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Experimental Analysis for the Use of Solid Waste Ordinary Organic Fraction, Case Study Market in Bogota, Colombia.

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Abstract

In the city of Bogota, as in many other cities, a huge quantity of solid waste with a high content of organic matter is generated. Particularly, in the marketplaces there is a low recovery level of such materials and a total lack of exploitation of their organic fraction with efficient alternatives that would help reduce their volume. At a pilot scale, an experimental assessment study was made of a treatment alternative for the exploitation of the organic fraction of the solid waste generated in a marketplace in Bogota. The options evaluated in this study were three piles of composting, using organic waste from the Kennedy District marketplace and the implementation of three different biological treatments; molasses, manure and beer yeast. Starting from the hypothesis that composting by means of these biotreatments, with a volume below $1m^3$, will indicate that the optimum alternative is aerobic composting with manure. However, it was found that the biological treatment with molasses was the most efficient with respect to the reduction of volume for aerobic composting; such treatment reduced volume by 54%. This information may contribute significantly to the search for solutions to the problems caused by the deficient exploitation of organic solid waste generated in marketplaces.

Keywords: Waste Composting, production

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INTRODUCTION

The world produces approximately 1600 million tons of solid waste per year (Skinner,2000), which generate serious problems, not only those related to the progressive deterioration of the environment, but also those analyzed from an economic point of view, since the costs of recollecting, transporting and the final disposal of solid waste are quite high. It is estimated that the disposal, treatment and exploitation of solid waste annually move a market of 100,000 million dollars, with 43,000 million corresponding to North America, 42,000 million to the European Union and just 6000 million to South America, with a waste production of 250, 200 and 150 million tons per year respectively (Cardona, 2004).

Although the consequences resulting from health and environmental problems derived from the inadequate handling of solid waste are widely known, not enough measures have been taken and the development of these public services has been relegated in most of Latin America and the Caribbean (LAC), the urban centers of the Region produce daily 361 thousand tons of municipal solid waste, with only 60 to 80% being collected and where only 23% of such amount is disposed in a sanitary and environmentally acceptable manner. The solid waste management situation is quite worrisome; approximately half of the solid waste generated in ALC is produced in medium and small sized urban centers which tend to have greater difficulty with respect to waste management, and where the impact upon the environment is quite significant since the disposal of such waste is generally considered deficient. (O.P.S, 2005)

In the particular case of Colombia, at the national level, approximately 30,886 tons of solid waste are generated daily, where 28.580 tons (92.54% of the national production) are disposed in sanitary landfills or solid waste integral treatment plants and 2.305 tons (7.46% of total production) are disposed in inadequate places, such as illegal dumping sites, or are burned, or dumped into bodies of water or buried. Currently 758 municipalities are disposing of their solid waste into 255 sanitary landfill (58 regional) and 34 solid waste integral treatment plants. (SSPD, 2008).

The city of Bogota has a population of 7 million inhabitants that generate a daily average of 6,700 tons of solid waste with 5,800 tons being dumped into the Doña Juana sanitary landfill and 900 tons are recovered through recycling and reutilization. (Bogota’s Mayor’s Office, 2006). Part of this volume of solid waste is generated in the marketplaces of the city. The capital of the country has 36 marketplaces, 18 of these are owned by the Capital District and 18 are privately owned. With respect to the generation of solid waste in marketplaces there is a large participation of the garden produce component (greater than 50%), followed by fruits (an average of 14%) (Cardozo, 2007). The main component of the solid waste generated in the marketplaces is a result of the commercialization of agricultural products such as green vegetables, herbs, vegetables, potatoes, plantains and fruits; this is the sort of waste that due to its characteristics presents a large humidity content and is easily degradable, a fact that defines short term storage in order to prevent foul smells and the arrival of insects, rodents and stray animals. The storage and stockpiling of waste before disposal, is carried out in rooms that do not meet the norms established by the Sanitary Code for the storage and presentation of waste before the entity in charge of recollecting and transporting the waste to the disposal system of the Capital District. (Bogota's Mayor's Office, 2001).

