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STABILIZATION BY CO-COMPOSTING OF SOLIDS REMOVED FROM WASTEWATER TREATMENT PLANT OF A CHEESE FACTORY

ESTABILIZACIÓN POR CO-COMPOSTAJE DE SÓLIDOS REMOVIDOS DE UNA PLANTA DE TRATAMIENTO DE AGUAS RESIDUALES DE UNA QUESERÍA

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Abstract

A wastewater plant of a dairy industry generates 1.6 tons/month of settleable solids and 650 kg/week of floatable solids, which if not adequately disposed off, can cause serious soil contamination and vector attraction. A composting process for stabilizing residues with high fat content that generate unpleasant odors is presented. Laboratory experiments were carried out for determining the appropriate process parameters, and scaled-up for the in situ process. Laboratory tests with cattle manure showed a reduction in the production of malodorous gases in three weeks. The resulting compost complied with national and international standards, and can be used in 1:3 compost:soil ratio for soil improvement. The waste stabilized in situ complied with most parameters established in the Mexican regulation (NOM-FF-109-SCFI-2007), excepting pH (9.6) and electrical conductivity (5 dS/m).

Keywords: co-composting, high grease content residues, dairy cattle manure, compost quality, cost.

Resumen

Una planta de tratamiento de aguas residuales de una industria láctea genera alrededor de 1.6 ton/mes de sólidos sedimentables y 650 kg/semana de sólidos flotantes; los cuales no se disponen adecuadamente, causando problemas de contaminación de suelo y atracción de vectores. Este trabajo presenta una solución práctica a la industria quesera; un proceso de compostaje para estabilizar los residuos con alto contenido de grasa, los cuales generan olores desagradables. Con la finalidad de establecer los parámetros del proceso se llevó a cabo experimentación a nivel laboratorio y posteriormente se escaló, para adaptar el proceso *in situ*. Los resultados de laboratorio mostraron la reducción en la producción de gases mal olientes en tres semanas con el uso de estiércol vacuno y el compost obtenido cumplió con la normatividad nacional e internacional; y puede ser usado a una relación 1:3 (compost:suelo) para mejorar el suelo de los jardines de la empresa. El proceso de estabilización *in situ* cumple con la mayoría de los parámetros que marca la normatividad, excepto en pH (9.6) y conductividad eléctrica (5 dS/m) (NMX-FF-109-SCFI-2007). El costo de producción del proceso de estabilización fue bajo comparado con el asociado al tratamiento típico de los residuos, aparte de su implícita sustentabilidad.

Palabras clave: co-compostaje, residuos con alto contenido de grasa, estiércol vacuno, calidad del compost, costo.

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1 Introduction

The main emission of the cheese industry is wastewater due to the large requirements of water during the process (cleaning, heating, cooling, and washing) and the generation of the product itself; these effluents are rich in organic matter with high protein and fat content that can cause significant damage to the receiving water bodies (Korsström and Lampi, 2008). Most countries have specific legislation that force industry to comply with strict wastewater discharge standards (OJEC, 2000; USEPA, 1995; DOF, 2003a) in order to avoid environmental problems in surface and groundwater bodies, and soil.

The dairy industries in the north of Mexico are not the exception to all these associated problems. A dairy company located in Nuevo Ideal, Durango, Mexico installed a Wastewater Treatment Plant (WWTP) to treat its effluents; which produced settleable solids at the skimmer and floatable solids from the maturation pond, skimmer, and the anaerobic tank with high fat content; partially disposed at an open dumpster and the rest was stacked within the premises. The dairy company does not fulfil the current environmental legislation (NOM-004-SEMARNAT-2002) regarding management and safe disposal of sludges and biosolids (DOF, 2003c).

The stabilization and disposal of sludge and biosolids represent 60% of the annual budget for operation and maintenance of the WWTP; so, this dairy company was looking for a better treatment to reduce costs. These include chemical, physical, and biological treatments, where the latter are more environmentally friendly. However, in the biological treatment of fat its insolubility in water is considered a limiting factor; but in the biological treatment of fat under thermophilic conditions there are favorable changes in physical properties of these compounds to increase its biodegradability (Becker *et al*., 1999). In this sense, composting, which is characterized by the rapid development of a thermophilic initial stage, can be an alternative to treat effectively fats and oils, at no additional cost.

