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Co-composting of poultry manure with other agricultural wastes: process performance and compost horticultural use

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Abstract The aim of this work was to evaluate the composting process of poultry manure mixed with other complementary organic wastes. Two mixtures (treatment 1 and 2) were prepared with corn bare cobs, sawdust, shavings and manure. Temperature, pH, electrical conductivity, organic matter loss, total organic carbon, solved organic carbon, N loss, ammonium and nitrate concentration, laccase activity and respiration indices were analyzed. These variables showed similar tendencies during the composting process in both treatments. A peak of biological activity, organic matter mineralization and salt release was observed after 6 days of the process. Treatment 2 showed a higher concentration of solved organic carbon and higher organic matter loss than in the mixture with less manure (treatment 1). Laccase activity increased when solved organic carbon decreased. Compost from treatment 1 showed lower phytotoxic effects than that from treatment 2, probably because of a low salt content. In conclusion, it was observed that 60 % content of poultry manure in the mixture does not affect the composting process. However, the final product is not as good for agricultural purposes as a mixture with a lower manure content. Finally, it can be stated that the valorization of these wastes in the form of compost adds value to the materials, closing the biogeochemical nutrient cycle.

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Introduction

Poultry production activities are steadily growing worldwide. In Argentina, in 2010, egg production increased 4 % compared to 2009 [1].

The production increase can be partly explained by the degree of intensification that has been implemented in the production systems in the last years. This kind of system causes large accumulations of manure. This accumulation, which does not have a clear disposal destination in the Pampean region of Argentina, poses several threats to the environment. The uncontrolled decomposition of hen manure releases NH_3, N_2O and CH_4 into the atmosphere. Dekker et al. [2] found that the average emission per layer was 144 ± 13.5 g year^{-1} for NH_3, 1.11 ± 0.33 g year^{-1} for N_2O and 27.4 ± 5.19 g year^{-1} for CH_4. These wastes can pollute soil and water if periodically applied as a direct organic amendment (without treatment) to soils.

Stabilization of organic waste through composting can prevent environmental damage, presenting a positive balance when applied to soil [3]. Although composting has been extensively studied, to the best of our knowledge, there are no published reports on the composting of wastes produced in the Pampean region. This region is facing the problems that come with significant economic growth, needing sustainable waste management strategies to be applied in the future.

However, the process of composting manure requires the presence of an adequate bulking agent and an extra source of carbon for balancing the C:N ratio. The benefits of this strategy are a reduction in nitrogen losses and high agricultural value of the compost.

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Therefore, the aim of this work was to evaluate different mixtures of wastes that may increase the use of poultry manure in the composting process with other wastes from high levels of production in the region. The resulting mixture must permit the correct development of the composting process and adequate development of the main parameters and the place where the waste is generated, without a large investment. A secondary objective of this study is to explore the possibility of using the compost obtained as growing media for horticultural use.

Materials and methods

Composting experiments

The experiments were carried out in the Instituto de Microbiología y Zoología Agrícola (IMyZA), Instituto Nacional de Tecnología Agropecuaria (INTA) (Buenos Aires, Argentina).

The poultry manure (PM) was obtained from automatized sheds for hens for egg production of the Zucami® type, located in a farm in Mercedes, Buenos Aires (34°42′43.18″ S; 59°31′19.91″O). This waste was mixed with corn bare cobs (CBC), sawdust (SA) and shavings (SH). The wastes used came from the same zone (Table 1).

Percentages in volume for treatment 1 (T1) contained 40 % PM (53 % in dry mass), 20 % CBC (9 % in dry mass), 20 % SA (24 % in dry mass) and 20 % SH (14 % in dry mass), whereas treatment 2 (T2) contained 60 % PM (71 % in dry mass), 20 % CBC (8 % in dry mass) and 20 % SA (21 % in dry mass). Table 1 shows the characterization of the wastes and initial mixtures to be composted.

Mixtures were homogenized using a 0.5 m^3-capacity mixer at the beginning of the trial. Piles were constructed in a trapezoidal shape (1.5 m high, 2 m wide and 2 m long). Each treatment was carried out using three replicates of 2 m^3 each in piles of an initial height of 1 m and approximately 1 mg total weight. The composting process lasted 83 days.

Composting piles were manually turned every 3 days during the first active decomposition phase of the process and every 5 days when the pile temperature was similar to the environmental temperature (maturation stage). The moisture content was maintained through irrigation and taking into account the local precipitation. Samples (about 10 kg) were taken weekly from the composting piles at three different locations (days 0, 6, 13, 21, 27, 34, 41, 48, 55, 62, 69, 76 and 83) and homogenized to obtain a representative aliquot of 1 kg per pile [4]. Table 2 summarizes the variables measured each sampling day.

