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Effects of the Manure Type on the Evolution of Its Co-Composting With Plant Residues and on the Agronomic Quality of the Compost Obtained

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Abstract: During the last decades, there has been an increase in population, with increased food production, and a concentration of inhabitants in cities. This fact has led to an increase in the generation of organic waste of urban, agricultural and livestock origin, which requires adequate management that allows the recycling of the waste generated. In this sense, composting can be a feasible treatment to recycle this waste, and, therefore, improve its properties for agricultural use. Thus, the objective of this study was to evaluate the effect of the type of manure during its co-composting with organic waste of municipal and agricultural origin from the northwest of the island of Gran Canaria, for the subsequent use of the compost obtained as organic amendment in soils or as a substrate for soilless cultivation. For this, three types of manure were used: chicken manure, goat manure and cow manure, which were subjected to a co-composting process mixing them with plant residues from municipal gardens and agricultural crop residues, in the following proportions (on fresh weight): 37.6% straw + 32.7% manure + 29.7% pruning. The composting system used was an open dynamic system of overturned rows, forming three trapezoidal piles 1.5 meters high × 2.5 meters wide and 16 meters long. During the composting process, the evolution of temperature, humidity and different physical-chemical and chemical parameters were studied, and the agricultural value, sanitation and maturity of the compost obtained were also evaluated. The results obtained showed that the three piles achieved adequate sanitation according to the thermal requirements established in the regulations (temperature ≥ 60°C for at least 7 days) and a final product or compost suitable for agricultural use was obtained.

Key words: organic waste, compost, degradation of organic matter, agricultural quality, sanitation

1. Introduction

During the last decades, a large amount of agricultural waste has been produced on the island of Gran Canaria, the management of which is necessary and which is aggravated by the condition of insularity, to which is added the advanced deterioration of the soils located in areas defined as vulnerable by Decree 49/2000, of April 10, which determines the bodies of water affected by the contamination of nitrates of agricultural origin and the vulnerable areas for said contamination are designated. In addition, it is necessary to reduce one of the most damaging agricultural practices where soils are treated as "hidden dumps", applying all kinds of manure on a massive and continuous basis. This application of manure on agricultural land could cause environmental damage, including atmospheric pollution from greenhouse gas emissions [1] and contamination of soil and water resources due to the spread of pathogens and pharmaceuticals [2], as well as excess nutrients [3, 4], which would negatively affect areas vulnerable to nitrate contamination, discussed above.

In this context, composting is considered a strategic technology for the sustainability of agricultural activities that can solve critical problems such as the

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elimination of manure with low cost and environmental impact. To carry out this composting process, it is necessary to co-compost the manures with plant residues that provide the necessary porosity to the mixture so that there is an adequate gas exchange during the composting process. In this way, the antibiotics and pathogens contained in manures can be degraded and reduced, respectively, during the composting process [5, 6]. For this reason, several works have reported the addition of plant residues to manures for co-composting, thus increasing the activity of microorganisms and maintaining the thermophilic stage to obtain a final material free of phytotoxins and disinfected and with a material stabilized and humified organic [7-9].

On the other hand, the compost obtained can be used as an organic amendment or fertilizer in the area of generation of these wastes, thus reducing the use of inorganic fertilizers and promoting efficient economic growth with reduced environmental impacts.

Based on the above, the objective of this work has been to evaluate the effects of three types of manure (chicken manure, goat manure and cow manure) during the evolution of their co-composting with organic waste of municipal and agricultural origin from nearby areas, and its influence on the agronomic quality of the compost obtained.

2. Material and Methods

The composting process was carried out within the Terracan Compost facilities, Santa Maria de Guía (Las Palmas). Three compost piles were prepared with different manures, pruning residues and wheat straw. The characteristics of the initial materials used were those shown in Table 1.

Table 1 Physico-chemical and chemical characteristics of the initial waste.

Residues	H (%)	EC (dS/m)	pH	OM (%)	TOC (%)	TN (%)	P (%)	K (%)	TOC/TN
Pruning	10.92	4.43	6.76	87.2	50.6	1.47	0.30	3.17	34.4
Wheat Straw	9.45	1.00	6.93	92.1	53.4	0.56	0.07	1.59	95.4
Manure chicken	39.80	7.11	8.64	50.0	29.0	3.36	3.53	5.36	8.6
Goat manure	19.81	5.94	8.28	65.6	38.1	2.41	1.10	5.92	15.8
Cow manure	46.40	7.16	10.21	43.6	20.1	1.19	0.73	4.33	16.9

H: humidity; EC: electrical conductivity; OM: organic matter; TOC: total organic carbon; TN: total nitrogen.