Usually, sludges and biosolids are treated anaerobically to produce biogas, and its biodegradability is increased by physical and/or chemical treatments (thermal, ultrasonic, alkali, thermal-alkaline, ultrasonic-alkaline and alkaline-ultrasonic) prior to digestion, to hydrolyze proteins, fats, carbohydrates, and other polymers of the sludge flocs; but the treatments are not always beneficial, because after digestion the amount of fecal coliforms (FC) increases above the limit allowed by the NOM-004-SEMARNAT-2002, except in the alkaline heat treatment according to what was reported by Vigueras-Carmona *et al*. (2013).

Composting high fat content wastes is difficult due to their low nitrogen and phosphorous content relative to carbon content, so they are mixed with another substrate to compensate the C/N ratio of the initial mixture; which is a process called co-composting, defined as the composting of a mixture of two or more types of waste residues (Dinis, 2010). Different types of sludge with low C/N ratio are considered suitable to be composted with fats or fat enriched wastes (Wakelin and Forster, 1997); manures of cow, horse, pig, poultry, and sheep can be also used to lower C/N ratio.

Additionally, fat composting requires a bulking agent to increase porosity to incorporate air into the mixture; the most widely used materials are wood chip, sawdust, grass clipping, and yard wastes. In this regard, Ruggieri *et al*. (2008) in the co-composting of animal fat with wastewater sludge used wood chips as bulking agent, in the range of 2:1-1:1 (bulking agent:sludge).

It is recommended not to compost dairy products due to odor and vector problems (Pleasant and Martin, 2008); nevertheless, the resulting material (compost) can be used at the premises to improve soil conditions and, at this specific case, for growing crops and forage for the dairy cattle.

According to the above, to reduce the negative impact of the settleable and floating solids of the WWTP, a co-composting process with dairy cattle manure was proposed to the industry; where manure compensates the C/N ratio of the initial mixture and acts as inoculum, and garden wastes as bulking agent. To determine the process parameters such as fat degradation time, changes in pH and electrical conductivity, product toxicity, among others, experimentation at laboratory level was conducted and then adjusted for *in situ* treatment in the company, in order to accomplish environmental legislation.

2 Materials and methods

Residues were collected from the WWTP located in the municipality of Nuevo Ideal, Durango, at the northern territory of Mexico. The WWTP system treats an effluent of approximately 50 m^3/day; 650 kg/week of floating solids from skimmer, anaerobic tank, and oxidation pond are removed and disposed at the municipal open dump. Settleable solids were collected on a straw filter, removed every 3 months (4.8 tons), and piled up within the premises; which during the degradation process generate malodorous gases and leachate that attracts vermin. Experimental work was carried out at laboratory scale (40 kg) with settleable solids and then the process was adapted for *in situ* treatment at the company in piles of 2000 kg.

2.1 Laboratory experiments

Settleable solids with straw filter were collected at the WWTP and transported to the laboratory (160 km) for further analyses; characterization is shown in Table 1. A completely randomized block design with two repetitions (one way ANOVA) was established to conduct the experiments, where the factor to evaluate was the influence of the co-composting material. Treatment 1 (T1) was 40 kg of residues without additives (control); treatment 2 (T2) was a mixture of 30 kg of residues and 10 kg of native soil; and treatment 3 (T3) was a mixture of 30 kg of residues and 10 kg of dairy cattle manure.

The experimental units were plastic rectangular containers of 90 L; perforated in an equidistant array of 10 cm at the bottom and at the sides with a 1/4" drill, to allow air flow. The containers were placed in a greenhouse, covered with rigid plastic. Temperature of the experimental units was monitored weekly using a 20 cm needle thermometer and ambient temperature with a maximum and minimum thermometer, and mixtures were homogeneously turned over once a week during the first 15 weeks; afterwards, the residues were undisturbed until the end of the process at week 18, water was added to maintain moisture content ranging between 45-60%.

Compost samples were taken every three weeks and analyzed for pH and electrical conductivity (EC) in a 1:10 water extract; organic matter, viable count of microorganisms (bacteria, fungi, and yeast), and oil/grease content. From week 12 onwards, samples were also used to determine maturation of the compost by the germination index (GI) of lettuce seeds (*Lactuca sativa*) using same water extracts and incubated at 20°C for 5 days.

2.2 Implementation of in situ composting of waste

Composting of floating solids of the WWTP was conducted *in situ* with a 1:1:0.5 ratio of garden waste: dairy cattle manure: floatable solids (total of 2.97 tons) mixed with 3.1 m^3 of treated wastewater and divided into three piles of approximately 2 tons each (on a wet weight basis).

Temperature of the piles was measured weekly using a 60 cm needle thermometer and ambient temperature was also monitored using a bulb (mercury) thermometer. Piles were turned over once a week using a small front loader and water was added as needed to maintain desired moisture content based on the squeeze method, samples were collected and analyzed in the laboratory to verify moisture content. Piles were covered with plastic to preserve moisture and heat.

