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RESEARCH ARTICLE

Effect of Different Tannery Sludge Composts on the Production of Ryegrass: A Pot Experiment

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Abstract:

Background:

Tannery industry produces high amounts of nutrient rich sludges that can be used as organic fertilizers.

Objective:

The aim of this study was to evaluate the fertilizing potential of composted tannery sludge.

Methods:

A pot experiment was carried out with ryegrass (*Lolium perenne* L.) to test two different composts: 2.0 kg dry matter (DM) tannery fatty sludge + 1.5 kg DM sheep manure + 1.5 kg DM wheat straw (Compost 1) and 2.0 kg DM tannery sludge + 1.5 kg DM sheep manure + 1.5 kg DM wheat straw (Compost 2). Five treatments, with three replicates each, were assigned: Control (C); Compost 1 at 6 t (C1-6) and 12 t (C1-12) DM ha^{-1}; Compost 2 at 6 t (C2-6) and 12 t (C2-12) DM ha^{-1}. Each treatment was applied in a pot and mixed with 5 kg of sieved soil (<2 mm).

Results:

Results showed that production of DM ranged between 1.2 t DM ha^{-1} for C1-6 and 2.4 t DM ha^{-1} for C2-12. The highest B, Na and N levels in ryegrass was observed in C2-12, with 175 mg kg^{-1} DM, 9 g kg^{-1} DM and 30 g kg^{-1} DM, respectively. At the end of the experiment no differences were observed between treatments for C, N, P_2O_5, and K_2O levels. Differences were observed at Zn level ranged between 101 mg kg^{-1} DM for C1-6 and 71 mg kg^{-1} DM for C2-12.

Conclusion:

The C2-12 treatment was the best because induces higher DM production and nutrients in ryegrass and without dangerous concentration of heavy metals in soil. Composted waste from the tannery industry is a good source of nutrients for agriculture.

Keywords: Composting, Heavy metals, Nitrogen uptake, Organic fertilizer, Ryegrass, Tannery sludge.

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1. INTRODUCTION

The tanning industry produces high amounts of nutrient-rich waste that can be used as organic fertilizers after being subjected to composting. The tanning industry is criticized around the world for its massive waste generation, thus there is an opportunity to employ recycling and safe disposal practices of this waste [1]. The process of tanning consists of the transformation of animal skin into leather. Animal skin is submitted to different processes to eliminate meat, fat and hair [2]. The tanning industry uses skin of different animal species, and in Portugal, usually it comes from cattle, sheep and goats.

The skin is a by-product of the food industry, obtained through the skinning of the animal, carried out in slaughterhouses, which can be manual or mechanical. After skinning, the skin must be immediately subjected to a

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preservation process, which can be carried out in several ways: salting, brining, drying, mixed salting and drying at cold temperature, so that the skin is ready to be marketed and transported to the tannery factory, where it will be transformed. When the skins are received at the tanneries, they are normally trimmed, generating "raw chips", a solid residue with high chloride content. After being trimmed, the skins are subjected to a long chemical process in an aqueous bath. This process takes place in reactors such as barges and rotating drums - Foulon's. This initial phase - Sauce, Soak and Lime - generates a large volume of liquid effluents and has as its main objectives the cleaning and rehydration of the skins, as well as the destruction of the epidermis and its production, as is the case of the hair. After being subjected to this treatment, the skin is skinned, a mechanical operation by which the subcutaneous tissue of the skin, rich in proteins and fats, is removed. The solid residue resulting from the fleshing is called "gut shavings". The tanning industry generates a large quantity of wastes, being estimated that each ton of raw skin results in about 200 kg of finished skin, 120 kg of raw shavings, 150 kg of gut scrap, 100 kg of tanned waste (shavings and gut scraps) and about 50 m^3 of liquid effluents.

Environmental and economic implications, simultaneous with the proper eco-friendly removal of wastes, have made it crucial to come up with alternative waste management practices that reduce the environmental pressures resulting from imprudent disposal of such wastes [3]. To increase the productivity of the crops and to meet the heavy demand for food to feed a growing population projected to double by 2050 and natural resources to be limited due to rapid global climate change [4], it is necessary to recycle available resources and waste [5].

