agronomy

MDPI

Article

Spectroscopic and Physicochemical Characterization of Poultry Waste-Based Composts and Charcoal–Compost Mixtures for the Prediction of Dry Matter Yield of Giant of Italy Parsley

Francielly T. Santos [1], Mônica S. S. M. Costa [1], Luiz A. M. Costa [1], Henrique Trindade [2], Larissa M. S. Tonial [3], Higor E. F. Lorin [1] and Piebiep Goufo [2,*]

[1] Agricultural Engineering Graduate Program, Universidade Estadual do Oeste do Paraná, Street University 2069, Cascavel 85819-110, Brazil; francielly_torres@hotmail.com (F.T.S.); monicasarollisilva@gmail.com (M.S.S.M.C.); lmendo1947@gmail.com (L.A.M.C.); higorf@hotmail.com (H.E.F.L.)

[2] CITAB—Centro de Investigação e Tecnologias Agroambientais e Biológicas, Departamento de Agronomia, Universidade de Trás-os-Montes e Alto Douro, Quinta de Prados, 5000-801 Vila Real, Portugal; htrindad@utad.pt

[3] Departamento de Química, Universidade Tecnológica Federal do Paraná, Campus Pato Branco, Via do Conhecimento Km 1, Bairro Fraron, Pato Branco 85501-390, Brazil; larissasantos@utfpr.edu.br

* Correspondence: pgoufo@utad.pt

Abstract: Plant growing substrates obtained by composting agro-industrial waste can serve as organic soil amendments. However, it is crucial to determine the maturity and quality of organic amendments before their application to soil. This study aimed to evaluate the suitability of compost obtained from poultry wastes combined with five different vegetal residues (tree trimmings, sugarcane bagasse, sawdust, cotton residues, and Napier grass) as growth media for container-grown Giant of Italy parsley. Fourier-transform infrared and laser-induced fluorescence spectra were used to characterize the humification extent in composts before and after the addition of charcoal at five inclusion rates (0%, 15%, 30%, 45%, and 60%, weight basis). Spectroscopic measurements identified absorption bands between 1625 and 1448 cm^{-1} specific to each of the 25 organic amendments evaluated. The most suitable amendments (composts made from sawdust and sugarcane bagasse) were associated with O–H stretching of phenols and aromatic rings. Charcoal addition to composts changed some of their physical characteristics, leading to increased nutrient availability in some cases. Experimental and calculated dry matter yield were compared via multiple linear regression and simple non-linear regression as a function of the spectroscopic and physicochemical (N, P, K, pH, EC, C, H_{LIF}, C:N, CEC, HA:HA) properties of the organic amendments. Regression models accurately assigned high yields to the sawdust- and bagasse-based composts and low yields to the Napier grass- and cotton-based composts. Electrical conductivity (EC) was the main factor limiting potted-parsley productivity, an indication that efficient management of charcoal rate and compost EC levels can aid in predicting parsley yield.

Keywords: electrical conductivity; hatchery waste; *Petroselinum crispum*; Fourier-transform infrared spectroscopy; broiler litter; laser-induced fluorescence spectroscopy

check for updates

Citation: Santos, F.T.; Costa, M.S.S.M.; Costa, L.A.M.; Trindade, H.; Tonial, L.M.S.; Lorin, H.E.F.; Goufo, P. Spectroscopic and Physicochemical Characterization of Poultry Waste-Based Composts and Charcoal–Compost Mixtures for the Prediction of Dry Matter Yield of Giant of Italy Parsley. *Agronomy* **2022**, *12*, 256. https://doi.org/10.3390/agronomy12020256

Academic Editors: Kyoung S. Ro and Ariel A. Szogi

Received: 9 December 2021
Accepted: 18 January 2022
Published: 20 January 2022

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Copyright: © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

Poultry farming is an important industry in Brazil; in fact, the country is currently the second largest producer of chicken meat in the world [1]. The poultry industry generates large amounts of solid waste both at the pre-finishing stages (i.e., broiler feed waste, broiler-breeder litter, and hatchery waste) and during meat production (i.e., floating sludge, sausage casings, charcoal, and ash from burning of wood for heat generation). Additionally, the poultry industry produces substantial amounts of liquid waste [2]; furthermore, with the rapid development of modern society and the continuous increase in human population

worldwide, the generation of poultry wastes, and other agro-industrial wastes is expected to continue soaring [3–5].

Composting is typically used for recycling wastes produced by a range of agroindustries [6–8]. Several waste types, including those from the poultry industry, are high in nitrogen (N) content; thus, it is convenient to mix them with vegetable wastes or other materials during compositing to achieve a more suitable carbon-to-nitrogen (C:N) ratio. Maximum crop productivity is dependent not only on the C:N ratio of the composts, but on other nutritional quality parameters as well, which enable growing substrates to act as a nutrient reservoir, thus contributing to successful seedling establishment and vigorous plant growth [9]. This is particularly important for pot-grown plants, as in this case, the growing substrates must sustain plants throughout their entire life cycle [10]. Organic amendments produced from agro-industrial wastes are well known to be rich in nutrients and to play vital roles in plant development [11–14]. However, studies are needed on the assessment of the chemical and physical properties of organic amendments, especially when they are used as growth media for potted spice plant species.

Physicochemical properties of organic amendments are dependent on the formation of humic substances produced by humification during the stabilization of organic matter [15]. Thus, a reliable test of compost maturity is extremely important to prevent any damage due to the application of immature or toxic composts. Various techniques have been used to assess the degree of stabilization of organic matter, including Fourier-transform infrared spectroscopy (FTIR) and laser-induced fluorescence (LIF) spectroscopy [16]. FTIR spectroscopy can be used to gain information on the functional chemical groups present in humic substances, especially those groups that are associated with the stabilization of organic matter [17,18]; in turn, LIF spectroscopy can be used to determine the degree of humification of organic amendments as measured by the humification index (H_{LIF}) [19]. Besides the degree of humification, special attention should be given to toxic elements that might be present in the organic amendments [12,20]. For example, some agro-industrial wastes show excessively high levels of N accumulated during the composting process [21]. Composts with excessive amounts of N must be diluted with other materials to make them suitable for use as a growth medium by preventing any possible toxic effects [22]. Additionally, growth medium components must be stable and contribute to improve not only the chemical, but the physical characteristics of the soil as well. Graceson et al. [23] evaluated the use of crushed bricks and crushed tiles as inorganic materials for improving the physical properties of organic growth media; their study showed that several inorganic materials with appropriate characteristics, and adapted to any particular soil and crop, can alter the physical properties of the growth medium for better.

Peat is widely used as a growing substrate for several potted crop-plants, primarily due to its excellent physical properties; thus, this spongy-textured material absorbs water for a slow release that benefits the crop for a longer period [7]. However, peat is poor in nutrients. Recently, some organic and inorganic wastes have been proposed as substitutes to peat [24,25]. For example, numerous studies have investigated the use of biochar as a plant growing substrate [26–29]. However, production costs for biochar and other components must be systematically assessed and compared with peat, as recommended by Haeldermans et al. [30], who evaluated the techno-economic viability of biochar production. Charcoal waste resulting from the incomplete burning of wood in furnaces for heating water for industrial boilers in poultry processing plants reportedly has similar properties to biochar and peat, and might be used to produce desirable organic amendments [22]. While evaluating different organic amendments obtained by adding charcoal to composted organic wastes for the production of lettuce seedlings, Lorin et al. [22] found that charcoal enhanced both the physical and chemical characteristics of the growing substrates. Additionally, charcoal waste from the poultry industry is presumably physically, chemically, and structurally stable over time. Thus, poultry industry wastes converted biologically by composting may produce an organic amendment that enhances not only the chemical (in the case of, e.g., broiler litter) but also the physical (in the case of charcoal) properties of the

soil. Therefore, these organic amendments may be used as seedling-starter substrates and for growing potted plants, thereby adding market value to the poultry industry.

Costa et al. [8] evaluated the use of five lignocellulosic materials (tree trimmings, sugarcane bagasse, sawdust, cotton residues, and Napier grass) as bulking agents during composting of poultry wastes; the composts generated by mixing lignocellulosic materials and poultry wastes showed distinct chemical characteristics, several of which render these composts relatively suitable for use as soil conditioners and nutrient carriers. However, the structural and functional properties of the organic matter of the composts remain unknown. In this study, the productivity of Giant of Italy parsley (*Petroselinum crispum*) plants grown in the five composts combined with charcoal (organic amendments) was evaluated with respect to the following parameters: (i) the functional groups present in organic amendments and (ii) the H_{LIF} of organic amendments. Multiple linear regression (MLR) and simple non-linear regression (SNLR) analyses were conducted to assess the influence of functional groups and H_{LIF} on dry matter (DM) yield (i) to predict parsley yield based on the physicochemical characteristics of the organic amendments and (ii) to predict the optimum charcoal waste rate required to achieve the maximum DM yield of parsley plants.

