REMOVAL OF ORGANIC MATTER AND NUTRIENTS FROM SLAUGHTERHOUSE WASTEWATER BY USING *Eichhornia crassipes* AND EVALUATION OF THE GENERATED BIOMASS COMPOSTING

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ABSTRACT: The objective of this research was to evaluate the performance of the aquatic macrophyte *Eichhornia crassipes* applied *in situ* in a slaughter house treatment system, located in the west of the Paraná state, Brazil, regarding the nutrients removal and organic matter. Moreover, it aimed to obtain data from the production, management and composting practices of the biomass generated in the system. During 11 months of macrophytes development, physic and chemical parameters were monitored and plant density was controlled by periodical removal of excess biomass, which was weekly monitored and it is expressed in kg of aquatic plant per m^2 covered area. The degradation of the macrophytes removed from the treatment system was evaluated at the pilot scale in eight composting piles of 0.60 m^3 that underwent four different treatments and two repetitions: T1 - water hyacinth (*Eichhornia crassipes*); T2 - water hyacinth and swine excrement (7:1), T3 - water hyacinth, swine excrement and earth (7:1:0,67), and T4 - water hyacinth, swine excrement and cellulosic gut (7:1:0,67), for a period of 90 days. The results indicated maximum removal efficiencies of 77.2% for COD; 77.8% for BOD, 87.9% for total nitrogen, 47.5% for ammonia nitrogen and 38.9% for total phosphorus for a five-day retention time. For biomass stabilization by composting, considering the C:N ratio as an indicator of compost maturity, it was observed that treatment T4 resulted in the shortest stabilization period (60 days). No difference was verified in the biostabilization rates at 5% level by the F test.

KEYWORDS: agroindustrial effluent, nutrient removal, water hyacinth, composting, C:N ratio.

REMOÇÃO DE MATÉRIA ORGÂNICA E NUTRIENTES DE EFLUENTE DE ABATEDOURO E FRIGORIFICO UTILIZANDO *Eichhornia crassipes* E AVALIAÇÃO DA COMPOSTAGEM DA BIOMASSA GERADA

RESUMO: O presente trabalho teve por objetivo avaliar o desempenho da macrófita aquática *Eichhornia crassipes*, aplicada *in situ* em sistema de tratamento de abatedouro e frigorífico, localizado no Oeste do Paraná, com relação à remoção de nutrientes e matéria orgânica, bem como obter dados da produção, de práticas de manejo e de compostagem da biomassa gerada no sistema. Durante 11 meses de desenvolvimento das macrófitas na lagoa, realizou-se o monitoramento de parâmetros físico--químicos e controlou-se a densidade das plantas, retirando-se periodicamente a biomassa em excesso por meio do acompanhamento semanal da densidade de plantas, expressa em kg de aguapé por m^2 de área líquida coberta. Avaliou-se, em escala-piloto, a degradação das macrófitas retiradas do sistema de tratamento, montando-se oito leiras de compostagem com aproximadamente 0,60 m^3, com quatro tratamentos distintos e duas repetições, sendo: T1- aguapé (*Eichhornia crassipes*); T2 - aguapé e dejeto suíno; T3 - aguapé, dejeto suíno e terra, e T4 - aguapé, dejeto suíno e tripa celulósica, por período de 90 dias. Os resultados obtidos demonstraram as eficiências máximas de remoções: DQO de 77,2%; DBO de 77,8%; nitrogênio total de 87,9%; nitrogênio amoniacal de 47,5% e fósforo total de 38,9%, para o tempo de detenção de cinco dias. Quanto à estabilização da biomassa via processo de compostagem, considerando a relação C:N como indicador da maturidade do composto, observou-se que o tratamento T4 obteve o menor período de estabilização: 60 dias. Não houve diferença significativa a 5%, pelo teste F, para a taxa de bioestabilização.

PALAVRAS-CHAVE: aguapé, efluente agroindustrial, compostagem, remoção de nutrientes.