Given the aforementioned considerations, it has become necessary to experimentally evaluate an alternative for the exploitation of the organic fraction of the solid waste generated by the Marketplace in the Kennedy district, for the purpose of finding the best biological treatment option for the exploitation of the organic fraction, in order to decrease the difficult situation presented by the management of solid waste in this important marketplace of the city. In this regard, the question that shall guide this study is: **Which of the three biological treatments studied utilizing composting is the best for the stabilization of the organic matter of the solid waste generated in the Kennedy District Marketplace in Bogota?**

Aerobic composting is used in the biological conversion of the organic fraction of solid waste produced at marketplaces; this type of composting produces humus, carbon dioxide, reduces the volume of waste by 50% with a retention time of 20 to 30 days and additionally it is a net consumer of energy. (Tchobanoglous, 1998). With the implementation of composting through different activators such as beer yeast, molasses, manure and the control (standard of comparison in the experiment) with a volume below $1m^3$, **it is assumed that the optimum alternative for the Kennedy marketplace is the aerobic composting with manure**, which is a main component and additionally produces in the plants important improvements in the aspects of sanitation and performance. This hypothesis is based on economy criteria, an easy transformation mechanism and income projection for the players involved in the problem (Canovas, 1993).

MATERIALS AND METHODS

For the purpose of comparing four treatments for the composting of organic solid waste generated at the Kennedy District Marketplace that would allow the assessment of the best alternative for the composting process, with a volume below $1m^3$, the following is a presentation of the procedure for each reactor to make compost including its respective treatment:

- Reactor 1: Control organic waste. Material employed: 20 Kg of organic waste from the marketplace, 0.10 Kg of lime and 8 Kg of sawdust. Process: The materials were laid in 10-cm high layers, except the lime which was a very thin layer, organized in the following manner: organic solid waste – lime – sawdust and left out in the open for six days to later make the mix in the reactor.

- Reactor 2: Organic waste with molasses. Material employed: 20 Kg of organic waste, 0.10 Kg of lime and 8 Kg of sawdust and 2 liters of water mixed with molasses. Process: The materials were laid in 10-cm high layers, except the lime which was a very thin layer, organized in the following manner: organic solid waste – lime – sawdust and at the end 2 liters of water with molasses were added, and left out in the open for six days to later make the mix in the reactor.

- Reactor 3: Organic waste with manure. Material employed: 20 Kg of organic waste, 4.06 kg of manure, 0.10 Kg of lime and 8 Kg of sawdust layer. Process: The materials were laid in 10-cm high layers, except the lime which was a very thin layer, organized in the following manner: organic solid waste – manure - lime and sawdust, and left out in the open for six days to later make the mix in the reactor.

- Reactor 4: Organic waste with beer yeast. Material employed: 20 Kg of organic waste from the marketplace, 0.10 Kg of lime and 8 Kg of sawdust and 1 liter of water mixed with 0.02 Kg of beer yeast. Process: The materials were laid in 10-cm high layers, except the lime which was a very thin layer, organized in the following manner: organic solid waste – lime - sawdust, and at the end I liter of water with beer yeast was added, and left out in the open for six days to later make the mix in the reactor.

For the three treatments (beer yeast, molasses, and manure) and one control treatment as the guide, studied for aerobic composting in a static pile, certain parameters were measured such as temperature, humidity. pH, C/N ratio, percentage of organic matter, total nitrogen, total organic carbon. Before discussing the results it is necessary to describe in detail the actions carried out in each of the reactors since they are very useful to understand the results obtained. The data processing includes different parameters such as pH, temperature, humidity percentage, total nitrogen, organic carbon percentage, organic matter percentage and carbon - nitrogen ratio, analyzed by C.I.I.A., for four treatments (control, molasses, manure and beer yeast). The statistics analysis was performed using SPSS- 15, in order to find out which of the three treatment options (beer yeast, molasses, and manure) and one control as the guide, is the most efficient, using as indicators: volume reduction, quality of the compost and the use that may be given to such material. A variance analysis with a confidence interval of 95% was used; the differences of the treatments were evaluated with a significance value of 5%, a multiple comparison test of the measurements of groups by Sheffé was employed, relating the treatments with variables such as temperature, humidity, pH, organic carbon %, organic matter %, total nitrogen and carbon – nitrogen ratio in order to evaluate the best treatment for the organic fraction of the solid waste generated in this marketplace.