2. Materials and Methods

2.1. Organic Amendments

2.1.1. Production of Composts

Organic amendments were produced by first composting poultry industry wastes with different lignocellulosic (carbon) sources used as bulking agents, as previously detailed by Costa et al. [8]. Briefly, the lignocellulosic sources used were urban tree trimmings, milled sugarcane bagasse, sawdust, cotton residues, and ground Napier grass (*Pennisetum purpureum*). A mixture of the following poultry industry wastes was used in all compost formulations: poultry litter, hatchery waste, floating sludge, and cellulosic casing. Piles of bulking agents and poultry wastes with a C:N ratio of ca. 30 were prepared. Five compost windrows were built for processing the piles. Windrow temperature was measured daily, and a compost was considered stable when there was little or no difference between windrow temperature and ambient temperature. The stabilization and maturation time of each compost prior to use as organic amendment and the C:N ratio of mature composts are shown in Table 1. The mature composts were designated TR, BA, SA, CO, NA for the composts obtained using as bulking agent tree trimmings, sugarcane bagasse, sawdust, cotton residues, and Napier grass, respectively.

Table 1. Compost stabilization time, maturation time, and final C:N ratio. Composts were made from poultry industry wastes and tree trimmings (TR), sugarcane bagasse (BA), sawdust (SA), cotton residues (CO), and Napier grass (NA).

Compost *	Stabilization Time (Days)	Maturation Time (Days)	C:N
TR	91	375	15
BA	91	375	15
SA	154	312	23
CO	84	382	11
NA	91	375	16

* Source: Costa et al. [8].

2.1.2. Physicochemical Characterization of Composts and Organic Amendments

Electrical conductivity (EC) and pH (5:1 water:compost) of the experimental composts were determined using the methods described by Brazil [31]. All composts showed high EC values, ca., over 10 dS m^{-1} (data not shown). The possibility of using charcoal to dilute the composts such as not to exceed the recommended EC range for horticultural crops was tested by adding charcoal at different rates, namely: 0%, 15%, 30%, 45%, and 60%, on a weight basis. The charcoal and compost mixtures constituted the organic amendments

studied in this experiment. Portions of the organic amendments were digested in a nitric-perchloric solution, and P content was determined according to the method described by Lana et al. [32] by measuring the absorbance at 725 nm using an ultraviolet (UV)–visible spectrophotometer (Femto 700 Plus, São Paulo, Brazil). In turn, K was measured using a DM-62 flame photometer (Digimed, São Paulo, Brazil). N content was determined by digesting the samples with sulfuric acid followed by distillation using a Kjeldahl system (TE-0364 Kjeldahl analyzer, Tecnal, São Paulo, Brazil) according to the method of Malavolta et al. [33]. Total organic carbon (TOC) of the organic amendments was determined gravimetrically according to Cunha-Queda et al. [34]. The C:N ratio was calculated from the values of TOC and N [35]. Cation exchange capacity (CEC) was determined by titration with a calcium acetate solution and activated charcoal according to the EMBRAPA method [36]. The C contents of the humic acid (HA) and fulvic acid (FA) fractions were determined quantitatively using the extraction and fractionation method for humic substances described by Benites et al. [37]. Finally, the HA:FA ratio was calculated from the values of HA and FA. All analyses were performed in triplicate. Unless otherwise stated, all reagents used in this study were obtained from Sigma-Aldrich Brasil Ltda (São Paulo; Brazil).

2.1.3. Fractionation and Spectroscopic Characterization of Organic Amendments

The functional groups present in HA of the organic amendments were characterized using FTIR spectroscopy according to the method described by Stevenson [38]. Briefly, samples were compressed with potassium bromide (KBr) into pellets at a ratio of 1:100 (i.e., 1.5 mg of sample to 150 mg of KBr). Next, FTIR spectra were averaged from 64 scans measured from 4000 to 400 cm^{-1} with a 4-cm^{-1} spectral resolution. FTIR analyses were performed using a Frontier™ MIR-FIR spectrometer (PerkinElmer, Waltham, MA, USA) in the Analysis Center at the Federal University of Technology–Paraná in Pato Branco, Paraná, Brazil.

LIF spectroscopy was performed using the method of Milori et al. [39]. The spectroscopy system (OPL- WO2010069017A1, Embrapa Instrumentação, São Carlos, Brazil) comprised an argon laser, a prism to remove background gas fluorescence, mirrors for conducting the excitation to the sample, a lens to collect the fluorescence, an optical chopper, a filter to suppress excitation in the detector, a monochromator (CVI, L = 25 cm), a photomultiplier, a lock-in amplifier, and a notebook computer fitted with an acquisition board, a data control and acquisition software. The H_{LIF} was calculated from the ratio between the area under the fluorescence emission spectrum (acriflavine; 440–800 nm) and the TOC content.

2.2. Giant of Italy Parsley Production

The experiment was conducted in a 105 m^2 glasshouse with a 30% Aluminet® shade-cloth roof. The glasshouse is located at the Western Paraná State University (UNIOESTE) in Cascavel, state of Paraná, southern Brazil (24°54′01″ S; 53°32′01″ W, average elevation of 781 m). Giant of Italy parsley seedlings were purchased locally at 30 days after seedling emergence and transplanted—one seedling per pot—into 1-L pots (10.5 cm height, 12.5 cm top diameter, 10 cm bottom diameter). Giant of Italy parsley plants were grown in the five compost formulations listed above, each combined with charcoal at the five inclusion rates listed above, and the experiments were replicated four times. Pots were placed on 0.80 m × 2.20 m wooden benches. Plants were watered manually based on estimated daily soil evaporation loss by changes in pot weight. Pots were rotated among benches and rows daily to reduce border effects on plant growth.

The crop was harvested 50 days after transplanting. Samples were washed with running water to remove any soil or debris attached to the aerial parts (stems and leaves). DM was determined after freeze-drying at −20 °C for ≈18 h.

2.3. Statistical Analysis

Spectroscopic and physicochemical analyses of the composts and composts-charcoal mixtures were performed in triplicate ($N = 3$). For parsley growth, a complete randomized 5×5 factorial design was established with five composts and five charcoal inclusion rates with four replications ($N = 4$) for a total of 100 experimental units. Analysis of variance (ANOVA) was used to determine treatment effects on DM yield of parsley, and treatment means were compared using the Scott-Knott test ($p \leq 0.05$). Spectroscopic and physicochemical characteristics of the organic amendments were used to estimate the degree of accuracy for predicting DM yield via MLR analysis with DM as response variable and physicochemical characteristics (N, P, K, pH, EC, TOC, C/N, CEC, HA/FA, H_{LIF}) of organic amendments as explanatory variables. The best-fitting MLR model was selected using the best subsets of the regression tool. The combination of explanatory variables with the highest R^2, lowest standard error, and Mallows's Cp closest to the number of parameters was selected. To validate the model, the following assumptions were assessed: error (ξ) randomness; ξ, zero mean; ξ, homoscedasticity (Goldfeld–Quandt test); ξ, normality (Anderson-Darling test); absence of serial autocorrelation (Durbin-Watson test); absence of Xi measurement error; and absence of multicollinearity (variance inflation factor). The following estimates were used to detect influential points: hii element (leverage), Cook's distance (Di), and modified Cook's distance (DFit). Concomitantly, SNLR analysis was used to predict the optimum charcoal rate required to achieve the maximum theoretical DM yield of parsley plants.

3. Results and Discussion

3.1. Spectroscopic Characterization—Functional Groups

The availability of nutrients to plants is influenced by the amount and type of C in the growing substrate, whereas the humification process is affected by the quality of the C present in the compost [13,40,41]. In this respect, FTIR spectra have been widely used to investigate the changes to structural and functional HA groups associated with composting [42–45]. Thus, the spectroscopic characterization of the HA fraction extracted from the different experimental composts may provide important information regarding the quality of the organic amendments used in this study for parsley production. FTIR spectra of the HA fraction from composts prepared from poultry wastes and different bulking agents combined with charcoal are shown in Figure 1a–e. The FTIR spectra of HA from all composts showed similar absorption bands that differed only in their relative intensity. The main spectra were identified; the corresponding characteristics are described as follows: (a) an absorption band at approximately 3438 to 3418 cm^{-1}, commonly attributed to the O–H stretching of alcohols, phenols, and organic acids, as well as H-bonded N–H groups; (b) a weak band at approximately 2998 to 2943 cm^{-1}, caused by the C–H stretching of alkyl structures; (c) an absorbance band at approximately 1600 to 1646 cm^{-1}, primarily attributed to aromatic and olefinic C=C and C=O bonds in carboxyl, amide, ketone, and quinone groups; (d) a peak near 1448 cm^{-1}, generally associated with the O–H bond of phenols, COO^{-}, $–CH_3$, and amides; and (e) a sharp band centered at approximately 1141 cm^{-1}, attributed to the C–O stretching of secondary alcohols and/or ethers.