The residues were mixed in the following fresh weight proportions:

Pile 1 (CP1) = 29.7% pruning + 37.6% chicken manure + 32.7% wheat straw

Pile 2 (CP2) = 29.7% pruning + 37.6% goat manure + 32.7% wheat straw

Pile 3 (CP3) = 29.7% pruning + 37.6% cow manure + 32.7% wheat straw

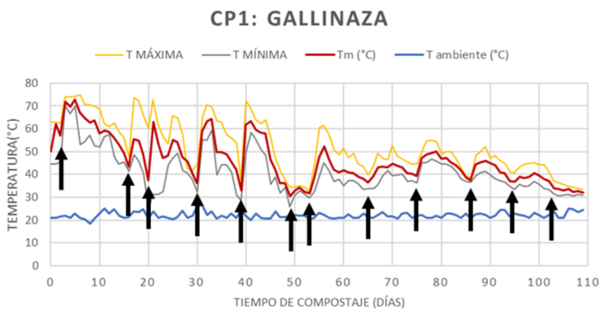
All the piles were composted using the mobile pile system, with aeration by turning, and with a trapezoidal section at the beginning with dimensions of 1.5 m high × 2.5 m wide × 16 m long. In addition, they were composted under textile covers to protect the piles from rain and wind. These covers allowed perspiration and gas exchange. At the beginning of the process, several turner passes were carried out to homogenize the mixture and in the bio-oxidative phase the turns were periodic according to the required oxygen needs for the biomass, turning every three or five days at the beginning, weekly in the thermophilic phase. and then increasingly spaced out in time. These flips were carried out more often when there was a drop in temperature or the temperature rose above 65°C. The bio-oxidative phase was considered finished when the temperature was close to ambient temperature (105, 95 and 65 days for CP1, CP2 and CP3, respectively), allowing the batteries to mature for a subsequent period of one month. Temperature and humidity were controlled daily. The humidity of the mixtures was adjusted to values between 40-60% during most of the process by means of its irrigation with the necessary water. A total of four samplings were carried out in all the piles throughout the composting process, corresponding to the phases of the beginning of the process, thermophilic phase, end of the cooling phase and end of the maturation phase. The pile sampling was carried out by taking seven subsamples from seven different points, along the profile of the pile, so that the final sample taken would be representative of the totality of the material at the time of collection. The collected samples were dried, ground and sieved to a size less than 0.5 mm, prior to their analysis. In the starting materials and in the samples obtained during the composting process, humidity, electrical conductivity (EC), pH, organic matter (OM), total nitrogen (TN), total organic carbon (TOC), macronutrient and heavy metal content and the presence of pathogenic microorganisms were determined according to the analytical methods described in Table 2.

Table 2 Determinations made and their analytical methods.

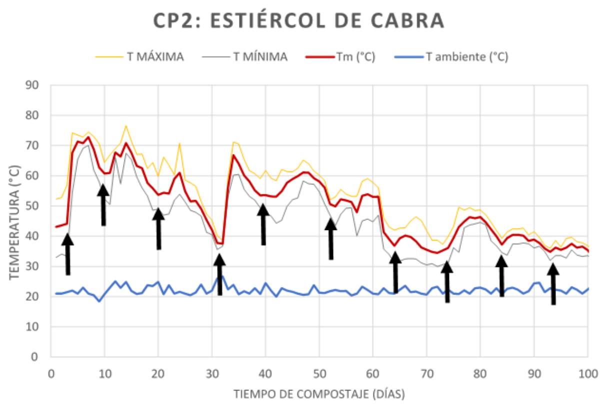
Determinations	Metodología
Humidity	PTA-FQ-024, desiccation a 105°C
Dry material	PTA-FQ-024, desiccation a 105°C
Electrical Conductivity in extract 1/5 (v/v)	PTA-FQ-005, conductivity meter, based on UNE- EN 13038
pH in extract 1/10 (p/v)	PTA-FQ-004, pH-meter, based onUNE-EN 13037
Ashes	PTA-FQ-022, calcination to 540°C, based on UNE-EN 13039
Total organic matter (TOM)	PTA-FQ-022, calcination to 540°C, based on UNE-EN 13039
Total organic carbon (TOC)	PTA-FQ-022, mathematical calculation
Total nitrogen (TN)	PTA-FQ-036, Dumas, based on UNE-EN 13654-2
Total Phosporus (TF)	PTA-FQ-029, Extraction based on UNE-EN 15956, ICP-AES based on UNE-EN 16963
Total Potasium (TP)	PTA-FQ-027, ICP-AES based on UNE-EN 16963
Cd, Cu, Cr, Hg, Ni, Pb, Zn	PTA-FQ-027, ICP-AES based on UNE-EN 16963
ChromiumVI	PTA-FQ-034, HPLC-UV, based on UNE-EN 16318
Escherichia coli Count by NMP	PTAMC 042. Miniaturized Most Probable Number
Salmonella investigation spp	PTA-MC-025. isolation and identification based onISO 6579-1