2.3 Analytical methods

Residues for the laboratory scale experiments (settleable solids and oat straw of the WWTP, dairy cattle manure, and native soil); and residues for the *in situ* pilot scale experiment (floatable solids, garden waste, and dairy cattle manure) were collected and transported to the laboratory for analyses. Moisture, dry matter content (105°C), ashes, and organic matter content were determined following Zhu *et al*. (2004) method; total organic carbon (TOC) was estimated according to Haug (1993), and total Kjeldahl nitrogen (TKN) was analyzed following DOF (2003b).

Table 1. Average values ± Std. Dev. (n = 2) of the individual chemical characteristics of the co-composting residues

	Moisture	Fat	Carbon	TKN	TP	TK
	%					
Settleable solids	59 ± 2.2	7.7 ± 0.1	22 ± 1.5	0.7 ± 0.007	0.25 ± 0.02	0.44 ± 0.01
Dairy manure	43 ± 0.9	0.15 ± 0.06	27 ± 2.0	1.5 ± 0.03	0.64 ± 0.001	0.57 ± 0.001
Soil	6 ± 0.08	0.04 ± 0.001	3 ± 0.02	0.05 ± 0.004	0.014 ± 0.001	0.12 ± 0.09
Floatable solids	83.6 ± 1.0	72.1 ± 5.8	52.2 ± 0.6	0.4 ± 0.02	0.23 ± 0.02	0.21 ± 0.09
Garden waste	10.1 ± 1.0	0.78 ± 0.1	48.3 ± 1.4	3.7 ± 0.05	0.15 ± 0.001	1.40 ± 0.001

TKN = Total Kjeldahl Nitrogen; TP = Total Phosphorus; and TK = Total Potassium

Oil and grease were analyzed by the Soxhlet method established by DOF (2004); total potassium (TK) and total phosphorus (TP) were determined by incineration and acid digestion of solid samples. Potassium was quantified by atomic adsorption using a Perkin Elmer Atomic Absorption Spectrometer model A-Analyst 700, with WinLab 32 software. A Perkin Elmer hollow cathode lamp with a wavelength of 766.5 nm was used as the light source. Carrier gases were acetylene and air with an internal pressure of 14 and 70 psi, respectively; a Perkin Elmer standard was used for calibration. Quantification of phosphorus was determined following DOF (2003b). The GI was determined following the procedure and calculations according to Tiquia and Tam (1998).

Viable count of microorganisms was carried out by spreading samples on poured plates with standard agar (Bioxon) and incubated at 35 ± 2°C for 48 h for mesophilic bacteria; and on poured plates with potato dextrose agar (Bioxon) incubated at 20 ± 2°C for 5 days for fungi and yeast.

Chemical quality of compost was evaluated by the methods described in DOF (2003b) and the presence of pathogen bacteria was determined by fecal coliform microorganisms as an indicator, samples were spread on brilliant green bile agar plates (Bioxon) and were incubated at 35 ± 2°C for 24 h. Residual water from the cheese factory comes exclusively from washing equipment and facilities.

2.4 *Cost of WWTP waste stabilization*

To estimate the cost of waste stabilization the following aspects involved in the process were considered: hauling manure (freight), cut grass (labor and gasoline for the mower), 2 workers for building piles, backhoe rent, an operator once a week to mix material and add treated water of WWTP to the piles, and 27 square meters of silage plastic to cover piles.

2.5 *Analyses results*

Results were plotted to observe the parameters behavior with time and were analyzed statistically. In order to determine significant differences, results were standardized to z values to improve distribution and were evaluated by an ANOVA followed by Newman-Keuls test with a 95% confidence interval ($\alpha = 0.05$); using STATISTICA 7® software version 7.0.

3 Results and discussion

Laboratory experimental phase generated a substantial amount of data and results are discussed as follows. At the laboratory stage, tree treatments (T1, T2, and T3) with two repetitions were used to predict the changes of pH, EC, oil and grease, organic matter, viable count of microorganisms, and GI. Based on the results with manure in the T3 treatment (bad odor was removed in a shorter period of time); we proceeded to compost, *in situ*, floating solids with yard waste and manure into three piles of 2 tons each.

3.1 *Laboratory experiments*

3.1.1. Temperature

Temperature values increased during the first week of composting, ranging from 35 to 45°C. The behavior in all treatments followed a similar decreasing trend, with no significant differences ($F = 1.41$, $p = 0.24$), reaching about 23°C after week 4 and remained constant towards the end of the experiment with values around 20°C.

