temperatures contributed to intense mineralization of all wastes, evidenced by their marked weight loss over the experiment (Tables 2 and 3). In fact, as shown in Fig. 5, moisture and weight loss have a strong negative correlation. The weight losses in all wastes at T24 were similar or slightly higher than those reported by other authors (Berg and Ekbohm, 1991), in which all kinds of litter studied lost around 45–50% of the biomass after 24 months (Tables 2 and 3).

The bivariate correlations between the time course of weight and of water input (Table 4 and Fig. 5) were significantly negative for all pruning waste, indicating that the higher the water inputs the lower the sample weights. Nevertheless, water inputs were higher in avocado, but this greater moisture and the consequent differences in ETo did not cause a greater weight loss at T6 and T24 in comparison with CC and MM (Table 2). Neither GA registered the greatest weight loss at T6, although at T24 it lost significant weight similar to that found for GC (Table 3), where mineralization was more intense. This result is consistent with the findings of García-Palacios *et al.* (2013), who have noted that, in agrosystems, litter composition is a better predictor of the decomposition rates than climate. On the other hand, Aerts (2006) and Rasse *et al.* (2006) pointed out that temperature predetermines the mineralization of organic waste to a greater degree than does soil moisture. Although temperature data are not shown in this study, the field observations suggest that the cherimoya plantation is likely to reach the highest temperatures because this crop receives great pruning that greatly reduces the canopy, so agricultural practices appear to be decisive. However, the latter does not significantly change the weight loss in cherimoya in comparison with avocado (Table 2).

The initial C concentrations in the subtropical waste were similar to those described by other authors for eucalyptus and pine species (Valenzuela-Solano and Crohn, 2006), exceeding 45% of the total weight. Meanwhile, the N concentrations were similar to those established in other studies for pine needles (Lado-Monserrat *et al.*, 2016). Garden waste registered C concentrations similar to those in the subtropical waste but with a higher N concentration, which promoted a lower C : N ratio (Table 3). In general, both the C concentration and C : N ratio in the garden waste were higher than those found by other authors in such waste from other areas (Benito *et al.*, 2009). However, at T24 the C : N ratio was similar to that reported by these authors after 190 days of composting. This may indicate that for the studied crops, crushed pruning waste into small sizes do not require composting before being applied on the field, as pointed out by other authors (Torres *et al.*, 2015) in semiarid soils.

Our results show that C and N concentrations properly explain the humification and mineralization processes of the vegetable waste, in agreement with Peña-Peña and Irmler (2016). As reflected in Table 4 and Fig. 5, a significant positive correlation was found between C concentrations and weight and a significant negative correlation was noted between N concentrations and weight in all wastes except for MM. The C : N ratio had a positive correlation with weight but with different significance, being lower also for MM. This lower significance was because, despite having similar weight loss to all the other waste, MM did not vary in the C concentration between T6 and T24, and the N concentration did not increase in any of these periods (Table 2). In the orchard waste, CC showed the lowest C : N ratio and the highest weight loss at T6 and T24 (Table 2), in accord with other authors (Sanaullah *et al.*, 2010). The highest C : N ratio appeared in AA and declined more than the C : N ratio in MM at T6 and T24. However, the weight losses in AA and MM did not significantly differ (Table 2). In the garden waste, the lower C : N ratio at T6 is consistent with less weight loss. Nevertheless, at T24 the lowest C : N ratio was found in GA and the greatest weight loss in GC (Table 3). The differences in the C : N ratio between GA and GC and GM were due to the C concentration, which significantly diminished at T24, and its N concentration, which increased significantly less than did the others at T6. This suggests that, given that the garden waste were the same in the three orchards, in the long term (T24) the climatic and/or biological conditions under avocado appear to promote a longer and

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more intense decomposition of the organic waste than under cherimoya and specially mango, which could be due to by the formation of recalcitrant aromatic compounds or the inhibition of enzymes involved in the decomposition processes (Sanaullah *et al*., 2010).

The N pool at T6 increased in all cases except for AA and MM (Fig. 3). This has also been observed by other authors (Sjöberg *et al*., 2004; Valenzuela-Solano and Crohn, 2006; Torres *et al*., 2015), who related the larger N pool with intensified microbial activity rates during the first stages of mineralization, suggesting that N-liberation rates depend on both the chemical composition of the waste and the microbial activity. On the other hand, Kaiser *et al*. (2015) suggested that the higher N accumulation could be associated with microorganisms capable of producing extracellular enzymes that could make them more efficient at mineralizing the organic waste, as may occur in most of the experiments of our study.

The N concentrations between T6 and T24 in MM did not register significant differences (Table 2). However, in GM the N concentration sharply increased at T6, as in GA and GC. The lower C : N ratios in the garden waste compared to MM do not explain the observed differences, especially compared to AA, CC and garden waste. In no case does the ratio appear to be related to the climatic conditions because the time course of the garden waste was similar in the three orchards (Fig. 5). These differences are likely associated with the biochemical composition of MM or the performance of several organisms related to the composition of these waste.

