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THE EFFECT OF LIMITED AERATION ON SWINE MANURE PHOSPHORUS REMOVAL

Jun Zhu,* Ancheng Luo, and Pius M. Ndegwa

University of Minnesota, Biosystems & Agricultural Engineering Department, Southern Research and Outreach Center, 35838 120th Street, Waseca, MN 56093

ABSTRACT

Two low level aeration schemes (intermittent vs. continuous) were investigated on a laboratory scale, in conjunction with swine manure pH adjustment using sodium hydroxide (1.0 *M*), for manure phosphorus (P) removal. According to the data, an 80% reduction in soluble P was observed when the manure pH was increased to 8. Both intermittent and continuous aeration treatments could raise manure pH above 8 with an airflow rate of 1 L/ minute in a period of 15 days. A drastic increase in pH (about 1 unit) was observed for both aeration schemes within the first day of test, resulting in a 76% reduction in soluble P concentration in the liquid. It appeared that there is no difference in terms of P removal between the two aeration programs, suggesting that the intermittent aeration be preferred to save energy while still achieving the same level of P removal.

Key Words: Aeration; pH changes; Phosphorus reduction; Swine manure.

INTRODUCTION

While much effort having been directed to solving odor problems caused by large swine production facilities, excess nutrients in the manure associated with such intensified operations have started to draw attention from the public. Traditionally, the manure was spread in cropland as fertilizers and soil conditioners.

* Corresponding author. Fax: 507-835-3622; E-mail: zhuxx034@umn.edu

However, the tremendously increased volume of manure produced at the present time seriously challenges this traditional practice due to possible environmental pollution caused by the excess nutrients present in the manure. One of the major concerns that are voiced most by the public is related to the potential pollution of surface and groundwater by phosphorus.

Reviewing literature has indicated an insufficiency in research to remove phosphorus from animal wastes, although there has been a considerable amount of work reported in removing phosphorus from municipal and industrial wastewater[1,2,3,4,5]. The major hindrance in using those techniques developed for treating municipal and industrial wastewater rests with the cost and sophistication of the techniques, which makes them cost ineffective. In recent years, several researchers have attempted to modify some of the advanced techniques in order for them to fit into the waste management plan at farm level[6,7,8]. However, limited success has been reported in this respect because the modified techniques are still too expensive and require high maintenance. The criterion based on which these techniques were developed is to produce final effluent with P concentration less than 1 mg/kg, so the water can be used as drinking water for animals without causing health problems. However, under most circumstances, the treated liquid will be applied to cropland as fertilizer or soil amendment. Thus, the criterion for producing livestock drinking water is obviously too stringent and entails unnecessary capital and operational expenses. As a matter of fact, so far as the P concentration in the receiving land can be balanced to prevent significant runoff from occurring that may cause pollution, low level treatment, which could be inexpensive, may suffice to reduce the excess P in swine manure before discharge. Unfortunately, to date, little information has been made available in development of economically viable methods to remove P from swine manure that are specially tailored to the needs and financial capabilities of the majority of small- to medium-size swine producers.

Removal of soluble P by pH adjustment is to form insoluble P compounds that precipitate. Within the pH range from 7 to 12, the precipitates will not be hydrolyzed to release P into the solution. In most industrial wastewater treatment plants, chemical compounds (e.g., CaO, $Ca(OH)_2$, $Al_2(SO_4)_3$, and $Fe_2(SO_4)_3$) are added to the wastewater to form phosphate precipitates such as, $AlPO_4$, $Ca_5(PO_4)_3OH$, and $FePO_4$[9]. In doing so, the P concentrations in the treated waste are reduced. This process, however, has not been adopted for treating swine wastewaters because of the cost as well as the possible secondary environmental pollution associated with it[10]. Reports have not been found that adjusting manure pH to assist the reactions between the existing Ca and Fe in manure to form insoluble compounds without additional chemicals can reduce soluble P. As a matter of fact, past research indicated that the manure pH could be raised by passing an aerating gas mixture through the slurry[11]. The process is predicated upon purging CO_2 out of solution, which breaks up the neutral condition established by the dissolved CO_2 that forms ammonium bicarbonate. This area surely deserves further research.