Generally, if pile size, moisture, oxygen content, and the C/N ratio are adequate, temperature may increase up to 55°C (Dalzell *et al*., 1991). However, when the pile size is rather small, the heat generated by the aerobic process can be dissipated rapidly, causing a slowdown of the composting process as observed by the gradual removal of organic matter (Fig. 1A). In the composting process, the ambient temperature also influences the development of heat, it is noteworthy that the experiment was conducted during the winter (November-March); so that the temperature of the experimental units ranged parallel with ambient temperature changes; similar results were reported by Corral (2011) in the waste composting of oregano with cattle manure.

When composting greasy waste, the heat generated in the process depends not only on the size of the pile, but also in the type and amount of fat. Garcia-Gomez *et al*. (2003) results about the co-composting of olive oil mill wastes with olive leaves, in aerated static piles of 2.5 tons with 7 and 15% of fats in the initial mixture, showed longer thermophilic phase of 50°C for 4 weeks and of 55°C for 6 weeks, respectively. In the co-composting of wastewater sludge with animal fat and wood chips (47.5% fat) aerated by mechanical tumbling, reported thermophilic temperatures of 60-65°C in the first three weeks of process (Ruggieri *et al*., 2008).

3.1.2. pH

An increasing trend in pH values at the experimental units were observed during the first 9 weeks of operation, being T3 the one that reached the highest value; afterwards, pH values remained stable around 7.3 ± 0.1 (T1), 7.7 ± 0.2 (T2), and 8.7 ± 0.6 (T3); showing significant differences ($F = 50$, $p < 0.001$), according to statistical analysis.

A change in pH is another important factor in the composting process; optimal pH values for composting ranges between 5.5 and 8.0, being 7.0 for mature compost (Bertoldi *et al*., 1983). Final pH values for T1 and T2 were within the normal reported ranges; nevertheless, pH values for T3 were slightly above optimal range.

Behavior of pH in the process also depends on temperature, when degradation of organic matter takes place different groups of microorganisms (mesophilic and thermophilic) are involved and basic compounds (NH_3/NH_4^+) are produced to increase pH and then when oxidized (production of NO_3^-) pH lowers again. In this investigation pH of T3 treatment did not decrease, probably because not all ammonia generated during the degradation of manure was nitrified; however, a large amount of NO_3^- was found in the compost (1482.6 ± 65.7 mg/kg).

Composting experiments of rabbit manure and trimming lawn garden (Santamaría-Romero *et al*., 2001), pig manure, and rice straw (Zhu *et al*., 2004), and oregano residues with cow manure (Corral, 2011) reported pH values of 8.6, 8.0, and 8.9, respectively; therefore alkalinity of T3 treatment in the present research is attributed to the of manure added. As additional information, WHO (1985) considers a pH range of 6-9 for compost, because it depends on the type of waste being composted.

3.1.3 Organic matter

Results showed the breakdown of materials during the composting process with removal efficiencies of 64 ± 1.9% (T1), 48.2 ± 6.8% (T2), and 37.5 ± 4% (T3) (Fig. 1A). There were significant statistical differences between T1 and T3 for organic matter removal ($F = 3.8$, $p = 0.03$); however, fat removal efficiencies (Fig. 1B) in all treatments showed similar trends with no significant differences ($F = 0.06$, $p = 0.94$). Approximately 75% of fat was degraded after 3 weeks of operation in all treatments. After 9 weeks of operation fat removal reached approximately 93.4 ± 0.2% (T1), 93.8 ± 1.2% (T2), and 92.5 ± 0.6% (T3); from this week onwards fat degradation slowed down.

Gea *et al*. (2007) results for composting sewage sludge and animal fat (30%), at temperatures between 45 and 60°C, reported 85% fat removal in 35 days; while in our results for WWTP residues with 7.7% fat at temperatures between 35 and 45°C, 82.6% was removed in 42 days (Fig. 1B).