Wastes of animal origin, such as animal manures and tannery wastes, are a major under-utilized resource in most countries with potential for utilization in crop production [6], because they are usually high in heavy metals, namely chromium (Cr) [7 - 9]. Heavy metals are not biodegradable and can be harmful to human health [10]. Animal fleshing is a rich source of nutrients, but cannot be utilized in its current form [5, 11]. Eco-friendly technologies for managing these solid wastes, such as composting, are being widely promoted as effective and environmentally friendly processes for solid waste management [12, 13]. Composting has been used to process sludge of different origins, such as textile sludge [7, 14], and is considered an efficient method for tannery sludge recycling before its application to the soil [15, 16]. Composts can be used as fertilizers because during composting, organic matter decomposes to produce a high nitrogen content [5] and reduce pathogens and toxic organic compounds [16 - 18]. Composting is a dynamic process of rapid successive reactions that involve the breaking down of organic matter, under controlled aerobic conditions, into valuable products [18].

Miranda *et al*. [8] reported that the use of composted tannery sludge improved the physical and chemical properties of soil. Recently, within the European Union (EU) "Circular Economy Package", there has been a renewed interest in the utilization of compost for agricultural purposes, especially as a potential substitute for chemical fertilizers, ensuring, at the same time, the restoration/maintenance of soil organic carbon and biological fertility [19]. Organic waste amendment positively affects the chemical and physical properties of the soil [4]. The effects of compost on soil depend on the composting feedstock and composting procedures quality and, consequently, the crop productivity is determined by the properties of the compost applied, and these properties vary greatly [18]. To evaluate the effect of compounds on crop productivity, it is necessary to resort to tests with plants. Hence, ryegrass has been proven to be a suitable test material because it is a fast-growing species and has been widely referred to by literature for this objective [19]. For the production of 1 t DM of ryegrass, between 20 to 30 kg of N, 6 to 10 kg of P_{25} and 25 to 35 kg of K_2O are exported by this species [20]. In a similar experiment, Grigatti *et al*. [19] compared mineral fertilization with compost and used a soluble chemical reference that provided the following values: N = 140 kg ha^{-1}, P = 30 kg ha^{-1}, and K = 100 kg ha^{-1}.

Large quantities of tannery sludges are generated from industry and nutrients are not recovered/valued, becoming an environmental problem. Since this waste is rich in organic matter, the present study aimed to evaluate the potential fertilizer and/or organic corrective of composted residues from different stages and treatment processes of the tanning industry.

2. MATERIALS AND METHODS

2.1. Composting the Tannery Sludge

Two different tannery sludges, namely tannery fatty sludge and tannery sludge, were collected in a commercial tanning facility located in Seia, Portugal, and subjected to composting together with sheep manure and wheat straw. The physicochemical properties of the wastes were characterized by standard analytical methods [21] and are given in Table **1**. Briefly, pH and EC were determined by potentiometry, dry matter content by the gravimetric method, total C by dry combustion, total N by the Kjeldahl method, NH_4^+ and NO_3^- by absorption spectrophotometry, total P and K by the Egner-Riehm method, Na, Zn, Cr, Pb, Cu and Cd by atomic absorption spectrophotometry.

A pilot scale composting was performed for 135 days by a similar procedure to those described by Contreras-Ramos *et al*. [2], considering the following two mixtures with three replications: Compost 1 - 2.0 kg DM tannery fatty sludge + 1.5 kg DM sheep manure + 1.5 kg DM wheat straw; and Compost 2 - 2.0 kg DM tannery sludge + 1.5 kg DM sheep manure + 1.5 kg DM wheat straw. Each mixture was placed inside a plastic container. Twice a week, the mixture was revolved manually, and the humidity was maintained close to 50% by weighing the containers and adding deionized water whenever necessary. Sub-samples of Compost 1 and Compost 2 were collected at 0 and 135 days and characterized by standard analytical methods [21] (Table **2**). Briefly, the physicochemical composition was analysed by similar procedures as those previously referred for (Table **1**), biological characteristics using the colony count technique for the detection of total/faecal coliforms and the horizontal method for the detection of *Salmonella* spp.

Table 1. Physicochemical properties of raw wastes used to obtain tannery composts (*n*=1).

