

NUTRIENT AND SOLIDS REMOVAL BY LIME AND ALUM TREATMENT OF
FLUSHED DAIRY MANURE

By

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Hector Lago Jopson

This thesis is dedicated to my loving wife Ann and daughter Harriet, my parents, Reyland and Matilde Jopson, and to my sister Hilda and brother Reyland Jr.

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Abstract of Thesis Presented to the Graduate School
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Dairy farms utilizing flushed manure systems deal with voluminous liquid manure on a daily basis. To maintain the effective storage capacity of storage ponds, tanks, and lagoons, an irrigation system is usually employed for land application of wastewater. This repeated application of dairy wastewater on limited cropland can result in high levels of nutrients, especially phosphorus (P), in the soil. Runoff from these areas can potentially increase the risk of eutrophication of nearby surface water and leaching into the groundwater. Presently, solids separators have proven inefficient in removing the solids and nutrients from the liquid dairy manure. An effective and sustainable system must be developed to further reduce the solids and nutrients.

The field demonstration project in Riverview, Florida, where hydrated lime slurry and alum were used to remove nutrients and solids from a flushed dairy manure system, was the basis for this laboratory evaluation. This study evaluated the effectiveness of hydrated lime, a commercial quicklime product, alum, and combined hydrated lime and

alum in reducing the levels of solids and nutrients, especially P, in liquid dairy manure after mechanical separation.

Preliminary investigation on the effect of hydrated lime and alum on the pH of the wastewater with respect to time was conducted on 100 ml samples. With high dosages of hydrated lime (≥ 406 mg Ca/L), the pH stabilized to about 11.4 and 11.5 in about 5 minutes. When 216 mg Al/L of alum was added to untreated wastewater, the pH after 5 minutes decreased rapidly to about 4.4. The combination of each dosage of hydrated lime (135 mg Ca/L, 271 mg Ca/L, 406 mg Ca/L, and 541 mg Ca/L) with 108 mg Al/L of alum resulted in a final pH range of 6.6 to 9.0 after 15 minutes.

Laboratory tests of liquid dairy manure containing an average of 0.70% total solids (TS) showed that, when compared to the control (no chemical addition), the addition of hydrated lime combined with alum performed best in reducing the levels of total phosphorus (TP), dissolved reactive phosphorus (DRP), and total Kjeldahl nitrogen (TKN) by 98%, 99%, and 59%, respectively. Treatment with hydrated lime reduced the volatile solids (VS) by about 66.2%, while the addition of only alum reduced VS by about 34%. When the resulting pH of the solution is considered, especially for potential applications on dairy flush systems that recycle the treated wastewater, the combination of hydrated lime (676 mg Ca/L) and alum (432 mg Al/L) performed best by achieving a pH between 7 and 8 and at the same time reducing TP and DRP by about 95% and 98%, respectively. However, the combination of hydrated lime (676 mg Ca/L) and a lesser amount of alum (108 mg Al/L) removed 77.7% of TP. Curve fitting analysis showed that effects on P removal were greatest with removal curves best described by a quadratic polynomial (TP $r^2 = 0.99$ and DRP $r^2 = 0.97$).

CHAPTER 1 INTRODUCTION AND OBJECTIVES

Introduction

A significant amount of pollutants entering lakes, estuaries, streams, and groundwater in the United States (U.S.) results from agricultural activities. The harmful consequences of farm production on water quality include soil erosion; runoff into lakes, rivers, and streams of fertilizers, animal wastes, and pesticides; and leaching into groundwater of nutrients and pesticides. Pollution from agricultural operations is only one source of water quality problems. Discharges from industrial activities and municipal sewage treatment plants, stormwater runoff, and naturally occurring contaminants are also potential sources of water pollution. However, the U.S. Environmental Protection Agency (EPA) considers nonpoint source pollution from agriculture as the primary contributor to the nation's surface water quality deterioration. A 1998 EPA Water Quality Inventory report showed that more than one-third of the river miles, lake acres, and estuary miles are impaired to some degree (U.S. EPA, 2000).

Water pollution may be categorized into two types based on sources. Point sources discharge effluent directly into water bodies through an identifiable pipe, ditch, or other conveyance. Industrial and municipal effluents are examples of this category. Non-point source (NPS) pollution comes from diffuse sources such as runoff and leachate from rain or snow melt. Unlike point source pollution, NPS pollution is difficult to regulate because it is not readily identifiable. Nutrients, sediments, pesticides, salts, and pathogens are the major agricultural pollutants contributing to NPS pollution.

Nutrients such as nitrogen (N), phosphorus (P), and potassium (K) are essential for plant growth. Of these three nutrients, N and P can cause quality deterioration when they enter water systems. Nitrogen and P accelerate aquatic plant and algal production in receiving surface waters, a condition known as eutrophication. Accelerated eutrophication causes a variety of problems, including fish kills, human health issues, clogged pipelines, and reduced recreational opportunities. Nitrogen is primarily the limiting nutrient in brackish or salt water and P in freshwater.

In Florida and many other areas in the U.S., there have been serious concerns over surface water and groundwater pollution from agriculture, especially from animal production facilities. Florida's water resources such as lakes, rivers, springs, and beaches attract millions of tourists annually. But with the threat of diminishing water quality due to eutrophication, this multi-million dollar industry may be adversely affected. In addition, Florida's drinking water supplies come largely from groundwater. Since surface water is ultimately linked to groundwater at some point, N from agricultural operations can leach through underwater systems and become a health problem for those who drink water directly pumped from groundwater. The U.S. national drinking water standard sets a maximum nitrate-N concentration as 10 mg/L. Above this level it is considered harmful, especially to infants, causing a condition called methemoglobinemia (Craun et al., 1981).

In recent years, Florida's dairy industry has been striving to meet the needs of the state for milk. Though the number of dairy farms has decreased in Florida, the herd size has increased. Figure 1-1 shows the distribution of dairy farms in the state of Florida. The average herd size in the state is about 693 milk cows per dairy farm, one of the

nation's largest (University of Florida Institute of Food and Agricultural Sciences [UF/IFAS], 2001). The Florida Agricultural Statistics Service (FASS) reported that as of January 2004, dairy cow numbers were estimated at 140,000 milk cows and 40,000 replacement cows (FASS, 2004). This translates to a fresh manure production of 9,907 tons/day or 3.6 million tons/year (American Society of Agricultural Engineers [ASAE], 2003). Handling and disposal of these voluminous wastes create additional burdens to the dairy farmers, not to mention the environmental issues these wastes pose. Growing public concerns associated with nutrient losses from manure of large dairy herds as well as other sources have been overwhelming in Florida. The eutrophic condition in Lake Okeechobee (second largest freshwater lake in the continental U.S.) due to P contamination from farm runoff and nitrate-N losses into the groundwater through the sandy soils of the Suwannee River Basin (largest undammed drainage basin in the U.S. Coastal Plain) are causes of these major concerns.

Most dairy farms in Florida utilize flushing to a lagoon, storage pond, or storage tank to remove manure from confinement facilities. An irrigation system is usually employed for land application of wastewater. Dairy farm wastewater normally contains a large percentage of solids and nutrients, and one conventional method being used to deal with them is by separating the solids through sedimentation and mechanical solids separators. By separating the solids, less sludge is formed in the lagoon, thus extending its capacity. However, this method has proven to be inefficient because only a small percentage of the solids and nutrients are removed. Most of the solids and nutrients end up in the lagoon or storage pond. When the liquid waste from the lagoon is applied to limited cropland through spray irrigation, more nutrients, especially N and P,

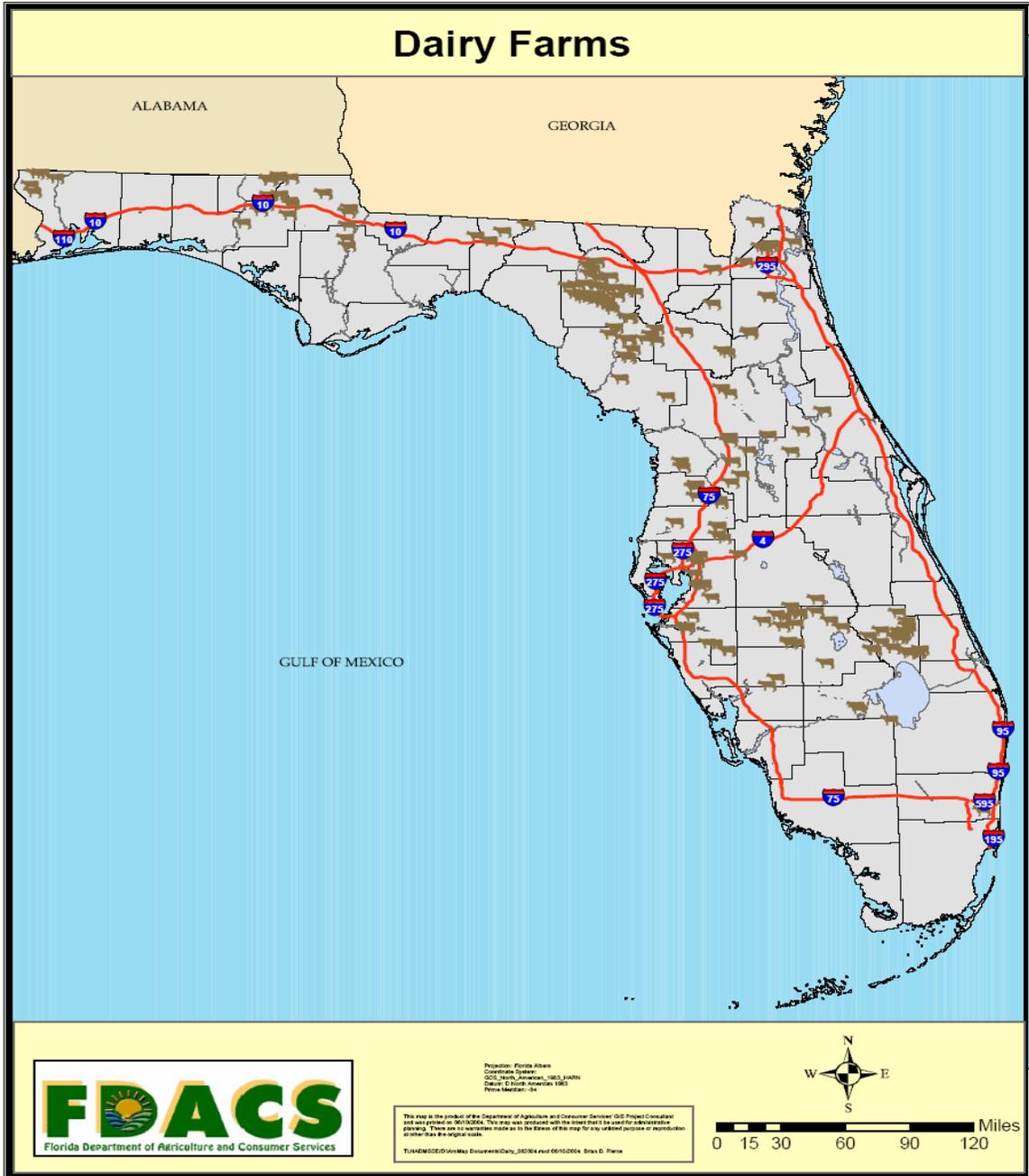


Figure 1-1. A GIS map of the distribution of dairy farms in Florida, courtesy of Florida Department of Agriculture and Consumer Services (personal correspondence, June 15, 2004).

accumulate in the soil and increase the risk of surface and ground water contamination.

