Optimization of the composting process of sugarcane filter-pressed mud in the Santa Rosalia sugar mill, Tabasco, Mexico

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ABSTRACT

Objective: To optimize the composting process of sugarcane filter-pressed mud, straw, and ash as an alternative to reduce the environmental contamination of sugarcane cultivation in the Santa Rosalía sugar mill (Ingenio Santa Rosalía) of Chontalpa, Tabasco, Mexico.

Design/Methodology/Approach: A completely randomized experimental design in a factorial arrangement was used, with compost mixtures and the aeration times as study factors. Ten treatments were generated with six repetitions each. The study variables were pH, organic matter (%), and nitrate $\left(NO_3^-\right)$ and ammonium $\left(NH_4^+\right)$ content.

Results: The compost mixture factor had significant effects on compost quality parameters. Aeration times did not affect the quality of the different compost mixtures. Chemical characteristics of pH and organic matter did not present differences between the treatments.

Study Limitations/Implications: The use of industrial sugarcane residues generates quality organic fertilizers through the composting process; therefore, it is necessary to test more residues, such as molasses and vinasses.

Findings/Conclusions: The 100% sugarcane filter-pressed mud and the 100% sugarcane filter-pressed mud+0.5% N treatments presented the highest amount of NO_3^- and NH_4^+ and were therefore considered the best treatments. All treatments were classified as mature composts, rich in organic matter, with alkaline pH, and made of steady materials.

Keywords: Compost, waste, sugarcane filter-pressed mud, quality, sugarcane.

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INTRODUCTION

Sugarcane (*Saccharum* spp.) is an important crop in Mexico, due to the monetary incomes and jobs it generates (Palma-López *et al.*, 2016). From 2007 up to date, Ingenio Santa Rosalia (ISR), located in the region of Chontalpa, Tabasco, has increased its cultivated area from 9,038 to 13,012 ha. Its cane yield has likewise increased from 41.6 to 67 t ha^{-1}, although they still are lower than the national average (68.7 t ha^{-1}) (CONADESUCA, 2020). In order to increase productivity, sugarcane crops in Mexico and in the state of Tabasco are generally subjected to burn, mechanization, and an excessive use of fertilizers. These activities have several adverse effects, including:

reduction of soil organic matter, increase of erosion, and decrease in the density of microbial populations that are beneficial for crops (Palma-López *et al.*, 2016). The use of compost or organic fertilizers, biofertilizers, green manures, and covers crops is an alternative for soil restoration (Pérez *et al.*, 2011). Sugarcane generates excess organic matter such as vinasse, bagasse, and sugarcane filter-pressed mud. Although sugarcane filter-pressed mud is used in the ISR, it has not been possible to optimize its composting and, consequently, to reduce production and application costs (Salgado *et al.*, 2013). The contribution of these modifications can help preserve and promote the structure of the soil, because organic matter favors aggregation in clay soils through physical and chemical mechanisms. This type of soils includes vertisols, fluvisols, and gleysols, which have low aggregation and poor drainage problems (Sánchez Hernández *et al.*, 2006; Palma-López *et al.*, 2016; Salgado *et al.*, 2013) that are typical of ISR area.

MATERIAL AND METHODS

Origin of compost

The collection of materials for the 2019-2020 composting was performed on May 2021 in the area of influence of ISR in la Chontalpa, Cárdenas Tabasco, at the end of the harvest season. The newly generated sugarcane filter-pressed mud was left outdoors for 30 days for cooling. Sugarcane straw were collected 4 days after the harvest of a commercial plot (4 days of sun exposure) and fractionated with a forage mill. Ash was obtained from the ISR boiler and FYPA® urea was applied as a nitrogen source (46% N).

Experimental site

The composting process was established indoors at the facilities of the Universidad Popular de la Chontalpa, located at km 2 of the Cárdenas-Huimanguillo road, in the municipality of Cárdenas, Tabasco, Mexico.

