University of Alberta

Land Application of Treated Swine Manure

By

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A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment

of the requirements of the degree of Master of Science in

Environmental Engineering

Department of Civil and Environmental Engineering

Edmonton, Alberta

Fall, 2005

Your file Votre référence
ISBN: 0-494-09317-X
Our file Notre référence
ISBN: 0-494-09317-X

I dedicated this manuscript to my family, teachers, and friends, for providing constant support, encouragement, tenacity, and perspective in my academic and life pursuits.

ABSTRACT

In many areas, the regionalization and growth of the swine industry has resulted in large, concentrated volumes of manure. The simplest and most efficient means of utilizing swine manure is to apply it to agricultural land. Consequently, the concern arises that manure can pose a serious threat to the quality of soil and water resources if it is not managed properly. Physical/chemical treatment methods can remove most of the total suspended solid (TSS) and total phosphorous (TP) content in liquid swine manure, but these methods do not effectively reduce the total Kjeldahl nitrogen (TKN) and organic matter contents. Soil treatment processes can be used to remove total nitrogen and organic matter from a variety of domestic and industrial waters, and from manure. So, the Nitrogen and Organic Processing Area (NOPA) system was developed to further treat the partially treated swine manure coming from a physical/chemical treatment pilot plant. The treated effluent was stored in the tank and then reused for land irrigation and fertilization in the summer.

This research was conducted to evaluate the effects of partially treated swine manure on soil and leachate characteristics for three different application rates. After the eight week application, TKN and ammonia-N significantly increased in both soil layers and there was no significant effect on TP content. There differences between the final soil characteristics for the three different rates were insignificant. Leachate TKN and NH_4-N significantly increased and there was no significant effect on TP content after manure addition. Leachate qualities showed no significant differences for the three different rates.

ACKNOWLEDGEMENTS

The completion of this thesis would not have been possible without the contributions and support of many individuals and collectives. First and foremost of these are my supervisor, Dr. Ian Buchanan, and my co-supervisor, Dr. Mohamed Gamal El-Din. It was an honor to work with individuals who processes not only exemplary professional capabilities, but also admirable personal characters. Their guidance, support, encouragement, and great skills have helped to make me a better researcher, scientist, and person.

I would like to express my sincere appreciation and gratitude to Maria Demeter, Garry Solonynko, and Nick Chernuka for support, assistance, advice, and most of all-perspective. They gave me confidence and encouragement throughout the whole project.

I would also like to acknowledge that the necessary funding, assistance, and in-kind support for this project were provided by David Bromley of David Bromley Engineering Ltd., Vancouver, BC and NSERC.

Lastly, and most of all, I have greatly appreciated the strong support, assistance, advice and encouragement of my classmates Hao Yang, Tao Jin, and Kevin Zhang. I would also like to thank the Department of Civil and Environmental Engineering for providing the facilities for this research.

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1 INTRODUCTION

1.1 Overview

Recent changes in the livestock industry have resulted in increased confinement feeding and larger concentrations of livestock (Jackson et al., 2000). These changes have been a result of both economic factors and regulations aimed at reducing the polluting effects of livestock operations, especially under the influence of a public's growing concern and awareness for environmental safety (Innes, 2000). The concentration of livestock systems has increased efficiency and improved overall economic return for animal producers. However, with the large amounts of manure produced in localized areas, manure management must be undertaken in a manner that does not contribute to soil or water pollution.

As a rapidly developing livestock industry, the swine industry also faces the same challenges. In the U.S.A, the number of hogs and pigs increased 7% from 1996 to 1997 (Kansas Agricultural Statistics, 1997). According to Alberta Agriculture, Food, and Rural Development (AAFRD) (2003), there were 14.63 million swine in Canada in 2003. With the large numbers of swine, considerable amounts of manure were produced. Based on the 1993 estimate of the world pig population of 871.87 million, the world swine population produces about 1.7 billion tonnes of liquid manure (Choudhary et al., 1996).

Because swine manure contains essential plant nutrients, the efficient use of swine manure can be an agronomically and economically viable management practice for sustainable crop production in temperate regions such as the Canadian prairies. An increase in swine production on the Canadian prairies could have a positive impact on the local economy. However, as swine operations generate large amounts of animal manure, manure storage and utilization have become important management considerations (Larson, 1991).

Manure is a useful soil amendment that can serve as a low-cost source of organic fertilizer for crop production and as a soil conditioner that may improve the chemical and physical conditions of the soil (Campbell et al., 1986). However, this remains realistic only as long as the manure is managed properly. Unrestricted repeated applications of large volumes of manure might deteriorate the quality of soils and reduce crop production (Chang et al., 1990). Currently, as a BMP (Best Management Practice) for reclaiming its fertilizer value, the land application of swine manure is being carried out in many countries. There has been growing public concern that land application of swine manure may adversely affect the environment. Two particular concerns are nitrate leaching into the groundwater and phosphorus running off into surface waters. Nitrates in groundwater are a human health concern, while phosphorus in surface water increases eutrophication, which decreases the water's usability for drinking, wildlife, and recreation. Also, soluble salts from swine manures can cause problems for crop growth and soil tilth when excessive levels accumulate in the soil.

1.2 Current Information

The swine industry is a significant part of Alberta's economy. Of the 14.63 million swine in Canada, 13.9% are in Alberta (2.03 million) (AAFRD, 2003). Utilization and storage of the manure produced annually is a significant challenge to ensure minimum adverse effects on soils, water, and air resources. Because of the limited amount of available land in the proximity of confined feeding operation feedlots, it is not always possible to apply manure through the soil at the rates recommended to achieve a balance with crop requirements. Therefore, the preliminary treatment of swine manure may be considered to reduce the intensities of nutrient contents before land application. The advantages of treating the manure before its utilization include separation of liquid and solid fractions, utilization of larger quantities of treated manure on limited areas, and the possibility of reusing treated effluents in animal barns etc. (Singh, 2005).

Several studies of swine manure treatment have been conducted in the Swine Research and Technology Center (SRTC) located at the University of Alberta Farm in Edmonton using a physical/chemical treatment pilot plant. The processes in the pilot plant include the primary settlement of fresh swine manure for 24 hours, clarification (coagulation, flocculation, and settlement) in a customized sludge blanket clarifier, and then filtration of the clarified supernatant through glass bead media filters (patented Martin filters). As a cost-effective preliminary treatment alternative, the physical/ chemical treatment method has been applied and shown to be potentially effective in removing total suspend solids (79%) and total phosphorous (78%) from animal manure. However, it could not reduce TKN and BOD_5 in swine liquid manure (Singh, 2005). The treated effluent was stored in the tank and then reused the following summer for land irrigation and fertilization.

Some investigators have suggested using simple methods through natural soil to treat a variety of domestic and industrial waters, and pig and cattle manures (Ho et al., 1990; Lam et al. 1993; Zelechwska and Rybinski, 1985). Therefore, a soil treatment system, termed the nitrogen and organic processing area (NOPA), was considered to further treat the partially treated liquid swine manure produced by the physical/chemical pilot plant. The objective was to reduce the nitrogen content, total dissolved solids, and organic matter in the liquid by using the physical/biochemical functions of soil as a bioreactor and/or biofilter.

1.3 Goals of the Research Project

This research project was conducted to evaluate the effects of the land application of treated swine manure on soils in semi-arid Alberta. The main goal of this project was to identify the proper application rate of treated swine manure to match the ability of soil treatment. The second goal of the project was to assess and quantify changes in leachate nutrient composition under different application rates, and the third goal was to assess and quantify changes in soil nutrient composition under different application rates.

2 LITERATURE REVIEW

2.1 Swine Manure Production and Characteristics

The swine industry is a significant part of Alberta's agriculture economy. Of the 14.63 million swine in Canada, 13.9% are in Alberta (2.03 million) (AAFRD, 2003). With the large numbers of swine in Alberta, there are considerable amounts of manure produced. Daily manure production (wet weight) is about 30 kg/animal unit (450 kg live weight basis) for growing swine (Midwest Plan Service, 1985). The characteristics of manure produced in animal operations depend primarily on the characteristics of the feed provided to the animals (Loehr, 1977). Swine manure can be over 90% liquid, depending on the quantity of water spilled during drinking. The manure containing less than 4% solids is termed liquid manure and that containing 4 to 10% solids is termed slurry (MWPS, 2004). ASAE (2003) published some data showing details of manure properties; these are shown in Table 2-1. The treatment and utilization of such a large amount of manure are significant challenges.

Table 2-1 Fresh manure characteristics per 1000 kg live animal per day

Parameter	Amount	Unit (wet basis)
Total manure	84	kg
Urine	39	kg
Density	990	kg/m^3
Total solids	11	kg
Volatile solids	8.5	kg
BOD_5	3.1	kg
COD	8.4	kg
pH	7.5	NA
TKN	0.52	kg
Ammonia nitrogen	0.29	kg
TP	0.18	kg
Orthophosphorus	0.12	kg
Calcium	0.33	kg
Magnesium	0.070	kg
Sodium	0.067	kg
Chloride	0.26	kg
Total Coliform	45	CFU
Fecal Coliform	18	CFU
Fecal streptococcus	530	CFU

2.2 Legislation and Regulation

The environmental consequences of livestock production and manure management are an increasing source of concern for the public and regulators/administrators (Innes, 2000). Despite the advantages of large-scale animal production, legislation in some countries limits the use of animal manure (Jongbloed and Lenis, 1998). In Alberta, spreading manure on arable land and cultivated and non-cultivated land is permitted (Agriculture Operation Practice Act, 2001). The Code of Practice for Responsible Livestock Development and Manure Management (2000) states that manure application poses a minimal risk to the environment when it is applied in appropriate locations at rates that are in balance with crop uptake. Manure utilization through land application must consider meteorological, topographical, and soil conditions together with the application time and rate to the avoid groundwater or surface water contamination. The code also indicates that odor nuisance associated with the land spreading of manure can be minimized through proper timing, method of incorporation, and frequency of application. AOPA (2001) proclaimed that the amount of manure applied must not increase the soil salinity by more than 1 dS/m, as measured by the electrical conductivity from a soil depth of 0 to 15 cm. Moreover, for the irrigated medium and fine textured soils, the amount of manure applied must not increase soil nitrate-nitrogen levels in 0 to 60 cm depth to a level that equals or exceeds 270 kg/ha. Also, for determining the land base guidelines, the crop nitrogen requirement for irrigated soil is assumed to be 112 kg/hectare.

2.3 Alternative Methods of Manure Treatment

To date, many attempts have been made to adapt municipal or industrial waste treatment technologies to treat livestock manure. The treatment process may be designed to solve odour problems, recover nutrients or energy from the manure, increase the fertilizer value, reduce the volume, or decrease the pollution potential of the manure to allow for safe discharge in the environment. In regions of very intensive production, manure management practices are strictly regulated and enforced to minimize pollution problems. In these circumstances, treatment systems can be justified economically.

As discussed in the literature, treatment processes for livestock manure fall into three categories: physical, chemical, and biological. Physical treatment systems involve such simple processes as settling, filtering, and drying to change the characteristics of the manure. Chemical treatments add something to the waste to help condition it. Biological treatments take advantage of naturally occurring microorganisms in the manure to change the properties of the waste.

2.3.1 Physical Treatment Processes

For the best management of animal manures, it is sometimes desirable to separate the solid and liquid portions of livestock manure. This can be accomplished through physical treatment for the following purposes:

- To reuse manure solids for bedding or refeeding
- To improve the treatment efficiency of vegetative infiltration areas and leach fields
- To use the liquids for flushing
- To reduce the volume of manure to be hauled

The natural settling of solids simply takes advantage of gravity to separate the solids from the liquids. Lott et al., (1994) examined solids in manure from cattle feedlots and concluded that large particles settled within 10 minutes and small particles needed extremely long settling times. The typical settling portion varied from 45 to 75% of the total solids. Zhu (2003) reported 60 to 75% suspended solids removal from liquid swine manure containing 5 to 6% total solids after 24 hours of preliminary settling in a circular settling tank.

Mechanical separation of animal manure mainly involves screening, centrifugation, and filtration/pressing. Screen separators include stationary inclined, vibrating, rotating, and in-channel flighted conveyor screens. All separators of this type involve a screen of a specified pore size that allows only solid particles smaller in size than the openings to pass through. This type of separator generally works best with manure having a solids content of less than 5% (Bicudo, 2001). Centrifugation involves solid-liquid separation using the centrifugal forces from either centrifuges or hydrocyclones to increase the settling velocity of suspended particles. These separators function best with liquid slurries of 5 to 8% solids, and are not as efficient when the solids content is lower (Sheffield et al., 2000). Filtration/pressing separators involve the application of mechanical pressure to provide additional separation of the manure slurry. They are often used to remove additional water from the separated solids portion produced following screening or centrifugation. Pieters et al. (1999) tested a chamber filter press using swine manure containing 1.5 to 2% dry matter. The maximum capacity varied from 3.3 to 5.8 depending on the size of the press-give units, such as L/min/m^2. The separation efficiency was expressed as the percent of the original mass of the respective substances in the concentrated solid fraction. The solid fraction consisted of the following percentages of the influent: 51% of the TS, 77% of the SS, 31% of the TN, 42% of the TP, and 31% of the potassium.

Drying is used primarily for volume reduction by encouraging the water to evaporate and therefore concentrating the solids. Incineration is an extension of drying. Manure is converted to an ash requiring application or disposal. Freezing has been demonstrated to improve dewatering in manure, improving settling and filtering. Tchobanoglous and Burton (1991) mentioned that self-sustaining incineration requires a manure of approximately 30% solids. A lower solids content requires supplemental fuel to sustain incineration.

Media filtration is also a solid-liquid separation process in which the liquid passes through a porous medium to remove as many fine suspended solids as possible. In the study of Szogi et al. (1997), a marl gravel media filter enclosed in a tank was used to treat swine manure after anaerobic treatment in a lagoon. It was found that the media filter achieved 54% and 50% COD and TSS removal, respectively, after one cycle.

2.3.2 Chemical Treatment Processes

Chemical treatment involves the addition of chemicals to alter the physical state of dissolved or suspended solids and to facilitate their removal by physical separation processes. This form of treatment includes chemical precipitation, particle coagulation, and particle physical transport (Zhang and Lei, 1998).

Chemical precipitation is the formation of an insoluble precipitate through the chemical reactions occurring between the ions dissolved in wastewater, such as phosphate, and the metal ions commonly added: calcium (Ca^{2+}), iron (Fe^{2+} or Fe^{3+}), or aluminum (Al^{3+}). This process is most commonly used for the removal of dissolved phosphorous in swine wastewater. Coagulation involves combining suspended particles to form settleable flocs through the addition of electrolytes or organic polymers. Finally, flocculation combines coagulated particles into large rapidly settling particles, or flocs.

The addition of alum was found to be effective in removing a significant portion of solids from liquid manure in a settling basin. The basin removed approximately 60% of the solids present in the effluent and, when amended with alum at 0.5% volume, the separation efficiency increased to approximately 70% (Worley and Das, 2000). Zhang and Lei (1998) reported that the use of a metal salt together with a polymer considerably enhanced the removal of phosphorous from manure and would potentially reduce the amount of polymer required , thus lowering the cost of chemicals.

2.3.3 Biological Treatment Processes

Manure is a biologically active material, alive with bacteria and other microorganisms that depend on the energy contained in the manure. The use of manure energy by microorganisms-microbial-activity is a natural process of decomposition. Biological treatment of manure can be used to manage the odour, nutrients, consistency, and stability of the treated manure product.

Biological treatment processes can be classified into five major groups: aerobic processes, anaerobic processes, anoxic processes, facultative processes, and combined aerobic/anoxic/anaerobic processes (Metcalf and Eddy, 2003). The processes most widely used to treat livestock manure are described in the following sections.

2.3.3.1 Anaerobic Lagoons

Anaerobic lagoons are designed to store and treat livestock manure diluted with water. A lagoon acts as a biological tank to stabilize livestock manure by taking advantage of natural processes. In the absence of oxygen, all high-strength organic wastes will be digested by anaerobic bacteria. Anaerobic lagoons for livestock manures have several advantages:

- Odours are reduced in the treated manure used for application.
- Volume is reduced due to the conversion of solids to methane gas and carbon dioxide.

Also, anaerobic lagoons for livestock manures have several limitations:

- Lagoons create odours.

- Ammonia nitrogen is lost.
- A large area is necessary.

Safley and Westerman (1992) studied a single-stage anaerobic lagoon used to treat dairy manure. Influent and lagoon liquid concentrations for several parameters were monitored. They reported that the chemical oxygen demand, total solids, volatile solids and volatile fatty acid reductions exceeded 80%. Cheng et al. (1999) measured significant reductions in COD, TS, VS, and pathogenic bacteria in the covered anaerobic lagoon. Nutrient concentrations in the storage lagoon were approximately 40 to 60% of that of a typical single-cell lagoon. Less land application area is required for subsequent nutrient removal.

2.3.3.2 Anaerobic Digesters

Anaerobic digestion is a biodegradation process which converts organic matter and produces a biogas such as methane. Anaerobic digesters are used to more fully control the anaerobic processes taking place in an anaerobic lagoon. They can produce and recover methane gas from the decomposition of manure. The application of anaerobic digestion to swine manure was used to reduce carbonaceous pollution and odour (Ra et al., 2000).

Anaerobic digesters used for livestock manures have several advantages, including small size, limited or no odour from either the digester or the treated manure, and digester gas can be used as an energy source. The disadvantage of anaerobic digestion was that the total amount of nitrogen was not reduced. Consequently, the solution to achieve nitrogen removal was to combine anaerobic digestion and denitrification (Bernet et al., 1996). Bernet et al. tested a combination of anaerobic digestion and denitrification in batch mode flasks on screened and centrifuged swine manure and showed that the denitrification performance was highly dependent on the C/NO_x-N ratio and, to a lesser extent, on the initial nitrogen oxide concentration. The complete conversion of nitrate to molecular nitrogen by denitrification was obtained when the TOC/NO_3^--N ratio was higher than 3.4.

Gronauer and Neser (2003) summarized the efficiency of anaerobic digestion processes. The process efficiency depends on the availability of nutrients and on their composition. The C:N ratio of the input material should be between 20:1 and 40:1. The pH should be between 6.8 and 7.2. The microbiological degradation of fat, protein, and other carbohydrates reduced the dry material, 83% of COD, and 81% of BOD. In practice, the degradation varied between 30% and 70% of organic matter.

2.3.3.3 Aerobic Lagoons

Aerobic lagoons stabilize livestock manure through the addition of oxygen. By adding large amounts of oxygen to the manure, naturally occurring bacteria will begin to break down the waste and reduce its odour. Mechanical aerators are used in aerobic lagoons to ensure constant mixing of the manure. The aeration system is intended to continuously bring the manure to the surface, where it is exposed to air.

Animal and Poultry Waste Management Center (APWMC) (1999) reported that nutrient concentrations in the test lagoon under aerated conditions were less than those observed under non-aerated conditions. The reductions of TKN, ammonia-N, total P, and ortho-phosphate-P were 18%, 17%, 22%, and 19%, respectively.

2.3.3.4 Sequential Batch Reactors

Sequential batch reactors (SBR) are relatively compact waste treatment systems where the growth of aerobic bacteria is controlled for efficient biodegradation of organic matter and nitrification of nitrogen in the liquid. SBR showed high efficiency and flexibility for treating different types of wastewaters, such as municipal, domestic, hypersaline, tannery, brewery, dairy, swine manure, and landfill leachate (Mace and Mara-Alvarez, 2002). The use of SBR can also achieve advanced nitrogen and phosphorus removal in practice (Ra et al., 2000).

Obaja et al. (2005) conducted some experiments in a lab-scale SBR to demonstrate the feasibility of using an internal carbon source for removing biological nitrogen and phosphorus from digested piggery wastewater. They concluded that 99.8% of nitrogen and 97.8% of phosphate were removed in the SBR. APWMC (1999) also reported the efficiency of SBR for the treatment of flushed swine manure. Project results summarized that under treatment loading conditions of a 10 day hydraulic retention time, COD, volatile solids, total N, and total P were reduced by 93%, 75%, 95%, and 70%, respectively. Odour concentration intensity and odour irritation intensity were significantly reduced in both the treated effluent and bio-solids that the treatment system generated. In British Columbia, a full scale SBR manure treatment system has been operating since 1998 (BCMAFF, 1993). The final results showed that BOD and TSS reductions of over 90% were achieved under optimum conditions. Also, TN and TP reductions were 75% and 67%, respectively.

2.3.3.5 Constructed Wetlands

Constructed wetlands offer an innovative technology for the treatment of residential, commercial, and agricultural wastewater. These systems provide a number of benefits, including a natural treatment system, improvement of water quality, and potential cost savings over traditional disposal and treatment systems. In addition, a constructed wetland may be used to remove nutrients from animal manure effluents and for microbial reductions.

Poach et al. (2003) conducted some research to determine if the partial nitrification of swine wastewater prior to wetland application affects nitrogen removal by constructed wetlands. Partially nitrified and unaltered swine wastewaters from an anaerobic waste lagoon were applied to two parallel sets of constructed wetlands. The final results indicated that constructed wetlands were more efficient at removing total nitrogen from partially nitrified (64 and 78%) than from unaltered wastewater (32 and 68%). Both wetlands were effective in removing nitrate/nitrite from partially nitrified wastewater.

Knight et al. (2000) conducted a review of the literature concerning the use of constructed wetlands for treating concentrated livestock wastewaters. Types of livestock wastewater being treated by constructed wetlands include dairy manure and milkhouse wash water, runoff from concentrated cattle-feeding operations, poultry manure, swine manure, and catfish pond water. Over 1300 operational data indicated that removal rates for BOD_5, TSS, NH_4-N, TN, TP, COD, and fecal coliforms were potentially very high in concentrated wetlands receiving animal wastewaters. The average concentration reduction efficiencies were: BOD_5 65%, TSS 53%, NH_4-N 48%, TN 42%, and TP 42%.

Lee et al. (2004) employed a subsurface flow constructed wetland to treat swine manure. Three hydraulic retention times were adopted: 8.5 days, 4.3 days, and 14.7 days. The average reduction efficiencies for the three hydraulic retention times were: SS 96-99%, COD 77-84%, TP 47-59%, and TN 10-24%.

2.3.3.6 Biofiltration

Biofiltration is a biological wastewater treatment technology which uses microorganisms that consume organic compounds as a food source. Park et al. (2003) conducted a study to investigate a small sewage treatment system that could improve nitrogen and BOD_5 removal efficiency, as well as generate less solid waste, using an anaerobic-anoxic-aerobic biofiltration system. After 100 days operation, the overall removal efficiencies of COD and total nitrogen (TN) were above 94% and 70%, respectively, at the recycle ratio of 300%. Total wasted solids from the system constituted only 44% of the solids generated from a controlled activated sludge system operated at a sludge retention time of eight days.

Aerobic treatment of pre-screened flushed liquid manure for purposes of reducing COD, odour, and ammonia volatilization was accomplished by two upflow, fixed-media biofilters connected in a series (Westerman et al., 2000). The aerated biofilters, operated under warm weather conditions (27°C), were able to remove about 88% of BOD, 75% of COD, and 82% of TSS with a loading of 5.7 kg COD/m^3/day of biofilter media. The TKN, NH_3-N, and Total-N reductions averaged 84%, 94% and 61%, respectively, during warm weather, with a significant portion of the NH_3-N being converted to nitrite plus nitrate nitrogen. At higher organic loading (over 9 kg COD/m^3/day) during September, the biofilters had only slightly lower percentage removal rates. Operation at lower temperatures (average of 10°C) resulted in poorer performances. The COD, TKN, NH_3-N, and Total-N removal averaged 56%, 49%, 52%, and 29%, respectively, from December through to March.

2.3.3.7 Soil Filter

A lot of studies have been carried out around the world to treat animal manure by soil filter. From 1991 to 1995, the soil purification capacity for treating pig slurry was evaluated using a hydrologically isolated field treatment plant, the so-called "Solepur" process in France (Martinez, 1996). Three operations were involved: overdosing the managed field with surplus slurry; collecting and treating the nitrate rich leachate; and irrigating the final treated water over other fields. The facility consisted of a managed field, which allows the total recovery of all the leachate water, which percolates through growing ryegrass to which the pig slurry is applied, a storage-pump-reactor system for denitrification, and a non-managed field for completing treatment. The purpose of the study was to evaluate the feasibility and performance of the Solepur process, and to determine the optimum operating conditions. With an annual nominal load of 1000 m^3/ha/yr of pig slurry, the first stage of the process, soil and biological filtration, led to the removal of 90% of nitrogen and 99.9% of phosphorous, with similar reductions in COD and BOD_5. The Solepur's final leachate contained a very low concentration of organic matter, but showed relatively high nitrate levels resulting from the oxidation of slurry nitrogen in soil. The nitrate removal was effectively achieved through batch denitrification sequences with the addition of raw pig slurry as a carbon source. A C/NO_3^-N ratio of 3:1 was found to be essential for the complete denitrification of nitrate-rich leachate.

A reed bed system is also an effective approach to treat liquid manure. Garcia et al., (2004) reported that reed beds removed 70-80% COD, 70-85% BOD_5, 40-50% ammonia, and 10-22% dissolved reactive phosphorus. Connolly et al. (2004) also showed that the reed bed system removed 44% NH_4-N in a three hour treatment by adsorption onto the reed bed media, followed by nitrification. In the process of manure treatment through a soil matrix, clogging became a problem because of the accumulation of suspended solids by sedimentation and filtration in the bed matrix, and because of the production of biomass due to the growth of microorganisms (Zhao, et al., 2004).

2.4 Nutrient Availability in Soil by Manure Land Application

Land application, the most widely used strategy which not only treats but also utilizes the animal manure, has long since been adopted around the world. Animal manures have been successfully used as agricultural soil amendments and nutrient sources for centuries. For almost 2000 years, until the advent of chemical fertilizers in the 1940's, animal manures were one of the primary sources of plant nutrients for world agriculture (Sims, 1995).

The use of manure affects nutrient availability to crops, either directly, by contributing to the nutrient pool, or indirectly, by influencing the soil chemical and physical environment (Egrinya et al., 2001). According to the soil test and crop nutrient requirements, manure application by the appropriate method can optimize the availability of nutrients in the soil.

2.4.1 Nitrogen

The availability of nutrients, particularly N, from applied manure can be influenced by the forms of the nutrients contained in the manure, and the methods and times of application. Ammonia is a form of inorganic nitrogen that is immediately available for crop use. About 20-30% of N in the organic form is estimated to be mineralized and to become available to plants. Manure with a higher content of immediately available ammonium offers greater short-term crop response. Some studies in Saskatchewan have shown that the total N content of hog manure ranges from 1.7 to 5.9 kg per 1000 L, of which 30 to 90% is ammonium (Schoenau et al., 2000). The same study reported that solid manure from cattle pens had only 10 to 20% of the total N present in the inorganic form. Beauchamp (1983) conducted some studies in Ontario and reported that the proportions of ammoniacal N were around 50, 70, and 10% of the total N for liquid dairy cattle, liquid poultry, and solid farmyard manures, respectively.

