Evaluation of Three Manure Pit Additives in Commercial Scale Manure Channels and Simulated Outdoor Lagoons

A Thesis Submitted to the

College of Graduate Studies and Research

in Partial Fulfilment of the Requirements

for the Degree of Master of Science in the

Division of Environmental Engineering

University of Saskatchewan

Saskatoon

By

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Fall 1999

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Abstract

The objective of this thesis was to evaluate the effectiveness of three manure pit additives in commercial scale manure channels and simulated outdoor storage. The additives were American BioCatalysts (ABC), Pit Boss (PB) and Westbridge (WB). Results from two sets of indoor trials were combined to provide eight replicates of each additive. The protocol consisted of manure accumulation, pretreatment and treatment. Air and slurry samples were taken on Days 28 and 35 of the treatment phase. The outdoor phase that followed determined if residual effects resulting from indoor treatment existed. Manure was transferred from the manure channels to outdoor storage lagoons where it was stored in simulated lagoons. Samples were taken on Days 49 and 63.

In terms of odour threshold reduction, the additives' effectiveness varied from producing no reduction to reductions of 66%. The 66% reduction produced by PB in the outdoor trial was the only significant odour threshold reduction in the experiment. During indoor storage, the additives produced minor odour threshold reductions. The additives were able to promote H_2S reductions of 14 to 76% and consistent yet minor NH_3 reductions in the indoor trials. None of the additives produced practical reductions in Total Solids or solubilization that could have improved manure-handling ease. Perhaps the strongest attribute of all of the additives was the ability to maintain elevated nutrients and micronutrient levels. Higher levels of TKN were maintained by all of the additives and the ability of the additives to maintain nitrogen in the available form,

especially on Day 35 representing a potential of 9 to 25% more available nitrogen during field application. Likewise, the additives resulted in 4 to 23% more P while promoting elevated ortho-phosphate levels during the indoor trial. Improvements in nutrient value were also observed in potassium, copper and zinc results. Only with respect to waste strength reduction was the effectiveness of the additives relatively poor.

In order to make more progress in the field of manure pit treatment, research must be directed towards understanding the modes of action of manure pit additives. With this information, optimization of their performance would lead to better results.

Acknowledgements

I would sincerely like to thank Drs. Stéphane Lemay and Al Jobson for their contributions to my thesis and to my development as an individual. Their patience, guidance and insight have made this a positive experience. Likewise, the guidance and contributions of Professors Jon Gillies, Jim Bugg, and Terry Fonstad in my studies, project design and preparation of the thesis are greatly appreciated. I would also like to thank Dr. Jeff Schoenau for serving as the external examiner.

I would also like to acknowledge the efforts of Drs. Bob Baker, Brian Thompson and Ernie Barber for their advice in examining and interpreting the results statistically and scientifically.

Special thanks are also extended to all of the technicians and barn staff that aided in making my experiment run smoothly. These people include, but are not limited to, Rob Fengler, Colin Peterson, Garth McDonald, Brent Hill and John Meier.

I would kindly thank Saskatchewan Agriculture and Food (ADF), the additive companies (American BioCatalysts, Chem-A-Co International and Westbridge), SaskPork, Alberta Pork, Manitoba Pork and the University of Saskatchewan for their financial support.

Lastly, I would like to thank all other friends and family that stood behind me and supported me through both the good and the bad times. As such, I dedicate this thesis to a dear friend that passed too soon, Marina Lambert. Her friendship and personality enriched my life and with her support, I made it through some of the roughest times. She will be greatly missed and always remembered.

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1. CHAPTER ONE

INTRODUCTION

Odour control is a primary concern of the swine industry. In some cases, public perception of odour as a nuisance has given swine production a bad reputation. To remedy this perception, efforts have focused on controlling odour at various stages of production. These efforts are usually successful in suppressing odour production, and while suppressing odour production may be a good short-term solution, nuisance odour still remains a problem at a later point during storage. To complicate the issue, producer's attempts to locate or expand their operations have been blocked by legal action based on odour complaints. In these cases, opponents are typically neighbours or nearby communities that have heard about or experienced the nuisance odour. Publicity from such cases has been costly to producers both socially and economically. For this reason, many companies have developed manure pit additives in order to control odour. If effective, these products would be a great benefit to the swine industry, easing some of the controversy surrounding the odour issue.

In addition to odour, other issues regarding manure are becoming more of a concern. These other issues include manure handling ease, manure pit gas production, nutrient retention and waste strength. Manure pit additive manufacturers claim to address these concerns by reducing and solubilizing solids content, suppressing pit gas production, conserving nutrients and reducing waste strength. For any single treatment to be adequate, the additive would need to improve most or all of these issues and apply to all aspects of manure production. Improvements in any one of these areas may be all that is required depending on the circumstances at any individual production site.

In the past, most manure pit additive evaluations were not conducted independently of the manufacturer. Recently, more of the evaluations are being carried out by independent testing facilities, removing some of the doubt that may have been present in the past. However, most of the testing has been carried out on a bench scale (1 to 100 L), which may not adequately characterize the effectiveness of additives in actual barn applications. Many inconsistencies between commercial and bench-scale conditions exist. Bench-scale evaluations do not always correctly represent commercial surface area to depth ratios, manure additions are infrequent compared to barn conditions and manure is commonly homogenized (mixed) which does not occur to this extent in the actual manure channels. Moreover, the differences between bench-scale protocol and actual barn conditions introduce some question regarding the performance of the additives on a commercial scale when using bench-scale results as indicators.

A factor of many of the experiments that may also contribute to some of the mixed reviews of additives is the limited number of replications that have been conducted. Limited replication combined with large variations in manure composition can produce results with minimal statistical power.

In light of what has been done in the past and what the needs of the parties involved are, our experiment was designed to assess the effectiveness of three manure pit additives under commercial conditions in both indoor and outdoor storage, with a large number of replicates. This study provides some useful information for pork producers and regulators/policy makers to make educated decisions regarding the potential benefit of manure pit additive use in intensive hog production facilities. In doing so, the barriers to expansion discussed above regarding nuisance odour and gas control, nutrient management and manure handling may be reduced. By removing these barriers, all parties involved, including producers, neighbours and regulators would profit.

2. CHAPTER TWO

LITERATURE REVIEW

2.1 Background

The growing demand for pork has led to a rapid expansion of the swine industry in the last five years. Expansion in the industry requires either an increase in the size of existing facilities or development of new facilities. The general public, policy makers, interest groups and neighbours are meeting this proposed increase in production with some resistance. Their concerns revolve around a number of issues that include the environment, aesthetics, social and economic impacts. In many cases the most significant issue contributing to these concerns is nuisance odour, making odour-related research a priority. As a result, a great number of papers (SOTF 1995; Miner 1995; CEC 1989; Li et al. 1997; Sweeten 1995) have already been published, detailing all aspects of odour in the context of hog production facilities.

In an attempt to mitigate odour concerns, various treatment methods have been employed by hog producers. One popular method of treatment is the use of manure pit additives. Several of these commercially available additives have been developed to address the problem of odour generated by the manure. Manufacturers of manure pit additives make seemingly unfounded claims, often based on testimonials detailing realized benefits from use of the additives. These claims include reductions in odour and gas emissions from the manure, along with a reduction and solubilization of solids and maintenance of nutrient availability.

2.2 Swine Manure Production, Storage and Characterization

In most modern commercial hog operations pigs are raised indoors. While in the facility they produce manure that is collected in under-floor manure channels. These under-floor manure channels are used to temporarily store manure until sufficient quantities have accumulated which can be emptied from the channels and transferred to mid- or long-term storage lagoons.

The manure that pigs produce can be classified as a low volume, high strength mixture (Merkel 1981) that is comprised of feces, urine, feed, water and hooves/hair (Zhang et al. 1990; Aarnink et al. 1992). The approximate manure composition is 3.4 parts urine : 1 part feces and studies suggest that the manure production rate is dependent on the mass and type of pig (MWPS 1993; Schulte et al. 1980). Manure production rates reported by MWPS (1993) are presented in Table 2.1.

Table 2.1: Manure production rates (L/day) for various types of pigs (MWPS 1993).

Type of Animal	Manure Production Rate ($L \cdot pig^{-1} \cdot day^{-1}$)
Nursery pig	1.36
Growing pig (30 – 68 kg)	2.27
Finishing pig (68 – 90 kg)	5.45 to 7.26
Gestating sow	5.00
Sow and litter	12.26
Boar	6.36

Only urine and feces contributions are taken into consideration in these values. Other components (i.e. feed, water or hooves/hair) are added to the manure in a random manner that is dictated by the activity of the pigs. The resulting manure is a mixture that is 50 to 75% biodegradable, consisting of carbohydrates, proteins, fibrous material and fats (Elliot et al. 1978) which is an ideal medium for microbial growth.

2.3 Microbial and Chemical Activity in the Manure

Manure within the channel can be divided into three microbial zones based on depth and presence of oxygen (Zhang et al. 1990). The uppermost zone that is in contact with the air is classified as the aerobic zone. Directly below the aerobic zone is the micro-aerobic zone, and the bottom zone is the anaerobic zone. Microbial processes and the byproducts that are produced are dictated by the presence of these zones. Aerobic respiration that occurs in the aerobic zone contributes to the production of nonodorous gases because aerobic organisms use organic matter and ammonium (NH_4^+) as substrates to produce biomass, carbon dioxide (CO_2), water and nitrate (NO_3^{2-}) (ARC 1976). This suggests that aerobic activity is beneficial in regards to odour suppression, but aerobic respiration can only occur within the aerobic and/or micro-aerobic zones when conditions are favourable (i.e. sufficient oxygen is present).

Production of odour causing components like ammonia (NH_3), hydrogen sulphide (H_2S) and volatile fatty acids (VFAs) occurs within the anaerobic zone (MWPS 1993; Cumby et al. 1984; ARC 1976). Malodorous gases are produced via anaerobic reduction of organic matter, nitrate and sulphate (Roustan et al. 1977; ARC 1976). Anaerobic organisms that produce odorous gases are fermentative bacteria, acetogenic bacteria, methanogens and sulphate reducers. The gases they produce are formed at the bottom of the channel and slowly diffuse to the surface. For this reason, odour is typically perceived only after manure has been allowed to accumulate and an anaerobic zone has been established. Biological processes and physical parameters within the manure control evolution of both aerobically and anaerobically produced gases.

In addition to the microbial activity of the bacterial consortium present in manure, physicochemical characteristics also dictate gas and odour production. Characteristics that have been studied include temperature, storage time, dry matter content (Aarnink et al. 1992), nutrients (Merkel 1981; Sutton et al. 1997), oxygen, pH and moisture (Barth et al. 1984; ARC 1976). Of these characteristics, oxygen levels and pH are most commonly altered to affect the type and amount of gases that are produced. Higher oxygen levels permit aerobic reactions to prevail by providing the necessary free oxygen for respiratory reactions. Manure pH has a significant effect on the type of byproducts produced by influencing the amount of available hydroxyl ions and free hydrogen atoms for reactions. Considering two important gases associated with odour production, a low pH favours H_2S production and a high pH favours NH_3 production (Zhang et al. 1990). The other physicochemical characteristics mentioned above relate to gas and odour production by affecting the bacterial environment. Increases in temperature, amount of inoculation material, nutrients and moisture can result in increases in microbial activity which may increase the production of odorous components. For this reason, these factors have also been targeted as variables that can be altered to reduce gas production and ultimately odour.

Several articles (Merkel 1981; Williams 1995a; Zhang et al. 1990) provide extensive coverage of chemical and microbiological activity in manure and how these processes relate to odour and gas production.

2.4 Odour

In order to properly evaluate the impact of manure-derived odour, an understanding of the human olfactory process, odour measurement and odour sampling are required. These processes are discussed in some detail in the following sections.

2.4.1 Human Olfactory Process

Humans detect odour when molecules come into contact with olfactory bulbs located in the nasal cavity. Resulting stimulatory signals are transmitted to the olfactory centre located in the brain where odour is evaluated (Miner 1995). One aspect that complicates the study of odour sensation is that each individual perceives odour in a slightly different manner, making it difficult to predict or quantify an individual's response to any given odourant. Characteristics that may affect the sensory process are an individual's memory and social background.

Olfaction becomes even more unpredictable when one considers that odour emanating from a swine facility cannot be related solely to any single odourant, but rather to a mixture of odourants. Gas chromatography performed on the mixture of gases produced in pig barns suggests that a large number of gases may interact to produce the perceived odour. The gases and odour-producing substances may be divided into four categories. These categories are: volatile fatty acids (i.e. acetic, propionic and butyric acids), phenols, reduced sulphur compounds (i.e. thiols, sulphides, disulphides and thiophenes) and nitrogen derivatives (i.e. ammonia, amines, indoles and skatoles). The wide range of odour-producing agents and the human factor involved in odour perception makes predicting the impact of an odour based on measurement of these components unreliable. This fact has necessitated that a number of odour quantification and qualification techniques be researched and adopted.

2.4.2 Odour Measurement

The most cost-effective means of determining odour offensiveness are by measuring gas concentration, using gas chromatography (GC), wet chemistry and/or absorption (Elliot et al. 1978). In the past, the range of estimates of the number of gases that contribute to odour have varied from 60 to 200 (Schmidt and Jacobson 1995; O'Neill and Phillips 1992; Spoelstra 1980). Still, most air sampling and gas determination has focused on ammonia and hydrogen sulphide. Researchers have investigated the correlations between the concentrations of a number of gases and odour concentration. The consensus is that the following components are odour causing: p-cresol, phenols, sulphides, mercaptans, amines, indoles, skatoles, n-butyric acid, 2,3-butanediol, ammonia, and hydrogen sulphide (SOTF 1995; Barth et al. 1984; Yasuhara 1980; Elliot et al. 1978; Lunn and Van De Vyver 1977).

Unfortunately, few correlations between gas and odour concentrations using inexpensive methods have been identified, and scientists do not wholly accept those that have been identified. This is mostly due to the highly complex means by which odour is perceived. The correlations with perceived odour that have been identified are: supernatant 5-Day Biological Oxygen Demand (BOD_5; $p=0.96$), total organic acids (TOA; $p=0.93$) (Evans and Thacker 1984), p-cresol and ammonia (Schaefer 1980). These correlations were statistically significant but are not likely reliable under all conditions and cannot account for the human factor involved in odour perception. Despite the fact that these limitations exist, reductions of known odour components like volatile organic acids, volatile fatty acids and especially hydrogen sulphide and ammonia have been used to indicate a reduction in odour concentration of unknown magnitude (Barth et al. 1984; Hashimoto 1972; Burnett and Dondero 1969).

Even though limited success has been obtained with these methods, it is still very difficult to measure odour by any means that does not involve humans. Human perception of odour is too complex to duplicate successfully. Therefore, most accepted means of odour measurement involve human odour panels and an olfactometer because the human nose is the best-known tool for such evaluations.

Current olfactometry methods include ranking, rating, magnitude evaluation, dilution and triangular forced-choice olfactometry methods involving human panelists (Riskowski et al. 1991). Ranking is an effective method of comparing odour samples but does not allow for accurate quantification of the differences between odour samples. Ranking is carried out by successively comparing pairs of odour samples and ranking them until all samples are ordered from least to most strong (Riskowski et al. 1991). Rating of odour samples is a very subjective test relying on panelists to rate odour samples on a scale (Cole et al. 1975). The rating technique may work quite well but the results cannot be compared to results from another experiment. Magnitude evaluation utilizes a rating system with the addition of reference odours that function as reference points, aiding in the ranking process. The use of reference odorants may make this a more comparable process but the results are not normalized so comparisons are still very limited. Notwithstanding the cost-effectiveness of these techniques, these three methods are not used with much frequency because of a major limitation; namely the inability to quantify odour, hence the inability to compare odours in different experiments.

More recent developments in odour research have led to the concept of odour concentration, a measure of odour that allows comparisons to be drawn from one odour to another. For this reason, the most important aspect of odour appears to be odour concentration. It is typically determined using an olfactometer to dilute an odour to its detection threshold. The dilution factor necessary to dilute the odour to this threshold is used to determine the odour concentration. The concentration of an odour can be expressed in odour units per cubic metre (o.u/m^3), odour units (OU) or detection threshold (DT).

Regarding the process itself, odour concentration is determined using an olfactometer and an odour panel of at least eight members. The panelists are trained individuals that are capable of detecting odours within the normal range of humans. The olfactometer is used to statically or dynamically dilute the odour sample with odorless air until the panel has determined the odour threshold. The most commonly accepted method of olfactometry is the triangular forced-choice dynamic olfactometry procedure. In this procedure, each odorous sample is presented to the panelist along with two blanks. After sniffing the three air streams that are presented, each panelist is required to choose which of the three sniffing ports that the odour sample is being presented in. Then the panelist must indicate whether this decision is a guess, detection or recognition. This process is repeated by all of the odour panelists with more concentrated samples until at least 50% of the panelists have correctly detected the odour.