Table 2 Parameters analyzed on each sampling day

Parameters	Sampling days
Temperature, pH, EC, δ, % moisture, % ash, % OM loss, % N_T loss, % TOC, % SOC, C:N, NH_4^+ and SRI	0, 6, 13, 19, 21, 27, 34, 41, 48, 55, 62, 69, 76 and 83
LEA	0, 13, 27, 41, 55, 69 and 83
TP, DRP, NO_3^-, Ca, Mg, Na, K, RGI_R, RGI_L, IG_R and IG_L	83

EC electrical conductivity, *δ* density, *% OM loss* organic matter loss percentage, *% N_T* total nitrogen percentage, *% TOC* total organic carbon percentage, *% SOC* dissolved organic carbon percentage, *C:N* carbon:nitrogen ratio, *NH_4^+* ammonium, *SRI* static respirometric index, *LEA* laccase enzymatic activity, *TP* total phosphorous, *DRP* dissolved reactive phosphorous, *NO_3^-* nitrate, *Ca* calcium, *Mg* magnesium, *Na* sodium, *K* potassium, *RGI_R* root growth index radish, *RGI_L* root growth index lettuce, *IG_R* germination index radish, *IG_L* germination index lettuce

Table 1 Characterization of the wastes and mixtures (T1 and T2)

Parameter	Units	Agricultural wastes				Treatments	
		PM	CBC	SH	SA	T1	T2
pH		8.0 ± 0.3	6.3 ± 0.0	6.0 ± 0.1	7.6 ± 0.1	8.3 ± 0.2	7.9 ± 0.3
EC	mS cm^{-1}	21.8 ± 0.6	1.3 ± 0.0	1.2 ± 0.0	0.8 ± 0.0	18.7 ± 4.4	21.4 ± 1.6
δ	g L^{-1}	996 ± 41	95 ± 2	165 ± 7	265 ± 12	564 ± 62	663 ± 38
Moisture	%	73.9 ± 0.2	8.4 ± 0.1	10.9 ± 0.1	11.5 ± 0.1	72.4 ± 1.6	71.9 ± 1.0
OM	%	75.3 ± 1.6	96.8 ± 0.9	99.1 ± 0.1	98.9 ± 0.0	73.8 ± 3.0	80.8 ± 6.2
Ash	%	24.7 ± 1.6	3.2 ± 0.9	0.8 ± 0.1	1.1 ± 0.0	26.1 ± 3.0	21.6 ± 2.1
TOC	%	37.6 ± 0.8	48.4 ± 0.4	49.6 ± 0.0	49.5 ± 0.0	36.9 ± 1.5	40.4 ± 3.1
SOC	%	1.5 ± 0.6	0.7 ± 0.0	0.9 ± 0.1	1.4 ± 0.1	48.5 ± 5.8	79.5 ± 11.8
N_T	%	6.2 ± 0.9	2.5 ± 0.1	1.7 ± 0.0	2.1 ± 0.0	1.6 ± 0.4	2.9 ± 0.4
C:N	%	6.2 ± 0.8	19.1 ± 0.2	29.1 ± 0.0	23.5 ± 0.0	23.5 ± 5.7	14.4 ± 2.2

EC electrical conductivity, *δ* density, *OM* organic matter, *TOC* total organic carbon, *SOC* dissolved organic carbon, *N_T* total nitrogen, *C:N* carbon:nitrogen ratio, *PM* poultry manure, *CBC* corn bare cobs, *SH* shavings, *SA* sawdust, *T1* treatment 1, *T2* treatment 2

Composting monitoring and compost characterization

Environmental temperature and local precipitation were recorded daily at the meteorological station of the INTA.

Parameters suggested by the TMECC [4] were monitored during the composting trials: temperature, pH, electrical conductivity (EC), moisture content, carbon:nitrogen ratio (C:N), bulk density (δ), free airspace (FAS), total phosphorous (TP) and dissolved reactive phosphorous (DRP), calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), total organic carbon (% TOC), dissolved organic carbon (% SOC), dry matter (% DM), organic matter (% OM), total nitrogen (N_T) and ash (%ash) percentages. The percentages of OM and N_T losses were determined using Eqs. 1 and 2 as suggested by Paredes et al. [5]:

$$\mathrm{OM\ loss}(\%) = 100{-}100[X_1(100{-}X_2)]/[X_2(100{-}X_1)]. \tag{1}$$

$$N_{\mathrm{T}}\ \mathrm{loss}(\%) = 100{-}100(X_1N_2)/(X_2N_1) \tag{2}$$

where: N_1 and N_2 are the initial and final N_T concentrations, and X_1 and X_2 are the initial and final ash concentrations, respectively.

Ammonium (NH_4^+) and nitrate (NO_3^-) concentrations were measured using the microdistillation method [6].

Laccase enzymatic activity (LEA), expressed as μmol min^{-1} g DM^{-1}, was determined spectrophotometrically (420 nm) by measuring the oxidation of 0.5 mM ABTS (2.2′-azinobis (3-ethyl benzothiazoline-6-sulfonate)) in 0.1 M acetate buffer, pH 3.6 [7].