RESULTS AND DISCUSSION

Statistical Analysis

The comparison of the average temperature, pH, humidity percentage, organic carbon, organic matter, total nitrogen and carbon/nitrogen ratio is based on the following hypothesis:

$$Ho: \mu_{control} = \mu_{molasses} = \mu_{manure} = \mu_{yeast}$$

Versus the alternative that any pair of treatments presents a difference. The table for the analysis of variance obtained for temperature is:
It can be concluded that there are no statistically significant differences in the average temperature levels of the four treatments considered (f_c= 0,459, value-p=0,712). Versus the alternative that any pair of treatments presents a difference. The table for the analysis of variance obtained for pH is:

It can be concluded that there are statistically significant differences in the average levels of pH of the four treatments considered (f_c= 5,652, valor-p=0,001). To detect which averages were different, the Scheffe test was used, where it was found that the average pH obtained in the control is significantly lower that the one obtained with molasses (valor – p = 0,006). Versus the alternative that any pair of treatments presents a difference. The table for the analysis of variance obtained for humidity is:

It can be concluded that there are no statistically significant differences in the average levels of humidity of the four treatments considered (f_c= 1,632, valor-p=0,189). Versus the alternative that any pair of treatments presents a difference. The table for the analysis of variance obtained for the C/N ratio is:

It can be concluded that there are no statistically significant differences in the average levels of the C/N ratio of the four treatments considered (f_c= 0,864, valor-p=0,463). Versus the alternative that any pair of treatments presents a difference. The table for the analysis of variance obtained for total nitrogen is:

It can be concluded that there are no statistically significant differences in the average levels of total nitrogen of the four treatments considered (f_c= 1,335, valor-p=0,269).

Analysis of the results of the experiment

Figure 1, shows that the experimental design did not exceed 40°C for any of the treatments, which evidences that the experimental composting process did not develop the thermophilic microorganisms phase. The next step was the creation of a model that would allow predicting for which values of the variables involved in the experimental process, such phase could be reached. The reasons why the three treatments and the control did not present a temperature increase above 40°C could have been: Since the temperature did not exceed 40°C, from the beginning of the process, it is probably indicating that there is not enough nitrogen in the pile to activate the process (INTEC, 2000), the average total nitrogen reported in the four reactors was 0.92%, which is a low value for total nitrogen content. There was a sizable amount of rainfall during the development period of the composting, which generated a decline in ambient temperature and an increase in relative humidity, producing a reduction of the temperature of the composting substrate. Another reason is that the external portion of a composting mass will be cold and its temperature will vary, between the ambient temperature of the surface and the temperature in the nucleus of the mass 15 cm from the surface. Therefore, the greater the mass of the pile, the greater would be the volume of the central nucleus that reaches adequate temperatures for the destruction of pathogens and weed seeds. (Porras,1999). The lowest temperature values were registered after the reaeration of the system and the addition of water to maintain humidity; afterwards, the temperature increased due to the homogenization of the material in each of the reactors.