The rate, time, and method of manure application depend on numerous factors including climatic conditions, soil properties, type of crop, and rate of nutrient mineralization. Beauchamp (1983) found that the availability of N from liquid dairy cattle manure ranges from 33 to 60% with different application methods and times. The variability in the amount of N available from the manure is attributed to different degrees of ammonia volatilization, with surface applications having high volatilization loss and leading to lower N availability (Beauchamp, 1983). Likewise, Schoenau et al. (2000) reported that the availability of N from liquid hog manure effluent (of which about 50% of the N was present as ammonium) was in the range of 60 to 70% of that observed for urea applied at equivalent rates of added N in fields in east-central Saskatchewan.

Nutrient availability in soils also can be determined by soil properties. Chang et al. (1991) observed increased levels of soil total N due to 11 annual applications of solid cattle feedlot manure in southern Alberta. In the 0-30 cm depth, the total N content of the soil was increased from about 6 to 8.2 Mg/ha by applying 90 Mg/ha of manure to the non-irrigated soil, and from 6 to 12 Mg/ha by applying 180 Mg/ha of manure to the irrigated soil.

Three annual applications of dairy cattle manure at varying rates of 22.5, 45, 90, 180, and 270 Mg/ha to a silty clay loam soil in Huntsville, Alabama increased the total N and NO_3-N in the top 1-15 cm (Mugwira, 1979). By the fourth year, the 45 and 270 Mg/ha manure applications had increased the total N content of the soil by about 100% and 400%, respectively, and the NO_3-N content by 30% and 200% , respectively.

2.4.2 Phosphorus

The phosphate in fertilizers and manure is initially quite soluble and readily available. Usually, manure contains soluble phosphate, organic phosphate, and inorganic phosphate compounds that are quite available. When the fertilizer or manure phosphate comes into contact with the soil, various reactions begin to occur which make the phosphate less soluble and less available. The rates and products of these reactions are dependent on such soil conditions as pH, moisture content, temperature, and the minerals already present in the soil.

As one of the nutrients required by plants, P levels following manure application in the soil have been reported in some studies. Eghball (1999) reported increases in surface soil P levels following repeated manure applications (25.8 kg P/ha/yr). In contrast, no significant increases in extractable inorganic phosphorus levels in the soil following a single manure application were observed in east-central Saskatchewan (Schoenau et al., 1999). In a 16-week incubation experiment, soil total P was increased from 708 to 738 mg P/kg soil by a single liquid hog manure addition at the rate of 40 mg of total P/kg of soil (Qian and Schoenau, 2000a).

2.4.3 Other Nutrients

The effects of manure application on soil are manifold. It can not only increase N and P availability, but also alter the chemical properties of soil. For example, due to four annual applications of cattle feedlot manure, the potassium content in the top 15 cm of a medium-textured soil was 11 times higher than that of soil with no manure addition (Olson et al., 1998). After four years of manure application, Pratt and Lag (1977) reported that K had been removed to a depth of 90 to 120 cm below the surface in an irrigated soil. Also, manure can increase the availability of other macro and micronutrients required by plants. Chang et al. (1991) observed increased levels of soluble Ca, Mg, Na, Cl, and Zn following 11 annual cattle feedlot manure applications.

2.5 Environmental Concerns Related to Manure Land Application

2.5.1 Air Pollution

The emission of ammonia from stored and land-applied manure into the atmosphere can result in not only a significant loss of nitrogen for crop production, but can also impact the environment. A high atmospheric concentration of ammonia can result in acidification of land and water surfaces, cause plant damage, and reduce plant biodiversity in natural systems. Ammonia emissions from manure also coincide with nuisance odours. Likewise, molecular N gas (N_2) and oxides of nitrogen (NO_2) from denitrification are associated with vegetation or ecosystem changes and climatic changes.

The current United States Occupational Safety and Health Administration (OSHA) Threshold Level Volume (TLV) for ammonia is 25 ppm, with a short-term exposure limit of 35 ppm. Exposure to 300 to 500 ppm for 30 to 60 minutes might be hazardous to health (ATSDR, 1990).

Some studies have shown manure N to be the nutrient most susceptible to loss to the atmosphere, mainly via ammonia volatilization and denitrification. Loss of nitrogen following manure application seems unavoidable, but the degree of loss varies depending on the form and method of manure application.

Chantigny et al. (2004) conducted a study to evaluate ammonia volatilization following the application of anaerobically stored and digested pig slurry to a bare loamy soil. They indicated that 35% of slurry-added NH_4-N was lost as NH_3-N for both slurries after two days, and the net soil NH_4-N disappearance accounted for about 60% of slurry-added NH_4-N for both slurries after nine days. They assumed that biological processes, such as immobilization and nitrification, would play a significant role in slurry NH_4-N disappearance.

Vitosh et al. (1988) reported that 15-30% of the N from surface applied solid feedlot manure can be lost via ammonia volatilization within a period of four days. Sutton (1994) suggested that as much as 5% of the N can be lost through volatilization when liquid manure is broadcast and incorporated within three days after application. If the manure were to be injected, the loss would be only 0-2%. Hoff et al. (1981) reported that soil injection of hog manure reduced the N loss through ammonia volatilization from 12.5% to 2.5% when the manure was broadcast on the soil.

Beauchamp et al. (1982) reported that up to 33% of the surface applied ammoniacal-N in liquid dairy cattle manure was lost during a seven day period. As a result, injection is recommended as the best method of applying liquid hog manure for the purpose of reducing odour and surface runoff, while minimizing the loss of nitrogen and other valuable nutrients (Hoff et al., 1981).

Denitrification, the reduction of nitrate to molecular N or oxides of N by microbial activity, is the other major pathway for N loss in manure. Kimble et al. (1972) observed that the potential for denitrification was greater in soils from manure treated plots, as compared to those that received inorganic N. Guenzi et al. (1978) suggested that N loss by denitrification could occur following the application of large amounts of manure to field soils, and that the amount of denitrification could be raised by wet weather and warm temperature. Manure provides available C that simulates respiration in nitrifying and denitrifying soil microbes. Ammonium applied with manure would rapidly be nitrified into nitrates and thus become susceptible to denitrification. Increased consumption of diffused O_2 could create the conditions (anaerobic) required for denitrification. The denitrified nitrogen is eventually lost to the atmosphere as a molecular N gas or oxides of nitrogen.

2.5.2 Nitrate Leaching

Nitrate-N in water can cause a public health risk associated with the consumption of water containing high levels of nitrate-N by infants. The public health standard for nitrate-N in drinking water is 10 mg/L. Nitrate is a mobile form of nitrogen (not adsorbed to soil particles) and will move freely in water. When water moves through soil it will pick up and transport (leach) nitrate if it is present. This becomes a problem when the downward movement of nitrate exceeds the crop rooting depth. Therefore, nitrate leaching will pose greater problems in well-drained soils (such as sands) that receive abundant N applications (either as commercial fertilizer or animal manures) in areas with high rainfall (or irrigation) and with shallow groundwater depth. Numerous studies have evaluated the potential for the accumulation and movement of nitrate through the soil profile caused by the application of animal manures.

In southern Alberta, Chang and Entz (1996) investigated the long-term effects of annual application and movement in Dark Brown Chernozemic clay loam soils. Annual applications of feedlot manure at 0, 30, 60, and 90 Mg/ha and 0, 60, 120, and 180 Mg/ha to nonirrigated and irrigated fields, respectively, represented zero, one, two, and three times the maximum recommended rates. The results of the study indicated accumulations of nitrate in the root zone under the nonirrigated conditions and minimal leaching loss below 1.5 m, with the exception of a year with unusually high precipitation. In contrast, in the irrigated soils, significant nitrate leaching and contamination of groundwater were observed at all rates of manure application.

In a higher rainfall area, Evans et al. (1977) showed the effect of the disposal of liquid swine manures on a silt loam soil in Minnesota. The annual application rate (wet weight basis) was 636 metric tonnes/ha of liquid swine manure. The total N content averaged 9.8% for the liquid swine manure (dry weight basis). The total amount of N in the manure applications each year was about 2390 kg/ha for liquid swine manure (far exceeding any crop's N requirement). After one year of manure application, the nitrate-N levels in the top 90 cm of soil were increased by the liquid swine manures. A peak in soil nitrate concentration was observed at a depth of 45 cm with about 100 ppm nitrate-N. Little movement of nitrate was reported past 90 cm. After two years of application, nitrate-N levels were increased to a depth of 240 cm. Evans et al. (1977) concluded that the application rates were excessive, resulting in significant nitrate movement below the rooting depth of corn, the crop being grown in this case, which is usually about 150 cm.

The greatest nitrate movement occurred in years with above normal precipitation.

In Kansas, there have been several studies that examined the impact of beef manure on nitrate movement. Beginning in 1969, beef feedlot manure was applied to a silty clay loam soil near Pratt, KS (Wallingford et al., 1975). The manure was either applied annually at rates of about 28 to 68 metric tonnes/ha or in a single application of 123 to 590 metric tonnes/ha performed at the start of the study. The average N concentration of the manure was 0.92%. All treatments except the lowest one supplied N in excess of what could be removed by the corn forage and the excess N was subject to leaching. After three years of annual applications, all treatments except the lowest one showed evidence of nitrate movement to a depth of 160 cm. The higher rates of annual manure application also showed nitrate movement to a depth of 190 cm, but gave little indication of leaching to lower depths. Significant nitrate leaching was also observed from a single manure application. Nitrate analysis carried out three years after a single manure application of 230 metric tonnes/ha found increased nitrate at the 160 to 200 cm depth under the plots. The nitrate concentration was over 20 ppm at the 200 cm depth for the 481 metric tonnes/ha rate, compared with less than 5 ppm for the control. There was also some indication of elevated nitrate levels to a depth of 300 cm. With respect to crop response, corn forage yield was enhanced by annual manure application rates of 28 to 68 metric tonnes/ha and depressed by higher rates.

Researchers in other states have also evaluated the effect of manure disposal from beef feedlots on nitrate leaching. Mathers and Stewart (1974) applied beef feedlot manure at rates of 0, 22, 45, 112, and 224 metric tonnes/yr annually for three successive years to irrigated corn in western Texas. The N content of the manure ranged from 1.0 to 1.8% with an average of 1.37%. The 22 and 45 metric tonnes/ha rates maintained soil nitrate at a fairly constant level over the three year period, but higher rates caused large accumulations of nitrate in the soil profile. Accumulations of soil nitrate were small the first year but increased markedly each successive year. After three years of applying 224 metric tonnes/ha, there was over 1300 kg/ha of nitrate in the top 180 cm of soil, compared to about 200 kg/ha at the start of the study. For the 112 metric tonnes/ha rate, soil nitrate was over 900 kg/ha in the top 180 cm of soil. Researchers noted peaks in nitrate concentration at a depth of about 45 cm of 60 and 85 ppm nitrate-N for the 112 and 224 metric tonnes/ha rates, respectively, and significant nitrate accumulation below 180 cm to a depth of 360 cm. Nitrate concentrations were above 10 ppm at the 360 cm depth for the 112 and 224 metric tonnes/ha application rates. Only small differences in nitrate levels were observed below 360 cm to a depth of 600 cm, indicating that only small amounts of nitrate had leached below 360 cm. With respect to corn response, the optimum rate of manure application was 22 metric tonnes/ha.

In the study of Mathers and Stewart (1974), manure was also applied at rates of 448 and 896 metric tonnes/ha for two years. For application rates of 224 metric tonnes/ha or less, soil nitrate increased with increased application rates. However, this trend did not continue when manure was applied at higher rates. The authors concluded that application rates could be so great as to inhibit nitrification, thereby preventing mineralization of ammonium to nitrate. After two applications of 896 metric tonnes/ha, they found 65 ppm nitrate-N in the top 30 cm of soil. However, in the next 150 cm of soil, the nitrate-N concentration averaged only 2.5 ppm. After one season without manure application, the nitrate-N increased to 118 ppm in the top 120 cm of soil and considerable amounts of nitrate were found to a depth 360 cm. Mathers and Stewart suggested that denitrification occurs when very large applications of manure are made each year, and that when applications stop, the large residual N supply is nitrified causing nitrate accumulation and movement in the soil.

The potential for nitrate leaching from land application of animal manures was evident in all of the research studies reviewed. However, when manure applications were limited to the crop N requirements, there was little indication that nitrate leaching from any manure source was a threat to groundwater. Nitrate leaching can be a problem when manures are applied at excessive rates. Land application of animal manures using a 'utilization' approach, rather than being employed as a disposal mechanism, should minimize potential nitrate leaching problems.

2.5.3 Phosphorus

Unlike nitrate, phosphorus loss from soil is not a human health concern. Instead, the concern is that P increases eutrophication of fresh water streams and lakes.

Eutrophication is the overenrichment of waters with mineral nutrients. Phosphorus is generally the limiting nutrient for biological productivity in fresh water streams and lakes. Excess biological productivity increases growth of undesirable algae and aquatic weeds, which cause oxygen shortages when they senesce and decompose. This deteriorates the waters' usability for drinking, fisheries, recreation, and industry. Limiting P transport into surface waters is critical for reducing eutrophication in fresh water lakes and streams. The problems are most severe where water movement from soil to surface water is greatest and where soil P levels are highest. Since animal manures contain significant quantities of P, the potential P loss following manure applications is apparent.

Qian et al. (2004) conducted some studies about phosphorus amounts and distribution in a Saskatchewan soil. In that research, animal manures were applied to a loamy textured Black Chernozem. The concentrations of soil phosphorus in various inorganic and organic fractions were investigated in soils sampled from long-term field research plots (Dixon, SK) with a five year history of annual application of liquid swine manure or solid cattle manure. Annual rates of manure application over the five years were based on the N contents in the manures and were equivalent to 0 (control), and approximately 100 (low), 200 (medium), and 400 (high) kg total N/ha/yr. The total P concentration in the surface soil (0-15 cm) was significantly increased only by the addition of cattle manure and only in the medium and high rate treatments, as compared to the control. The most labile P fractions (Resin-P and $NaHCO_3$-P) were also significantly increased with an increasing rate of cattle manure addition. No significant increases in either soil total P or labile P fractions were observed in liquid swine manure treatments, which is attributed to the lower amount of P added with the swine manure treatment than with the cattle manure treatment. Added P in the swine manure treatment more closely matched P removal in crop harvest than in the cattle manure treatment, where more P was added than was removed by the crop.

Levels of P in animal manure vary greatly and may exist both in the organic and inorganic forms. Phosphorous ions react quickly with other ions in the soil solution, resulting in precipitation and adsorption to mineral colloids (Foth, 1990). Schoenau et al. (2000) reported that in Saskatchewan, manure P tends to be readily fixed to soils by sorption and precipitation. As a result, P leaching is not a critical problem in most soils. However, P losses can occur through runoff from manured fields leading to the eutrophication of nearby water bodies. Furthermore, the P content of surface soils directly influences the loss of P in runoff (Daniel et al., 1994). Surface water runoff is the major cause of P loss in soil. Although P losses from runoff are generally less than 5% of the applied P, concentrations of dissolved and total P often exceed the critical values associated with accelerated eutrophication (0.05 for dissolved P and 0.1 mg/L for total P) (Sharpley et al., 1994).

Field research has shown a relationship between P lost in runoff and the rate and method of P application. An increase in the amount of P lost in runoff has been reported with increased application rates of dairy manure (Mueller et al., 1984) and swine manure (Edwards and Daniels, 1994). Phosphorus loss from runoff is much greater with surface applications than when the fertilizer or manure is injected or incorporated. Incorporation of dairy manure reduced total phosphorus loss from runoff five-fold, as compared to broadcast applications without incorporation (Mueller et al., 1984).

The timing of P applications also affects the amount of P in runoff. The major portion of P loss from runoff generally results from one or two intense storms. When P applications are made during the time of the year when intense storms are most likely, then the potential for greater P loss is increased (Edwards et al., 1992). Another factor that influences P loss, particularly from manure, is the length of time between manure application and the first storm. Westerman and Overcash (1980) found a 90% reduction in P loss from poultry and swine manure applications when simulated rainfall was delayed from one hour to three days after the application. This reduction in P loss was attributed to increased time for P sorption.

The most direct method for reducing P accumulation in soil is to apply manure at lower rates. Basing manure application rates on crop P rather than N requirements reduces application rates several-fold. This prevents excessive P accumulation in soil and reduces the risk of nitrate leaching. However, this approach requires more land area for manure application and increases handling and transportation costs. Also, this may prevent application on land with a history of long-term application, since many years are required to lower soil test P levels once they have become very high. Land application of animal manures using a "utilization" approach combined with appropriate conservation practices will limit P losses to surface waters and minimize the risk of eutrophication.

2.5.4 Heavy Metals

The potential toxicity of heavy metals in the environment depends on their concentration in the soil and soil solution. Land application of animal manures may impact the heavy metal status of soils. The solubility of heavy metals in manured soils is of particular concern in areas where animal manures are applied in excess. The normal range of Cu in many plants is 5 to 20 mg/kg, with concentrations greater than 20 mg/kg causing possible toxicity (Plank, 1979). For Zn, the normal range is 20 to 100 mg/kg with toxicity generally not occurring until concentrations exceed 200 mg/kg (Plank, 1979). Macnicol and Beckett (1985) report similar critical values for plant toxicity of 21 to 40 mg/kg for Cu and 210 to 560 mg/kg for Zn.

A recent study in Saskatchewan (Qian et al., 2003) showed that three to five years of annual swine and cattle manure applications at low (100 kg N/ha) and high (400 kg N/ha) rates resulted in only small increases in total and bioavailable copper and zinc in surface soils at three study sites.

Payne et al. (1988) evaluated the effects of eight annual applications of Cu-enriched swine manure on Cu availability in three soils in Virginia. The manure averaged about

1300 mg Cu and 300 mg Zn/kg (dry weight basis). These levels were comparable to metal concentrations in other manure collected from pigs fed similar diets. They found that application of Cu at rates near the maximum safe loading rate of 280 kg Cu/ha caused no decrease in corn yield, nor any increase in Cu concentration in the grain. The Cu levels in the plant tissues increased less than 2.1 mg/kg with the highest rate of Cu additions and remained within acceptable levels. Soil Cu increased with increased Cu application, but showed little downward movement and a substantial portion of the applied Cu reverted to forms not available to plants. The lack of adverse effects from applied Cu was attributed to the relatively high soil pH (greater than 6.1) and to the conversion of applied Cu to more stable forms that were not available to plants.

King et al. (1985) reported that application of swine effluent at high rates for six years affected soil copper (Cu) concentrations, although actual concentrations were low (less than 2 mg/kg). The authors found evidence of the downward movement of Cu due to high application rates, but the treatment effects dissipated after several years. In the same study, Cu concentration in bermudagrass forage was 8 mg/kg at the low rate of effluent application and increased to 10 mg/kg when the effluent rate was increased four-fold (Burns et al., 1985), though it still remained within acceptable limits.

Van der Watt et al. (1994) evaluated the impact of poultry litter on plant uptake of Cu and Zn using three soils in a greenhouse experiment. The poultry litter contained about 1200 mg Cu and 630 mg Zn/kg and was applied at rates equivalent to 0, 15, 30, and 60 metric tonnes/ha. Metal concentrations in sorghum plant tissue ranged from 5 to 15 mg Cu/kg and 19 to 55 mg Zn/kg, all within the normal range. The authors also determined Cu and Zn concentrations in soils collected from five fields with a history of poultry litter applications. In only one field, a field that had received 60 metric tonnes/ha of poultry litter for 16 years, were Cu and Zn concentrations at possibly phytotoxic levels.

The use of animal manures is generally less likely to cause heavy metal contamination than is the use of municipal manures. Limiting the use of heavy metals as feed additives and avoiding excessive rates of manure application can usually prevent the accumulation of heavy metals in soil.

2.5.5 Soil Salinity

Animal manure varies widely in chemical composition, but generally contains a considerable amount of total salts. When applied to soil, some of these salts can be used as plant nutrients to increase productivity, but excess salts can create salinity and dispersion problems.

Hao and Chang (2003) conducted an investigation into the effect of livestock manure on soil salinity. The study reported on the impact of 25 annual cattle feedlot manure applications on the soil salinity, soluble salt content, and composition of a clay loam soil in the semi-arid region of southern Alberta, Canada. Cattle manure has been applied at rates of 0, 30, 60, and 90 Mg/ha per year under non-irrigated, and at 0, 60, 120, and

180 Mg/ha per year under irrigated conditions each fall since 1973. Soil salinity was assessed in the fall of each year before manure application by examining the electrical conductivity (EC) using saturated paste extraction methods. The soluble ions, sodium adsorption ratio (SAR), and potassium adsorption ratio (PAR) were also determined each year. Soil EC values increased with the cumulative amount of manure used over the years and the increases were greater under non-irrigated conditions than under irrigated conditions. For every tonne of salt applied through the cattle manure, the average soil EC (0–150 cm) increased by 0.1108 dS/m under non-irrigated conditions. The soluble Na^+, K^+, Mg^{2+} Cl^-, HCO_3^-, SAR, and PAR all increased with the cattle manure application and the increases were greater under non-irrigated conditions than under irrigated conditions. On the other hand, under both conditions, Ca^{2+} decreased in surface soil (0–15 cm), but increased at depths below 30 cm. The K^+ ions became the dominant cation in manured surface soil. The increases in EC and soluble ions were lower under irrigation due to greater downward movement. High rates of manure application are not sustainable because they lead to soil salinization under non-irrigated conditions and leaching losses of soluble salts that could potentially pollute groundwater under irrigated conditions.

Eleven annual applications of cattle feedlot manure at the rate of 90 Mg/ha/yr increased the electrical conductivity of a soil in southern Alberta by about 6 dS/m and the sodium adsorption ratio by about 3 $mmol^{0.5}$ (Chang et al., 1990 & 1991). Horton et al. (1981) reported that repeated annual applications of manure, which had high salt content, caused a build-up of soluble salts in the soils to the extent that crop productivity was lowered. In a study conducted in the Peace River region of Alberta, single hog manure applications to Gray Luvisolic soils at rates as high as 176 kL/ha did not pose any significant problem for soil salinity (Assefa, 2002). In the same study, however, in east-central Saskatchewan, four annual applications of cattle manure at the rate of 15 Mg/ha increased the salinity of the soil from 0.3 to 1.6 dS/m and increased the SAR from 0.7 to 1.7 at one site and from 0.3 to 0.8 at another site. Similarly, four annual applications of hog manure at the rate of 75 kL/ha raised the SAR of the soil from 0.4 to 1.3.

Mathers and Stewart (1974) reported increased soil salinity with increased rates of application of cattle feedlot manure. After three annual applications of 112 metric tonnes/ha or more, soil salinity was increased to a high enough level to decrease the germination of corn. However, rates of 45 metric tons/ha or less did not increase soil salinity concentrations above that of the control. They concluded that the optimum manure rate was 22 metric tonnes/ha. Evans et al. (1977) reported increases in soil Na and electrical conductivity following two annual applications of liquid swine manure. The application rate was 636 metric tonnes/ha and the electrical conductivity was 5.0 dS/m.

2.5.6 Groundwater Quality

Even though manure can benefit crop production through its fertilizing and soil-amendment qualities, research has shown that excess livestock manure can have a negative impact on the environment. Much public concern has arisen over the extent of groundwater and surface water contamination due to agricultural practices. The main concerns are eutrophication of water bodies resulting from the presence of phosphorus and/or nitrogen and contamination of drinking water with nitrates.

A recent study carried out in an extensive farming area in the province of Nova Scotia revealed that 13% of the wells tested had nitrate levels in excess of the Canadian drinking water standard of 10 mg/L. The study did not determine the source of the nitrates (Moerman and Briggins, 1994). Patni (1982) reported annual nitrate loss to surface drainage from manured and chemically fertilized watersheds to be similar, ranging from 5.9 to 26.4 kg/ha. Manure nutrients were applied at rates of 151-197, 45-76, and 124-151 kg/ha of N, P, and K respectively over the four years of the study. Transport of total phosphorus to surface drainage ranged from 0.1 to 0.8 kg/ha/yr and was dependent on surface clay content and soil erosion rates.

High rates of manure application have been shown to produce nitrate levels in tile outflow water in excess of 10 mg/L, even for several years after applications are stopped (Patni, 1995). However, it is not just poor manure management practices that can cause excessive nitrate levels in surface or groundwater. Nitrate levels in tile effluent can exceed 10 mg/L even when N is applied at agronomically recommended rates (Patni, 1995).

Kachonoski (1996) reported that nitrogen applications from manure or chemical fertilizer had little effect on nitrate concentrations in shallow groundwater, provided that the applications did not exceed crop nitrogen requirements. However, every kilogram of nitrogen applied in excess of crop requirements can produce a corresponding increase in nitrate pollution. In Ontario, various schedules of manure application that supplied 140 kg/ha of N resulted in average nitrate concentrations in shallow groundwater that were in excess of 10 mg/L. However, total P and K concentrations were low (Patni and Culley, 1989).

There has been limited work on the environmental effects of manure application on agricultural land in southern Alberta. Riddell and Rodvang (1992) monitored selected sites in southern Alberta and found soil nitrate-nitrogen in excess of 200 kg/ha in the lower root zone and groundwater nitrate concentrations near 100 mg/L at three of the seven sites investigated. Nitrate contamination of groundwater was most evident beneath sandy-loam soils to which high rates (60 to 150 Mg/ha) of cattle manure had been applied annually for extended periods.

To address the increasing concerns about land-applied manure affecting groundwater quality, a long term field study was carried out over a six-year period to examine the effects of different annual manure application rates on soil and groundwater quality in the County of Lethbridge in southern Alberta (Barry et al., 2003). Two field sites were established: one on a sandy-loam soil (coarse-textured site), and the other on a loam to clay-loam soil (medium-textured site). The experimental treatments included the application of commercial nitrogen (N) fertilizer at three different rates (60, 120, 180 kg N/ha/yr), the application of cattle manure at four different rates (20, 40, 60, and 120 tonnes/ha/yr on a wet-weight basis), and a control treatment, which received no manure or fertilizer applications. The average concentration of nitrate-N in the groundwater prior to the start of the study was well above the Canadian drinking water quality guideline of 10 ppm.

Manure application had no effect on groundwater nitrate-N after five annual manure applications at the medium-textured site. This supports the soil data since excess nitrate-N had not yet leached to the water table, which was about 2.7 meters below the soil surface. The highest manure application rate significantly increased the groundwater nitrate-N content at the coarse-textured site. From 1997 to 1999, the other three manure-rate treatments consistently gave groundwater nitrate-N concentrations higher than the control treatment. During this period, nitrate-N concentration increased with increases in the manure application rate. The nitrogen fertilizer treatments had no effect on the groundwater nitrate-N levels at the medium-textured site. However, the effects of the nitrogen fertilizer were less clear at the coarse-textured site. Groundwater nitrate-N levels during 1998 and 1999 tended to be higher under the 180 kg/ha treatment compared to the other application rates. This suggests that some nitrate-N from commercial fertilizer was leached to groundwater.