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INTRODUCTION

Agroindustries stand out as large polluters in Brazil, particularly because of the large amounts of waste rich in organic substances, nutrients (particularly nitrogen and phosphorus), solids, oils and greases. In this category, slaughterhouses and meat processing plants are known for their high polluting potential.

These pollutants can be removed by physical operations and chemical and biochemical processes (GRADY et al., 1999). However, in slaughterhouse/meat processing plant wastewaters, these processes are not always capable of reducing nutrient and soluble organic matter concentrations to their respective regulatory levels. Therefore, it is necessary to use modern or tertiary techniques to provide a more refined treatment.

Due to economic reasons, these treatment technologies are currently being replaced by alternative systems involving biological treatment systems with aquatic macrophytes.

ROQUETE PINTO et al. (1986) reported that *Eichhornia crassipes i*s one of the most promising aquatic plant species for industrial use. It is capable of absorbing nutrient amounts higher than their actual biological needs, as well as chemical elements that do not participate in their metabolism. According to KIVAISI (2001), the extensive root system of the aquatic plant provides a large surface area for attached microorganisms, thus increasing the potential for decomposition of organic matter.

One of the greatest limitations of the use of *Eichhornia crassipes* (water hyacinth) to remove pollutants from domestic and industrial effluents is the temperature. The maximum plant growth temperatures are between 20 ºC and 30 ºC (ROMITELLI, 1983; KAWAI & GRIECO, 1983; PERAZZA et al., 1985). Besides the temperature, many other factors influence plant growth, including light intensity, phosphorus and nitrogen concentrations, dissolved inorganic carbon and water velocity (CARR et al., 1997). Appropriate maintenance of the system is also an important factor, that is, the periodic removal of excess biomass to promote plants growth and to increase nutrients removal (DUARTE et al., 2002). After its usage for pollutants removal, the excess biomass may also be used for composting (WOLVERTON & MCDONALD, 1979).

The present research focused on the evaluation of the use of the macrophyte *Eichhornia crassipes* (water hyacinth) to reduce nutrients (phosphorus and nitrogen) and organic matter in a slaughterhouse/meat processing plant effluent at the field scale. The study also aimed to obtain data regarding biomass production and management practices by testing different substrates in the composting process of the excess biomass removed from the macrophyte treatment system.

EXPERIMENTAL

Experiment implementation

The experiment was set and monitored in the vicinity of a slaughterhouse/meat processing plant in the city of Medianeira (latitude 25º17’40’’ south, longitude 54º05’30’’ W-GR, altitude 402 m) in the state of Paraná, Brazil. About 1500 pigs are slaughtered and processed at the plant daily, which generates 1350 m^3day^{-1} of liquid waste.

The wastewater undergoes screening pretreatment, followed by primary treatment, including sedimentation and flotation, and then a largely biological secondary treatment consisting of five sequential stabilization ponds. The first two ponds were anaerobic, followed by a complete-mixed aerated pond, a decantation pond, and a facultative pond which was undergoing deactivation at the time of the study.

The experiment was set in the fourth stabilization cell as the last one was being deactivated. The cell has a surface area of approximately 4,200 m^2, a volume of approximately 7,000 m^3, and a retention time of 5 days.

An area of 870 m^2 was delimited for the study and the experiments were initiated in October 2004 with the introduction of the aquatic macrophytes. Young water hyacinths (*Eichhornia crassipes*) with abundant root systems, uniform greenish yellow leaves and total size (root, stem, and leaves) ranging between 15 and 20 cm were initially placed in the experimental area at 5.85 kg m^{-2}. The plants were collected and transported thirty days before the experiment started to allow the biological adaptation of the plants to the new environment, as recommended by KAWAI & GRIECO (1983).

Experimental procedure

After completely covering the delimited area with plants, the biomass was monitored and removed according to aquatic plants density, expressed in kg of plants per m^2 of covered water surface. Biomass removal was constantly calculated as a function of plant development in periods ranging between 15 and 25 days, depending on the number of employees and machines available for the management process. Manual removal was carried out by using collecting forks and a boat when necessary (MORAES & RODRIGUES, 2002). The extracted biomass was sent for stabilization through composting.

