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Nitrogen removal from swine wastewater by combining treated effluent with raw manure

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ABSTRACT: Effluents from swine raising can be harmful to the environment if not correctly managed. Nitrogen (N) is usually the main element present at high concentrations in the effluent. Since the use as biofertilizer is not always a feasible alternative, the treatment of swine wastewater is necessary. Variations in N species and water solubility make the treatment difficult and expensive. Additional N removal at low cost via denitrification may be possible by recirculating nitrified effluent in the barns. In this study, raw manure (RM) was homogenized with treated effluent (TE) at RM/(RM + TE) ratios of 1.0, 0.9, 0.8, 0.7, 0.6, 0.5 and 0 in order to simulate the effect of reused water on swine wastewater nitrogen removal. Samples were collected daily during four days and analyzed for pH, oxidation-reduction potential, NH_4-N, NO_2-N, NO_3-N and chemical oxidation demand. The oxidized nitrogen (NO_x-N) half-life degradation was estimated using linear regression. NO_x-N species half-life less than one day was obtained when treated effluent was combined and thoroughly homogenized with raw manure. It is suggested that combining raw manure with treated effluent (e.g. water reuse) can be a simple and cost-effective strategy to remove nitrogen from swine wastewaters.

Keywords: nutrient removal, swine effluent, treatment, water reuse

Introduction

Swine raising has changed considerably in the last 30 years with an increase in intensive production systems. Whereas intensive systems minimize production costs, the high animal densities can pose impacts to environments that have low soil absorption capacity (Kunz et al., 2009a; Vanotti et al., 2009). Thus, confined animal feeding operations (CAFOs) while reducing the production costs can increase the use of water and the environmental impacts associated with the residues generated during production (Bradford et al., 2008).

The need for swine manure treatment is usually dependent on factors such as soil/plant nutrient absorption capacity and land availability. Nitrogen is usually the most critical compound that needs to be removed due to its relatively high concentrations, treatability limitations and high costs of removal (Vanotti and Szogi, 2008).

Conventional nitrogen removal technologies are commonly based on aerobic autotrophic nitrification (i.e., nitrification) followed by anoxic heterotrophic process (i.e., denitrification). The reactions involved in both steps are shown in Equations 1 to 4. These processes are generally performed using separate reactors and the carbon for denitrification is obtained from the organic matter in the swine effluent (Ahn, 2006; Zhu et al., 2008).

$$NH_4^+ + 1.5O_2 \rightarrow NO_2^- + 2H^+ + H_2O \quad (1)$$

$$NO_2^- + 0.5O_2 \rightarrow NO_3^- \quad (2)$$

$$2NO_3^- + 10H^+ + 10e^- \rightarrow N_2 + 2HO^- + 4H_2O \quad (3)$$

$$2NO_2^- + 6H^+ + 6e^- \rightarrow N_2 + 2HO^- + 2H_2O \quad (4)$$

Treatment technologies should rely on the possibility of water reuse to minimize high quality water demand for barns washing and manure flush. A possibility that can be considered is to have the denitrification process occurring directly in the pits using the organic carbon present in raw manure. This strategy can reduce the costs of treatment facilities and clean water input for swine production (O´Connor et al., 2008; Vanotti et al., 2009). It avoids the use of high quality water for manure management, observing the biosecurity criteria, reducing the demand of water for swine production (Vanotti et al., 2005).

This study aimed to evaluate the potential for water reuse at swine barns as a strategy for denitrification enhancement and to study the effectiveness of nitrogen removal from swine wastewaters in swine facilities by simulating pit conditions and combining treated effluent with raw manure.

Materials and Methods

Sampling and storage

The raw swine manure used in this study was collected from an experimental swine production system located in Concórdia, Santa Catarina State, Brazil (27°18' S, 51°59' W). Raw manure produced in the first 24 h was collected directly from reception pits inside the finishing houses. Samples were prepared and stored according to Kunz et al. (2009b). Samples of treated effluent were collected from a swine manure treatment system (SMTS) also located in Concórdia (Kunz et al., 2009a). The samples were collected after an aerobic nitrification reactor and the biological sludge settling tank (Figure 1A) and homogenized with raw manure at different ratios.