Finally, the authors recommend that repeated annual rates of cattle manure be less than 60 tonnes/ha (at 50% moisture content) in the short term (three to five years), particularly on coarse-textured, irrigated soils over shallow groundwater. However, much lower rates (20 or less tonnes/ha) may be required if repeated, annual applications are continued over a longer term (five to 10 or more years).

An assessment of agricultural practices on groundwater quality was also carried out in Missouri (Sievers and Fulhage, 1992). Researchers sampled 226 wells in eight sampling areas in the state. Nitrate-N was detected in 88% of the wells, while 19% exceeded the EPA drinking water standard of 10 mg/L. The number of wells exceeding 10 mg/L was consistent with results from other states. A number of factors were examined to determine the relationship between agricultural practices and well water quality. It was concluded that nitrate-N concentrations were most strongly related to well depth, with increasing nitrate-N with decreasing well depth. Little relationship was found between nitrate-N concentration and the number of livestock in an area, or the distance of the well from a livestock operation.

A study in Oklahoma looked at long-term changes in the nitrate-N content of well water (Phillips et al., 1997). Between 1993 and 1995 the authors sampled 46 wells in north central Oklahoma that had previously been sampled between 1953 and 1972. This older data provided benchmark levels of nitrate-N to determine long-term changes in nitrate-N concentrations. Over 50% of the wells (24 out of 46) had nitrate-N concentrations exceeding 10 mg/L when sampled in the 1990's, as compared to 17% (eight wells) of the wells exceeding 10 mg/L in the benchmark sample period. Seven of the 18 wells that showed increases were identified as likely having been contaminated by point source pollution, either because of poor well construction or as a result of being sited near livestock corrals on sandy soils overlying a shallow water table. In the other wells with increased nitrate-N concentrations, the authors found little indication that surface application of N materials was the cause for the elevated levels and suggested instead that they stemmed from some other non-point source.

3 MATERIALS AND METHODS

3.1 Overall Research Program

This research represents parts of the final phase of a larger research program that has included four phases over a three-year period. The first phase was carried out from 2002 to 2003, where the major objective was to investigate the best operating conditions (including preliminary settling, coagulant type and dose, rapid and slow mixing conditions, flow rate, and mode of filter operation) for swine manure treatment by physical/chemical processes at the bench and pilot scale (Zhu, 2003). The second phase was carried out from 2003 to 2004. The major objectives of this phase were to optimize the functioning of the pilot plant by investigating the best operating conditions (optimum flow rates, alum dose, and in-line pressures) for the customized sludge blanket clarifier and patented Martin filters; to simulate the treatment processes performed at the pilot plant in the laboratory under controlled conditions; to compare the results obtained from both levels to check for their relative effectiveness and consistency; and to test the feasibility of UV irradiations for the microbial reduction of treated swine manure effluents (Singh, 2005). Those two phases have been successfully completed and have provided a lot of information for later researches.

The last two phases of the full project began in May, 2004. The goal was to simulate the following proposed full-scale swine manure treatment system. Swine manure would be stored for 24 hours and then subjected to physical/chemical treatment, primarily to reduce its phosphorus and solids content. Effluent from these operations/processes would be sent to a nitrogen and organic processing area (NOPA). This area would consist of an isolated storage/treatment pond surrounded by an apron of un-vegetated land that is hydraulically isolated from the surrounding area, but linked to another pond by an under-drain system. Effluent treated by physical/chemical treatment would be stored in the NOPA pond until the following spring. This would allow for the biodegradation of much of the wastewater's organic content under anaerobic conditions, as well as some sedimentation and perhaps a small degree of pathogen reduction. The following spring, the pond's liquid contents would be irrigated over the apron area for further treatment. This soil application is intended to reduce the manure's nitrogen content, total dissolved solids, and organic matter through the physical and bio-chemical functions of soil as a bioreactor and/or biofilter. In this stage of treatment, interception, adsorption, and nitrification/denitrification processes could occur within the soil. Infiltrated water would be captured by the under-drains and directed back into the second pond, where it would be stored and present with the fully treated swine manure, ready to be reused. Figure 3-1 shows the full treatment process for the swine manure. Possible reuses include crop irrigation, barn watering, or use as livestock drinking water following dilution, if necessary. The last two phases included four projects: two of these projects involved the operation and optimization of pilot-scale physical-chemical treatment trains, and the other two projects focused on the land treatment of swine manure treated in the pilot-plants.

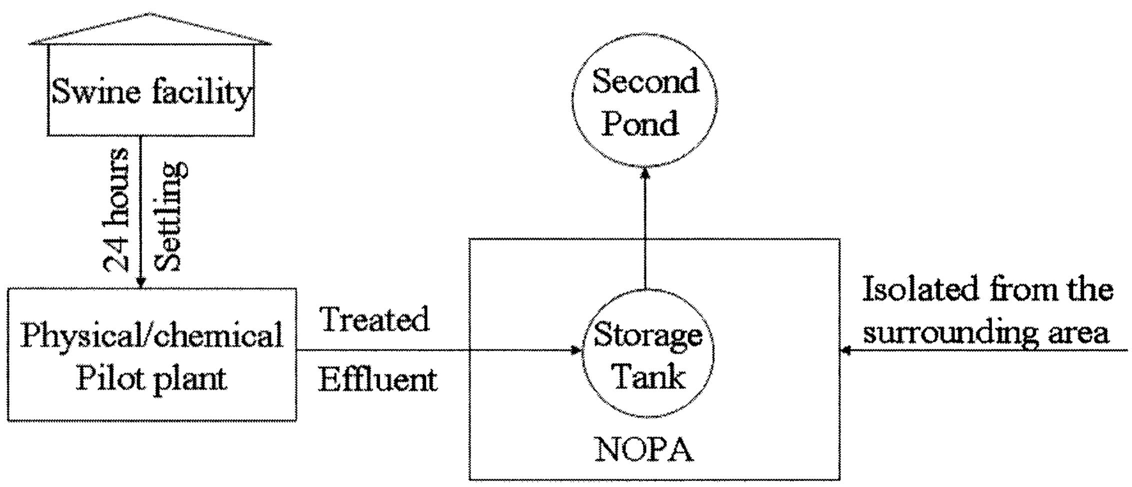


Figure 3-1 Full treatment process for swine manure

3.2 Land Application Projects

The land application project was divided into three phases and used to simulate NOPA processing. Soil columns were used to represent the actual NOPA field. There were a total of nine soil columns to which partially treated swine manure was applied. Two graduate students worked closely to complete these phases.

In Phase I, partially treated swine manure was applied to the test columns at three application rates including 12 mm/d, 25 mm/d, and 50 mm/d. The main goal was to find the best application rate suitable for liquid swine manure infiltration through the test soil. Also, soil physical and chemical characteristics were investigated and the leachate quality and quantity were determined. Nine soil columns were used with three different application rates. The nine columns were divided into groups of three, with each group being dosed at one of the three application rates. One column within each group served as a control and received only dechlorinated tap water. Prior to the application of liquid swine manure, Kentucky bluegrass sod was planted over the soil columns. If the sod could not tolerate the liquid manure and consequently died, it would be removed. All columns were operated over an eight-week period. Subsequently, the columns which had received the application rate of 25 mm/d were irrigated continually with swine manure at the rate of 17 mm/d over a two-week period and at 6 mm/d over an additional two-week period (see Table 3-1).

In Phase II, the three columns which had received the 12 mm/d application were rested without any irrigation for one and half months. The three columns that had originally received the 25 mm/d application rate were irrigated with tap water for 10 weeks. The application rate (10 mm/d) of tap water was calculated based on precipitation levels in the summer of 2004. The objective was to investigate the ability of the soil to recover after the manure application.

In Phase III, fresh soil was placed in the remaining six columns. Four of these received swine manure at an application rate of 17 mm/d, which had been determined as optimal in Phase I. This treatment was applied to bare soil for eight weeks. A fifth column was used as a control. The objective was to analyze the soil response to treated swine manure applied at the best rate. Likewise, the nitrogen budget of the whole system was determined. In order to provide more information about crop production (using collected leachate as irrigation water), bermudagrass was planted over the sixth soil column and irrigated with collected leachate.

This thesis focuses on Phase I and the tap water recover columns of Phase II. The thesis of Yang, H. (2005) focuses on the three columns to which manure was applied at the 12mm/d rate in Phase I, the rest period without irrigation in Phase II, and Phase III. A summary of the soil column treatments is shown in Table 3-1.

Table 3-1 Summary of soil column treatments

Column Number	Time				
	08-Jun-04 – 03-Aug-04	03-Aug-04 – 14-Sep-04	14-Sep-04 – 05-Oct-04	05-Oct-04 – 30-Nov-04	30-Nov-04 – 30-Jan-05
Col. 1	12 mm/d	Rest without application		Grass development	Irrigated with leachate
Col. 2	12 mm/d	Rest without application		17 mm/d, control	
Col. 3	12 mm/d, control	Rest without application		17 mm/d	
	Phase I	Phase II		Phase III	Phase III

Column Number	08-Jun-04 – 16-Aug-04	16-Aug-04 – 31-Aug-04	31-Aug-04 – 14-Sep-04	14-Sep-04 – 23-Nov-04
Col. 4	25 mm/d, control	17mm/d	6 mm/d	Tap water recovery (10 mm/d)
Col. 5	25 mm/d	17mm/d	6 mm/d	
Col. 6	25 mm/d	17mm/d	6 mm/d	
	Phase I	Phase I	Phase I	Phase II

Column Number	08-Jun-04 – 03-Aug-04	03-Aug-04 – 05-Oct-04	05-Oct-04 – 30-Nov-04
Col. 7	50 mm/d, control		17 mm/d
Col. 8	50 mm/d		17 mm/d
Col. 9	50 mm/d		17 mm/d
	Phase I		Phase III

3.3 Experimental Design

The land application project was conducted at the University of Alberta Swine Research Facility located in Edmonton, Alberta, Canada. Phase I was carried out outdoors, while Phases II III were conducted indoors at a temperature of between 24.5 and 31.5°C. The nine cylindrical columns used in this project (see Figure 3-2) were made of PVC pipes 500 mm in diameter and 1000 mm deep. Each column was fitted with an under-drain infiltration capture system. In order to reduce the volatilization of ammonia and balance the distribution of the liquid manure over the soil columns during application, some irrigation trays, made of the same material and having the same diameter were used to irrigate. Holes of 2 mm in diameter were evenly distributed over the bottoms of the irrigating trays. Locally available soil was placed in each column to a depth of 900 mm. Each soil column was divided into two layers to simulate natural soil status: top soil layer (0-300 mm) and sub soil layer (300-900 mm). The bottoms of the columns were filled with gravel to prevent the collection system from becoming clogged (see Figure 3-3).

Col 1, 2, 3 were irrigated at the application rate of 12 mm/d for eight weeks; Col 4, 5, 6 were irrigated at the application rate of 25 mm/d for eight weeks, at 17mm/d for two weeks, and then at 6 mm/d for two weeks; and Col 7, 8, 9 were irrigated at the application rate of 50 mm/d for eight weeks. Randomly, Col 3, Col 4, and Col 7 were selected as the control columns. Aged, partially treated swine manure was irrigated over the soil columns every day and infiltrated liquid (leachate) was collected through the under-drain system. Daily applications were planned, but this frequency had to be modified to allow standing liquid time to penetrate the soil following heavy rainfalls. A surface crust developed on the soil columns, which also retarded liquid penetration into the soil.

Figure 3-2 Soil column and capture system

During the application period, the irrigated swine manure and leachate were sampled and analyzed every two weeks. Also, the soil samples were collected and analyzed every two weeks. If necessary, the frequency of sampling could be increased. With respect to water samples, the following analyses were performed: pH, EC, TS, TDS, TSS, TP, TKN, Ammonia-N, Nitrate-N, Nitrite-N, TOC, BOD_5, COD, and Chloride. For soil samples, the following parameters were measured: pH, EC, Moisture Content, TN, TP, Ammonia-N, Nitrate-N, Nitrite-N, Na, Ca, Mg, SAR, and Chloride.

In Phase II, after the 12-week application of swine manure to the soil columns, three columns with a 25-17-6 mm/d application rate were recovered using tap water for more than two months. The application rate of tap water was 10mm/d, which was calculated based on precipitation levels recorded in the summer of 2004. The objective of soil column recovery was to observe the effects of rainfall on soil characteristics, to assess and quantify changes in soil nutrient composition, and to assess and quantify changes in leachate nutrient composition. During the recovery period, leachate samples were collected and analyzed every two weeks; the main parameters were pH, EC, TP, TKN, Ammonia-N, Nitrate-N, and Nitrite-N. The soil samples were analyzed at the beginning and at the end of the recovery period. The following parameters were tested: pH, EC, Moisture Content, TN, TP, Ammonia-N, Nitrate-N, Nitrite-N, Na, Ca, Mg, SAR, and Chloride.

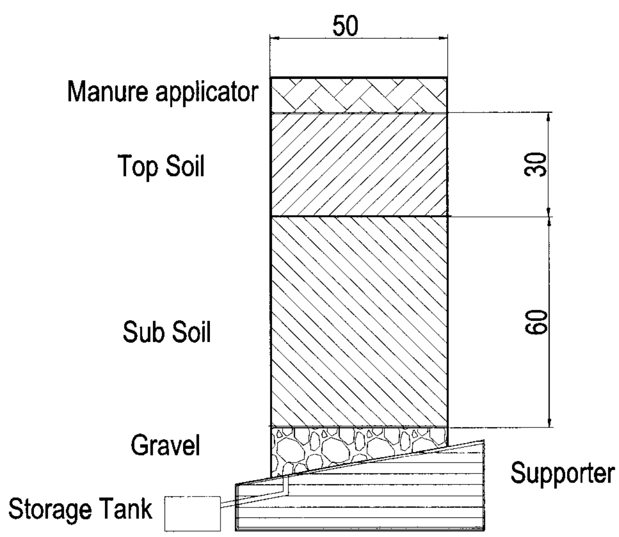


Figure 3-3 Soil column profile (cm)

3.4 Materials

3.4.1 Treated Swine Manure

In this project, partially treated swine manure was obtained from the underground tank that is isolated from the surrounding area at the University of Alberta farm. The tank contained liquid manure that had been treated in 2003 by the existing physical/chemical treatment pilot plant and then stored in this tank for six months. The characteristics of the treated swine manure were tested several times during the application period. The main parameters and their corresponding average values have been listed and tabulated in Table 3-2.

Table 3-2 Characteristics of partially treated swine manure

pH	EC (dS/m)	TS (mg/L)	TDS (mg/L)	TSS (mg/L)	TP (mg/L)	TOC (mg/L)
8.16	10.96	4527	4337	191	13	1611
TKN (mg/L)	NH_4-N (mg/L)	NO_3-N (mg/L)	NO_2-N (mg/L)	BOD_5 (mg/L)	COD (mg/L)	Chloride (mg/L)
1496	1405	0.35	0.15	3870	8118	551

3.4.2 Soil

A representative soil type was selected by David Bromley Engineering Ltd. This soil type was a candidate soil for swine manure application and had a viable indigenous microbial population. In order to simulate field status, the soil in the columns consisted of two parts: top soil layer (0-300 mm) and sub soil layer (300-900 mm). The content of the initial soils used in the land application project have been analyzed and tabulated in Tables 3-3 and 3-4.

Table 3-3 Particle content of the soils (%)

Sample ID	Clay	Silt	Sand	Type
Initial Top Soil	32.31	36.27	31.42	Clay loam
Initial Sub Soil	11.43	40.40	48.17	Loam

Table 3-4 Initial soils characteristics

Top Soil

pH	EC (dS/m)	Moisture (%)	SAR	TP (%)
8.25	0.857	25.41	0.91	0.17
TKN (%)	NH_4-N (mg/kg)	NO_3-N (mg/kg)	NO_2-N (mg/kg)	Chloride (mg/kg)
0.42	1.9	21.4	0.3	13.4

Sub Soil

pH	EC (dS/m)	Moisture (%)	SAR	TP (%)
8.27	0.904	34.1	0.82	0.06
TKN (%)	NH_4-N (mg/kg)	NO_3-N (mg/kg)	NO_2-N (mg/kg)	Chloride (mg/kg)
0.103	2.0	34.7	0.3	9.4

During the process of filling in the soil columns, a weight balance and steel tamper of around 15 kg were used to control the weight of air-dried soils in each layer. The aim was to obtain a constant density in the same layers for all the columns. Therefore, it was assumed that all the columns were identical with a top soil weight of 65.88 kg and a sub soil weight of 150.7 kg.

3.5 Manure Application

Beginning on June 08, 2004, partially treated swine manure was applied to the soil columns at the three application rates over the eight-week period. Due to clogging and the occurrence of heavy rain storms, the swine manure was not applied every day. The daily records of the applied swine manure and precipitation quantities are shown in Table 3-5 with the three application rates. For the control columns, the quantities of applied tap water were the same as those for the corresponding manured soil columns.

Starting on Aug. 16, swine manure continued to be applied to only the soil columns having received manure at the 25 mm/d rate. For the soil receiving manure at the 17 mm/d rate, four days of application were conducted at the beginning of the application period, and then application was stopped until Aug. 31. Under the 6 mm/d rate, swine manure was applied for the first four days and then application was stopped due to serious clogging. No precipitation occurred.

Table 3-5 Applied manure and precipitation quantities

Day \ Quantity	12 mm/d (mm)	25 mm/d (mm)	50 mm/d (mm)	Rain (mm)	Day \ Quantity	12 mm/d (mm)	25 mm/d (mm)	50 mm/d (mm)	Rain (mm)
1	12	25	50	0	29	12	25	0	1.3
2	12	25	50	0	30	12	0	0	7.6
3	12	25	50	0	31	12	25	50	5.5
4	12	25	50	19.8	32	0	0	0	5.1
5	12	25	50	2.5	33	0	0	0	0
6	12	25	50	0	34	0	0	0	0
7	12	25	50	2.0	35	0	0	0	85.1
8	12	25	0	1.5	36	0	0	0	0
9	12	25	0	2.0	37	0	0	0	0.3
10	12	25	0	0	38	0	0	0	0
11	12	25	0	0	39	0	0	0	0
12	12	25	0	0	40	0	0	0	0
13	12	25	0	0	41	0	0	0	18.3
14	12	25	50	0	42	0	0	0	2.5
15	12	25	50	0	43	0	0	0	3.0
16	12	25	50	0	44	12	25	50	0
17	12	25	0	0	45	12	25	0	1.9
18	12	25	0	0	46	12	25	0	1.8
19	12	0	0	0	47	12	0	0	0
20	12	25	0	0	48	0	0	0	0
21	12	25	50	0	49	12	25	50	6.6
22	12	25	0	0	50	12	25	50	1.3
23	12	25	0	0	51	12	25	0	0
24	12	25	50	0	52	12	0	0	0
25	12	25	0	0	53	12	0	0	0.6
26	12	25	50	27.7	54	0	0	0	3.2
27	12	25	50	17.8	55	12	25	50	0.4
28	12	25	50	2.3	56	0	25	50	0

3.6 Sampling

3.6.1 Leachate Sampling

After the partially treated swine manure was applied to the soil columns, the infiltrated effluents (leachate) were collected into the plastic tanks by the under-drain infiltration capture system. The leachate was sampled every two weeks, or each week starting June 08, 2004. Before sampling, the total volume of the leachate was measured and recorded. Sampled leachate was stored at $4^{o}C$ prior to analysis. The leachate for testing the phosphorous content was sampled into an acid-washed bottle in order to reduce interference. Over the first eight-week period, a total of 49 samples were collected for nine soil columns, including four raw manure samples, 15 leachate samples for the control columns, and 30 leachate samples for the soil columns to which swine manure was applied. For the 25 mm/d columns, another four-week application period was carried out after the first eight-week period. The leachate was sampled each week and a total of 14 samples were collected, including two raw manure samples, four leachate samples for the control columns, and eight leachate samples for the soil columns to which swine manure was applied.

3.6.2 Soil Sampling

Before filling the air-dried soil into the soil columns, the initial soil samples for top-soil and sub-soil were collected, stored in plastic bags at $4^{o}C$, and sent directly to the Natural Resources Analytical Laboratory of the Department of Renewable Resources at the University of Alberta. From piles of top and sub soil, the soil samples were grabbed randomly at ten positions. The composite samples were prepared as the initial soil samples for top soil and sub soil.

Starting on June 08, 2004, in Phase I of the project, soil samples were collected every two weeks using soil cores across each column at two different depths: top soil (5-25 cm) and sub soil (50-70 cm) in the soil profile. Soil samples from two layers were used in an attempt to track the vertical movement of material within the soil profile. In order to reduce the effects of sampling on the soil columns, one sample from each layer was collected randomly from each column. After sampling, the soil hole was refilled with the corresponding initial soil and care was taken to avoid the formation of a channel within the soil column. Consequently, a sample of topsoil and one of subsoil was obtained from each column, giving a total of six soil samples collected every time for each application rate, including two samples (top and sub layers) for the control column, and four samples (2 top and 2 sub layers) for the replicated soil columns.

In the period of column soil recovery started on Sep. 14, 2004, tap water was used to irrigate the soil columns that had received swine manure at 25 mm/d. In order to observe the forms and concentrations of nutrients, and the movement of nutrients within the soil profile, the soil samples were collected from each column to a depth of 90 cm in 15 or 20 cm increments on Oct. 12 and Nov. 23, 2004. Therefore, there were five soil samples collected from each column at the sampling time, including two samples of top soil and three samples of sub soil since Oct. 12, 2004.

3.7 Methods for Raw Water and Leachate Analysis

In this project, all liquid parameters were analyzed according to the Standard Methods (APHA, 1995). Storage guidelines found in the Standard Methods were also followed.

3.7.1 Total Kjeldahl Nitrogen (TKN) and Ammonia Nitrogen

The compounds of nitrogen are of great interest to environmental engineers because of their importance in the atmosphere and in the life processes of all plants and animals. The most common and important forms of nitrogen in wastewater, listed here in order of decreasing oxidation state in the water/soil environment, are ammonia (NH_3), ammonium (NH_4^+), nitrogen gas (N_2), nitrite ion (NO_2^-), and nitrate ion (NO_3^-). Total nitrogen is comprised of organic nitrogen, ammonia, nitrite, and nitrate.

The total Kjeldahl Nitrogen method is a means of determining the concentration of organic nitrogen and ammonia nitrogen. TKN was measured according to methods 4500-N_{org} B and 4500-NH_3 (APHA, 1995). The instruments used included Tecator Kjeldahl 2020 digestion, a Tecator 1026 distillation apparatus, and a Mettler-Toledo DL 50 automatic titrator. Ammonia nitrogen analysis was achieved according to method 4500-NH_3 (APHA, 1995). The Tecator 1026 distillation apparatus and the Mettler-Toledo DL 50 automatic titrator were used.

3.7.2 Nitrate and Nitrite Nitrogen

Nitrate and nitrite are sources of nitrogen, an important nutrient for plants and algae. Normally, the concentrations of nitrate and nitrite in surface and groundwater are low. For this reason, sensitive methods are needed for their measurement. An instrumental approach using ion chromatography (Dionex Corporation) was adopted as a standard procedure according to standard methods 4500-NO_2^- C and 4500-NO_3^- C (APHA, 1995).

3.7.3 Total Phosphorus (TP)

Phosphate determination has rapidly grown in importance as an environmental engineering practice. Dissolved phosphorous occurs in water systems almost entirely in the form of reactive phosphates (mostly orthophosphate), condensed phosphates (generally polyphosphates), or organically bound phosphate. Phosphorus occurring as orthophosphate can be measured quantitatively by gravimetric, volumetric, or colorimetric methods.

In this project, the colorimetric method was used to test the total phosphorous according to standard methods 4500-P B 5 and 4500-P E (APHA, 1995). A spectrophotometer (Ultraspec® 2000 Pharmacia Biotech) and autoclave were adopted.

3.7.4 Five-day Biochemical Oxygen Demand (BOD_5)

Biochemical oxygen demand (BOD) is usually defined as the amount of oxygen required by bacteria while stabilizing decomposable organic matter under aerobic conditions. The most widely used parameter of organic pollution applied to both wastewater and surface water is the five-day BOD (BOD_5). This determination involves measuring the dissolved oxygen used by microorganisms in the biochemical oxidation of organic matter. The BOD_5 test is performed more often than the longer BOD tests (such as BOD_7 and BOD_{20}) because it takes less time for completion and it avoids the nitrification process that normally occurs after five to seven days. In this project, BOD_5 was measured according to method 5210-B (APHA, 1995). A Dissolved Oxygen Meter (YSI Incorporated Model 50B) was adopted.

3.7.5 Chemical Oxygen Demand (COD)

The chemical oxygen demand (COD) test is widely used as a means of measuring the organic strength of domestic and industrial wastes. This test allows for the measurement of a waste in terms of the total quantity of oxygen required for oxidation to carbon dioxide and water (Sawyer et al., 1994). There are two methods commonly used to determine the COD of a sample: the open reflux method and the close reflux method. In this project the close reflux method was used according to standard method 5220-D (APHA, 1995). A Spectrophometer (Pharmacia Biotech Novaspec II) was adopted.

3.7.6 Total Solids (TS)

“Total solids” (TS) is the term applied to the material residue left in the vessel after evaporation of a sample and its subsequent drying in an oven at a defined temperature

(103 to 105°C). Total solids includes total suspended solids, the portion of total solids retained by a filter, and total dissolved solids, or, the portion that passes through the filter. During TS determination, a well-mixed sample is evaporated in a weighed dish and dried to constant weight in an oven heated to 103 to 105°C. The increase in weight over that of the empty dish represents the total solids. TS measurement was conducted according to standard method 2540-B (APHA, 1995).

3.7.7 Total Dissolved Solids (TDS)

Total dissolved solids is the portion of the solids that passes through a filter of 2.0 μm (or smaller) nominal pore size under specified conditions. A well-mixed sample is filtered through a standard glass fiber filter, and the filtrate is evaporated to dryness in a weighted dish and dried to constant weight at 180°C. The increase in dish weight represents the total dissolved solids. TDS measurement in this project was conducted according to standard method 2540-C (APHA, 1995).

3.7.8 Total Organic Carbon (TOC) and Total Inorganic Carbon (TIC)

The organic carbon in water and wastewater is composed of a variety of organic compounds in various oxidation states. The majority of these compounds can be easily oxidized and measured using either BOD or COD. However, some forms of carbon are not detected by either of these methods. Total organic carbon (TOC) is a convenient and direct expression of total organic content.

Total carbon can usually be divided into two categories. Total Organic Carbon includes all covalently bonded carbon atoms in the dissolved material. Total Inorganic Carbon (TIC) includes dissolved carbon dioxide, bicarbonates, and carbonates. Total Carbon (TC) is the combined total of both.