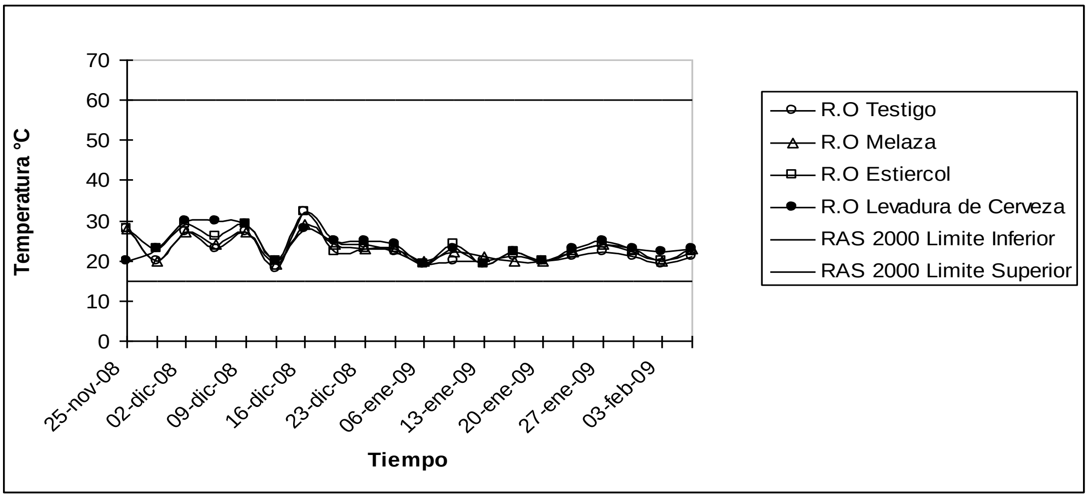

Figure 1. Variability of temperature versus time for the four reactors

According to some authors the evolution of the pH in the composting process presents three phases. During the initial mesophilic phase a decrease in the pH is observed (figure 2) due to the action of microorganisms over the most labile organic matter that produces a release of organic acids. Eventually, this initial decrease of the pH could be quite steep if anaerobic conditions exist, since a greater quantity of organic acids will be formed. During a second phase a progressive alkalinization of the medium took place, due to the lost of organic acids and the generation of ammonia generated by the decomposition of proteins (Sánchez - Monedero 2001). During the third phase, the pH presents a tendency towards neutrality due to the formation of humic compounds with buffering properties. The following can be analyzed from the data obtained regarding the pH for the four reactors: At the beginning of the composting process in each reactor, the pH dropped below 8 nearing a neutral pH. This was due to the fact that at the beginning of the process the mixture was turned over at each reactor thus allowing aeration of the mixture, given that if at any time anaerobic conditions are created, organic acids are released that provoke a drop in the pH below 7, a condition that did not occur. The evolution of the pH at each reactor presented three phases. During the initial mesophilic phase a reduction of pH was observed, which corresponds to the first four weeks from the start of the process, and it is caused by the action of the microorganisms over the most labile organic matter that produces a release of organic acids. Such reduction in the pH was not very significant because the conditions of the system were aerobic due to the turning over carried out at the beginning of the process. During a second phase a progressive alkalinization of the medium took place, due to the lost of organic acids and the generation of ammonia generated by the decomposition of proteins. And during the third phase, where normally the pH presents a tendency towards neutrality, such situation never occurred, but on the contrary, the pH increased even more due to an increase in the humidity content of the reactors. The decrease of the pH during the third phase to a neutral pH did not occurred in this research due to the fact that there was an increase in the humidity and the pH levels were above 7.5, and at such pH levels only fungi can survive. At each reactor the pH level did no dropped below 7, which confirms the analysis that at each of the four reactors aeration was adequate, thus preventing the generation of anaerobic processes in the reactors.