This paper presented information regarding the removal of soluble P from swine manure by increasing pH via low-level aeration. For comparison, sodium hydroxide (NaOH) was also used to raise the manure pH so its effect on P removal was examined. Data from this study may reveal the possibility and feasibility of developing cost effective treatment techniques for swine manure P management. Areas that need further research are also discussed.

MATERIALS AND METHODS

Manure Source

The manure used for the test was collected from a finishing building located at the University of Minnesota Southern Research & Outreach Center at Waseca, Minnesota. The building was equipped with a shallow pit with a pull-plug system. The manure was about two to three weeks old with 2.5% total solids content and the initial phosphorus concentration was around 128 mg/kg. The pigs were fed on a regular corn/soybean diet.

pH Adjustment By NaOH

Manure samples of 100 ml each were contained in eight 200 ml flasks and sodium hydroxide (1 *M*) was added to each flask at ascending quantities from 1 to 8 ml at 1 ml increment. When the mixture became uniform after gently shaking, the manure pH was measured using a pH/mV/ORP meter (Catalog No.: P-05938-52, Cole-Parmer, Vernon Hills, IL 60061) for all the samples. And the soluble P concentrations were also determined at different NaOH levels by the standard methods[12]. A raw manure sample was measured for both pH and soluble P as the control.

pH Adjustment By Aeration

Plexiglass tubes, 91.6 cm in height and 15.3 cm in diameter, were used as reactors in the experiment. Each reactor was filled with liquid manure up to about 84 cm, leaving a headspace of 7.5 cm. Aeration was realized by an air pump (Catalog No. 13-875-220, Fisher Scientific Company, Hanover Park, Illinois 60103), which provided air to each reactor at an airflow rate of 1 L/minute and was controlled by individual airflow meters mounted on each reactor. The air was bubbling from the bottom of the reactor to maximize the travel distance and mixing effect. The reason that 1 L/minute was chosen is to avoid the creation of a fully aerated environment in which the biological P removal process may become predominant, thus interfering with the planned research regarding the effect of pH on the P removal. On the other hand, high energy input in connection with increased aeration is not desired if the results from this research are intended to be used for full-scale treatment at farm level.

Three treatments were studied, i.e., two aeration treatments (continuous vs. intermittent) and one control. In the continuous mode, air was supplied to the reactors continuously throughout the test period, while in the intermittent mode, aeration was controlled by a timer (Catalog No. 06-662-43, Fisher Scientific Company, Hanover Park, Illinois 60103) that turned the air pump on and off at a two-hour interval. A total of 9 reactors were used for the test so for all the treatments, measurements were made in triplicate. The length of the test was 15 days.

The manure in each reactor was sampled and analyzed daily for total soluble P and pH. The oxidation-reduction potential (ORP) was measured, also on a daily basis, directly from the manure in the reactors using the above mentioned pH/mV/ORP meter. Statistical t test at a significance level of $P < 0.05$ was used for comparisons throughout the analysis.

RESULTS AND DISCUSSIONS

Soluble P Changes by pH Adjustment Using NaOH

Figure 1 showed the changes in manure pH caused by the addition of NaOH. Apparently, in the first several additions, the manure pH increased with the increase in NaOH in an almost linear manner. When the manure pH reached about 8.25, the rate of increase decreased. The difference in pH between the last two points was only about 0.04 (8.88 vs. 8.92).