The physical-chemical parameters monitored on a monthly basis were: organic matter (BOD and COD) and nutrients (total nitrogen, ammonia nitrogen and total phosphorus), which were analyzed according to APHA (1998).

The mean air temperature was 22.8 ºC, with a maximum of 26.5 ºC in February (summer) and a minimum of 16.5 ºC in July (winter). The experiment was kept during a period of 11 months and it was concluded in August 2005, when the plants reached their maximum development and went into senescence. All the plants were manually removed (approximately 28 tons of water hyacinth) and sent for composting, which generated over 4 tons of organic compost.

Composting of the removed biomass

Composting was carried out at the pilot scale in an open system with a delimited area of 50 m^2, in piles of 1.0 x 1.0 x 0.60 m (length x width x height) under four different treatments with two repetitions: T1 - Water hyacinth (*Eichhornia crassipes*); T2 - Water hyacinth and swine excrement (7:1); T3 - Water hyacinth, swine excrement, and earth (7:1:0.67), and T4 - Water hyacinth, swine excrement and cellulosic gut (7:1:0.67), where composting mixture proportions were determined on a wet basis. The material used was composed of wastes from the meat processing plant, such as semi-solid swine excrement from pigsties and transportation trucks and cellulosic gut from the sausage production. The composting pile was monitored for 90 days. The temperature was weekly evaluated and moisture, ashes, total nitrogen, and total organic carbon on a monthly basis. Aeration was carried out in biweekly manual compost turning cycles.

To optimize the composting process, the biostabilization rate of the biodegradable organic matter was determined, which, according to LEITE & PAVINELLI (1999), can be expressed by an exponential model representing the process:

$$dMb/dt = - K1\ Mb \quad (1)$$

The integration of equation (1) gives:

$$Mb = Mbo\ e^{-kt}$$

where,

dMb/dt - substrate use rate, d^{-1};
Mb - mass of the substrate transformed at any time, g;
Mbo - mass of the substrate applied at t = 0, g, and
K - first order biostabilization constant, d^{-1}.

The experimental design was randomized and the F Test was used for variance analysis (ANOVA) by using SISVAR software. The constant biostabilization was determined and fit by linear regression.

RESULTS AND DISCUSSION

Production and management of water hyacinth biomass (*Eichhornia crassipes*)

The biomass initially introduced comprised young plants ranging between 15 and 20 cm in size and distributed in the pond at a density of 5.85 kg m^{-2}. Pilot studies by OLIVEIRA et al. (2000) suggest a young plant density distribution of 5.9 kg m^{-2} of coverage area.

Biomass removal started in the seventh week, when the delimited area was completely covered with plants to maintain the ideal density. The biomass produced during that time was approximately 14,100 kg for an area of 0.087 ha. The plant development and density data, as well as monthly amounts of biomass removed throughout the experiment are presented in Table 1.

TABLE 1. Plant development, maintained densities and monthly removed biomass.

Period (months)	Plant Size (cm)	Density (kg m^{-2})	Removed Biomass (kg)
Dec. 2004	37 to 50	14 to 15	1,640
Jan. 2005	37 to 50	14 to 15	2,180
Feb. 2005	70 to 90	28	3,200
Mar .2005	85 to 100	30	2,010
Apr. 2005	85 to 100	30	4,830
May 2005	90 to 110	32	5,640
Jun. 2005	90 to 110	32	6,120
Jul. 2005	90 to 110	32	6,200

The density was calculated to allow enough free surface for proper plant development. It should be noted (Tab 1) that amounts of removed biomass were proportional to plant development throughout the whole experiment, except in March, when only 2,010 kg of biomass was removed due to operational problems, which was less than the expected amount. The ideal method according to ROMITELLI (1983) is selective harvests through the removal of old and diseased plants. However, due to the operational area size, this rule could not be effectively followed.

System efficiency evaluation

The results of removal of COD, BOD, TN, TAN, and TP during the experiment are shown in Figure 1.