Treatments and experimental design

The treatments were developed using a completely randomized design with 5×2 factorial arrangement (5 compost mixtures and 2 aeration times: 7 and 14 days), which generated 10 treatments (Table 1) that were distributed randomly in the experimental site with six replicates (Figure 1). Sixty 38-kg experimental units were generated. A 20-liter bucket was used to mix the compounds of the different experimental units and scales were used for the measurement reference. For the application of the sugarcane filter-pressed mud only the scales were used.

Handling of the composting process

The treatments were established in a site with a concrete floor and ceiling on a 2×2 m plastic film (Table 1). The materials were mixed for homogenization over the film (Figure 2a). Subsequently, they were wrapped with the same nylon to protect them and prevent leaching (Figure 2b); the treatments were subject to an aeration process every 7 or 14 days.

Table 1. Study treatments with different mixtures and aeration times.

Treatments	Compost mixtures	Aeration time (days)
1	Sugarcane filter-pressed mud 100%	Seven days*
2	Sugarcane filter-pressed mud 100% + 0.5% N*	Seven days
3	Sugarcane filter-pressed mud 75% + bagasse 25%	Seven days
4	Sugarcane filter-pressed mud70% + 20% straw + 10% ash	Seven days
5	Sugarcane filter-pressed mud 60% + 30% straw + 10% ash	Seven days
6	Sugarcane filter-pressed mud100%	Fourteen days
7	Sugarcane filter-pressed mud 100% + 0.5% N*	Fourteen days *
8	Sugarcane filter-pressed mud 75% + bagasse 25%	Fourteen days
9	Sugarcane filter-pressed mud 70% + 20% straw + 10% ash	Fourteen days
10	Sugarcane filter-pressed mud 60% + 30% straw + 10% ash	Fourteen days

*Applied as FYPA urea, with a 46% N content.

3	10	1	7	2	5	9	6	4	8
1	7	8	5	4	3	6	9	2	10
1	2	7	5	8	10	3	6	4	9

5	6	9	8	7	10	3	7	2	4
8	2	10	7	1	4	5	3	9	6
8	4	9	7	1	5	10	3	2	6

Figure 1. Random distribution of treatments according to their numbering in the experimental site. Each number represents an experimental unit of a treatment (10 treatments with 6 repetitions = 60 experimental units).

Figure 2. a) Treatment mixture and b) wrapped treatments.

Study variables

At the beginning of the process, four sugarcane filter-pressed mud, bagasse, ash, and straw samples were collected for their physical and chemical characterization. Every 30 day, samples were collected to analyze the pH, MO, NH_4^+, NO_3^- variables (three repetitions per variable) (Figure 3). They were dried in the shade, ground, and sieved using a 2 mm mesh for their analysis according to Pérez *et al.* (2011) and the NMX-FF-109-SCFI (2008). Two-hundred seventy analyses were carried out.

Figure 3. Sampling process: a) sampling and b) sample labelling every 30 days.

Statistical analysis

The study variables were subjected to an analysis of variance with a 5×2 factorial arrangement, considering the mixture factors (100% sugarcane filter-pressed mud, 100% sugarcane filter-pressed mud + 0.5% N, 75% sugarcane filter-pressed mud + 25% bagasse, 70% sugarcane filter-pressed mud + 20% straw + 10% ash, and 60% sugarcane filter-pressed mud + 30% straw + 10% ash), aeration times (7 days and 14 days), and six repetitions. Variables with significant differences between treatments were subject to Tukey's multiple comparison test ($P \leq 0.05$) using the SAS 9.2 statistical software.

RESULTS AND DISCUSSION

Physical and chemical characteristics of sugarcane filter-pressed mud compost

Table 2 shows the analysis of variance of the physical and chemical characteristics of the various compost mixtures and aeration times under review. Neither the different mixtures nor the aeration times affected the pH. Organic matter content (OM, %) was significantly affected by different compost mixtures. Nitrates (NO_3^-, ppm) were not affected by any factor. Ammonium (NH_4^+, ppm) showed significant differences regarding the compost mixture factor.