Parameter	Raw Wastes				Methods
	Tannery Fatty Sludge	Tannery Sludge	Sheep Manure	Wheat Straw	
pH (H_2O)	6.7	7.9	8.1	6.4	EN 13037
EC (mS cm^{-1})	13.9	2.4	0.7	3.5	EN 13038
Dry matter (g kg^{-1})	403	318	254	827	EN 13040
Total C (g kg^{-1} DM)	252	486	170	422	Dumas method
Total N (g kg^{-1} DM)	5.1	26.6	2.6	3.6	EN 13654
C/N	49	18	64	118	
NH_4^+-N (g kg^{-1} DM)	0.2	2.3	0.0	0.4	EN 13652
NO_3^--N (g kg^{-1} DM)	0.1	0.1	0.1	0.1	EN 13652
Total P (g kg^{-1} DM)	0.1	0.2	0.1	0.8	EN 13650
K (g kg^{-1} DM)	13.6	0.2	9.3	154.3	EN 13650
Na (g kg^{-1} DM)	98.0	4.5	1.6	13.0	EN 13650
Zn (mg kg^{-1} DM)	15	23	20	265	EN 13650
Cr (mg kg^{-1} DM)	4	27	6	35	EN 13650
Pb (mg kg^{-1} DM)	6	13	6	37	EN 13650
Cu (mg kg^{-1} DM)	4	8	6	29	EN 13650
Cd (mg kg^{-1} DM)	4	8	6	29	EN 13650

Table 2. Physicochemical properties of the two tannery mixtures subjected to composting (*n*=3).

Parameter	At 0 Days		At 135 Days		Methods
	Compost 1	Compost 2	Compost 1	Compost 2	
pH (H_2O)	7.3[b]	7.7[b]	8.2[a]	7.7[b]	EN 13037
EC (mS cm^{-1})	7.0[b]	3.1[c]	8.6[a]	1.5[d]	EN 13038
Dry matter (g kg^{-1})	435[a]	345[b]	430[a]	319[b]	EN 13040
Total C (g kg^{-1} DM)	225[c]	383[a]	193[c]	295[b]	Dumas method
Total N (g kg^{-1} DM)	5[c]	11[b]	8[c]	28[a]	EN 13654
C/N	45[a]	35[b]	25[c]	11[d]	
NH_4^+-N (g kg^{-1} DM)	0.3[b]	0.8[a]	0.3[b]	0.5[a]	EN 13652
NO_3^--N (g kg^{-1} DM)	0.2[b]	0.1[b]	0.3[a]	0.1[b]	EN 13652
P total (g kg^{-1} DM)	0.1[c]	0.1[c]	0.5[b]	1.0[a]	EN 13650
K (g kg^{-1} DM)	nd	nd	1.5[a]	0.7[b]	EN 13650
Na (g kg^{-1} DM)	nd	nd	4.7[a]	0.5[b]	EN 13650
Zn (mg kg^{-1} DM)	nd	nd	2.1[b]	22.5[a]	EN 13650
Cr (mg kg^{-1} DM)	nd	nd	0.5[b]	4.0[a]	EN 13650
Pb (mg kg^{-1} DM)	nd	nd	0.5[a]	0.7[a]	EN 13650
Cu (mg kg^{-1} DM)	nd	nd	0.5[a]	0.6[a]	EN 13650
Cd (mg kg^{-1} DM)	nd	nd	0.5[a]	0.6[a]	EN 13650
Total coliforms (CFU g^{-1})	3500[b]	8000[a]	10[c]	10[c]	ISO 4832:1991(E)
Faecal coliforms (CFU g^{-1})	10[a]	10[a]	10[a]	10[a]	ISO 4832:1991(E)
Salmonella sp.	+	+	-	-	ISO 6579:2002

Compost 1: 2.0 kg DM tannery fatty sludge + 1.5 kg DM sheep manure + 1.5 kg DM wheat straw; Compost 2: 2.0 kg DM tannery sludge + 1.5 kg DM sheep manure + 1.5 kg DM wheat straw. nd: not determinate. +: presence, -: absence. Values presented with different superscripts within rows, are significantly different (p<0.05) by Tukey test.