Limitations exist for panel evaluations including: cost, saturation of olfactory senses, irritation of nasal nerves, individual sensitivity, fatigue, illness, temperature, age, sex, smoking habits, and uncertainty (SOTF 1995; Ritter 1981). Despite these limitations, the human nose is much more sensitive than any other device that has been used for odour measurement.

Besides the measurement of odour concentration, a complete odour analysis should also consider odour intensity and hedonic tone. Determining the intensity of an odour involves ranking offensiveness with an intensity scale (Ex: 0 (not perceptible) to 6 (extremely strong)). Similarly, hedonic tone is generally determined by ranking the odour on a scale from –4 (extremely unpleasant) to 4 (extremely pleasant) (Berglund et al. 1988). Neither intensity nor hedonic tone ranking involves dilution of the odour sample.

Frequency and duration of the odour can also influence the nuisance level of an odour. Low frequency and duration disturbances are often more acceptable than high frequency disturbances (Sweeten 1995).

The complex human aspect of odour perception makes it very difficult to duplicate odour perception with an electronic instrument using an algorithm to assess odour concentration based on the presence and concentration of odorous compounds. However, there have been significant advances in this field that may allow these instruments to be more effective in the future. Other previously used methods for quantifying and qualifying odour that might be used in conjunction with olfactometry include cotton swatches (Miner and Licht 1984) and odour monitors (Davidson et al.

1984). Both methods display varying degrees of success. Cotton swatches are used to absorb odour, followed by the odour panel procedure. Research has also been initiated into the design of electronic noses for evaluating odour concentration (Classen et al. 1997; SOTF 1995).

2.4.3 Odour Sampling

Problems related to standardizing odour measurement also involve the technique and equipment used in odour sampling. Therefore, methods for collecting odour samples have also been evolving to deal with the concerns. Early trials utilized a cotton swatch to collect the odour but this method was observed to be unreliable, especially when odour concentrations were in the upper ranges (Miner and Licht 1984). Plastic bags were then adopted, but limitations were recognized when compounds became adsorbed/absorbed by the bag themselves (CEC 1989). This adsorption problem made plastic bags unsuitable for odour or gas concentration analysis. To remove the absorption/adsorption problem, Tedlar, Nalophan and Teflon bags were adopted (ECS 1995) and found to be very successful if odour measurements were performed within a short period of time after sampling (within 48 h). More recent experiments indicate that Tedlar bags are capable of preserving odour samples for even longer periods of time, up to seven days, without any decay in the measured odour concentration (Li et al. 1997).

Consideration of the method and materials used in the sampling apparatus were also reviewed (ECS 1995) and indicated that the materials should meet the following criteria: odourless, inert, low permeability and smooth surface. For this reason stainless steel and Teflon are often used in construction of sampling devices. It is also suggested that samples be taken either where the entire odour source can be isolated, or from a point source. Further to this, it was found that pulmonary pumping used in sampling reduced the interaction between the pump and the odour sample, providing a more representative sample. Many or all of these odour sampling principles hold true for gas sampling procedures as well.

2.5 Manure Pit Gases

Many aspects of gas production from manure have been discussed by a number of authors (Yu et al. 1990; Cumby et al. 1984; Miner 1982; Roustan et al. 1977; Elliot et al. 1978). From these articles, it is apparent that the gases of primary concern are ammonia, hydrogen sulphide, carbon dioxide and methane. The main concerns stem from health-related issues, odour and greenhouse gas emissions.

Regarding ammonia, nitrogen derived from amino acids present in feed passes through the digestive tract or is spilled by the pigs during feeding, and ends up in the manure channels. The fraction, which constitutes the majority, that passes through the digestive tract of the pig appears in the form of urea that is passed in the urine of the animals. Within the manure, urease enzyme converts urea-N into ammonium-N, which can quickly be converted into ammonia-N. The transformation of ammonium to ammonia is both pH and temperature dependent. Manure temperature affects the solubility of ammonium, while pH regulates the equilibrium between ammonia and ammonium. High pH levels favour ammonia production, while lower pH levels favour ammonium (Ritter 1989). Besides these factors, surface area, presence of a top crust, and air movement over the top of the manure affect the volatilization rate of ammonia. When ammonia is emitted, it can act as a respiratory irritant for both pigs and workers, it can degrade equipment and barn structure due to its acidogenic properties, and it may affect nearby ecosystems (MWPS 1993).

As mentioned previously, H_2S is created in the anaerobic zone of the manure. Sulphate is used as a terminal electron acceptor by sulphur-reducing bacteria to produce H_2S that bubbles to the surface where it is released to the atmosphere. Temperature and pH also regulate H_2S formation. Temperature increases result in increased solubility, while low pH favours the formation of H_2S (Ritter 1989). Hydrogen sulphide production is a concern for both workers and animals. Levels as low as 50 ppm may result in respiratory and eye irritation. Inability to detect its presence by olfaction occurs at around 150 ppm, headaches and dizziness at 200 ppm, and fatality occurs between 500 ppm and 2000 ppm (MWPS 1993). The severe nature of the biological response to H_2S makes control of its production a major concern within the production facility.

Carbon dioxide is primarily produced through the respiration of the pigs, with a small fraction coming from decomposition of manure. Elevated levels of CO_2 are a respiratory concern for both workers and pigs but levels seldom reach dangerous concentrations due to the effectiveness of ventilation systems. Of greater concern is the fate of CO_2 when it is removed from the facility. Carbon dioxide is a well-documented greenhouse gas, thus measures are required to regulate its production to minimize the effect of pig production on the external environment (Schulte 1997).

Many techniques for gas measurement and identification have been used in evaluating odourous air samples. The gas sample can be collected and concentrated by freeze vacuum distillation (Yasuhara et al. 1984), chemical traps and/or Tedlar bags, with subsequent analysis by gas chromatography and mass spectrometry (Al-Kanani 1992) or Dräger style colorimetric detection tubes (Lunn and Van de Vyver 1977). The best method often depends on the detection level and accuracy required, as well as cost.

2.6 Manure Solids

Swine manure is comprised of a number of different solid fractions. Loehr (1974) reports average values of 5 to 9% solids, of which approximately 83% are volatile. It is this volatile portion that is of concern when discussing odour. As the name indicates, this fraction of the solids can be converted and volatilized from the manure. These components have the potential to be odour-producing.

Solids are also an important factor in dictating the fluidity of manure as well as giving some indication of strength. The types of solids found in manure are volatile (organic) and fixed (inorganic) which together represent total solids. Both volatile and fixed solids can be further divided into suspended and dissolved fractions. Suspended solids are maintained in manure until they settle out as a flocculent and the dissolved fraction is a solubilized solid fraction (Merkel 1981). Ease of manure handling can be attained in two manners: total solids can be reduced or a solubilization of suspended solids can occur, resulting in more liquid manure. Solubilization involves transformation of the suspended solid fraction into the dissolved solid fraction. This process can be attributed to microbial activity and temperature in the manure. The process also creates manure, high in colloids and solutes, that possess a low chemical oxygen demand (COD) and high nitrogen content (Hobson and Robertson 1977). Determination of solids fractions involves dry matter and filtering procedures that are standardized (APHA 1992).

2.7 Macronutrients

Nutrients are an important component of the manure. Nitrogen (N), phosphorus (P) and potassium (K) are essential elements in the development of pigs (Jongbloed and Lenis 1992). Much of the nutrient load that is fed to pigs is not assimilated and consequently enters the manure channels (Van der Peet-Schwering 1998). Once in the manure channel, the importance of nutrients is in application as a fertilizer. Most investigations into nutrient content in manure focus on nitrogen, phosphorus and potassium. Zublena and Campbell (1996) report that these nutrient levels are highly variable with average nutrient values per ton of manure of 62 kg, 60 kg and 24 kg for N, P and K, respectively. To explore the issue in more depth, the nutrients can be broken down into available and unavailable fractions. In nitrogen analyses, commonly measured fractions are Total Kjeldahl Nitrogen (TKN), ammonium nitrogen and nitrate nitrogen. Total Kjeldahl Nitrogen determinations represent the level of oxidizable forms of nitrogen, ammonium nitrogen represents the level of available nitrogen, and nitrate nitrogen is the available fraction that may be leached through the soil when applied as a fertilizer. The amount of nitrogen present in the ammonium-nitrogen form is a valuable nutrient addition when added to farmland. When phosphorus determinations are carried out, total phosphorus and ortho-phosphorus levels are often measured. The ortho-phosphorus fraction represents the plant available fraction that is an important nutrient addition when applied to farmland as a fertilizer. Both nitrogen and phosphorus can lead to environmental concerns when they are transported by surface and groundwater to water bodies, resulting in eutrophication (Barrington 1994). Potassium that is present in manure is also a valuable nutrient addition when applied as a fertilizer.

To illustrate the magnitude of potential for using manure as a nutrient source, one need only examine the amount of nutrients available in manure in the state of North Carolina alone. The SOTF (1995) estimates that 10.5 million pigs produce 9 million tonnes of manure, which contains 52,500 tonnes of nitrogen, 40,000 tonnes of phosphorus and 37,000 tonnes of potassium. This amount of manure could be used to fertilize approximately 78,000 acres of land at a 2.5 cm application rate. If the manure is not applied to land where feed for the pigs is grown, nutrient cycles are incomplete. The unbalanced nutrient cycle creates poor farming practices that steal fertility from the land both now and in the future (Van der Peet-Schwering 1998).

2.8 Micronutrients

Micronutrients that are essential to pig development, which later contribute to fertilizer value are incorporated in swine diets. Some of these micronutrients include copper (Cu^{3+}), zinc (Zn^{2+}), magnesium (Mg^{2+}) and sodium (Na^{+}). Similar to the fate of macronutrients, micronutrients are intended for assimilation in the pig, but some of the micronutrient content passes through the pig without being absorbed. Once in the manure, copper and zinc may act as anti-microbial agents, reducing pit gas production. Some concern exists regarding the level of these micronutrients in manure that is land applied. Determination of micronutrient levels is most often conducted by extraction with an acid, followed by measurement using inductively coupled plasma (ICP) methods (de Abreu and Berton 1996).

2.9 Waste Strength

Manure strength refers to the amount of organic matter present in the manure. Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD) are commonly used measurements of this characteristic. COD represent the fraction of manure that is oxidizable by chemical processes and BOD represents the fraction that is oxidizable by microorgansims. One goal of manure treatment is to reduce COD and BOD (Price 1991).

2.10 Manure Pit Additives

A large number of additives are available to producers. Manufacturers of the additives claim that the products reduce odour, ammonia losses, pit gas production, and solids content, while promoting breakdown of crusts, improving handling, and maintaining nutrient levels. These additives can be separated into the following categories: masking agents that cover up odour, counteractants that neutralize odour, adsorbents that adsorb the odour, chemical deodorants that function as oxidizing agents or biocides, and digestive deodorants that control odour biochemically (SOTF 1995).

2.10.1 Pit Additive Effectiveness

Despite manufacturer's claims, none of the additives have proven to be totally effective. A large number of evaluations have been carried out with these additives and the results from the experiments are summarized below.

Recent studies suggest that some progress has been realized with the application of manure pit additives. In a study conducted by Zhu et al. (1997) all five additives tested (MPC, Bio-Safe, Shac, X-Stink and CPPD) reduced odour concentration by 58 to 87%, as determined through dynamic triangle forced-choice olfactometry. In the same experiment, only MPC was capable of producing a significant TS reduction and Bio-Safe produced significant increases in NH_4-N levels. Lorimer (1996) also reported on results from the experiments conducted by Zhu and Bundy, which indicated that none of the additives reduced TS significantly, but some were observed to promote elevated NH_4-N levels.

In another experiment, eight products (Bio Charge, Roebic Deod, Pit Boss, Shac, Bio-409, MS-4, Pit Stop and Deo Odorase) were evaluated in full-scale rooms, resulting in odour reductions of 5 to 48% and NH_3 reductions of 42 to 51% (AURI 1997). The AURI study also indicated that the additives produced significant increases in P relative to control and small increases in NH_4-N.

Two (NX23 and BioSuper) of the five additives tested by Martinez et al. (1997) reduced NH_3 emissions by 40 to 50%. Heber et al. (1997) reported reductions of NH_3 emissions from 1.8 to 5.9 $g \cdot day^{-1} \cdot pig^{-1}$ and small decreases in overall NH_3, H_2S and CO_2 concentrations. Successful application of acid treatments and sphagnum peat moss reduced losses of NH_3 by 74.6% (Al-Kanani 1992). Williams and Schiffman (1995) conducted a series of bench-scale tests on a neutralizing agent, an oxidizing agent (potassium permanganate), an absorbent (sphagnum peat moss), a digestive deodorant and a chemical additive. Results indicated that the neutralizing agent and oxidizing agent improved odour quality, but found the other additives to be ineffective in controlling odour.

Testing of Deodorase, a feed additive, indicated the ability to reduce ammonia concentrations significantly (26%), but no ability to significantly impact the odour concentration (Amon et al. 1995). Patni and Jui (1993) reported on the effectiveness of seven commercially available additives (Agri-Scents, Biosurge, Hydrogen cyanimide, Micro-Aid, Natural Odor Catalyst, Sphagnum peat moss and Roebic), none of which were effective in improving all measured parameters. They were evaluated on a bench scale using 200 L of manure in grey plastic barrels over a ten-week period. Only hydrogen cyanamide was capable of significant reductions in H_2S production and a 10 cm peat cover reduced NH_3 production.

Testing of the products Bio-Surge and BiologicSR2, carried out by Barrington (1993; 1994), showed promising results in terms of odour reduction and nutrient retention and availability. In previous studies conducted by Warburton et al. (1979), Miner and Stroh (1976), and Ritter et al. (1975), disappointing results were reported.

Many of these evaluations were carried out on a bench scale (Zhu et al. 1997; Patni and Jui 1993; Al-Kanani 1992) that may not represent actual commercial conditions adequately for testing purposes. As a result, it was suggested that the manure additive testing protocol reported in this thesis be performed in commercial-scale manure channels and simulated outdoor storage. By carrying out the experiment in this manner, the results may be more indicative of what might be expected by hog producers when the additives are applied in their production facilities.

There may be some question as to whether inconsistencies in results were a function of differences in experimental protocol or simply the activity of the manure pit additives.

These questions arise from the use of procedures that were not representative of typical commercial activities. In addition, some of these poor performances and inconsistencies in results may in part be attributable to bacterial die-off (SOTF 1995), insufficient inoculation (Ritter 1981), and antibiotics or the presence of copper sulphate (Nicolai 1996), which limit the activity of the microbes in the additives.

2.10.2 Evaluation Protocol

As illustrated above, a large number of trials have been conducted to determine the effectiveness of manure pit additives. The general procedure is the same, involving manure stored in a container, manure additives being applied and testing results being compared to control results. Some variation in results may have been due to the methods and equipment that were used. Variations on the simulated manure pit included: plastic lined steel drums (Warburton et al. 1981), plastic drums (Patni and Jui 1993; Yu et al. 1990), cylinders (120 cm tall with a diameter of 37.5 cm; Lorimer 1996; Martinez et al. 1997), and one litre glass jars (Williams and Schiffman 1996; Williams 1995b; Miner et al. 1995). Use of large plastic drums seems to have been the best option in terms of volume and reduction of interaction between the manure and the container.

With all of these variations on the container, it still seems evident that commercial scale evaluation is a necessity. However, even with a limited number of commercial scale evaluations having been carried out (AURI 1997; Heber et al. 1997; Barrington 1993), comparisons were difficult because the differences between environmental conditions in the barns were difficult to control.

Other major factors that have been varied in bench-scale testing are mixing of manure (homogenization) and frequency of manure addition. Mixing the manure is normally accepted in experimental protocols, but as manure is not physically mixed in the pit, it does not represent typical commercial conditions accurately. Mixing may increase mobility of microorganisms, allowing them to populate the manure pit more rapidly, as well as potentially breaking down some of the solid fraction (active mixing with a propeller for example). Thus, mixing could produce results that exceed those observed in actual manure channels.

Frequency of manure addition is another factor that has been altered. It has typically been done once a week, but has also been carried out as a single manure addition (Patni and Jui 1993) and every two days (Yu et al. 1990). Frequent manure addition most accurately represents manure addition to actual pits, but Patni and Jui (1993) argue that frequent addition of manure exhausts resources while producing very little extra information for the study. With so many potential variations in protocols, it has been difficult for the scientific community to agree on a specific protocol for evaluation. Furthermore, the most complex component of the experiment, odour measurement, still causes a great deal of debate.

In contrast to odour analysis, analysis of slurry samples for the purpose of evaluating manure pit additives is fairly standard. Determinations include COD, total solids (TS), total volatile solids (TVS), total suspended solids (TSS), total dissolved solids (TDS), ammonium nitrogen, TKN, phosphorus, ortho-phosphorus, micronutrients, pH and electrical conductivity (Nicolai et al. 1997). All of these determinations are carried out using standard analytical laboratory procedures.

2.11 Objectives

After reviewing the broad knowledge base that is available, it is evident that a number of strengths and weaknesses have been present in past experiments. By evaluating the previous protocols, and trying to incorporate the strengths and improve on the weaknesses, it is believed that this experiment can make progress in pit additive evaluation.