Biological activity was measured using the static respiration index based on the OM content (SRI) [4]. A static respirometer was built according to the original model described by Iannotti et al. [8] and modified following the TMECC [4] recommendations. The drop in oxygen content in a flask containing a sample was monitored with a dissolved oxygen meter (Lutron 5510, Lutron Co. Ltd., Taiwan). The rate of respiration of the sample (oxygen uptake rate, based on OM content) was calculated from the slope of the oxygen level decrease according to standard procedures [8].

Ecotoxicology bioassays were carried out with the final composts using two species: *Lactuca sativa* (lettuce: L) and *Raphanus sativus* (radish: R). Seed germination and root elongation were measuredaccording to the US Environmental Protecton Agency (EPA) standardized protocols [9]. These measurements were used to calculate the germination index (GI) according to Zucconi et al. [10, 11] and the root growth index (RGI) [12].

Considering the observed toxicity effect, RGI values were classified into three categories: root elongation inhibition (I): $0 < \mathrm{RGI} > 0.8$; non-significant effects (NSE): $0.8 \leq \mathrm{RGI} \geq 1.2$; root elongation stimulation (S): $\mathrm{RGI} > 1.2$ [13].

According to Barbaro et al. [14], the results from the agricultural valorization of the produced compost were analyzed. The use of different substrates formulated with T1 (compost 1, C1), T2 (compost 2, C2) and pine bark (PB) compost in different proportions was evaluated in *Salvia splendens* L. and hybrid *Impatiens walleriana* Hook. for plant development.

Statistical analyses

Variables were analyzed by ANOVA and with the Kruskal-Wallis nonparametric test when the data did not satisfy the assumptions. A p value of 0.05 was considered to establish significant differences. The variables measured in the final composts were analyzed by principal component analysis. Statistical analyses were run using the statistics program InfoStat, version 2010, Grupo InfoStat, Córdoba, Argentina.

Results and discussion

Physicochemical characterization of composted wastes

The results shown in Table 1 indicate that the principal limitations of PM for decomposition in composting are a slightly alkaline pH, high salt content, high δ and low porosity [15], and a low C:N ratio. To overcome these limitations and improve the aerobic biodegradation of PM, three other typical abundant wastes in the egg production region were mixed with the PM. The addition of SA, CBC and SH to the PM improved the porosity and C:N ratio of the mixtures proposed (Table 1).

Development of routine parameters of the composting process

Both treatments showed the typical composting thermophilic profile [3]. According to Ugwuanyi et al. [16], a temperature above 45 °C can be considered thermophilic and suitable for killing pathogenic microorganisms. They highlighted the need to reach a minimum temperature of 45 °C for at least 5 days. In this assay, the thermophilic phase lasted 35 and 37 days for T1 and T2, respectively, which is a clear indication of compost sanitation. Within the thermophilic phase, two peaks were observed in both treatments. During the first weeks, the temperature increased to 60–65 °C. T1 remained within this range for 13 days, whereas in T2 it lasted 8 days. The maximum temperature was reached at day 15, and then a drop in this parameter was observed. This moment corresponded to a 5-day precipitation period, which could have favored the temperature decrease. A new temperature increase was

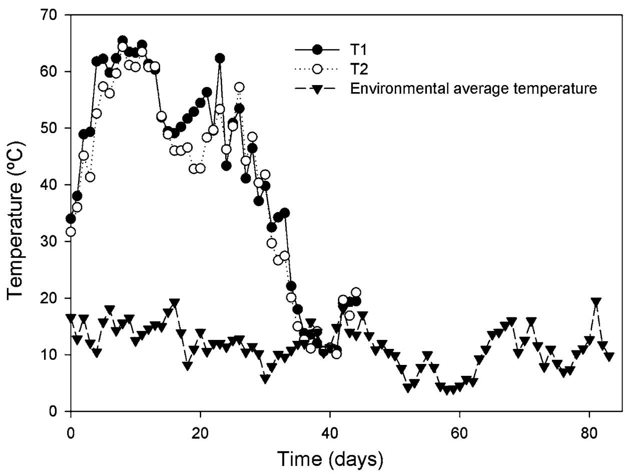

Fig. 1 Temperature development of T1 and T2 and environmental temperature

observed from day 25 until day 40. Then, the composting piles started to cool down to a second stage of maturation, from day 55, when the temperature was similar to that of the environment (Fig. 1).