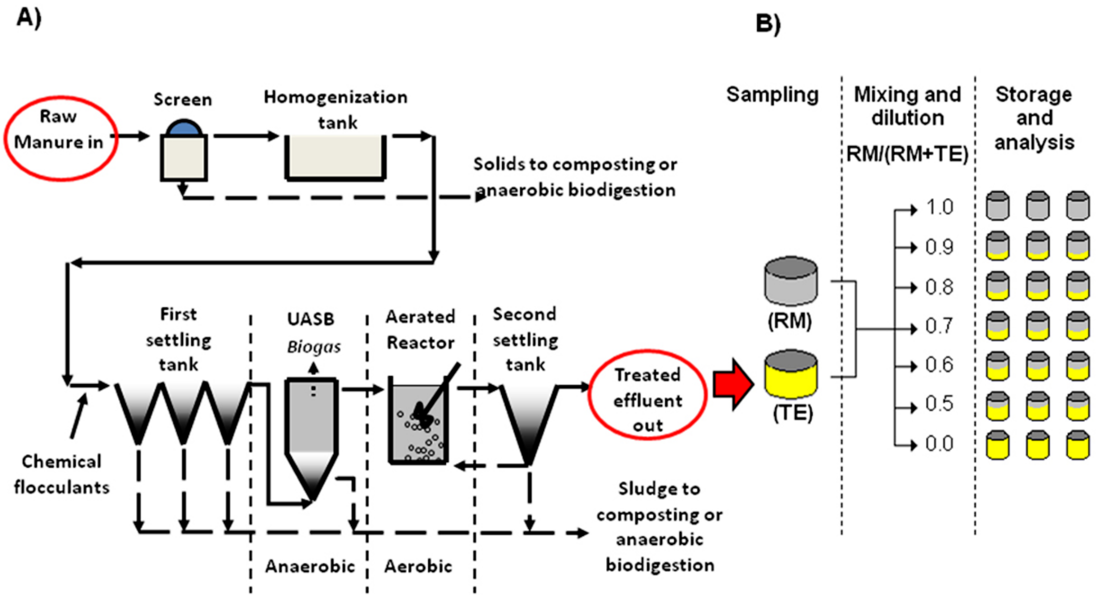


Figure 1 – A) Swine manure treatment system (SMTS) scheme, and B) Experimental design.

Experimental design

To mimic the pit storage processes and investigate the denitrification potential after adding the nitrified effluent to raw manure, raw manure was mixed with treated effluent at different ratios [raw manure/(raw manure + treated effluent)] of 1.0, 0.9, 0.8, 0.7, 0.6, 0.5 and 0 to simulate different reuse conditions. The mixed effluent was stored in triplicate in 20 L polyethylene buckets (Figure 1B) at room temperature during five days. From these stored buckets, 100 mL of the homogenized samples were collected every 24 hours and analyzed for pH, oxidation-reduction potential (ORP), ammonia (NH_3-N), nitrite (NO_2-N), nitrate (NO_3-N) and chemical oxygen demand (COD). All analyses were performed according to APHA (1995). NO_x-N concentration was obtained by adding up NO_2-N and NO_3-N concentrations.

Results obtained at different mixing ratios of raw manure with treated effluent are important to help understand what will happen with the treated effluent when reused in the barns, especially for the fate of nitrogen. For instance, when reused to wash the swine facilities and flush the manure. In this study, raw manure was combined to treated effluent at different ratios varying from 0 to 50 % (v v^{-1}). These dilution ratios are consistent with wastewater reuse, especially in Brazilian CAFOs, when considering the water demand for managing manure in the houses (Perdomo et al., 2003).