Due to stricter environmental regulations, dairy farms have to implement systems that

incorporate significant levels of new or existing technology to ensure that nutrients are handled efficiently in an environmentally friendly manner.

For the past several decades, chemical treatment of municipal wastewater has proven effective in precipitating solids and P. The coagulants most commonly used have been lime, alum, and iron salts. Recently, applications of chemical removal with flocculants and coagulants to treat animal manure have shown promising improvement in solids and P removal compared to physical separation methods only. Since water is the major constituent of liquid manure, it is very expensive to transport off of the farm. If a fairly significant amount of the solids and nutrients can be concentrated into a small portion of the total manure volume, then it may be economical to haul this concentrated portion farther and to land that may not have an oversupply of nutrients. The treated wastewater can then be diverted back to flush tanks for reuse.

Since this technology has proven successful in municipal wastewater treatment, it is therefore worth investigating whether this treatment process can increase the removal efficiency of solids and nutrients in liquid dairy manure. Earlier investigations on the use of coagulants to treat various types of animal wastewater have to be re-evaluated in terms of correlation between laboratory and field scale test results. Furthermore, to minimize the cost of chemical treatment, dairy farmers must know how many chemicals are needed to efficiently reduce the nutrients and solids in the wastewater. Adding more chemicals does not necessarily mean that the dairy wastewater treatment system will work more efficiently. Thus, finding the best combination of chemicals in minimum amounts that will satisfactorily meet the desired removal efficiency is highly important for the system to be cost effective.

Objectives

The overall objective of this research was to improve solids, nitrogen, and phosphorus removal from a flushed dairy waste management system using alum and lime. Specifically, it aimed to a) evaluate and characterize the liquid dairy manure following mechanical separation, and b) compare the effectiveness of varying concentrations of lime and alum, alone or in combination, in maximizing removal of solids and nutrients from the wastewater.

CHAPTER 2 REVIEW OF LITERATURE

In recent years, there has been tremendous progress in addressing various aspects of water pollution. As a result of the Clean Water Act, point source pollution such as industrial discharges has been controlled by permits, and raw sewage discharges have been reduced by the construction of sewage treatment plants. Nonpoint source pollution (NPS) such as runoff from agricultural operations has become the main focus of extensive scientific research. Nutrients such as nitrogen (N) and phosphorus (P) from fertilizers and animal manure contaminate surface and groundwater, preventing the attainment of the water quality goals stipulated in the Clean Water Act (U.S. EPA, 1988; Parry, 1998). The presence of P in runoff from agricultural land is a significant component of NPS pollution and has been reported to cause surface water eutrophication (Corell, 1998).

Eutrophication is the overenrichment of receiving waters with mineral nutrients resulting in excessive production of autotrophs such as algae and cyanobacteria. According to the U.S. Environmental Protection Agency (EPA), major surface water quality deterioration is brought about by increased eutrophication due to anthropogenic activities (U.S. EPA, 1996). Sharpley et al. (1999) reported that the presence of P is especially correlated to or associated with nutrient enrichment of normally oligotrophic surface water. Algal blooms and the growth of thick masses of weeds can limit the use of a water body for recreation, fisheries, and industries. Anoxia, a condition of deficiency of dissolved oxygen due to high bacterial population and high respiration rates, can

decimate aquatic animal populations (Corell, 1998). The zone of hypoxia in the Mississippi delta is attributed partly to excessive release of nutrients from agricultural runoff (Fouss et al., 2003). Eutrophication of Chesapeake Bay and North Carolina's estuaries and coastal waters in recent years is a classic example of a public health issue associated with nutrient loadings of surface water. Outbreaks of the toxic dinoflagellate *Pfiesteria piscicida* resulted in fish kills and short term memory impairment in fishermen and other workers involved with sampling the rivers (Boesch, 2000).

Among various sources of P, the most significant threat of accelerated eutrophication of adjacent surface water occurs in watersheds having a large concentration of animal manure production (Duda and Finan, 1983; Daniel et al., 1994; Sharpley et al., 1997). The continuous application of animal wastes based on plant N requirements has caused build up of P in an increasing number of areas, thus increasing the likelihood of excessive P in runoff (McFarland and Hauck, 1995). Sharpley et al. (1999) reported that P levels exceeding 0.02 mg/L have been shown to significantly increase the rate of eutrophication in lakes and streams. States such as Delaware, Maryland, and Virginia have passed nutrient management laws and regulations to reduce P inputs to surface waters (Sims, 2000). Phosphorus applications in agricultural productions are restricted or prohibited in areas where high P soils are tested. For example, in Delaware the Nutrient Management Act of 1999 allows a maximum P application rate to high P soils equivalent to the three year crop removal rate or one application every three years (Sims, 1999).

Sandy soils such as those found in Florida require a different approach in terms of management of P. Harris et al. (1996) pointed out that soils with seasonally high water

table and poor P retention capacities are potentially susceptible to P leaching. Most of the large animal production facilities such as beef and dairy operations are situated in the south and central part of Florida where the dominant types of soils are Histosols, Spodosols, and Entisols (Flaig and Reddy, 1995). Excess nutrients, especially P accumulated in soils treated with organic waste (such as animal manure), have the potential to leach into the soil and enter the surface water through lateral transport when clay, Fe, Al, and Ca compounds adsorbing P are absent or low in concentration in the surface horizon (Campbell et al., 1995; Graetz and Nair, 1995).

Dairy farms with solids separation systems are still dealing with high concentrations of nutrients and solids in the effluents. This is chiefly a result of the inefficiency of solid separators which remove only a small fraction of the solids (<30%) and about 10 to 20% of organic N and P (Barrow et al., 1997; Vanotti and Hunt, 1999). A study conducted by Moller et al. (2000) concluded that simple mechanical separators can separate dry matter into a solid fraction, however, the efficiency of P removal is low and almost no N is separated. As a result, substantial amounts of N, P and solids are still present in the liquid waste. Storage ponds and lagoons continuously fill up with solids containing P and odorous compounds. Due to the high cost of transporting manure slurry, liquid wastes are often land applied to limited land areas. These repeated liquid waste applications could exceed the crop uptake and the P sorption capacity of soil and increase P leaching and losses through subsurface drainage (Johnson et al., 2004). In order to remove more solids and nutrients from animal liquid waste handling operations, another method should be employed that will eventually meet the desired removal efficiency.

Municipal and industrial wastewater treatment systems using chemical coagulants such as lime, alum, ferric sulfate, and ferric chloride have been commonplace since 1970 (Lind, 2003). Recently, the use of these coagulants and flocculants after solids separation in animal wastes to efficiently reduce solids and P has been reported (Sherman et al., 2000; Chastain et al., 2001).

Lime is often used to treat wastewater to remove solids and phosphorus. Control of pathogenic microorganisms in wastewater is also possible when lime is applied due to its high pH which destroys the cell membranes (National Lime Association, 2004). In addition, when pH is high, calcium ions react with odorous sulfur species such as hydrogen sulfide and organic mercaptans, thereby reducing odor (National Lime Association, 2004). When lime is added, it reacts with the natural bicarbonate alkalinity of wastewater forming CaCO_3 . Above pH 10, calcium ions react with phosphate ions precipitating hydroxylapatite $[\text{Ca}_{10}(\text{PO}_4)_6(\text{OH})_2]$ (Metcalf and Eddy, 2002). Thus, the alkalinity of wastewater is important in determining the chemical dosage of lime rather than the amount of phosphate present. Metcalf and Eddy (2002) suggest that lime dosage required to precipitate P is about 1.4 to 1.5 times the total alkalinity expressed as CaCO_3 . A study by Barrow et al. (1997) showed that the addition of hydrated lime to simulated dairy flushwaters reduced total solids by about 70%. In batch level jar tests, Karthikeyan et al. (2002) showed that lime was effective in removing total phosphorus (TP) and dissolved reactive phosphorus (DRP) by 96% and 92%, respectively, for dairy wastewater with 1.6% total solids (TS). Vanotti et al. (2002) reported the removal of almost 100% of P from swine wastewater using lime after a nitrification pre-treatment.

The researchers explained that without a nitrification process the presence of ammonia and alkalinity would exert high buffering capacity which prevented P from precipitating.

Alum [$\text{Al}_2(\text{SO}_4)_3$] has been commonly used to chemically treat water and wastewater. Metcalf and Eddy (2002) reported that aluminum metal ions bind with phosphate on a 1:1 molar ratio. However, the reactions are dependent upon several factors such as alkalinity, pH, trace elements and ligands found in wastewater, thus necessitating bench scale and if possible full-scale tests to determine the required dosages (Metcalf and Eddy, 2002). Laboratory tests conducted by Jones and Brown (1999) showed that 99% of ortho-phosphorus (initial concentration was 13.86 mg P/L) was reduced by treating dairy wastewater with a dosage of 3 g/L of alum but beyond this dosage, removal efficiency actually decreased. A similar study by Karthikeyan et al. (2002) reported removal efficiencies of 99%, 92%, and 92% for DRP, total dissolved phosphorus (TDP), and TP, respectively, for a dairy manure with 0.8% TS and dosage rate of 8 mM as Al. The concentrations of DRP, TDP, and TP prior to treatment were 15.5 mg/L, 38.1 mg/L and 255.8 mg/L. A detailed laboratory study by Zhang and Lei (1998) reported that additions of aluminum sulfate effectively enhanced settling of manure solids by promoting coagulation of suspended particles. Moore et al. (1995, 1996) evaluated several chemical additives for broiler litter and concluded that alum was the most effective and economical in reducing soluble P and ammonia volatilization. In a study by Ndegwa et al. (2001) utilizing swine manure, suspended solids (SS) and P were reduced by 96% and 78%, respectively, using a dosage of 1,500 mg/L of alum. However, the authors did not specify the P concentration prior to chemical treatment.