3. Results and Discussion

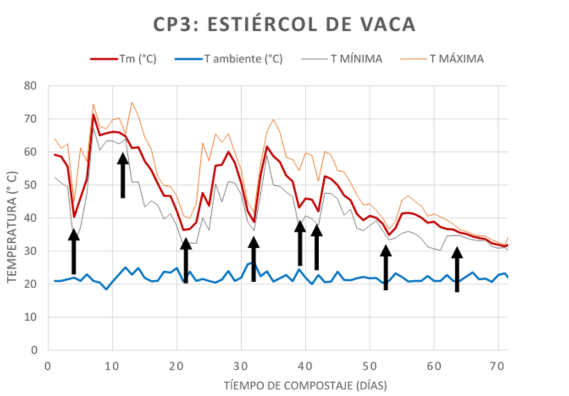
Fig. 1 represents the different temperature profiles of the three study piles with respect to ambient temperature. CP1 reached the highest temperature values (72.9°C) from the fifth day, managing to maintain these temperatures higher than 60°C during the first seven days. CP2 reached the thermophilic stage from the third day, reaching a temperature of 71.3°C on the fourth day and with temperatures above 60°C for fourteen consecutive days, at the beginning of the process. In CP3, the highest mean temperature was 71.3°C, the maximum temperature reached on the sixth day, and from that day on, temperatures remained above 60°C for eight days. This rapid increase in temperature at the beginning of the composting process has also been observed by other authors when co-composting manures with plant residues [8-10]. In all the piles, a temperature increase was observed after each turning, due to the improvement of oxygenation and homogenization of the mixture. The bioxidative stage in CP1 lasted a period of 105 days, in CP2 approximately 95 days and CP3 was considered the most effective with a duration of 65 days. Once the bio-oxidative stage was finished, the piles matured in the maturation hall, without turning over, for a period of one month. In all piles, temperatures > 60°C were maintained for more than seven days. In this way, the destruction of weed seeds, eggs and larvae of insects and pathogenic microorganisms was achieved, in accordance with the European requirements on compost sanitation (Regulation (EU) 2019/1009, which establishes relative provisions to the making available on the market of EU fertilizer products).



(a) CP1: 37.6% straw+32.7% chicken manure+29.7% pruning



(b) CP2: 37.6% straw+32.7% goat manure+29.7% pruning



(c) CP3: 37.6% straw+32.7% cow manure+29.7% pruning. The arrows indicate the days where the flips were performed.

Fig. 1 Evolution of the temperature with respect to the ambient temperature of each of the three batteries.

Table 3 shows the main physical-chemical and chemical properties of the piles during the composting process. In the initial stage of the process, the pH of CP3 with a value of 9.61, which was the highest, decreased throughout the process. However, in the CP1 and CP2 piles an increase in pH was observed during composting, due to the degradation of acidic compounds such as phenolic and carboxylic groups, and the mineralization of proteins, amino acids and peptides to ammonia [11]. The final pH values of all compost were quite high. Therefore, acidic products such as micronized sulfur will have to be added so that the agronomic application of these compost is adequate.