2.2. Soil Application of Tannery Sludge Compost

A pot experiment was run outdoors from May to November (196 days), and the agricultural soil was collected in central Portugal (latitude: 40º38´29´´N, longitude: 7º54´37´´W). The physicochemical properties of this soil (0-200 mm) were characterized by standard analytical methods [21] and are given in Table **3**. Briefly, the texture was determined by the sieving method, bulk density by the Keen & Raczkowski method, pH(H_2O) by potentiometry, water retention capacity by the gravimetric method, organic matter by determination of organic matter content and ash, extractable P and K by the Enger-Riehm method, base saturation by the ammonium acetate method, and Zn and Cr by atomic absorption spectrophotometry.

Table 3. Physicochemical characteristics of the soil used in the pot experiment (*n*=1).

Parameter	Value	Methods
Soil classification	Dystric Cambisol	World Reference Base
Texture	Silt loam	International pipette
Coarse sand (0.2-2 mm)	450 g kg^{-1}	International pipette
Fine sand (0.02-0.2 mm)	40 g kg^{-1}	International pipette
Silt (0.002-0.02 mm)	390 g kg^{-1}	International pipette
Clay (<0.002 mm)	120 g kg^{-1}	International pipette
Bulk density	1.05 g cm^{-3}	Keen & Raczkowski method
pH (H_2O)	6.0	EN 13037 method
Water retention capacity at pF 2.0	339.5 g kg^{-1}	Gravimetric method
Organic matter	41.7 g kg^{-1} dry soil	Dumas method
Extractable P	351 mg kg^{-1} dry soil	Enger-Riehm method
Extractable K	176 mg kg^{-1} dry soil	Enger-Riehm method
Base saturation	99.3%	Ammonium acetate method
Zn	6.2 mg kg^{-1} dry soil	Atomic absorption spectrophotometry
Cr	8.3 mg kg^{-1} dry soil	Atomic absorption spectrophotometry

The two tannery composts (Compost 1 and Compost 2) were applied at two rates (6 and 12 t DM ha^{-1}) in a pot experiment, giving a total of five treatments, including Control with three replicates. The treatments considered were:

(1) Non-amended soil as control (Control treatment);

(2) Application of 6 t DM ha^{-1} of Compost 1 as basal fertilizer (C1-6 treatment);

(3) Application of 12 t DM ha^{-1} of Compost 1 as basal fertilizer (C1-12 treatment);

(4) Application of 6 t DM ha^{-1} of Compost 2 as basal fertilizer (C2-6 treatment);

(5) Application of 12 t DM ha^{-1} of Compost 2 as basal fertilizer (C2-12 treatment).

The three replications of each treatment were added homogenously and incorporated by hand in each pot (200 mm depth) filled with 5 kg of sieved soil (<2 mm). Perennial ryegrass (*Lolium perenne* L.) was seeded (18 May) at a rate of 60 kg ha^{-1} and soil moisture content was maintained close to 30% water filled pore space during the growing season, being corrected whenever necessary [22, 23]. The pots were stored inside an agricultural greenhouse and air temperatures ranged from 5 to 35 ºC.

The yield of the aboveground biomass of the ryegrass was obtained by cutting the crop (46 and 196 days after the beginning of the experiment) to a height of 50 mm in each pot and weighting it, and determining dry matter (DM) yields by drying to a constant mass at 65 ºC in a forced draft oven. The soil samples of each pot were also collected at 0 and 196 days, being analysed by an elemental analyzer by Dumas (Primac SC, Skalar, Breda, NL) and near infrared detection (SanPlus, Skalar, Breda, NL), according standard laboratory methods [21].

2.3. Statistical Analysis

The data were analyzed using STATISTIX 10 (Analytical software, Tallahassee, FL, USA) by performing a one-way analysis of variance, where significant differences were observed between treatments, and means were separated using Tukey Honestly Significant Difference test at $p<0.05$.