Data analysis

Nitrogen removal rates were estimated using linear regression of the raw manure/(raw manure + treated effluent) ratios according to Equation 5:

$$y = \alpha + \beta t + e \qquad (5)$$

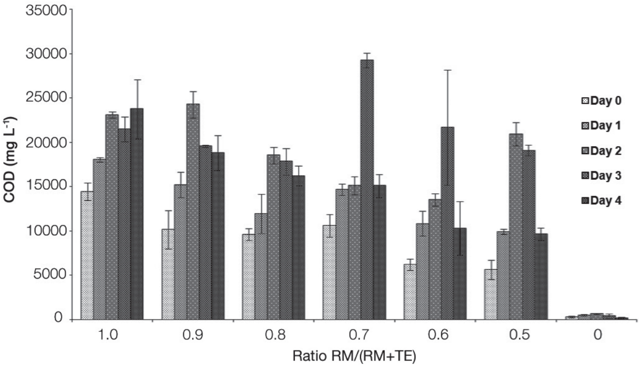
Where y is the observed value from the variables of interest (NO_2-N and $\sum NO_x$-N) transformed into natural logarithm; α is the day zero concentration logarithm; β represents the degradation constant, t the time; e is the random error distributed independently and identified. The effect of β was tested by the F-test. The above model estimates the half-life of each effluent concentration from exponential first-order regression analyses as demonstrated in Equation 6 (Pedersen, 2009) and its confidence interval by t distribution. Data values equal to zero were neglected.

$$Half\ Life = -\frac{Ln(2)}{\hat{\beta}} \qquad (6)$$

Results and Discussion

Variations in COD (Figure 2) and NH_3-N (Figure 3) concentrations were high for all mixture ratios tested. These variations were likely due to hydrolysis and dissolution caused by biodegradation of carbon-rich fresh manure (Kunz et al., 2009b, Markevich et al., 2010). Increasing ammonium concentrations lead to ammonification (free amino acids are produced by enzymatic protein hydrolysis) that is favored in reducing conditions (low ORP) (Figure 4) typically observed in swine effluents (Cantrell et al., 2008; Garcia and Angenent, 2009).

Except for treated effluent (ratio 0), pH decreased in all mixture ratios (Figure 5), probably due to substrate hydrolysis and formation of volatile fatty acids as byproducts from bacterial metabolism (Kashyap et al., 2003). For treated effluent, the content of organic matter is very low (Figure 2) favoring autotrophic processes like algae proliferation, which can be the responsible for pH increasing (Zanotelli et al., 2002).



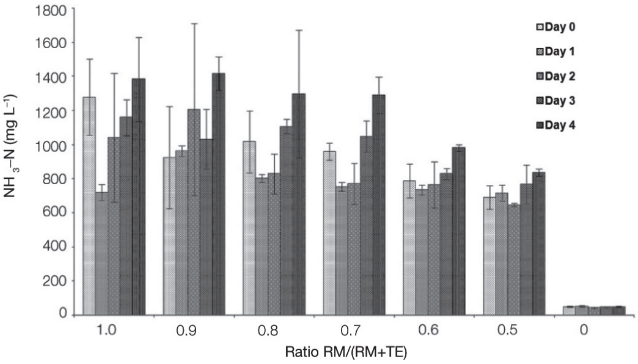
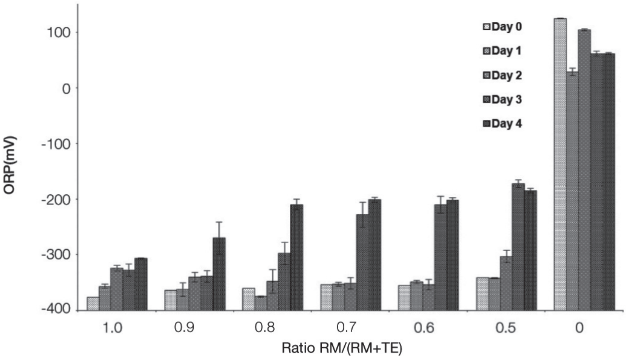


Figure 2 – Chemical Oxigen Demand (COD) concentration for ratios of raw manure (RM) and treated effluent (TE), during four days. Bars represent the average and lines represent the standard deviation of 3 samples.