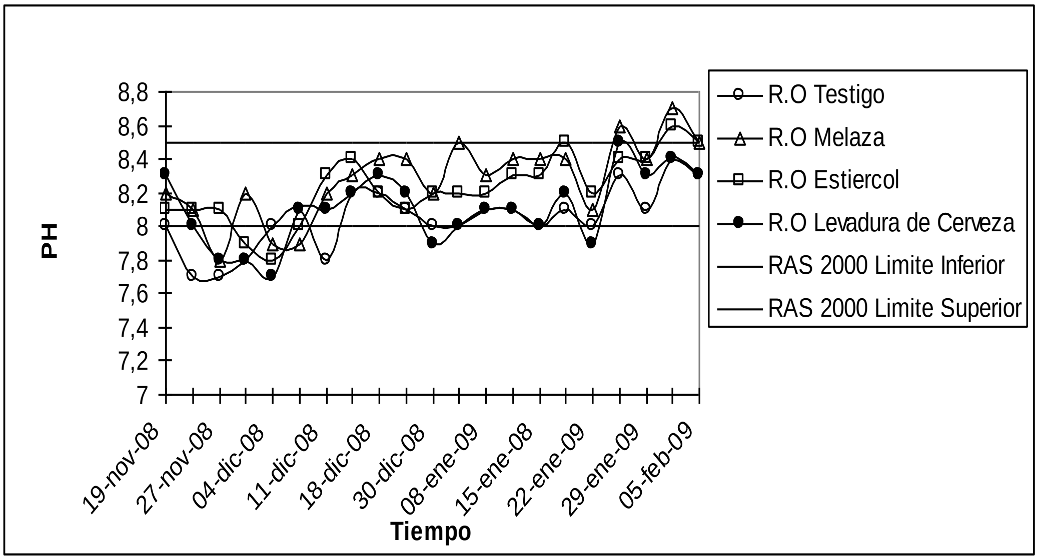

Figure 2. Variability of pH versus time for four reactors

Figure 3 shows that the percentage of humidity, most of the time, remained within the limits stipulated by RAS 2000 (Technical Regulations for the Potable Water and Basic Sanitation Sector), except for the last few days of the experiment when humidity increased. This same figure shows a considerable drop of the humidity percentage in the reactor with beer yeast, which could be due to the fact that the reduction of humidity may be responsible for the suspension of the microbial activity and consequently the decrease of assimilable organic matter. Throughout this study an adequate level of humidity was maintained given that humidity is a very important element of microbial activity. According to the above, the following can be argued: The optimum value for humidity in the compost, according to RAS 2000 should be between 40% - 60%, as shown by figure 8 most of the data is within the established range. The humidity percentage ratio started with a substrate of 71.5%, but with the passage of time the humidity percentage decreased, as well as the weight; such weight lost, is due to the production of compounds such as carbon dioxide and to water evaporation (Castrillon, 2008). When chopping the organic waste to begin the composting process, such organic waste from the Kennedy District marketplace had a high percentage of humidity, which required spreading the chopped material in thin layers so that it would lose humidity through natural evaporation, the material was spread out over a plastic sheet for five days and then placed into each reactor and mixed well with dry materials such as sawdust, always trying to maintain an adequate C/N ratio. The osmotrophic nature of most of the physiological groups implies that with humidity below 20% the populations move to stationary phases or in extreme conditions to a phase of death, delaying or stopping the composting process. The adequate humidity for each stage depends on the nature, compacting and texture of the materials of the pile. Fibrous and fine materials retain greater humidity and increase the specific contact surface. (OMS, 1999).