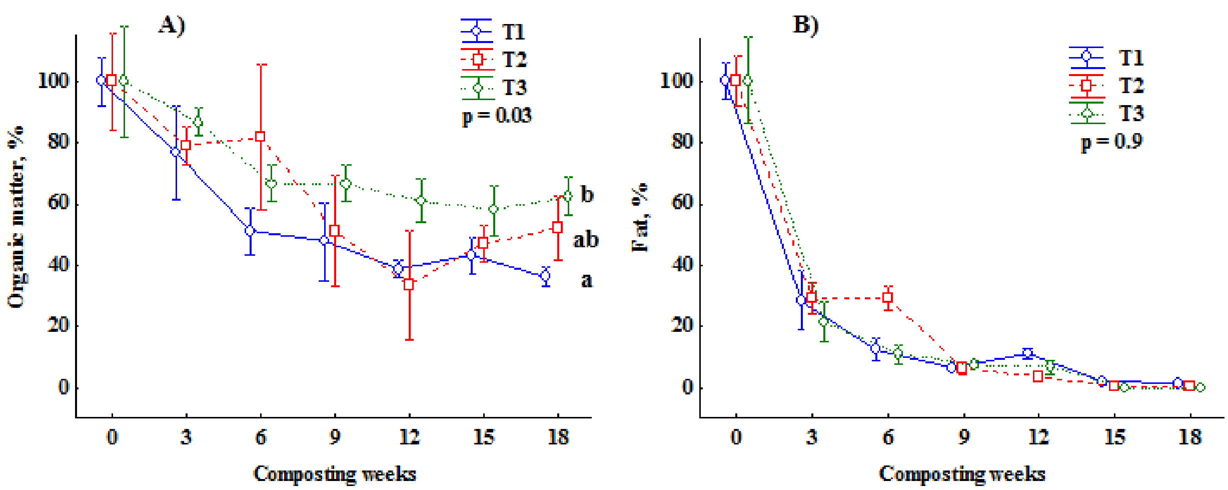

Fig. 1. Removal percentage of organic matter (A) and fat (B) during composting of residues in the laboratory scale experiments. Different letters indicate statistical significant differences ($\alpha = 0.05$).

It is important to mention that the composting of waste fat removal not only depends on its origin and quantity, but also how oxygen (electron acceptor) is supplied in the aeration process needed to couple the redox reaction. Ruggieri *et al*. (2008) reported that for static piles, a maximum fat reduction was reached in 11 days at 60°C (35% removal), and a minimal decrease from that time onwards; however, when the composting process was carried out with mechanical tumbling, thermophilic temperature was maintained for 3 weeks and a 92% removal of grease was reached in 7 weeks. The latter results are similar to those found in this investigation; co-composting of WWTP settleable solids of the cheese factory using mechanical tumbling, with 92% fat removal in 9 weeks. It is important to point out that in order to achieve higher fat removals in a composting process it requires longer periods of time; so, it is suggested to evaluate its cost.

Although most of the fat degrades in the first month of the process, it is considered that waste is stabilized until the mixture is composted; the amount of organic matter degraded and the time it takes will depend on the complexity of the material used as structure corrector (agricultural waste, sawdust, shavings, garden waste or grass, etc.). According to results, the addition of dairy cattle manure or native soil did not accelerate the composting process. However, the addition of manure helped to significantly reduce malodourous gases in T3 as from week 3 onwards, similar to experiments carried out by Schlegelmilch *et al*., (2005); whereas malodourous gases were still detected until week 6 and 9 for T1 and T2, respectively.

3.1.4 Electrical conductivity (EC)

In T1 and T2, electrical conductivity remained relatively constant during the entire experiment, from 0.96 to 1.0 dS/m and from 0.75 to 0.7 dS/m, respectively; whereas T3 started at higher initial values, increased from 2.5 to 3.0 dS/m after 3 weeks of operation, and gradually decreased to 2.6 ± 0.1 dS/m at the end of the experiment. T3 exhibited significant differences when compared to T1 and T2 (F = 14.5, $p < 0.001$).

It has been reported that dairy cattle manure contains more than 10% of soluble salts on a dry basis and provides 3 to 5% of these salts to the environment when applied to the soil (Salazar *et al*., 2003). Corral (2011) also reported a 9.5 dS/m EC value for composted cow manure, supporting the fact that EC of T3 treatment is due to the salts from manure.

3.1.5 Microbial growth

Mesophilic bacteria and fungi growth was similar during the composting process in treatments, without showing any statistical significant differences (F = 1.35, p = 0.27) and (F = 1.5, p = 0.22), respectively. Yeast growth showed variable behavior trends where T1 exhibited the highest yeast content, contrary to T3 that showed a more gradual decrease during the entire process; T1 was statistically significant different when compared to T2 and T3 (F = 11.4, $p < 0.001$).

At the end of the composting process (week 18), there was a substantial amount of mesophilic bacteria, fungi, and yeast, with minimal differences between treatments (Table 2); which shall enrich the soil when compost is applied.