In this project, the combustion infrared method was used according to standard method 5310-B (APHA, 1995). In this method, TC and/or TOC is oxidized to carbon dioxide in a high temperature furnace (680°C), which is continually flushed with pure oxygen. The resulting oxygen/Carbon dioxide mixture is passed to the detector. The TIC can be effectively removed from a sample by oxygen stripping at low pH (purging the sample with pure oxygen) prior to analysis. Analysis to determine total inorganic carbon involves acidifying the sample so that inorganic carbon can be purged from the samples as carbon dioxide and measured directly. Carbon dioxide from either TC or TIC analysis is passed to a nondispersive infrared detector (NDIR) where it is measured directly. All samples are analyzed in reference to a blank (deionized water). Total organic carbon is determined by subtracting TIC from TC. In this project, a Dohrmann Carbon Analyzer (DC-80) was adopted.

3.7.9 pH

pH is a term used rather universally to express the intensity of the acid or alkaline condition of a solution. It is a way of expressing the hydrogen-ion concentration, or more precisely, the hydrogen-ion activity. It is important in almost every phase of environmental engineering practice. Many chemical processes are either pH dependent, or affect the pH of the system in question. pH is measured on a logarithmic scale ranging from 0 to 14, where pH < 7.0 is acidic, pH > 7.0 is basic, and pH = 7.0 is neutral (at 20°C).

$$pH = -\log[H^+]$$

Potentiometric pH determination is a direct measurement of the concentration of the H^+ ions in water. Since temperature affects both the electrode and the equilibrium of H^+, pH measurements are temperature dependant. Constant temperatures should be maintained wherever possible when determining pH (Sawyer et al., 2003). In this project, a Fisher AR 20 pH/Conductivity Meter was adopted.

3.7.10 Electrical Conductivity (EC)

The electrical conductivity (EC) of a water sample is a measure of the solution's ability to conduct an electrical current. Because the electrical current is transported by the ions in solution, the conductivity increases as the concentration of ions increases. The measured EC value can, therefore, be used as a surrogate measure of the total dissolved solids concentration. At present, the EC of a water sample is one of the most important parameters used to determine the suitability of the water for irrigation. The salinity of treated wastewater to be used for irrigation is estimated by measuring its electrical conductivity (Metcalf & Eddy, 2003). In this project, the EC values of leachate samples were determined using a Conductance- Resistance Meter (YSI Model 34) (YSI

Incorporated).

3.8 Methods for Soil Analysis

The analysis of soil samples was achieved, for the most part, by the Natural Resources Analytical Laboratory of the Department of Renewable Resources at the University of Alberta. Detailed accounts of the methods and procedures of soil analysis can be found in Maynard and Kalra (1993), Page et al. (1982), Kalra and Maynard (1991), and Kalra (1994). Here, brief introductions are provided.

3.8.1 Soil pH and EC

3.8.1.1 General Consideration

Soil pH is a measure of the activity of ionized H (H^+) in the soil solution. It is one of the most indicative measurements of the chemical properties of a soil. Total soluble salts are estimated from the electrical conductivity (EC) of aqueous soil extracts. In this project, soil pH and EC were determined by placing a soil sample in a water suspension at a ratio of 1:2 (Kalra and Maynard, 1991).

3.8.1.2 Apparatus

Fisher AR 20 pH/Conductivity Meter

3.8.1.3 Procedure

a. Weigh 10 g of 2 mm air-dried soil and place in a 100 mL beaker; add 20 mL of DI water;

b. Allow soil to absorb DI water without stirring, then thoroughly stir for 10 seconds using a glass rod;

c. Further stir suspension four or five times during the next 30 minutes;

d. Allow suspension to settle for 30 minutes;

e. Measure pH and EC by immersing the combination electrode in the supernatant solution;

f. Record pH and EC values when the reading has stabilized (usually after one minute);

3.8.2 Moisture Content

3.8.2.1 General Consideration

Moisture content is determined by weighing the field-fresh sample, drying the soil in a force-air oven, and then reweighing the sample. The loss in weight (water) is expressed as a percentage of the oven-dried weight.

3.8.2.2 Apparatus

Disposable aluminium dishes; Drying oven; Desiccator.

3.8.2.3 Procedure

a. Weigh an aluminium dish (0.01 g accuracy);

b. Transfer an approximately 5 g mineral soil sample to the dish and weigh soil plus dish;

c. Place the dish plus sample in oven at 105°C. Dry to a constant weight (24 hours);

d. Cool in desiccator for 30 minutes. Weigh to an accuracy of 0.01 g.

3.8.3 Sodium Adsorption Ratio (SAR)

3.8.3.1 General Consideration

The sodium adsorption ratio (SAR) is a measure of the sodium permeability hazard, or the potential for excess sodium to cause structural deterioration of the soil, which greatly impedes water movement and aeration. SAR is used to estimate the exchangeable sodium percentage (ESP) by analyzing for Na, Ca, and Mg in a soil. In this project, saturated paste extract (SPE) was used as the standard means for measuring the SAR.

3.8.3.2 Apparatus

Spectr AA-880 (Varian)

3.8.3.3 Procedure

Saturated-paste water extractable calcium, magnesium, and sodium cations were measured using an AA-880 spectrometer. The sodium adsorption ratio was calculated using the following formula:

$$SAR = \frac{Na^+}{\sqrt{\frac{1}{2}\left(Ca^{2+} + Mg^{2+}\right)}}$$

3.8.4 Ammonia, Nitrate and Nitrite

3.8.4.1 General Consideration

The determination of exchangeable NH_4^+, NO_3^-, and NO_2^- in soils is complicated by the rapid biological transformations that may occur, and consequently change the amounts and forms of inorganic N in the sample. Ideally, soil samples taken for the purpose of determining inorganic forms of N should be analyzed immediately in order to obtain valid results. Nitrate, nitrite, and ammonium are extracted by shaking 10 g of air dried soil with 2M KCl for 30 minutes and then filtering. The nitrate in the filtrate is measured colorimetrically on a Technicon Flow Analyzer at 520 nm. In this method, the nitrate is reduced to nitrite in a copperized cadmium column and then the total nitrite is measured. Nitrite in the filtrate is determined by the same process, but without the use of the copperized column. To test for ammonium in the filtrate, the extract is analyzed colorimetrically on a Technicon Flow Analyzer at 630 nm.

3.8.4.2 Apparatus

Technicon AutoAnalyzer II (Technicon)

3.8.4.3 Procedure

Place 10 g of air dried soil in a 250 mL widemouth bottle and add 50 mL of 2 M KCl.

Stopper the bottle and shake it on a mechanical shaker for 30 minutes. Filter the soil-KCl suspension and analyze for NH_4^+, NO_3^-, and NO_2^- using a Technicon AutoAnalyzer II.

3.8.5 Total Kjeldahl Nitrogen and Kjeldahl Phosphorus

3.8.5.1 General Consideration

Total nitrogen is determined by converting all of the various nitrogen forms to NH_4^+. To accomplish this, 0.15-1.00 g of very fine (100mesh) air-dried soil is digested in 10 mL of concentrated H_2SO_4 with one Kjeltab (K_2SO_4 and $CuSO_4$). The mixture is slowly ramped to 360°C in an electrically heated aluminium block and digested for four hours. The ammonium formed in this way is determined colorimetrically. Color intensity is measured on a Technicon AutoAnalyzer at 660 nm. The determination of phosphorus is based on the colorimetric method in which a blue colour is formed as a result of the reaction of orthophosphate, the molybdate ion, and the antimony ion, followed by reduction with ascorbic acid at an acidic pH. The colour intensity is also read at 660 nm on a Technicon AutoAnalyzer.

3.8.5.2 Apparatus

Technicon BD-20 Heating Unit; Technicon AutoAnalyzer II (Technicon); Digestion Block.

3.8.5.3 Procedure

See 3.7.7.1

3.9 Statistical Analysis

Referring to Montgomery (2001), the results were analyzed using an analysis of variance (ANOVA) to test the effects of three different application rates. Soil data were analyzed to test the effects of each application rate on two different soil layers (Top and Sub layers) and to determine any significant differences in soil characteristics resulting from an eight week period of treated swine manure being applied at three different rates. Leachate data were also analyzed to test the effects of each application rate on the leachate collected by the under-drain systems on June 22, and Aug. 03, 2004, and to determine any differences in the qualities of the leachates obtained from samples treated for eight weeks at different applications rates. $P < 0.05$ was adopted in ANOVA analysis.

4 Results and Discussion

4.1 Treated Swine Manure and Leachate

4.1.1 Characteristics of Partially Treated Swine Manure

The swine manure used in this project was treated by the existing physical/chemical treatment pilot plant in 2003 and stored in the underground tank for half a year. Before being applied to the soil columns (Substitution of NOPA), a quantity of swine manure pumped from the underground tank was transferred and stored in 200 L plastic barrels as stock liquid swine manure. The liquid swine manure was sampled randomly several times and analyzed according to the standard methods. The results are summarized and tabulated in Table 4-1.

Table 4-1 Parameters analysis of partially treated swine manure

Parameter	Number of sampling	Maximum	Minimum	Mean	Standard Deviation
pH	6	8.42	7.91	8.16	0.17
EC (dS/m)	6	12.13	9.81	10.96	0.97
TS (mg/L)	6	5195	4193	4527	396.22
TDS (mg/L)	6	5042	3937	4337	445.16
TSS (mg/L)	6	301	65	191	84.80
TP (P mg/L)	6	14	10	13	1.43
TKN (N mg/L)	6	1547	1424	1496	53.02
NH_4-N (mg/L)	5	1439	1357	1405	36.09
NO_3-N (mg/L)	2	0.4	0.3	0.35	0.07
NO_2-N (mg/L)	2	0.3	0	0.15	0.21
TOC (mg/L)	2	1653	1569	1611	60.01
BOD_5 (mg/L)	5	4314	3124	3870	560.86
COD (mg/L)	5	8807	7258	8118	556.90
Chloride (mg/L)	3	663	457	551	104.29

The values in Table 4-1 indicate that the characteristics of stock liquid swine manure varied from sample to sample with the sampling time. In this project, it was assumed that the content of the stock liquid swine manure was constant and the mean value was considered to be the baseline value for each parameter. Therefore, ammonium in liquid swine manure was determined to constitute around 93% of the total nitrogen and total dissolved solids accounted for more than 95% of the total solids. The ratio of TP to TKN is 1:110 in the liquid swine manure.

4.1.2 Cumulative Volumes of Applied Manure and Collected Leachate

After the eight-week application at three different application rates, the cumulative volumes of applied manure, collected leachate, and rainfall were calculated and are shown in Figure 4-1. At the same time, the volumes collected from the control columns are also illustrated in Figure 4-1.

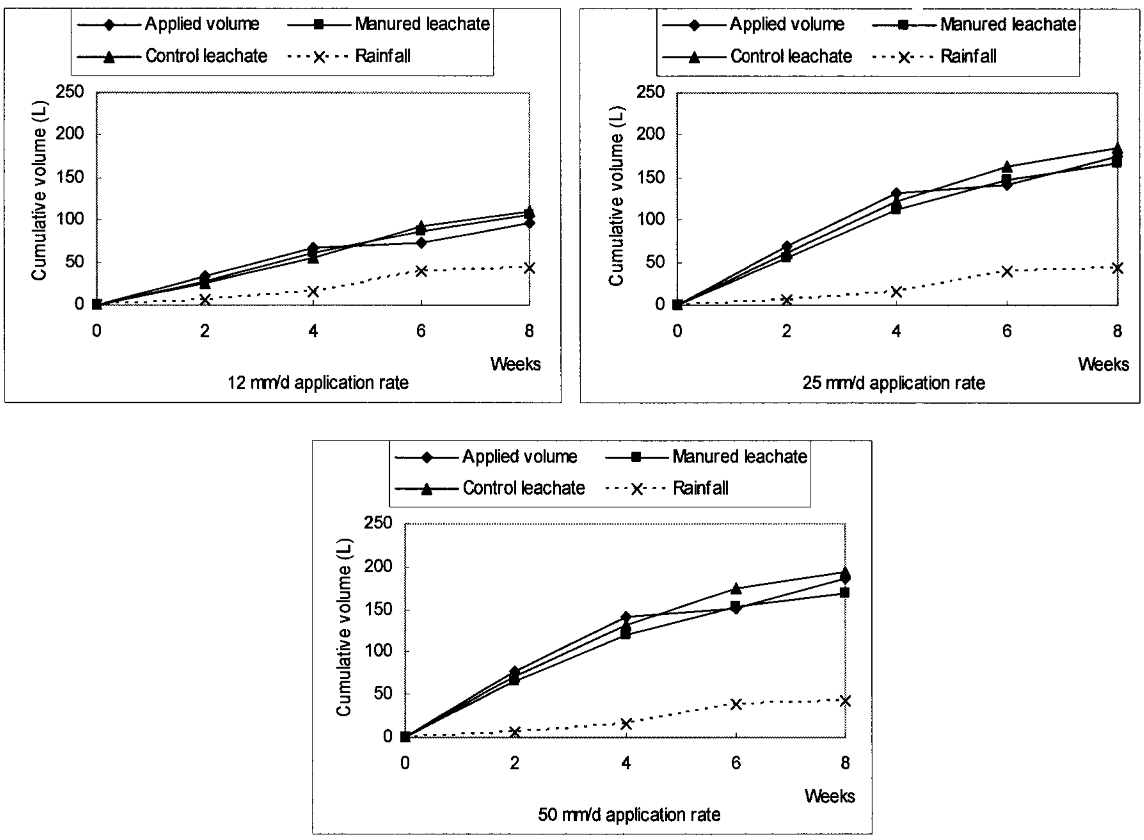


Figure 4-1 Cumulative volumes of the applied manure and leachate

4.1.3 TKN, NH_4-N, NO_3-N, and NO_2-N in Leachate

4.1.3.1 Phase I: Three different rates of application of manure to soil columns

Leachate samples were collected and analyzed for the first time on June 22, 2004, after two weeks of application. Figure 4-2 shows that the trends of TKN change are almost the same with time for the three application rates. The TKN concentration in the leachate increased from zero in the first two weeks to maximum values after six to seven weeks of application, and then decreased again to the lower values. Figure 4-3 shows the similar trends of NH_4-N variation in the leachate for three application rates. Under the 12 mm/d application rate, the NH_4-N concentration increased from zero to a maximum value during the seventh week, and then decreased. Under the 25 and 50 mm/d rates, the NH_4-N in the leachate reached its maximum concentration during the fourth week and then decreased with time, with the exception of a slightly higher value recorded during the seventh week.

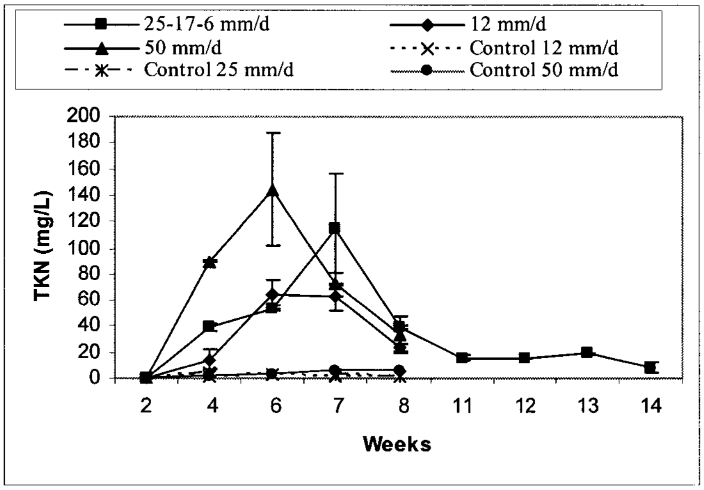


Figure 4-2 Variation in leachate TKN over the application period

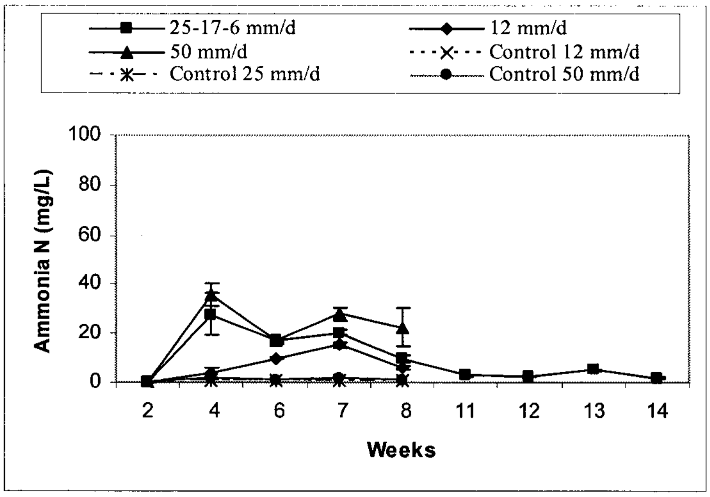


Figure 4-3 Variation in leachate ammonia-N over the application period

Figures 4-2 and 4-3 indicate that the TKN and NH_4-N concentrations are zero at the second week for all columns undergoing the three application rates. At that time, the NO_3-N and NO_2-N concentrations were 15.46 and 2.82 mg/L for the columns with the 12 mm/d rate, respectively. These concentrations were significantly higher than those initially observed for the swine manure content, which means that there was nitrification within the soil columns. Based on the hydraulic conductivity records, in the first two weeks, the applied liquid swine manure thoroughly passed through the soil columns under the 12 mm/d rate. With the downward movement of nutrients, nitrate and nitrite appeared in the leachate. The applied NH_4-N was oxidized or kept within the soil columns; consequently, TKN or NH_4-N was not detected in the leachate. NO_3-N and NO_2-N concentrations in the leachate from the 12 mm/d columns suggested that denitrification was not well established in these columns. The leachate characteristics for each application rate throughout the test period can be found in Appendix I.

Contrary to the findings for the leachate from the 12 mm/d columns, NO_3-N and NO_2-N could not be detected in the leachate from the 25 and 50 mm/d columns at any point during the trials. The hydraulic conductivity records illustrate that all of the applied liquid swine manure could not pass through the soil columns after one week of application at the 25 and 50 mm/d rates. This means that partial clogging occurred within the soil columns. Clogging, to some extent, resulted in the existence of anaerobic or anoxic conditions in the sub soil (saturated zone). The lack of NO_3^- and NO_2^- in the leachate from the 25 and 50 mm/d columns suggested that very little nitrification occurred, and little if any denitrification (as in 12 mm/d columns). Due to the serious clogging, the applied NH_4-N accumulated within the soil columns and no TKN or NH_4-N was detected in the leachate.

With the continual manure application, clogging occurred in all the soil columns. Oxygen availability within the column decreased as the zone of saturated soil rose. This promoted denitrification and hampered nitrification. Denitrification occurred continually and, after two weeks, no nitrate or nitrite was detected in the leachate from the 12 mm/d columns. At the same time, owing to the limitation of soil ability, excess TKN and NH_4-N were washed out and into the leachate under all three application rates because of the reduced aerobic zone in which nitrification could occur. These results suggest the need to maintain an unsaturated section of topsoil to support nitrification.

After Aug. 03 (the eighth week), manure continued to be applied to only those soil columns with the 25 mm/d application rate. The effective application rate varied from 17 mm/d to 6 mm/d, depending on the remaining hydraulic conductivity of the column. With the low amount of swine manure applied, the TKN and NH_4-N concentrations in the leachate were gradually reduced.

During the application period, the cumulative masses of the main elements composing the applied manure and collected leachate were calculated. Figure 4-4 shows the cumulative mass of TKN under the three application rates with time. With the manure application, the cumulative mass of TKN in the leachate increased, but remained a low value. Compared to the cumulative mass of the applied manure, TKN content was significantly reduced.

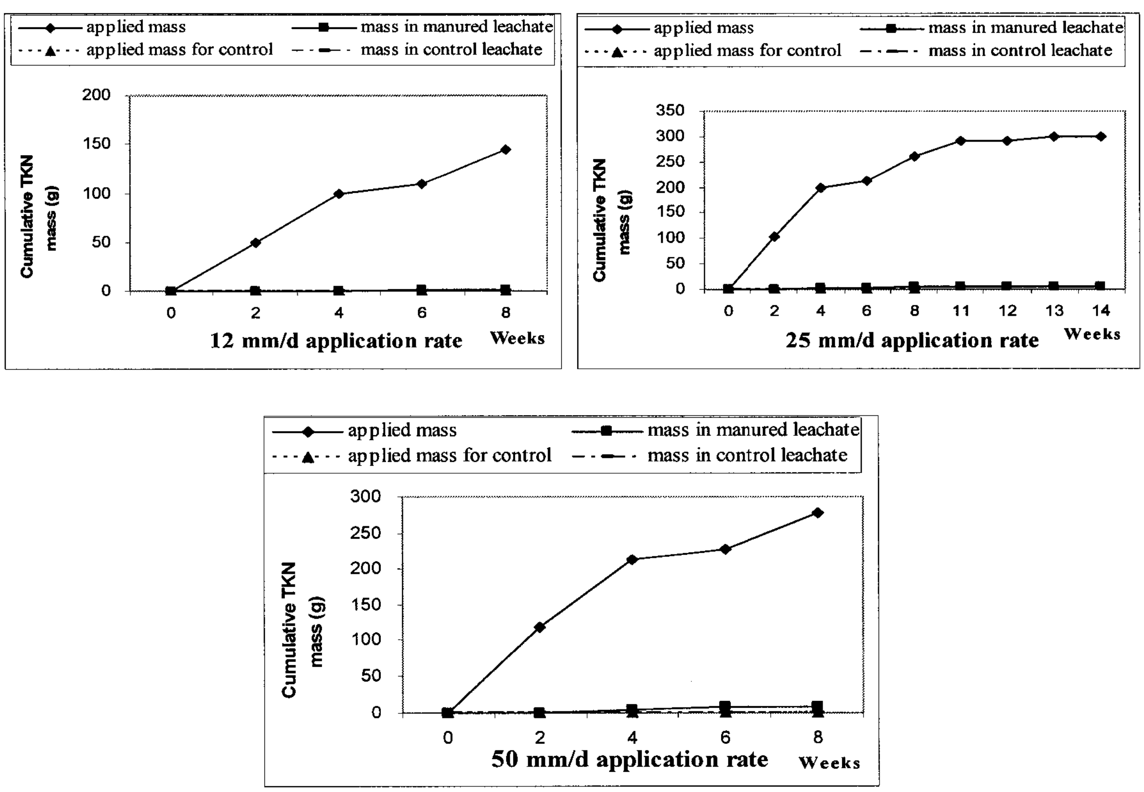


Figure 4-4 Cumulative TKN mass variation with manure application

Figure 4-5 illustrates the variation in the cumulative masses of NH_4-N under the three application rates with time. With the manure application, the cumulative mass of NH_4-N in the leachate increased, but remained a low value. Compared to the cumulative mass of the applied manure, the NH_4-N content was significantly reduced.

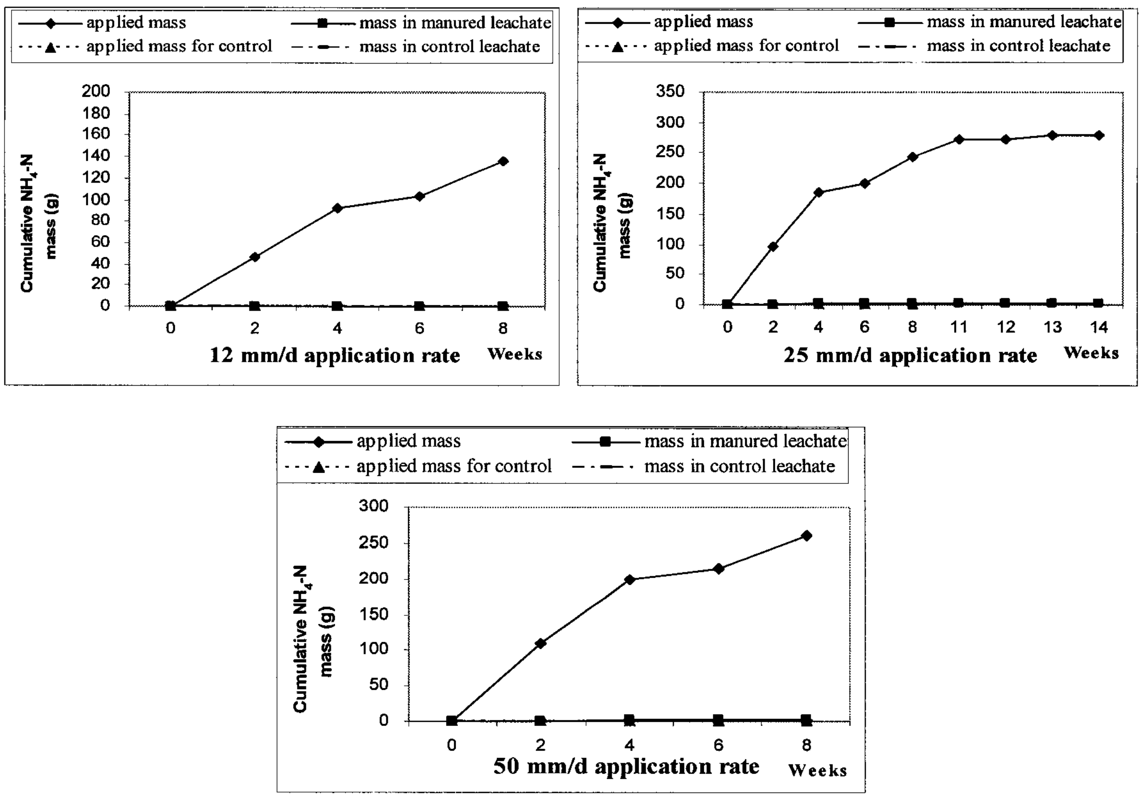


Figure 4-5 Cumulative NH_4-N mass variation with manure application

4.1.3.2 Phase II: Recovery of columns (Sep. 14 to Nov. 23, 2004)

The three columns with the 25 mm/d application rate were recovered by tap water for 10 weeks, beginning Sep. 14, 2004. The application rate of tap water was 10 mm/d. The leachate was collected and analyzed.

Figures 4-6 and 4-7 illustrate the variations with time of TKN and NH_4-N, respectively, in the leachate during the recovery period. TKN did not vary significantly with time. NH_4-N concentrations remained constant in the leachate samples. Figure 4-8 shows the trend of total NO_3^- and NO_2^- variation. The concentrations of total NO_3^- and NO_2^- remained constant throughout most of the recovery period. With the addition of tap water, the extra oxygen possibly resulted in the occurrence of nitrification within the soil column; consequently, the total nitrate and nitrite nitrogen increased in the last weeks.