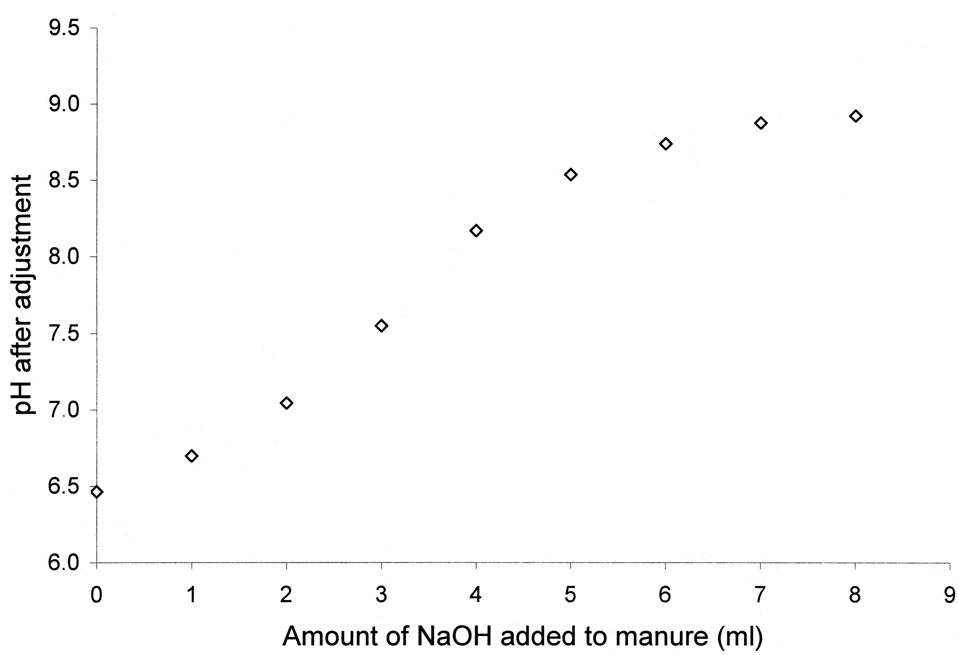

Figure 1. Adjustment of pH using NaOH.

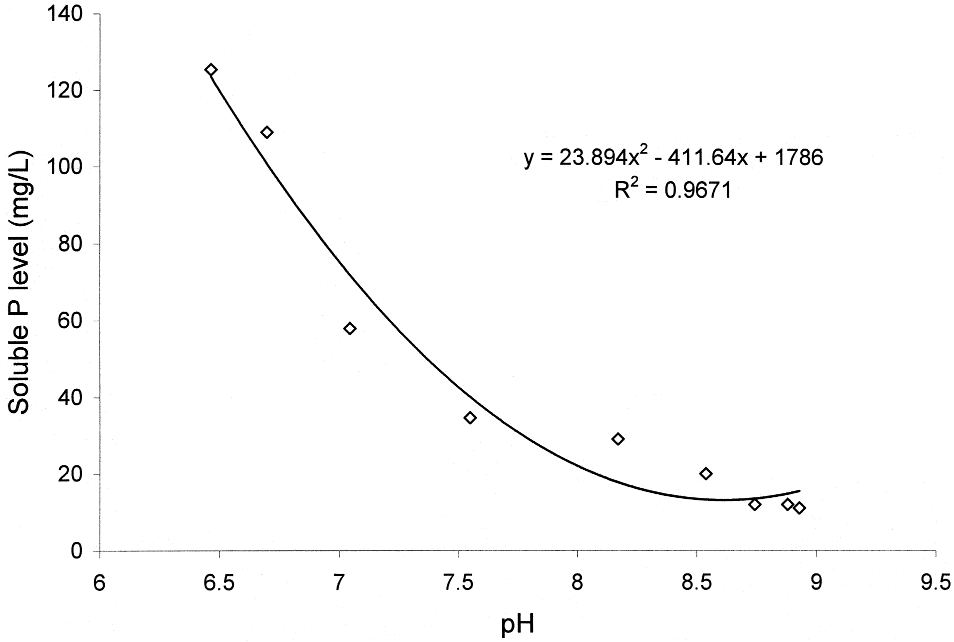

Figure 2. The changes in manure soluble phosphorus concentrations due to the pH increase caused by addition of sodium hydroxide.

Figure 2 showed a strong effect of pH on the soluble P concentrations in the manure. When pH increased from around 6.5 to 9, the concentrations of soluble P decreased drastically from about 130 mg/L to about 10 mg/L (a 92% reduction). A quadratic relationship was revealed for P concentration with pH with a correlation coefficient of 0.983. An 80% reduction of total soluble P can be achieved if pH is raised to 8 according to the quadratic equation.

Literature showed that the reactions between P and Ca or Fe are highly pH dependent[13]. With a pH range from 4.7 to 7.1, iron will effectively react with soluble P to form iron phosphate precipitates. When pH goes beyond 7.1, calcium, with an optimum pH range from 7.2 to 12, will become the major reactant in the reactions for P removal. Since swine manure contains much more calcium ($110 g/m^3$) than iron ($6.6 g/m^3$), a great deal of P will be removed if pH moves towards the range in favor of the formation of calcium phosphate[9]. The continuous removal of P over pH range from 7 to 9 observed in this study was likely due to this mechanism.