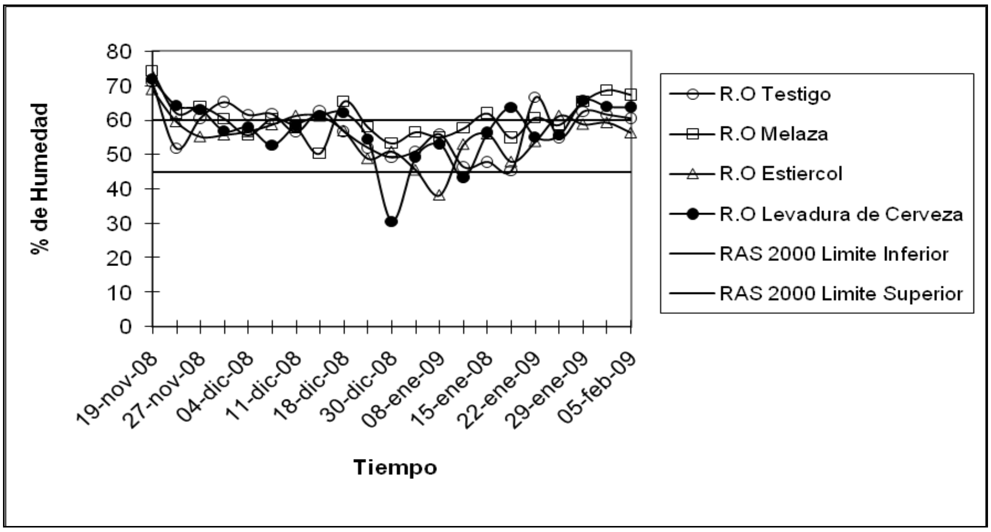

Figure 3. Variability% moisture versus time for four reactors

In figure 4 the C/N ratio decreases during composting due to the fact that part of the carbon is lost as CO_2 as a result of microbial respiration, while most of the nitrogen is recycled. A very high C/N ratio limits the quantity of nitrogen available for cellular growth at the expenses of the organic matter, which leads to the inactivation of the process: while the opposite initially accelerates microbial growth and the decomposition of organic matter (Moreno, 2009). On the other hand, the value of the C/N ratio can not be taken as absolute indicator of maturity, given the relatively wide variation range set between 5 and 20, which depends, among other factors, on the nature and origin of the material. In this research, as well as that of other authors (Hirai et al., 1983; Seekins, 1996; Jiménez and García, 1989; Zuccuni et al., 1987) the final value close to 15 turns out to be adequate and lies within the quality range accepted for the final compost product (Pino, 2005). The C/N ratio of the mass is an important factor to be controlled in order to obtain adequate degradation; during the composting process, it is important to avoid high values of this ratio since that situation obstructs the development of an extensive microbial activity, which delays the process. However, low C/N ratios lead to volatilization of NH_3, which provokes N losses and foul odors (Zhu, 2006).

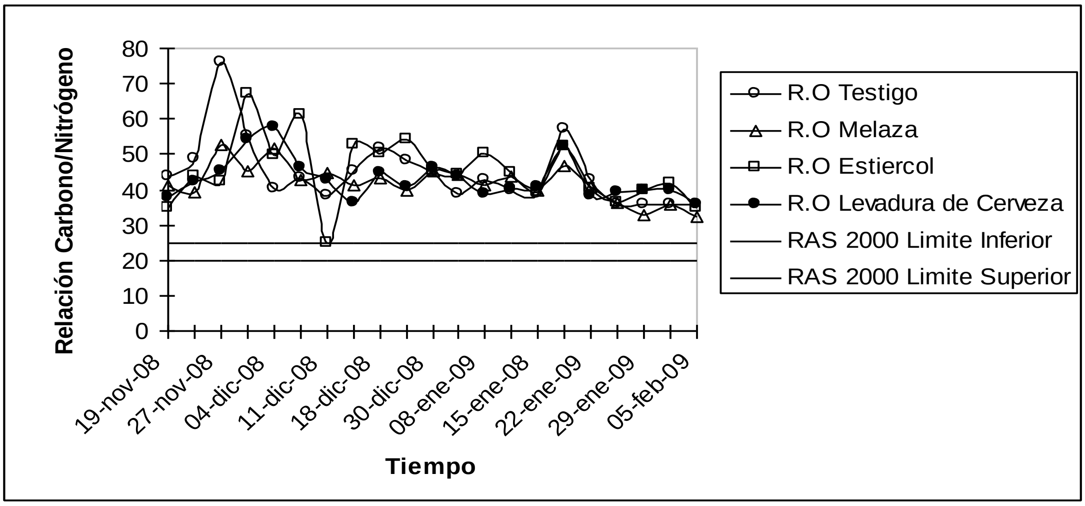

Figure 4 Variability C / N ratio for the four reactors

According to the above, the following can be argued: The bacteria and microorganisms in charge of aerobic decomposition require a greater presence of carbon than nitrogen to create an optimum environment for their growth and development (OMS, 1999). In accordance with the above, the four reactors presented a high content of carbon and a low content of Nitrogen, making the C/N ratio presented in some texts of Table 27 above the ranges established, except the ranges established by Infoagro and George Tchobanoglous. In the four reactors it can be observed that the C/N ratio decreases in week 12 and remains steady, Nitrogen begins to increase above one, due to the increase in microbial activity, increasing temperature by two degrees above the normal registered during the previous days. The material to be composted presented a C/N ratio above 30, which indicates that it would require for its biodegradation a greater number of generations of microorganisms and the time necessary to reach a final C/N ratio set between 12 – 15 (considered appropriate for agronomic use). Figure 4 shows the evolution of the C/N ratio during the experimental work of the four reactors, where a gradual drop was observed during composting, this may have been due to the decrease of the carbon percentage and the increase of the nitrogen percentage throughout the process; however, it must be pointed out that at the beginning of the process the nitrogen content is quite low, reason why these C/N ratios are high. According to RAS 2000, optimum ranges for the C/N ratio should be between 20 – 25, with respect to the experimental data, this ratio is above the established range, and it can be assumed that the product obtained at the end of the process requires more time to mature in order to obtain a quality range acceptable for the final compost product.