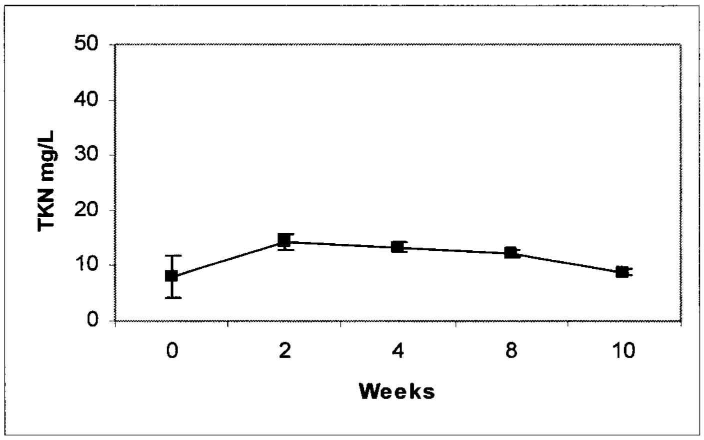


Figure 4-6 TKN variation in the leachate during the recovery period

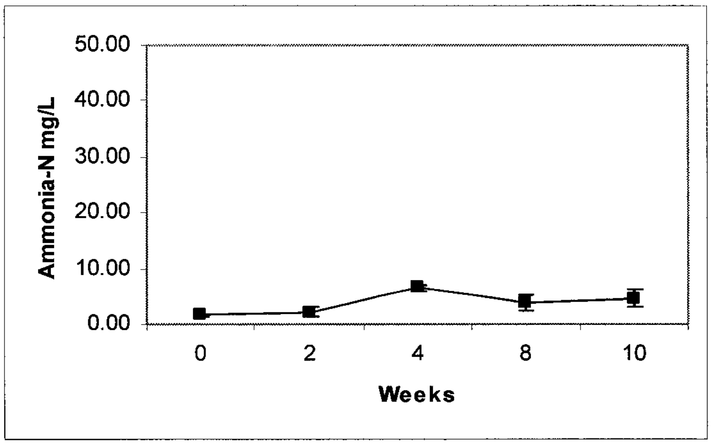


Figure 4-7 Ammonia-N variation in the leachate during the recovery period

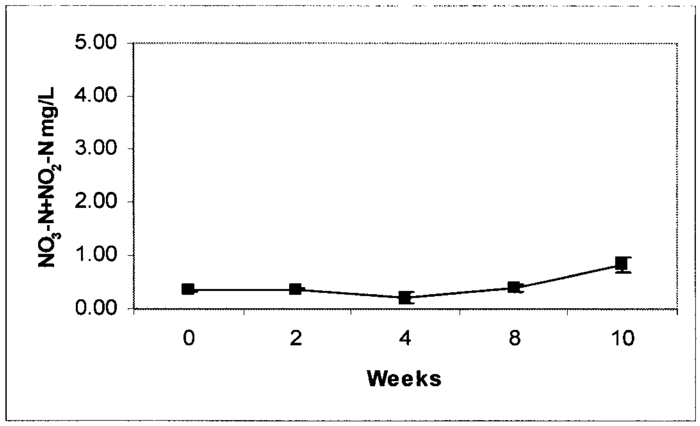


Figure 4-8 NO_3-N & NO_2-N variation in the leachate during the recovery period

After a 10-week recovery period using tap water, the cumulative masses of TKN, NH_4-N, and total NO_3^- and NO_2^- in the collected leachate were calculated and are shown in Figure 4-9.

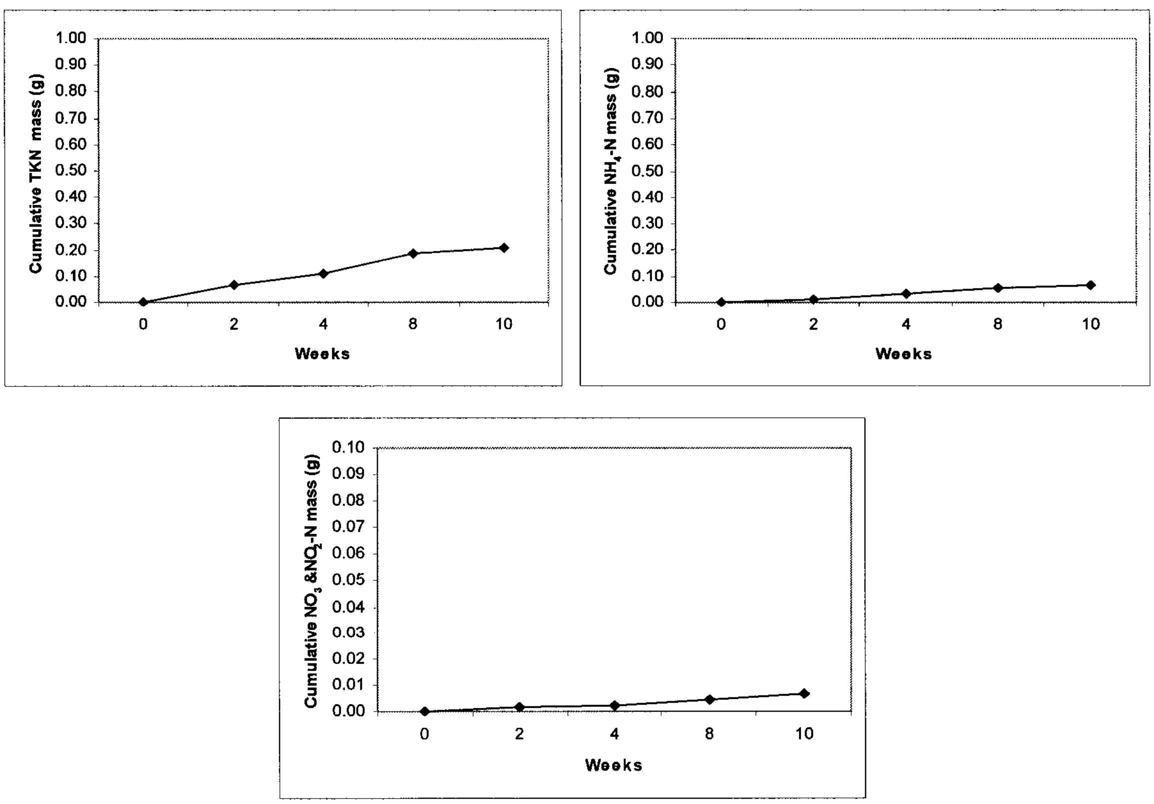


Figure 4-9 Cumulative masses variation in leachate during the recovery period

With the recovery using tap water, the cumulative masses of TKN, NH_4-N, and total NO_3^- and NO_2^- in the collected leachate increased, but stayed within a narrow range.

4.1.4 Total Phosphorus (TP) in Leachate

4.1.4.1 Phase I: Three different rates of application of manure to soil columns

The trends of TP variation with time in the leachate were similar for the three different application rates (Figure 4-10). The TP concentration in the leachate remained lower than 1 mg/L at all times, under all application rates. Due to the low TP concentration in swine manure (13 mg P /L), manure addition did not significantly impact the TP concentration in the leachate. Also, a heavy rain storm occurred and no swine manure was applied from July 09 to July 20, resulting in low TP concentration in the leachate samples.

For the 25-17-6 mm/d soil columns, owing to the serious clogging, the application rate was gradually reduced and TP content in the leachate decreased accordingly.

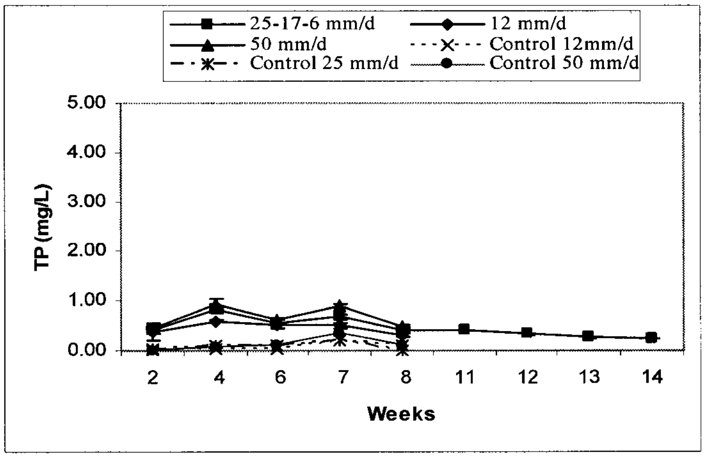


Figure 4-10 TP variation in the leachate with manure application

Figure 4-11 illustrates the variations with time of cumulative TP mass for the applied manure and collected leachate. With the addition of swine manure, the cumulative TP mass for the applied manure increased. Likewise, the cumulative TP mass in the collected leachate increased, but remained at a very low level. Comparing the TP mass in the leachate to the applied mass, most of the TP content was removed through the soil treatment.

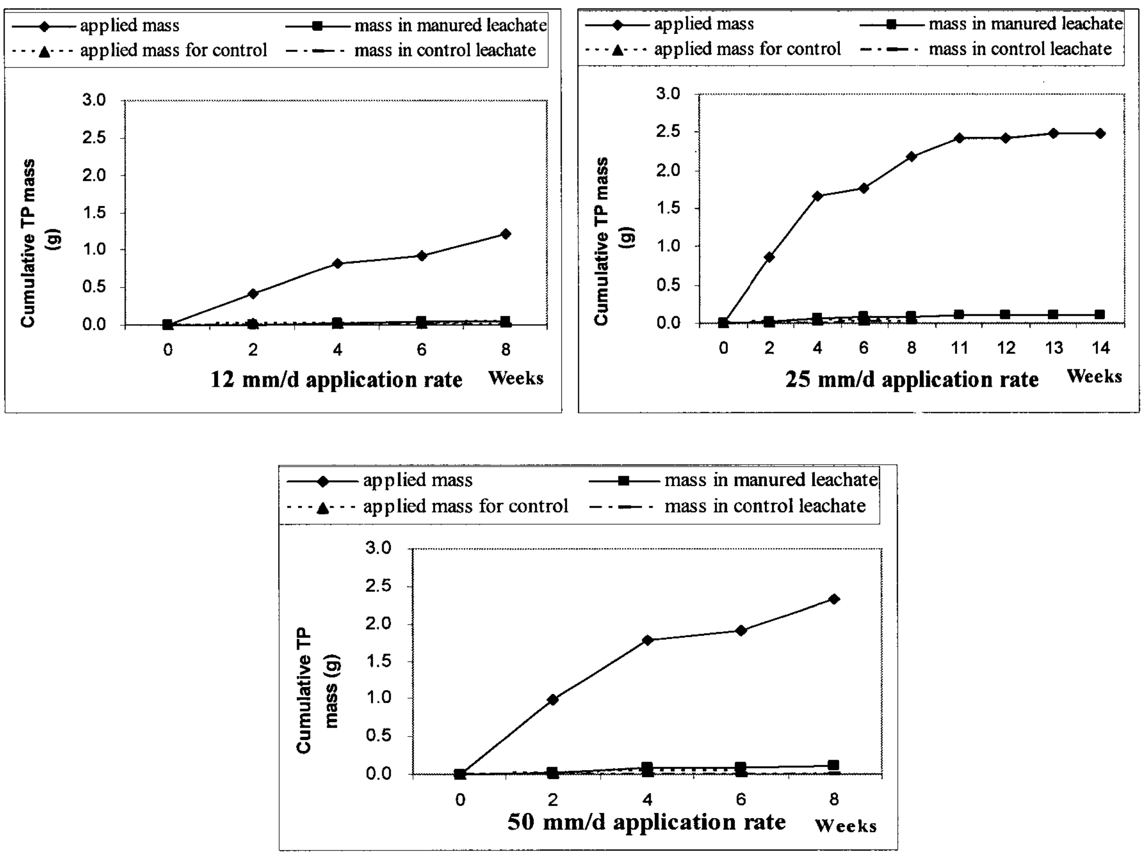


Figure 4-11 Cumulative TP mass variation with manure application

4.1.4.2 Phase II: Recovery of columns

The trend of TP variation in the leachate during the recovery period is illustrated in

Figure 4-12. The TP concentrations in the leachate also remained at low values. Owing to no further addition of swine manure, the TP concentration in the leachate remained stable.

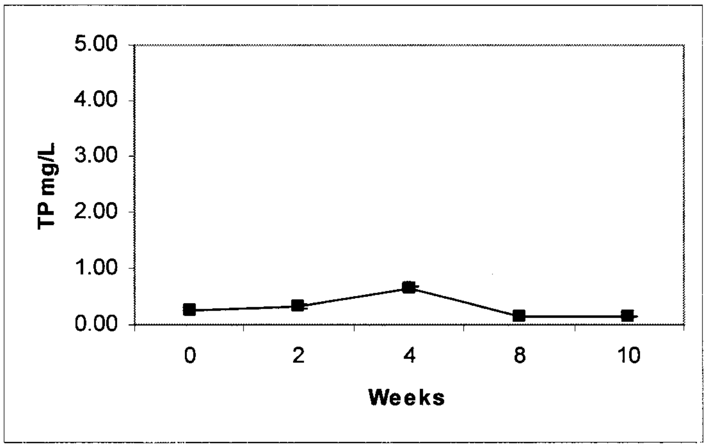


Figure 4-12 TP variation in the leachate during the recovery period

The cumulative TP mass in the leachate during the recovery period is shown in Figure 4-13. TP masses remained at very low levels.

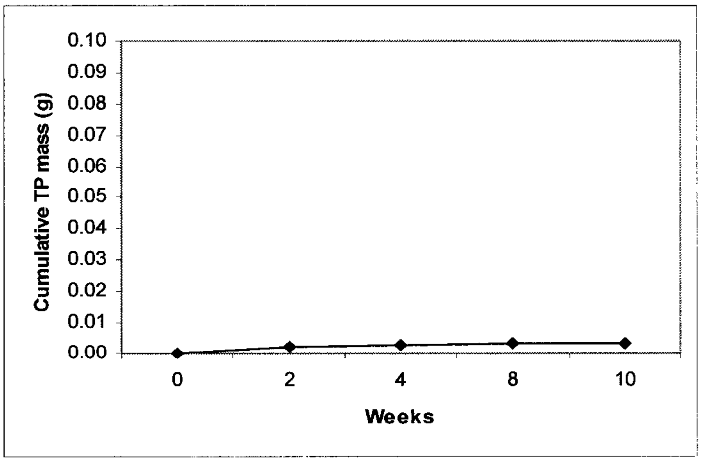


Figure 4-13 Cumulative TP mass variation during the recovery period

4.1.5 Electrical Conductivity (EC) and TDS

4.1.5.1 Phase I: Three different rates of application of manure to soil columns

Figure 4-14 shows the similar trends in EC value variation for the three application rates. In the first four weeks, EC values increased with time, and then decreased gradually. Comparing Figure 4-15 to Figure 4-14, very similar trends can be observed for TDS concentrations and EC values in the leachate. Due to the high concentration of TDS (more than 4000 mg/L) in swine manure, manure addition resulted in the leaching of TDS in the early weeks of the application period. With the heavy storm occurrence, both the pause in swine manure application and the dilution by rainfall affected the EC and TDS contents in the leachate. Therefore, EC and TDS values decreased in the following weeks.

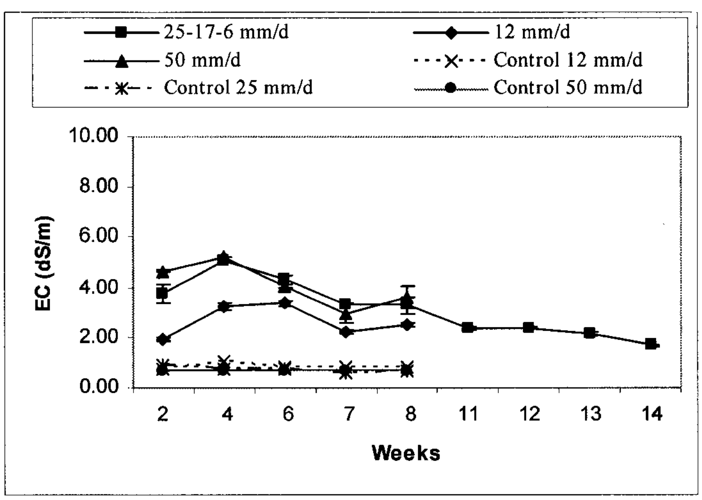


Figure 4-14 Variation in leachate EC with manure application

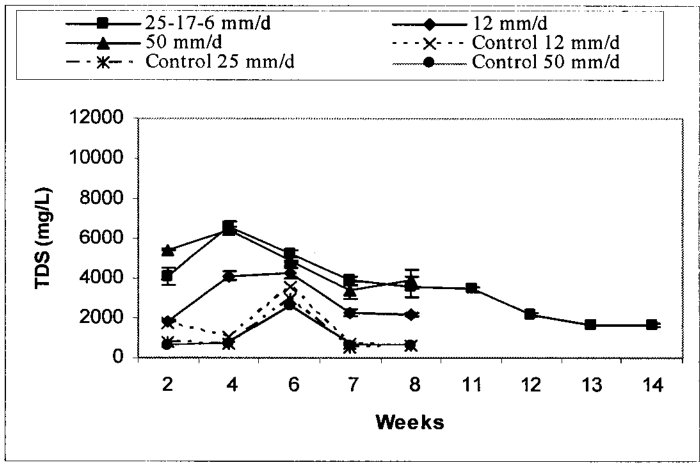


Figure 4-15 Variation in leachate TDS with manure application

According to Metcalf & Eddy (2003), the measured EC value can be used as a surrogate measure of total dissolved solids concentration. Here, the relationship determined between TDS and EC is shown in Figure 4-16. A linear relationship was obtained between the EC and TDS in the leachate collected through the soil column.

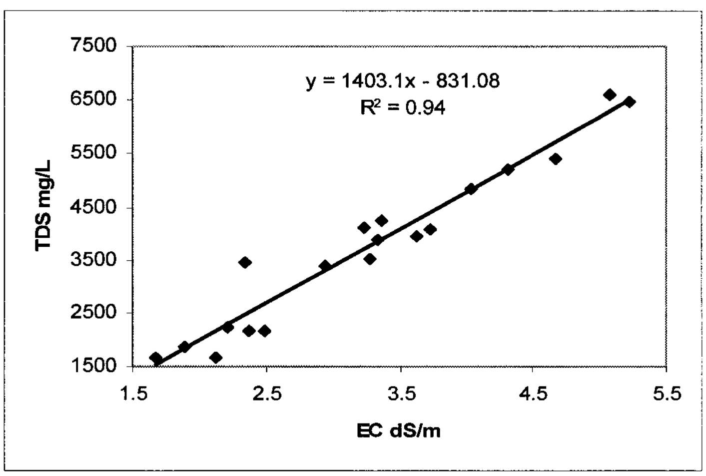


Figure 4-16 The linear relationship between EC and TDS in the leachate

Figure 4-17 shows the cumulative TDS mass variations with time for the applied manure and collected leachate. At the 12 mm/d rate, cumulative TDS masses for the applied manure and collected leachate increased with time, but the mass in the leachate was lower than the applied mass. This means that, to some extent, TDS was removed by the soil treatment. However, at the 25 and 50 mm/d rates, the cumulative TDS masses collected in the leachates were higher than the applied TDS masses, especially at the 50 mm/d rate. A low, even negative, TDS removal efficiency was obtained. A reasonable explanation attributes these findings to the washout of TDS arising from the soil column.

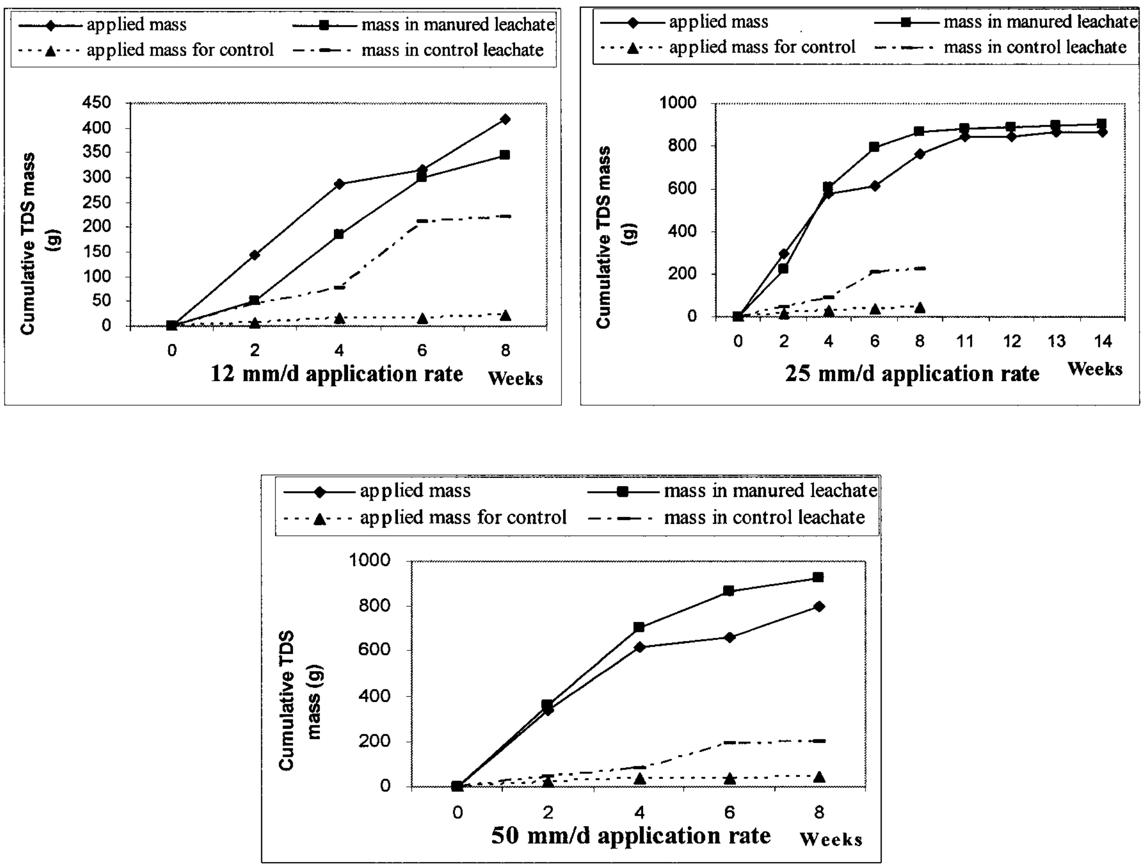


Figure 4-17 Cumulative TDS mass variation with manure application

4.1.5.2 Phase II: Recovery of columns

During the recovery period, the EC values in the leachate were not significantly affected by the tap water irrigation (Figure 4-18). The average EC value of the tap water was 0.33 dS/m, with a standard deviation of 0.04.

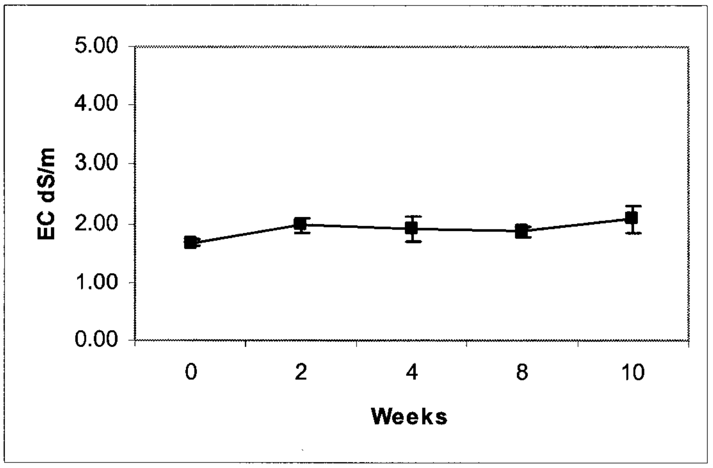


Figure 4-18 EC variation in the leachate during the recovery period

4.1.6 pH

4.1.6.1 Phase I: Three different rates of application of manure to soil columns

Figure 4-19 shows the variation with time of pH values in the leachate for the three application rates. With the addition of manure, the pH values remained constant.

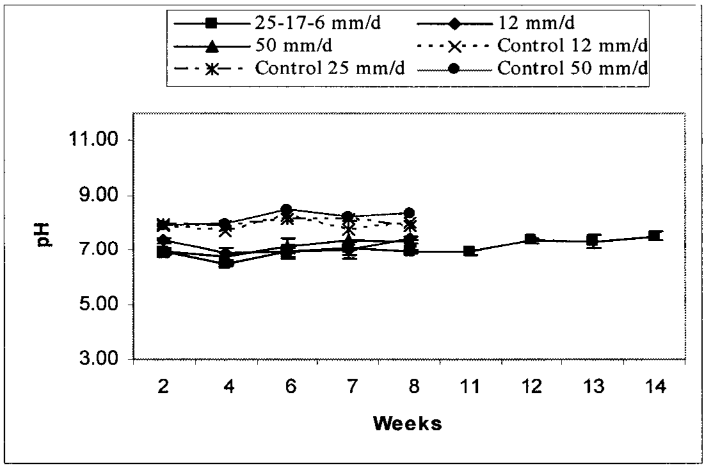


Figure 4-19 Variation of leachate pH with manure application

4.1.6.2 Phase II: Recovery of columns

For the recovery columns, the pH values in the leachate also changed little with time (Figure 4-20).

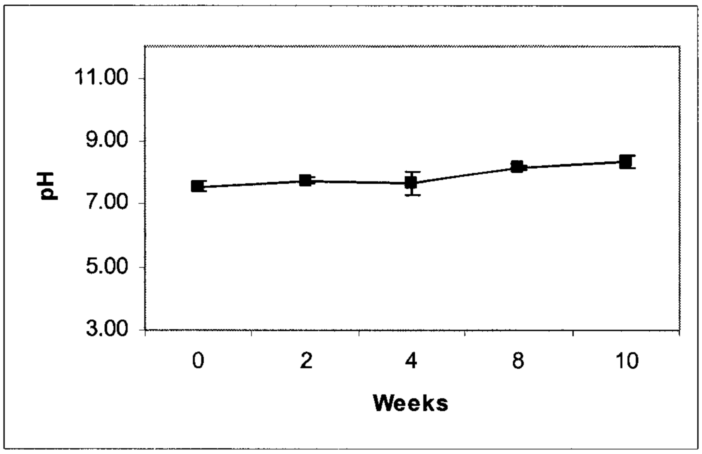


Figure 4-20 Variation of leachate pH during the recovery period

4.1.7 BOD_5, COD and TOC

4.1.7.1 Phase I: Three different rates of application of manure to soil columns

During Phase I, BOD_5, COD, and TOC values were determined for the leachate. Due to some experimental errors, such as instrument disturbance and improper dilution factors, there were not enough useful BOD_5 values obtained. Discontinuous results could not effectively represent the trend of BOD_5 changes with time. Therefore, only COD and TOC vales for the leachate are described here.

Figure 4-21 shows that similar trends in COD changes were observed under all three application rates. With the manure application, COD concentrations decreased gradually after four weeks of manure application. The increase trend was obtained from the TOC data collected in the first four weeks. Therefore, it can be supposed that COD values increased in the first four weeks. For all columns under the three application rates, COD contents were removed effectively during the eight-week period, in particular for the columns with the 12 mm/d rate. The COD value for these columns was 432 mg/L at the end of eight-week period, as compared to 8118 mg/L in the liquid swine manure. Figure 4-22 shows that the TOC values increased in the first four weeks with the continual application, and then generally decreased with time. All variations in COD and TOC in the leachate depended on changes in the contents of the soil columns arising from physical, chemical, and biological functions.