For all spectra (Figure 1), a broad band of weak intensity was identified at the end of composting in the region near 3420 cm^{-1}, commonly attributed to the O–H stretching. The region from 3200 to 2500 cm^{-1} is characterized by asymmetric stretches of C–H bonds with possible intramolecular bonds between phenols; the band is generally weak and may not even be observed, which is supported by the weak signal identified at 2965 cm^{-1} in all amendments. This signal is important because it correlates linearly with compost humification and maturity; in contrast, the presence of a strong signal from aliphatic C–H stretching is associated with poorly humified amendments [46–48]. Thus, the low intensity observed for this signal indicates that growing substrates were highly humified, stable and mature, which would presumably enhance parsley yield. For all spectra, an inconspicuous signal was identified in the vicinity of 1625 cm^{-1}, which can be assigned to aromatic ring

stretching of lignin monomers which is characteristic of compost [49]. Meanwhile, the peak at approximately 1448 cm^{-1} is attributed to O–H stretching in phenols, aromatic rings, and carbonates. The high signal intensity observed for all compost formulations at 1448 cm^{-1} is likely due to an increase in the relative intensity of polycondensed aromatic structures, primarily aromatic ethers-esters, which are associated with compost humification and maturation [50]. The signal with highest intensity was observed at 1141 cm^{-1} for all amendments and corresponds to C–O stretching of polysaccharides [51]. In general, although the addition of charcoal to compost did not result in any changes to the structural composition of the HA fraction, there were variations in signal intensities associated with O–H stretching of phenols, aromatic rings, and carbonates (1625 to 1448 cm^{-1}), for all amendments. Overall, these results showed that the intensities of the signals characteristic of aromatic structures were higher in composted SA–, BA–, and TR–derived amendments, compared with CO- or NA-derived amendments (Figure 1a–e).

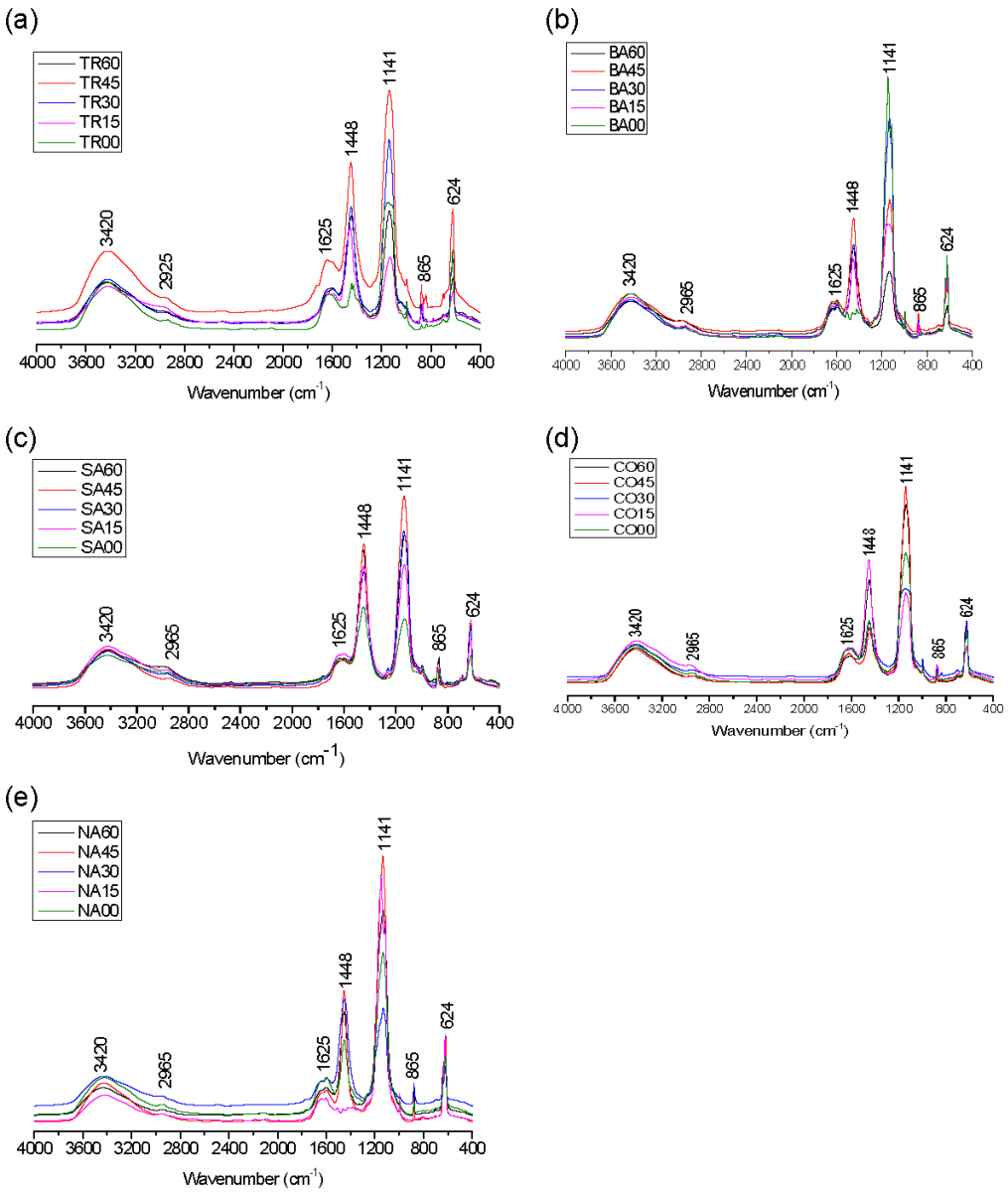

Figure 1. FTIR spectra of the humic acid (HA) fraction in composts made from poultry industry wastes mixed with (**a**) tree trimmings; TR (**b**) sugarcane bagasse; BA (**c**) sawdust; SA (**d**) cotton residues; CO and (**e**) Napier grass; NA. The number following the compost letter corresponds to the proportion of charcoal in the organic amendment, i.e., 0% 15%, 30%, 45%, and 60% (weight basis).

Humification is a process to which plant and microbiota residues are subjected in natural soils under the actions of microorganisms and other environmental factors [52]. Data from various spectroscopic and other analytical techniques (e.g., UV–Visible, synchronous fluorescence, FTIR, and ^{13}C-nuclear magnetic resonance) have shown that composting of organic wastes may be seen as an artificial process of humification. Indeed, these techniques coupled with principal component analysis [52,53] were able to group together composted materials and standards humic and fulvic acids samples from the International Humic Substances Society (https://humic-substances.org; accessed on 9 December 2021). The data from this study showed that composting could share secondary reactions and processes with the first steps of natural humification occurring in soils.

3.2. Spectroscopic Characterization—Humification Degree

LIF spectroscopy is a promising technique for organic matter studies [39], allowing for rapid analysis of samples without any prior chemical treatment. Furthermore, LIF has been used to assess the degree of humification of organic matter in soil/substrate samples using spectra comparable to electron paramagnetic resonance and nuclear magnetic resonance spectra to estimate the H_{LIF} [16,19]. The H_{LIF} values for TR, BA, SA, CO, and NA composts without the addition of charcoal are shown in Figure 2a.

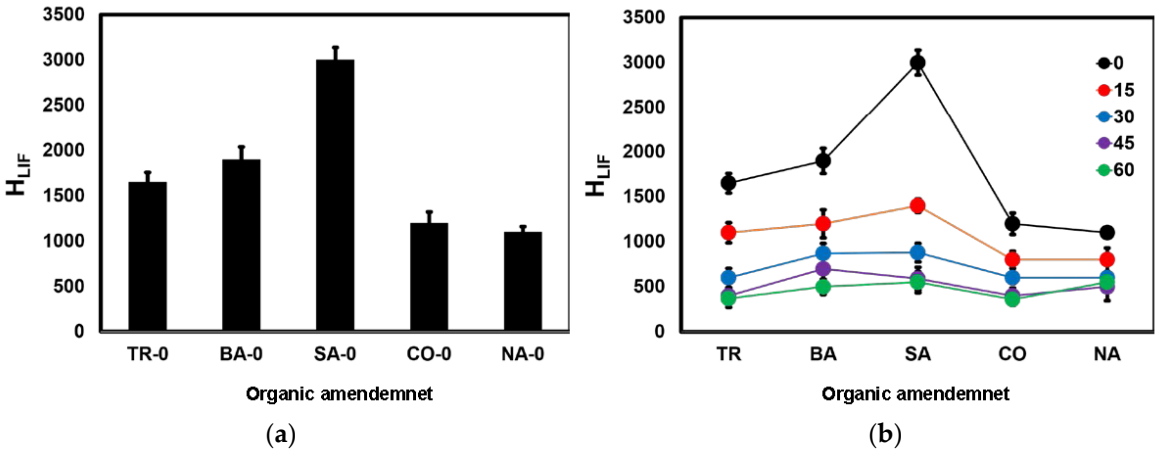

Figure 2. Humification index (H_{LIF}) (**a**) of the composts without charcoal addition, and (**b**) of the organic amendments with charcoal addition. Composts were made from poultry industry wastes added with tree trimmings (TR), sugarcane bagasse (BA), sawdust (SA), cotton residue (CO), and Napier grass (NA). The numbers 0, 15, 30, 45, and 60 correspond to the proportion of charcoal in the organic amendment (%, weight basis). Error bars represent standard deviations.