Organic matter and nutrient removal was more efficient in the first eight weeks of operation for all the analyzed parameters except for total nitrogen and total phosphorus. This large removal is associated with the initial development of *Eichhornia crassipes* in a period known as the Rhizome growth period when the plants reproduce by vegetative processes by producing rhizomes (ROMITELLI, 1983). The mean plant duplication time is two weeks (PERAZZA et al., 1985).

The mean COD and BOD removal efficiencies were 26.3% and 32.5%, respectively, with maximum removals of 77.2% for COD and 77.8% for BOD. Higher removal efficiencies were observed during the rainy months and at temperatures higher than 20 ºC. Observations by BEYRUTH (1992) during a two-year period indicate that *Eichhornia crassipes* presents an intense development phase in spring and summer, reaching maximum vegetative development.

Nutrient and organic matter removal were higher at the beginning of the experiment with a sharp reduction from June on. According to BEYRUTH (1992), seasonal variations have an effect on the development of aquatic plants, which was also observed by LAUQUET et al. (2001) in Wetland systems.

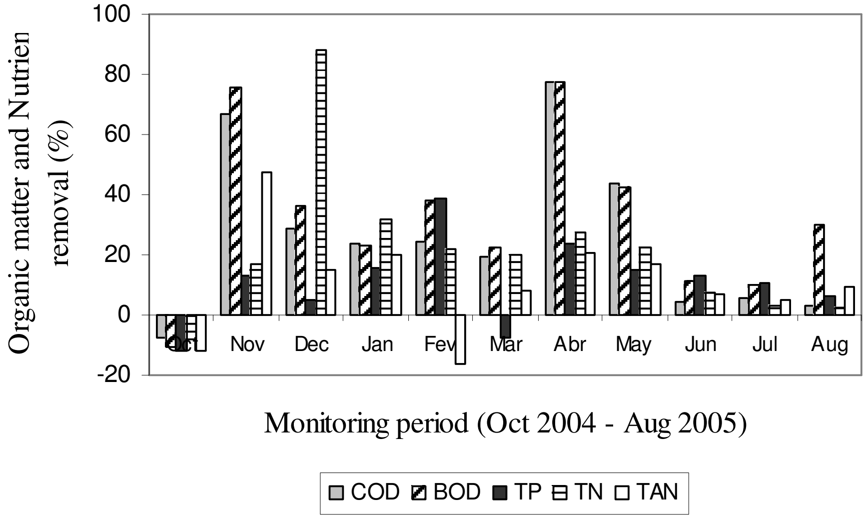


FIGURE. 1. Removal of organic matter and nutrients throughout the experiment.

The average and the maximum removals of total nitrogen, ammonia nitrogen and total phosphorus were 21.2% and 87.9%; 11.0% and 47.5%; and 11.1% and 38.9%, respectively, for a mean retention time of five days. KAWAI & GRIECO (1983) obtained removal levels of 52% and 58% for nitrogen and phosphorus, respectively, in 72 m^2 concrete ponds containing water hyacinth with retention time of 10 days, and 12% and 14%, respectively, with retention time of 2.5 days. MORAES & RODRIGUES (2002) obtained a mean reduction of 60% and 55% for total phosphorus and COD, respectively, from a slaughterhouse and a meat processing plant effluent, with a fifteen-day retention time by using macrophytes *Eichhornia crassipes*, *Salvinia sp*., and *Pistia estratiotes*. REIDEL et al. (2005) employed *Eichhornia crassipes* in the post-treatment of poultry slaughterhouse effluents and obtained maximum removals of 73, 80, and 39.2% for COD, total nitrogen, and total phosphorus, respectively, with a five-day retention time.

Water hyacinth (*Eichhornia crassipes*) biomass composting

The characteristics of the different substrates tested in the composting process are given in Table 2.

TABLE 2. Characteristics of the different substrates tested in the composting process.