In this study, the weight loss was positively correlated with the lignin : N ratio only in the garden waste (Table 4). This was due to the greater lignin concentration and the higher N increases over time in the garden waste compared to the orchard prunings. The initial lignin concentration varied from 30% in AA, MM and garden waste and 20% in CC (Table 2). The highest values were similar to others described for eucalyptus and pine waste having 23.6% of lignin (Valenzuela-Solano *et al*., 2005) and for Black spruce [*Picea mariana* (Mill) B.S.P.] having 28.3% of lignin or Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] having 21.3% of lignin described by Preston *et al*. (2000), although the cellulose values were higher than those found by these authors. CC showed the highest cellulose values (Table 2), similar to those described for red cedar (*Thuja plicata* Donn) having 35.6% of lignin, but the lignin values were lower and similar to species of deciduous trees such as white birch (*Betula papyrifera* Marsh.) having 24% of lignin (Preston *et al*., 2000).

Carbohydrates are quickly decomposed by soil organisms (Gleixner *et al*., 2001). On the other hand, Geng *et al*. (2012) indicated that water-soluble materials are the chemical variable that most affects the time course of forest waste in the early stages of decomposition. The mineralization rates of other components in the vegetable waste are related to their relative position in the waste. According to Thevenot *et al*. (2010), lignin is chemically connected with cellulose and forms fibre walls with the hemicellulose that bolster resistance to biodegradation of the vegetal waste. Consequently, microbial mineralization will first affect solvable carbohydrates (included in the 'other extracts' fraction), then to hemicellulose, cellulose and finally lignin (Sjöberg *et al*., 2004).

Weight differences in all wastes are correlated with their hemicellulose content (Table 4). The correlations between weight and cellulose content proved to be positively significant for all wastes except for AA and MM. Thus, other extracts, hemicellulose and cellulose pools diminished in cherimoya and avocado waste, which registered the greatest weight losses at T6 (Fig. 4). Valenzuela-Solano and Crohn (2006) noted large losses of these components in the first 6 months of mineralization. MM underwent less weight loss than did the other wastes during the first 6 months because they had very little hemicellulose content that disappeared at T6 together with the other extracts, retaining the cellulose content.

At T24, part of the lignin mineralized in all wastes (Fig. 4), in accord with Rasse *et al*. (2006), who reported turnover rates of these lignin pools in a loamy temperate soil of 1.9/year. However, the decrease in lignin content was lower in AA (with significant differences with CC and MM) and GM. In this sense, Thevenot *et al*. (2010) indicated that the degradation of lignin is related to vegetation type, soil use, climate and especially temperature.

The garden waste present different decomposition dynamics in the different crops, probably due to the characteristics of each crop. Mineralization in GC is more favourable than in GM over the short term (T6) and more favourable than in GA over the long term (T24). At T6 the hemicellulose disappeared in all the garden waste under the three crops (Table 3). However, 54.3% of other extracts and 49% of cellulose mineralized in GM and 95.8% of other extracts and 37.8% of cellulose disappeared in GC. This loss of labile elements in the first weeks of mineralization has recently been reported elsewhere (Sanghaw *et al*., 2017). Nevertheless, in GA the other extracts and cellulose contents hardly vary at T6.

At T6 the N concentration increased in the garden waste under the three subtropical crops (Table 3), coinciding with major losses of the other extracts, hemicellulose and cellulose pools (Fig. 4). These compounds are immediate energy sources for soil microorganisms (Torres *et al*., 2015), this explaining the increase in N.

At T24, there was a high weight loss in GA and GC (Table 3), along with a significant decline in the lignin pool (Fig. 4), but not in GM. The irrigation rate in the mango crop was lower than that in the other crops (Table 1), perhaps explaining the lower biological activity. Other authors indicated that moisture limitations could be more important than limitations in N in the decomposition of the organic waste. On the other hand, Palosuo *et al*. (2005) noted that the N content limits the decomposition of litter with high lignin contents and stated that temperature is a key factor in litter decomposition. However, in the current study, at T24 the N pool in GM was higher than that in GA and GC, and at T6 the decrease of the lignin pool in GM was similar to that in GC (Fig. 4). Nevertheless, at T24 the lignin continued declining in GC but not in GM. This suggests that, over the long term, the mineralization of GM depends on the activity of other soil organisms and the changes in the structure and in the biological community within the wastes and not on the climatic conditions or the microbial activity. Thus, in the short term, mineralization is related more to soil microbial biomass than to the chemical structure of the substrate (Dalmonech *et al*., 2010; Torres *et al*., 2014; Sanghaw *et al*., 2017), but over the long term, other biotic or abiotic factors associated with fragmentation processes (e.g. the presence of microarthropods; Valenzuela-Solano and Crohn, 2006) may affect mineralization. Further studies on soil organism biomass are needed to explain more fully the decomposition of the garden waste, especially under mango trees.

Conclusions

The pruning waste of the different subtropical orchards and gardens underwent intense mineralization reflected in great weight losses throughout the experiments. The agricultural practices on

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avocado crop (much irrigation and largest tree canopy) allowed longer and more extensive mineralization of the garden waste than under cherimoya and mango, probably due to the formation of recalcitrant aromatic compounds or the inhibition of enzymes involved in the decomposition processes as noted in other studies. The high mineralization rates of the garden waste in the studied crops (avocado, cherimoya and mango), affected by the climate, involved a quick decrease of the C : N ratios, which suggests that these wastes could be directly applied without undergoing a previous external composting process. The recalcitrant C at the end of the experiment could be the result of the lignin concentration in the case of the garden waste applied to the different crops. Further studies are needed to determine the carbon quantities provided to the soil with this management technique.

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