H_{LIF} values were lowest in NA and CO amendments (Figure 2a). It is important to note that the low H_{LIF} values of these two organic amendments were in addition to the low presence of aromatic structures suggested by FTIR results described above for the two amendments (Figure 1). Conversely, high H_{LIF} values were associated with a high concentration of aromatic groups in the amendments, compared with initial TOC, i.e., a higher degree of humification for SA and BA amendments. Interestingly, the addition of charcoal to the composts caused a reduction in H_{LIF} value (Figure 2b), an indication that charcoal diluted the polyphenols and reduced the aromaticity of the composts [22,35], thereby reducing the degree of humification of the organic amendments. The results suggest that addition of charcoal to composts cannot be considered a method to enhance humification. Other materials such as biochar [54] and clay [55] have been found to stimulate the synthesis of HA during composting of pig manure. In the study by Ren et al. [55], clay promoted the degradation of organic matter, which occurred in parallel with the formation of aromatic carbon compounds.

3.3. DM of the Aboveground Plant Body of Giant of Italy Parsley

In this study, there was a significant difference ($p \leq 0.05$) in the DM yield of parsley plants grown in composts with different charcoal amounts (Table 2). The results showed that, on average, DM yields of parsley plants grown in CO and NA amendments were lower than those of plants grown in TR, SA, and BA amendments. Parsley DM yield of aerial plant parts reflects the nutrient composition of the growing substrate and has been typically used to assess plant responses to nutrient availability [14]. The low H_{LIF} values for NA and CO (Figure 2), in addition to other previously discussed factors—such as the scarcity of aromatic structures in the two amendments (Figure 1)—may explain the low yield of Giant of Italy parsley grown in these organic amendments. In contrast, parsley yield and C/N ratio were highest in the SA and the BA amendments, which were characterized by the highest H_{LIF} values (Figure 2).

Table 2. Dry matter (DM) and fresh matter (FM) yields (g plant^{-1}) of Giant of Italy parsley grown on organic amendments made from mixtures of composts and charcoal. Composts were made from poultry industry wastes and tree trimmings (TR), sugarcane bagasse (BA), sawdust (SA), cotton waste (CO), and Napier grass (NA). Different lowercase letters in the rows indicate statistical differences between the means for organic amendments; different capital letters in the columns indicate statistical differences between the means for the amount of charcoal ($p \leq 0.05$; Scott-Knott test).

Charcoal Amount		Organic Amendments				
		TR	**BA**	**SA**	**CO**	**NA**
60%	DM	1.61 ± 0.07 cA	4.33 ± 0.18 aA	3.11 ± 0.39 bC	2.81 ± 0.74 bA	1.73 ± 0.14 cA
	FM	11.80 ± 3.05 cB	29.04 ± 2.34 aA	19.06 ± 1.90 bC	22.49 ± 2.40 bA	10.21 ± 1.20 cA
45%	DM	1.82 ± 0.92 cA	3.88 ± 0.57 aA	4.38 ± 0.35 aB	2.81 ± 0.52 bA	0.47 ± 0.02 dB
	FM	12.29 ± 2.69 cB	23.84 ± 5.85 abB	30.65 ± 0.09 aB	21.99 ± 3.83 bA	3.76 ± 0.04 dB
30%	DM	2.64 ± 0.03 bA	3.80 ± 0.73 aA	4.33 ± 0.53 aB	3.20 ± 0.15 bA	0.03 ± 0.41 cB
	FM	18.20 ± 3.26 bA	23.51 ± 2.62 abB	26.88 ± 5.81 aB	26.63 ± 1.48 aA	0.24 ± 3.34 cB
15%	DM	2.49 ± 0.76 bA	2.74 ± 1.58 bB	5.65 ± 0.84 aA	0.41 ± 0.79 cB	0.02 ± 0.07 cB
	FM	17.78 ± 1.80 bA	17.80 ± 1.83 bC	38.64 ± 3.80 aA	2.42 ± 3.84 cB	0.18 ± 0.41 cB
0%	DM	1.79 ± 0.27 bA	2.34 ± 0.92 bB	3.85 ± 0.29 aB	0.27 ± 0.23 cB	0.03 ± 0.11 cB
	FM	14.72 ± 5.12 bAB	15.76 ± 2.38 bC	29.77 ± 3.25 aB	1.52 ± 1.58 cB	0.42 ± 0.40 cB

3.4. Physicochemical Characteristics of the Organic Amendments

The main physical properties and the chemical composition of the organic amendments were determined to enhance understanding of the factors related to variations in parsley yield. The results of the determinations are summarized in Figures 3 and 4. The highest EC values were measured in the organic amendments produced from CO; among these, EC values recorded were: 18.30, 15.50, 13.20, 7.94, and 6.55 dS m^{-1} for CO composts combined with 0%, 15%, 30%, 45%, and 60% charcoal, respectively (Figure 3). NA amendments also exhibited high EC values, which partly explained the low yield of parsley grown on CO and NA amendments (Table 2). The Napier grass used in composting the NA amendment reportedly exerts strong negative allelopathic effects on the germination of several plants [56,57], parsley among them. P, K, and N values were within the range of those reported for conventionally grown parsley in the state of Paraná in Brazil [14,58]. Levels of P, K, and N tended to be high in amendments with high EC values (Figure 3); however, elevated EC values are known to reduce the availability of several nutrients (e.g., P, N, Ca, and Mg) [59]. Contrary to nutrients and EC, pH valued tended to increase with higher inclusion rates of charcoal; at alkaline pH values, P tend to react quickly with Ca and Mg to form less soluble compounds [59,60]. Indeed, excessive levels of a given soil parameter may reduce the rate of absorption of some nutrients, thereby leading to deficiency symptoms [60]. Findings of elevated levels of nutrients in CO and NA amendments were consistent with observed TOC and CEC levels but not with C:N and FA:HA values (Figure 4).

3.5. Modeling of the Relationship between DM Yield and Physicochemical Characteristics of the Organic Amendments

Regression analyses were used to predict DM yield as a function of the spectroscopic and physicochemical characteristics of the organic amendments. The original analysis included all the variables, including namely N, P, K, pH, EC, TOC, C:N, CEC, HA:FA, and H_{LIF}. *p*-values for C:N, CEC, and HA:FA were highly insignificant, and since the addition of these variables did not improve the model, the variables were excluded. Data were subjected to MLR analysis and a non-linear equation fitted to the observed data is shown below:

$$DM = 116 + 3.68 \times N + 0.00699 \times P + 0.00222 \times K - 10.3 \times pH - 3.78 \times EC - 1.24 \times TOC - 0.00027 \times H_{LIF}$$

where, DM = dry matter (g); N = nitrogen (g kg^{-1}); P = phosphorus (g kg^{-1}); K = potassium (g kg^{-1}); pH = hydrogen potential; EC = electrical conductivity (dS m^{-1}); TOC = total organic carbon (g kg^{-1}); H_{LIF} = humification index.