Figure 3 – Ammonia (NH_3 -N) concentration for ratios of raw manure (RM) and treated effluent (TE), during four days. Bars represent the average and lines represent the standard deviation (n = 3).



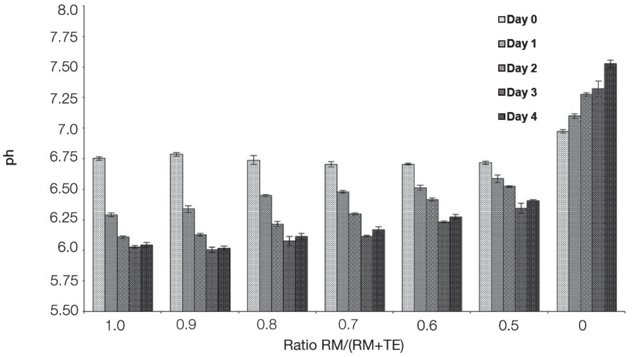


Figure 4 – Oxidation-reduction potential (ORP) variation for ratios of raw manure (RM) and treated effluent (TE), during four days. Bars represent the average and lines represent the standard deviation (n = 3).

Figure 5 – pH variation for different ratios of raw manure (RM) and treated effluent (TE), during four days. Bars represent the average and lines represent the standard deviation (n = 3).

NO_x-N depletion was found when fresh manure was combined with the nitrified treated swine effluent (Figure 6). NO_x-N species (NO_3-N + NO_2-N) reduction was observed ($p < 0.0001$) for all tested mixture ratios, except for ratios 0.9 and 1.0. Thus, NO_x-N was not observed in the samples after 48 h of experiment for ratios between 0.6 and 0.8. NO_x-N concentrations were not detected at all times at the 1.0 ratio. NO_2-N and NO_x-N concentrations in raw manure were negligible due to the reducing conditions (Figure 4) that prevent generation of these oxidized species. For the 0.9 ratio the NO_x-N concentrations were close to the detection limit of chemical analysis for zero and one day and not detected for sequential times.

Table 1 shows the half-life for different raw manure and treated effluent ratios. Similar concentrations of NO_2-N and NO_x-N were estimated using α from Equation 5. Although NO_x-N was detected at the first days in the 0.9 treatment, the very low concentration did not allow for half-life estimation ($p > 0.05$). NO_2-N and NO_x-N half-life, resulting from slope ($\hat{\beta}$), were lower than 0.5 days for the treatments between 0.5 and 0.8 ratios.

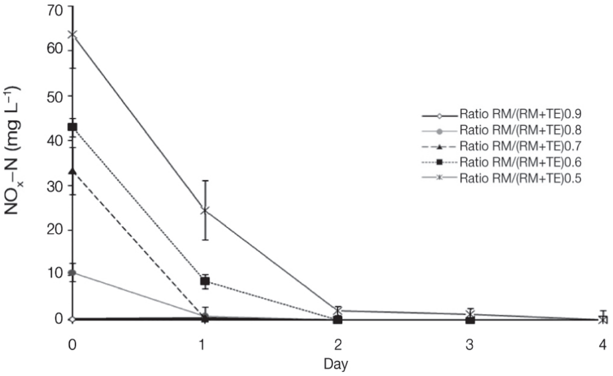


Figure 6 – Nitrogen oxidized species concentration (NO_x-N) observed for ratios of raw manure (RM) and treated effluent (TE), during four days. Points represent the average and vertical lines represent the standard deviation (n = 3).

If the reuse of treated effluent possibilities were considered in a commercial farm (eg, first pave cleaning and pit flushing), treatment 0.7 could be a reference. In this case a very fast NO_x-N decrease (half-life near 0.12

Table 1 – Nitrogen concentration as NO_2-N and NO_X-N in the RM/(RM+TE) ratios, (β) estimative of the degradation half life and half life confidence interval.