With this in mind, the objective of this research was to evaluate the effectiveness of three manure pit additives to reduce odour threshold and gas concentrations above the manure surface and reduce solids and waste strength, and maintain nutrient and micronutrient content in the manure, in commercial-scale manure pits and simulated lagoons. To do so, different analyses were made in two phases of the experiment, the indoor phase (manure channel) and the outdoor phase (simulated lagoon) representing the stages of manure storage while it is at the production facility.

3. CHAPTER THREE

MATERIALS AND METHODS

3.1 General Description

Two trials were conducted to assess the effectiveness of additives in commercial-scale manure channels. Manure treated with three pit additives was compared with control manure, using air and slurry samples taken on Days 28 and 35 of the treatment phase of the indoor trials.

The outdoor portion of the experiment was designed to determine if the additives had any residual effect on manure and air characteristics during the outdoor storage phase of manure-handling. The additives were not applied during the outdoor experiment. Manure was transferred from the indoor manure channels to the simulated lagoons at the end of the first indoor trial. Samples were taken on Days 49 and 63 of the outdoor trial.

3.2 Indoor Experimental Protocol and Design

3.2.1 Room Setting

The experiment was conducted in a commercial production room at Prairie Swine Centre Inc. (PSCI). PSCI is a pig research centre located approximately 10-km southeast of Saskatoon. Within the room, environmental conditions were controlled with the existing ventilation system (fans, air inlets, controllers), to maintain temperature and relative humidity at optimal conditions, according to pig weight and outside conditions. Figure 3.1 is a sketch of the commercial production room configured for the experiment.

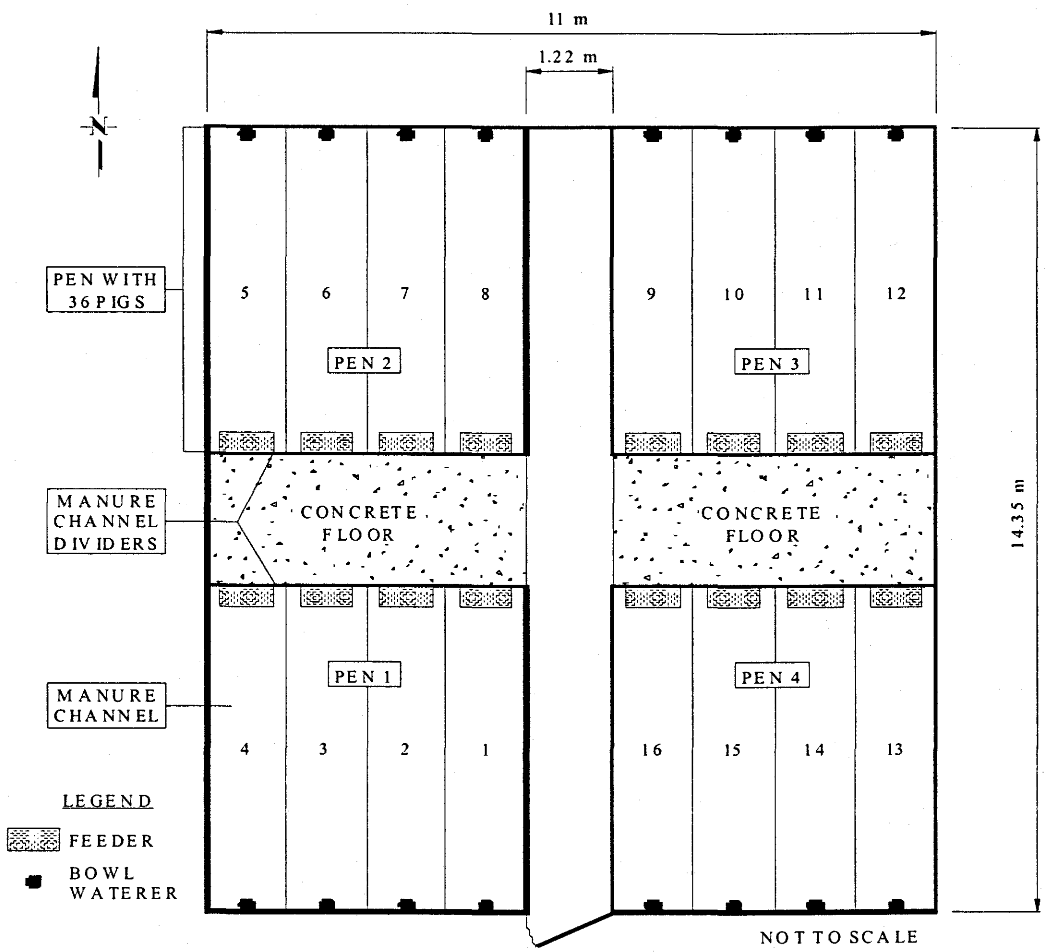

Figure 3.1: Sketch of Room 132 configured for indoor trials.

Before starting the experiment the entire room was thoroughly power-washed, the slatted flooring was removed and all existing manure channels were drained by gravity and power-washed. After power-washing was completed, the sidewalls and floor of the manure channels were free of all manure and crusted solids.

After the manure channels were left to dry, dividers were constructed in eight of the nine existing manure channels. These dividers were positioned with a 2.44 m space between them, creating two smaller manure channels (16 in total) from each original manure channel.

To build the dividers, a band of roofing pitch was applied to the walls and floor. A 2x4 frame was then placed over the applied pitch and was fastened to the walls and floor with concrete anchors, creating a watertight seal around the frame. More roofing pitch was applied to the 2x4 frame and a sheet of weather-treated plywood was attached to the manure-holding side of the frame. To complete the divider, roofing pitch was applied to the edges of the frame where it contacted the sidewalls and floor.

After these dividers were completed, a 2x4 frame was also constructed over the pit plug of each manure channel. The pit plug frames were used to lock the pit plugs in place, preventing the manure pit plug from leaking during the experiment. Once the pit plugs were locked in place, the pits were filled with water to determine if any leaks were present. All leaks were patched by applying roofing pitch. After repairing the leaks the manure channels were drained, the slatted floor was replaced, and four pens were constructed.

Pens were located in each corner of the room, above each block of four manure channels. Penning was constructed directly above the manure channel dividers, leaving a 2.44 m alleyway between the pens on each side of the room (Figure 3.1). A solid concrete floor was created with concrete blocks in each of these alleyways. The concrete blocks were intended to reduce manure addition in those portions of the existing manure channels that could no longer be drained.

To complete each pen, a bowl waterer and feeder were positioned over each of the manure channels on opposite ends of the pen. This arrangement of feeders and bowl waterers was intended to standardize the addition of wasted feed and water to each manure channel.

For each indoor trial, 36 pigs (18 males and 18 females) were housed in each pen. The pigs were introduced to the pens at the beginning of each trial at an average weight of approximately 28 kg. They were randomly distributed between the four pens, such that the combined weight of the pigs in each pen was approximately even. The total weight of either males or females was also approximately even.

Sick pigs were either treated in their pen or removed from their pen until they were healthy enough to return. Dead pigs were removed from the pen and replaced if early enough in the trial (one to two weeks after the start).

Pigs were fed *ad libitum* on a standard set of diets consisting of formulated feeds PSC 8, PSC 10 and PSC 9. These diets are designed to meet dietary requirements of pigs in certain weight/development stages. When the pigs in the room were observed to be of an average weight requiring a certain dietary formulation, all of the feeders in the experiment were changed over to that formulation of feed. Decisions regarding diet were made by an experienced stockperson. Feeders were filled at least once daily in order to prevent any of the feeders from becoming empty at any time.

Bowl waterers were used in the experiment to reduce water wastage. It was observed that pigs sometimes defecated in the bowl waterers. To reduce the effect of this behaviour on the composition of the manure, bowl waterers were cleaned daily to encourage the use of all of the waterers for drinking.

3.2.2 Manure Accumulation and Treatment

The experiment consisted of three distinct phases: manure accumulation (three weeks), manure pretreatment/conditioning (two weeks) and manure treatment (five weeks). To begin the manure accumulation phase, a 350-L addition of water was made to each manure channel to reduce odours and flies. Then, manure produced by the pigs was allowed to accumulate for a three-week period, in order to simulate continuous barn operations. During this three-week period, manure that accumulated was not treated. Following the accumulation phase, a two-week pretreatment phase was initiated. During the two-week pretreatment phase manure was treated as recommended by manufacturers of the additives. This allowed the channels to be conditioned with the treated manure for two weeks, before the treatment phase.

Following the pretreatment phase, the treatment phase was initiated. First, all of the manure channels were drained by gravity, and then another 350-L addition of water was made to each manure channel. Then, for a five-week period, manure accumulated and was treated at recommended rates.

3.2.3 The Additives

The three additives being evaluated against the control were American Bio-Catalysts (ABC), Pit Boss (PB) and Westbridge (H4-502). These additives were chosen to be tested in the experiment because they represented three of the possible modes of action employed in additives. They might provide some insight into which modes could be effective, but are by no means representative of all additives. The ABC additive is a combination of enzymes and microbes intended to break down manure constituents both chemically and biologically. Pit Boss is an acidified copper sulphate mixture, believed to react chemically and electrically with complex slurry components. The Westbridge additive is an organic amendment intended to increase microbial activity and oxidize organic components of manure. The control manure was untreated and no specific intervention was performed, to maintain naturally occurring processes in the manure.

3.2.4 Additive Preparation and Application Rates

Additives were prepared as recommended by the manufacturers for the duration of the experiment. The ABC additive consisted of ABC 100E (the enzymatic portion) and ABC 200M (the microbial portion). The ABC 100E portion required no preactivation and was added to the manure at a rate of 1:100,000 on the initial addition (Day 0). ABC 200M was preactivated with a combination of mild aeration and heating to 35°C for 24 h, then applied at a ratio of 1:100,000 on Day 1. For maintenance additions, both ABC 100E and preactivated ABC 200M were applied together at a rate of 1:500,000 every two weeks.

Pit Boss consisted of a pH adjustment component used to adjust the pH of the manure to a level between 6.7 and 7.0, and a single addition of the product on Day 0. The application rate of Pit Boss was 1:60,000 calculated based on the estimated full volume of each manure channel at the end of the experiment.

Westbridge (H2-504) was added on a daily basis at an application rate of 1:100,000, based on daily manure production rates. This meant that very small amounts of the product were added to the manure on a daily basis. To apply this additive properly the additive was combined with 1-L of water. To standardize the water addition of all additives, 1-L of water was added daily to all manure channels treated with the other additives. For all additives, application rate calculations included the residual amount of manure present in the manure channel after the pretreatment phase.

Application of additives was carried out with a 3-L common lawn atomizer (applicator). Prepared additives were transported into the barn in plastic vials and transferred into applicators. An applicator was dedicated to each additive to avoid cross-contamination. Once additives were poured into applicators, the volume was topped up to one litre because the actual volumes of the additives were very small. The increased volume made application easier, and allowed even distribution of the additive throughout the manure channels. To apply the additive, the applicator was pressurized, the wand was inserted through the slatted floor and the additive was sprayed evenly over the entire manure surface. After each use, the applicator was thoroughly flushed with water to remove any residual additive.

3.2.5 Observations

A number of measurements were carried out on a daily basis to provide a record of ambient environmental parameters and physicochemical characteristics of the manure.

Room temperature determined from the room's environmental controller was recorded on a daily basis. Within each manure channel, depth and temperature were measured daily with a meter stick and a common thermometer. Both of these measurements were taken at three locations throughout the channel: the waterer end, the middle, and the feeder end. Every two weeks, psychrometer readings were taken to determine the relative humidity of the room and to verify the temperature readings from the controller.

3.2.6 Air Sampling

To collect air samples, a special pulmonary pumping box and manifold were designed and constructed. The manifold and sampling box are illustrated in Figure 3.2. Quarter-inch stainless steel tubing was used to construct the sampling manifold (CEC 1989) and a 22-L plastic pail and fittings were used to construct the sampling box.

The manifold consisted of three 2-m lengths of tubing, connected at a central cross fitting. Equal lengths of stainless steel tubing were used to allow a single sample to be obtained by combining air taken from three locations (waterer end, middle and feeder end), 5 cm above the manure surface, as recommended by Jacobson et al. (1997).

Before air samples were taken, each manure channel was isolated by placing a length of polyethylene over it and securing the edges with 2x4 studs. Then, the manifold tubes were pushed through the polyethylene sheet and suspended 5-cm above the surface of the manure. The manifold was connected to the 3-way valve (A) attached to the pulmonary pumping box. Airflow into the pulmonary pumping box was controlled with 3-way valves (A and D).

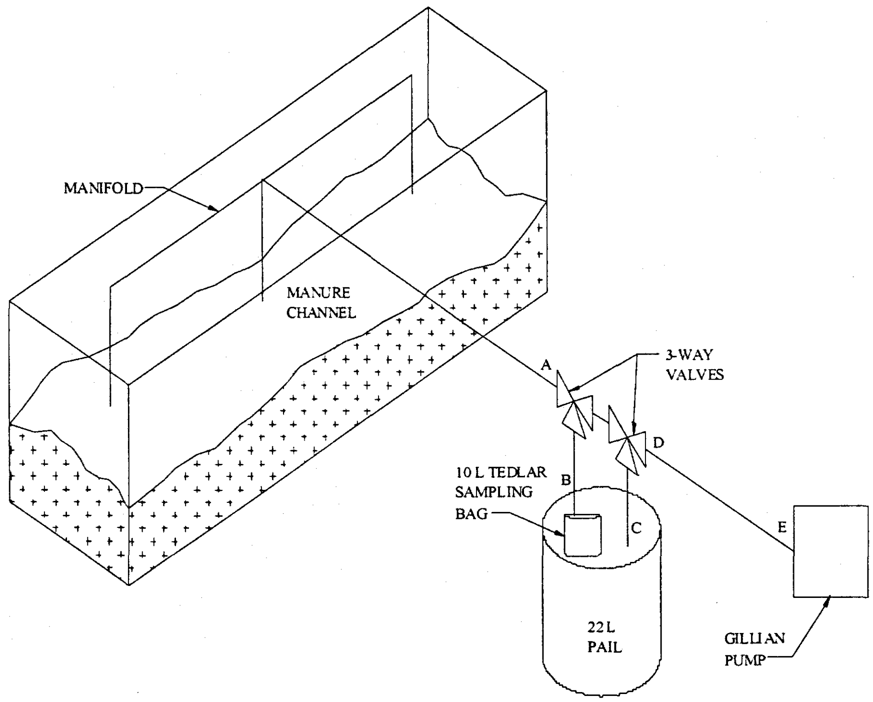

Figure 3.2: Sketch of indoor air sampling setup.

Before a sample was taken, the line was purged by directing airflow through the manifold and Gilian AirCon-2 air sampler (Gilian Instrument Corp., W. Caldwell, NJ, USA; A to D to E). The line was purged for one minute at a flow rate of approximately 2 L/min and then the sample was taken (CEC 1989). When sampling, a 10-L Tedlar sampling bag (B) placed inside the 22-L pail, was connected to the tubing that ran to three-way valve A. Then the lid of the 22-L sampling pail was closed, and a vacuum was created in the pail when air was drawn out of the pail with the pump (C to D to E). Air was drawn into the Tedlar bag, by opening three-way valve A which allowed air to flow from surface of the manure through the manifold to A and end in the Tedlar bag (B). The air sample was taken at a flow rate of approximately 2 L/min for 5 min, as recommended by Jacobson et al. (1997).

Two air samples were taken from each manure channel, one for odour analysis and the other for gas measurements. Both air samples were taken on Days 28 and 35 of the treatment phase. Odour samples were packaged and sent to the Alberta Research Council (ARC) for dynamic olfactometry analysis within 24 h and gas samples were transported to the PSCI laboratory for gas concentration determination at a later date.

3.2.7 Slurry Sampling

Slurry samples were also taken on Days 28 and 35 of the treatment phase. A single slurry sample was taken from each channel to be analyzed. Each slurry sample was a composite sample taken by combining subsamples from three positions throughout each manure channel. These positions were 2 m from the waterer end, the middle, and 2 m from the feeder end. This arrangement of samples was chosen because manure in these locations could be quite different in composition due to addition of feed and water spillage. The subsamples were taken with a clean 10-L plastic pail used to remove a representative sample from each area. To do so the pail was lowered into the manure and a sample representing the entire vertical column was removed. Subsamples taken from all three locations were combined in a clean plastic container and briefly stirred with a clean plastic rod. Then the samples were transferred into 500 ml plastic jars that were sent to NorWest Laboratories for analysis, and 1-L mason jars used for pH and electrical conductivity analyses at PSCI. All sampling materials were thoroughly cleaned with water to remove the possibility of cross contaminating future samples.

The NorWest Laboratories samples were placed on ice and sent to the laboratory at the end of the sampling day. Mason jar samples were transported to the PSCI laboratory and refrigerated until analysis was completed. Slurry sampling was always performed following air sampling in order to reduce agitation of the manure that could release gases and odour.