According to figure 5, the following can be argued for Total Nitrogen: According to RAS 2000, Total Nitrogen for stable composting should not be greater than 1%, which indicates that Total Nitrogen, most of the time, remained within the range (Figure 5). For manure and yeast there was a 1.1% increase in the Total Nitrogen of the first sampling; it can be said that this was due to the heterogeneity of the organic waste in the reactor with yeast, and also that there may have been green vegetables and therefore the presence of nitrogen, and in manure that this was due to its composition where the presence of nitrogen is characteristic. During the seventh and eighth week there was also an increase of nitrogen which could have been due to the biological activity of the process, since greater values of biomass and respiration carbon are boosted up, (Burbano, 1989) and during the last four weeks there was an increase of nitrogen above one, associated to the use of nitrogen by the microorganisms to synthesize cellular protoplasm and the fact that when microorganisms die, they increase the concentration of recyclable nitrogen during the process. During the last four weeks there was an increase of total nitrogen which correlates with the increase of organic carbon; however, the C/N ratio was quite high which implies that it is not due to an activity of the microorganisms; therefore, the hypothesis that can be raised is that the increase of carbon and nitrogen is due to the decomposition resulting from the mortality of the microorganisms.

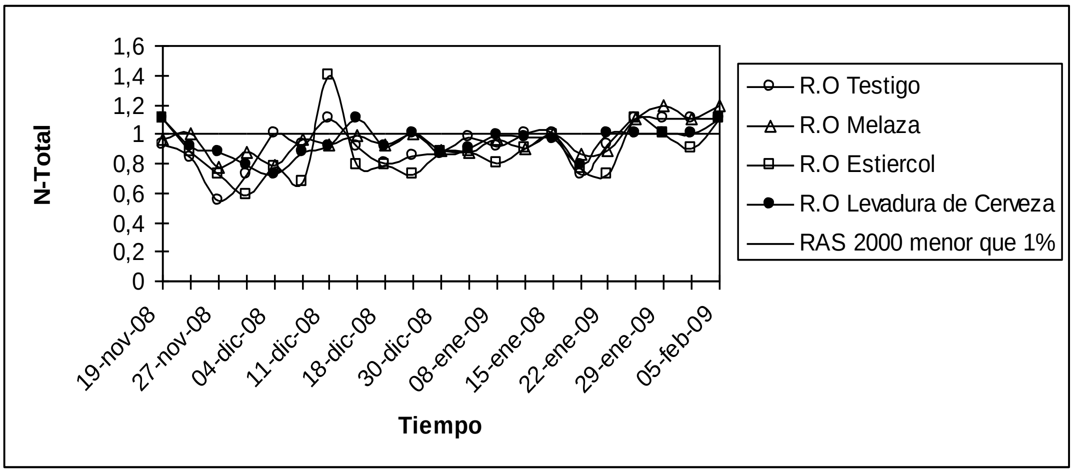

Figure 5. Total Nitrogen Variability for the four reactors

According to figure 6, for the analysis of organic carbon the following can be argued: The velocity of the reduction of the percentage of organic carbon in the four reactors is very low, due to the fact that during the composting process in all four reactors the thermophylic phase was not reached, given that in a more prolonged thermophylic phase the activity of the microorganisms is much greater (Iglesias, 1992). For that reason the percentage of organic carbon did not vary much since during the experiment the thermophylic phase was not reached, but on the contrary it remained in the mesophylic phase. In the three reactors (control, molasses and beer yeast) as from day 27 the content of organic carbon stabilized at values close to 40% and for manure at values close to 39%. The behavior of the variation of organic carbon throughout the process can be attributed to the fact that the consumption of carbonated sources is greater during the first weeks when the microorganisms utilized sugars and other easily degradable substances; afterwards the decrease rate is reduced since the consumption of cellulose and hemicellulose begins (Melgarejo, 1997).