Ratio RM/(RM+TE)	Estimated Concentration (t_0)	$\hat{\beta}$	Linear regression (Pr > F)	Half life	Half life confidence interval (95 %)
	mg L^{-1}			days	
			NO_2-N		
0.5	62.80	-1.552	<0.001	0.446	(0.347; 0.626)
0.6	42.97	-1.615	<0.001	0.429	(0.382; 0.490)
0.7	32.99	-5.799	<0.001	0.120	(0.116; 0.123)
0.8	10.63	-4.666	<0.001	0.149	(0.145; 0.152)
0.9	0.22	1.274	0.528	NE	NE
1.0	NE	NE	NE	NE	NE
			ΣNO_X-N		
0.5	64.98	-1.523	<0.001	0.455	(0.355; 0.634)
0.6	42.97	-1.615	<0.001	0.429	(0.382; 0.490)
0.7	32.99	-5.150	0.001	0.135	(0.108; 0.179)
0.8	10.63	-2.672	0.001	0.259	(0.211; 0.337)
0.9	0.32	≈ 0	1	NE	NE
1.0	NE	NE	NE	NE	NE

RM: Raw manure, TE: Treated effluent, NE: Not estimated, $\approx$ 0: Approximately zero.

day) was observed, allowing conditions for NO_x-N extinction in approximately 2 days.

The heterotrophic medium in raw manure offered good conditions for quick nitrogen removal under anoxic conditions. The chemical reducing conditions in raw manure, shown as negative ORP values in Figure 4, benefited NO_x-N removal when mixed with nitrified effluent due to the oxidation of the organic carbon using nitrogen oxidized species as an electron acceptor (Gilbert et al., 2008; Vanotti and Szogi, 2008). Heterotrophic microorganisms have a very high growing rate which favors denitrification processes (Potter et al., 1998; Ahn, 2006). The specific growth rate (μmax) for NO_3^- and NO_2^- reduction are 2.6 d^{-1} and 1.5 d^{-1}, respectively. These are significantly higher than μmax for nitrification ($\mu max_{NH4\ oxidation}$ = 0.77 d^{-1} and $\mu max_{NO2^-\ oxidation}$ = 1.08 d^{-1}) (Wiesmann, 1994).

Another factor that influences denitrification is the C/N ratio. For a good nitrogen removal efficiency, the C/N ratio must be higher than 3.5 (Grady Jr. et al., 1999; Ahn, 2006; Ginige et al., 2009). In this study (Table 2), the COD/NO_x-N was extremely high for all mixtures and dates; they ranged from 89 to 43,514.

High C/N ratios can also hinder the generation of N_2O, an important greenhouse gas (Ravishankara et al., 2009) that is produced in low C/N ratio environments. Bernet et al. (1996) studied the denitrification of piggery wastewater and concluded that when TOC/N was between 1.6 and 2.4 (COD/N between 4.26 and 6.4), N_2O emission was observed, but when TOC/N was higher than 2.4, N_2O was not emitted. Itokawa et al. (2001) investigating the nitrous oxide production under low COD/N ratios conditions concluded that 20-30 % of the total influent nitrogen was emitted as N_2O with influent COD/N less than 3.5.

Table 2 – Observed Chemical Oxidation Demand (COD) and Oxidized Nitrogen (NO_X-N) ratios at different experimental conditions.

Ratio RM/(RM+TE)	Day 0	Day 1	Day 2	Day 3	Day 4
0.9	43514	41455	24253	19548	18807
0.8	902	14917	18540	17833	16240
0.7	318	48867	15127	29227	15100
0.6	144	1255	13507	21680	10303
0.5	89	404	10292	13946	9650

RM: Raw manure, TE: Treated effluent.

Conclusions

NO_x-N can easily and quickly be removed from swine effluents by mixing raw manure with treated effluent. High NO_x depletion due to denitrification was observed for all RM/(RM + TE) ratios tested with half-life less than 12 h which is within a reasonable time considering the manure management in the swine production facilities.

It is possible to remove nitrogen by carbon-rich manure degrading bacteria during denitrification. This can minimize the input of treated water in CAFOs by reusing the nitrified effluent at different ratios back in the barns for cleaning and flush the manure.

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