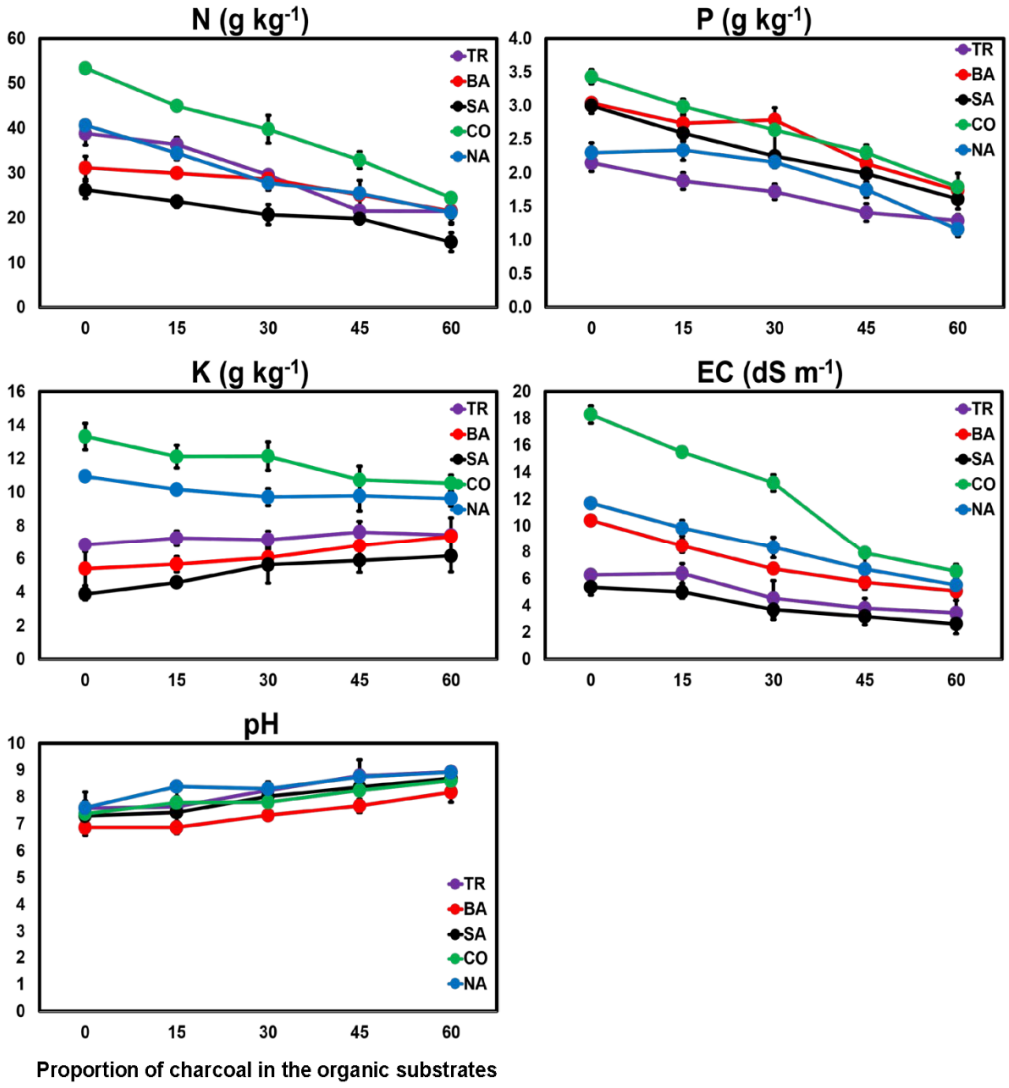

Figure 3. Mineral content (N, P, K), electrical conductivity (EC), and pH of organic amendments made from mixtures of composts and charcoal. Composts were made from poultry industry wastes and tree trimmings (TR), sugarcane bagasse (BA), sawdust (SA), cotton residues (CO), and Napier grass (NA). The numbers 0, 15, 30, 45, and 60 correspond to the proportion of charcoal in the organic amendment (%, weight basis). Error bars represent standard deviations.

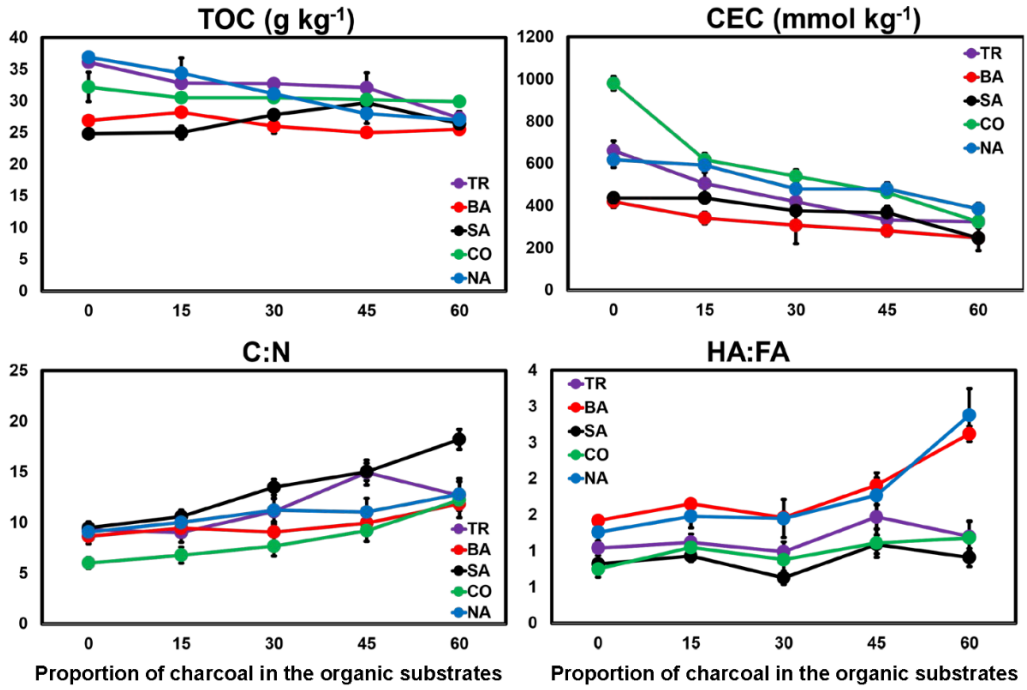

Figure 4. Total organic carbon content (TOC), cation exchange capacity (CEC), C:N and humic acid/fulvic acid (HA/FA) ratios of organic amendments made from mixtures of composts and charcoal. Composts were made from poultry industry wastes and tree trimmings (TR), sugarcane bagasse (BA), sawdust (SA), cotton residues (CO), and Napier grass (NA). The numbers 0, 15, 30, 45, and 60 correspond to the proportion of charcoal in the organic amendment (%, weight basis). Error bars represent standard deviations.

ANOVA showed that the model was statistically significant ($p \leq 0.05$) (Table 3). The coefficient of determination R^2 and adjusted R^2 values were 73.0% and 61.8%, respectively, for F (test statistics) = 6.55 (a large F ratio showing that there is evidence against the null hypothesis), indicating that the explanatory variables explained a large proportion of the variability in DM yield. SNLR models considering "DM" as the response variable and each of the spectroscopic and physicochemical parameters as the explanatory variable were also constructed seeking to identify those explanatory variables having a significant effect on the model. Of all explanatory variables included in the model, only EC had a significant effect ($p = 0.016$) on DM yield (Table 3).

EC is a direct measurement of energy flow in the soil system. Energy itself is a function of soil ionic concentrations, soil organic matter, CEC, moisture content, porosity, and salinity, among other parameters [61]. Thus, EC can serve as a proxy of a variety of soil and substrate characteristics that are correlated to crop productivity. In this study, the most significant relationship was the negative correlation between EC and parsley yield. Indeed, biomass production was negatively affected by high EC values at low charcoal rates (Table 2). EC has traditionally been used to measure salinity. High osmotic pressure of a saline solution leads to decreased water absorption, reduced nutrient transport and inhibition of plant growth [59,62]. The negative effects of salinity can be attributed to high toxicity of Na^+, Cl^-, SO_4^{2-}, CO_3^-, HCO_3^-, and BO_3^- ions [43,63,64]. The harmful effects of salinity are more evident on the translocation of photoassimilates, directly affecting biomass accumulation in the aboveground plant body [65]. In this study, the lowest EC values were measured in the SA amendments, specifically 5.37, 5.01, 3.69, 3.18, and 2.63 dS m^{-1} for composts mixed with 0%, 15%, 30%, 45%, and 60% charcoal, respectively (Figure 3), suggesting that the concentrations of ionizable salts in the SA amendments were below the levels that are toxic to plants. Thus, low ionizable salt concentrations may have contributed to higher parsley DM yield in the SA amendments than in any other amendments.

Table 3. Result of the Multiple Linear Regression analysis (MLR) using "parsley DM" as the response variable and "spectroscopic and physicochemical parameters of the organic amendments" as explanatory variables. ANOVA calculations (Regression, Error and Total) that formed the basis for the test of significance for the model are also displayed in the table.

Source of Variation	Degrees of Freedom (DF)	Sum of Squares (SS)	Mean Square (MS)	*p* Value
Regression	7	1418.69	202.67	0.001
Error	17	525.70	30.92	-
Total	24	1944.39	-	-
Explanatory variable	Least-squares (Coef)	Standard deviation (SD)	Two-sided test (T)	*p* value
CONSTANT	116.050	49.970	2.32	0.033
N	3.683	4.913	0.75	0.464
P	0.006	0.005	1.28	0.217
K	0.002	0.001	1.13	0.275
pH	−10.304	5.990	−1.72	0.104
EC	−3.778	1.406	−2.69	0.016
TOC	−1.239	0.594	−2.09	0.052
H_{LIF}	−0.000	0.003	−0.08	0.937

3.6. Modeling of the Relationship between DM, FM Yield and Amount of Charcoal Added to the Organic Amendments

In this study, increasing rates of charcoal from the poultry industry were added to composts to reduce the EC of the experimental organic amendments used. The results showed that DM yield seem to increase with increasing amounts of charcoal only in the NA and BA amendments (Table 2). An SNLR model that considers "charcoal rate" as the explanatory variable and "DM yield" or "FM yield" as the response variable produced the regression equations in Table 4. For each compost studied, the equations were used to examine overall plant's responses to organic amendments and, when applicable, to estimate the optimum charcoal rate for parsley productivity. The equations indicated less deviation between observed and fitted values for the BA (R^2 = 0.9513), TR (R^2 = 0.7739), and CO (R^2 = 0.7854) amendments, compared with the SA and NA amendments (Table 4). A linear equation was generated only for the NA amendments, i.e., biomass yield of plants grown on NA increased as the proportion of charcoal in compost increased. However, increases were very small, which is somewhat an impediment to the use of NA as growing substrate for parsley production.