The initial pH values in both treatments were close to the upper limit of the range (6–8) suggested by Rink [17] as suitable for aerobic degradation. T1 showed an average initial value of 8.3 ± 0.2, while the initial value for T2 was 7.9 ± 0.3 (Table 1). Although T2 used more PM, no significant differences in pH were observed between the mixtures. The alkaline condition in both mixtures was a consequence of the high PM content, which has an alkaline pH (Table 1). The development of this parameter was similar in both treatments (Fig. 2a). Extreme pH levels were 7.8 and 9.0 for T1 and 7.9 and 9.0 for T2. Bustamante et al. [18] related the pH increase during the first phase to the high concentration of NH_3 released from proteins and amino acid decomposition. The highest pH values (T1 8.9 ± 0.1, T2 9.1 ± 0.1) recorded in the first stage of the composting process also correlated well with the highest temperatures (T1 63.0 ± 0.5 °C, T2 61.0 ± 0.5 °C) reached on the same days (Fig. 1), which again are associated with the NH_3 formation and release [19]. Later, the NH_4^+ profiles and N loss during the process for both treatments support the hypothesis of the formation and release of NH_3 during the first part of the process, which presents an exponential correlation with temperature in the first active decomposition stage of composting and a soft linear evolution during the maturation stage [19]. Moisture percentage of the composting piles was adjusted based on the results of the squeeze test (4) by watering. When it was necessary, water was sprayed over the material and mixed thoroughly. Figure 2b shows the moisture profiles for *T1* and *T2* and the days when the piles were watered. Rainfall days are also shown in Fig. 2b. The cumulative precipitation was

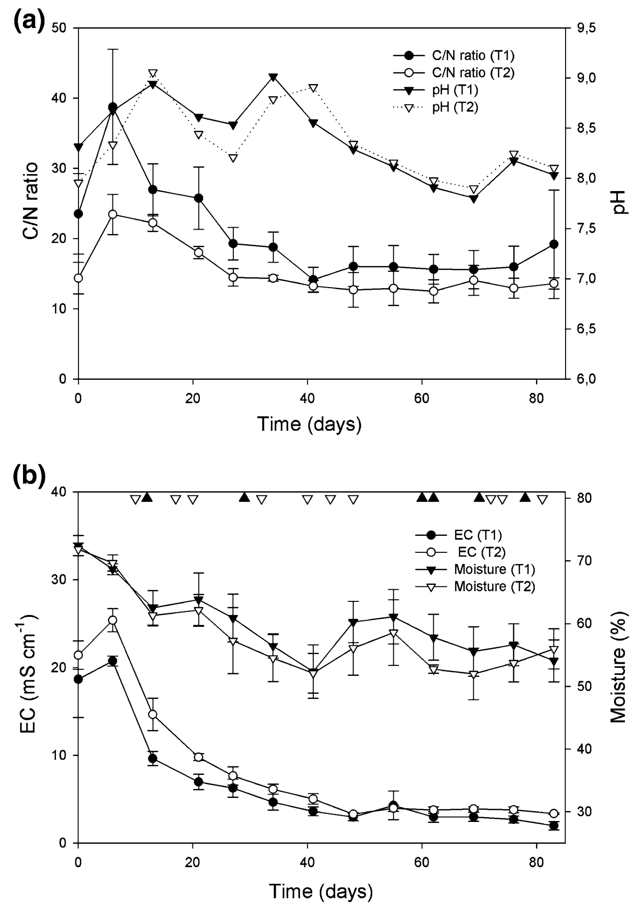

Fig. 2 **a** pH and C:N ratio evolution in T1 and T2; **b** EC and moisture content evolution in T1 and T2. Watering of piles (*full symbols*) and rainfall days (*empty symbols*) are indicated

216.3 mm after 83 composting days. The initial moisture percentage was similar (72 %) for T1 and T2 (Table 1). Both values were over the optimum moisture percentage range of 40–60 % [3]. However, the results obtained by Petric et al. [20] suggest that the initial moisture percentage should be around 69 % when composting PM. For this type of waste, Ahn et al. [21] found that the optimum moisture percentage was in the range of 60–80 % depending on the water-holding capacity. In the case under study, as seen in Fig. 2b, the moisture content decreased to 60 % in the first weeks of the process, showing the correct evolution of the process. In both treatments, the moisture percentage remained within the range of 52–72 %. An increase of the amount of water content in the piles was observed from day 40, corresponding to 3 consecutive days of an accumulated precipitation of 55 mm.

The initial EC showed average values of 18.7 ± 4.4 and 21.4 ± 1.6 mS cm^{-1} for T1 and T2, respectively (Table 1). The profile development of EC for T1 and T2 is shown in Fig. 2b together with the moisture content profiles. This high salt concentration can be related to the high