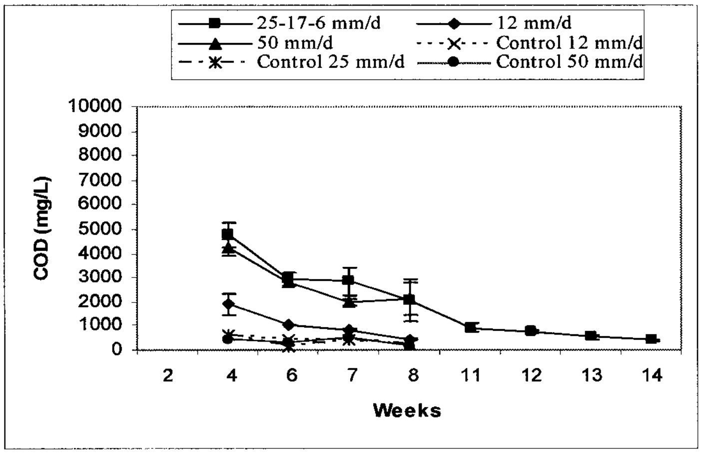


Figure 4-21 COD variation in the leachate with manure application

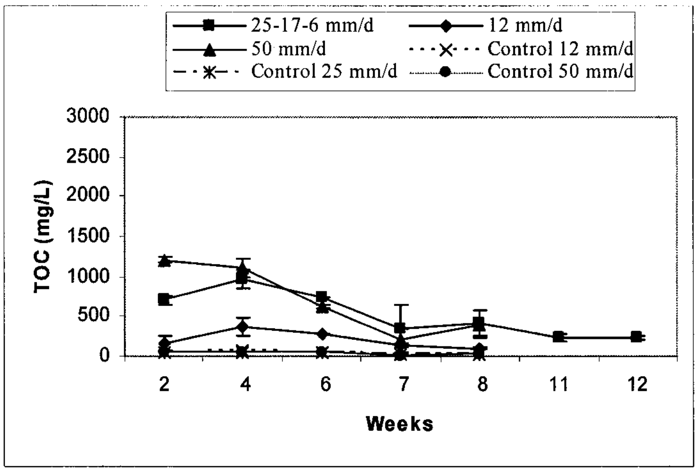


Figure 4-22 TOC variation in the leachate with manure application

The increase of organic matter in the leachate was attributed to excessive manure application and downward movement through the soil profile in the early period. With the clogging occurring in the soil columns, organic matter was stored in the soil column. As a carbon source, organic matter was continually consumed by microorganisms. Therefore, COD and TOC decreased. Also, the heavy rain and break in manure application resulted in a decrease of COD and TOC in the leachate.

The cumulative COD masses for the applied manure and collected leachate were determined and are shown in Figure 4-23 as they vary with time.

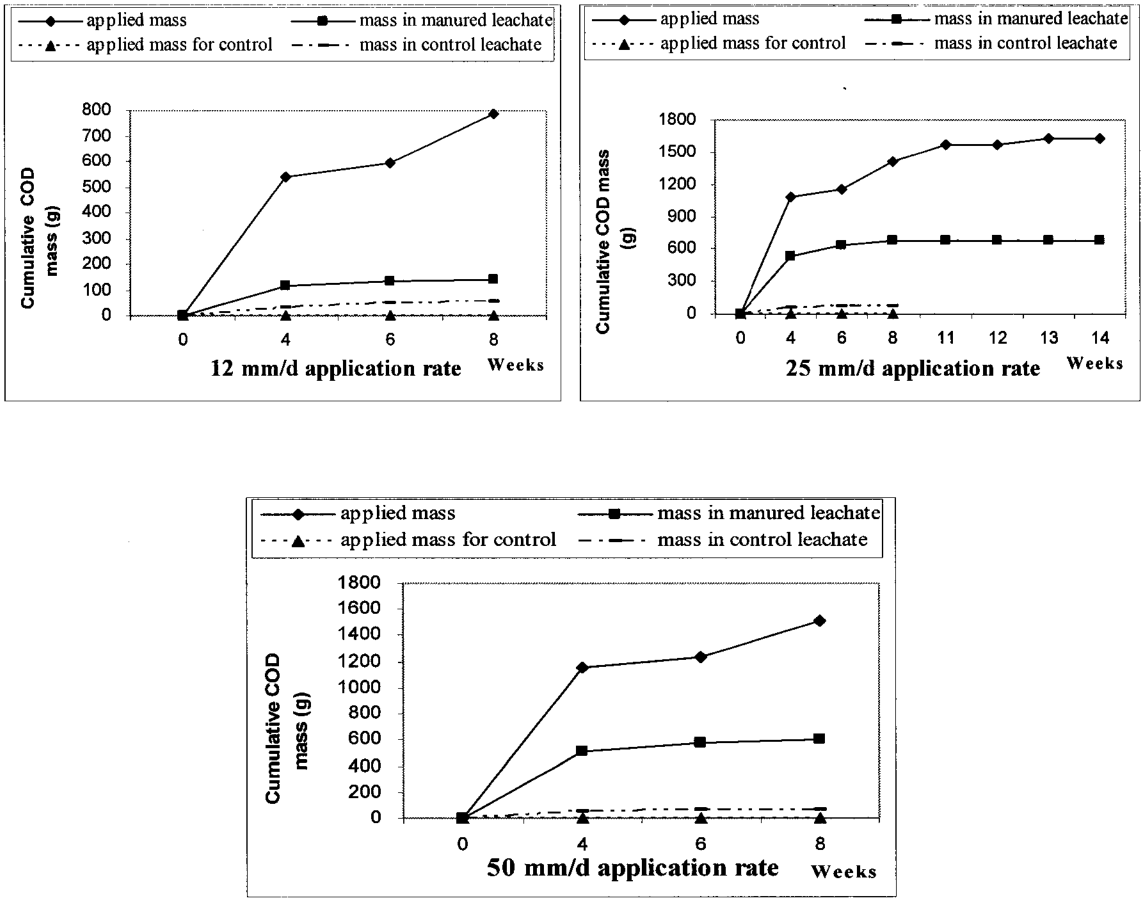


Figure 4-23 Cumulative COD mass variation with manure application

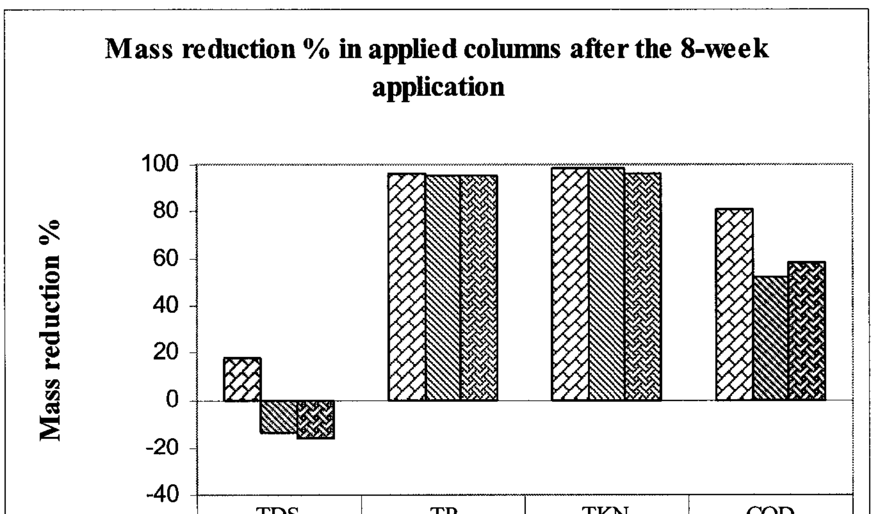
With the manure application, the cumulative COD masses for the applied manure and collected leachate increased. Up to 80% and 50% removal efficiencies were observed at the 12mm/d rate and at the 25 and 50 mm/d rates, respectively.

4.1.7.2 Phase II: Recovery of columns

During the recovery period, no TOC values were determined for the leachate due to the limited time and tight budget. Also, only limited values for BOD_5 and COD were obtained from the leachate. It was observed that, in the first two weeks, BOD_5 and COD values decreased with the recovery process using the tap water.

4.1.8 Reduction for TDS, TP, TKN, and COD

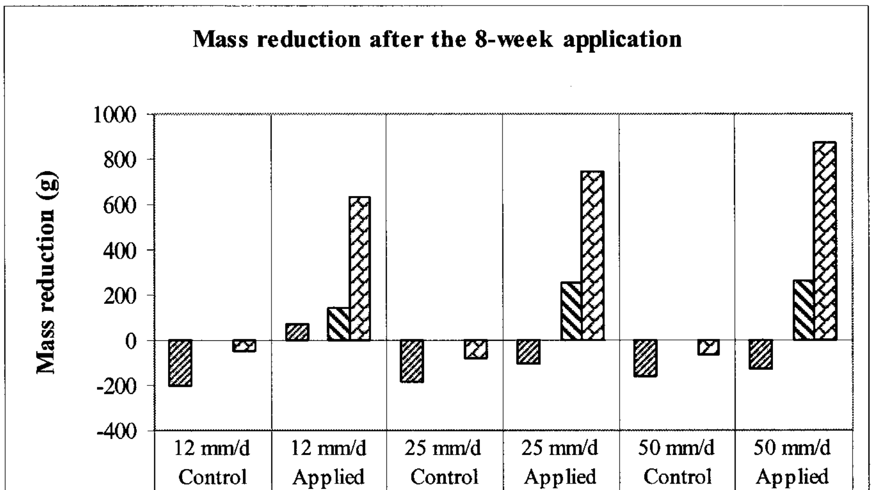
Following from the collected leachate volumes and the concentrations of TDS, TP, TKN, and COD in the captured leachate, the total collected masses of TDS, TP, TKN, and COD were calculated for the eight-week application period. Comparing to the total applied masses, mass reduction percentages for TDS, TP, TKN, and COD were determined and are shown in Figure 4-24. More than 95% TP and TKN were removed by soil columns under all three application rates. Soil columns with the 12 mm/d rate removed up to 80% COD. However, the columns with the 25 and 50 mm/d rates demonstrated lower removable percentages of approximately 50% efficiency. With respect to TDS, low or even negative reduction percentages were observed. This result is a consequence of the washout of dissolved solids arising from soil column irrigation.



	TDS	TP	TKN	COD
12 mm/d	17.73	95.96	98.18	80.80
25 mm/d	-13.22	95.73	98.12	52.01
50 mm/d	-15.56	95.33	96.32	57.84

Figure 4-24 Mass reduction percentages for TDS, TP, TKN, and COD

Figure 4-25 illustrates mean mass reductions of TDS, TP, TKN, and COD after the eight-week application, as compared to the control columns, at the different application rates. With respect to TDS through the control columns under the three application rates, negative reduction efficiencies were obtained. These results suggest the washout of TDS through the soil columns by irrigation. Also, organic matter was washed out through the soil columns.



	12 mm/d Control	12 mm/d Applied	25 mm/d Control	25 mm/d Applied	50 mm/d Control	50 mm/d Applied
TDS	-199.01	74.39	-181.30	-100.82	-158.50	-125.15
TP	0.03	1.16	0.05	2.10	0.06	2.20
TKN	0.10	142.16	0.20	258.19	0.28	267.35
COD	-51.43	634.71	-81.89	742.47	-67.89	871.03

Figure 4-25 Mass reduction after the eight-week application

4.1.9 Water Balance and Average Application Rates

In this project, one of objectives is to identify the proper application rate of treated swine manure for soil treatment. Three different application rates were conducted to obtain the proper application rate. During the process of land application, the volumes applied to the soil columns could be modified according to the hydraulic conductivity of the soil and the expected rainfall.

In the eight-week period from June 08 to August 03, 2004, taking into consideration the precipitation measured by the rain gauge, the water balances for all three application rates were determined and tabulated in Table 4-2. Based on the actual average application rate, the 17 mm/d rate should be suitable for land application of partially treated swine manure. Removal volumes in Table 4-2 represent the excessive rain water that was taken out from the soil columns. Loss volumes in Table 4-2 represent the losses of liquid caused by evaporation and storage in the soil columns. After the eight-week application, the actual application rates were compared to the intended application rates. The results are shown in Figure 4-26.

Table 4-2 Water Balance and Average Application Rates

	12 mm/d Control	12 mm/d Applied	25 mm/d Control	25 mm/d Applied	50 mm/d Control	50 mm/d Applied
Irrigation (mL)	96760	96760	175850	175850	185490	185490
Precipitation (mL)	43168	43168	43168	43168	43168	43168
Removal (mL)	0	10880	0	5960	0	10510
Leachate (mL)	111010	107068	185620	167492	193140	168338
Loss (mL)	28918	21980	33398	45566	35518	49810
Effective application rate (mm/d)	8.8	8.8	16.0	16.0	16.8	16.8

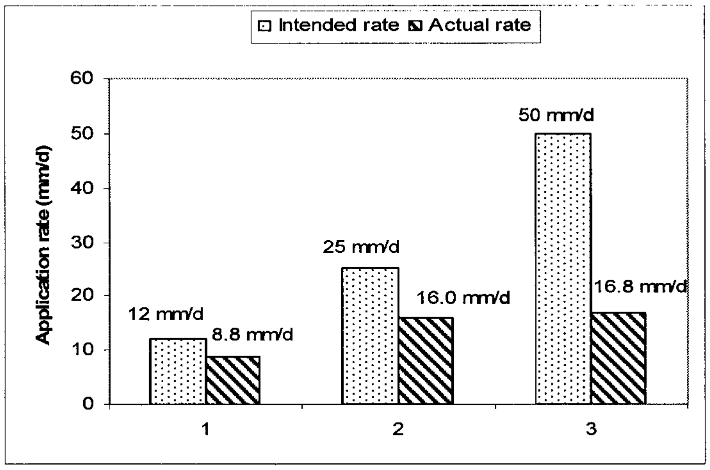


Figure 4-26 Intended application rate VS. Actual application rate

After two weeks rest, soil columns which had been irrigated at the 25 mm/d rate received manure at the 17 mm/d application rate and then the 6 mm/d application rate until Sep. 14, 2004. Several significant leachate parameters were tested. The experimental results indicate that new soil column tests should be conducted to determine the effect of a 17 mm/d application rate on soil characteristics and leachate in a future project.

Based on an effective application rate (17 mm/d) and TKN concentration in swine manure (1496 mg/L), the application rate of TKN would be 25.4 g N/day/m^2. Compared to the recommended supply of nitrogen of about 0.03 g N/day/m^2 from manure for crop fertilization (AOPA, 2001), the actual application rate is considerably higher than the agricultural application rate.

4.1.10 Determination of Hydraulic Conductivity

During the application period, the hydraulic conductivities of the soil columns were observed for all three different application rates. For the soil columns with the 12 mm/d rate, the liquid swine manure penetrated well through the surface of the soil until July 13 (the fifth week). Due to the continually heavy rain and hail, all of the soil columns were soaked and no more liquid swine manure was applied. The water did not completely pass through soil columns for several days, until July 21 (the sixth week), 2004. The hydraulic conductivities remained between 10 and 17 mm/d.

For the soil columns with the 25 mm/d application rate, the liquid manure could easily pass through the surface soil until June 16 (the first week), 2004. At that time, the hydraulic conductivity decreased, ranging from 10 to 12 mm/d until the occurrence of the rain storm. After restarting application on July 21 (the sixth week), the hydraulic conductivity was only 5 mm/d or less.

For the soil columns with the 50 mm/d application rate, the liquid manure could pass through the surface soil in the first week. Thereafter, the hydraulic conductivity decreased, ranging from 9 to 12 mm/d until the occurrence of the rain storm. After re-starting application on July 21 (the sixth week), it remained at only 5 mm/d or less.

4.1.11 Statistical Analyses

The main nutrient contents were analyzed using an ANOVA to test for the effects of the three application rates. Comparing the values of TP, TKN, and NH_4-N in the leachate from the second week to the values obtained during the eighth week, it was shown that TKN and NH_4-N significantly increased at $p < 0.05$ with the continual application of swine manure; however, there was no significant effect on TP concentration in the leachate from the swine manure application. After the eight-week application, the final leachate samples were analyzed statistically for each of the three application rates. The conclusions show no significant difference in leachate characteristics among the leachate samples for the three different application rates.

4.2 Total Nitrogen and Total Phosphorous Budgets

After the eight-week application of liquid swine manure, the total nitrogen and total phosphorous budgets for the three application rates were determined and are summarized in Table 4-3 and Table 4-4.

Table 4-3 Total nitrogen budget for the three application rates

Application rate (mm/d)	Total manure N added (g)	Initial total soil N (g)	Final total soil N (g)	Leachate total N (g)	Budget balance (g)
12 (Control)	0.99	341.50	485.51	5.92	148.94
12 (Applied)	145.16	341.50	709.90	2.49	225.73
25 (Control)	1.81	341.50	508.25	6.91	171.85
25 (Applied)	263.25	341.50	824.73	4.65	224.63
50 (Control)	1.91	341.50	496.93	6.50	160.02
50 (Applied)	277.68	341.50	684.36	8.76	73.94

[a]Budget balance = (final soil + leachate) – (initial soil + manure)

Table 4-4 Total phosphorous budget for the three application rates

Application rate (mm/d)	Total manure P added (g)	Initial total soil P (g)	Final total soil P (g)	Leachate total P (g)	Budget[a] balance (g)
12 (Control)	0.03	156.75	224.32	0	67.54
12 (Applied)	1.21	156.75	224.11	0.04	66.19
25 (Control)	0.06	156.75	220.46	0.01	63.66
25 (Applied)	2.19	156.75	305.27	0.09	146.62
50 (Control)	0.07	156.75	219.29	0.01	62.48
50 (Applied)	2.31	156.75	229.85	0.10	70.89

Table 4-3 shows that an excess in total nitrogen was calculated for all rates of application of manure. This means that a larger increase was calculated for the soil total N after the eight-week application than could be accounted for by the amounts added in the manure and lost in the leachate. However, deficiencies were expected due to nitrogen losses through the volatilization of ammonia and the occurrence of denitrification. No attempt was made to measure gaseous losses of nitrogen in this study. It was also noticed that the controls for each of the different rates may have indicated some inaccuracies in the total nitrogen budget balance. In the control treatment, there was approximately 150 g more total nitrogen after the applications, even though no nitrogen was added. Therefore, the accuracy of the total nitrogen budget balance can be questioned. The inaccuracy is believed to arise mainly from the results of the soil samples.

Barry et al. (2003) documented total nitrogen budgets for five manure-rate treatments at coarse- and medium-textured sites from 1993 to 2001. Excess total nitrogen was calculated for all manure-rate treatments at both sites. Sharpley et al. (1998) indicated that reliable nitrogen budgets are difficult to construct for manure because of the variable composition of manure, changes that occur in storage, nonuniform application, changes in soil properties, increased soil microbial activity caused by more available carbon, the unpredictable nature of gaseous nitrogen losses, and the many factors that influence mineralization. However, manure-nitrogen additions to soil will ultimately appear in the major nitrogen cycle outputs of ammonia volatilization, denitrification, leaching, crop uptake, or accumulation in the soil as organic or mineral nitrogen.

Table 4-4 shows the budget balances of total phosphorous for all application rates. An excess was calculated for all the manure application rates, even for the controls. Comparing the initial soil TP content to the final soil TP content, the calculated excess arises mainly from the soil analytical results.

Barry et al. (2003) also mentioned an excess in total phosphorous in the budgets from the coarse-texture site for the 0, 20, 40, and 60 Mg/ha/yr manure-rates. Whalen and Chang (2001) found that after 16 years of annual cattle manure application, 7 to 15 percent of the total phosphorus applied could not be accounted for in the soil and crop.

In this project, total nitrogen and phosphorous masses in the soil were calculated based on concentrations measured at depths of 5-25 cm and 50-70 cm. Because of the variations in total nitrogen and phosphorous within the soil profile, two values for the total nitrogen and phosphorous concentrations were not enough to calculate total nitrogen and phosphorus masses in the whole soil column. Therefore, in order to improve the accuracy of total nitrogen and phosphorous budget balances, more soil layers should be sampled.

4.3 Soil Properties Analysis

4.3.1 Characteristics of Original Soil

The soils in the columns were divided into two parts: Top soil (0-300 mm) and Sub soil (300-900 mm). Original composite top and sub soil samples were collected and analyzed. The characteristics are summarized in Tables 3-3 and 3-4. The texture of the top soil was a clay loam, with an average sand content of 31.42 percent and an average clay content of 32.31 percent. The texture of the sub soil was a loam, with an average sand content of 48.17 percent and an average clay content of 11.43 percent.

Analytical results in Table 3-4 indicate that the original top soil contained more total nitrogen and total phosphorus than did the sub soil, but had a lower ammonia nitrogen content. Likewise, the sub soil contained more nitrate and nitrite nitrogen than did the top soil. Soil pH values were similar for the two soil layers, whereas electrical conductivity was higher in the sub soil layer. SAR values in the top soil were higher than in the sub soil.

4.3.2 TKN and NH_4-Nitrogen

4.3.2.1 Phase I: Three different rates of application of manure to soil columns

Generally, liquid swine manure application increased the total nitrogen and ammonia nitrogen in both of the two soil layers. Comparing the contents of the initial soil layers to those of the final soils after the eight-week application of manure showed significant differences in both layers.

Figure 4-27 and Figure 4-28 show TKN and NH_4-N variations in the top soil, respectively, and illustrate that the overall trends in total nitrogen and ammonium nitrogen were increases in the top soil layers with the manure application. From the beginning of application on June 08, 2004, the concentrations of TKN and NH_4-N increased with time until the fourth week because of the accumulation of excess TKN and NH_4-N. According to the data obtained during the sixth week, the concentrations of TKN and NH_4-N decreased. The main reason for this was the occurrence of a heavy rain storm and hail on July 13, 2004. After the storm, a significant amount of rain water was stored on the surface of the soil columns until July 21, 2004. During this period, no liquid swine manure was applied. Therefore, the values of TKN and NH_4-N were low. With the resumed application of manure, the contents of TKN and NH_4-N increased again.

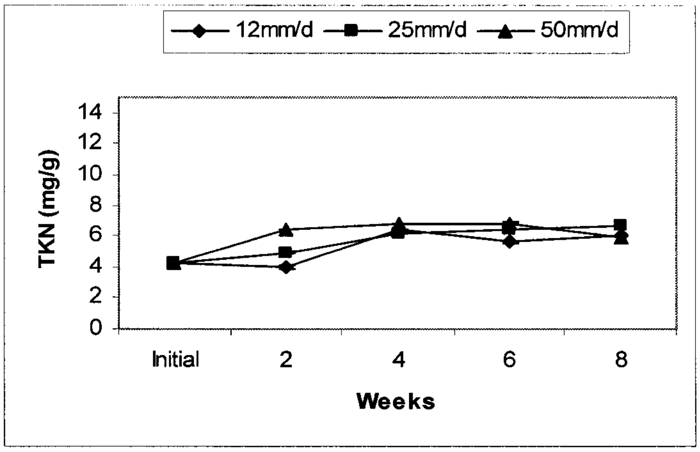


Figure 4-27 TKN variation in top soil with manure application

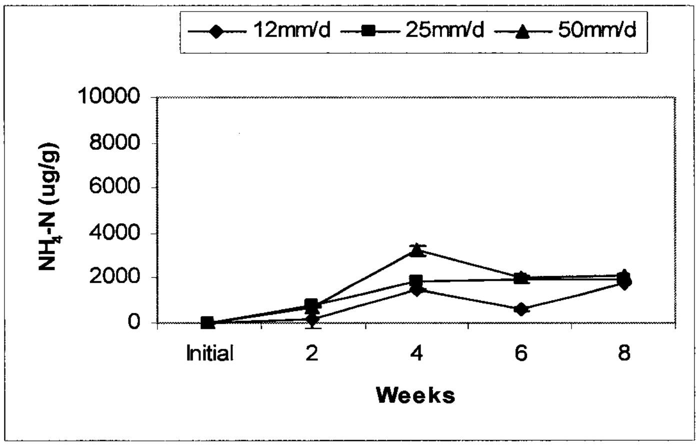


Figure 4-28 NH_4-N variation in top soil with manure application

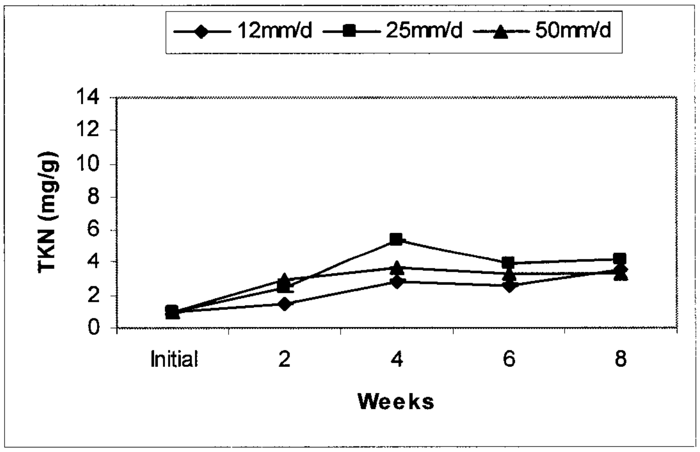


Figure 4-29 TKN variation in sub soil with manure application

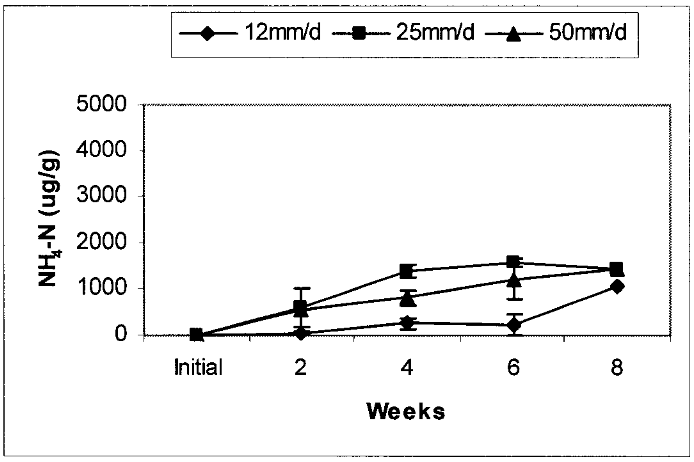


Figure 4-30 NH_4-N variation in sub soil with manure application

Figure 4-29 and Figure 4-30 show the contents of TKN and NH_4-N in the sub soil, and indicate that the trends in TKN and NH_4-N variation under the three application rates were similar. Before the occurrence of the heavy rain storm, the TKN content increased with time. During the period in which no swine manure was applied (from July 09 to July 20), the TKN content decreased during the sixth week. With the resumed application, TKN content increased again. With respect to NH_4-N, the content increased with time under the three application rates. There was no apparent decrease after the heavy storm, or during the period without manure application. This could possibly be explained by the washout of NH_4-N from the top soil by the heavy storm. It is worth noting that the contents of TKN and NH_4-N in the sub soil under the 25 mm/d application rate were higher than the contents under other application rates after two weeks of application. The record of the volume of leachate shows that the total volume that passed through the soil columns with the 25 mm/d application rate, after two weeks, was greater than that passing through the soil columns with the 50 mm/d application rate. The reason for the greater volume was the occurrence of clogging in the soil columns with the 50 mm/d rate. Consequently, the total amounts of nitrogen and ammonium nitrogen passing through the 25 mm/d soil columns were higher than those passing through the 50 mm/d soil columns. The results of the soil analyses conducted during the eight-week application period are tabulated in Appendix II.