Table 4. Nonlinear and linear regression equations for the relationship between the amount of charcoal (0%, 15%, 30%, 45%, and 60%, weight basis) added to the growth media (composts) and parsley DM and FM yields. The composts were made from poultry industry wastes and tree trimmings (TR), sugarcane bagasse (BA), sawdust (SA), cotton residues (CO), and Napier grass (NA).

Compost	Regression Equation	R^2
TR	$DM = -0.0009x^2 + 0.0459x + 1.8844$	0.7739
	$FM = -0.0048x^2 + 0.2074x + 14.291$	0.9311
BA	$DM = -0.0003x^2 + 0.0176x + 4.3221$	0.9513
	$FM = -0.0029x^2 + 0.317x + 17.703$	0.7777
SA	$DM = -0.0015x^2 + 0.0726x + 4.1324$	0.6926
	$FM = -0.0074x^2 + 0.3134x + 28.244$	0.6027
CO	$DM = -0.0011x^2 + 0.1163x - 0.093$	0.7854
	$FM = -0.0065x^2 + 0.6629x + 0.1381$	0.7683
NA	$DM = 0.0262x - 0.339$	0.6970
	$FM = 0.0768x - 0.896$	0.7863

The regression equations between charcoal rate in the growth medium and parsley DM yield did not permit the determination of the optimum charcoal amount, except for the TR and SA amendments. Such optimum proportions were estimated at 23.6% and

22.7%, for TR and SA amendments, respectively. This was an interesting finding, as the TR amendments resulted in low DM yield compared with the SA amendments (Table 2), implying that charcoal may be used to ameliorate the quality of even the most unsuitable organic amendments. Indeed, the addition of a moderate amount of charcoal to all the composts tested herein tended to lower EC values, which might have increased the availability of nutrients for plant growth [61,62]. According to Anower et al. [66], most crops prefer a growing medium with an EC value of 2.0 to 4.6 dS m^{-1}. However, further studies are required to determine the standard recommended range of EC for several horticultural crops, including Giant of Italy parsley. High yields ($\geq$3.5 g $plant^{-1}$ DW) in this study were obtained with plants grown on amendments with EC values ranging from 3.18 dS m^{-1} (4.38 g $plant^{-1}$ DW on SA45) to 6.75 dS m^{-1} (3.80 g $plant^{-1}$ DW on BA30). Further research is needed to identify the mechanism of action of charcoal as well as the most critical factors influencing EC that may be managed to obtain a good estimate of the amount of charcoal to add to each organic amendments to achieve maximum crop productivity. If well managed, charcoal waste from the poultry industry might well become an alternative to substrates such as peat [10].

4. Conclusions

In this study, the suitability of composts obtained from wastes of the poultry industry and five different plant debris as growth media for Giant of Italy parsley was evaluated. Because the EC of the composts was high ($\geq$10 dS m^{-1}), charcoal waste, another by-product from the poultry industry, was added to the composts to improve their physicochemical properties. The addition of charcoal to composts significantly lowered EC values within the range of those reported for optimum growth of several horticultural crops, but tended to increase the medium pH. A positive correlation was found between EC and the nutrients N, P, and K. For most composts, no linear relationship was identified between charcoal amount and parsley yield. FTIR spectroscopy showed that the organic amendments, particularly BA and SA, were rich in aromatic compounds, which is an important indicator of compost maturity. Indeed, for the signal at 1448 cm^{-1}, absorbance intensity varied depending on the organic amendments. Furthermore, LIF spectroscopy confirmed a higher humification degree (as measured by the H_{LIF}) of the SA amendments compared with those of any other amendments, which was associated with higher parsley productivity. All results showed that Napier grass should be avoided as a bulking agent in the composting of poultry wastes. Linear and non-linear regression equations were developed to determine the effects of functional groups, H_{LIF}, N, P, and K contents, pH, EC, C, C:N, HA:HA, and CEC on DM yield. These regressions showed that EC was the main factor affecting biomass production in parsley plants. Manipulations of the equations may be used for selection of compost sources, determination of the application rate of organic amendments, and prediction of DM yield.

Author Contributions: Conceptualization, M.S.S.M.C., L.M.S.T. and P.G.; methodology, F.T.S., P.G., L.A.M.C., M.S.S.M.C., L.M.S.T., H.E.F.L. and H.T.; validation, P.G. and M.S.S.M.C.; formal analysis, F.T.S., L.M.S.T., H.E.F.L. and P.G.; investigation, F.T.S., M.S.S.M.C., L.M.S.T., H.E.F.L. and L.A.M.C.; resources, M.S.S.M.C.; data curation, P.G. and L.M.S.T.; writing—original draft preparation, F.T.S.; writing—review and editing, F.T.S., P.G., L.A.M.C., M.S.S.M.C., L.M.S.T., H.E.F.L. and H.T.; supervision, M.S.S.M.C. and P.G.; project administration, M.S.S.M.C.; funding acquisition, M.S.S.M.C. and P.G. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the Fundação para a Ciência e a Tecnologia (grant number UIDB/04033/2020). The authors are grateful to the PhD scholarship awarded to Francielly T. Santos by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES sandwich mode PSDE, no. 6547-14-1).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data that support the findings of this study are available within the article.

Acknowledgments: The authors are grateful to the Agricultural Engineering Graduate Program PGEAGRI of Universidade Estadual do Oeste do Paraná (Brazil).