A number of analyses were carried out to characterize odour and gas concentrations in air samples, as well as solids content, nutrient and micronutrient levels, manure strength and physicochemical characteristics of the slurry samples. Table 3.1 summarizes characteristics that were evaluated, methods of analysis, detection limits and references.

Table 3.1: Methods, detection limits, precision and reference for analysis of slurry and air samples.

Parameter	Method	Detection Limit	Reference
COD	Micro dichromate digestion- colorimetry	5 mg/L	APHA 5220:D
Total Solids	Evaporation (105°C)	1 mg/L	APHA
Total Dissolved Solids	Filtration (0.45 micron), Evaporation (105°C)	5 mg/L	APHA 2540:B
Total Suspended Solids	Filtration (GFC), Evaporation (105°C)	5 mg/L	APHA 2540:D
Total Volatile Solids	Ignition (550 °C)	5 mg/L	APHA
TKN	Sulphuric acid digestion, automated colorimetry (Phenate)	0.05 mg/L	EPA 351.2
Ammonium-N	Automated colorimetry (Phenate)	0.005 mg/L	APHA 4500-NH_3:H
Ortho-phosphate	Automated colorimetry (Molybdenum blue)	0.05 mg/L	APHA 4500-P:E
Trace Metals (Cu, K, Mg, Na, P, Zn)	Nitric/hydrochloric acid digestion, ICP	Cu 0.001 mg/L K 0.4 mg/L Mg 0.05 mg/L Na 0.4 mg/L P 0.006 mg/L Zn 0.0005 mg/L	APHA 3030 APHA 3120 B
Odour Concentration	Forced-choice dynamic olfactometry		
Ammonia	Colorimetric detection tube	0.1 ppm 0.5 ppm	
Hydrogen Sulphide	Colorimetric detection tube	0.2 ppm	
Carbon Dioxide	Colorimetric detection tube	30 ppm	

APHA: American Public Health Association
EPA: Environmental Protection Agency

3.2.8 Experimental Design

The experimental design used in the indoor experiment was a balanced 4x4 Latin-square repeated twice in time. The two repetitions of the experiment in time (trials) represented two environmental regimes: summer and fall operating conditions. This meant that the entire procedure was carried out twice (two separate trials). Each room turn representing a balanced 4x4 latin-square. Within each block were four manure channels (the experimental units). Fixed effects of the Latin-squares were additive and pit positions. Pit positions were identified with the numbers 1 to 4. Position 1 represented pits closest to the midline of the room and position 4 represented the outermost pits. During each trial, sampling was conducted on Days 28 and 35 of the additive phase similar to Miner et al. (1995).

A dunging gradient was predicted to occur in the pens while manure accumulated. It was believed that the ventilation system and resulting air pattern would influence pigs to dung more in pit position 4 than in pit position 1. Cool air circulating in these areas, should stimulate defecation in pit position 4. This "dunging gradient" would result in different manure composition and addition rates amongst the manure pit positions. This should provide an unpredictable source of variation in the experiment, thus this effect was accounted for in the experimental design.

During each trial, each additive occupied each manure pit position once. No repetitions of additive x pit position x block were permitted for any of the trials. Table 3.2 summarizes the allocation of additives in manure channels for the indoor trials.

Table 3.2: Summary of manure channel allocation for additives during indoor trials.

Trial	Additive	Manure Channels
1	Control	4, 6, 10, 16
	ABC	1, 7, 11, 13
	Pit Boss	2, 5, 9, 14
	Westbridge	3, 8, 12, 15
2	Control	2, 8, 12 ,14
	ABC	3, 5, 9, 15
	Pit Boss	1, 6, 10, 13
	Westbridge	4, 7, 11, 16

3.2.9 Statistical Analysis

Both additive and pit position effects were evaluated to determine their effects on solids, odour and pit gas, nutrients and micronutrients, and manure strength in under floor-manure channels. The analysis of variance was based on two balanced 4x4 Latin-squares with separate analyses carried out on data from measurements taken on Days 28 and 35. Table 3.3 summarizes the analysis of variance.

Table 3.3: Analysis of variance for indoor trials.

Sources of Variation	Degrees of Freedom
Trial	1
Block	3
Position	3
Additive	3
Position * Trial	3
Error	18
Total	31

Statistical analysis was conducted using SAS Version 6.1 for Windows. Due to missing data, least-square means (LSMEANS) analysis was the most appropriate method for comparisons between additives and pit positions (Steel and Torrie 1980). The LSMEANS procedure, used in unbalanced experiments, creates estimates of class and subclass marginal means that represent predicted values if the experiment were balanced (SAS 1985). All comparisons between additive means were made using a pair-wise t-test (LSD) with a significance level of $P < 0.05$. This significance level was chosen because it is commonly used in animal and engineering research. Use of this significance level in this experiment may provide very restrictive mean separation, because the level of variability observed in swine manure is higher than is commonly observed in these other fields of research. *A posteriori* power analyses (Baker 1998) were also used to determine the size of true differences that could be considered statistically significant in this experiment.

3.3 Outdoor Simulated Lagoon Experimental Design and Protocol

3.3.1 Experimental Setting

The experiment was conducted in simulated lagoons located in the PSCI compound, north of Commercial Production Room 132. The area was located between two wings of the facility, with restricted wind access from the north, east and south.

3.3.2 Simulation Lagoon Preparation

In preparation for the outdoor trial, the area was cleared and a level gravel base was made. Then, the simulation lagoons were positioned in a line, running west to east, with the lagoons numbered from 1 to 16 (Figure 3.3). The lagoons were 1360 L (1.83 m diameter x 0.56 m high), heavy duty, black, plastic cattle waterers. These waterers were chosen because they were readily available and possessed a height to diameter ratio similar to the existing lagoons at PSCI.

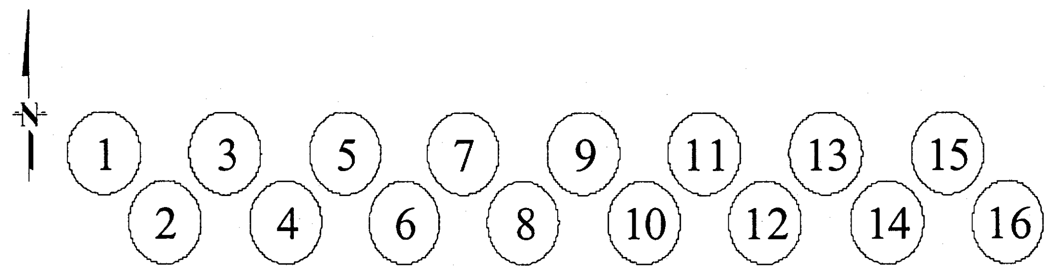

Figure 3.3: Sketch of outdoor simulated lagoon storage set up.

3.3.3 Manure Transfer

Following the first indoor trial, manure was transferred from the indoor manure channels to the outdoor simulated lagoons using a Goulds 3872 submersible sewage pump (Goulds Pumps Inc., Seneca Falls, New York, USA, 13148) and a flexible hose. Manure was transferred starting with manure channel 1 and ending with manure channel 16. Manure was transferred until indoor manure channels were empty or lagoons were almost full. The majority of the solids and liquids present in the manure channel were transferred during pumping. When filling any lagoon, it was ensured that any residual manure remaining in the length of hose was emptied into that lagoon. Then the hose was cleared out by pumping water through it, before the manure from the next manure channel was transferred to the next lagoon.

3.3.4 Measurements and Observations

Depth measurements were carried out on a weekly basis, to provide information on evaporation rates. These measurements were made at the centre of each lagoon. Outside ambient temperature was recorded daily.

3.3.5 Air Sampling

The same protocol that was used for air sampling in the indoor trial was used for the outdoor trial with a few exceptions (Figure 3.4). These exceptions were that the lagoons were covered with plywood instead of polyethylene to isolate them during sampling, and that the sampling manifold was configured to fit through holes arranged in an equilateral triangle on the plywood. Air sampling was carried out on Days 49 and 63.

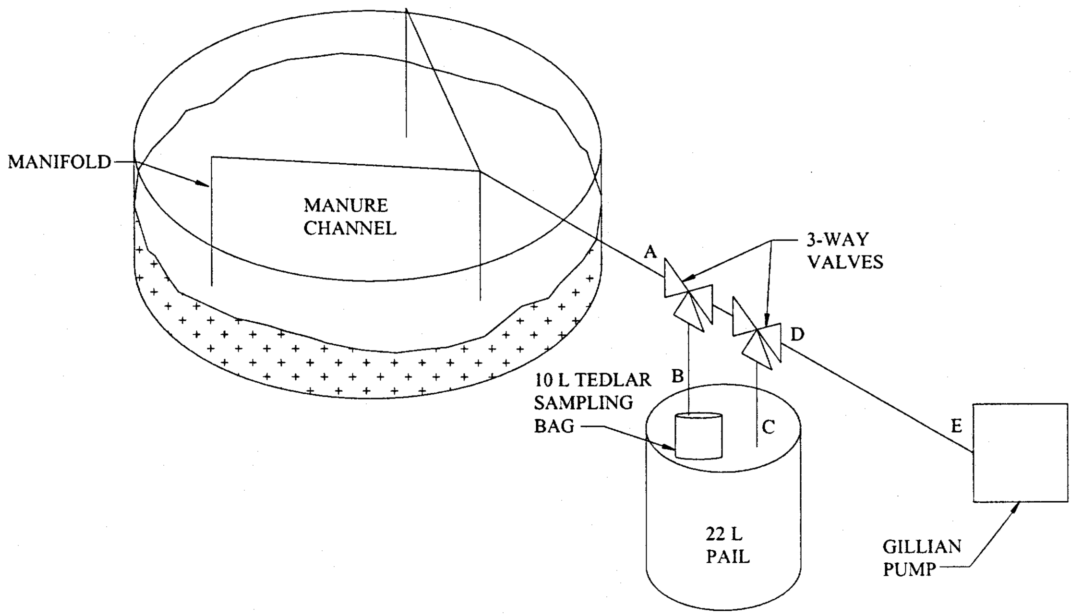

Figure 3.4: Sketch of outdoor air sampling setup.

3.3.6 Slurry Sampling

Slurry samples were taken in the same manner as the indoor trial. Samples representing the entire column of manure were removed with a clean pail. Slurry sampling was also carried out on Day 63, after air samples were taken. The same set of analyses for odour and chemical composition (Table 3.1) that was carried out in the indoor trial was used in the outdoor trial.

3.3.7 Experimental Design

The experimental design was a randomized complete block design with the simulated lagoon as the experimental unit. Manure from the indoor trial was transferred to outdoor simulation lagoons with each block comprised of four different additives from four different manure pit positions. The arrangement of additives and pit positions was the same as trial 1 in the indoor experiment (Table 3.2). Only one outdoor trial was conducted providing four replications of each additive.

3.3.8 Statistical Analysis

Additive effects were evaluated to determine the presence of residual effects on solids, odour and pit gases, nutrients and micronutrients and manure strength in simulated lagoon storage. The analysis of variance was based on a randomized complete block, with measurements taken on Days 49 and 63. Table 3.4 summarizes the analysis of variance. Statistical analysis was carried out in the same manner as the indoor trial.

Table 3.4: Analysis of variance for outdoor trial.

Sources of Variation	Degrees of Freedom
Block	3
Position	3
Additive	3
Error	6
Total	15

4. CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Experimental Limitations

In this experiment, a number of sources of variation were encountered. The sources of variation were either human or procedural. Human errors may have included preparation of additives and sampling procedures. Preparation of the ABC additive involved preactivation, intended to elevate the number of microorganisms in the additive. Slight differences in the preactivation procedure may have introduced some variation into ABC results. It is not believed that any major errors were made in the preactivation procedure that may have led to large variations in results. Sampling procedures for both air and slurry involved a human component. Minor deviations in the techniques used may have resulted in small variations in the results.

Procedural errors included the indoor experimental design and the analysis of air and slurry components and the transfer protocol. Regarding the indoor experimental design, the objective was to determine the effectiveness of the additives over a range of manure compositions and production rates that might exist in commercial facilities. Variation in manure production amongst pigs was controlled by separating the pigs into four pens. This arrangement led to large variations in manure composition and production rate between manure pit positions. Differences in manure production rates are displayed in

Table 4.2, and the variation in composition (chemistry) is summarized in Appendix A. In retrospect, it may have been better to conduct the experiment in 16 pens, each with nine pigs, located over the 16 manure channels. This would likely have standardized manure composition and production rate relative to manure pit position, making comparisons between additive means easier and more powerful because a large portion of the variation in the experiment would have been removed. However, this arrangement would have negated the effort to test the additives over a wide range of manure compositions and production rates.

Analyses of air and slurry components have error associated with them, but these errors were not likely to have contributed greatly to the variations that were encountered. The variation in these analyses was not likely very large because these methods are standardized methods performed by certified analytical laboratories.

The transfer protocol was likely the other largest source of variation in the experiment. The problem encountered with the transfer protocol was that relatively large volumes of manure needed to be transferred over fairly long distances and that the manure in the channels was not very homogenous. As a result of these circumstances, it appears that the ratio of solids to liquids in the manure was altered during the transfer process. It is logical that the liquids would be easier to pump and that the solids could be problematic in the transfer procedure. The problem was identified by slurry components that should be conserved through time (i.e. no emission via volatilization) being observed to have large reductions between Days 35 and 63. Table 4.1 summarizes the losses of insoluble components that occurred between these two sampling times.

It is evident that large amounts of insoluble components have been lost, in quantities that are not likely attributable to treatment effects. The pattern of losses were reasonably consistent relative to manure pit position and additive, unfortunately, no sample was taken on Day 36 to verify the efficiency of the transfer procedure. As a result, the differences between results on Days 35 and 63 were due to both additive effect and the inconsistent transfer procedure. These effects cannot be separated from one another making assessment of treatment effects for Day 49 and 63 results imprecise in most cases. Results from insoluble components were not interpretable because the exact portion of solids lost in each transfer is not known. Insoluble components were affected by the loss of solids because many of these components have a portion of their overall pool in the solid form. As we cannot calculate exactly what portion was lost, we cannot determine what the activity of the additive would have been if none were lost. Therefore, results from Days 49 and 63 for soluble and insoluble components cannot be interpreted confidently. For this reason, Day 49 and 63 results for soluble and insoluble components are displayed in Appendix B only.

However, some Day 49 and 63 results could be interpreted. Results that could still be interpreted were odour threshold and H_2S concentrations. Portions of the manure that can contribute to the production of these emissions have been lost, but correlations were made between odour threshold and H_2S concentrations and total solids concentration.

Table 4.1: Percent losses of insoluble components from Day 35 to Day 63, by additive and manure pit position (n=4).

Component	**Percent Loss by Additive (%)**			
	Control	**ABC**	**PB**	**WB**
Copper	-62	-69	-45	-42
Magnesium	-70	-80	-60	-48
Phosphorus	-56	-59	-55	-44
Total Solids	-33	-44	-28	-24
Zinc	-73	-81	-57	-56
	Percent Loss by Manure Pit Position (%)			
	1	**2**	**3**	**4**
Copper	-31	-34	-78	-88
Magnesium	-48	-46	-80	-92
Phosphorus	-33	-41	-68	-80
Total Solids	-17	-26	-41	-45
Zinc	-47	-49	-87	-96

ABC: American BioCatalysts
PB: Pit Boss
WB: Westbridge

Correlations indicate very weak relationships between solids concentrations and odour thresholds (R^2 = 0.01 to 0.18 for additives) and H_2S concentrations (R^2 = 0.00 to 0.07 for additives). Correlations for CO_2 and NH_3 were conducted, but the correlations were too high ($R^2 < 0.50$) to consider the effect of solids losses on these other parameters to be negligible. Odour thresholds and H_2S concentrations from Days 49 and 63 will be presented, but should be considered with caution due to the problem with the transfer procedure.

This section was not intended to detract from the quality of the work or the importance of the findings in this experiment. The purpose was to provide the reader with the necessary background information on the experiment to be able to interpret the findings from a proper viewpoint.

4.2 Deviations from Protocol

During the experiment two deviations from protocol occurred, leading to missing data. During the first indoor trial (July 11, 1998), pigs housed in pen 4 tore the water line for bowl waterers over channels 13 (ABC) and 14 (PB) from the wall, causing these channels to become nearly flooded. This caused a deviation in the experiment resulting in channels 13 and 14 being abandoned for this room turn. Fortunately the leaking waterline was found and repaired before channel 15 was affected. Other deviations were due to the laboratory's inability to carry out TDS and TSS analyses on samples from Days 28 and 35 in the second indoor trial. As a result of the missing data, the LSMEANS procedure was used during statistical analysis.