Nutrient removal using chemical additives involves three processes: a) coagulation, b) flocculation, and c) precipitation of the aggregated floc (Francois and Van Haute, 1985). Chemical coagulation entails reactions or processes that facilitate charge neutralization which results in the destabilization of suspended particles, allowing aggregation. Then, aggregated particles can be easily separated by passive or mechanical means. Flocculation refers to the process of particle size increase due to collision. Floc formation can result when a chemical coagulant is added to destabilize the colloidal particles in wastewater. A flocculant is used to enhance the flocculation process. The most common coagulants and flocculants include natural and synthetic polymers, metal salts such as alum, ferric and ferrous sulfate, and prehydrolyzed metal salts such as polyaluminum chloride and polyiron chloride (Metcalf and Eddy, 2002).

The practice of using coagulants has a long history that dates back to ancient times. Alum, alone or in combination with lime, ferric sulfate and ferric chloride, has been used to treat water. As early as 2000 B.C., the Egyptians used crushed almonds to clarify drinking water as well as waters from the Nile River (Faust and Aly, 1998). Alum and lime were reportedly used as coagulants by the early Romans to make bitter water potable (Faust and Aly, 1998). In 1885, the first scientific study on coagulation with the use of alum was conducted by Austen and Wilbur. They reported that alum clarified water, and this type of treatment would not impair the taste or physiological properties of water (Faust and Aly, 1998).

Although investigations and others have shown the effectiveness of chemical coagulants and flocculants, the results vary due to a lack of standardization. The concentration of flocculants and coagulants, percentage of total solids (TS) present in

samples, type of solids separator used (screening or sedimentation) are parameters that have to be fully investigated. Bench scale tests are therefore highly recommended to test appropriate dosages of chemical coagulants and flocculants specific to the characteristics of animal wastes and method of solid separation.

A more effective system will provide more benefits for animal waste handling facilities, such as reduced solids and P in effluents, less odor problems, easier handling and transport, and more capacity for storage ponds and lagoons.

CHAPTER 3 MATERIALS AND METHODS

Manure Characterization

Initial characterization of flushed dairy manure collected from the University of Florida Dairy Research Unit included the following parameters: total solids (TS), volatile solids (VS), total Kjeldahl nitrogen (TKN), ammonia-nitrogen (NH₃-N), total phosphorus (TP), dissolved reactive phosphorus (DRP), soluble potassium (K), and pH. Filtered samples were analyzed for DRP using the stannous chloride-based colorimetric method at a wavelength of 690 nm. For TP analysis, samples were digested using the persulfate digestion method prior to colorimetric analysis. Calibration curves prepared from known phosphorus standards were used to determine the concentrations of TP and DRP in mg/L (American Public Health Association [APHA], 1989).

For TKN determination, samples were digested and distilled following the semi-micro Kjeldahl procedure (APHA, 1989). Samples analyzed for NH₃-N underwent preliminary distillation. Both TKN and NH₃-N were measured using the titrimetric method. Soluble potassium was determined using a specific ion electrode (Orion Research Inc., Boston, MA), and pH was determined using a probe (Orion Research Inc., Boston, MA). A calibration curve using known standard solutions of K was used to determine the values in mg/L (APHA, 1989).

Total and volatile solids determination of the supernatant and settled solids was done by following the APHA (1989) standard methods.

Experimental Design

Effluent Samples

The University of Florida Dairy Research Unit employs a mechanical separator (Agpro Extractor, Agpro Inc., Paris, TX) followed by a settling basin to separate the solids from the wastewater (Figure 3-1). The samples used in this study were effluents from the mechanical separator and settling basin before the wastewater overflowed into an agitated feed tank for anaerobic digester (Figure 3-2). The wastewater was collected in a 20 L plastic container and transported immediately to the laboratory. The wastewater sample was stored at 4 °C for no more than 48 hours to inhibit microbial and chemical transformations.



Figure 3-1. University of Florida Dairy Research Unit.



Figure 3-2. Agitated feed tank where samples were collected.

Arrangement of Treatments

All chemical treatments were added to one liter of wastewater and evaluated as follows: Al as $\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$ alone at four concentrations, Ca as $\text{Ca}(\text{OH})_2$ alone at four concentrations, Ca as CaO alone at four concentrations, Ca as $\text{Ca}(\text{OH})_2$ at four concentrations in combination with two concentrations of Al as $\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$. A control with no chemical addition was included for each treatment. The source of CaO was blended metallurgical pulverized quicklime (BMPQ) produced by Chemical Lime Corporation, Ft. Worth, Texas. BMPQ contains 32.54% of MgO, SiO₂, Fe₂O₃, Al₂O₃, and 48.22% Ca (Appendix C).

Selection of Chemical Dosage

In a demonstration project in Riverview, Florida, the Agricultural and Biological Engineering Department at the University of Florida is involved in a demonstration of

hydrated lime slurry and alum treatment of dairy wastewater after mechanical separation (Figure 3-3). The lime slurry had 35% solids by weight. Once added to the wastewater, the pH significantly increased. Alum solution, which was 48% by weight, was added to the lime-treated wastewater to lower the pH before it was diverted into the flush tanks for reuse. The amount of chemicals added to the wastewater was controlled by a pH controller. Lime was continuously added into the mixing tank as long as the pH was below 11.5. Once this pH was achieved, lime feeding automatically stopped and alum was injected to lower the pH of the wastewater. Since the exact amounts of chemicals being added could not be measured, the chemical dosages for the laboratory test had to be prepared in such a way that the pH of the treated samples was similar to the actual field conditions. Preliminary laboratory tests for pH were conducted using 100 ml samples and the effects of chemical addition were recorded with respect to time.

Stocks of chemical solutions were prepared as follows: 133.2 g/L (200 mM) of alum [$\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$], 50 g/L (675 mM) of hydrated lime [$\text{Ca}(\text{OH})_2$], 50 g/L (890 mM) of BMPQ. BMPQ was included in the laboratory experiment to determine how it affected the pH, as well as the removal efficiency of solids and nutrients. In some cases Mg has been shown to decrease volume of settled solids (Wu, 2002). The chemical dosages (Table 3-1) for alum were 1.332 g/L (108 mg Al/L), 2.664 g/L (216 mg Al/L), 5.328 g/L (432 mg Al/L), 10.66 g/L (863 mg Al/L), and control (no alum addition). The dosages for hydrated lime were 1.25 g/L (676 mg Ca/L), 2.5 g/L (1,353 mg Ca/L), 5 g/L (2,705 mg Ca/L), 7.5 g/L (4,058 mg Ca/L), and control (no hydrated lime). For BMPQ, the dosages were 1.25g/L (603 mg Ca/L), 2.5 g/L (1,205 mg Ca/L), 5 g/L (2,411 mg

Ca/L), 7.5 g/L (3,616 mg Ca/L), and control (no BMPQ). Each chemical dosage was added to 1 liter of liquid dairy wastewater.

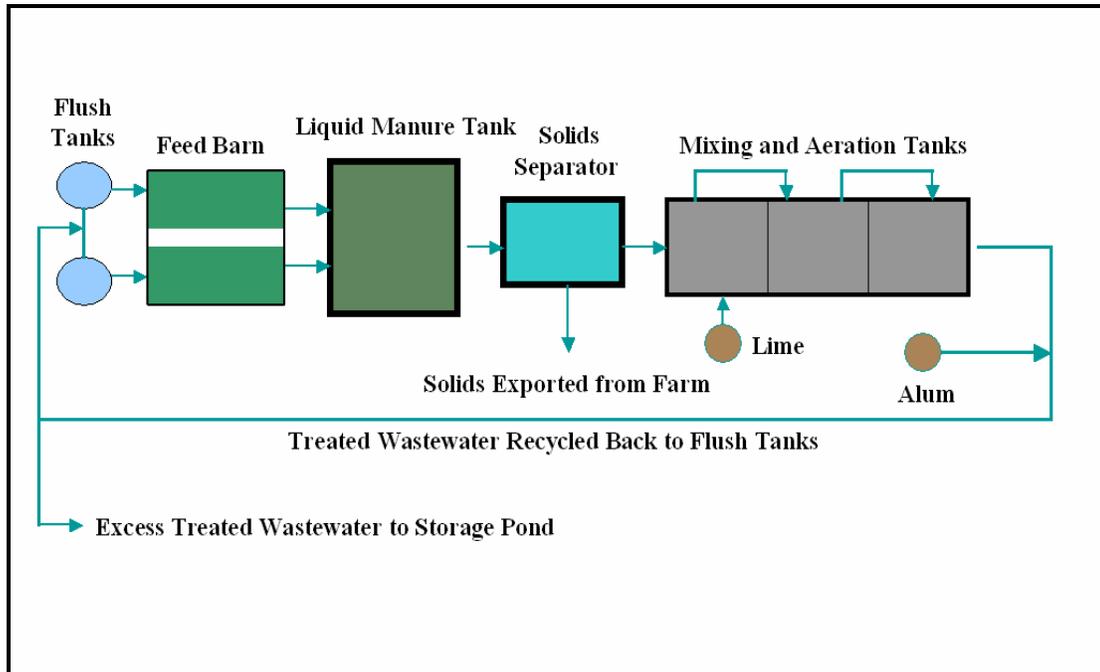


Figure 3-3. Simplified schematic diagram of liquid dairy manure treatment system, Riverview, Florida.

Table 3-1. Chemical dosages.

Alum (mg Al/L)	Control	108	216	432	863
Hydrated Lime (mg Ca/L)	Control	676	1353	2705	4058
BMPQ (mg Ca/L)	Control	603	1205	2411	3616
Hydrated Lime (mg Ca/L) + 108 mg Al/L Alum	Control	676	1353	2705	4058
Hydrated Lime (mg Ca/L) + 432 mg Al/L Alum	Control	676	1353	2705	4058

Treatment Procedure

Jar test experiments were employed to determine the effect of chemical coagulants on nutrients and solids in the wastewater. A 6-paddle Floc Illuminator bench top stirrer (Phipps and Bird, Inc. Richmond, Virginia) was used to mix one liter samples (Figure 3-3). The jar test procedure consisted of 3 steps: rapid mixing, slow mixing, and settling period. The stirrer was set to rapidly mix the samples at 100 rpm for 2 minutes, followed

by 8 minutes of slow mixing at 35 rpm. Finally, the flocs were allowed to settle for 50 more minutes without agitation. The pH of each sample was measured prior to chemical addition and after the settling stage. All chemicals were added at the beginning of the rapid mixing stage.