The EC generally tends to increase during the composting process due to the mineralization of organic matter, a fact that produces an increase in the concentration of nutrients. Sometimes a decrease in the EC occurs during the process, which may be due to leaching phenomena in the mass, caused by excessive wetting of the mass or by rain, if the process is carried out in the open air. Table 3 shows the evolution of the EC of the three study piles during the composting process, where these increases and decreases in this parameter can be observed. In the end, all the compost presented a higher salt content than that of the initial waste mix, with high EC values (final EC (CP1) = 7.60 dS/m; final EC (CP2) = 5.65 dS/m; final CE (CP3) = 7.46 dS/m), this fact being able to limit their use as organic fertilizers in crops sensitive to salinity or in soils with salinization problems.

The OM percentage decreased from values of 51.7, 51.1 and 53.8% to 30.2, 31.9 and 29.7% in the CP1, CP2 and CP3 cells, respectively (Table 3). In all the piles it was observed that the greatest loss of organic matter occurred during the bio-oxidative phase (mesophilic phase + thermophilic phase + cooling phase), the losses during the maturation phase being lower. This relative stability of the piles after the bio-oxidative phase has also been reported by other authors during the co-composting of plant waste with manure [7, 8, 11].

As can also be seen in Table 3, the initial TOC percentages had similar values of 30.0, 29.7 and 31.2% for the CP1, CP2 and CP3 cells respectively. The CP3 pile, with bovine manure, was the one that suffered the greatest decrease in this parameter, presenting as a final value 17.22% of TOC. The opposite happened with the CP2 pile, with goat manure, which with an initial value lower than the CP3 was left with a TOC value of 18.52%, which turned out to be the highest final TOC value. Over time, the TOC percentage of the piles experienced a progressive decrease during the bioxidative phase, remaining practically constant in the maturation phase, which is indicative of the OM stabilization in the three piles.

Table 3 Physical-chemical and chemical properties of the batteries during the composting process.

Parameters	CP1				CP2				CP3			
	I	T	FB	M	I	T	FB	M	I	T	FB	M
pH	8.34	8.62	8.49	9.70	8.19	9.12	8.46	9.09	9.61	8.37	9.05	9.22
EC (dS/m)	6.76	6.43	10.17	7.60	5.44	7.14	7.74	5.65	6.64	6.51	7.36	7.46
OM (%)	51.7	50.0	34.6	30.2	51.1	42.9	33.5	31.9	53.8	43.5	37.8	29.7
OTC (%)	30.0	29.0	20.1	17.5	29.7	24.9	19.4	18.5	31.2	25.2	21.9	17.2
TN (%)	2.57	2.46	2.02	1.61	1.61	1.52	1.83	1.37	1.62	1.52	1.52	1.28
OTC/TN	11.67	11.78	9.95	10.88	18.45	16.38	10.62	13.52	19.26	16.61	14.41	13.45

I: beginning of the process; T: thermophilic phase; FB: end of the bio-oxidative phase; M: end of the maturation phase; CE: electrical conductivity; OM: organic matter; TOC: total organic carbon; NT: total nitrogen. CP1: 37.6% straw + 32.7% chicken manure + 29.7% pruning; CP2: 37.6% straw + 32.7% goat manure + 29.7% pruning; CP3: 37.6% straw + 32.7% cow manure + 29.7% pruning.

Regarding the NT, the general evolution of this parameter was a decrease throughout the process (Table 3). This decrease can be attributed to NH3 gas volatilization losses, which are unavoidable during heap tumbling, as well as nutrient losses due to leaching during irrigation. In the CP1 piles, with chicken manure, and CP2, with goat manure, these losses were greater during the bio-oxidative phase, while in the CP3 pile at the end of the cooling stage the concentration of NT increased. The increase in NT that occurred in the CP3 heap could be due to the predominance of the concentration effect over losses due to volatilization and leaching. This concentration effect is caused by the net loss of dry mass as CO_2, as well as the loss of water by evaporation due to the release of heat during the oxidation of OM [11]. Regarding the greater richness of this nutrient in the final compost, it was the heap with chicken manure (CP1) that presented the highest final content of NT, even after the losses due to volatilization of NH3 and the minimum losses of NO3- due to leaching (NT final (CP1) = 1.61%; final NT (CP2) = 1.37%; final NT (CP3) = 1.28%).