4.3 Interpretation of Results

In almost all of the manure components that were evaluated, the differences between additive and control means were determined not statistically significant ($P<0.05$). Insignificant results do not necessarily indicate that additives were unable to produce improvements relative to control, but were a function of the variability encountered in the measurements. All of the individual measurements indicating the variation amongst treatments and manure pit positions encountered in the experiment are summarized in Appendix C. Throughout the experiment, a high degree of variability was encountered, and an inadequate number of replicates were carried out. The combination of a high degree of variability and low number of repetitions translated into large LSDs used for mean separation during statistical analysis. These LSDs often represented a large portion of the control mean (<30%), requiring relatively large improvements to be produced by the additives to be considered statistically significant. In most cases, smaller improvements might still be practically beneficial. Thus, percent difference between the additive and control means became a valuable tool in describing additive effectiveness.

A note must also be made stating that the results from this experiment only represent the effectiveness of the three additives under a given set of operation conditions. The activity of the additives may be other than observed in this experiment if any factors (i.e. feed, manure channel depth, temperature, etc.) were different than the ones encountered in this experiment.

4.4 Environmental Conditions

Throughout the experiment, measurements were made of ambient temperature (mean, minimum and maximum), mean manure temperature, mean manure production and dilution (due to initial water addition) rates, pH and electrical conductivity. Table 4.2 summarizes these conditions.

Ambient temperature data indicated that summer and fall temperatures were quite different, with the summer trial temperature being approximately 6°C warmer than the fall temperature. Both indoor trial temperatures were slightly lower than the temperature in the outdoor trial. These temperature differences directly impacted manure temperature and pig behaviour.

Table 4.2: Mean environmental conditions in the indoor (five weeks) and outdoor (four weeks) experiments.

Condition	Indoor Experiment		Outdoor Experiment
	Trial 1 (n=16)	Trial 2 (n=16)	(n=16)
Ambient Environment			
Ambient Temperature (°C)	23.9	17.8	25.5
Min Ambient Temperature (°C)	19.7	16.5	11.2
Max Ambient Temperature (°C)	31.2	23.5	44.1
Manure Pit Positions			
Position 1			
Manure Temperature (°C)	22.5	16.3	N/A
Manure Production Rate ($L \cdot pig^{-1} \cdot day^{-1}$)	10.8	9.6	N/A
Dilution Factor (%)	9.0	9.6	N/A
pH	7.19	7.36	7.73
Electric Conductivity (mS/cm)	29.9	33.7	49.0
Position 2			
Manure Temperature (°C)	22.4	16.3	N/A
Manure Production Rate ($L \cdot pig^{-1} \cdot day^{-1}$)	10.2	5.7	N/A
Dilution Factor (%)	9.5	14.7	N/A
pH	7.14	7.32	7.74
Electric Conductivity (mS/cm)	28.2	29.4	30.5
Position 3			
Manure Temperature (°C)	22.4	16.4	N/A
Manure Production Rate ($L \cdot pig^{-1} \cdot day^{-1}$)	7.1	2.0	N/A
Dilution Factor (%)	15.3	23.5	N/A
pH	7.05	7.20	7.67
Electric Conductivity (mS/cm)	19.8	20.6	14.3
Position 4			
Manure Temperature (°C)	22.4	16.5	N/A
Manure Production Rate ($L \cdot pig^{-1} \cdot day^{-1}$)	4.5	1.3	N/A
Dilution Factor (%)	18.5	37.0	N/A
pH	6.89	7.14	7.63
Electric Conductivity (mS/cm)	18.5	18.6	16.6

Similar to the ambient temperatures, mean manure temperatures in the first trial were approximately 6°C warmer than the second trial temperatures, which may have impacted the experiment by affecting microbiology and chemistry of the manure. Higher manure temperatures can result in stimulated microbial activity, increased solubility and more rapid reaction kinetics in the manure, ultimately providing higher decomposition rates. In comparison with past studies, manure temperatures corresponded with previously reported ranges of 15 to 22°C (Zhu et al. 1997; Patni and Jui 1993). Heat-related pig behaviour modification that could influence manure composition and production rate might have included reduced feed intake, increased water intake and reduced activity.

Examination of manure production rates relative to manure pit position indicated the presence of a dunging gradient (Table 4.2). As manure pit position increased, manure production rate decreased. This observed dunging gradient was the opposite of the expected gradient. This suggested that manure production was affected by alterations in sleeping and eating patterns due to ambient air conditions. Observations suggested that the pigs tended to rest and sleep along the walls. Due to this sleeping pattern, the pigs tended to dung in the middle of the room over manure pit positions 1 and 2. This activity allowed them to avoid lying in their own excrement.

Differences in manure production rate could potentially affect gas and odour production, solids composition, nutrient and micronutrient levels and manure strength. Higher production rates should correlate with increased concentrations of these manure components. In comparison with the MWPS (1993) reported manure production rate of 5.45 to 7.26 $L \cdot pig^{-1} \cdot day^{-1}$, the mean experimental manure production rate of 6 $L \cdot pig^{-1} \cdot day^{-1}$ is considered to be representative of average commercial conditions.

Manure dilution rates varied between trials and manure pit positions. Manure production in the second indoor trial, in terms of overall volume, was lower than the first indoor trial. As a result of this difference in overall volume, the 350-L of water added before each trial represented a larger fraction of the manure volume at the end of the second trial than the first trial. Dilution rates would also affect gas and odour production, solids composition, nutrient and micronutrient concentrations and manure strength. This effect would be manifested in lower concentrations of manure components in outside manure pit positions that were diluted to higher levels than the inside manure pit positions. The combined effects of manure production and dilution rate could greatly impact chemistry and microbiology of the manure, resulting in a high degree of variability in manure composition relative to manure pit position.

Electrical conductivity and pH were measured to characterize manure chemical conditions. Electrical conductivity was used as an indicator of the amount of ions present in the manure, and was, therefore a general indicator of manure chemistry. In the experiment, the electric conductivity of each manure pit position remained either nearly constant or increased with time. This was indicative of a solubilization of manure components into ionic forms. Differences in electric conductivity relative to manure pit position were present, with the electric conductivity in manure pit position 1 being the highest and steadily decreasing to manure pit position 4. The pH measurements indicated that the manure was neutral to mildly basic and that no difference between manure pit positions was present.

4.5 Odour and Gas Evaluation

4.5.1 Odour Threshold

Odour threshold measurements from trial 1 (summer indoor and outdoor trials) and the combined indoor trials (1 and 2) are presented in Tables 4.3 and 4.4, respectively.

Differences between additive means in Trial 1 were only significantly different ($P<0.05$) on Day 63, based on log transformations of odour thresholds. The control mean odour threshold was highest on Day 28 (1,030 OU), stabilizing until Day 49 at (1,010 OU) and finally decreasing to 680 OU on Day 63. This indicated that the majority of the odour emission during this relatively hot period of the year occurred in the manure channels with some dissipation in the lagoons. The dissipation may have resulted from the transfer problem encountered between the indoor and outdoor trial.

ABC additive was the most consistently effective additive during the indoor portion of the trial, reducing the odour threshold relative to control in the range of 11 to 16%. The levels of 870 and 900 OU measured on Days 28 and 35, respectively, were the lowest of any of the additives on any of these days. In the outdoor portion of the trial, ABC was not very effective on Day 49 resulting in an odour threshold higher than the control, but on Day 63, ABC performed better, providing a 31% reduction. The reduction produced by ABC on Day 63 was the smallest of any of the additives. The PB additive did not produce any odour reductions in the indoor portion of the trial, but produced the greatest reductions in the outdoor experiment. These reductions were 16 and 66% lower than the control thresholds on Days 49 and 63. The 66% percent reduction was the only reduction that was statistically ($P<0.05$) lower than the control in the entire experiment.

Table 4.3: Means and percent differences from control means, for odour threshold (OU) and Hydrogen Sulphide (ppm) on Days 28, 35, 49 and 63 during Trial 1.

Component	Sampling Day	Treatment							
		Control		ABC		PB		WB	
		Mean	% Diff.	Mean	% Diff.	Mean	% Diff.	Mean	% Diff.
Odour Threshold (OU)*	Day 28	1030 a	0	870 a	-16	1030 a	0	1010 a	-2
	Day 35	1010 a	0	900 a	-11	1250 a	24	1220 a	21
	Day 49	1010 a	0	1070 a	6	850 a	-16	920 a	-9
	Day 63	680 a	0	470 a	-31	230 b	-66	430 a	-37
Hydrogen Sulphide (ppm)	Day 28	0.63a	0	0.97 a	54	2.62 a	316	0.91 a	44
	Day 35	2.00 a	0	0.85 a	-58	0.48 a	-76	0.60 a	-70
	Day 49	9.38 a	0	4.03 a	-57	8.09 a	-14	3.13 a	-67
	Day 63	0.56 a	0	0.41 a	-27	0.37 a	-34	0.18 a	-68

Separation of means by row using LSD, P>0.05, df = 15

* Statistics carried out on log transformations of odour threshold values

Table 4.4: Air measurement means and percent differences for the combined indoor trials.

Component	Sampling Day	Treatment								LSD
		Control		ABC		PB		WB		
		Mean	% Diff.	Mean	% Diff.	Mean	% Diff.	Mean	% Diff.	
Odour Threshold (OU)	Day 28	770 a	0	810 a	5	940 a	22	730 a	-5	*
	Day 35	1030 a	0	990 a	-4	1080 a	5	920 a	-11	*
Hydrogen Sulphide (ppm)	Day 28	0.44 a	0	0.70 a	57	1.35 a	205	0.56 a	25	0.9
	Day 35	1.19 a	0	0.51 a	-57	0.29 a	-76	0.38 a	-68	1.1
Ammonia (ppm)	Day 28	12.4 a	0	11.7 a	-6	11.8 a	-5	10.1 a	-18	8.6
	Day 35	14.9 a	0	9.9 a	-33	16.3 a	9	12.1 a	-19	6.8
Carbon Dioxide (ppm)	Day 28	770 a	0	1190 a	55	1220 a	58	1010 a	31	621
	Day 35	920 a	0	620 a	-33	1060 a	15	910 a	-1	457

Separation of means by row using LSD, P>0.05, df = 31
* Separation of means using log values of observations

The WB additive also produced good odour threshold reductions in the outdoor experiment (9 and 37%), but did not produce any substantial reductions in the indoor trial. Some of the odour threshold reductions produced by the additives tended to be slightly lower than other reported reductions (AURI 1997; Zhu et al. 1997) but were generally within the same limits suggesting that different protocols may be able to produce comparable measurements.

In terms of the first indoor trial, ABC produced the best overall odour threshold reduction. This suggests that the microbial and enzymatic activity of ABC is the best option for odour threshold reduction in the indoor manure channels. In terms of the outdoor portion of the first trial, both PB and WB additives produced good odour reductions. In the simulated lagoons, the chemical activity of the PB additive appeared to be slightly better than the habitat enhancement of WB in suppressing odour production.

When data from both indoor trials were combined (Table 4.4), differences between additive odour threshold means were not statistically significant ($P<0.05$) and the variation among means are very large. The control odour threshold was 770 OU on Day 28 and rose to 1,030 OU on Day 35. On Day 28, WB was the only additive able to produce a minor (5%) odour threshold reduction, although this reduction is of little practical significance. Both ABC (810 OU) and PB (940 OU) did not provide any reduction in odour threshold at that time. These results indicated that application of these additives does not provide any real benefit at Day 28. The same can be claimed of the additives' ability to reduce odour emissions on Day 35. On Day 35, ABC and WB were able to produce small (4 and 11%) odour threshold reductions, but these reductions are of little practical value. Pit Boss (1,080 OU) was the least effective on Day 35, resulting in an odour threshold that was 5% higher than the control. This was inconsistent with the findings of AURI (1997) where PB resulted in a 48% odour threshold reduction. The differences may be attributable to differences in barn management or environmental conditions.

Overall, it is unlikely that small improvements observed with ABC and WB additives represented either a beneficial or a detrimental effect, whereas, the 22% increase in odour threshold produced by the PB additive likely represented a noticeable difference. In general there is too much variation in odour threshold results to provide a statistical analysis with the ability to separate means with smaller differences.

When comparing odour thresholds with gas and solids concentrations from this experiment, strong correlations were not found.

4.5.2 Hydrogen Sulphide Reduction

Data from trial 1 (Table 4.3) suggest that none of the additives were able to significantly ($P<0.05$) reduce H_2S concentrations relative to control. On Day 35, the reductions ranged from 57 to 76% indicating that the additives may be suppressing the sulphur metabolism that contributes to H_2S evolution. On Day 49, the H_2S concentrations for all of the additives and the control increased several fold over the corresponding Day 35 concentrations. Many factors may have contributed to these increased concentrations, including increased temperature in the outdoor storage lagoon and partial homogenization during the transfer protocol. Once, again, caution should be used when interpreting Day 49 and 63 (outdoor) results. On Days 49 and 63, all of the additives produced reductions in H_2S concentrations in the range of 14 to 76%. From Day 35 on, ABC and PB appeared to lose some of their ability to suppress H_2S emissions while WB maintained a consistent level of reduction.

The levels of H_2S in this study are low compared to the colorimetric tube detection limit (0.2 ppm). The low control concentrations of H_2S on Days 28, 35 and 63 also indicate that reductions produced by the additives may not have been necessary to reduce health and emission concerns, but the continued suppression on Day 49 indicates that the additives may be effective at higher levels of H_2S.

Means from the combined indoor trials concurred with trial 1 findings. The variation in concentrations, as indicated by relatively large LSD values, is quite large. These large variations in H_2S concentrations were consistent with large variations observed in odour threshold and NH_3 concentration. On Day 28, none of the additives were able to reduce the mean H_2S concentration relative to control. Then on Day 35, all of the additives reduced H_2S in the range of 57 to 76%, representing substantial reductions. However, none of the reductions were statistically significant ($P<0.05$).

4.5.3 Ammonia Reduction

Reductions of ammonia concentration relative to the control concentration represent a benefit in terms of improving air quality in the barn, maintaining nitrogen in the manure and possibly, the longevity of the facility. Mean ammonia concentrations indicated no significant differences ($P<0.05$) between additives and control (Table 4.4). The absence of significant differences may have resulted from the lack of power in the experiment illustrated by LSDs of 69% of the control concentration on Day 28 and 46% of the control concentration on Day 35. Control concentrations of ammonia were 12.4 and 14.9 ppm on Days 28 and 35. This reveals a natural increase in ammonia emission resulting from native microbial and enzymatic activity in the manure and once again indicated that a 28-day retention time in the manure channels may be beneficial. This increase in NH_3 gas production was consistent with the trend observed in odour and H_2S control means. Control ammonia concentrations in this experiment were at the lower end of the previously reported ranges of 9 to 56 ppm (Heber et al. 1997; Patni and Jui 1993; Riskowski et al. 1991).

The ABC additive produced a slight reduction (6%) in ammonia concentration on Day 28 and a 33% reduction on Day 35. The PB additive also produced a slight decrease (5%) in ammonia concentration on Day 28, but failed to result in any reduction compared to control in the remainder of the experiment. Westbridge was the only additive that provided a consistent reduction in ammonia for the whole experiment. The ammonia reductions produced by WB were approximately 18% lower than the control.

In terms of overall effectiveness, all of the additives produced minor reductions in ammonia which were not statistically significant. This is in contrast to other experiments, which have generally indicated that similar products have produced NH_3 reductions in the range of 40 to 70% (AURI 1997; Heber et al. 1997; Martinez et al. 1997). Ultimately, the reductions produced by the additives were minimal and the control concentrations were not in a range that should be considered a large emission.

4.5.4 Carbon Dioxide

The majority of CO_2 in the barn is produced through pig respiration but a small fraction is produced during degradation of the manure. The manure-derived CO_2 fraction was collected and quantified, allowing an additive effect to be determined. Similar to the gases that were previously discussed, differences in CO_2 concentrations do not exhibit a significant additive effect ($P<0.05$) but a significant trial effect was observed ($P<0.05$) with the CO_2 concentrations in the first trial being larger than the second trial. Control concentrations were 770 and 920 ppm on Days 28 and 35, respectively. The increase in gas concentration through time that was previously noted for the other gases was also present in the CO_2 results, appearing to be a natural tendency in the control manure.

On Day 28, all additives resulted in CO_2 concentrations 30 to 60% higher than the control. This suggests that the additives were promoting higher rates of degradation in the manure. By Day 35, only PB maintained a higher level of CO_2 (15%), while WB was near the control level and ABC had decreased to 33% below the control level. The differences in CO_2 concentration on Day 35 suggests that PB was more effective in stimulating respiration, while the other additives began to exhibit reduced degradation rates at or below the control rate. None of the additives produced CO_2 levels that would be harmful to workers or pigs.

Considering the overall effect of the additives on air characteristics, a few general points can be made. First, a 28-day manure retention time in the manure channels would be beneficial if no treatment were available but in cases where 35 days or more were required for the operation, the additives may produce benefits. Second, the apparent ability of the additives to reduce H_2S and NH_3 concentrations does not necessarily result in corresponding odour concentration reductions. The ABC treated manure had similar or higher H_2S and NH_3 concentrations than the other treated manures, but resulted in the greatest odour concentration reduction of any of the additives.