Data Analysis

Nutrient and solids reductions were determined by analyzing the supernatant solution and comparing the results to the analyses of the untreated wastewater. The volume of settled solids was measured after the settling period using a graduated cylinder, and subsamples were tested for TS. A sufficient amount of supernatant was collected from each beaker, and solids and chemical analyses were performed



Figure 3-4. Mixing stage.



Figure 3-5. A closer look during the settling stage.

immediately. Likewise, the difference between TKN, $\text{NH}_3\text{-N}$, TP, DRP, and soluble K concentrations in the control and their corresponding levels after chemical treatment was used to determine the percent reduction. The Dunnet test (Kuehl, 2000) was used to determine if the results generated from the treated samples were significantly different from the control. Curve fitting analysis using polynomial regression was done to determine which model best described the data.

CHAPTER 4
RESULTS AND DISCUSSIONS

Manure Characterization

Wastewater samples were collected from a sedimentation tank at the University of Florida Dairy Research Unit after the wastewater had undergone mechanical separation. The liquid manure samples were tested and were found to have TS and VS averages of 0.70% and 69.1%, respectively (Table 4-1). DRP and TP concentrations averaged 18.1 mg/L and 82.4 mg/L, respectively. The effluent samples contained an average of 257 mg/L of TKN. Similarly, the NH₃-N level was 175 mg/L. The average soluble K and pH were 976 mg/L and 7.5, respectively. A complete summary of the analyses for the effluent samples is shown in Table 4-1.

Table 4-1. Wastewater sample characterization results (n=10).

Characteristic	Units	Mean	Standard Deviation
TP	mg/L	82.4	25.4
DRP	mg/L	18.1	1.0
TKN	mg/L	257	75.7
NH ₃ -N	mg/L	175	13.9
K	mg/L	976	6.7
TS	%	0.70	0.10
VS	%	69.1	2.2
pH		7.5	0.20

Preliminary Test on pH with Chemical Treatment

Laboratory experiments were conducted to determine the pH response in terms of varying concentrations of hydrated lime, alum, and a combination of hydrated lime and alum (108 mg Al/L) with respect to time. For the combined treatment, hydrated lime was

added first followed by alum after 5 minutes. Results showed that after 15 minutes, higher dosages of lime (>406 mg Ca/L) achieved a final pH of 8 to 9 while at lower dosages (<271 mg Ca/L), the pH was between 6 and 7 (Table 4-2). Treatment with 216 mg Al/L of alum decreased the pH to 4.4 after 10 minutes and remained at 4.3 after 15 minutes, while for hydrated lime, the highest dosage of 541 mg Ca/L caused the pH to increase to 11.4 after 5 minutes and stabilized at 11.5 thereafter (Table 4-3 and Figure 4-1). Determining the pH response time was important for the field demonstration project to make sure that the pH of the wastewater in the lime mixing tank had stabilized before the addition of alum.

Table 4-2. Effects of hydrated lime and 108 mg Al/L of alum on the pH of the wastewater.

Time (min)	Hydrated Lime with 108 mg Al/L (mg Ca/L)			
	135	271	406	541
0	7.9	7.9	7.9	7.9
5	8.7	10.2	11.3	11.3
10	7.7	8.6	10.2	11.0
15	6.5	6.9	8.3	9.0

Table 4-3. Effects of alum and of hydrated lime on the pH of the wastewater.

Time (min)	Alum (mg Al/L)				Hydrated Lime (mg Ca/L)			
	27	81	108	216	135	271	406	541
0	7.8	7.8	7.8	7.8	7.3	7.3	7.3	7.4
5	6.6	6.1	5.4	4.4	8.4	9.0	11.3	11.4
10	6.6	6.0	5.2	4.3	8.6	10.7	11.4	11.5
15	6.6	6.0	5.2	4.3	8.8	10.8	11.4	11.5

Alum Treatment

Treatment with alum at 432 mg Al/L significantly reduced TP and DRP concentration by 94% and 97.9%, respectively. The levels of TKN, NH₃-N, and %TS significantly decreased (Table 4-4). VS decreased by 61.5% at dosage level of 432 mg Al/L. This was also the maximum dosage level before the TP and DRP

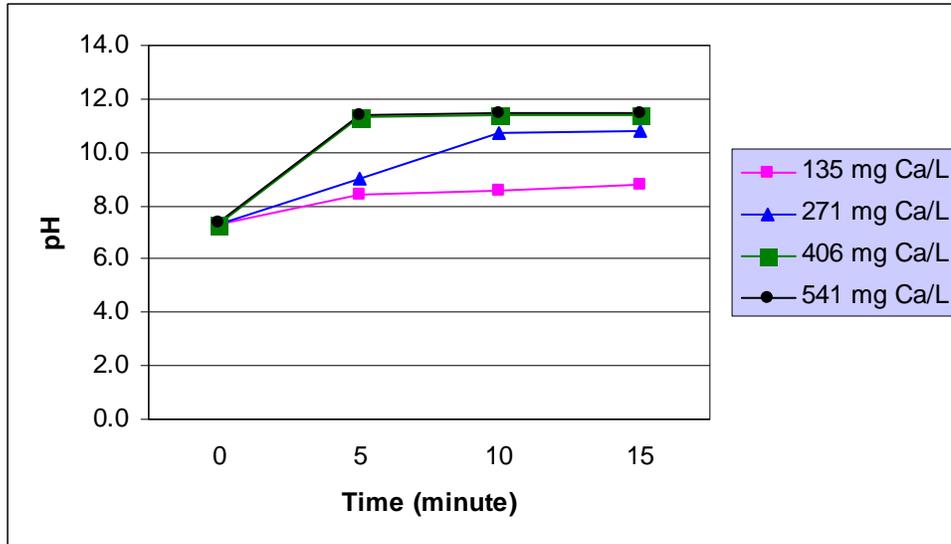


Figure 4-1. The response of pH over time with hydrated lime.

concentrations began to increase in the wastewater. Consistent decrease in pH was observed with increasing dosage of alum as shown in Figure 4-2. At pH level below 4.6, P resolubilized bringing about an increase of P concentration in the solution (Fig. 4-3).

Appendix A contains the actual measurements for all the parameters.

Table 4-4. Effects on nutrients and solids with alum treatment.

		Alum treatment level (mg Al/L)				
		Control	108	216	432	863
TP	mg/L	31.8	3.8	2.1	1.8	14.0
	% Removal		88.2	93.4	94.3	56.1
DRP	mg/L	29.7	10.3	3.0	0.60	12.4
	% Removal		65.4	90.1	97.9	58.3
TKN	mg/L	189	108	113	117	111
	% Removal		43.0	40.0	37.8	41.5
NH ₃ -N	mg/L	112	106	101	99.4	96.6
	% Removal		5.0	10.0	11.3	13.8
K	mg/L	397	380	362	355	372
	% Removal		4.2	9.0	10.5	6.3
TS	%	0.49	0.37	0.32	0.37	0.32
	% Removal		23.7	33.5	25.0	34.1
VS	%	64.3	49.8	32.2	24.8	43.1
	% Removal		22.7	50.0	61.5	33.0
pH		7.4	6.5	5.8	4.6	4.0

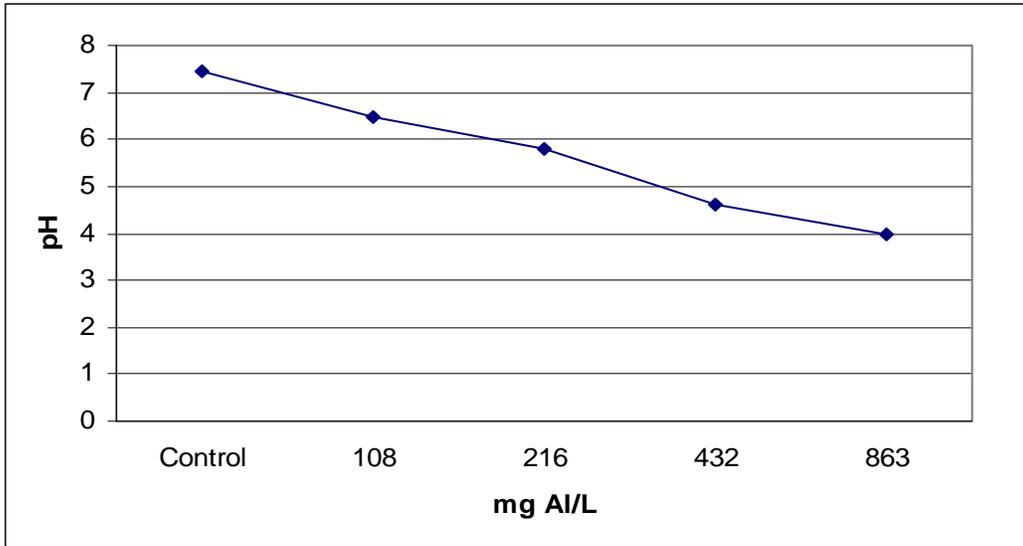


Figure 4-2. Effect of alum addition on the pH of the wastewater.

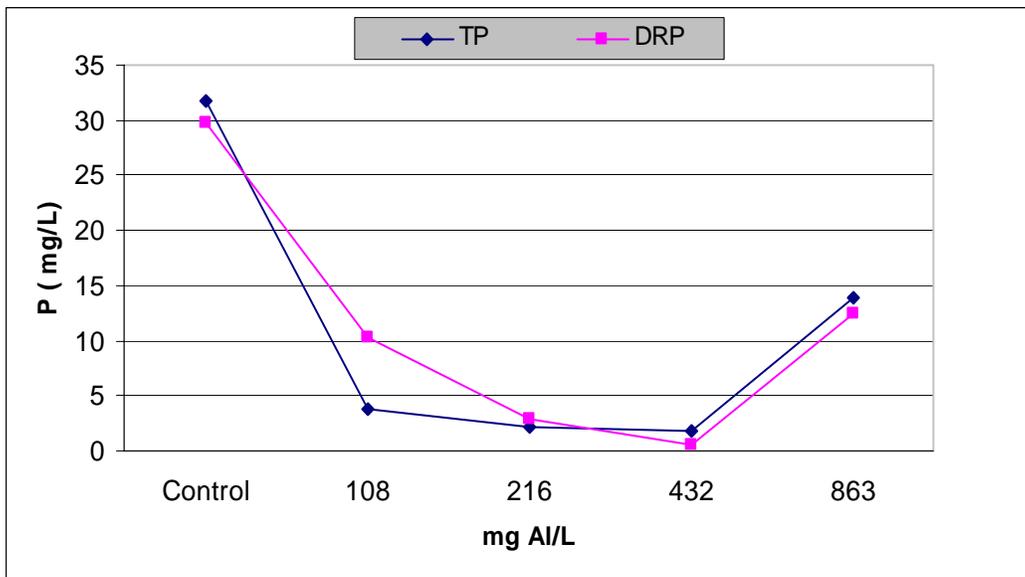


Figure 4-3. A comparison of the TP and DRP concentrations after adding alum.