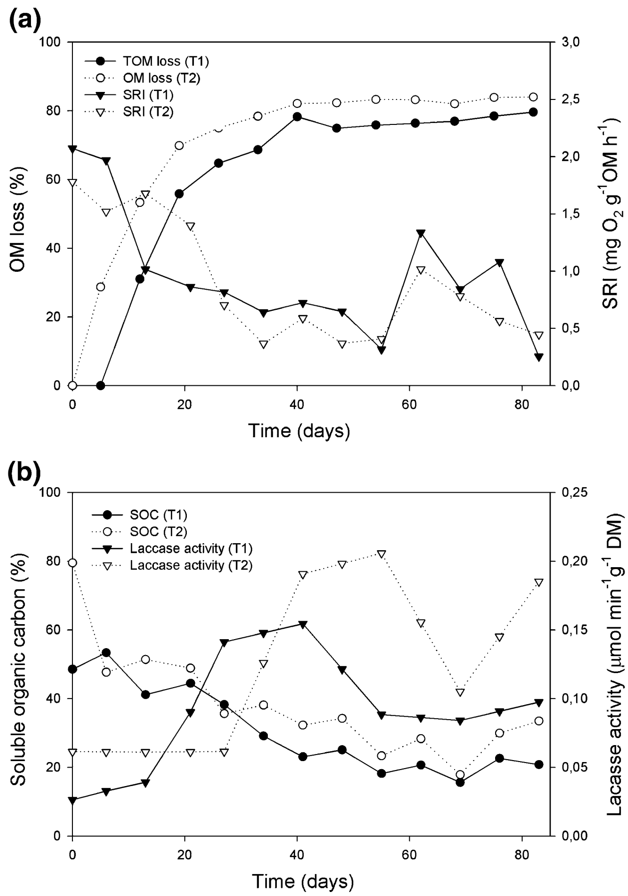

Fig. 3 **a** OM loss (%) and SRI (mg O_2 g^{-1} OM h^{-1}); **b** SOC (%) and LEA (EU) evolution in T1 and T2

PM content in the mixtures (Table 1). The maximum EC value was recorded 6 days after the beginning of the experiment in both treatments, coinciding with the highest OM loss and with an important decrease in moisture content. The fast mineralization rate observed between days 6 and 13 could have resulted in the release of salts. Also, mineral salt leaching can contribute to the decrease of EC observed in Fig. 2b. From day 6 on, this parameter decreased to reach a final average value of 2.0 ± 0.5 and 3.4 ± 0.1 mS cm^{-1} for T1 and T2, respectively.

OM decomposition, biological activity and N dynamics

Organic matter and TOC contents were higher in T2 than T1 because of the higher PM content in T2 (Table 1). In both treatments the % OM loss was more pronounced during the first weeks of the experiment, together with higher temperatures and higher biological activity, as shown by the SRI values during this period. Figure 3a shows a progressive drop in the SRI up to day 55 in both treatments. However, from this time point an increase in the biological activity was observed in both treatments. A relative increase of biological activity was also reflected in the temperature profiles and could be due to a partial degradation of more recalcitrant materials [22]. Although we do not have a definitive explanation for this specific period, all the indicators (SRI, temperature, drop of SOC, etc.) seems to show that this could be due to the breakdown of laccase typical substrates [23]. A faster drop in activity was observed for T1, indicating a higher degradation of OM during the first days of the process. Nevertheless, the SRI profile for T2 showed a pronounced drop from day 20 onward, suggesting that biodegradable OM was present in this mixture during for a long period of time.

The highest OM loss in T1 (31 ± 1) was observed at day 13, while in T2 it was observed at day 6 (29 ± 2). By day 33, the accumulated percentage of OM loss was of 69 ± 8 for T1 and 78 ± 6 for T2. From this time point onward, the OM loss was relatively stable, reaching final values of 80 ± 4 for T1 and 84 ± 2 for T2. Ruggieri et al. [24] and Colón et al. [25] also reported high OM losses OM during the first phase of the process, followed by a period of slower degradation and respiration activity.

The initial levels of % SOC decreased in both treatments throughout the experiment. Hsu and Lo [26] correlated this reduction to the breakdown of hemicellulose, sugars, phenolic substances, organic acids, peptides and other easily biodegradable substances. Laccase is responsible for the hydrolysis of the main fibers found in organic wastes [23]. In T1, LEA started to increase at day 13, when the SOC was 41.1 %, whereas in T2 it started to increase at day 27, when the SOC was 35.6 % (Fig. 3b). Both treatments achieved their maximum LEA at different times. The activity peaked at day 41 in T1, while in T2 it peaked at day 55 (Fig. 3b). These data seem to be related to the biological activity measured with the SRI and could be due to the composition of the mixtures. The higher SOC content in T2 could have been delaying the degradation of lignocellulosic materials. Also, T1 was richer in the lignocellulosic material (20 % of SH). De Bertoldi et al. [27] have observed similar effects when composting lignocellulosic materials. In this regard, fungi tend to grow in the later stages of composting and have been shown to attack polymers such as hemicellulose, lignin and cellulose. Tiquia [28] found that extracellular enzyme activities were greater in than in younger older compost. These previous studies seem to support the observations about the LEA determined for both mixtures.