4.3.2.2 Phase II: Recovery of columns

The three columns with the 25 mm/d application rate were recovered by tap water at 10 mm/d for 10 weeks beginning on Sep. 14. In order to determine the forms and concentrations of nutrients and observe the movement of nutrients within the soil profile, soil samples were collected from each column to a depth of 90 cm in 15 or 20 cm increments beginning on Oct. 12 after a four-week recovery. Therefore, there were five soil samples collected from each column at the sampling time, including two samples of top soil and three samples of sub soil. Because only two samples were collected from the soil profiles on Sep. 14 for each column, it is difficult to analyze the variations of nutrients by comparing the Sep. 14 results to the results from Oct. 12 and Nov. 23. Here, the soil characteristics were analyzed by comparing the results obtained on Oct. 12 to those obtained on Nov. 23.

Figure 4-31 illustrates that the TKN contents measured in all soil layers on Nov. 23 did not vary significantly from those results obtained on Oct. 12. The average TKN values of top and sub layers on Nov. 23 were 0.72% and 0.23%, respectively. These were almost the same as the results (0.74% for top soil and 0.26% for sub soil) obtained on Sep. 14.

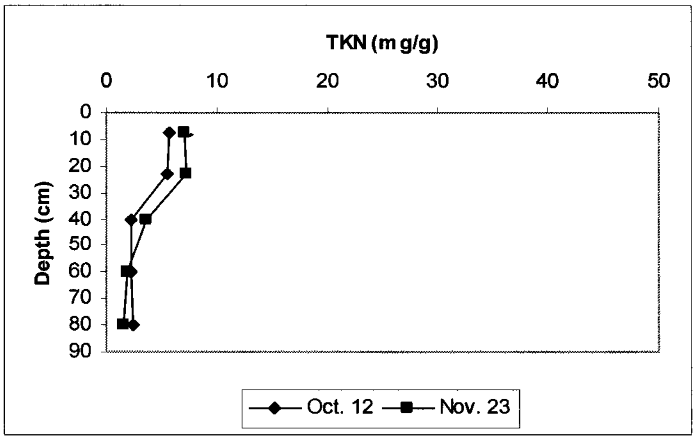


Figure 4-31 TKN variation through the soil profile during the recovery period

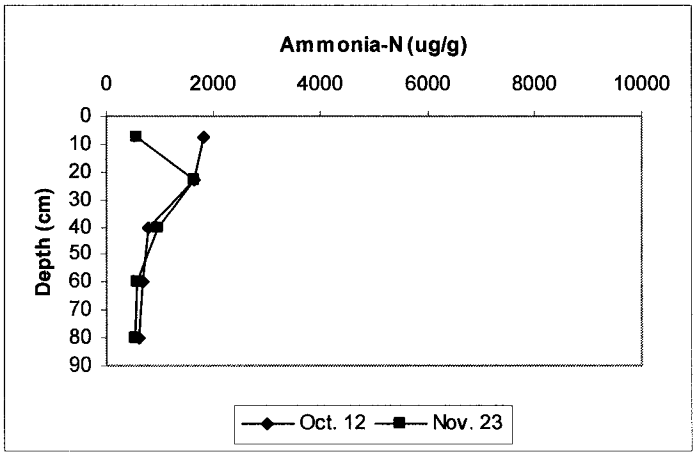


Figure 4-32 NH_4-N variation through the soil profile during the recovery period

Figure 4-32 shows the variation of NH_4-N through the soil profile from Oct. 12 to Nov. 23. In the first layer of top soil (0-15 cm depth), the NH_4-N content significantly decreased from 1817 μg/g to 573 μg/g. However, there was no apparent change in the second layer of top soil (15-30 cm depth). The loss of NH_4-N was attributed to the nitrification which occurred due to the increase in dissolved oxygen and the washout caused by the tap water irrigation. For the layers in the sub soil, there were insignificant changes in NH_4-N content. The results of soil analyses conducted during the soil recovery period are tabulated in Appendix III.

4.3.3 NO_3-N and NO_2-N Nitrogen

4.3.3.1 Phase I: Three different rates of application of manure to soil columns

Figure 4-33 describes the trends in the variation of total nitrate and nitrite content in the top soil. Under the 12 mm/d application rate, the total NO_3-N and NO_2-N in the top soil decreased, on the whole, until the fourth week. According to the hydraulic conductivity records, the liquid swine manure passed through the surface soil very well until the fifth week. In theory, the nitrification reaction should have occurred in the top soil with the application of ammonium and the presence of oxygen; the nitrate and nitrite nitrogen contents should have increased. In practice, it was concluded that the reverse occurred. The most likely explanation is that the lack of oxygen in the soil stopped nitrification. With the downward flow of liquid, the initial total NO_3-N and NO_2-N stored in the soil was largely washed out of the top soil, leaving only a small amount in the top soil layer. Consequently, lower contents of total NO_3-N and NO_2-N were observed.

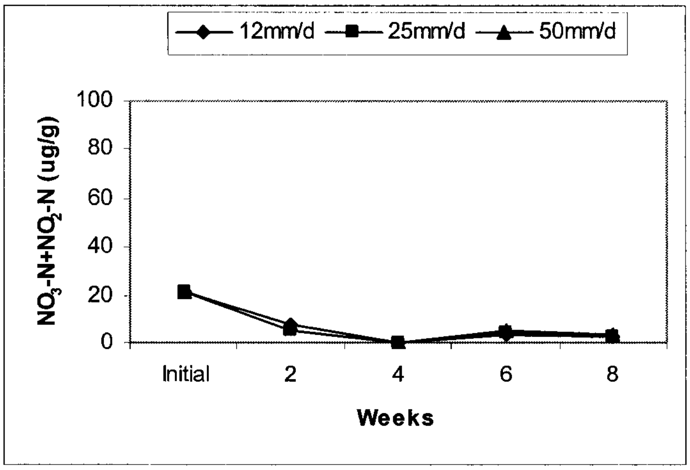


Figure 4-33 NO_3-N & NO_2-N variation in top soil with manure application

For the top soils with the 25 and 50 mm/d application rates, the reason behind the decrease in total NO_3-N and NO_2-N content is slightly different. The hydraulic conductivity records mentioned that the soil columns with the 25 mm/d rate were clogged since June 16, after eight days of manure application, and the soil columns with the 50 mm/d rate were clogged after the first week of manure application. Due to the insufficient presence of oxygen, no further nitrification occurred; theoretically, the denitrification reaction could take place. Therefore, the total NO_3-N and NO_2-N content decreased in the early four weeks. In the later weeks, there were insignificant changes in the contents of total NO_3-N and NO_2-N in the top soil.

Figure 4-34 illustrates that the trends of total NO_3-N and NO_2-N variation in the sub soil are similar to those found in the top soil. The main reasons for this similarity are the same as the explanations provided in regards to the top soil.

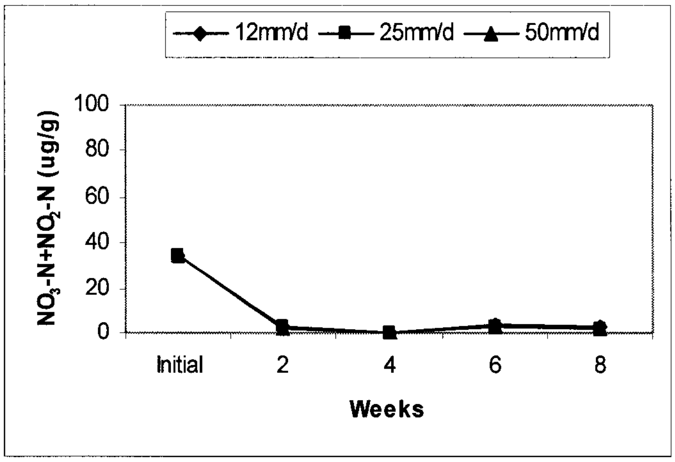


Figure 4-34 NO_3-N & NO_2-N variation in sub soil with manure application

4.3.3.2 Phase II: Recovery of columns

Figure 4-35 describes the distribution of total nitrate and nitrite nitrogen through the soil profile and the variation of content in the different layers on Nov. 23, as compared to Oct. 12. The total nitrate and nitrite content significantly increased from 1.2 to 425.8 mg/kg in the first layer of top soil (0-15 cm depth). There was also a significant increase in total NO_3-N and NO_2-N in the second layer of top soil (15-30 cm). The measured value changed from 1.1 to 60.2 mg/kg. The accumulation of NO_3-N and NO_2-N was attributed to the nitrification which occurred due to the increase in dissolved oxygen and the washout caused by the tap water irrigation. For the other three layers in the sub soil, there were insignificant changes in the total NO_3-N and NO_2-N content.

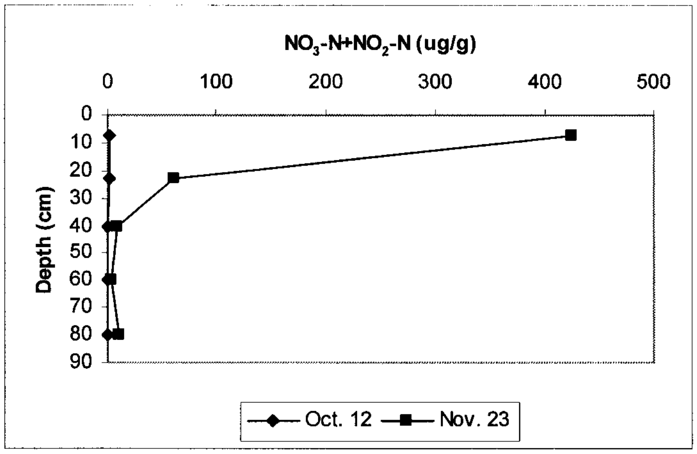


Figure 4-35 NO_3-N & NO_2-N variation through the soil profile during the recovery period

4.3.4 TP

4.3.4.1 Phase I: Three different rates of application of manure to soil columns

Figure 4-36 describes the variation of total phosphorous content in the top soil with manure application, for all three application rates. It indicates that the total phosphorous content increased in the top soil layers with increasing manure application rates. For the soil columns with the 12 mm/d application rate, the TP content gradually increased with time. Owing to the low TP concentration and the small amount of swine manure applied, TP changes in the top soil were in the narrow range. For the soil columns with the 25 and 50 mm/d application rates, the overall TP content increased with time in the first four weeks. The accumulation of applied TP accounted for the TP increase in the top soil. Due to the effects of a heavy rain storm and hail, no further liquid swine manure was applied from July 13 (the fifth week). With the washout by rain water, TP content decreased in the top soil layer based on the results observed during the sixth week. Because of serious clogging, the amount of swine manure applied was smaller in later weeks. Therefore, there were insignificant changes in TP content during the last two weeks.

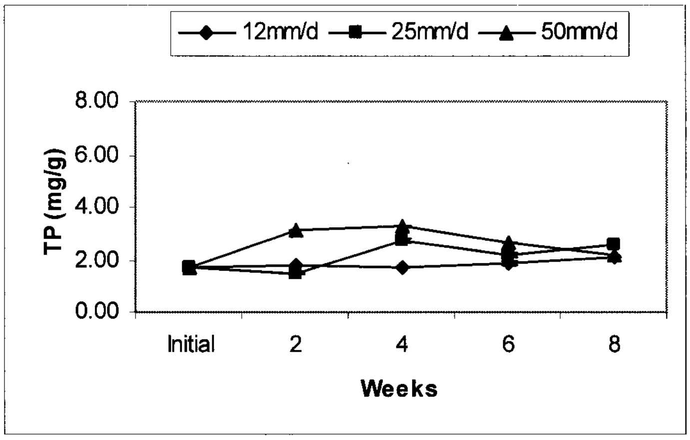


Figure 4-36 TP variation in top soil with manure application

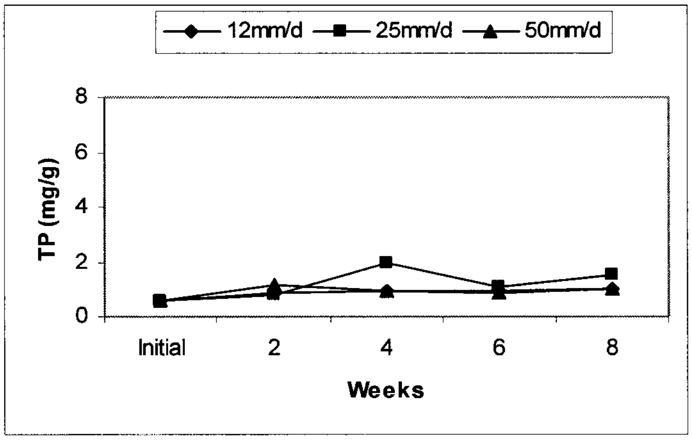


Figure 4-37 TP variation in sub soil with manure application

Figure 4-37 shows the trends in TP variation in the sub soil under all three application rates. Due to the low TP concentration in the swine manure and the occurrence of clogging within the soil column, TP contents in the sub soil varied insignificantly with time.

4.3.4.2 Phase II: Recovery of columns

Figure 4-38 illustrates the TP concentration distribution through the soil profile and the TP variations in the five soil layers from Oct. 12 to Nov. 23. There was no significant difference between Oct. 12 and Nov. 23, based on the results observed. Compared to the results for TP content obtained on Sep. 14 (Top soil: 0.26%; Sub soil: 0.08%), the average TP concentrations (0.22% in the top soil and 0.08% in the sub soil) had not changed significantly by Nov. 23.

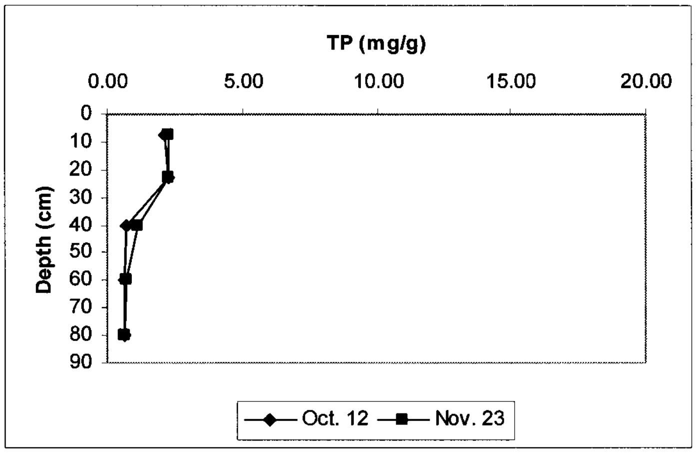


Figure 4-38 TP variation through the soil profile during the recovery period

4.3.5 pH

4.3.5.1 Phase I: Three different rates of application of manure to soil columns

Figure 4-39 illustrates pH variation in the top soil layer with the application of manure at three 3 different application rates. The trends in pH variation were almost the same for all three application rates. Generally, pH values changed within the narrow range of 7.20 to 8.67. After beginning the application of liquid manure, the top soil pH values decreased in the first two weeks and then remained constant in the following weeks. One possible reason of for the pH decrease observed during the first two weeks is the occurrence of nitrification in the soil (Wilczak et al. 1996).

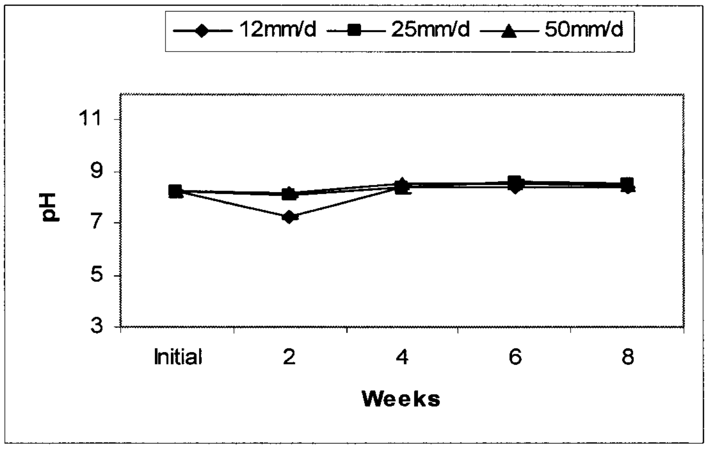


Figure 4-39 pH variation in top soil with manure application

Figure 4-40 shows pH variation in the sub soil for the three application rates. The three trends under all three application rates were very similar. pH values changed only within the narrow range of 7.96 to 8.60.

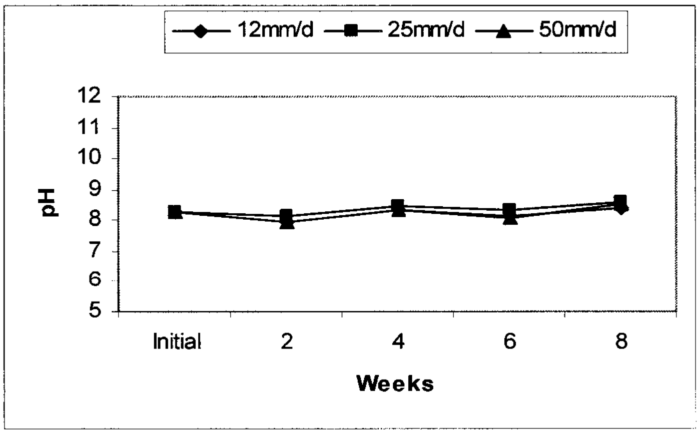


Figure 4-40 pH variation in sub soil with manure application

4.3.5.2 Phase II: Recovery of columns

Figure 4-41 represents the variation of pH values with soil depth from Oct. 12 to Nov. 23. For both the top soil layers, the pH values were lower on Nov. 23 than on Oct. 12. A possible reason for this is the occurrence of nitrification in the top soil layers with tap water irrigation and discontinued liquid manure application. During this process, NH_4-N is converted to NO_3-N and/or NO_2-N and pH decreases. In the sub soil layers, there was no significant change in pH.

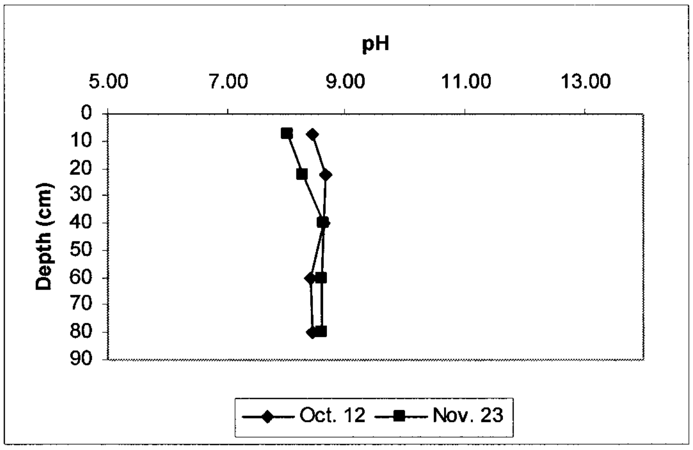


Figure 4-41 pH variation through the soil profile during the recovery period

4.3.6 Electrical Conductivity (EC)

4.3.6.1 Phase I: Three different rates of application of manure to soil columns

Figure 4-42 describes the variation of EC values with time in the top soil layer for all three application rates. It indicates that EC values increased with the manure application rates in the top soil layers. After the eight-week application, the top soils under all three rates were weakly saline (2 <EC< 4), where soils with EC of 0-2, 2-4, 4-8, 8-16, and >16 dS/m are considered non-saline, weakly, moderately, strongly, and very strongly saline, respectively (AAFRD, 2001). For the soil columns with the 12 mm/d application rate, EC values gradually increased with time. For the soil columns with the 25 and 50 mm/d rates, EC values increased with time during the first four weeks. The continual addition of TDS with the manure application accounted for the EC increase in the top soil. Due to the effects of a heavy storm and hail, liquid swine manure application was discontinued from July 13. With the washout by rain water, EC values decreased in the top soil layer based on the results observed during the sixth week. Following the resumed application of manure from July 21, EC values increased again.

For the sub soil layer, Figure 4-43 demonstrates the similar trends of EC value variations with time for all the soil columns. EC values increased with time in the first four weeks, and then decreased based on the results obtained during the sixth week. This decrease was the result of the effects of a heavy storm and discontinued manure application. With the resumed application, EC values increased again. Even though there were changes in the EC values with application, soil salinities varied only within the narrow range of 0.87 to 3.48 dS/m. According to AAFRD (2001), there were non-saline or weakly saline soils in the sub layers.

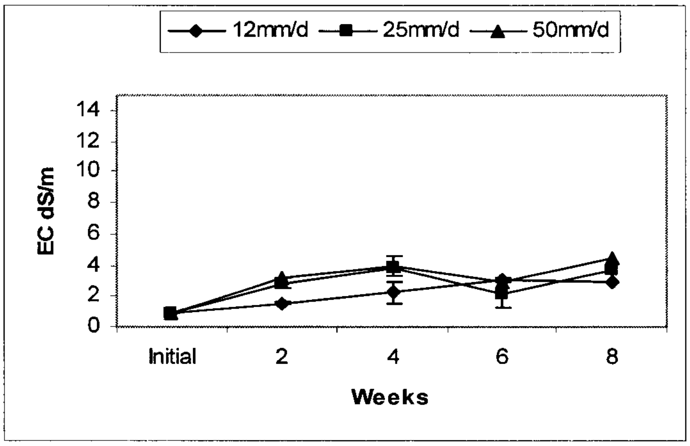


Figure 4-42 EC variation in top soil with manure application

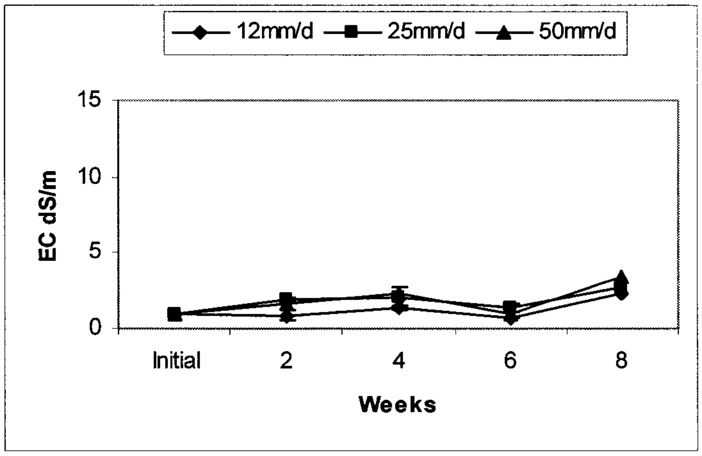


Figure 4-43 EC variation in sub soil with manure application

4.3.6.2 Phase II: Recovery of columns

With respect to EC value variations through the soil profile for the recovery project, Figure 4-44 describes the variable trends from Oct. 12 to Nov. 23. Changes in the EC values in the first top layer (0-15 cm depth) were insignificant. With the downward movement of total soluble salts washed out by tap water, total soluble salts could accumulate in the second top layer (15-30 cm depth). Therefore, the EC value in the second top layer increased. It was noticed that EC values for all three sub soil layers decreased with time. The main explanation for this decrease is the continual washout by irrigated tap water.

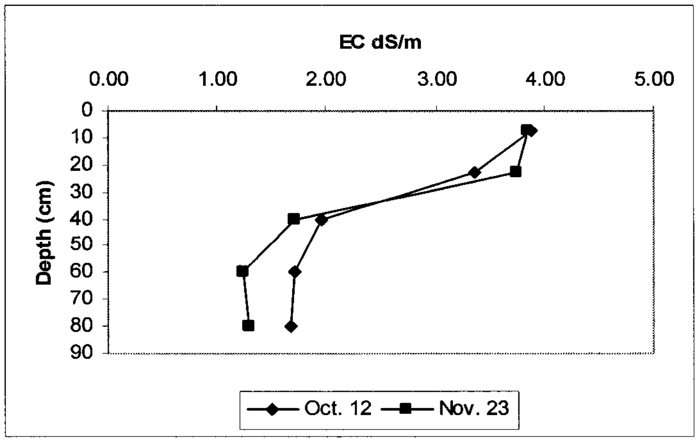


Figure 4-44 EC variation through the soil profile during the recovery period

4.3.7 SAR

4.3.7.1 Phase I: Three different rates of application of manure to soil columns

SAR is a measure of the sodium permeability hazard, or the potential for excess sodium to cause structural deterioration in the soil, which greatly impedes water movement and aeration. According to SSSA (1997), sodic soil has an SAR value of at least 13 in the saturation extract.

Figures 4-45 and 4-46 show that SAR values changed from 0.38 to 3.61 in the top soil and from 0.7 to 2.44 in the sub soil. Compared to an SAR value of 13, these SAR values are too low to affect the structure of the soil.

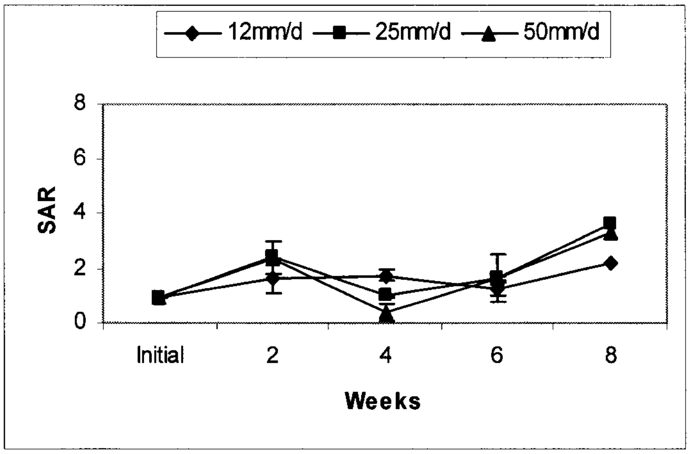


Figure 4-45 SAR variation in top soil with manure application

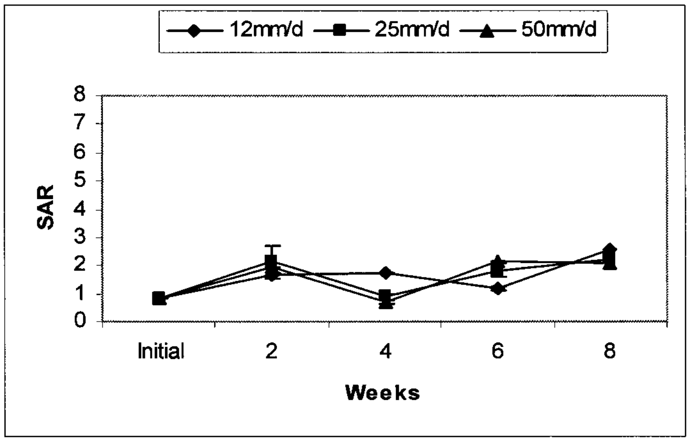


Figure 4-46 SAR variation in sub soil with manure application

4.3.7.2 Phase II: Recovery of columns

Figure 4-47 illustrates the SAR variations in the soil profiles from Oct. 12 to Nov. 23 for the recovery of soil columns. It is apparent that SAR values were reduced through the recovery by tap water.