4.6 Solids Evaluation

4.6.1 Total Solids Breakdown

A reduction in TS can have some effect on manure handling ease. No significant differences ($P<0.05$) between additive means were found (Table 4.5). Control levels on Days 28 and 35 indicated a trend of decreasing TS through time, from 43,200 to 37,300 mg/L. This suggested a natural breakdown of solids in the manure resulting from the native microbial population. In most cases the naturally occurring bacteria in the manure produced TS levels that were lower than the additive levels indicating that the additives may be of little value in TS reduction. The control levels of TS were within previously reported ranges measured by Zhu et al. (1997) and Riskowski et al. (1991).

During the indoor trial, the ABC additive did not reduce TS levels relative to control. Total Solids levels were 24 and 4% higher than the control on Days 28 and 35. Apparently, the added microbes and enzymes in the ABC additive did not promote solids breakdown in the indoor experiment, although the Day 35 level was the lowest level reached by of any of the additives.

Table 4.5: Solids measurement means and percent differences for the combined indoor trials.

Component	Sampling Day	Treatment								LSD
		Control		ABC		PB		WB		
		Mean	% Diff.	Mean	% Diff.	Mean	% Diff.	Mean	% Diff.	
Total Solids	Day 28	43200 a	0	53600 a	24	39600 a	-8	49400 a	14	20600
(mg/L)	Day 35	37300 a	0	38600 a	4	42700 a	15	45300 a	21	16000
Total Suspended Solids	Day 28	28500 a	0	38400 a	35	15300 a	-46	41100 a	44	23900
(mg/L)	Day 35	33400 a	0	35000 a	5	34800 a	4	27000 a	-19	19400
Total Dissolved Solids	Day 28	9700 a	0	11800 a	22	8800 a	-9	9400 a	-3	3820
(mg/L)	Day 35	9000 a	0	13200 a	47	10300 a	14	12500 a	39	3780
Total Volatile Solids	Day 28	33900 a	0	41800 a	23	30500 a	-10	38600 a	14	16600
(mg/L)	Day 35	27800 a	0	27200 a	-2	33100 a	19	34200 a	23	13800

Separation of means by row using LSD, P>0.05, df = 31

The PB additive resulted in TS levels with little change through time. On day 28, PB resulted in the only TS reduction (8%) produced by an additive, but it was not statistically significant. If PB were used as an additive in barns, the best management strategy to adopt might be a 28-day retention time in the manure channels to keep TS levels low. By keeping the TS levels low, manure handling might be improved. The better performance on Day 28 may have also resulted from the nature of addition of the additive. With only a single addition on the initial day of the treatment phase, perhaps the effectiveness of the additive was reduced with time. More frequent additions may have produced better results. If the retention time was in the 35-day range, this benefit might be negated because PB resulted in the second highest level of TS (42,700 mg/L) on Day 35, possibly making manure handling relatively more difficult compared to the ABC additive.

The WB additive resulted in TS levels slightly higher than control in the indoor trial, with the highest TS level on Day 35. In terms of manure handling ease (TS reduction), no real benefit above what can be expected in untreated manure channels is likely to be gained through the application of any of the additives. These results are inconsistent with other studies (Zhu et al. 1997) that have indicated that similar products have promoted TS reductions up to approximately 25%. Again, differences in the procedure and the environment may contribute to these conflicting results.

4.6.2 Solids Solubilization

In addition to solids breakdown, manure-handling ease may also be improved by solubilizing solids. To evaluate the effectiveness of the additives at solubilizing the solid fraction of the manure, both TSS and TDS levels were determined. Effective solubilization is represented by a transformation of TSS to TDS in the manure. Neither TSS nor TDS results had significant differences ($P<0.05$) among means, but the power of the experiment was again limited (Table 4.5). Least Significant Differences for separating additive means represented 84 and 58% of the control mean for TSS and 39 and 42% of the control mean for TDS on Days 28 and 35, respectively. For TDS data on Day 28, the second trial produced significantly ($P<0.05$) larger TDS concentrations than the first. The increased solubility does not seem to stem from environmental conditions like temperature. If temperature had influenced TDS results, the first trial with the higher temperature should have resulted in more solubilization.

Regarding TSS, the trend displayed by the control was an increase on Day 35 (33,400 mg/L) from the level on Day 28 (28,500 mg/L). This was accompanied by a decrease in TDS on Day 35 (9,000 mg/L) from the level on Day 28 (9,700 mg/L). This combination of increasing suspended solids and decreasing dissolved solids indicated that solubilization was not a natural tendency in the untreated manure.

The ABC additive did not appear to successfully solubilize solids relative to the control. Results indicated elevated TSS levels combined with elevated TDS levels compared to the control on both sampling days. The elevated TDS levels were indicative of increased solubilization but the elevated TSS levels reduce the impact of the solubilization.

The PB additive resulted in lower levels of TSS (46%) and TDS (9%) relative to control on Day 28, but increased to 34,800 and 10,300 mg/L of TSS and TDS respectively on Day 35. This suggests that the additive was more effective on Day 28 than Day 35. If

PB additive were used in the barn, adopting a 28-day retention time may provide more benefit in terms of solids solubilization than a 35-day retention time.

The WB additive reduced TSS, in combination with increased TDS levels from day 28 to 35. On Day 28, WB did not perform better than the control but appeared better than the control on day 35. On Day 35, TSS was reduced by 19% and TDS was increased by 39%.

4.6.3 Total Volatile Solids Evaluation

The TVS fraction is the fraction of solids that can contribute to odour and gas production. The additive effect was not found to be significant ($P<0.05$) in terms of differences between additive means (Table 4.5). Control manure was observed to decrease in TVS throughout the experiment indicating that the volatile fraction of solids was either being solubilized or converted into gas and released to the atmosphere. As solubilization was quite low in the control, it was likely released to the atmosphere.

This tendency was also observed in the ABC and WB treated manures, with the apparent decrease associated with ABC being larger. The ABC levels dropped from 41,800 to 27,200 mg/L while WB decreased from 38,600 to 34,200 mg/L. In light of these additives' performances relating to solids solubilization and gas production, it is possible that volatile solids were being solubilized rather than converted into gaseous emissions by WB, but not ABC. Still, this interpretation of these results must be made with caution because determining whether reduced TVS levels in ABC and WB treated manure represented a decrease in odour and gas production potential or a release in the form of gas is difficult. The PB additive maintained a fairly stable level of TVS throughout the experiment.

Considering the overall effect of the additives on solids, it was apparent that none of the additives produced solids reduction and only WB provided some apparent solubilization. As solids reduction is likely one of the main reasons for using the additives, the tested additives may not provide much benefit.

4.7 Nutrient Evaluation

Nutrient analyses included nitrogen (TKN and ammonium-nitrogen), phosphorus (phosphorus and ortho-phosphate) and potassium determinations. This section describes and discusses the findings of the experiment relating to nutrient levels in the manure (Table 4.6).

4.7.1 Nitrogen Retention and Availability

The two nitrogen fractions that were analyzed were TKN and ammonium, representing total oxidizable forms of nitrogen and the plant available form, respectively. Total Kjeldahl Nitrogen measurements indicate no statistically significant differences ($P<0.05$) between additive means (Table 4.6). Control TKN levels in the manure decreased with time, from 5,270 (Day 28) to 4,970 mg/L (Day 35). This indicated that a 28-day retention time may provide the best nitrogen retention if the manure was untreated, because the nitrogen metabolism likely increased with time.

Table 4.6: Nutrient, micronutrient and COD measurement means and percent differences for the combined indoor trials.

Component	Sampling Day	Treatment								LSD
		Control		ABC		PB		WB		
		Mean	% Diff.	Mean	% Diff.	Mean	% Diff.	Mean	% Diff.	
Total Kjeldahl Nitrogen	Day 28	5270 a	0	6290 a	19	5290 a	0	5070 a	-4	1760
(mg/L)	Day 35	4970 a	0	5770 a	16	5590 a	13	5300 a	7	1480
Ammonium-nitrogen	Day 28	3350 a	0	3530 a	5	3200 a	-5	3350 a	0	809
(mg/L)	Day 35	3060 a	0	3820 a	25	3550 a	16	3330 a	9	858
Phosphorus	Day 28	2010 a	0	2130 a	6	2480 a	23	2210 a	10	1335
(mg/L)	Day 35	1190 a	0	1330 a	12	1280 a	8	1240 a	4	597
Ortho-Phosphate	Day 28	660 a	0	820 a	24	640 a	-3	810 a	23	374
(mg/L)	Day 35	453 a	0	531 a	17	527 a	16	560 a	24	286
Potassium	Day 28	2220 a	0	2970 a	34	2470 a	11	2690 a	21	734
(mg/L)	Day 35	2420 a	0	3240 b	34	2630 ab	9	2820 ab	17	746
Copper	Day 28	12.4 a	0	14.6 a	18	13.8 a	12	16.2 a	31	7.8
(mg/L)	Day 35	11.5 a	0	12.1 a	5	13.4 a	17	13.4 a	17	5.7
Magnesium	Day 28	530 a	0	630 a	19	520 a	-2	660 a	25	326
(mg/L)	Day 35	532 a	0	551 a	4	546 a	3	551 a	4	285
Sodium	Day 28	530 a	0	678 a	28	587 a	11	623 a	18	158
(mg/L)	Day 35	525 a	0	692 a	32	574 a	9	619 a	18	159
Zinc	Day 28	37.92 a	0	43.37 a	14	34.43 a	-9	45.30 a	20	25.5
(mg/L)	Day 35	35.93 a	0	36.60 a	2	37.00 a	3	38.19 a	6	19
Chemical Oxygen Demand	Day 28	38800 a	0	40400 a	4	36900 a	-5	44200 a	14	15495
(mg/L)	Day 35	33000 a	0	40000 a	21	41100 a	25	40500 a	23	15958

Separation of means by row using LSD, P>0.05, df = 31

Increased nitrogen metabolism could result in losses of nitrogen in volatile forms. Control TKN values were 2 to 3 times higher than TKN measurements reported in previous experiments (Lorimer 1996; Barrington 1993).

A decline in TKN was also observed in the ABC additive from Day 28 to 35. This decline did not adversely affect the nitrogen retention associated with the additive. In spite of the losses, ABC had the highest levels of TKN on both days, with levels about 16 to 19% greater than the control. This suggests that ABC may be active in retaining nitrogen for the duration of the experiment.

Neither the WB nor PB additive displayed TKN levels higher than the control on Day 28 but both increased in TKN from Day 28 to 35. These TKN levels were maintained at 7% (WB) and 13% (PB) higher than the control on Day 35.

Ammonium-nitrogen levels representing the plant available fraction are perhaps more important in terms of immediate fertilizer value than the TKN measurements. Ammonium-nitrogen measurements indicated no significant differences ($P<0.05$) between additive means, but a significant difference ($P<0.05$) was found between trials (Table 4.6). Ammonium levels in the second trial were significantly higher than in the first trial. This may be a result of reduced ammonia production in the second trial when the temperatures were lower.

Control data indicated that the natural tendency was to maintain a relatively constant level of NH_4-N for the duration of the experiment. On days 28 and 35, the levels were 3,350 and 3,060 mg/L. This range of ammonium–nitrogen was higher than most previously reported values that ranged from 747 mg/L to 2,467 mg/L (Lorimer 1996; Barrington 1993), but below the value of 5,727 mg/L reported by Heber et al. (1997).

During the trial, ABC additive resulted in increases in NH_4-N, between days 28 and 35. On both sampling days, the levels were above the control levels by 5 to 25%. These apparent increases in available nitrogen may reflect the microbial and enzymatic activity of the additive and could be valuable in terms of fertilizer value. The PB ammonium levels also increased from Day 28 to 35 but did not result in as much being present as the ABC treatment. The ammonium level of 3,550 mg/L on Day 35 suggests a benefit of 16% more available nitrogen resulting from the chemical activity of the additive. Westbridge resulted in a consistent level of NH_4-N, providing a 9% increase relative to control on Day 35. Overall, the additives may provide some benefit in terms of nitrogen availability, especially at the retention time of 35 days.

4.7.2 Phosphorus Retention and Availability

Phosphorus retention and availability are a consideration when manure is land-applied as a fertilizer. The differences between phosphorus levels found in the additives (Table 4.6) were not statistically significant ($P<0.05$). A natural decrease in control levels was evident in the results, beginning at 2,010 mg/L on Day 28 and falling to 1,190 mg/L on Day 35. This could be due to a decrease in the rate of phosphorus addition to the manure and/or increased dilution with time. The control measurements corresponded with previously reported values ranging from approximately 1,400 to 1,500 mg/L (Heber et al. 1997; Barrington 1993).

All of the additives displayed the tendency to reduce phosphorus throughout the experiment but maintained levels higher than the control. For the indoor trial, all of the additives showed similar concentrations suggesting that their modes of action promoted similar phosphorus retention. Overall, the additives appeared to be successful, as all were able to retain phosphorus at levels above the control in the range of 4 to 23%.

Ortho-phosphate levels, representing the plant available fraction, are perhaps more important than total phosphorus measurements in terms of immediate fertilizer value. Similar to the phosphorus results, ortho-phosphate results indicated that the differences between additive means (Table 4.6) were not statistically significant ($P<0.05$). Control levels of ortho-phosphate on Days 28 and 35 were 660 and 453 mg/L, respectively. These values indicated that the control maintained approximately the same proportion of the total phosphorus in the plant available form on both sampling days.

The tendency for ortho-phosphate levels to decrease with time was present in the results representing the additives' performance. During the indoor trial, both WB and ABC were able to maintain ortho-phosphate levels at approximately 20% greater than the control. Unlike the other additives, PB was unable to promote phosphorus availability relative to control on Day 28, resulting in a 3% decrease. However, on Day 35, the PB ortho-phosphate level had rebounded to a level about 16% higher than the control. Therefore, a 35-day retention period might be the best management strategy in terms of phosphorus retention when applying PB.

These findings suggest that all of the additives might be able to provide ortho-phosphate retention compared to the control, which is a positive effect in terms of nutrient value of the manure.

4.7.3 Potassium Retention

Potassium is another essential nutrient important in the fertilizer value of the manure. Analyses were carried out to determine the ability of the additives to maintain potassium levels higher than those observed under control circumstances. On Day 28, differences between additive means were not significantly different ($P<0.05$) and on Day 35, ABC was significantly higher than the control (Table 4.6). On Day 28, the control level was 2,220 mg/L and then it increased to 2,420 mg/L on Day 35. This indicates that potassium addition exceeded the dilution of the manure between the two sampling days.

The ABC (2,970 mg/L), PB (2,470 mg/L) and WB (2,690 mg/L) levels were all higher than the control on Day 28. Day 35 results suggest that all of the additives produce benefits in terms of potassium retention but only ABC retention was significantly greater than the control. Thus, the microbial and enzymatic action of the ABC additive was much more effective than the control and slightly better than the other additives. Overall, potassium retention appeared to be an area where all of the additives were able to provide some benefit.

In terms of overall nutrient retention and availability, all of the additives appear to be able to produce benefits. The added value of increased overall and plant available nutrient concentrations from the application of the additives is one of the strongest advantages to using them. This value is passed on to the producer in terms of increased value in the manure and potential increases in crop yields.

4.8 Micronutrient Evaluation

Micronutrients in the manure are also a valuable resource when manure is applied as a fertilizer, but can also exhibit toxic effects at high levels. The objective of micronutrient analysis was to determine if any of the additives would provide micronutrient levels above control levels. The micronutrients considered in this experiment were copper, magnesium, sodium and zinc. None of the differences between additive means representing copper, magnesium or zinc concentrations (Table 4.6) were statistically significant ($P<0.05$).

The control maintained a fairly constant level of all micronutrients between Days 28 and 35. Copper and zinc levels were observed to have had a minor drop in concentration between the sampling days, while the magnesium and sodium levels remained almost identical. None of these levels appear to be in a harmful range for use as a fertilizer and adopting a 28 or 35 day retention period over the other option could derive little or no advantage.

The ABC additive maintained higher levels of all of the micronutrients than the control on both sampling days. The copper level of 14.6 mg/L on Day 28 was the second highest of the additives and the 12.1 mg/L determined for Day 35 was the lowest. This indicates that a 28-day retention period may provide more copper during landspreading. The magnesium levels of ABC on Days 28 and 35 were higher than the control by 19 and 4% indicative of a potential benefit in terms of magnesium in the fertilizer. Again, a 28-day retention period would have provided more benefit. Zinc levels in the ABC manure were highest on Day 28 (43.37 mg/L) falling to 36.60 mg/L on Day 35. This suggests that the 28-day retention time may be beneficial in terms of zinc as well. The only micronutrient concentration that increased with time was sodium, with levels of 678 mg/L on Day 28 and 692 mg/L on Day 35. Overall, the action of the ABC additive appeared to be effective in maintaining micronutrient levels higher than the control level.

The PB additive was also reasonably effective in maintaining micronutrient levels higher than control but a 35-day retention time appears to be a better management strategy. On Day 28, PB resulted in copper levels 12% greater than the control, which increased in the next seven days to 17% greater than the control. This may be a bit misleading because the actual concentration of the copper was higher on Day 28. However, it is strange that the copper level in PB was lower than the other treatments, considering that the additive itself consists of copper. The amount of additive applied to the manure was very low which may have limited some of its effectiveness.