Butterfat can be naturally degraded by several species of fungi of the *Aspergillus* and *Penicillium* genera that produce enzymes which catalyze the oxidation of free fatty acids to transform them into ketones; and lipolytic bacteria and yeast species, such as *Lactobacillus* and *Serratia* and *Candida*,

Table 2. Presence of microorganisms (Average values ± Std. Dev.; n = 3) in the laboratory experiments at the end of the composting process

Treatments	Mesophilic bacteria	Fungi	Yeast
	Log_{10} CFU/g		
T1	7.6 ± 0.04*a*	5.3 ± 0.07*a*	6.3 ± 0.04*a*
T2	7.5 ± 0.04*a*	5.5 ± 0.04*b*	6.4 ± 0.03*a*
T3	8.1 ± 0.06*b*	5.3 ± 0.1*a*	5.4 ± 0.20*b*
	(F = 236, $p < 0.001$)	(F = 14, $p < 0.001$)	(F = 93, $p < 0$ .001)

Different letters indicate statistical significant differences ($\alpha = 0.05$)

respectively (Banwart, 1979). So, fat of settleable solids from the dairy´s WWTP can be degraded by fungi, bacteria, and/or yeast; in this particular work, the viable count of microorganisms was only quantified. For future work, isolation is suggested to determine the type of organisms and species involved in fat degradation.

It is worth mentioning that the effluents with high content of fat and oil, are biologically pretreated with enzymes or microorganisms to avoid problems in the process; such as manufacture of olive oil, dairy industry, and slaughterhouse with *Bacillus thermoleovorans*; domestic water with *Penicillium restrictum*, and/or *Candida rugosa*, and grease traps of restaurants with *Pseudomonas aeruginosa* (Cammarota and Freire, 2006).

3.1.6 Fecal coliforms (FC)

FC was determined as indicator of pathogenic bacteria only for T3 due to the dairy cattle manure addition. Initially, there was 1067 ± 252 CFU (Colony Forming Units)/g; which increased 100 fold during the first 3 weeks of treatment and reduced considerably in week 12 to 448 ± 125 CFU/g and in the mature compost were found only 30 ± 8 CFU/g. For this work the FC were measured as CFU/g, which is comparable to units in the most probable number (MPN/g) according to the USEPA (1993b). According to this, compost with less than 1000 MPN FC/g (most probable number of fecal coliform bacteria) indicates absence of pathogenic bacteria: such as *Salmonella*, so it is assured that T3 compost can be used without causing any health problems (Haug, 1993).

EPA Part 503 (2002) mentioned that in order to obtain a Class B compost and biosolids sludge from a domestic wastewater treatment plant for tumbling aerated piles, it is required a 40°C temperature for 5 consecutive days, and 4 h above 55°C. In this work waste came from a WWTP that treats influent from washing of facilities and equipment of cheese production; in treatment with manure (T3), temperature rose from 35 to 45°C and the mature compost had 30 ± 8 CFU FC/g, which complies with NOM-004, classified as a class A biosolid.

Gómez *et al*. (2004) mentioned that heating compost at 38°C for 15 consecutive days, the number of pathogenic microorganisms decreased 99.9%; supporting the fact that composted residues with manure in this research showed a substantial reduction of pathogenic microorganisms.

3.2 Implementing co-composting process in-situ

It is important to mention that the main objective of this work was to solve the disposal problem of WWTP solid waste *in-situ*; to stabilize it by co-composting with other waste generated in the company or in the region, based on experience gained in previous laboratory experimentation. As a food company, composting floating solids was carried out with manure to reduce odor generated during the breakdown of fat; the process was monitored to check out that it was properly carried out.

Resulting compost satisfy current regulations and can be used to improve soil quality of farmland milk producers or sold to recover the production cost of stabilization, which is very low if compared to the associated cost of a typical waste disposal; and it can be reduced by increasing the amount of waste to compost.

3.2.1 Temperature

Temperature in the compost piles rose to 44°C, the lack of heat in the piles was not due to the size of the pile, but to abrupt changes in ambient temperature; which is consistent with results reported by Santamaría-Romero *et al*. (2001) and Corral (211), they observed that the temperature of the composts varied in parallel with changes in ambient temperature. It is noteworthy to mention that the process in this research was carried out in winter and although piles were covered with plastic, temperature reached a maximum of 45°C. Under these conditions the composting process can operate, but the process takes longer.

3.2.2 Organic matter

Organic matter removal efficiency of about 37% was reached within the first 10 weeks of operation (Fig. 2) followed by a gradual decrease towards the end of the experiment, an average removal efficiency of 43 ± 10%. Approximately 70% of fat content was removed during the first 4 weeks of operation (Fig. 2), from that week onwards grease content decreased gradually reaching an average of 86 ± 3.2% removal efficiency at the end of experimentation.