3. RESULTS

3.1. Composting

The physicochemical properties (at 0 and 135 days) of the tannery mixtures, subjected to composing, are presented in Table **2**. The initial value of pH did not differ significantly ($p > 0.05$) among treatments (Compost 1 and Compost 2) but was significantly higher ($p < 0.05$) in Compost 1 when compared with Compost 2 (8.2 against 7.7) at the end of the experiment (Table **2**). The initial and final values of electrical conductivity were significantly higher ($p < 0.05$) in Compost 1 (7.0 mS cm^{-1} at 0 days and 8.6 mS cm^{-1} at 135 days) relative to Compost 2 (3.1 mS cm^{-1} at 0 days and 1.5 mS cm^{-1} at 135 days) (Table **2**). For each treatment, the initial and final contents of dry matter were significantly higher ($p < 0.05$) in Compost 1 relative to Compost 2 but did not differ significantly ($p > 0.05$) between days 0 and 135 (Table **2**).

The initial and final values of total C were significantly lower ($p < 0.05$) in Compost 1 relative to Compost 2 (225 against 383 g kg^{-1} DM), being significantly reduced ($p < 0.05$) in 23% in Compost 2 at the end of the composting (day 135) (Table **2**). The initial and final values of total N were significantly higher ($p < 0.05$) in Compost 2 relative to Compost 1 and differ significantly ($p < 0.05$) between days 0 and 135 for Compost 2 (11 g kg^{-1} DM at 0 day and 28 g kg^{-1} DM at 135 day) (Table **2**). The initial values of C/N were significantly higher ($p < 0.05$) in both composts, being significantly reduced ($p < 0.05$) throughout the experiment (Table **2**). The initial and final values of C/N were significantly higher ($p < 0.05$) in Compost 1 relative to Compost 2 (Table **2**). The initial and final values of total ammoniacal N were significantly higher ($p < 0.05$) in Compost 2 relative to Compost 1 but did not differ significantly ($p > 0.05$) on days 0 and 135 (Table **2**). The initial values of nitric N did not differ significantly ($p > 0.05$) among treatments (Table **2**). The initial and final values of nitric N differ significantly ($p < 0.05$) to Compost 1 (0.2 g kg^{-1} and 0.3 g kg^{-1}, respectively) (Table **2**). The final values of nitric N were significantly higher ($p < 0.05$) in Compost 1 relative to Compost 2 (0.3 g kg^{-1} DM and 0.1 g kg^{-1} DM, respectively) (Table **2**).

The initial values of P did not differ significantly ($p > 0.05$) among treatments (Compost 1 and Compost 2) but were significantly higher ($p < 0.05$) in Compost 2, when compared with Compost 1 (1.0 g kg^{-1} DM against 0.5 g kg^{-1} DM) at 135 days (Table **2**). The final values of K, Na, Zn and Cr differ significantly ($p < 0.05$) among treatments (Compost 1 and Compost 2), whereas the final values of Pb, Cu and Cd were not significantly different ($p > 0.05$) among these same treatments ($p > 0.05$) (Table **2**). In addition, the value of Na was ten times higher, and the value of K was two times higher, while the values of Zn and Cr were ten times lower in Compost 1 when compared with Compost 2 but always lower than the maximum limits fixed by national legislation [21] (Table **2**).

The initial values of total coliforms were significantly lower ($p < 0.05$) in Compost 1 when compared with Compost 2 (3500 CFG g^{-1} against 8000 CFG g^{-1}, respectively). Furthermore, the total coliforms of the two composts decreased until the end of the experiment to 10 CFU g^{-1} (Table **2**). The faecal coliforms did not differ significantly ($p > 0.05$) among Compost 1 and Compost 2, both at the beginning and at the end of the experiment (Table **2**). *Salmonella* sp. was detected in Composts 1 and 2 at the beginning of the experiment (0 days) but was not detected at the end of the experiment (135 days) (Table **2**).