Magnesium and zinc levels also showed increases relative to the control levels from Day 28 to 35. The concentration of magnesium went from 2% lower than the control to 3% greater than the control and the zinc levels rose from 9% less than the 3% greater than the control. Sodium measurements were the only indication of a decrease in beneficial activity of the additive relative to control on Day 35. The sodium level dropped only a small fraction, but the percentage relative to the control dropped by 2% from 11 to 9% greater than the control. Overall, the PB additive appeared to be capable of providing beneficial retention of micronutrients through its chemical activity.

The WB additive provided excellent micronutrient retention, at a level almost always greater than the other additives. The only exception to this being that the ABC sodium levels was higher. The data also indicated that a 28-day retention period would be the best management strategy when using this product, in terms of increasing micronutrient content. Copper levels were 16.2 and 13.4 mg/L on Days 28 and 35 representing 31 and 17% increases relative to control. The previously mentioned copper level, the magnesium level of 660 mg/L and the zinc level of 45.30 mg/L on Day 28 were the highest of any of the additives indicating that WB was the best additive in terms of maintaining these micronutrients at that point in time. The sodium levels of approximately 620 mg/L on Days 28 and 35 were not the highest levels observed with the treatments but still represented a beneficial retention of approximately 17% relative to the control. Overall, WB additive was likely the best additive in terms of micronutrient retention, especially if a 28-day retention strategy was adopted.

Regarding micronutrients, the overall performance of the additives is quite good. The PB additive may be the least effective additive in retaining micronutrients while both ABC and WB are very comparable. In total, all of the additives appeared capable of producing some positive retention of these critical manure components. Coupled with the effective nutrient retention and availability discussed in the previous section, the additives may be a benefit in terms of fertilizer value.

4.9 Manure Strength Reduction

Chemical Oxygen Demand (COD) was determined from the manure to be used as an indicator of the strength of the manure. To be considered beneficial, an additive should produce reductions in COD levels. None of the differences between additive means (Table 4.6) in the experiment were statistically significant ($P<0.05$). Control levels began at 38,800 mg/L on Day 28 and dropped to 33,000 mg/L on Day 35, indicating a natural tendency to decrease with time.

The ABC additive was able to produce a decrease in COD from Day 28 to 35, but these levels were both higher than the control. The PB additive produced a minor reduction in COD on Day 28, but was unable to reduce COD on the subsequent sampling day. The decrease in COD of 5% on Day 28 was the only improvement relative to the control in terms of COD reduction. This might indicate that a 28-day retention period would be the best management option in terms of COD reduction when PB was being used. Especially when considering that the level of 41,100 mg/L determined for Day 35 was the highest of any of the additives. The COD levels for WB indicate that WB provided the worst COD reduction of any of the additives on Day 28 and the second best on Day 35. Neither of these levels (44,200 and 40,500 mg/L) was a reduction relative to control. These levels were above the control by 14 to 23%. Considering all of the additives' abilities to reduce COD none appeared to provide any substantial improvements. Even the 5% reduction produced by PB on Day 28 would likely be inconsequential considering the level was still 36,900 mg/L. Regarding additive performance, it might be that the additives are in fact increasing COD levels. These findings do not agree with previous results from evaluations of similar products that have reportedly produced reductions of up to 25% (Zhu et al. 1997).

4.10 Overall Additive Performance

The overall performance of the additives was (Table 4.7):

Table 4.7: Overall performance of the three manure pit additives.

Parameter	Treatment		
	ABC	PB	WB
Odour Reduction (%)	NRed to 31%	NRed to 66%	NRed to 37%
H_2S Reduction (%)	NRed to 58%	NRed to 76%	NRed to 70%
NH_3 Reduction (%)	6 to 33%	NRed to 5%	18 to 19%
CO_2 Production (%)	NRet to 33%	15 to 58%	NRet to 31%
TS Reduction (%)	NRed	NRed to 8%	NRed
Solids Solubilization	Little/no	Little/no	Little/no
TVS Retention (%)	NRet to 23%	NRet to 19%	14 to 23%
TKN Retention (%)	16 to 19%	NRet to 13%	NRet to 7%
NH_4-N Retention (%)	5 to 25%	NRet to 16%	NRet to 9%
P Retention (%)	6 to 12%	8 to 23%	4 to 10%
OPO_4 Retention (%)	17 to 24%	NRet to 16%	23 to 24%
K Retention (%)	34%	9 to 11%	17 to 21%
Copper Retention (%)	5 to 18%	12 to 17%	17 to 31%
Magnesium Retention (%)	4 to 19%	NRet to 3%	4 to 25%
Sodium Retention (%)	28 to 32%	9 to 11%	18%
Zinc Retention (%)	2 to 14%	NRet to 3%	6 to 20%
COD Reduction (%)	NRed	NRed to 5%	NRed
Cost ($/pig)	0.07	0.19	0.02

Nred: No reduction
Nret: No Retention

4.11 Protocol Evaluation

Being that this experiment represents the first attempt to test manure pit additives on a commercial scale with greater control of environmental conditions and other factors that may contribute to variation, it is important to discuss the protocol. In general, the protocol seemed to be effective in evaluating the performance of the additives. It allowed all of the desired characteristics to be evaluated and appears to represent continuous barn activities well. One of the characteristics of the protocol that was both a strength and a weakness was the variation in manure composition that was encountered. The variation allowed the performance to be determined in a range of manure composition that might be encountered by producers but also contributed to the limited statistical power of the experiment. Another potential strength of the protocol was the evaluation over the lifespan of the manure at the facility (indoor and outdoor storage). Unfortunately, the inadequacy of the transfer from indoor to outdoor led to some relatively large problems. In future attempts to replicate this work, transferring smaller amounts of manure or using a more appropriate transfer setup would improve the study tremendously.

Other ways to improve the experiment might be to have more continuous monitoring of gas emissions, better timing of the analyses and adding or eliminating some analyses. By increasing the frequency of gas measurements, a better understanding of the emission pattern through time may be accomplished. Better timing of analyses would include the following schedule of analyses. In the indoor phase it is most appropriate to measure odour, gases and solids, while odour, gases, solids, nutrients, micronutrients and waste strength would be appropriate at the beginning and the end of the outdoor phase. The reason that some of the analyses should only be conducted during the outdoor study is that these parameters are related to land application that would follow this phase. The fate of these characteristics is related to what happens in the indoor phase but the specifics are of little consequence in terms of the overall picture. In future trials, some of the nutrient and micronutrient analyses could be omitted because the value that these analyses offer is limited and it is unclear exactly how the additives can affect these parameters. The addition of nitrate determination might be of interest in future trials as nitrate leaching during land application is of environmental relevance. On the whole, it appears that the protocol was quite successful in allowing the hypotheses that were set forward, to be tested.

5. CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

Three manure pit additives have been tested in full-scale manure channels and simulated outdoor lagoons. The experimental design allowed the effectiveness of the additives to be determined in reducing odour threshold, gas and solids concentrations and maintenance of nutrients and micronutrients. It is believed that the results are more representative of what can be obtained in a commercial operation because the experiment tests the additives under continuous manure addition by pigs with no artificial mixing of the manure.

In the evaluation of odour threshold reduction effectiveness, trial 1 results suggested that ABC was able to provide a 11 to 31% odour threshold reduction, PB was able to provide 16 to 66% odour threshold reduction and WB was able to provide a 2 to 37% odour threshold reduction. The 66% reduction in odour threshold produced by PB was the only significant reduction in the experiment. Combined indoor trial data indicated that the ABC and WB additives were only capable of reducing odour thresholds to a small degree (4 and 11%) on Day 35. These conclusions indicate that the additives may be of value depending on the requirements of the facility and the degree of odour threshold reduction that is required.

Additive effectiveness based on gas production suppression illustrated in the mean H_2S concentrations from the first trial indicated that all of the additives were capable of producing relatively large reductions in the range of 14 to 76% from Day 35 to 63. These reductions were at both high and low levels of control H_2S. Mean H_2S concentrations from both indoor trials indicated that none of the additives reduced H_2S on Day 28, but all reduced H_2S by 57 to 76% on Day 35. Regarding NH_3 concentrations in the combined indoor trials, all of the additives provided reductions. ABC produced the largest reduction on Day 35 (33%) and WB provided the most consistent reduction (18%). Similar to odour threshold, the gas suppression data indicate that the use of the additives may be warranted depending on the levels of gas production in the facility.

Additive effectiveness relating to a reduction of total solids, a solubilization of solids and a reduction of total volatile solids was fairly conclusive. In this experiment none of the additives produced practical reductions in TS that could have improved manure-handling ease. Likewise, the additives provided little or no solubilization above the levels observed in the control. The only indication of solubilization was with the WB product, but the amounts were fairly limited. Both ABC and WB produced total volatile solids reductions. The data appeared to indicate that the reductions produced by WB may have been via solubilization and by ABC via gas emissions. Overall, little or no benefit was observed regarding solids fractions in the manure, so these additives would not be recommended if these benefits were a major objective of application.

Perhaps the strongest attribute of all of the additives was the ability to maintain levels of macronutrients and micronutrients above the control levels. The ABC additive produced TKN levels 16 to 19% higher than the control for the entire experiment while slightly smaller benefits were produced by PB and WB on Day 35. The ability of the additives to maintain nitrogen in the available form, especially on Day 35 represents a potential of 9 to 25% more available nitrogen during field application. Likewise, the 4 to 23% more P in the manure relative to the control levels increases the nutrient value of the manure as a fertilizer. Of equal importance was the additives' ability to maintain ortho-phosphate levels above the control levels during the indoor trial. Improvements in the nutrient value were observed in the potassium results. The ABC additive provided increases of 34%, WB of 17 to 21% and PB of 9 to 11%, relative to control levels. Another potential benefit that was observed was that additives increased levels of copper and zinc relative to the control. These combined improvements suggest that use of the additives to improve potential crop yields when the manure is appropriately applied could be beneficial to the producer.

The results relating the additives effectiveness based on ability to reduce waste strength was also quite conclusive. None of the additives were able to reduce COD levels relative to the control. If the specific situation that these additives are employed in necessitates a reduction in waste strength, the use of these additives would not be recommended.

Overall, it appears that manure pit additives may provide some benefits to hog producers in all aspects except solids reductions and solubilization and waste strength reduction. Some control over the effectiveness of the additives may be gained by altering the retention time of the manure in the indoor channels to target the most desired improvements. However, the large variability means that it is difficult to conclusively confirm how additives will perform.

To make progress in pit additive technology, more basic, bench scale investigations are required to observe and understand the mode of action of additives. Such understanding will likely allow for more control in the variability of manure pit additive effectiveness.

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APPENDIX A

Table A1: Summary of means from all measured air components on Days 28 and 35, relative to manure pit position for combined indoor trials.

Component	Sampling Day	Manure Pit Position				LSD
		1	2	3	4	
Odour Threshold (OU)	DAY 28	890 a	840 a	910 a	980 a	372
	DAY 35	1010 a	1170 a	1290 a	1340 a	819
Hydrogen Sulphide (ppm)	DAY 28	0.61 a	0.47 a	0.56 a	1.41 a	0.9
	DAY 35	0.46 a	1.14 a	0.24 a	0.53 a	1.1
Ammonia (ppm)	DAY 28	12.3 a	13.0 a	11.8 a	8.9 a	8.6
	DAY 35	19.6 a	15.1 ab	9.8 b	8.6 b	6.8
Carbon Dioxide (ppm)	DAY 28	1190 a	1140 a	980 a	870 a	621
	DAY 35	1120 a	980 a	710 a	690 a	457

Means separation by row using LSD, $P<0.05$, df = 31

Table A2: Summary of means from all measured slurry components on Days 28 and 35, relative to manure pit position for combined indoor trials.

Component	Sampling Day	Manure Pit Position				LSD
		1	2	3	4	
Total Solids (mg/L)	DAY 28	71300 a	45500 b	33700 b	35400 b	20600
	DAY 35	67500 a	44100 b	26200 c	26100 c	16000
Total Suspended Solids (mg/L)	DAY 28	40800 a	33500 a	22500 a	26400 a	23900
	DAY 35	60500 a	31200 b	20400 b	18300 b	19400
Total Dissolved Solids (mg/L)	DAY 28	15400 a	10300 b	6100 b	8000 b	3820
	DAY 35	17200 a	12200 b	7900 c	7700 c	3780
Total Volatile Solids (mg/L)	DAY 28	55800 a	35300 b	26400 b	27400 b	16600
	DAY 35	52500 a	33000 b	18700 c	18000 c	13800
Total Kjeldahl Nitrogen (mg/L)	DAY 28	9290 a	5630 b	3560 c	3450 c	1760
	DAY 35	8940 a	6040 b	3660 c	2990 c	1480
Ammonium-nitrogen (mg/L)	DAY 28	5540 a	3490 b	2300 c	2090 c	809
	DAY 35	5480 a	3600 b	2580 c	2120 c	858
Phosphorus (mg/L)	DAY 28	3560 a	1990 b	1700 b	1590 b	1335
	DAY 35	1910 a	1160 b	890 b	1080 b	597
Ortho-Phosphate (mg/L)	DAY 28	1030 a	760 ab	510 b	620 b	374
	DAY 35	961 a	441 b	349 b	320 b	286
Potassium (mg/L)	DAY 28	3760 a	2710 b	1870 c	2010 bc	734
	DAY 35	3970 a	2920 b	2010 c	2210 bc	746
Copper (mg/L)	DAY 28	21.0 a	15.0 ab	9.4 b	11.5 b	7.8
	DAY 35	20.3 a	11.7 b	8.2 b	10.2 b	5.7
Magnesium (mg/L)	DAY 28	790 a	640 ab	420 b	480 b	326
	DAY 35	797 a	493 b	378 b	511 ab	285
Sodium (mg/L)	DAY 28	830 a	643 b	440 c	506 bc	158
	DAY 35	835 a	624 b	443 c	508 bc	159
Zinc (mg/L)	DAY 28	65.83 a	42.11 ab	24.14 b	29.00 b	25.5
	DAY 35	62.36 a	34.21 b	22.79 b	28.31 b	19.0
Chemical Oxygen Demand (mg/L)	DAY 28	66400 a	38000 b	25300 b	30500 b	15495
	DAY 35	63500 a	41300 b	26500 bc	23200 c	15958

Means separation by row using LSD, $P<0.05$, df = 31

APPENDIX B

Table B1: Summary of air and slurry components on Day 49, relative to additives

Component	Treatment							
	Control		ABC		PB		WB	
	Mean	% Diff.	Mean	% Diff.	Mean	% Diff.	Mean	% Diff.
Odour Threshold (OU) *	1010 a	0	1070 a	6	850 a	-16	920 a	-9
Hydrogen Sulphide (ppm)	9.38 a	0	4.03 a	-57	8.09 a	-14	3.13 a	-67
Ammonia (ppm)	100	0	136	36	85	-15	131	31
Carbon Dioxide (ppm)	1480	0	2260	53	2060	39	1700	15

Means separation by row using LSD, $P<0.05$, df = 15

* Statistics carried out on log transformations of odour threshold values

Table B2: Summary of air and slurry components on Day 63, relative to additives

Component	Treatment								LSD
	Control		ABC		PB		WB		
	Lsmean	% Diff.	Lsmean	% Diff.	Lsmean	% Diff.	Lsmean	% Diff.	
Odour Threshold (OU)	680 a	0	470 a	-31	230 b	-66	430 a	-37	*
Hydrogen Sulphide (ppm)	0.56 a	0	0.41 a	-27	0.37 a	-34	0.18 a	-68	0.43
Ammonia (ppm)	5.0 a	0	10.7 a	113	6.3 a	27	4.6 a	-8	6.8
Carbon Dioxide (ppm)	431 a	0	208 a	-52	461 a	7	244 a	-43	278
Total Solids (mg/L)	29500 a	0	20500 a	-31	42100 a	43	27200 a	-8	19700
Total Suspended Solids (mg/L)	18800 a	0	7000 a	-63	32700 a	74	19000 a	1	22500
Total Dissolved Solids (mg/L)	13700 a	0	13000 a	-5	10900 a	-20	9600 a	-30	8120
Total Volatile Solids (mg/L)	19500 a	0	11400 a	-42	28700 a	47	18100 a	-7	16800
Total Kjeldahl Nitrogen (mg/L)	3880 ab	0	4230 ab	9	4730 a	22	3180 b	-18	1250
Ammonium-nitrogen (mg/L)	3400 a	0	4260 a	25	4130 a	22	2760 a	-19	1460
Phosphorus (mg/L)	620 a	0	400 a	-36	890 a	44	630 a	2	582
Ortho-Phosphate (mg/L)	388 a	0	332 a	-14	675 a	74	458 a	18	350
Potassium (mg/L)	2670 a	0	2950 a	11	3070 a	15	2170 a	-19	1062
Copper (mg/L)	6.1 a	0	3.4 a	-44	11.2 a	82	6.9 a	12	6.9
Magnesium (mg/L)	213 a	0	101 a	-53	376 a	77	272 a	28	318
Sodium (mg/L)	742 ab	0	740 ab	-0	878 a	18	605 b	-19	204
Zinc (mg/L)	13.59 a	0	6.43 a	-53	24.31 a	79	15.48 a	14	16.4
Chemical Oxygen Demand (mg/L)	40300 a	0	35300 a	-12	54800 a	36	32600 a	-19	23057