The N dynamics were similar to those of the OM. The highest decrease in N was detected during the first 6 days, with an average of 32 ± 15 and 58 ± 10 % for T1 and T2, respectively, as shown in Fig. 4. Thus, the highest OM loss was recorded during the first 13 days jointly with a pH close to 9 and high temperature. These conditions are often coupled with the organic N mineralization and provoke the

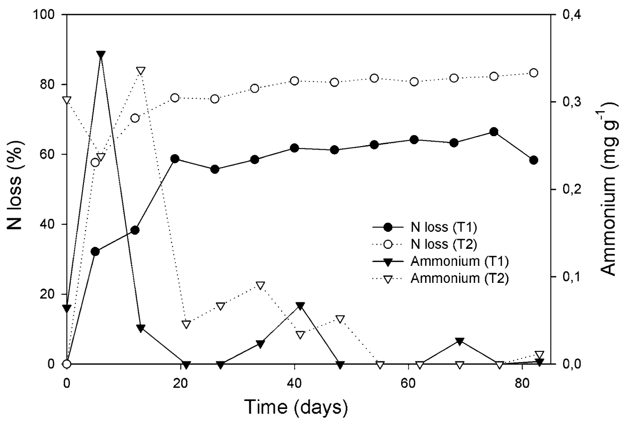

Fig. 4 N losses (%) and NH_4^+ concentration (mg g^{-1}) evolution in T1 and T2

release of NH_4^+ and NH_3 gas [19]. Figure 4 shows the coincidence in time of the highest values of N losses with the highest NH_4^+ concentration, confirming the results of previous studies [19]. NH_3 generation tends to increase with pH since the uric acid breakdown increases under alkaline (pH > 7) conditions, and the effect of uricase is greatest at pH 9 [28]. Regarding this, NH_3 emissions can be inhibited by acidic compounds that decrease the conversion of NH_4^+ to NH_3. These compounds can also inhibit enzymes involved in the formation of NH_3, decreasing its production [29]. In this case, the initial NH_4^+ content in T2 was significantly higher than in T1. Although the NH_4^+ dynamics were similar for T1 and T2, the decrease in NH_4^+ content was significantly delayed in T2. The higher amount of PM in the initial mixture (60 %) in T2 could be responsible for this delay.

Regarding the C:N ratio, the initial values were 24 ± 5 and 14 ± 2 for T1 and T2, respectively (Table 1). The C:N evolution of T1 and T2 is shown in Fig. 2a, whereas in Fig. 4 the N loss and NH_4^+ are presented. There was an important increase in the C:N ratio on day 6 the of process due to the N loss, as previously mentioned. After this moment, this ratio decreased at the beginning of the composting process, when the OM loss reached its maximum. Comparable results were found by Ferrer et al. [30] and Bustamante et al. [18]. However, it has to be emphasized that most of the published results on composting and the evolution of the C:N ratio referred to the overall C:N ratio, which is chemically determined and can be very different from biodegradable C:N ratio [31]. Accordingly, it is possible that SOC variations are more reliable for interpreting the available carbon present in each mixture than TOC or total OM.

Compost quality and agricultural valorization

The characteristics of the final composts are summarized in Table 3. In order to compare these properties, the recommended values for the most important parameters for using compost in growing media [32] and the minimum content of some nutrients according to the regulation proposal for organic fertilizers in Argentina [33] are included in Table 3.

pH values in both treatments were slightly alkaline. Compost with pH levels close to 8 decreases the heavy metals transference to the food chain, reducing their phytotoxicity potential [12]. On the contrary, the N availability was not affected by pH levels, whereas P was mainly associated with Ca^{2+} ions, resulting in TP and DRP concentrations similar for both treatments, reaching an average availability of 5 ± 1 and 4 ± 1 (%) for T1 and T2, respectively (Table 3).

The EC, Ca, Mg, Na and K contents were significantly higher in the compost obtained in T2 according to the initial amount of manure of this mixture. EC and Ca contents were above the recommend values for growing media [32]. One possible strategy to improve these parameters is to formulate mixtures with wastes with low EC values. The final values of the C:N ratio (T1: 14.4 ± 0.7 and T2: 13.6 ± 0.8) suggested that both composts had an acceptable maturity level since these values were lower than 20 [29, 32].

The stability limit of the SRI for compost samples is between 0.5 and 1 mg O_2 g^{-1} OM h^{-1} [4, 22, 34]. Both composts reached SRI values below this stability limit, with average values of 0.25 ± 0.05 and 0.45 ± 0.04 mg O_2 g^{-1} OM h^{-1} for T1 and T2, respectively (Table 3).