BMPQ Treatment

The average reduction of TP and DRP ranged from 26.6% to 85.8% and 57.5% to 89.4%, respectively. Compared with alum treatment alone, the reduction efficiencies with BMPQ were smaller. As shown in Figure 4-4, the concentrations of TP and DRP decreased with increasing amount of BMPQ, although a slight increase in DRP occurred

at a dosage level of 2,411 mg Ca/L. TKN and NH₃-N levels consistently decreased but the reduction efficiencies were below 50% (Table 4-5). VS also decreased by 45.7% at a maximum dosage level of 3,616 mg Ca/L.

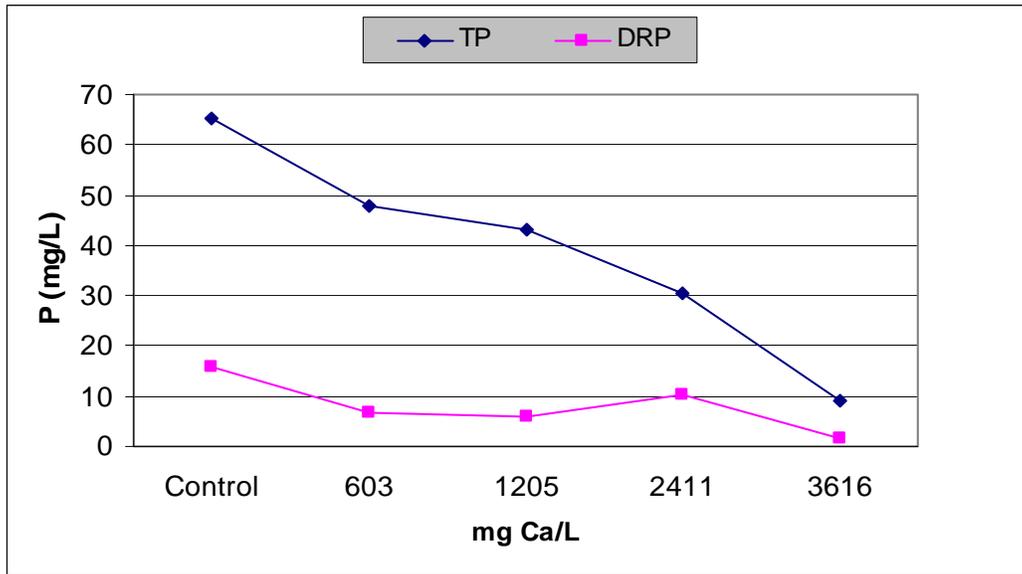


Figure 4-4. A comparison of the TP and DRP concentrations after adding BMPQ.

Table 4-5. Effects on nutrients and solids with BMPQ treatment.

		BMPQ treatment level (mg Ca/L)				
		Control	603	1205	2411	3616
TP	mg/L	65.4	48.0	43.0	30.3	9.3
	% Removal		26.6	34.4	53.7	85.8
DRP	mg/L	15.8	6.7	5.9	10.3	1.7
	% Removal		57.5	62.4	34.8	89.4
TKN	mg/L	295	273	266	232	175
	% Removal		7.6	10.0	21.3	40.8
NH ₃ -N	mg/L	188	168	161	151	141
	% Removal		10.5	14.2	19.4	24.6
K	mg/L	388	376	323	324	361
	% Removal		3.0	16.7	16.3	6.8
TS	%	0.41	0.37	0.35	0.31	0.35
	% Removal		8.2	13.0	24.1	14.7
VS	%	58.0	56.7	57.6	56.2	31.5
	% Removal		2.2	0.60	3.1	45.7
pH		7.2	9.1	10.0	10.3	11.3

Hydrated Lime Treatment With and Without Alum

Comparisons of the effects of hydrated lime alone and in combination with two concentrations of alum on TP and DRP are shown in Figures 4-5 and 4-6, respectively.

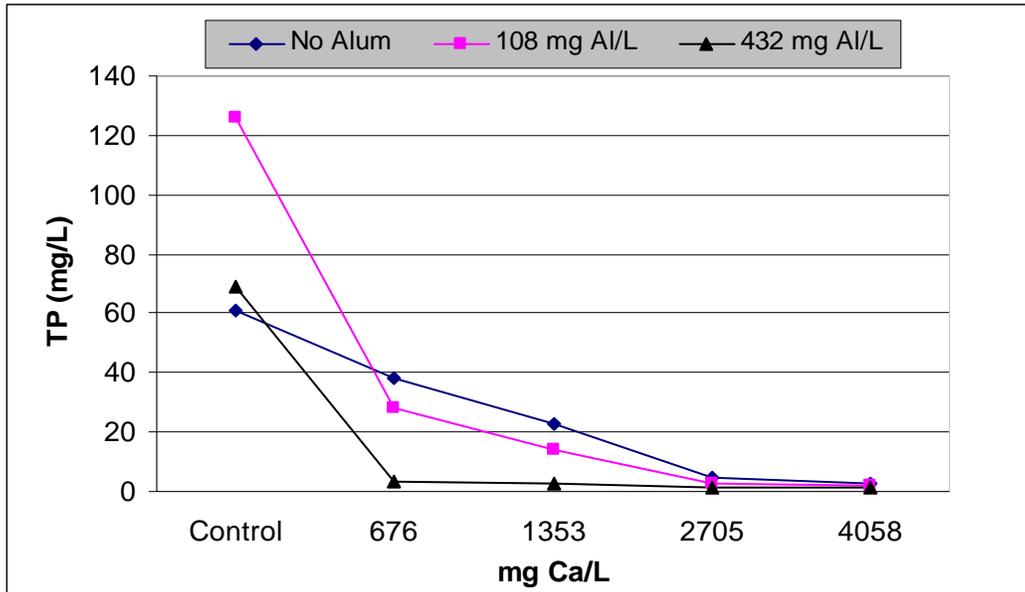


Figure 4-5. A comparison of the effects of hydrated lime alone and in combination with alum on TP concentration in three separate experiments.

The combination of hydrated lime and 108 mg Al/L showed a consistent significant decrease in the concentrations of TP and DRP. Treatment with hydrated lime and 432 mg Al/L resulted in a slight P increase in the solution at a maximum dosage of 4,058 mg Ca/L. DRP reduction of 99.7% occurred from the addition of 2,705 mg Ca/L in combination with 432 mg Al/L. The highest reduction for TP was 98.6%. This was achieved from the addition of 4,058 mg Ca/L and 108 mg Al/L. Treatment with hydrated lime and 432 mg Al/L reduced TKN levels by 59.4% (Table 4-6). Reductions in TKN and NH₃-N levels are shown in Figures 4-7 and 4-8. The combination of hydrated lime and 108 mg Al/L reduced the NH₃-N level by 18.0% (Table 4-7). A maximum reduction efficiency of 66.2% for VS occurred with treatment of hydrated lime alone (Table 4-8).

For the most part, the volume of settled solids increased with increasing dosages of hydrated lime and alum. Appendix A shows all measurements for all the parameters.

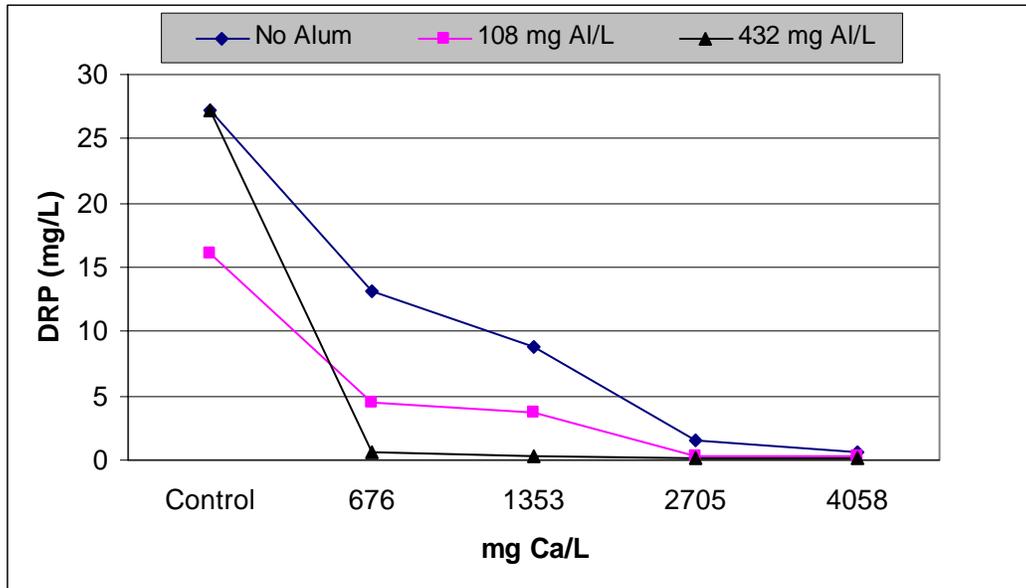


Figure 4-6. A comparison of the effects of hydrated lime addition alone and in combination with alum on DRP concentration in three separate experiments.

Table 4-6. Effects on nutrients and solids with hydrated lime and 432 mg Al/L treatment.