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

References

1. ABPA. *Anual Report 2020*, 1st ed.; Associação Brasileira de Proteína Animal: São Paulo, Brazil, 2020; pp. 1–116. Available online: https://abpa-br.org/wp-content/uploads/2021/04/ABPA_Relatorio_Anual_2021_web.pdf (accessed on 9 December 2021).
2. Chiarelotto, M.; Damaceno, F.M.; Lorin, H.E.F.; Tonial, L.M.S.; de Mendonça Costa, L.A.; Bustamante, M.A.; Moral, R.; Marhuenda-Egea, F.C.; Costa, M.S.S.M. Reducing the composting time of broiler agro-industrial wastes: The effect of process monitoring parameters and agronomic quality. *Waste Manag.* **2019**, *96*, 25–35. [CrossRef] [PubMed]
3. Sosa, L.L.; Benítez, E.; Girón, J.; Madejón, E. Agro-industrial and urban compost as an alternative of inorganic fertilizers in traditional rainfed olive grove under mediterranean conditions. *Agronomy* **2021**, *11*, 1223. [CrossRef]
4. Wainaina, S.; Awasthi, M.K.; Sarsaiya, S.; Chen, H.; Singh, E.; Kumar, A.; Ravindran, B.; Awasthi, S.K.; Liu, T.; Duan, Y.; et al. Resource recovery and circular economy from organic solid waste using aerobic and anaerobic digestion technologies. *Bioresour. Technol.* **2020**, *301*, 122778. [CrossRef] [PubMed]
5. Guilabert, F.J.; Barber, X.; Pérez-Murcia, M.D.; Agulló, E.; Andreu-Rodríguez, F.J.; Moral, R.; Bustamante, M.Á. Management of green waste streams from different origins: Assessment of different composting scenarios. *Agronomy* **2021**, *11*, 1870. [CrossRef]
6. Santos, C.; Goufo, P.; Fonseca, J.; Pereira, J.L.; Ferreira, L.; Coutinho, J.; Trindade, H. Effect of lignocellulosic and phenolic compounds on ammonia; nitric oxide and greenhouse gas emissions during composting. *J. Clean. Prod.* **2018**, *171*, 548–556. [CrossRef]
7. Adamczewska-Sowińska, K.; Sowiński, J.; Jamroz, E.; Bekier, J. Combining willow compost and peat as media for juvenile tomato transplant production. *Agronomy* **2021**, *11*, 2089. [CrossRef]
8. de Mendonça Costa, M.S.S.; Bernardi, F.H.; Costa, L.A.M.; Pereira, D.C.; Lorin, H.E.F.; Rozatti, M.A.T.; Carneiro, L.J. Composting as a cleaner strategy to broiler agro-industrial wastes: Selecting carbon source to optimize the process and improve the quality of the final compost. *J. Clean. Prod.* **2017**, *142*, 2084–2092. [CrossRef]
9. Paula, F.S.; Tatti, E.; Abram, F.; Wilson, J.; O'Flaherty, V. Stabilisation of spent mushroom substrate for application as a plant growth-promoting organic amendment. *J. Environ. Manag.* **2017**, *196*, 476. [CrossRef] [PubMed]
10. Santos, C.; Monte, J.; Vilaça, N.; Fonseca, J.; Trindade, H.; Cortez, I.; Goufo, P. Evaluation of the Potential of Agro-Industrial Waste-Based Composts to Control Botrytis Gray Mold and Soilborne Fungal Diseases in Lettuce. *Processes* **2021**, *9*, 2231. [CrossRef]
11. Santos, F.T.; Fehmberger, C.; Aloisio, C.M.; Bautitz, J.R.; Hermes, E. Composting of swine production chain wastes with addition of crude glycerin: Organic matter degradation kinetics, functional groups, and carboxylic acids. *Environ. Sci. Pollut. Res.* **2021**, *28*, 50542–50553. [CrossRef] [PubMed]
12. dos Santos, F.T.; Ludwig, F.; Costa, L.A.M.; Costa, M.S.S.M.; Remor, M.B.; Silva, P.E.R. Growth analysis of potted gerbera conducted with mineral fertilization and organic fertigation. *Cienc. Investig. Agrar.* **2016**, *43*, 111–120. [CrossRef]
13. Fehmberger, C.; Santos, F.T.; Aloisio, C.M.; Hermes, E.; Zenatti, D.C.; Bautitz, I.R. Effectiveness of incorporation of crude glycerin as a source of labile carbon in the composting of poultry production residues. *J. Clean. Prod.* **2020**, *251*, 119739. [CrossRef]
14. Santos, F.T.; Trindade, H.; Costa, M.S.S.M.; Costa, L.A.M.; Goufo, P. Effects of composts made from broiler chicken residues and blended with biochar on the minerals and phenolic compounds in parsley (*Petroselinum crispum* Mill.). *Agriculture* **2021**, *11*, 1168. [CrossRef]
15. Zhang, S.; Wen, J.; Hu, Y.; Fang, Y.; Zhang, H.; Xing, L.; Wang, Y.; Zeng, G. Humic substances from green waste compost: An effective washing agent for heavy metal (Cd, Ni) removal from contaminated sediments. *J. Hazard. Mater.* **2019**, *366*, 210–218. [CrossRef] [PubMed]
16. Dieckow, J.; Bayer, C.; Conceição, P.C.; Zanatta, J.A.; Martin-Neto, L.; Milori, D.B.M.; Salton, J.C.; Macedo, M.M.; Mielniczuk, J.; Hernani, L.C. Land use, tillage, texture and organic matter stock and composition in tropical and subtropical Brazilian soils. *Eur. J. Soil Sci.* **2009**, *60*, 240–249. [CrossRef]
17. El Ouaqoudi, F.Z.; El Fels, L.; Lemée, L.; Amblés, A.; Hafidi, M. Evaluation of lignocellulose compost stability and maturity using spectroscopic (FTIR) and thermal (TGA/TDA) analysis. *Ecol. Eng.* **2015**, *75*, 217–222. [CrossRef]
18. Tahiri, A.; Richel, A.; Destain, J.; Druart, P.; Thonart, P.; Ongena, M. Comprehensive comparison of the chemical and structural characterization of landfill leachate and leonardite humic fractions. *Anal. Bioanal. Chem.* **2016**, *408*, 1917–1928. [CrossRef]
19. Segnini, A.; Posadas, A.; Quiroz, R.; Milori, D.M.B.P.; Saab, S.C.; Martin-Neto, L.; Vaz, C.M.P. Spectroscopic assessment of soil organic matter in wetlands from the high Andes. *Soil Sci. Soc. Am. J.* **2010**, *74*, 2246–2253. [CrossRef]
20. Burnett, S.E.; Mattson, N.S.; Wiliams, K.A. Substrates and fertilizers for organic container production of herbs, vegetables, and herbaceous ornamental plants grown in greenhouses in the United States). *Sci. Hort.* **2016**, *208*, 111–119. [CrossRef]

21. Bernardi, F.H.; Costa, M.S.S.M.; Costa, L.A.M.; Damaceno, F.M.; Chiarelotto, M. Microbiological activity during the composting of wastes from broiler productive chain. *Engenharia Agricola* **2018**, *38*, 741–750. [CrossRef]
22. Lorin, H.E.; Costa, M.S.D.M.; Chiarelotto, M.; Santos, F.T.; Costa, L.A.M. Addition of boiler charcoal waste to compost for use as substrate for vegetable seedlings. *Engenharia Agrícola* **2019**, *39*, 753–762. [CrossRef]
23. Graceson, A.; Hare, M.; Hall, N.; Monaghan, J. Use of inorganic substrates and composted green waste in growing media for green roofs. *Biosyst. Eng.* **2014**, *124*, 1–7. [CrossRef]
24. Li, Y.; Gu, J.; Zhang, S.Q.; Shi, L.X.; Sun, W.; Gian, X.; Duan, M.L.; Yin, Y.N.; Wang, X.J. Effects of adding compound microbial inoculum on microbial community diversity and enzymatic activity during co-composting. *Environ. Eng. Sci.* **2018**, *35*, 270–278. [CrossRef]
25. Santos, F.T.; Goufo, P.; Santos, C.; Botelho, D.; Fonseca, J.; Queirós, A.; Costa, M.S.S.M.; Trindade, H. Comparison of five agro-industrial waste–based composts as growing media for lettuce: Effect on yield, phenolic compounds and vitamin C. *Food Chem.* **2016**, *209*, 293–301. [CrossRef] [PubMed]
26. Di Lonardo, S.; Baronti, S.; Vaccari, F.P.; Albanese, L.; Battista, P.; Miglietta, F.; Bacci, L. Biochar-based nursery substrates: The effect of peat substitution on reduced salinity. *Urban For. Urban Green.* **2017**, *23*, 27–34. [CrossRef]
27. Huang, L.; Niu, G.; Feagley, S.E.; Gu, M. Evaluation of a hardwood biochar and two composts mixes as replacements for a peat-based commercial substrate. *Ind. Crops Prod.* **2019**, *129*, 549–560. [CrossRef]
28. Fascella, G.; D'Angiolillo, F.; Ruberto, G.; Napoli, E. Agronomic performance, essential oils and hydrodistillation wastewaters of *Lavandula angustifolia* grown on biochar-based substrates. *Ind. Crops Prod.* **2020**, *154*, 112733. [CrossRef]
29. Nocentini, M.; Panettieri, M.; Barragan, J.M.G.C.; Mastrolonardo, G.; Knicker, H. Recycling pyrolyzed organic waste from plant nurseries, rice production and shrimp industry as peat substitute in potting substrates. *J. Environ. Manag.* **2021**, *277*, 111436. [CrossRef] [PubMed]
30. Haeldermans, T.; Campion, L.; Kuppens, T.; Vanreppelen, K.; Cuypers, A.; Schreurs, S. A comparative techno-economic assessment of biochar production from different residue streams using conventional and microwave pyrolysis. *Bioresour. Technol.* **2020**, *318*, 124083. [CrossRef]
31. MAPA. *Official Analytical Methods for the Analysis of Substrates and Soil Conditioners of Ministry of Agriculture, Livestock and Supply*, 1st ed.; Official Gazette of the Federative Republic of Brazil: Brasília, Brazil, 2007; p. 8.
32. Lana, M.C.; Fey, R.; Francoloso, J.F.; Richart, A.; Fontaniva, S. *Chemical Analysis of Soil and Plant Tissue: Laboratory Practices*, 1st ed.; Edunioeste: Cascavel, Brazil, 2010; pp. 1–130.
33. Malavolta, E. *ABC of Fertilization*, 5th ed.; Agronômica Ceres: São Paulo, Brazil, 1989.
34. Cunha-Queda, A.C.; Vallini, G.; Sousa, R.F.X.B.; Duarte, E.C.N.F.A. Study of the evolution of enzymatic activities during the composting of residues from fruit and vegetable markets. *An. Inst. Super. Agron.* **2003**, *49*, 193–208.
35. Lorin, H.E.F.; Costa, M.S.S.M.; Costa, L.A.D.M.; Pereira, D.C.; Carneiro, L.J. Stabilization of confined beef cattle manure: Characteristics of produced fertilizers. *Eng. Agrícola* **2016**, *36*, 877–885. [CrossRef]
36. EMBRAPA. *Manual de Análises Químicas de Solos, Plantas e Fertilizantes*, 2nd ed.; Embrapa Solos—Empresa Brasileira de Pesquisa Agropecuária: Brasília, Brazil, 2009. Available online: https://livimagens.sct.embrapa.br/amostras/00083136.pdf (accessed on 9 December 2021).
37. Benites, V.M.; Madari, B.; Machado, P.L.O.A. *Extração e Fracionamento Quantitativo de Substâncias Húmicas do Solo: Um Procedimento Simplificado de Baixo Custo*; Embrapa Solos—Empresa Brasileira de Pesquisa Agropecuária: Rio de Janeiro, Brazil, 2003; pp. 1–7. Available online: https://ainfo.cnptia.embrapa.br/digital/bitstream/cnps/11578/1/comtec16_2003_extracao.pdf (accessed on 9 December 2021).
38. Stevenson, F.J. *Humus Chemistry: Genesis, Composition, Reactions*, 2nd ed.; John Wiley & Sons: New York, NY, USA, 1994.
39. Milori, D.M.P.B.; Galeti, H.V.A.; Martin-Neto, L.; Diekow, J.; González-Peréz, M.; Bayer, C.; Salton, J. Organic matter study of whole soil samples using laser-induced fluorescence spectroscopy. *Soil Sci. Soc. Am. J.* **2006**, *70*, 57–63. [CrossRef]
40. Primo, D.C.; Menezes, T.O.; Silva, T.O. Substâncias húmicas da matéria orgânica do solo: Uma revisão de técnicas analíticas e estudos no nordeste brasileiro. *Scientia Plena* **2011**, *7*, 1–13.
41. Jindo, K.; Martim, S.A.; Navarro, E.C.; Pérez-Alfocea, F.; Hermandez, T.; Garcia, C.; Aguiar, N.O.; Canellas, L.P. Root growth promotion by humic acids from composted and non-composted urban organic waste. *Plant Soil* **2012**, *353*, 209–220. [CrossRef]
42. Maia, C.M.B.F.; Fukamachi, C.R.B.; Piccolo, A.; Mangrich, A.S. EPR and DRIFT spectroscopic characterization of humic fractions during composting of sawdust and paper mill sludge. *Pesquisa Florestal Brasileira* **2012**, *32*, 117–122. [CrossRef]
43. Wang, K.; Li, X.; He, C.; Chen, C.L.; Bai, J.; Ren, N.; Wang, J.Y. Transformation of dissolved organic matters in swine, cow and chicken manures during composting. *Bioresour. Technol.* **2014**, *168*, 222–228. [CrossRef]
44. Fan, Y.V.; Lee, C.T.; Klemes, J.J.; Chua, L.S.; Sarmidi, M.R.; Leow, C.W. Evaluation of effective microorganisms on home scale organic waste composting. *J. Environ. Manag.* **2018**, *216*, 41–48. [CrossRef] [PubMed]
45. Hagemann, N.; Sbdiaga, E.; Orsetti, S.; Rosa, J.M.; Knocker, H.; Schimidt, H.P.; Kappler, A.; Behrens, S. Effect of biochar amendment on compost organic matter composition following aerobic composting of manure. *Sci. Total Environ.* **2018**, *613*, 20–29. [CrossRef] [PubMed]
46. Wang, Q.; Awasthi, M.K.; Zhao, J.C.; Ren, X.N.; Li, R.H.; Wang, Z.; Wang, M.J.; Zhang, Z.Q. Improvement of pig manure compost lignocellulose degradation, organic matter humification and compost quality with medical stone. *Bioresour. Technol.* **2017**, *243*, 771–777. [CrossRef]