3.2. Pot Experiment

The dry matter yield and nutrient uptake by ryegrass in the pot experiment are presented in (Table **4**). The application of the two rates (6 and 12 ton ha^{-1}) of compost (C1 and C2) increased significantly ($p < 0.05$) the dry matter yield of the ryegrass at the higher rate of C1, but not ($p > 0.05$) of C2 (Table **4**). The dry matter yield of the ryegrass was significantly higher ($p < 0.05$) in treatment C1-12 (2.7 t DM ha^{-1}) when compared with all other treatments, including the treatment Control (1.2-1.8 t DM ha^{-1}) (Table **4**). The N uptake by ryegrass was significantly increased ($p < 0.05$) in treatment C1-12 relative to treatment C1-6 (29.9 g kg^{-1} DM against 15.5 g kg^{-1} DM) but significant differences were not observed ($p > 0.05$) between the treatments C2-6 and C2-12 (Table **4**). The N uptake was significantly higher ($p < 0.05$) in treatment C1-12 when compared with the treatment Control (29.9 g kg^{-1} DM against 24.0 g kg^{-1} DM) (Table **4**). The P uptake by ryegrass was not significantly reduced ($p < 0.05$) in treatment C1-12 relative to treatment C1-6, while no significant difference was found ($p > 0.05$) among treatments C2-6 and C2-12 (Table **4**). Comparative to the treatment Control, the P uptake by ryegrass decreased significantly ($p < 0.05$) with the addition of compost C1, whereas no such effect ($p > 0.05$) was observed with the addition of compost C2 (Table **4**). The uptake of K, Ca, Mg, B, Fe, Cu, Zn, Mn and S by the ryegrass did not differ significantly ($p > 0.05$) among the treatment Control and all amended treatments (C1-6, C1-12, C2-6 and C2-12) (Table **4**). The Na uptake by ryegrass was significantly increased ($p < 0.05$) in treatment C1-12 relative to treatment C1-6 (9.0 g kg^{-1} DM against 2.6 g kg^{-1} DM) but significant differences ($p > 0.05$) between the treatments C2-6 and C2-12 were not observed (Table **4**). The Na uptake by ryegrass was significantly higher ($p < 0.05$) in treatment C1-12 (9.0 g kg^{-1} DM) when compared with all other treatments, including the treatment Control (1.3-2.6 g kg^{-1} DM) (Table **4**).

The nutrient and heavy metal content of the pot experiment is presented in (Table **5**). The initial values (0 days) of total C and N, organic matter, extractable P, Cr and Zn did not differ significantly ($p > 0.05$) among the treatment Control and all amended treatments (C1-6, C1-12, C2-6 and C2-12) (Table **5**). The initial values of extractable K were significantly higher ($p < 0.05$) in all amended treatments (316-406 g kg^{-1} dry soil) relative to the treatment Control (191 g kg^{-1} dry soil) (Table **5**). The initial values of mineral N and EC were significantly higher ($p < 0.05$) in treatments C1-6 (47.7 mg kg^{-1} and 0.292 dS m^{-1}, respectively) and C1-12 (63.2 mg kg^{-1} and 0.372 dS m^{-1}, respectively) when compared with all other treatments, including the treatment Control (Table **5**). The final values (0 days) of total C and N, mineral N, organic matter, extractable P and K, Cr, Zn and EC did not differ significantly ($p > 0.05$) among the treatment Control and all amended treatments (C1-6, C1-12, C2-6 and C2-12) (Table **5**).

Table 4. Dry matter yield and nutrient uptake by ryegrass in the pot experiment (*n*=3).

-	*Treatments*	-	-	-	-
Parameter	***Control***	***C1-6***	***C1-12***	***C2-6***	***C2-12***
Yield (t DM ha^{-1})	1.36^{b}	1.79^{b}	2.74^{a}	1.22^{b}	1.55^{b}
N (g kg^{-1} DM)	24.0^{b}	15.5^{c}	29.9^{a}	27.7^{ab}	24.1^{b}
P (g kg^{-1} DM)	5.4^{a}	3.4^{d}	4.3^{c}	5.3^{ab}	4.7^{bc}
K (g kg^{-1} DM)	49.9^{a}	49.0^{a}	46.7^{a}	54.8^{a}	57.2^{a}
Ca (g kg^{-1} DM)	3.8^{a}	3.8^{a}	4.5^{a}	3.5^{a}	3.8^{a}
Mg (g kg^{-1} DM)	1.6^{a}	1.3^{a}	1.4^{a}	1.4^{a}	1.4^{a}
B (mg kg^{-1} DM)	47^{a}	72^{a}	175^{a}	81^{a}	50^{a}
Fe (mg kg^{-1} DM)	266^{a}	237^{a}	274^{a}	288^{a}	214^{a}
Cu (mg kg^{-1} DM)	11^{a}	13^{a}	14^{a}	9^{a}	8^{a}

(Table 4) contd.....