One scenario was noticed by reviewing Figure 2 that there were two pH ranges in which the rates of P reduction were apparently different. When pH increased from 6.5 to 8, the rate of P reduction observed was much greater than that when pH went beyond 8. Interestingly, similar phenomenon was observed for the pH changes during the course of NaOH adjustment (Figure 1). This observation may deserve an explanation.

As discussed early, the optimum pH for calcium can be up to 12. Therefore, the reduced rate of P removal could be due to the slowdown of pH increase, as shown in Figure 1. Therefore, to maintain the P removal rate, it can be inferred that further increase of manure pH with addition of more NaOH should help. Since little information is available in terms of reducing soluble P in wastewater by increasing pH alone without adding other chemicals such as CaO, $Ca(OH)_2$, $Al_2(SO_4)_3$, and $Fe_2(SO_4)_3$, the findings in this study may provide impetus for further research on the utility of this method in treating diluted swine wastes for P removal.

Soluble P Changes by pH Adjustment Using Aeration

Variations of pH over the entire test period for different treatments were presented in Figure 3. For both intermittent and continuous aeration treatments, the manure pH increased by about 1 unit in the first day of treatment and continued to increase gradually thereafter. In the conclusion of the test, the values of pH were 8.0 and 8.4 for the intermittent and continuous aeration, respectively. For the control treatment, the pH remained nearly unchanged in the course of the test.

The means and error bars of P and the oxidation-reduction potential (ORP) during aeration for different treatments were presented in Figures 4 and 5. It can be seen from Figure 4 that after one-day aeration, the P concentrations in both

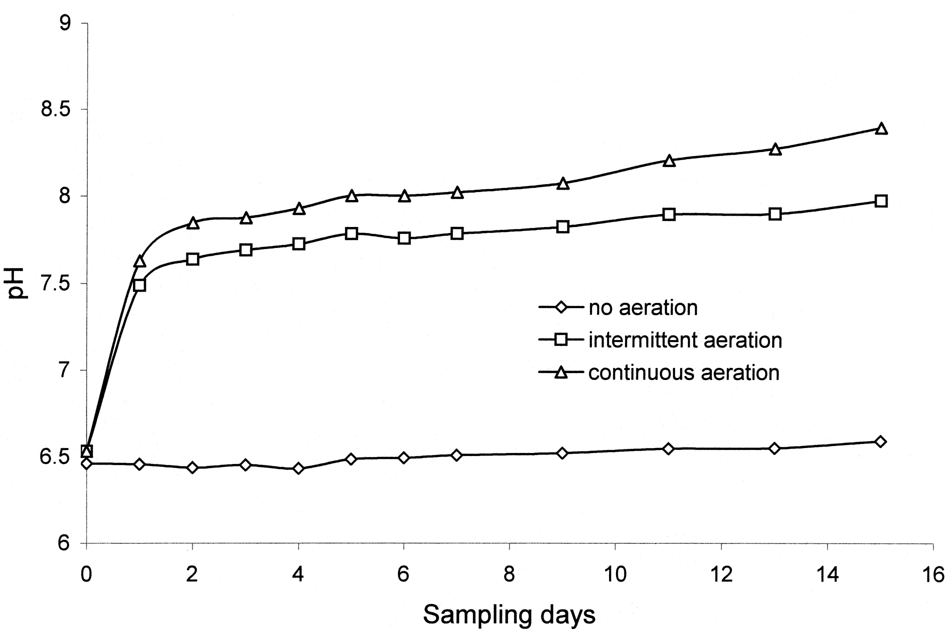

Figure 3. The changes in manure pH over time due to aeration for different treatment schemes.