According to the principal component analyses, the highest values for pH, EC, Ca, Mg, Na, K, N, TP and δ were associated with T2, whereas the NO_3^- concentration, C:N ratio, GI_L and GI_R were associated with T1 (Fig. 5). The RGI_L was lower than 0.8 from 25 % in both composts. On the other hand, the RGI_R was lower than 0.8 from 50 and 80 % of the T1 and T2 compost, respectively. RGI values below 0.8 indicate inhibitory effects on the root growth [13]. The GI in both species was less affected in T1 compost. Figure 5 shows that the GI_L and GI_R were inversely correlated with the salt content and the EC. As mentioned, a mixture with other materials with low salt content can improve the final use of these composts, especially from T2. Domènech et al. [35] compared two composts from two different wastewater treatment plants in several phases of the degradation process. They found that seed emergence was significantly affected by compost dosage but also by the time of composting.

Both composts were mixed with PB compost at 20, 50 and 80 % [14]. The six formulated substrates were also compared with a *Sphagnum* commercial substrate as control. Each substrate was a treatment: (1) 80 % C1 + 20 % PB; (2) 50 % C1 + 50 % PB; (3) 20 % C1 + 80 % PB; (4) 80 % C2 + 20 % PB; (5) 50 % C2 + 50 % PB; (6)

Table 3 Physicochemical and ecotoxicological characterization of the final composts

Parameter	Units	T1	T2	Target value or range/upper limit	Reference
pH		8.0 ± 0.2	8.1 ± 0.0	6–8/9	[32]
EC	mS cm^{-1}	2.0 ± 0.5	3.4 ± 0.1	<0.6/1.5	[32]
				4	[33]
δ	g L^{-1}	685 ± 41	767 ± 43	400–500/550	[32]
Moisture	%	54 ± 2	56 ± 3	35–40/50	[32]
OM	%	35 ± 2	37 ± 2	≥15	[33]
Ash	%	65 ± 2	63 ± 2	–	–
TOC	%	17.2 ± 0.9	18.0 ± 1.0	–	–
SOC	%	21 ± 1	33 ± 3	–	–
SRI	mg O_2 g^{-1} OM h^{-1}	0.2 ± 0.0	0.4 ± 0.0	0.5–1	[4], [22]
C:N	%	14.4 ± 0.7	13.6 ± 0.8	20:1	[33]
N_T	%	1.2 ± 0.1	1.3 ± 0.1	NPK ≥ 6	[33]
NH_4^+	mg g^{-1} DM	0.0 ± 0.0	0.0 ± 0.0	<40/50	[32]
NO_3^-	mg g^{-1} DM	11 ± 6	6 ± 1	–	–
TP	mg g^{-1} DM	23 ± 1	25 ± 2	NPK ≥ 6 %	[33]
DRP	mg g^{-1} DM	1.1 ± 0.4	1.1 ± 0.2	NPK ≥ 6 %	[33]
Ca	mg L^{-1}	817 ± 40	981 ± 20	≥1 %	[33]
Mg	mg L^{-1}	251 ± 6	348 ± 5	≥0.05 %	[33]
K	mg L^{-1}	6563 ± 215	8700 ± 352	NPK ≥ 6 %	[33]
Na	mg L^{-1}	2013 ± 52	3392 ± 145	<100/150	[32]
RGI_R		0.5 ± 0.0	0.3 ± 0.1	>0.8	[13]
RGI_L		0.4 ± 0.1	0.3 ± 0.1	>0.8	[13]
GI_R	%	46 ± 2	26 ± 10	80	[32]
GI_L	%	34 ± 5	16 ± 6	80	[32]

EC electrical conductivity, *δ* density, *OM* organic matter, *TOC* total organic carbon, *SOC* dissolved organic carbon, *SRI* static respirometric index, *C:N* carbon nitrogen ratio, N_T total nitrogen, NH_4^+ ammonium, NO_3^- nitrate, *TP* total phosphorous, *DRP* dissolved reactive phosphorous, *Ca* calcium, *Mg* magnesium, *K* potassium, *Na* sodium, RGI_R root growth index radish, RGI_L root growth index lettuce, IG_R germination index radish, IG_L germination index lettuce, *DM* dry matter, *T*1 treatment 1, *T*2 treatment 2