Hydrogen potential (pH)

No significant pH differences were observed for the mixture, aeration times, and interaction factors (Table 2). The mean pH value of the treatments fluctuated between 8.4 and 8.9, which are normal values for organic substrates (Hernández *et al.*, 2013). Torres-Lozada *et al.* (2021) also reported an 8.13 pH in a sugarcane filter-pressed mud-based compost. The presence of sugarcane filter-pressed mud treated with lime ($CaCO_3$) —as is the case of the sugarcane filter-pressed mud produced at ISR during this study— increased pH values above 8; therefore, it is useful to alkalinize the pH of acid soils (Dotaniya *et al.*, 2016). Mendez *et al.* (2011) observed that composts containing a higher proportion of sugarcane filter-pressed mud in relation to bagasse have a higher pH than those cases when there is more cane bagasse than sugarcane filter-pressed mud. According to the NMX-FF-109-SCFI-2008, the pH values of compost must range from 5 to 9.

Mendez *et al.* (2011) observed that adding ammonia to sugarcane filter-pressed mud and bagasse mixtures caused a pH decrease in treatments with ammonia, while treatments without ammonia maintained a steady pH value of 7.70. Such was the case of the 100% sugarcane filter-pressed mud + 0.5% N mixture in this study, which recorded the lowest pH values (8.43), in contrast to the 100% sugarcane filter-pressed mud treatment, at both aeration time levels. Towards the end of the composting process, pH drops as a result of the formation of low-molecular weight organic acids.

Furthermore, Official Mexican Standard NMX-AA-180-SCFI-2018 states that the pH of the finished composts ranges from 6.7 to 8.5, which seems to be the case only of the ammonium-added treatment.

Organic matter (OM, %)

The organic matter (OM, %) content of different compost mixtures ranged from 28.03 to 33.89%, values that are considered to be within the optimum range (20-50% OM) established by the Official Mexican Standard NMX-FF-109-SCFI-2008. Our results are also in line with the organic matter content of organic substrates of sugarcane filter-pressed mud reported by Martínez *et al.* (2021) and are lower than those reported by Hernández-Melchor *et al.* (2008) for the sugarcane filter-pressed mud-based compost (58.6% OM). At 7 days of aeration, the 75% sugarcane filter-pressed mud + 25% bagasse treatment, with an average 33.89% OM, showed the highest pH values compared to the other treatments (Table 3). Treatments including a certain proportion of cane bagasse have a higher OM percentage regarding sugarcane filter-pressed mud-based treatments, since bagasse mainly contains organic compounds such as cellulose, hemicellulose, and lignin (Méndez *et al.*, 2011; Salgado *et al.*, 2013).

Nitrates (NO_3^-, mg kg^{-1})

NO_3^- values ranged from 5 to 13.15 ppm. According to the CCQC criteria (2001), <100 ppm values are found in very mature composts. For their part, Méndez *et al.* (2011)

Table 2. Mean squares of ANOVA for the chemical properties of the different compost mixtures and aeration times under review.

Factor of variation	GL	Mean Square			
		pH	MO (%)	NO_3^- (mg kg^{-1})	NH_4^+ (mg kg^{-1})
Mixtures (M)	4	0.42 NS	52.83**	19.02 NS	584.22**
Time (T)	1	1.4×10^{-3} NS	7.23 NS	0.20 NS	53.92 NS
M*T	4	0.11 NS	8.86 NS	129.45 NS	19.69 NS
Error	80	0.30	8.10	183.8	45.54
CV (%)		6.3	9.21	48.91	58.98

C=cycle, V=variety, SS=soil subunit SS>V=nested factor (V within SS), GL=degree of freedom, *=P<0.05, **=P<0.01, NS=not significant.

Table 3. Tukey's multiple comparison test of the organic matter content (OM, %), pH, NO_3^- (ppm), and NH_4^+ (ppm) of the various compost mixtures and aeration times under review.