		Hydrated lime treatment level (mg Ca/L)				
		Control	676	1353	2705	4058
TP	mg/L	69.1	3.2	2.5	1.3	1.4
	% Removal		95.4	96.3	98.2	98.0
DRP	mg/L	27.2	0.59	0.27	0.09	0.10
	% Removal		97.8	99.0	99.7	99.6
TKN	mg/L	335	186	174	153	136
	% Removal		44.4	48.1	54.4	59.4
NH ₃ -N	mg/L	181	175	167	150	148
	% Removal		3.1	7.8	17.1	17.8
K	mg/L	377	330	320	313	367
	% Removal		12.6	15.1	17.1	2.8
TS	%	0.49	0.43	0.39	0.30	0.38
	% Removal		10.5	20.2	38.0	22.1
VS	%	65.1	26.9	24.5	38.0	22.2
	% Removal		58.7	62.4	41.7	65.9
pH		7.4	7.6	8.3	10.8	11.3

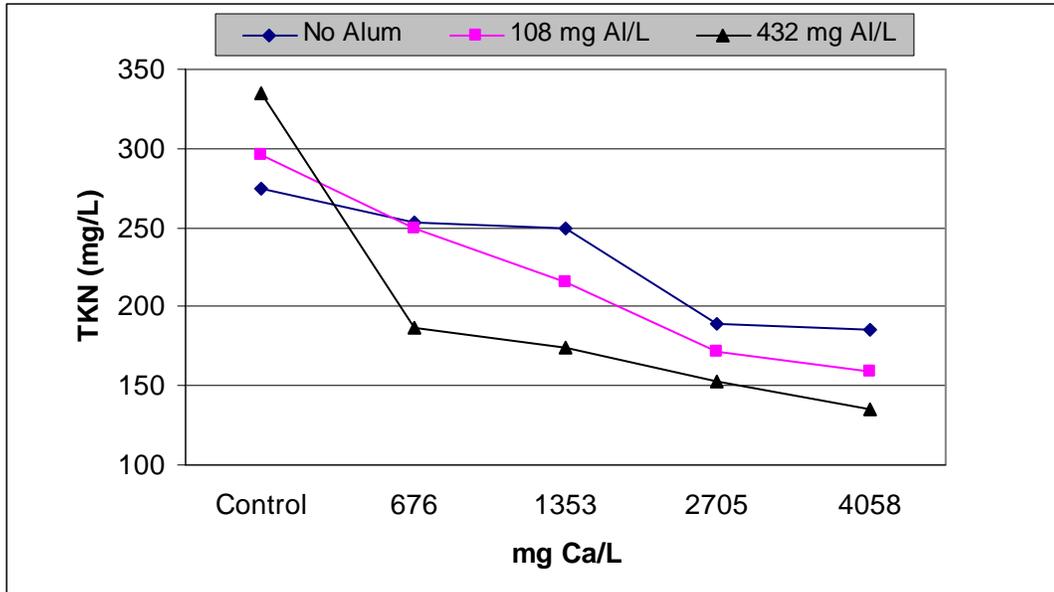


Figure 4-7. A comparison of the reduction levels of TKN with treatment of hydrated lime alone and in combination with 108 mg Al/L and 432 mg Al/L in three separate experiments.

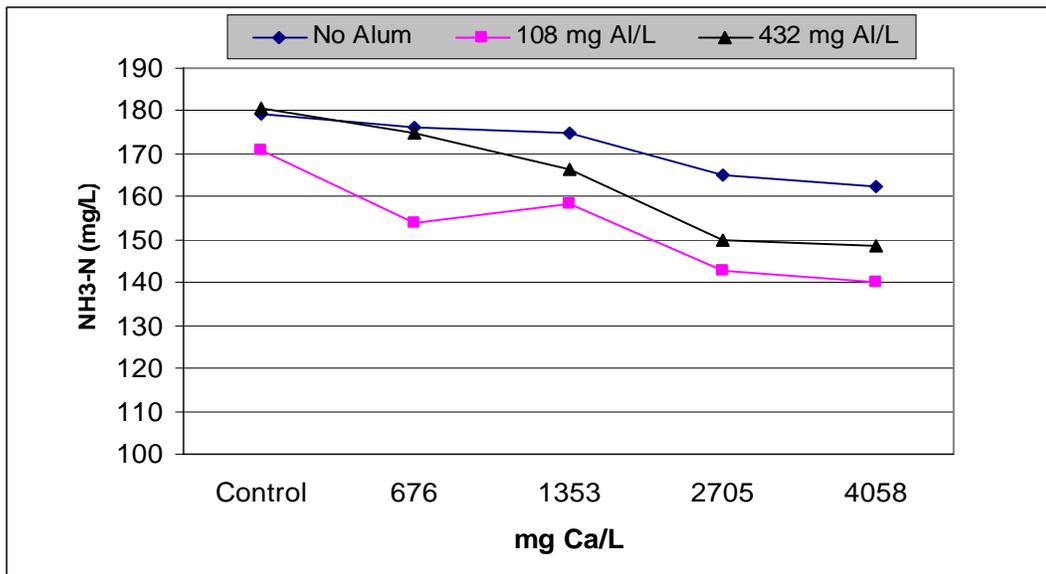


Figure 4-8. A comparison of the reduction levels of $\text{NH}_3\text{-N}$ with treatment of hydrated lime alone and in combination with 108 mg Al/L and 432 mg Al/L in three separate experiments.

The pH of the treated wastewater is a major consideration in the demonstration project in Riverview, Florida. Combined dosage levels of lime and alum which could

Table 4-7. Effects on nutrients and solids with hydrated lime and 108 mg Al/L treatment.

		Hydrated lime treatment level (mg Ca/L)				
		Control	676	1353	2705	4058
TP	mg/L	125.9	28.1	14.0	2.4	1.8
	% Removal		77.7	88.9	98.1	98.6
DRP	mg/L	16.1	4.5	3.8	0.30	0.30
	% Removal		72.1	76.8	98.5	98.5
TKN	mg/L	295	249	216	172	160
	% Removal		15.6	27.0	41.7	46.0
NH3-N	mg/L	171	154	158	143	140
	% Removal		9.8	7.4	16.4	18.0
K	mg/L	415	399	399	389	409
	% Removal		3.8	3.8	6.2	1.3
TS	%	0.46	0.39	0.36	0.42	0.43
	% Removal		16.4	21.2	9.2	7.4
VS	%	62.6	55.8	52.2	30.3	24.2
	% Removal		10.8	16.7	51.6	61.3
pH		7.2	8.4	9.2	11.4	11.4

Table 4-8. Effects on nutrients and solids with hydrated lime treatment.

		Hydrated lime treatment level (mg Ca/L)				
		Control	676	1353	2705	4058
TP	mg/L	60.7	38.1	22.5	5.0	2.8
	% Removal		37.3	63.0	91.8	95.5
DRP	mg/L	27.2	13.1	8.8	1.5	0.70
	% Removal		51.7	67.8	94.5	97.6
TKN	mg/L	274	253	249	189	185
	% Removal		7.7	9.2	31.1	32.7
NH3-N	mg/L	179	176	175	165	162
	% Removal		1.6	2.3	7.8	9.4
K	mg/L	411	359	353	368	377
	% Removal		12.6	14.1	10.4	8.1
TS	%	0.38	0.34	0.32	0.34	0.37
	% Removal		10.9	15.1	10.77	2.90
VS	%	55.8	55.5	49.8	25.5	18.9
	% Removal		0.50	10.7	54.2	66.2
pH		7.2	9.2	10.8	11.3	11.4

achieve a final pH of 7 to 8, and could reduce considerable amounts of N and P, would be most ideal for the field situation. From Figure 4-9, pH levels of the samples are shown in relation to the different dosages of hydrated lime and alum. At a combined dosage of 676

mg Ca/L and 432 mg Al/L, the pH was about 7.6. Going back to Table 4-6, TP and DRP concentrations were reduced by 95.4% and 97.8%, respectively, at this combined dosage. TKN concentration was reduced by 44.4%, while for $\text{NH}_3\text{-N}$ it was 3.1%. Further increases in the reduction efficiencies were achieved when 1,353 mg Ca/L was combined with 432 mg Al/L. However, at this dosage, the final pH increased to about 8.3.

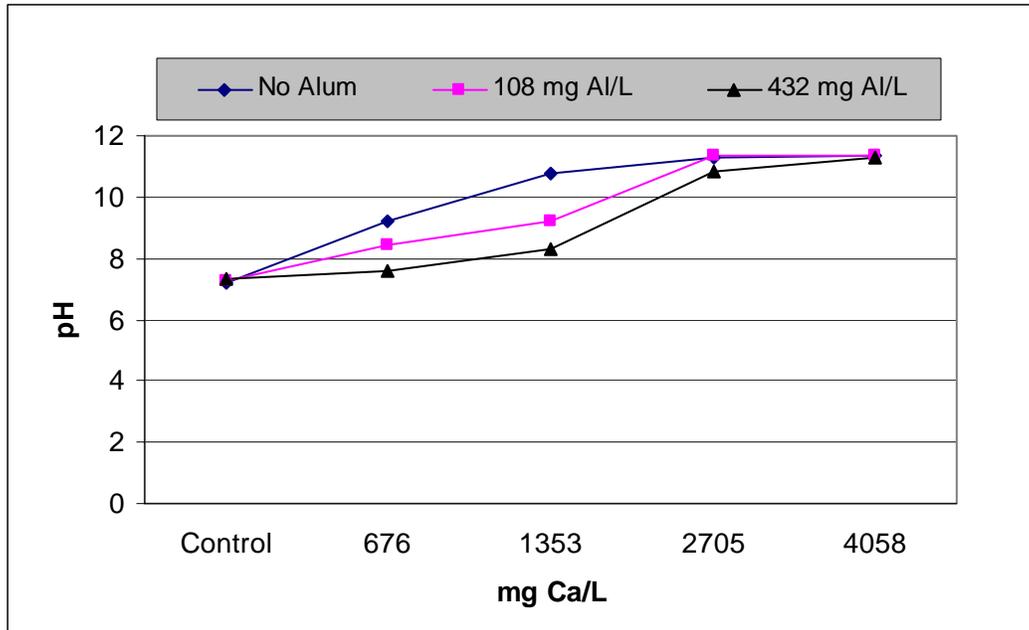


Figure 4-9. Effects of hydrated lime addition alone and in combination with alum on the pH of the samples.

Test for Determining Difference of Treatments from Control

To determine whether there was a significant difference between the controls and the treatments, the Dunnet test was used (Kuehl, 2000). An assumption that the data points were normally distributed was made. All parameters except K were significantly different [D (4, 0.05)] when treated with alum, BMPQ, and hydrated lime containing 108 mg Al/L. Treatment with BMPQ also showed that VS reduction was not significantly different from the control on the first 3 dosages (603 mg Ca/L, 1,205 mg Ca/L, and 2,410 mg Ca/L). Appendix B shows a summary of the results for the Dunnet test.