Temperature of the piles was the main driving force for organic matter and fat removal efficiency, removal occurred mainly during the first 4 weeks of operation when average temperature of the piles was above 45°C.

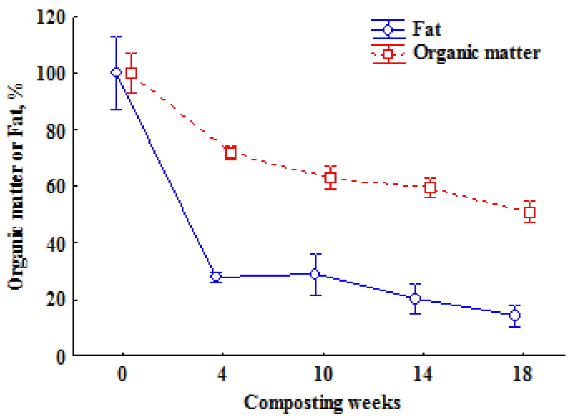

Fig. 2. Removal percentage of organic matter and fat during composting of residues in the pilot scale.

Most lipolytic activity takes place at thermophilic temperatures (Gea *et al*., 2007); degradation of fat continues by oxygen addition (as electron acceptor in aerobic degradation) when piles are turned over, reaching higher removal efficiencies, as in the co-composting of animal fat with sludges and wood chips (Ruggieri *et al*., 2008); and the co-composting of floating solids of the WWTP with dairy cattle manure and garden wastes, as in this research.

3.3 *Compost maturity*

Maturity was determined based on the negative effect that the use of immature compost had on seed germination and seedling growth by the presence of phytotoxic compounds. Compost samples of the laboratory experiment were tested at weeks 12, 15, and 18 to determine organic matter stabilization using lettuce seeds (*Lactuca sativa*), and maturity of compost was reached when GI was $\geq$ 90. Results showed that T1 and T2 reached maturity at week 15, whereas T3 until week 18 (Table 3).

Compost samples from the pilot scale were tested at week 14 and 18, using lettuce seeds; additionally, bean and corn seeds were also tested because they are typical grains of Durango. Although bean seeds reached a GI value above 90 at week 14, compost was allowed to continue the maturation process because lettuce seeds did not reach the target value of 90; finally, at week 18, compost reached GI values higher than 90 for all seeds.

Tquia and Tam (1998) consider compost reaches maturity with a GI of 80%, as a fact that composts samples did not contain phytotoxic substances; whereas Sánchez (2009) considers GI $\geq$ 90% because

Table 3. Average values ± Std. Dev. (n = 4) of the Germination Index of the compost from the laboratory experiment

Treatment	Weeks		
	12	15	18
T1	86 ± 6.5*b*	90 ± 0.9*b*	94 ± 5.4*a*
T2	86 ± 15*b*	96 ± 1.2*b*	99 ± 2.4*a*
T3	61 ± 23*a*	63 ± 2.1*a*	94 ± 2.0*a*

Different letters indicate statistical significant differences (α = 0.05)

values above 90% are satisfactory in the commercial production of seedlings

3.4 *Quality of the compost*

Theoretically compost quality is defined by its stability and maturity. Stability refers to the level of biological activity in the compost, which depends on the degradation of organic matter reached during the composting process; whereas maturity refers to the absence of phytotoxic substances in compost when applied to crops (Hue and Liu, 1995). Results showed that T3 compost had more nutrients than T1 and T2 (Table 4), accomplishing national and international standards (at pH 8.7). In this regard, WHO marks a range of 6 to 9, but its use may be restricted. Regarding density and electrical conductivity, compost fulfilled the NMX-FF-109-SCFI-2007 standards of 0.9 g/mL and $\leq$ 4 dS/m, respectively.

Table 4 summarizes the physicochemical quality of the pilot scale composts. It is believed that the difference between laboratory and pilot scale final compost, in organic matter, total Kjeldahl nitrogen, and phosphorus content, was due to the modification of the original mixtures wetted with treated water of WWTP instead of tap water. These changes in the mixture modified pH (8.7 to 9.6) and EC (2.6 to 5 dS/m) values of the compost, which restrained its direct use; this can be solved by reducing the amount of compost applied to the soil. However, these changes did not affect germination index of lettuce, beans, and corn seeds.