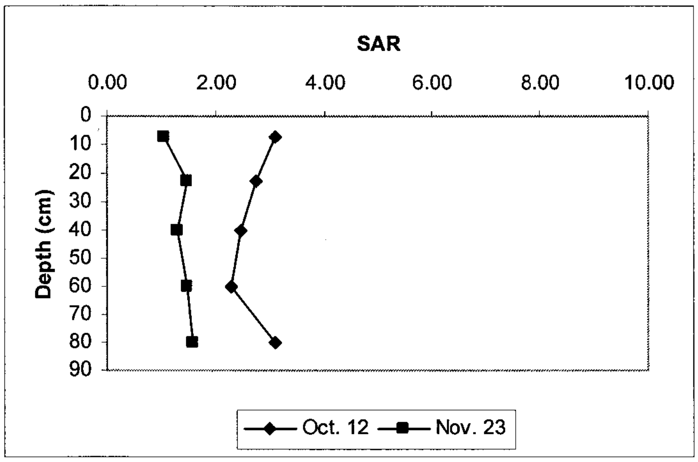


Figure 4-47 SAR variation through the soil profile during the recovery period

4.3.8 SEM Images

In order to observe the clogging phenomenon, typical SEM images were adopted. Figure 4-48 shows the surface appearances of the top soils of a control column and a soil column to which swine manure was applied at the 12 mm/d rate. As shown in these images, the control surface (left) had large spaces existing among soil granules. However, the manured soil surface was compact, with no sizeable spaces existing among soil granules. This means that the swine manure application changed the soil structure.

The occurrence of clogging can likely be attributed to the accumulation of suspended solids and the growth of microorganisms in the soil columns (Zhao et al., 2004). Koerner and Koerner (1992) investigated the permeabilities of soil filters as well as geotextiles by using six different types of leachate, and concluded that permeabilities decrease over time due to a combination of sediment clogging and/or biological clogging.

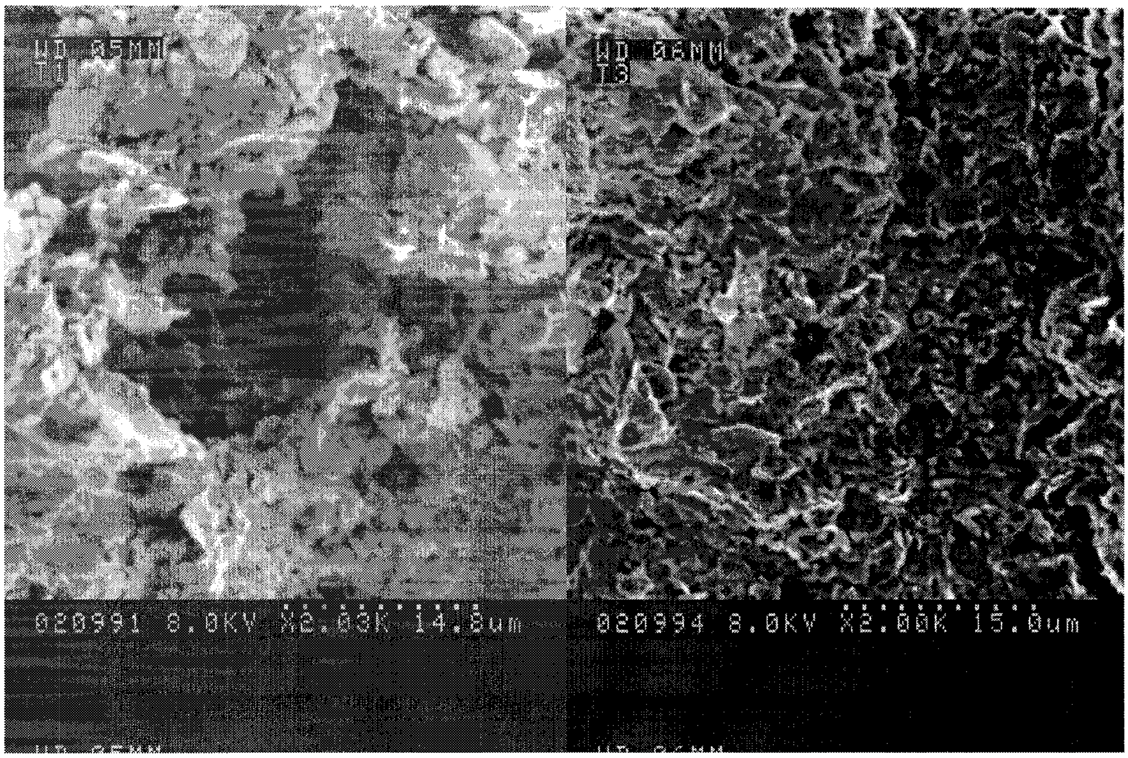


Figure 4-48 SEM images of the top soil surface of the control column (left) and soil column receiving swine manure at the 12 mm/d rate (right)

4.3.9 Accumulation of TKN, NH4-N, NO3-N & NO2-N, and TP in soil

After the eight-week application of liquid swine manure to the soil columns, the accumulations of TKN, NH_4-N, total NO_3-N and NO_2-N, and TP in the soil columns were calculated and are described in Figure 4-49. Generally, swine manure application increased the TKN, NH_4-N, and TP contents in both soil layers. For the control columns, TKN and TP contents increased even though little nitrogen and phosphorous were added. In particular, the TP content which accumulated in the control column at the 12 mm/d rate was higher than that of the column to which swine manure was applied. Therefore, the soil analysis results are questionable.

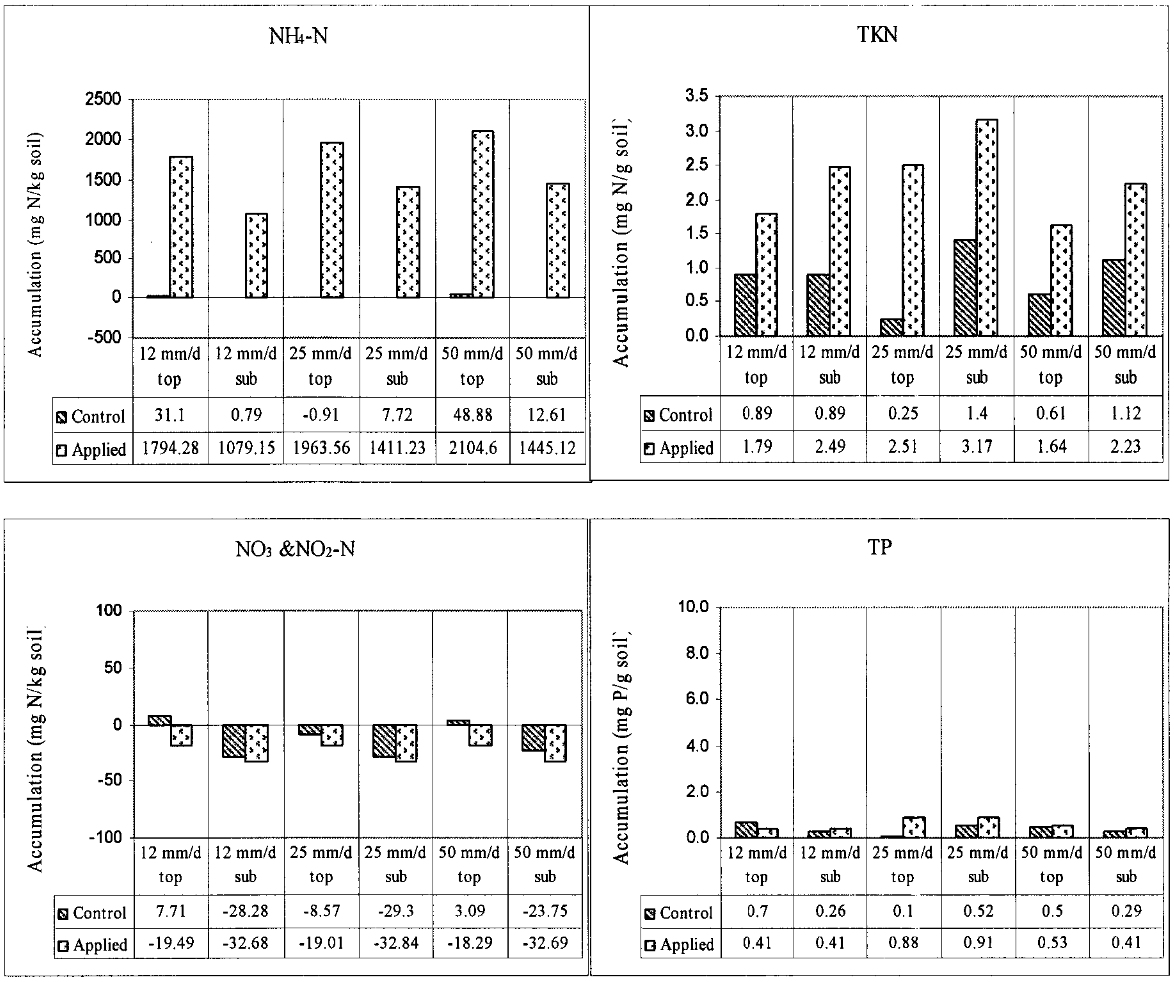


Figure 4-49 Accumulations in soil columns after the eight-week application

4.3.10 Statistical Analyses

The main nutrient contents were analyzed using an ANOVA to test for the effects of three application rates on soil characteristics. Comparing the values of TP and TKN in the top and sub layers after the eight-week application to initial soil values showed that TKN had significantly increased at $p < 0.05$ in both soil layers with the continual application of swine manure; however, there was no significant effect on TP concentration in the soil layers with the swine manure application. After the eight-week application, the final soil characteristics were analyzed statistically for each of the three application rates. The conclusions show no significant differences among the soil layers under the three different application rates.

5 CONCLUSIONS AND RECOMMENDATIONS

With the current expansion of confinement swine production into semi-arid areas of Alberta, utilization and storage of the manure produced annually presents a significant challenge to ensuring minimum adverse effects on soils, and water and air resources. The full treatment process for swine manure involves a pilot plant (physical and chemical treatment method) and a NOPA processing system. The fully treated swine manure contains low nitrogen, phosphorous and organic matter contents. Therefore, a considerable amount of the fully treated swine manure can be irrigated beneficially for crop production. Likewise, the soil that receives abundant nutrients through the NOPA system can be reused as a kind of concentrated manure for crop production.

Over the course of the eight-week application, TKN and NH_4-N contents in the leachate increased significantly for all three application rates. However, there was no significant difference in TKN and NH_4-N contents among the leachate samples from the three application rates at the end of the eight-week period. Total phosphorous content in the leachate was not significantly affected by the manure treatments at each application rate. Nitrate and nitrite could not be detected in most of the leachate samples from the different application rates, with the exception of the samples collected during the first two weeks under the 12 mm/d application rate. Leachate COD and TOC contents increased in the first month and then decreased significantly as carbon sources. A linear relationship was derived between the EC value and TDS in the leachate. Compared to the applied swine manure after the eight-week application under three different application rates, the mass reduction percentages of TP, TKN, and COD in the leachate were 95%, 98%, and 50-80%, respectively. Based on the actual volume of treated swine manure applied during the eight-week period, the proper application rate is 17 mm/d for the NOPA system. Consequently, the application rate of TKN is 25.4 g N/day/m^2, which is considerably higher than the agricultural application rate of about 0.03 g N/day/m^2 from manure for crop fertilization.

After the eight-week swine manure application, the final soils characteristics were compared to those of the initial soils for each of the three application rates. The addition of treated swine manure significantly increased TKN and NH_4-N contents in both soil layers under the three application rates. The TP content was not significantly affected due to the low TP concentration in the treated swine manure. Total nitrate and nitrite nitrogen significantly decreased due to the oxygen deficiency arising from clogging within the soil columns. Statistical analysis indicated that there was no significant difference in soil characteristics among the soils receiving the different application rates after the eight-week irrigation. However, it was noticed that the extent, and the time of occurrence, of soil clogging were different under the three application rates.

Based on the actual applied volume of treated liquid swine manure, a 17 mm/d application rate is recommended for future column tests. In order to improve the ability of the soil system to treat the swine manure, the application frequency can be adjusted by, for example, applying manure every second or third day. Based on the soil recovery project in this study, the soil system can be recovered by rainfall after two months intensive application. In order to minimize the volatilization of nitrogen and maximize the oxygen availability in the top soil, tilling is strongly recommended before manure application. Also, in order to improve the accuracy of total nitrogen and phosphorous budget balances, more soil layers should be sampled.

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Appendix I

Summary of leachate characteristics over the whole application period

Parameter	Initial wastewater Ave.	12 mm/d application rate				
		Jun. 22	Jul. 06	Jul. 20	Jul. 27	Aug. 03
pH	8.16	7.40	6.87	6.97	7.04	7.47
EC	10.96	1.90	3.23	3.36	2.21	2.50
TS (mg/L)	4527.22	1962.50	4193.75	4400.00	2468.75	2616.25
TDS (mg/L)	4336.72	1863.75	4115.00	4265.00	2236.25	2178.75
TSS (mg/L)	190.50	98.75	78.75	135.00	232.50	437.50
TP (P mg/L)	12.48	0.38	0.60	0.51	0.51	0.31
TKN (N mg/L)	1496.38	0.00	14.17	64.24	62.57	23.53
NH_4-N (mg/L)	1404.84	0.00	3.74	9.87	15.47	5.97
TOC (mg/L)	1611.06	160.41	370.80	267.53	139.55	97.00
BOD_5 (mg/L)	3869.45	243.75	737.25	NA	136.00	88.00
COD (mg/L)	8118.05	NA	1908.22	1027.50	848.10	432.21
Chloride (mg/L)	550.57	75.79	237.37	404.52	320.47	280.22
NO_3-N (mg/L)	0.35	15.46	BDL	BDL	BDL	BDL
NO_2-N (mg/L)	0.15	2.82	BDL	BDL	BDL	BDL

Parameter	Initial wastewater Ave.	50 mm/d application rate				
		Jun. 22	Jul. 06	Jul. 20	Jul. 27	Aug. 03
pH	8.16	6.95	6.74	7.15	7.41	7.35
EC	10.96	4.67	5.22	4.03	2.94	3.62
TS (mg/L)	4527.22	5502.50	6526.25	4903.75	3552.50	4082.50
TDS (mg/L)	4336.72	5421.25	6476.25	4836.25	3387.50	3945.00
TSS (mg/L)	190.50	81.25	50.00	67.50	165.00	137.50
TP (P mg/L)	12.48	0.46	0.93	0.64	0.91	0.50
TKN (N mg/L)	1496.38	0.00	90.16	144.42	72.04	34.00
NH_4-N (mg/L)	1404.84	0.00	35.88	16.93	28.05	22.75
TOC (mg/L)	1611.06	1203.31	1101.95	612.69	204.10	402.05
BOD_5 (mg/L)	3869.45	NA	NA	717.00	775.00	1305.00
COD (mg/L)	8118.05	NA	4240.47	2805.24	1989.76	2120.24
Chloride (mg/L)	550.57	238.02	291.84	479.15	473.24	469.89
NO_3-N (mg/L)	0.35	BDL	BDL	BDL	BDL	BDL
NO_2-N (mg/L)	0.15	BDL	BDL	BDL	BDL	BDL

Parameter	Initial .ww Ave.	25 mm/d application rate					17 mm/d, 4 days/week		6 mm/d, 4 days/week	
		Jun. 22	Jul. 06	Jul. 20	Jul. 27	Aug. 03	Aug. 24	Aug. 31	Sep. 07	Sep. 14
pH	8.16	6.96	6.47	6.92	7.06	6.96	6.94	7.39	7.34	7.55
EC	10.96	3.72	5.08	4.31	3.34	3.28	2.34	2.37	2.13	1.68
TS (mg/L)	4527.22	4183.75	6735.00	5267.50	4122.50	3847.50	3543.75	2282.50	1803.75	1726.25
TDS (mg/L)	4336.72	4087.50	6618.75	5223.75	3902.50	3533.75	3457.50	2178.75	1672.50	1653.75
TSS (mg/L)	190.50	96.25	116.25	43.75	220.00	313.75	86.25	103.75	131.25	72.50
TP (P mg/L)	12.48	0.40	0.82	0.54	0.68	0.41	0.40	0.34	0.27	0.25
TKN (N mg/L)	1496.38	0.00	39.05	53.81	114.05	39.45	15.95	14.95	19.11	8.10
NH_4-N (mg/L)	1404.84	0.00	27.96	16.83	20.17	9.96	2.75	1.87	4.98	1.63
TOC (mg/L)	1611.06	712.91	970.64	741.19	342.65	411.30	230.75	223.40	NA	NA
BOD_5 (mg/L)	3869.45	NA	NA	1218.00	1177.00	1222.50	183.75	206.13	166.05	58.65
COD (mg/L)	8118.05	NA	4762.38	2952.02	2854.17	2055.00	904.75	762.47	534.00	387.35
Chloride (mg/L)	550.57	213.50	294.58	455.22	418.64	388.18	364.91	346.65	365.94	352.02
NO_3-N (mg/L)	0.35	BDL	BDL	BDL	BDL	BDL	0.15	BDL	0.41	0.35
NO_2-N (mg/L)	0.15	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL

Appendix II

Summary of soil characteristics over the eight-week application period

Top Soil

Parameter	Initial	12 mm/d				25 mm/d				50 mm/d			
		22-Jun	6-Jul	20-Jul	03- Aug.	22-Jun	6-Jul	20-Jul	03- Aug.	22-Jun	6-Jul	20-Jul	03- Aug.
pH	8.25	7.20	8.35	8.40	8.39	8.06	8.40	8.59	8.50	8.16	8.52	8.53	8.44
EC, dS/m	0.857	1.58	2.23	3.08	2.96	2.85	3.76	2.10	3.74	3.16	3.95	2.91	4.41
moisture content, %	25.41	39.70	43.29	46.71	46.15	40.42	42.25	48.00	53.45	42.94	50.74	40.07	52.64
NO_3-N, mg/kg	21.4	5.62	0.23	2.81	2.17	4.08	0.00	4.04	2.65	6.90	0.00	5.00	3.37
NO_2-N, mg/kg	0.26	2.25	0.00	0.70	0.00	0.79	0.00	0.47	0.00	1.21	0.00	0.23	0.00
NH_4-N, mg/kg	1.89	207.04	1461.11	633.17	1796.17	831.18	1867.20	1918.76	1965.45	688.86	3243.08	1994.45	2106.49
TKN mg/g	4.20	3.97	6.41	5.58	5.99	4.93	6.21	6.42	6.71	6.40	6.78	6.85	5.84
TP mg/g	1.70	1.80	1.69	1.88	2.11	1.50	2.75	2.20	2.58	3.10	3.29	2.69	2.23
Na, meq/L	1.49	3.36	2.60	1.94	4.07	4.96	1.12	2.42	11.95	5.52	0.37	3.00	7.32
Ca, meq/L	3.43	5.47	2.62	3.04	4.53	5.40	1.32	2.93	13.83	6.41	1.27	3.27	6.12
Mg, meq/L	1.96	2.86	1.94	1.57	2.36	3.04	0.76	1.35	7.15	4.74	0.65	3.36	3.86
SAR	0.91	1.65	1.75	1.27	2.19	2.41	0.99	1.66	3.61	2.34	0.38	1.65	3.28
Cl mg/kg	13.38	168.91	100.63	465.22	183.90	161.66	94.50	46.39	187.00	179.39	93.56	59.70	245.45

Sub Soil

Parameter	Initial	12 mm/d				25 mm/d				50 mm/d			
		22-Jun	6-Jul	20-Jul	03- Aug.	22-Jun	6-Jul	20-Jul	03- Aug.	22-Jun	6-Jul	20-Jul	03- Aug.
pH	8.27	7.96	8.33	8.16	8.41	8.16	8.47	8.36	8.60	7.96	8.34	8.10	8.53
EC, dS/m	0.904	0.87	1.42	0.67	2.31	1.89	1.99	1.37	2.78	1.57	2.27	1.00	3.48
moisture content, %	34.1	29.52	31.44	33.00	33.10	34.85	30.91	34.73	41.60	31.84	33.04	33.00	35.84
NO_3-N, mg/kg	34.73	2.55	0.00	2.90	2.34	2.42	0.00	2.64	2.03	1.36	0.00	2.46	2.06
NO_2-N, mg/kg	0.29	0.17	0.00	0.39	0.00	0.00	0.00	0.24	0.15	0.24	0.00	0.42	0.27
NH_4-N, mg/kg	1.98	54.02	271.05	240.60	1081.13	605.77	1397.13	1558.01	1413.21	537.78	819.52	1188.87	1447.10
TKN mg/g	1.03	1.48	2.88	2.64	3.52	2.40	5.40	3.98	4.20	2.96	3.67	3.32	3.36
TP mg/g	0.60	0.90	0.97	0.98	1.01	0.80	1.93	1.10	1.51	1.20	0.91	0.89	1.01
Na, meq/L	1.69	3.38	2.05	2.60	4.47	5.42	1.09	2.16	3.77	5.31	0.69	2.65	3.61
Ca, meq/L	5.42	5.41	1.58	7.08	3.75	7.69	1.64	1.95	3.65	9.96	1.39	2.04	3.37
Mg, meq/L	3.06	3.07	1.25	2.66	2.20	4.65	0.93	0.87	2.11	5.37	0.55	1.01	2.83
SAR	0.82	1.64	1.73	1.19	2.60	2.18	0.88	1.82	2.24	1.92	0.70	2.15	2.07
Cl mg/kg	9.38	80.53	63.90	24.19	142.61	151.79	67.72	35.89	164.58	143.44	71.29	123.88	260.19

Summary of soil characteristics with the 25-17-6 mm/d application rate

Top Soil

Parameter	Initial	25 mm/d, 17mm/d, 6 mm/d					
		23-Jun	7-Jul	20-Jul	03-Aug.	31-Aug	14-Sep
pH	8.25	8.06	8.40	8.59	8.50	8.68	8.66
EC, dS/m	0.857	2.85	3.76	2.10	3.74	3.95	3.54
moisture content, %	25.41	40.42	42.25	48.00	53.45	47.78	49.36
NO_3-N, mg/kg	21.4	4.08	0.00	4.04	2.65	2.68	1.44
NO_2-N, mg/kg	0.26	0.79	0.00	0.47	0.00	0.22	0.13
NH_4-N, mg/kg	1.89	831.18	1867.20	1918.76	1965.45	2510.92	1849.61
TKN mg/g	4.2	4.93	6.21	6.42	6.71	5.90	7.38
TP mg/g	1.7	1.50	2.75	2.20	2.58	2.33	2.58
Na, meq/L	1.49	4.96	1.12	2.42	11.95	8.54	5.23
Ca, meq/L	3.43	5.40	1.32	2.93	13.83	6.50	5.67
Mg, meq/L	1.96	3.04	0.76	1.35	7.15	8.88	3.50
SAR	0.91	2.41	0.99	1.66	3.61	3.06	2.44
Cl mg/kg	13.38	161.66	94.50	46.39	187.00	228.52	228.53

Sub Soil

Parameter	Initial	25 mm/d, 17mm/d, 6 mm/d					
		23-Jun	7-Jul	20-Jul	03-Aug.	31-Aug	14-Sep
pH	8.27	8.16	8.47	8.36	8.60	8.66	8.63
EC, dS/m	0.90	1.89	1.99	1.37	2.78	1.76	1.74
moisture content, %	34.10	34.85	30.91	34.73	41.60	29.61	29.95
NO_3-N, mg/kg	34.73	2.42	0.00	2.64	2.03	0.00	0.00
NO_2-N, mg/kg	0.29	0.00	0.00	0.24	0.15	0.12	0.21
NH_4-N, mg/kg	1.98	605.77	1397.13	1558.01	1413.21	1088.80	855.39
TKN mg/g	1.03	2.40	5.40	3.98	4.20	2.62	3.64
TP mg/g	0.60	0.80	1.93	1.10	1.51	0.88	0.77
Na, meq/L	1.69	5.42	1.09	2.16	3.77	3.76	3.29
Ca, meq/L	5.42	7.69	1.64	1.95	3.65	2.70	3.59
Mg, meq/L	3.06	4.65	0.93	0.87	2.11	3.77	2.02
SAR	0.82	2.18	0.88	1.82	2.24	2.09	2.13
Cl mg/kg	9.38	151.79	67.72	35.89	164.58	113.25	117.75

Appendix III

Summary of soil characteristics for recovery from Oct.12 to Nov. 23

Parameter	Top soil (0-15cm)		Top soil (15-30 cm)		Sub soil (30-50 cm)		Sub soil (50-70 cm)		Sub soil (70-90 cm)	
	Oct.12	Nov. 23	Oct.12	Nov. 23	Oct.12	Nov. 23	Oct.12	Nov. 23	Oct.12	Nov. 23
pH	8.46	8.05	8.67	8.28	8.63	8.63	8.42	8.61	8.46	8.61
EC, dS/m	3.88	3.84	3.36	3.74	1.95	1.72	1.72	1.24	1.68	1.29
moisture content, %	53.39	41.48	48.98	40.59	26.29	28.65	27.02	26.30	28.83	25.42
NO_3-N, mg/kg	1.16	335.71	0.96	47.47	0.62	8.10	0.53	2.90	0.36	10.19
NO_2-N, mg/kg	0.07	89.94	0.09	12.73	0.11	1.13	0.08	0.48	0.08	1.05
NH_4-N, mg/kg	1817.84	573.04	1651.83	1638.20	766.98	969.80	681.55	566.95	611.60	517.24
TKN mg/g	5.65	7.08	5.58	7.26	2.25	3.54	2.25	1.86	2.40	1.62
TP mg/g	2.10	2.27	2.23	2.25	0.70	1.12	0.60	0.69	0.65	0.61
Na, meq/L	4.97	4.65	4.26	4.90	4.79	3.87	3.71	3.95	7.07	3.89
Ca, meq/L	2.51	28.91	2.64	15.26	4.47	11.99	2.91	10.28	5.27	11.15
Mg, meq/L	2.84	11.75	2.60	6.63	3.20	5.47	2.35	5.68	5.24	5.64
SAR	3.12	1.04	2.75	1.49	2.45	1.31	2.30	1.47	3.09	1.57
Cl mg/kg	213.75	70.63	213.32	426.25	135.17	101.25	123.28	104.01	121.90	98.83