Curve Fitting Analysis

Using regression analysis in SAS version 8.2 (SAS Inst., Cary, NC), most of the data points were found to have a good fit with a quadratic polynomial model. This result was consistent with the study conducted by Sherman et al. (2000). For the curve in Figure 4-10, the equation $y = 4.95 \times 10^{-6}x^2 - 0.034x + 59.88$ estimates TP reduction by the addition of hydrated lime.

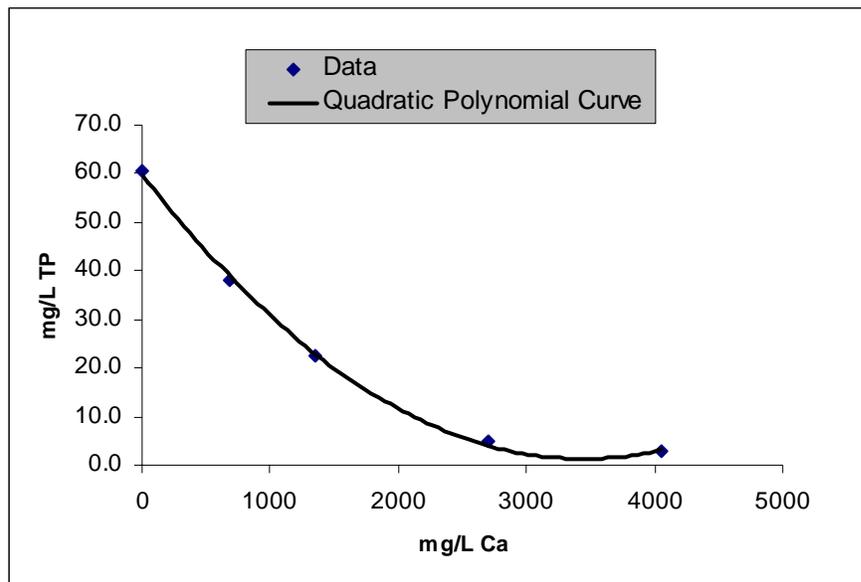


Figure 4-10. A quadratic regression curve fit with the TP data points taken from the treatment with hydrated lime alone. The calculated r^2 for this curve was 0.997.

In this procedure, the chemical dosages in mg Ca/L was used as the continuous independent variable (x) and the mg/L of TP, DRP, TKN, and $\text{NH}_3\text{-N}$, levels of pH, %TS, and %VS as the dependent variables (y). A linear model was also tested, but the results were not significant. A comparison of the SAS generated r^2 for the linear and quadratic regression analysis is shown in Table 4-9.

Table 4-9. A comparison of r^2 between linear and quadratic regression for all parameters.

	Linear Regression r^2	Quadratic Polynomial Regression r^2
TP		
Hydrated lime	0.857	0.997
Hydrated lime with 108 mg Al/L	0.544	0.866
Hydrated lime with 432 mg Al/L	0.3875	0.752
Alum	0.0425	0.731
BMPQ	0.971	0.967
DRP		
Hydrated lime	0.794	0.974
Hydrated lime with 108 mg Al/L	0.636	0.894
Hydrated lime with 432 mg Al/L	0.378	0.747
Alum	0.1195	0.897
BMPQ	0.4786	0.847
TKN		
Hydrated lime	0.919	0.862
Hydrated lime with 108 mg Al/L	0.907	0.997
Hydrated lime with 432 mg Al/L	0.606	0.833
Alum	0.267	0.535
BMPQ	0.969	0.983
NH3-N		
Hydrated lime	0.961	0.922
Hydrated lime with 108 mg Al/L	0.836	0.875
Hydrated lime with 432 mg Al/L	0.929	0.964
Alum	0.746	0.924
BMPQ	0.903	0.959
K		
Hydrated lime	0.104	0.612
Hydrated lime with 108 mg Al/L	0.003	0.698
Hydrated lime with 432 mg Al/L	0.065	0.939
Alum	0.225	0.719
BMPQ	0.18	0.641
%TS		
Hydrated lime	0.438	0.645
Hydrated lime with 108 mg Al/L	0.002	0.545
Hydrated lime with 432 mg Al/L	0.53	0.928
Alum	0.499	0.986
BMPQ	0.542	0.936

Table 4-9. Continued.

	Linear Regression r^2	Quadratic Polynomial Regression r^2
%VS		
Hydrated lime	0.937	0.937
Hydrated lime with 108 mg Al/L	0.9627	0.964
Hydrated lime with 432 mg Al/L	0.332	0.494
Alum	0.187	0.977
BMPQ	0.673	0.954
pH		
Hydrated lime	0.862	0.999
Hydrated lime with 108 mg Al/L	0.941	0.946
Hydrated lime with 432 mg Al/L	0.90	0.928
Alum	0.881	0.999
BMPQ	0.836	0.942

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

Conclusions

This study demonstrated that chemical treatment of dairy wastewater using hydrated lime, BMPQ, and alum is capable of reducing the concentration of P (TP and DRP) and N (TKN and NH₃-N), as well as considerable amounts of TS and VS.

The combination of hydrated lime and alum performed very well in reducing the levels of TP and DRP in the wastewater. At a combined dosage of 2,705 mg Ca/L and 432 mg Al/L, DRP concentration was reduced by 99.7%. In the case of TP, 98.6% reduction was observed. This was achieved by the combined dosage of 4,058 mg Ca/L and 108 mg Al/L.

The combination of hydrated lime and alum that resulted in a final pH range between 7 and 8 was 676 mg Ca/L and 432 mg Al/L. At this dosage, TP and DRP concentrations were reduced by 95.4% and 97.8%, respectively. TKN and NH₃-N were reduced by 44.4% and 3.1%, respectively. Also, the combination of 676 mg Ca/L of hydrated lime and 108 mg Al/L of alum removed 77.7% TP. Although these particular combinations did not attain the maximum reduction efficiencies for P, N, and solids, less chemical was needed.

The addition of alum alone showed that there is a limit in terms of P reduction, because the solution tended to become very acidic as alum dosage level increased. Phosphorus re-solubilization was observed at a dosage level of 863 mg Al/L when the pH decreased to about 4. However, when the lowest dosages of the chemicals selected for

this experiment were compared, alum performed best compared to hydrated lime and BMPQ in reducing TP, DRP, and TKN. With an alum dosage of 108 mg Al/L, the levels of TP, DRP, and TKN were reduced by 88.2%, 65.4%, and 43%, respectively. For the same parameters, the lowest dosage of hydrated lime (676 mg Ca/L) reduced the levels by 37.3%, 51.7%, and 7.7%, respectively. Similarly, BMPQ with the lowest dosage of 603 mg Ca/L, removed 48%, 57.5%, and 7.6% of TP, DRP, and TKN.

BMPQ treatment was not as effective in the jar test experiments compared to hydrated lime and alum. The maximum dosage of 3,616 mg Ca/L of BMPQ only removed 85.8%, 89.4%, 40.8%, and 24.6% of TP, DRP, TKN, and NH₃-N, respectively. However, BMPQ was slightly more effective than alum in removing VS. BMPQ removed 45.7% of VS, while for alum the removal efficiency was only 43.1%

The test for pH response with varying concentrations of hydrated lime showed that at higher dosages pH stabilized after 5 minutes, and for lower dosages it took 10 minutes. For alum, it took only 5 minutes to stabilize the pH for all the dosages. These results were important in relation to the field demonstration project to make sure that hydrated lime had enough time to stabilize the pH before alum was added.

Curve fitting analysis showed that removal of nutrients and solids best fit a quadratic polynomial model.

Finally, since this laboratory evaluation showed that lower dosages of hydrated lime and alum combination were effective in removing considerable amounts of TP and DRP, using excessive quantities of hydrated lime to achieve unnecessary P removals may not be necessary in actual field conditions. When adequate cropland is available to handle the remaining N and P in the wastewater, then there is no need to apply excessive

amounts of hydrated lime. It will result in a final pH which will be too high and will be too expensive for the dairy farmers. Thus, achieving a final N/P ratio that is closer to fertilization requirements will be more ideal.

Recommendations

This laboratory evaluation showed that chemical treatment with hydrated lime combined with alum has a potential for field scale application. In line with the demonstration project in Riverview, Florida, consideration should be given to evaluating the amount of chemicals added rather than depending on the prescribed range of pH for disinfection, as the latter maybe more expensive. Lesser amounts of hydrated lime and alum should be investigated in the pilot project, since the laboratory results showed that significant reductions in the concentrations of nutrients and solids from the wastewater took place at even lower dosages. Moreover, further investigation should be done to evaluate the performance of other chemical coagulants such as ferric chloride and aluminum chloride to come up with better cost-effective combinations of dosages. The addition of polymers is also a possibility, since there has been a growing interest in the performance of polymers in municipal wastewater treatment.

APPENDIX A
TABULATED MEANS

Table A-1. Treatment with hydrated lime.

Parameters	Control (No Lime)	676 mg Ca/L	1352 mg Ca/L	2705 mg Ca/L	4058 mg Ca/L
TP (mg/L)	60.7	38.1	22.5	5.0	2.8
DRP (mg/L)	27.2	13.1	8.8	1.5	0.70
TKN (mg/L)	274	253	249	189	185
NH3-N (mg/L)	179	176	175	165	162
K (mg/L)	411	359	353	368	377
pH	7.2	9.2	10.8	11.3	11.4
TS (%)	0.38	0.34	0.32	0.40	0.42
VS (%)	55.6	55.5	49.8	25.5	18.9
Volume of Settled Solids (ml/L)	85.0	105	161	166	176
TS (Settled Solids) (%)	9.16	15.5	18.5	28.2	30.9
VS (Settled Solids) (%)	77.4	53.2	46.8	40.2	22.0

Table A-2. Treatment with hydrated lime and 108 mg Al/L.

Parameters	Control (No Lime)	676 mg Ca/L	1352 mg Ca/L	2705 mg Ca/L	4058 mg Ca/L
TP (mg/L)	125.9	28.1	14.0	2.4	1.8
DRP (mg/L)	16.1	4.5	3.8	0.30	0.30
TKN (mg/L)	295	249	216	172	160
NH3-N (mg/L)	171	154	158	143	140
K (mg/L)	415	399	399	389	430
pH	7.2	8.4	9.2	11.4	11.4
TS (%)	0.46	0.39	0.36	0.42	0.43
VS (%)	62.6	55.8	52.2	30.3	24.2
Volume of Settled Solids (ml/L)	40.0	120	115	172	185
TS (Settled Solids) (%)	2.5	3.9	3.3	4.0	4.7
VS (Settled Solids) (%)	75.3	36.6	39.3	32.2	13.0

Table A-3. Treatment with hydrated lime and 432 mg Al/L.