Substrate	Total N (%)	Total P (%)	K (%)	TOC* (%)	Moisture (%)	C:N ratio
Water hyacinth	4.28	0.68	3.4	36.69	83.71	8.6
Swine excrement	3.65	2.5	3.1	38.2	54.17	10.5
Earth	0.49	0.23	0.1	0.39	1.48	0.8
Cellulosic gut	0.17	0.097	0.1	44.02	5.96	259

* TOC: total organic carbon.

KAWAI & GRIECO (1983) obtained mean values of 37, 3.1, and 0.54% for carbon, nitrogen, and phosphorus, respectively, in water hyacinths extracted from experimental ponds. O'BRIEN (1980), quoted by KAWAI & GRIECO (1983), stated that the elemental levels in water hyacinths range between 36.9 and 51.6% for carbon; 1.56 and 3.94% for nitrogen; and 0.31 and 0.89% for phosphorus. GOYAL et al. (2005) studied different organic composting substrates and obtained 41.8 and 2.31% for total organic carbon (TOC) and total nitrogen (TN) in water hyacinths, respectively.

As shown in Table 2, cellulosic gut is a waste of high C:N ratio, so it was mixed with swine excrement to narrow down the C:N ratio.

The results obtained during the composting process are given in Table 3.

Exponential equations were fitted to total organic carbon and total nitrogen compost concentrations during the organic matter biostabilization process. Table 4 gives the best fits.

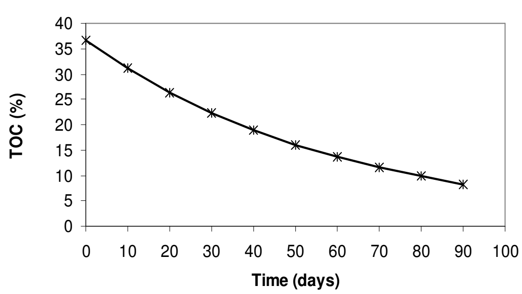
TABLE 3. Total N, TOC, moisture values and C:N ratio, after 30, 60 e 90 days of composting.

Treatments		Total N (%)			TOC (%)			Moisture (%)			C:N		
		30	60	90	30	60	90	30	60	90	30	60	90
T1	1	2.16	1.97	2.10	8.4	7.0	5.0	43.9	31.2	29.0	3.9	3.6	2.4
	2	2.33	2.12	2.50	13.3	11.0	10.0	39.3	30.5	26.8	5.7	5.2	4.0
T2	1	0.80	1.17	1.10	9.2	8.0	6.5	30.2	28.4	27.2	11.5	6.8	5.9
	2	0.62	1.88	1.90	7.4	8.0	7.0	48.4	35.7	28.9	11.9	4.3	3.7
T3	1	0.36	0.83	0.92	4.1	4.0	4.5	30.9	31.5	31.6	11.4	4.8	4.9
	2	0.28	1.25	1.20	4.3	2.5	2.7	32.2	29.3	20.4	15.4	2.0	2.3
T4	1	0.32	0.92	0.87	5.0	5.0	4.5	24.3	29.8	29.1	15.6	5.4	5.2
	2	0.57	1.28	1.17	5.5	11.0	10.0	32.5	30.9	21.0	9.6	8.6	8.5

TABLE 4. Exponential equation fit to total organic carbon and total nitrogen data for four different treatments.

Treatment	T_1	T_2	T_3	T_4
TOC	$36.69.e^{-0.0165t}$	$36.87.e^{-0.0171t}$	$34.06.e^{-0.0233t}$	$37.43.e^{-0.0151t}$
TN	$4.28.e^{-0.00651t}$	$4.2.e^{-0.00771t}$	$3.91.e^{-0.00911t}$	$3.89.e^{-0.01041t}$

The variance analysis applied to the fit equations to predict TOC and TN concentrations did not present differences at a probability level of 5%, since F = 6.59 for a confidence level of 95% and the F values calculated for TOC and TN concentrations were smaller. These results indicate that the four different treatments resulted in similar TOC and TN compost pile biostabilization constants, $K_{TOC} = 1.8 \times 10^{-2}$ day^{-1} and $K_{TN} = 0.8 \times 10^{-3}$ day^{-1}. Figure 2 shows the TOC and TN concentration curves as a function of time.