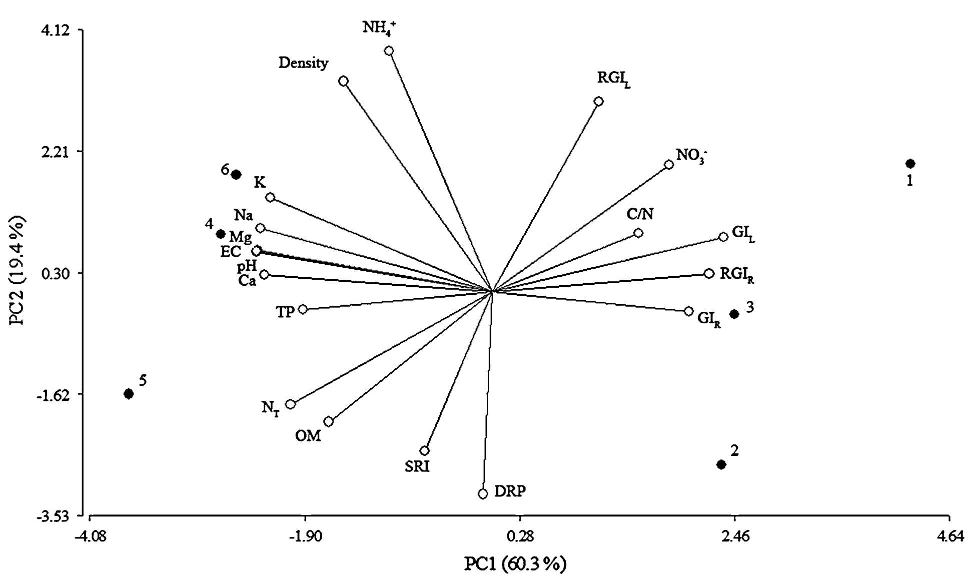

Fig. 5 Principal component analyses of parameters determined in the final composts. Dots 1, 2 and 3 correspond to the replicates of T1; dots 4, 5 and 6 correspond to T2

20 % C2 + 80 % PB; (7) commercial substrate. *Salvia splendens* L. var. red and hybrid *Impatiens walleriana* Hook. f. var. Accent Pink Imp. were used. Each species was grown in the seven treatments with five replicates.

All substrates' total porosity (TPo) exceeded the 80 % optimum value [36]. The substrates that showed significantly higher TPo percentages were the ones made of 80 % compost. On the other hand, significant differences were found in the water-holding capacity (WHC), which was higher in the substrates with 20 % and 50 % compost. The free airspace (FAS) higher values were found in the substrates with 80 % compost. These results suggest that the evaluated compost made of poultry manure improved aeration and reduced the WHC of the substrates. However, according to several authors [35, 37] all the substrates presented an adequate WHC (24–40 %) and a high FAS percentage (20–30 %).

Both substrates with 80 % compost had the highest pH values (7.9–8.3) followed by the substrates with 50 % (7.0–7.6), exceeding the optimum range established for most of the cultivated species according to Handreck and Black [38] (pH between 5.5 and 6.3). However, all values were in the range recommended for the use of compost as a growing media [32]. Therefore, the selected cultivated species will finally determine its use as well as the dosage in the mixture with other substrates.

The substrates with 80 % C1, 50 % and 80 % C2 showed EC values higher than 1 dS cm^{-1} (1.1, 1.3 and 1.6 dS cm^{-1}, respectively). If the substrate exceeds this value, it could lead to salinity problems, depending on the plant, environmental conditions, management practices and species characteristics [39].

The plants cultivated in the commercial substrate had the greatest aerial and radicular dried matter (1.3 and 0.5 g), followed by the plants developed in both substrates with 20 % compost. The substrates with 50 % C2 and 80 % C1 and C2 had ECs higher than 1 dS m^{-1}. *Salvia splendens* plants grown in the substrates with 80 % C2 died 3 days after being transplanted. The *Salvia splendens* plants died from an EC of 1.6 dS m^{-1}, while *Impatiens walleriana* died from 2 dS m^{-1} on.

The chemical analysis of aerial dried matter showed that both species of plants developed in the commercial substrate and in 20 % compost had higher Ca and Mg concentrations and lower K concentrations. On the other hand, the substrates with 80 %, 50 % C1 and C2 had higher K contents but were lower in Ca and Mg. These results suggest that there was an excessive K consumption and Ca and Mg adsorption inhibition [37]. Carmona et al. [39] mentioned the high salinity and low WHC of most composts as one of its principal disadvantages. They suggested that it is necessary to mix composts with other materials to formulate a substrate.

The substrates formulated with smaller percentages of C1 and C2 (20 %) and with 50 % C1 were the ones with higher WHCs and lower salinity, favoring the development of *Salvia splendens* and *Impatiens walleriana* plants.

Conclusions

It can be concluded that the addition of sawdust, corn bare cobs and shavings to poultry manure improves its porosity, reduces the initial pH and balances its C:N ratio. Regarding the composting process, the thermophilic phase lasted over 30 days in both treatments, favoring pathogen elimination. However, the thermophilic phase was longer in T2 than in T1. Differences in the rate of biodegradation were observed in both mixtures.

According to compost characteristics, T1 showed fewer phytotoxic effects than T2, probably related with the high salt content in T2. It was found that 60 % poultry manure content in the mixture had no adverse effects on the composting process. Nevertheless, the final product had more limitations to agricultural use than a mixture with less poultry manure.

This problematic waste, once composted at a correct dosage, can be used as a substrate component for ornamental plant cultivation, closing the biogeochemical nutrient cycle.

These results suggest that further research is necessary to determine the best strategies to reduce the compost processing time, for example, by co-compostimg poultry manure with others wastes. The final use of these composts in agricultural applications is also worth investigating.

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