Parameters	Control (No Lime)	676 mg Ca/L	1353 mg Ca/L	2705 mg Ca/L	4058 mg Ca/L
TP (mg/L)	69.1	3.2	2.5	1.3	1.4
DRP (mg/L)	27.2	0.59	0.27	0.09	0.10
TKN (mg/L)	335	186	174	153	136

Table A-3. Continued.

Parameters	Control (No Lime)	676 mg Ca/L	1353 mg Ca/L	2705 mg Ca/L	4058 mg Ca/L
NH3-N (mg/L)	181	175	167	150	148
K (mg/L)	377	329	320	313	367
pH	7.4	7.6	8.3	10.8	11.3
TS (%)	0.49	0.43	0.39	0.30	0.38
VS (%)	65.1	26.9	24.5	38.0	22.2
Volume of Settled Solids (ml/L)	44.0	110	127	182	184
TS (Settled Solids) (%)	2.9	7.4	8.3	9.0	9.64
VS (Settled Solids) (%)	75.0	50.0	44.3	32.6	28.3

Table A-4. Treatment with alum.

Parameters	Control (No Alum)	108 mg Al/L	216 mg Al/L	432 mg Al/L	863 mg Al/L
TP (mg/L)	31.8	3.76	2.1	1.8	14.0
DRP (mg/L)	29.7	10.3	2.95	0.62	12.4
TKN (mg/L)	189	108	113	118	111
NH3-N (mg/L)	112	106	101	99.4	96.6
K (mg/L)	397	380	362	355	372
pH	7.4	6.5	5.8	4.6	4.0
TS (%)	0.49	0.37	0.32	0.37	0.32
VS (%)	64.3	49.8	32.2	24.8	43.1
Volume of Settled Solids (ml/L)	46.0	80.0	155	150	152
TS (Settled Solids) (%)	3.4	3.3	6.8	6.3	8.5
VS (Settled Solids) (%)	72.9	72.6	72.5	69.5	73.1

Table A-5. Treatment with BMPQ.

Parameters	Control (No BMPQ)	603 mg Ca/L	1205 mg Ca/L	2411 mg Ca/L	3616 mg Ca/L
TP (mg/L)	65.4	48.0	43.0	30.1	9.3
DRP (mg/L)	15.8	6.7	5.9	10.3	1.7
TKN (mg/L)	295	273	266	232	175
NH3-N (mg/L)	188	168	161	151	141
K (mg/L)	387	376	323	324	361
pH	7.2	9.1	10.0	10.3	11.3
TS (%)	0.41	0.37	0.35	0.31	0.35
VS (%)	58.0	58.1	58.9	56.2	31.5
Volume of Settled Solids (ml/L)	52.0	86.0	79.0	116	133
TS (Settled Solids) (%)	4.3	5.8	7.2	5.3	4.9
VS (Settled Solids) (%)	77.4	57.9	46.8	50.7	46.9

APPENDIX B
STATISTICAL ANALYSIS RESULTS

Dunnet Method for a Comparison of all Treatments with a Control

The formula for the Dunnet criterion to compare k treatments to the control is:

$$D(k, \alpha_E) = d_{\alpha, k, v} \sqrt{\frac{2s^2}{r}}$$

where: k = number of treatment

s^2 = variance

r = replicates

$\alpha_E = 0.05$

If $|y_i - y_c|$ exceeds $D_{(4, 0.5)} = 1.39770$, then the treatment mean is significantly different from the control (Table B-1). The value for D is taken from Table VI (Kuehl, 2000).

Table B-1. Sample calculation for Dunnet method.

	Observation	y_i	$(y_i - y_c)^2$
Controla	31.953	31.824	0.01656
Controlb	31.696		0.01656
T1a	3.77	3.757	0.00023
T1b	3.742		0.00023
T2a	2.099	2.103	0.00002
T2b	2.107		0.00002
T3a	1.833	1.804	0.00085
T3b	1.775		0.00085
T4a	14.592	13.971	0.38562
T4b	13.350		0.38562
	SSE =	0.80657	D = 3.48
	MSE = s^2 =	0.16131	D(k, α_E) = 1.39770
	df =	5	
	r = replicates =	2	

Table B-1. Continued.

Treatment	Mean	yi-yc	95% SCI		yi-yc	Different From Control
			Lower	Upper		
Control	31.824	-	-	-	-	
T1	3.757	-28.068	28.068	28.068	28.068	yes
T2	2.103	-29.721	31.119	29.721	29.721	yes
T3	1.804	-30.020	31.418	30.020	30.020	yes
T4	13.971	-17.854	19.251	17.854	17.854	yes

Table B-2. Summary of the test for difference between control and treatments using Dunnet method D(4, 0.05) for treatment with hydrated lime alone.

	Control (No Lime)	676 mg Ca/L	1353 mg Ca/L	2705 mg Ca/L	4058 mg Ca/L
TP	-	yes	yes	yes	yes
DRP	-	yes	yes	yes	yes
TKN	-	yes	yes	yes	yes
NH3-N	-	yes	yes	yes	yes
K	-	yes	yes	yes	no
pH	-	yes	yes	yes	yes
%TS	-	yes	yes	yes	yes
%VS	-	no	yes	yes	yes

Table B-3. Summary of the test for difference between control and treatments using Dunnet method D(4, 0.05) for treatment with hydrated lime and 108 mg/L alum.

	Control (No Lime)	676 mg Ca/L	1353 mg Ca/L	2705 mg Ca/L	4058 mg Ca/L
TP	-	yes	yes	yes	yes
DRP	-	yes	yes	yes	yes
TKN	-	yes	yes	yes	yes
NH3-N	-	yes	yes	yes	yes
K	-	no	no	no	no
pH	-	yes	yes	yes	yes
%TS	-	yes	yes	yes	yes
%VS	-	yes	yes	yes	yes

Table B-4. Summary of the test for difference between control and treatments using Dunnet method D(4, 0.05) for treatment with hydrated lime and 432 mg/L alum.

	Control (No Lime)	676 mg Ca/L	1353 mg Ca/L	2705 mg Ca/L	4058 mg Ca/L
TP	-	yes	yes	yes	yes
DRP	-	yes	yes	yes	yes
TKN	-	yes	yes	yes	yes
NH3-N	-	yes	yes	yes	yes
K	-	yes	yes	yes	no
pH	-	yes	yes	yes	yes
%TS	-	yes	yes	yes	yes
%VS	-	yes	yes	yes	yes

Table B-5. Summary of the test for difference between control and treatments using Dunnet method D(4, 0.05) for treatment with alum.

	Control (No Alum)	108 mg Al/L	216 mg Al/L	432 mg Al/L	863 mg Al/L
TP	-	yes	yes	yes	yes
DRP	-	yes	yes	yes	yes
TKN	-	yes	yes	yes	yes
NH3-N	-	yes	yes	yes	yes
K	-	no	no	no	no
pH	-	yes	yes	yes	yes
%TS	-	yes	yes	yes	yes
%VS	-	yes	yes	yes	yes

Table B-6. Summary of the test for difference between control and treatments using Dunnet method D(4, 0.05) for treatment with BMPQ.

	Control (No BMPQ)	603 mg Ca/L	1205 mg Ca/L	2411 mg Ca/L	3616 mg Ca/L
TP	-	yes	yes	yes	yes
DRP	-	yes	yes	yes	yes
TKN	-	yes	yes	yes	yes
NH3-N	-	yes	yes	yes	yes
K	-	no	no	no	no
pH	-	yes	yes	yes	yes
%TS	-	yes	yes	yes	yes
%VS	-	no	no	no	yes

Sample Output of SAS 8.2 Regression Analysis

TP with Hydrated Lime alone

The REG Procedure
 Model : MODEL1
 Dependent Variable: y

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	4676.37109	2338.18555	991.26	<.0001
Error	7	16.51162	2.35880		
Corrected Total	9	4692.88271			

Root MSE	1.53584	R-Square	0.9965
Dependent Mean	25.78782	Adj R-Sq	0.9955
Coeff Var	5.95568		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > t
Intercept	1	59.88392	0.96397	62.12	<.0001
x	1	-0.03407	0.00126	-27.11	<.0001
x2	1	0.00000495	2.953355E-7	16.77	<.0001

APPENDIX C
PRODUCT SPECIFICATIONS OF CHEMICAL COAGULANTS

Table C-1. Blended metallurgical pulverized quicklime product specification. Product of Chemical Lime Corporation, Forth Worth, Texas.

PARAMETER	NORMAL RANGE
Sizing	0" x #18 mesh
Bulk density	58 lb./ft. ³ average
L.O.I.	2.0% max. 1.5% average
MgO	26% +/- 2%
SiO ₂	2.5% max. 1.5% average
Fe ₂ O ₃	1.0% max. 0.35% average
Al ₂ O ₃	1.0% max. 0.55% average
S	0.035% max. 0.018% average

Note: Total CaO may be determined by difference of the sum of L.O.I. (Loss on Ignition), MgO, SiO₂, Fe₂O₃, and Al₂O₃. In this case, CaO is 67.46%.

Table C-2. Hydrated lime product specification. Product of Fisher Scientific, Fair Lawn, New Jersey.

PARAMETER	ACTUAL LOT ANALYSIS
Chloride (Cl)	0.02%
Heavy metals (as Pb)	0.001%
Insoluble in HCl	0.01%
Iron (Fe)	0.05%
Mg and alkali salts	0.8%
Sulfur compounds (as SO ₄)	0.02%

Table C-3. Alum product specification. Product of Fisher Scientific, Fair Lawn, New Jersey.

PARAMETER	ACTUAL LOT ANALYSIS
Assay (as 18H ₂ O)	101.6%
Chloride	0.004%
Heavy metals (as Pb)	0.0008%
Insoluble matter	0.008%
Iron (Fe)	0.0016%

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BIOGRAPHICAL SKETCH

Hector Lago Jopson was born in May 14, 1971, in Zamboanga City, Philippines, to Reyland and Matilde Jopson. He received his undergraduate degree in agricultural engineering at Xavier University, Philippines, in 1993. In 1999, he married Ann Rochelle Arranguez and the following year became a proud father of Harriet. He is presently on study leave from Western Mindanao State University where he works as a member of the faculty of the Department of Agricultural Engineering. In 2002, he became a recipient of the Fulbright-Philippine Agriculture Scholarship Program to pursue graduate studies in the U.S. After the completion of his master's work, he will return to the Philippines to share his knowledge to help improve the agricultural sector and continue his service at Western Mindanao State University.