Means separation by row using LSD, $P<0.05$, df = 15

* Statistics carried out on log transformations of odour threshold values

APPENDIX C

Table C1: Odour Threshold (OU) observations

Treatment	Trial	Sampling Day	Manure Pit Position			
			1	2	3	4
Control	1	28	980	880	1600	1100
		35	270	1200	2900	810
		49	4200	2400	150	700
		63	1400	3100	160	300
	2	28	360	1150	410	650
		35	230	3700	660	2100
ABC	1	28	980	1200	640	.
		35	1100	510	1900	.
		49	2900	480	1000	.
		63	730	610	610	.
	2	28	240	520	1250	1150
		35	1800	660	1300	660
PB	1	28	1300	1200	.	980
		35	2100	990	.	1100
		49	1400	2800	.	320
		63	2700	270	.	85
	2	28	1850	220	1000	720
		35	1200	730	1100	980
WB	1	28	1100	890	820	1700
		35	870	1200	630	2600
		49	1000	700	580	1800
		63	1100	380	85	990
	2	28	290	680	520	760
		35	470	380	890	1400

Table C2: Hydrogen Sulphide observations

Treatment	Trial	Sampling Day	Manure Pit Position			
			1	2	3	4
Control	1	28	0.75	0.65	0.55	1.1
		35	0.4	6	0.5	0.55
		49	30	6	1	0.5
		63	1	0.15	0.1	1
	2	28	0.15	0.5	0.15	0.25
		35	0.05	0.7	0.3	0.45
ABC	1	28	0.45	1.25	0.6	.
		35	2	0.5	0.5	.
		49	5	1.0	1.0	.
		63	0.55	0.2	0.2	.
	2	28	0.15	0	0.7	0.65
		35	0.4	0.05	0.45	0.4
PB	1	28	1.45	0.5	.	6
		35	0.2	1.5	.	0.5
		49	15	3.0	.	0.5
		63	1	0.05	.	0.1
	2	28	0.35	0.1	0.3	0.55
		35	0.2	0.05	0.3	0.3
WB	1	28	1.45	0.65	0.5	1
		35	0.2	0.2	0.55	1.5
		49	3	0.5	3	6
		63	0.3	0.15	0.05	0.2
	2	28	0.15	0.1	0.05	0.5
		35	0.2	0.1	0.1	0.25

Table C3: Ammonia observations

Treatment	Trial	Sampling Day	Manure Pit Position			
			1	2	3	4
Control	1	28	37.5	8	19	8
		35	32.5	9.5	17	11
		49	280	40	20	60
		63	6	2	5	7
	2	28	2	10	7	4.5
		35	14	24.5	2.5	11
ABC	1	28	17.5	23	5	.
		35	19	10	4	.
		49	140	40	70	.
		63	5.5	16	5.5	.
	2	28	1	17	7	3
		35	2.25	2.5	17	11
PB	1	28	9.5	16.5	.	10
		35	30	17	.	6
		49	40	75	.	75
		63	6	3	.	8
	2	28	12	10.5	3.5	9.5
		35	23	20	5.5	7.5
WB	1	28	9	9	5.5	11
		35	21	19	5	6
		49	100	160	40	225
		63	4	10.5	2	2
	2	28	10	10	25	2
		35	15	18	6	6

Table C4: Carbon Dioxide observations

Treatment	Trial	Sampling Day	Manure Pit Position			
			1	2	3	4
Control	1	28	1900	350	400	750
		35	1800	1300	600	800
		49	2000	1200	1200	1500
		63	425	400	450	450
	2	28	350	1650	350	350
		35	925	500	900	550
ABC	1	28	1000	1450	1050	.
		35	1350	450	1050	.
		49	5000	1200	1000	.
		63	125	125	375	.
	2	28	200	2150	1350	1050
		35	300	425	350	250
PB	1	28	2450	1250	.	450
		35	1875	1100	.	700
		49	1000	3600	.	1950
		63	400	550	.	300
	2	28	1550	400	1150	1100
		35	450	1900	275	950
WB	1	28	1150	650	875	550
		35	1800	1100	1050	1000
		49	1500	1300	2800	1200
		63	300	400	175	100
	2	28	950	1250	1050	1400
		35	475	1100	400	500

Table C5: Total Solids observations

Treatment	Trial	Sampling Day	Manure Pit Position			
			1	2	3	4
Control	1	28	101000	37200	51200	32800
		35	62000	34600	38400	15600
		63	79200	18300	11600	8680
	2	28	85100	25800	8860	21100
		35	70700	21500	8480	29500
ABC	1	28	65100	36800	13800	.
		35	51400	42400	17800	.
		63	34100	18900	10200	.
	2	28	73600	62900	71300	50200
		35	66800	40800	46200	26700
PB	1	28	58000	29200	.	34800
		35	92400	46800	.	24800
		63	63000	45100	.	12600
	2	28	44600	70600	26600	13900
		35	50700	75100	18800	12200
WB	1	28	74800	40200	12400	28400
		35	77200	35800	9400	21600
		63	54200	37000	8440	9040
	2	28	67900	61100	49100	64600
		35	68600	55900	46700	44400

Table C6: Total Suspended Solids observations

Treatment	Trial	Sampling Day	Manure Pit Position			
			1	2	3	4
Control	1	28	46500	55500	31500	30000
		35	102000	16000	32500	8000
		63	63500	7100	3730	734
	2	28	.	21800	4350	13700
		35	55300	11700	3000	16900
ABC	1	28	23500	18500	7000	.
		35	57000	34500	11000	.
		63	20100	2050	2000	.
	2	28	.	61900	78200	41900
		35	.	20600	33900	13900
PB	1	28	27500	13500	.	21000
		35	74000	68500	.	14000
		63	51000	39500	.	1000
	2	28	23600	.	10700	7200
		35	29400	.	9600	1800
WB	1	28	58500	22500	4500	29000
		35	61500	29000	4010	8500
		63	45000	28500	1200	1370
	2	28	.	56300	43700	63300
		35	.	32200	23600	18500

Table C7: Total Dissolved Solids observations

Treatment	Trial	Sampling Day	Manure Pit Position			
			1	2	3	4
Control	1	28	16000	9500	5990	7000
		35	14500	8510	5020	8490
		63	23000	14700	8900	8130
	2	28	.	7760	4460	7240
		35	17200	7740	3980	8200
ABC	1	28	16000	11500	992	.
		35	14500	14500	5510	.
		63	17100	18000	5500	.
	2	28	.	14300	13300	12400
		35	.	13300	15400	11500
PB	1	28	12000	11000	.	8980
		35	23000	10500	.	4500
		63	16000	9500	.	11700
	2	28	14100	.	6980	4490
		35	12400	.	6900	4360
WB	1	28	13000	2000	7510	3510
		35	17000	12000	5000	6010
		63	15000	7000	7530	8770
	2	28	.	14600	10700	12300
		35	.	16400	12800	11100

Table C8: Total Volatile Solids observations

Treatment	Trial	Sampling Day	Manure Pit Position			
			1	2	3	4
Control	1	28	81300	30200	42000	25400
		35	45600	26800	30400	12800
		63	58400	10300	5940	3500
	2	28	67000	18300	5340	14600
		35	54200	14500	4880	20500
ABC	1	28	51900	29600	11400	.
		35	36400	30400	13000	.
		63	21000	8820	5140	.
	2	28	57500	48100	55000	36600
		35	50900	29400	32700	16800
PB	1	28	45400	21800	.	27600
		35	80600	35600	.	17000
		63	43500	31400	.	5600
	2	28	32800	55000	19600	9220
		35	38300	58500	12300	7700
WB	1	28	58600	33000	6800	23800
		35	61200	27400	8600	16000
		63	39300	25200	3700	4080
	2	28	51700	46000	37300	49700
		35	52800	41600	35100	32300

Table C9: Total Kjeldahl Nitrogen observations

Treatment	Trial	Sampling Day	Manure Pit Position			
			1	2	3	4
Control	1	28	9400	5300	4800	2800
		35	9600	4400	4000	2500
		63	9100	3700	1400	1300
	2	28	11400	4280	2340	2170
		35	9000	4800	2590	2580
ABC	1	28	8100	5900	2200	.
		35	8400	6100	2100	.
		63	7700	4600	1600	.
	2	28	10400	7550	7180	5050
		35	9080	6740	6690	4130
PB	1	28	8500	4800	.	3700
		35	9500	5500	.	3200
		63	8700	4700	.	2000
	2	28	7690	9060	3250	2250
		35	7480	9520	3850	2250
WB	1	28	9000	4300	2100	2900
		35	8700	4000	2100	2400
		63	6300	3800	1200	1400
	2	28	9830	3830	3530	5080
		35	9760	7270	4500	3640

Table C10: Ammonium-Nitrogen observations

Treatment	Trial	Sampling Day	Manure Pit Position			
			1	2	3	4
Control	1	28	5460	3600	2910	1650
		35	5740	2420	2310	1830
		63	7610	3570	1190	1210
	2	28	5940	3070	2280	1670
		35	5350	2600	2400	2040
ABC	1	28	4980	3350	1540	.
		35	5870	3180	1430	.
		63	7930	5110	1490	.
	2	28	5610	4520	3490	2980
		35	5390	5010	4230	3210
PB	1	28	5660	996	.	2520
		35	5530	2770	.	2100
		63	8350	4180	.	1850
	2	28	5390	4950	2670	1760
		35	5210	5150	3240	1960
WB	1	28	5380	2570	1420	1710
		35	5140	2320	1650	1360
		63	5720	2990	1060	1260
	2	28	5930	4850	2230	2500
		35	5580	5320	3160	2370

Table C11: Phosphorus observations

Treatment	Trial	Sampling Day	Manure Pit Position			
			1	2	3	4
Control	1	28	5900	928	4300	655
		35	2000	605	1380	570
		63	1910	311	116	126
	2	28	2850	774	198	549
		35	2140	658	259	1840
ABC	1	28	4200	932	453	.
		35	2030	936	372	.
		63	650	270	226	.
	2	28	2070	2020	2260	1700
		35	1720	900	1610	1920
PB	1	28	4350	3320	.	2840
		35	2190	1720	.	643
		63	1320	967	.	128
	2	28	1520	2930	569	410
		35	1500	2370	638	281
WB	1	28	5120	3270	380	889
		35	1680	963	420	560
		63	1340	965	108	107
	2	28	2450	1720	1510	2300
		35	1990	1120	1600	1620

Table C12: Ortho-phosphate observations

Treatment	Trial	Sampling Day	Manure Pit Position			
			1	2	3	4
Control	1	28	985	592	907	256
		35	1170	208	300	314
		63	1110	246	89.1	106
	2	28	1390	537	157	383
		35	883	354	166	285
ABC	1	28	870	531	147	.
		35	1020	277	154	.
		63	567	221	187	.
	2	28	1170	1020	1220	1050
		35	786	462	779	435
PB	1	28	806	581	.	596
		35	1100	231	.	158
		63	912	857	.	96.1
	2	28	735	1400	432	331
		35	644	1190	299	230
WB	1	28	930	436	150	388
		35	978	219	279	216
		63	811	855	82.8	84.4
	2	28	1370	998	724	1360
		35	1110	585	584	640

Table C13: Potassium observations

Treatment	Trial	Sampling Day	Manure Pit Position			
			1	2	3	4
Control	1	28	3430	2020	1570	1440
		35	3680	2130	1580	1310
		63	4160	2740	2020	1760
	2	28	4140	2040	1200	2020
		35	4340	2130	1250	2830
ABC	1	28	3330	2530	1140	.
		35	3740	2900	1080	.
		63	4290	3810	1540	.
	2	28	4000	3740	3830	3480
		35	4600	3830	4120	3620
PB	1	28	3950	1880	.	1730
		35	4130	2210	.	1810
		63	4800	2860	.	2580
	2	28	3900	3980	1990	1210
		35	3730	4300	2300	1320
WB	1	28	3320	1470	1120	1280
		35	3870	1620	1140	1310
		63	3360	2030	1590	1700
	2	28	3990	4030	2980	3270
		35	3650	4230	3410	3330

Table C14: Copper observations

Treatment	Trial	Sampling Day	Manure Pit Position			
			1	2	3	4
Control	1	28	21.8	11.3	18.1	7.75
		35	22.1	5.51	10.7	5.63
		63	21.2	2.32	0.522	0.539
	2	28	29	7	1.33	4.81
		35	22.1	5.88	1.85	16.2
ABC	1	28	18.7	10.7	4.17	.
		35	18.1	8.9	3.27	.
		63	6.27	1.09	1.47	.
	2	28	20.7	16.4	19.5	14.9
		35	18.9	8.65	13.9	15.5
PB	1	28	16.8	13.1	.	16
		35	20.6	16.2	.	7.59
		63	15.5	13.1	.	0.777
	2	28	13.8	31.6	5.45	4.84
		35	16.3	27.7	6.56	3.31
WB	1	28	22.2	14	3.55	11.1
		35	19.6	9.78	3.81	4.73
		63	13.4	12.6	0.671	0.811
	2	28	25.2	15.7	14	23.2
		35	25	11.1	16.7	16.8

Table C15: Magnesium observations

Treatment	Trial	Sampling Day	Manure Pit Position			
			1	2	3	4
Control	1	28	797	534	908	302
		35	906	267	568	240
		63	725	77.1	33	15.4
	2	28	1140	326	59.1	240
		35	865	255	83.4	1010
ABC	1	28	715	479	197	.
		35	818	418	154	.
		63	124	7.95	68.3	.
	2	28	785	733	889	721
		35	667	313	614	863
PB	1	28	551	572	.	534
		35	811	760	.	296
		63	400	498	.	15.5
	2	28	534	1180	238	168
		35	604	1120	260	94
WB	1	28	839	631	172	441
		35	751	460	178	252
		63	488	551	18.8	29.2
	2	28	975	633	568	1010
		35	954	347	755	715

Table C16: Sodium observations

Treatment	Trial	Sampling Day	Manure Pit Position			
			1	2	3	4
Control	1	28	780	599	434	318
		35	802	465	334	359
		63	1010	829	602	527
	2	28	888	435	273	469
		35	916	457	282	629
ABC	1	28	761	705	293	.
		35	797	599	249	.
		63	1010	897	451	.
	2	28	840	783	802	777
		35	935	818	866	790
PB	1	28	907	521	.	513
		35	858	472	.	422
		63	1160	866	.	820
	2	28	846	849	449	303
		35	795	904	515	327
WB	1	28	753	409	260	378
		35	781	358	293	314
		63	803	618	468	530
	2	28	862	846	666	780
		35	793	919	741	785

Table C17: Zinc observations

Treatment	Trial	Sampling Day	Manure Pit Position			
			1	2	3	4
Control	1	28	54.7	30.4	50.4	23.3
		35	70	15.3	32.1	15.9
		63	48	4.71	1.09	0.571
	2	28	116	19.5	3.17	13.3
		35	76.7	16.6	4.95	48.5
ABC	1	28	47.7	28.4	11.7	.
		35	50.5	25.4	9.09	.
		63	12.4	1.11	2.49	.
	2	28	84.5	49.9	58.1	43.3
		35	62.3	25.6	43.5	47.7
PB	1	28	39.7	31.2	.	36.9
		35	56.1	43.3	.	18.7
		63	33.9	28.3	.	0.693
	2	28	41.9	92.9	13.2	9.98
		35	44.5	87.6	16.2	6.34
WB	1	28	58	38.6	8.72	30.4
		35	54.3	27.6	9.3	11
		63	31.5	29.1	0.68	0.655
	2	28	84.1	46	37.6	58.4
		35	84.5	32.3	44.5	42.6

Table C18: Chemical Oxygen Demand observations

Treatment	Trial	Sampling Day	Manure Pit Position			
			1	2	3	4
Control	1	28	85000	34200	45700	24100
		35	57900	25400	36200	17600
		63	104000	30400	15700	11000
	2	28	74700	23900	10200	19000
		35	62100	26800	10500	20600
ABC	1	28	57900	37800	18900	.
		35	63400	40400	17300	.
		63	60200	33900	13800	.
	2	28	55100	39300	38800	38200
		35	62300	38700	52900	27000
PB	1	28	62500	26300	.	37400
		35	59600	39200	.	28000
		63	79300	62200	.	21700
	2	28	43300	67400	17600	11700
		35	58600	89300	19500	12000
WB	1	28	77900	35400	14400	31000
		35	58100	29700	11700	19900
		63	62600	42900	9160	15600
	2	28	75000	40200	31200	51500
		35	85900	40500	39000	36200