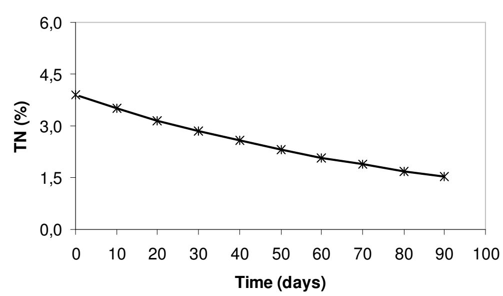


FIGURE. 2. TOC and TN concentration curves for ninety-day composting.

The average external and internal compost pile temperatures were weekly monitored. The Figure 3 presents the profile of temperature.

An initial temperature rise was observed for all the treatments, exceeding external temperature from the second week on. Temperature values were below the ideal for the decomposition process. This was probably due to the biomass particle size and compost pile size. CEZAR et al. (2005) studied the composting of aquatic plants during 90 days and observed temperatures ranging from approximately 10 to 30 ºC.

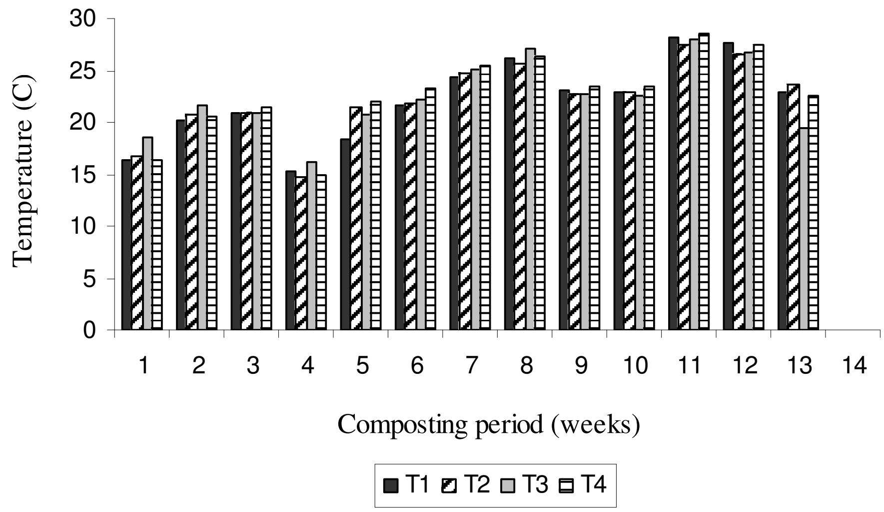


FIGURE 3. The average external and internal compost pile temperatures throughout the experiment.

There is no single parameter which can be used as a suitable indicator of maturity of a wide range of composts prepared from different materials. One ratio, which is frequently used as an index of maturity is C:N ratio. When a waste is composted, generally there is a decrease in C:N ratio with time due to losses of C as CO_2. In the present study, significant reductions were observed for all treatments during the period of 30 and 90 days. And when evaluating the period of 60 and 90, T4 showed the minimum reduction. Considering the C:N ratio as an indicator of compost maturity, treatment T4 resulted in the shortest stabilization period (60 days).

After 90 days of composting, a reduction of approximately 90% in the volume of T1, 88% in the volumes of T2 and T4, and 67% in the volume of T3 was observed, considering wet weight basis. CESAR et al. (2005) observed a volume reduction of 80% in ninety-day composting studies of aquatic plants in 2.5m³ piles.

CONCLUSIONS

The process was proven viable and efficient if the biomass removal management is conducted in a proper and consistent way including control of the system density according to plant development.

Regarding the composting process, the treatment T4 (water hyacinth, swine excrement and cellulosic gut) was found to be the most suitable, because it adds value to cellulosic gut and swine excrement, whose disposal was costly for the company.

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