Compost produced fulfilled with most parameters established by Mexican standard NMX-FF-109-SCFI-2008 (DOF, 2008), World Health Organization (WHO, 1985), and United States Environmental Protection Agency (USEPA, 1993a) (Table 4), except for pH and EC. However, it is recommended that compost should be used in a 1:3 ratio (compost:soil) to dilute the amount of salts and lower pH, in order to minimize

Table 4. Pilot Compost quality (Average values ± Std. Dev.; n = 3) versus values established by Mexican and International Standards

Parameters	T1	T2	T3	CIS	NMX-FF-109-SCFI-2007	WHO (1985)	USEPA (1993a)
OM (%)	14.3± 0.4*a*	12.4 ± 0.8*a*	22.2 ± 1.4*b*	31.9 ± 2.3	20 - 50	10 - 30	17.1 - 63.5
TKN (%)	0.74 ± 0.01*a*	0.67 ± 0.007*a*	0.92 ± 0.01*b*	1.5 ± 0.1	1 - 4	0.1 - 1.8	0.67 - 2.4
NO_3^- (%)	0.18 ± 0.009*c*	0.08 ± 0.004*a*	0.15 ± 0.007*b*	-	-	-	-
*P_2O_5 (%)	0.07 ± 0.04*b*	0.04 ± 0.01*a*	0.19 ± 0.02*c*	1.1 ± 0.05	-	0.1 - 1.7	0.40 - 4.1
*K_2O (%)	0.09 ± 0.008*a*	0.1 ± 0.007*a*	0.46 ± 0.003*b*	0.43 ± 0.09	-	0.1 - 2.3	-
C/N	10.7	10.3	13.1	11.9	≤ 20	14 - 20	8 - 40
pH	7.3 ± 0.05*a*	7.8 ± 0.03*b*	8.7 ± 0.05*c*	9.6 ± 0.1	5-8.5	6 - 9	-
EC, dS/m	1.04 ± 0.02*b*	0.07 ± 0.04*a*	2.6 ± 0.05*c*	5 ± 0.3	≤ 4	-	-
Density, g/mL	0.858 ± 0.005*a*	0.964 ± 0.004*c*	0.901 ± 0.003*b*	0.8551 ± 0.08	0.40 - 0.90	-	-
CFU FC/g	-	-	30 ± 8	213 ± 54	< 1000	-	< 1000

CIS: Compost *in situ*; * P and K available. Different letters indicate statistical significant differences (α = 0.05)

detrimental impact of sensitive crops.

Bacteriological analyses of the final compost from laboratory and pilot scales showed that the content of indicator organisms (FC) were below the limits (< 1000 MPN FC/g) established in NOM-004-SEMARNAT 2002 (DOF, 2003c) and NMX-FF-109-SCFI-2007 (DOF, 2008), considering it as a safe product for field applications (Table 4).

3.5 *Estimating cost of WWTP waste stabilization*

Costs of the *in situ* stabilization of solid waste generated at WWTP was estimated considering material, labor, and equipment rental; $ 2775.00

Mexican pesos for a total of about 1.5 tons produced. Those costs can be reduced by increasing the amount of waste to compost. Even though further stabilization of waste will optimize the amount of each residue in the mixture and thereby improve the quality of compost, it is important to point out that the main objective of this research was to solve the problem faced by the industry. This alternative allowed industry to fulfill sustainability by disposing all solid waste properly without generation of malodorous gases, no vector attraction, and most important protecting soil from contamination by accomplishing standards set by Mexican legislation (NOM-004-SEMARNAT-2002).

Conclusions

Co-composting of settleable and floating residues with dairy cattle manure was achieved, malodorous gases and vermin at the premises were substantially reduced within a period of 3 weeks, but time of the composting process was not reduced. Special attention should be paid to increase pile size or the amount of fat added to raise pile temperature and lipolytic activity as well, that will give conditions needed to get better results.

Compost produced fulfils almost all quality standards: NMX-FF-109-SCFI-2008, WHO (1985), and USEPA (1993a), except for pH values which were at the alkaline range, and electrical conductivity of 5 dS/m. Compost should be used in a 1:3 ratio (compost:soil) to dilute the amount of salts and lowering pH, in order to minimize detrimental impact of sensitive crops.

Proposed *in situ* co-composting alternative, of WWTP residues with dairy cattle manure, allowed industry to solve the problems the Cheese Company were struggling with, to achieve sustainability by properly disposing all solid waste without the generation of malodorous gases, attraction of vermin was highly reduced, social image of the company was improved, and most important protecting native soil from contamination; achieving standards set by Mexican legislation, regarding management and safe disposal of sludge and biosolids.

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