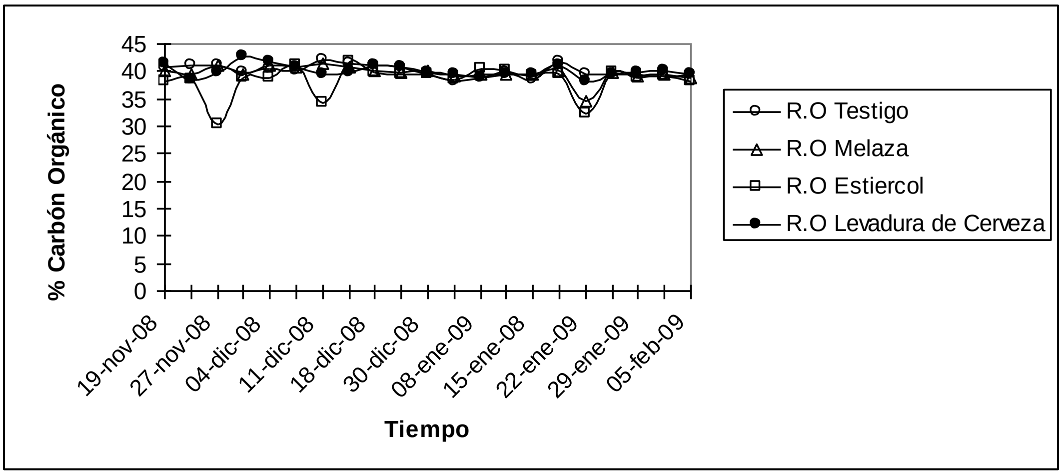

Figure 6. Variability percentage of total organic carbon for four reactors.

According to figure 7, for the analysis of organic matter, the following can be argued: There is a rapid distribution of the organic matter available as a consequence of the temperature increase during composting and the compounds nitrogenated by the microorganisms. Since organic matter has stabilized, the microbial activity and the decomposition of organic matter decreased gradually with the temperature at ambient levels, which indicates the end of the thermophylic phase (Raut, 2007). The levels of the percentage of organic matter did not decrease due to the fact that in the four reactors temperatures above 40ºC were not reached, which is where the thermophylic phase begins, something that could have caused an inhibition of the microorganisms, consequently the decomposition of the organic matter did not decreased. Figure 7 presented variations in the four reactors. If there had been a loss of organic matter the data would decrease since it is originated by the microorganisms that initially consume easily degradable or water-soluble carbon as energy source and the transformation of carbon into CO_2, something that did not occur in the reactors. The heterogeneity of the organic matter is transformed, after a composting period that includes the bio-oxidative and the maturation phases, it stabilizes into a partial final product through mineralization and humidification (Gray, 1971). From the above, it can be analyzed that the experimental study also presented heterogeneity of the organic matter to be composted in the reactors which should have generated stabilization during the maturation phase, something that was missing in the four reactors.

Figure 7. Variability percentage of total organic matter for four reactors

CONCLUSIONS

According to the experimental results presented, the working hypothesis of the manure as the best biological treatment is rejected. In comparison, as relevant scientific result, it was found that the process with molasses was the most efficient treatment, followed by the process with beer yeast. This is deduced from the reduction of volume obtained and the measurement of the variables that fluctuated within the range established by RAS 2000 as a percentage of humidity, pH, total nitrogen and temperature. With respect to the C/N ratio for molasses, the figures were more stable in comparison to the other treatments; however, the values suggested by RAS 2000 were not reached. The volume reduction of composting with molasses was 54%, followed by the reactor with beer yeast with a reduction of 52%.

It is important to point out that nitrogen is a good indicator of the maturity of the compost necessary for protein synthesis and the development of beneficial microorganisms. The closer it gets to the volume of one, it means that nitrogen is not being lost through lixiviate (nitrate) or gasses (ammonia) or the production of foul odors. The biodegrading of the materials during composting depends on the microbial activity and such activity in turn is related to the content of humidity in each reactor, according to the results, this variable remained between the 50% and 70% range, and these are adequate values for biodegradation.

Variables such as temperature, total nitrogen, C/N ratio, organic matter and organic carbon for the treatment with manure present a greater standard deviation than the other treatments, being more changeable with respect to the average. Therefore it can be concluded that it was less stable in comparison with the other treatments. The development of composting in the four reactors requires more time to achieve maturity of the compost before it can be used as organic fertilizer or soil conditioner. The above is due to the fact that the results of the carbon – nitrogen ratio did not fall below 30 (figure 15) indicating that more time is required for the reaction to reach 20, which it is an indicator of the maturity of acceptable compost according to RAS 2000.

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