-	*Treatments*	-	-	-	-
Zn (mg kg^{-1} DM)	42[a]	41[a]	50[a]	44[a]	43[a]
Mn (mg kg^{-1} DM)	171[a]	202[a]	171[a]	209[a]	126[a]
S (g kg^{-1} DM)	2.1[a]	2.0[a]	2.7[a]	2.1[a]	2.3[a]
Na (g kg^{-1} DM)	1.3[b]	2.6[b]	9.0[a]	1.8[b]	1.9[b]

Values presented with different superscripts within rows are significantly different (p<0.05) by Tukey's test.

Table 5. Nutrient and heavy metal content of soil-residue mixture at 0 and 196 days in the pot experiment (*n*=3).

	Treatments				
Parameter	*Control*	*C1-6*	*C1-12*	*C2-6*	*C2-12*
At 0 days after soil application					
Total C (g kg^{-1} dry soil)	39.1[a]	38.5[a]	39.5[a]	38.9[a]	39.8[a]
Total N (g kg^{-1} dry soil)	1.6[a]	1.8[a]	1.9[a]	1.3[a]	1.8[a]
Mineral N (mg kg^{-1} dry soil)	8.2[b]	47.7[a]	63.2[a]	12.2[b]	16.7[b]
Organic matter (g kg^{-1} dry soil)	39.0[a]	39.0[a]	40.0[a]	39.0[a]	40.0[a]
Extractable P (g kg^{-1} dry soil)	245[a]	275[a]	284[a]	284[a]	286[a]
Extractable K (g kg^{-1} dry soil)	191[b]	365[a]	406[a]	316[a]	376[a]
Cr (mg kg^{-1} dry soil)	3.8[a]	4.7[a]	3.5[a]	8.8[a]	4.7[a]
Zn (mg kg^{-1} dry soil)	83.2[a]	54.8[a]	46.2[a]	58.5[a]	68.0[a]
EC (dS m^{-1})	0.031[b]	0.292[a]	0.372[a]	0.056[b]	0.105[b]
At 196 days after soil application					
Total C (g kg^{-1} dry soil)	44.2[a]	48.4[a]	52.4[a]	48.4[a]	48.7[a]
Total N (g kg^{-1} dry soil)	1.5[a]	1.6[a]	1.7[a]	1.7[a]	1.7[a]
Mineral N (mg kg^{-1} dry soil)	24.5[a]	38.6[a]	33.1[a]	28.2[a]	31.1[a]
Organic matter (g kg^{-1} dry soil)	4.4[a]	4.8[a]	5.2[a]	4.8[a]	4.9[a]
Extractable P (g kg^{-1} dry soil)	341[a]	308[a]	392[a]	352[a]	332[a]
Extractable K (g kg^{-1} dry soil)	188[a]	303[a]	357[a]	255[a]	241[a]
Cr (mg kg^{-1} dry soil)	8.0[a]	10.0[a]	10.7[a]	21.5[a]	9.5[a]
Zn (mg kg^{-1} dry soil)	74.2[a]	75.8[a]	70.8[a]	100.8[a]	94.2[a]
EC (dS m^{-1})	0.097[a]	0.116[a]	0.115[a]	0.097[a]	0.114[a]

Values presented with different superscripts within rows are significantly different (p<0.05) by Tukey's test.

4. DISCUSSION

The composting process is affected by the physicochemical properties of raw materials. In this study, the high heavy metal content in original tannery sludges decreased sharply during the composting process, like in studies developed by Gonçalves *et al*. [7]. The presence of heavy metals in the composted residues proved to be much lower than the limits established in national legislation [21], being possible for their application to the soil as organic fertilizers. Also, EC decreased during composting. This variation, also reported by Lambu *et al*. [17], gives rise to composts with EC values suitable for soil application, a threshold value of 3 mS cm^{1} recommended for application of compost to the soil [24].