47. Guo, X.; Li, C.; Zhu, Q.; Huang, T.; Cai, Y.; Li, N.; Liu, J.; Tan, X. Characterization of dissolved organic matter from biogas residue composting using spectroscopic techniques. *Waste Manag.* **2018**, *78*, 301–309. [CrossRef] [PubMed]
48. Kong, Z.; Wang, X.; Liu, Q.; Li, T.; Chen, X.; Chai, L.; Liu, D.; Shen, Q. Evolution of various fractions during the windrow composting of chicken manure with rice chaff. *J. Environ. Manag.* **2018**, *207*, 366–377. [CrossRef]
49. Fialho, L.L.; Silva, W.T.L.; Milori, D.M.B.P.; Martin-Neto, L.; Saab, S.C. Interference of lignin in the quantification of free radicals in the process of composting. *Rev. Química Nova* **2010**, *33*, 364–369. [CrossRef]
50. Jouraiphy, A.; Amir, S.; Gharous, M.; Revel, J.C.; Hafidi, M. Chemical and spectroscopic analysis of organic matter transformation during composting of sewage sludge and green plant waste. *Int. Biodeterior. Biodegrad.* **2005**, *56*, 101–108. [CrossRef]
51. Portes, M.L.; Dick, D.P.; Dalolin, R.S.D.; Knicker, H.; Rosa, A.S. Soil organic matter in highland leptosols: Influence of pasture management on composition and content. *Rev. Bras. Ciências Solo* **2010**, *34*, 23–32. [CrossRef]
52. Fuentes, M.; Baigorri, R.; Garcia-Mina, J.M. Maturation in composting process, an incipient humification-like step as multivariate statistical analysis of spectroscopic data shows. *Environ. Res.* **2020**, *189*, 109981. [CrossRef] [PubMed]
53. Martín-Mata, J.; Lahoz-Ramos, C.; Bustamante, M.A.; Marhuenda-Egea, F.C.; Moral, R.; Santos, A.; Sáez, J.Á.; Bernal, M.P. Thermal and spectroscopic analysis of organic matter degradation and humification during composting of pig slurry in different scenarios. *Environ. Sci. Pollut. Res.* **2016**, *23*, 17357–17369. [CrossRef] [PubMed]
54. Wang, C.; Ta, Q.; Dong, D.; Strong, P.J.; Wang, H.; Sun, B.; Wu, W. Spectroscopic evidence for biochar amendment promoting humic acid synthesis and intensifying humification during composting. *J. Hazard. Mater.* **2014**, *280*, 409–416. [CrossRef]
55. Ren, X.; Wang, W.; Li, R.; Chang, C.C.; Pan, J.; Zhang, Z. Effect of clay on greenhouse gas emissions and humification during pig manure composting as supported by spectroscopic evidence. *Sci. Total Environ.* **2020**, *737*, 139712. [CrossRef]
56. Norhafizah, M.Z.; Ismail, B.S.; Chuah, T.S. Herbicidal activity of *pennisetum purpureum* (Napier grass). *Afr. J. Biotechnol.* **2012**, *11*, 6269–6273. [CrossRef]
57. Ismail, B.S.; Tan, P.W.; Chuah, T.S. Assessment of the potential allelopathic effects of *Pennisetum purpureum* schumach. On the germination and growth of *Eleusine indica* (L.) Gaertn. *Sains Malaysiana* **2015**, *44*, 269–274. [CrossRef]
58. Trani, P.E.; Raij, B.; Cantarella, H.; Quaggio, J.A.; Furlani, A.M.C. *Boletim Técnico 100: Recomendações de Adubação e Calagem Para o Estado de São Paulo*, 2nd ed.; Instituto Agronômico & Fundação IAC: Campinas, Brazil, 1997; pp. 1–285.
59. Moraes, P.L.D.; Dias, N.S.; Oliveira, A.M.; Sousa-Neto, O.N.; Sarmento, J.D.A.; Gonzaga, M.I.S. Effects of nutrient solution salinity on the physiological performance of melon cultivated in coconut fiber. *Revista Caatinga* **2018**, *31*, 713–718. [CrossRef]
60. Luz, J.M.Q.; Andrade, L.V.; Dias, F.F.; Silva, M.A.; Haber, L.L.; Olviveira, R.C. Hydroponic production of coriander and curly parsley under concentrations of nutrient solution and plant positions in hydroponic profiles. *Biosci. J.* **2012**, *28*, 589–597.
61. Seo, M.W.; Yang, D.S.; Kays, S.J.; Kim, J.H.; Wood, J.H.; Park, K.W. Effects of nutrient solution electrical conductivity and sulfur, magnesium, and phosphorus concentration on sesquiterpene lactones in hydroponically grown lettuce (*Lactuca sativa* L.). *Sci. Hort.* **2009**, *122*, 369–374. [CrossRef]
62. Gao, Y.; Li, D.; Chen, Y. Differentiation of carbonate, chloride, and sulfate salinity responses in tall fescue. *Sci. Hort.* **2012**, *139*, 1–7. [CrossRef]
63. Hikashi, M.; Ishikawa, K. Analysis of deep groundwater in the Sambagawa belt in relation to growth of Komatsuna (*Brassica rapa* var. *Perviridis*). *Environ. Control Biol.* **2014**, *52*, 79–86. [CrossRef]
64. Agrawal, R.; Gupta, S.; Gupta, N.K.; Khandelwal, S.K.; Bhargava, R. Effect of sodium chloride on gas exchange, antioxidative defense mechanism and ion accumulation in different cultivars of Indian jujube (*Ziziphus mauritiana* L.). *Photosynthetica* **2013**, *51*, 95–101. [CrossRef]
65. Carmo, A.I.; Antonino, A.C.D.; Martins, J.M.F.; Silva, V.L.; Morel, M.C.; Gaudet, J.P. Leaching transport of naphthalene in urban soils from the metropolitan region of Recife, Pe. *Rev. Bras. Ciências Solo* **2013**, *37*, 1415–1422. [CrossRef]
66. Anower, M.R.; Mottb, I.W.; Peel, M.D.; Wu, Y. Characterization of physiological responses of two alfalfa half-sib families with improved salt tolerance. *Plant Physiol. Biochem.* **2013**, *71*, 103–111. [CrossRef]