Treatment	Compost mixtures	Aeration time (days)	pH	OM (%)	NO_3^- (ppm)	NH_4^+ (ppm)
1	Sugarcane filter-pressed mud 100%	7	8.81a	31.14ab	6.92a	11.29bc
2	Sugarcane filter-pressed mud 100% + 0.5% N	7	8.43a	30.62ab	12.02a	20.62ab
3	Sugarcane filter-pressed mud 75% + bagasse 25%	7	8.87a	33.89a	11.38a	9.77c
4	Sugarcane filter-pressed mud70% + 20% straw + 10% ash	7	8.52a	28.03b	8.57a	10.35bc
5	Sugarcane filter-pressed mud 60% + 30% straw + 10% ash	7	8.8a	29.36b	6.79a	9.06
6	Sugarcane filter-pressed mud100%	14	8.78a	31.62ab	13.15a	10.64bc
7	Sugarcane filter-pressed mud 100% + 0.5% N	14	8.43a	31.86	8.37a	22.16ab
8	Sugarcane filter-pressed mud 75% + bagasse 25%	14	8.71a	32.23ab	5a	5.87c
9	Sugarcane filter-pressed mud 70% + 20% straw + 10% ash	14	8.78a	28.67b	7.33a	7.62c
10	Sugarcane filter-pressed mud 60% + 30% straw + 10% ash	14	8.7a	31.49ab	11.36a	7.04

* Results with different letters are significantly different ($P \leq 0.05$). The values represent the means of each treatment.

recorded that NO_3^- content diminished as cane bagasse increased in the substrate, while the content increased in treatments with a higher proportion of sugarcane filter-pressed mud. These results are explained by the almost null nitrate $\left(NO_3^-\right)$ formation during the initial stages of composting. NO_3^- is only released until the substrate has got past the thermophilic phase and reached a mesophilic range, because that is the moment when organisms emerge transforming NH_4^+ into NO_3^- (Montoya-Jasso *et al.*, 2021): Therefore, we can infer that the changes that occur during the thermophilic phase —such as the decrease in pH and increase in EC— favor the increase of N-ammoniacal and nitrates (Méndez *et al.*, 2011), as was the case of the ammonium-added treatments with the lowest pH values.

Ammonium (NH_4^+, mg kg^{-1})

Ammonium $\left(NH_4^+\right)$ showed significant differences only in the mixing factor (Table 2). According to the criteria established by CCQC (2001), the NH_4^+ concentration of a compost depends on its degree of maturity: >500 ppm means an immature compost; between 100-500 ppm, a mature compost; and <100 ppm, a very mature compost. The third category corresponds to the composts studied in this research. Our results pointed out that adding ammonia to the 100% sugarcane filter-pressed mud + 0.5% N treatments in both aeration times achieved the highest values of NH_4^+ compared to the treatments without additional ammonia (Méndez *et al.*, 2011; Torres-Lozada *et al.*, 2021).

In our study, composts are classified as very mature stabilized organic materials (CCQC, 2001). The lower NH_4^+ content recorded in the mixture with bagasse was the result of the transformation of ammonium and the slow degradation of residues with a high C:N ratio, such as sugarcane bagasse (Méndez *et al.*, 2011; Salgado *et al.*, 2013; Martínez *et al.*, 2021). The combination of sugarcane filter-pressed mud and bagasse with 90-day composting showed a stable carbon-nitrogen (C:N) ratio, as well as a low amount of ammoniacal nitrogen $\left(NH_4^+\right)$. Consequently, the plant has enough nitrate available (Quiroz and Pérez, 2013), as was the case of the 75% sugarcane filter-pressed mud + 25% bagasse treatment at 7 days of aeration time (Table 3).

CONCLUSION

Aeration time did not show significant differences regarding the quality parameters of composts. All treatments had optimal pH and OM levels. The 100% sugarcane filter-pressed mud and 100% sugarcane filter-pressed mud + 0.5% N treatments obtained the highest nitrate $\left(NO_3^-\right)$ values (13.12 and 12.02 ppm, respectively), as well as high ammonium $\left(NH_4^+\right)$ content (22.16 and 11.29 ppm, respectively). All the mixtures were mature composts and suitable for replacing chemical fertilization.

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