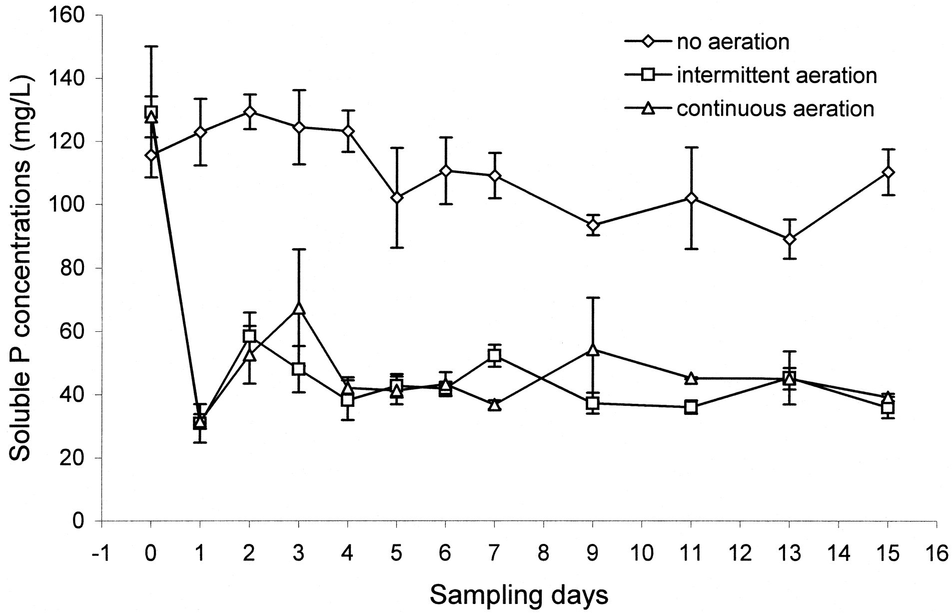

Figure 4. The means and error bars of soluble P concentrations in the test manure during the entire test period.

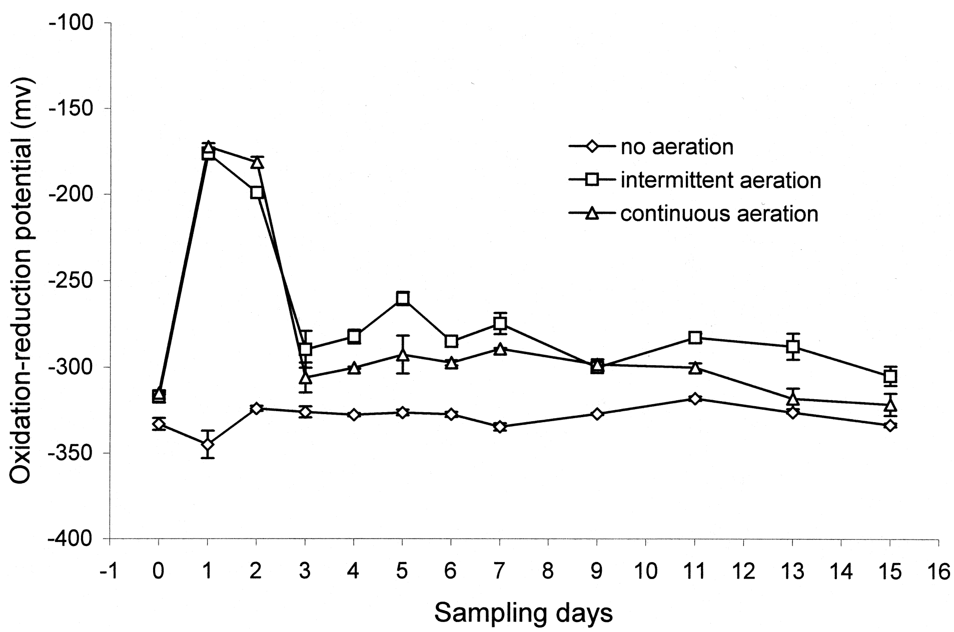

Figure 5. The means and error bars of oxidation-reduction potentials for different treatment over the test period.

aeration treatments dropped dramatically from around 127 mg/kg to around 31 mg/kg (a reduction by 76%), with a rise of pH in the liquid manure from 6.5 to 7.5 and 7.7, respectively (Figure 3). The sharp decreases of soluble P in the liquid for both cases were therefore mainly due to the increase in pH. Examining the data presented in Figures 2 through 5 may support this statement. By entering pH values of 7.5 and 7.7 into the equation in Figure 2 to calculate the P concentrations for both cases, the results are 43 mg/kg for the intermittent aeration and 33 mg/kg for the continuous aeration, respectively. These numbers were not far off the numbers actually measured in the test, i.e., 31 mg/kg for the intermittent aeration and 32 mg/kg for the continuous aeration (Figure 4). The differences could be due to measurement errors. Therefore, it may be concluded that the P reductions in the first day of aeration for both aeration schemes were caused by the pH rises.