The content of salts and heavy metals did not show significant differences between Control and amended treatments. Thus, the composting process proved to be efficient in removing these soil contaminants. The values of heavy metals present in treatments were lower than the maximum limits fixed in national legislation [21], in which soil pH from 6 to 7 admits as maximum values of Cr = 60 mg Kg^{-1} and Zn = 150 mg kg^{-1}. All values of heavy metals are within the range allowed by the national legislation and are well below these maximum values [21].

The effects of compost on soil quality and, consequently, on crop productivity are determined by the properties of the compost applied [18]. We observed in this study significant differences in ryegrass DM production and soil quality. The treatment C1-12 has a larger ryegrass DM production and a higher N content (Table **4**) in ryegrass, when compared to the other treatments and Control. Goswami *et al*. [25] suggested that different solid waste utilized through composting is essential for environmental sustainability and restoring soil quality. Also, in the present study, soil quality after the ryegrass crop was in better condition than before the experiment. Organic matter and N mineral are higher than ryegrass. As referred by de Sousa *et al*. [15] and Rocha *et al*. [11], the application of compost improves the organic matter of the soil. Relative to the content of heavy metals observed in this study, no differences exist between Control and treatments.

The electrical conductivity increased with the increase of the compost rate, with significantly higher values in C1 relative to C2 or Control (Table **5**), in line with the study developed by de Sousa *et al*. [15]. Also, the C and P content did not increase with the increase of the compost rates applied, but the results of this study showed an increase at the end of the experiment (day 196), being comparable to those reported by de Sousa *et al*. [15] and Rocha *et al*. [11]. At 0 days after application of the composts, EC showed significant differences between C1 treatments and all others, yet at the end of the experiment, no significant differences subsisted between treatments. However, this difference on day 0 was not an obstacle to obtaining the best production of dry matter.

The application of composted tannery sludge in agriculture may lead to a risk for humans and the environment, as a result of heavy metals and toxic organic compounds accumulation to high levels enough to cause damage, such as soil contamination, phytotoxicity, and the accumulation of trace elements in the food supply chain [14]. Despite the significant differences between composts in heavy metals contents, there were no differences when added to the soil (mixture soil + residues) or at the end of the experiment. In addition, the content of heavy metals in the composts and in the soil profile was much lower than those allowed by national legislation [21].

The P content in ryegrass of the Control was significantly higher than in other treatments, except in C2-6. On the other hand, at the beginning and at the end of the experiment, the P content in the mixture of soil + residue did not differ between treatments. Thus, this result means that compost did not provide large amounts of P to the soil, which contradicts previous studies developed by Lemming *et al*. [26] and Grigatti *et al*. [19].

CONCLUSION

The results showed that the compost of tannery fatty sludge (C1-12) increased the nitrogen concentrations in ryegrass and yielded the highest increase of dry matter. The composting process significantly reduced pathogens (total coliforms and *Salmonella* sp.), producing stable and mature compost. This process was also efficient in the reduction of heavy metals, which in the final compound presented values much lower than those fixed by legislation. These results showed that composted waste from the tannery industry is a good source of nutrients for agriculture, however, these results were obtained under laboratory conditions and should be carefully extrapolated, being necessary to evaluate their results in the field experiments.

LIST OF ABBREVIATION

EU = European Union

AUTHORS' CONTRIBUTIONS

Conceptualization, J.L.S.P.; methodology, J.L.S.P., F.M. and A.P.; software, J.L.S.P., F.M. and A.P.; validation, J.L.S.P., F.M. and A.P.; formal analysis, J.L.S.P., F.M. and A.P.; investigation, J.L.S.P., F.M. and A.P.; resources, J.L.S.P., F.M. and A.P.; data curation, J.L.S.P., F.M. and A.P.; writing—original draft preparation, J.L.S.P. and A.P.; writing—review and editing, J.L.S.P., F.M.. and A.P.; visualization, J.L.S.P., F.M.. and A.P.; supervision, J.L.S.P.; project administration, J.L.S.P.; funding acquisition, J.L.S.P. All authors have read and agreed to the published version of the manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable.

HUMAN AND ANIMAL RIGHTS

No animals/humans were used for studies that are the basis of this research.

CONSENT FOR PUBLICATION

Not applicable.

AVAILABILITY OF DATA AND MATERIALS

Not applicable.

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CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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