On the other hand, in all the piles initial values of the TOC/NT ratio were obtained below the appropriate interval to start the composting process properly (TOC/NT = 25-35) (Table 3). This was due to the fact that it was intended to compost the maximum amount of manure with the minimum proportion of structuring agent, which would provide adequate aeration and porosity for optimal gas exchange during the process. Regarding the evolution of this parameter, a decrease was found throughout the composting process, which indicated the stabilization of the OM of the composted waste. In relation to the final value of the TOC/NT ratio in all compost, a value < 20 was obtained, which indicates an acceptable degree of maturity according to the requirements for compost of the regulations (Royal Decree 506/2013, of June 28, on fertilizer products). However, this value had already been reached in the initial samples of these piles, with which other parameters will have to be seen that indicate that the stabilization of the OM has been achieved

Regarding the agronomic evaluation of the compost obtained, Table 4 shows the results of the main physical-chemical, chemical and microbiological properties of the compost obtained.

In all compost, the moisture contents were below the maximum value established by the compost regulations (humidity < 40%; Royal Decree 506/2013).

The salt content of CP2 was the lowest of all compost obtained. However, both the pH and EC values were high in all compost, these parameters being the main limitations for its agricultural use. Also in all compost, the OM content was below the minimum value of percentage of organic matter established by the legislation for compost (OM > 35%; Royal Decree 506/2013), being the CP1 compost closer to this limit value and CP2. Regarding the content of macronutrients, the CP1 compost, with chicken manure, was the one that presented the highest fertilizing capacity, since its NT, P and K contents were the highest. In addition, the heavy metal contents were, in general, below those marked to classify the compost as class A, except in the case of the Ni contents, which in all the compost were higher than those established for this classification (Ni < 25 mg/kg), as well as the CP1 compost presented Zn values above those allowed for classification A (Zn < 200 mg/kg). Therefore, the classification of the compost obtained had to be B. Finally, the presence of pathogenic microorganisms was below the requirements of the regulations to ensure the sanitation of the compost (E. coli < 1000 MPN/g and Salmonella = absent in 25 g of product; Royal Decree 506/2013). This indicated that the temperatures developed during the thermophilic stage were adequate for the reduction of pathogens, thus contributing to the sanitization of the final product obtained.

Table 4 Values of the main physical-chemical, chemical and microbiological parameters of the compost obtained.

Parameters	CP1	CP2	CP3
Humidity (%)	33.90	27.20	16.39
EC (dS/m)	7.60	5.65	7.46
pH	9.70	9.09	9.22
OM (%)	30.2	31.9	29.7
OTC (%)	17.5	18.5	17.2
TN (%)	1.61	1.37	1.28
P (%)	1.98	0.79	0.72
K (%)	2.95	1.99	2.58
Cd (mg/kg)	< 0.50	< 0.50	< 0.50
Cu (mg/kg)	53	33	50
Cr (mg/kg)	60	48	82
Hg (mg/kg)	< 0.200	< 0.200	< 0.200
Ni (mg/kg)	49	45	59
Pb (mg/kg)	< 2.00	< 2.00	< 2.00
Cromo (VI) (mg/kg)	n.d.	n.d.	n.d.
Zn (mg/kg)	312	124	97
E. coli (NMP/g)	< 58	< 58	< 58
Salmonella (presence)	n.d.	n.d.	n.d.

CE: electrical conductivity; OM: organic matter; TOC: total organic carbon; NT: total nitrogen. CP1: 37.6% straw + 32.7% chicken manure + 29.7% pruning; CP2: 37.6% straw + 32.7% goat manure + 29.7% pruning; CP3: 37.6% straw + 32.7% cow manure + 29.7% pruning. n.d.: not detected. Limit of quantification <0.5 mg / kg, in the case of Cr (VI).

4. Conclusion

From the results obtained, it can be concluded that the co-composting of the manures with the studied plant residues constituted an efficient method, not only to recycle these residues but also to obtain compost with potential use in the agricultural production cycle. Also, the waste mixtures were adequate with respect to achieving the necessary temperature increase to ensure the sanitization of the compost obtained. In addition, the degradation of the waste was high during the composting process with a percentage of loss of organic matter between 37.6-44.8%, obtaining compost with a content of organic matter below the minimum value indicated in the regulations for compost.

This intense degradation of organic matter led to the obtaining of compost with high pH and electrical conductivity values, which are the most important factors for limiting the agricultural use of the final compost.

The type of manure used mainly influenced the fertilizing capacity of the compost obtained, being the CP1 compost, made from chicken manure, the one with the highest macronutrient content. Finally, the compost obtained has been classified as B, with respect to its content of heavy metals, therefore there are no limitations on the amount of application of the same per hectare and year.

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