There are three possible mechanisms for pH increase due to aeration, i.e., phosphoric acid removal by aerobes, CO_2 purging, and ammonia production. Although there was theory on phosphoric acid removal from wastewater by the aerobes which would accumulate it for polyphosphate synthesis, thus leading to a pH increase, there was not enough evidence that these phosphate accumulating aerobes could thrive to reach a significant population in order to be effectively functioning within only one day of aeration at such a low level[14]. Neither would the time allow nitrification to take place in order to produce ammonia, thus resulting in a pH rise[15]. Therefore, as indicated early, the large increase in pH observed in the first day of study was primarily due to the purge of CO_2 out of the liquid manure[11]. With the aeration in progress, as the amount of oxygen in the air bubbling through the slurry increased, the increase in liquid manure pH may have been due in part to the increased rate of organic matter degradation and urea hydrolysis, which resulted in increased ammonia production. Therefore, the maintained high pH levels after the first day of aeration may result from the combination of the above discussed mechanisms.

In the first several days, aeration significantly increased the ORPs of the treated liquid manure, as compared to the control (Figure 5). Although the levels of ORP dropped dramatically after three days of operation, due to small variations, the overall ORP levels were still statistically higher than the control over the entire test period. For the control, although there were some significant differences ($P < 0.05$) in ORP on a day-to-day basis due to small standard deviations, the average value was around −330 mV. It has to be recognized that although the ORPs were significantly enhanced by the aeration treatments, the aeration level is still considered low as defined by Burton[16].

It is interesting to note that starting from day 3, there was a tendency that the ORPs in the continuous aeration treatment became significantly lower than those in the intermittent aeration mode. The reason for this observation is unknown. By definition, ORP represents the oxidation-reduction power of the solution. Thus, high ORP means high oxidizing but low reducing potential. The data in this study appeared to show that intermittent aeration would provide more oxidizing power to the solution than continuous aeration with the same aerator, which seemed impossible. Further research is needed to gather more information to verify this finding.

There appeared no significant difference in terms of P concentration for the treatment without aeration during the course of the test (Figure 4). In contrast, statistically significant reductions in P concentrations were revealed by data following day 1 for the two treatments with aeration. The data also showed that although there were small fluctuations in P concentrations in the aerated manure on a day-to-day basis, further reduction of P was not observed, suggesting that extended aeration beyond one day be unnecessary if removal of P is the main purpose of the treatment. This finding is of practical significance because it provides information that could make it possible to design a simple aeration system to accomplish P removal before spreading manure in cropland.

Figure 4 also revealed that the continuous aeration treatment did not show precedence over the intermittent aeration for P removal, indicating that it could be possible to reduce the energy consumption by 50% while still accomplishing the same reduction of P concentration.

SUMMARY AND CONCLUSION

According to this study, swine manure soluble phosphorus can be reduced solely by raising pH alone, without using external chemicals. An increase in pH to 8 can achieve a reduction in soluble P concentration by 80%. The rate of pH increase by using NaOH appeared characteristic of linearity before the pH reached 8, while further increase in pH beyond 8 appeared to be reduced. Similar trend was observed for P reduction. This implies that the most effective pH value for P removal by precipitation is around 8 without assistance of external chemicals. More data is needed to verify this observation.

Use of low level aeration to raise manure pH without using NaOH was another option investigated in this study and the data showed that for both intermittent and continuous aeration treatments, the manure pH increased by about 1 unit within the first day of operation. In return, a reduction in soluble P concentration by 76% was obtained. There is no difference in terms of soluble P removal between continuous and intermittent aeration schemes, suggesting that the intermittent aeration be a better option that can potentially reduce energy consumption by 50%, while still achieving the same level of P removal.

In contrast to many expensive techniques to remove soluble P from wastewater, the aeration technique presented in this paper, although preliminary, has indicated the possibility of effectively reducing soluble P concentration in liquid swine manure at a potentially low cost. More research is needed to develop a complete system that will encompass not only the P removal process but also the subsequent treatments that handle different fractions of animal wastes to minimize the pollution and sustain swine production.

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