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CSBE | SCGAB

Paper No. 06-116

Soil Column Testing for Nutrient Reduction in Partially Treated Swine Manure

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Written for presentation at the
CSBE/SCGAB 2006 Annual Conference
Edmonton Alberta
July 16 - 19, 2006

ABSTRACT

Liquid swine manure, pre-treated by physical and chemical methods to precipitate phosphorus and remove suspended solids, was applied to a series of soil columns. The soil columns simulated proposed nitrogen and organics processing area that would form part of an overall swine manure management system intended to reduce the land-base required to accommodate manure produced by large concentration animal feeding operations. The specific objectives of the study were to determine an appropriate manure application rate and to assess the soil's ability to remove nitrogen and organic material from the partially treated liquid swine manure. Three groups of three soil columns were used. Each triad included a control and two treatment columns. Each triad received a different application rate (nominally 12, 25 or 50 mm/d) over an 8-week period. The higher application rates caused excessive pooling on the soil surface due to soil permeability limitations and the formation of a crust on the soil surface. The maximum effective application rate was found to be 20 mm/d (including precipitation), under the conditions tested. The mass removals of total phosphorus, total Kjeldhal nitrogen and chemical oxygen demand over the 8-week application period were 95%, 98%, and 50 to 80%, respectively. The lower COD removal was observed at the 25 and 50 mm/d application rates; however, application rate had little effect on nitrogen or phosphorus removal.

INTRODUCTION

Approximately 2 million, of the nearly 15 million, pigs on Canadian farms are raised in Alberta (AAFRD, 2003). The trend in the swine production industry has been toward fewer, but larger, facilities termed confined (or concentrated) animal feeding operations (CAFO). The large amount of manure produced at a CAFO has highlighted the need for efficient manure management. Because manure contains essential plant nutrients, land application has historically been an agronomically and economically beneficial manure management practice, regulated with respect to crop nutrient requirements and environmental protection.

Due to the large amount of manure produced at a CAFO, it may not always be possible to apply manure directly to nearby land at rates dictated by crop and regulatory requirements. In such cases, transportation costs may become considerable, and methods to reduce the nutrient content of the manure may become economically attractive. The advantages of treating the manure before its utilization include: (1) separation of the liquid and solid fractions; (2) ability to apply larger quantities of treated manure to smaller land areas; and (3) reuse possibilities of treated effluents in animal barns (Zhu et al., 2004). Manure management is most efficient when the liquid and solid portions of the manure are separated prior to subsequent treatment. The solid portion is amenable to composting to produce Class a fertilizer. The remaining liquid portion can be treated for carbon and nutrient removal, pathogenic microorganism reduction, and reused in the CAFO operation as wash water, or to irrigate and fertilize nearby farmland, as required.

Figure 1 shows a proposed liquid swine manure management system. The system comprises preliminary sedimentation, phosphorus precipitation, sludge blanket clarification, filtration and landfarming. Raw swine manure would be allowed to settle for 24-hours to separate the majority of the solids from the liquid portion before receiving primary treatment to reduce its solids and phosphorus content (Zhu et al, 2004). The effluent from these physical-chemical treatment processes would then flow to a nitrogen and organics processing area (NOPA). The NOPA would consist of a storage/treatment pond adjacent to a non-vegetated parcel of land that is hydraulically isolated from the surrounding soil, but which is linked to a second pond by an under-drain system. The partially treated liquid swine manure would be stored for 6 to 9 months in the first pond. During storage, some organic content will be degraded under anaerobic conditions, suspended solids will settle, and some ammonia nitrogen will volatilize. The liquid manure in the pond would then be spread over the adjacent non-vegetated land. The soil of this hydraulically isolated land will act as a biofilter to store and decompose organic material and utilize nutrients in the manure. The leachate would be collected and flow to a second pond where it would be stored until it is applied to irrigate and fertilize nearby cropland, or re-used in the CAFO operation.

The objectives of this preliminary research project were to (1) identify an appropriate protocol and application rate for pre-treated swine manure to a locally available soil; and (2) quantify the leachate nutrient composition under the different application rates.

MATERIALS AND METHODS

Liquid swine manure from the University of Alberta Swine Research Facility was treated by physical and chemical means in a previous project to decrease its solids content and phosphorus concentration (Zhu et al., 2004). The pre-treated liquid waste was stored for 6 to 9 months in an in-ground tank prior to its application to soil. The characteristics of the pre-treated manure are summarized in Table 1.

Soil columns were employed to simulate treatment by the hydraulically isolated land parcel. Tests were conducted outdoors at the University of Alberta Farm in Edmonton using nine cylindrical columns grouped into three experimental triads. Each column consisted of a 1000 mm long, 500 mm diameter PVC pipe equipped with an under-drain system to collect leachate (see Fig. 2). Rapid drip applicators were used to irrigate each column in order to reduce the volatilization of ammonia and to distribute the liquid manure evenly over the soil surface. The bottom of each applicator was pierced with equally spaced 2 mm holes. Locally available soil was placed in each column to a depth of 900 mm. The soil was placed as a 60 cm subsoil layer overlain by a 30 cm topsoil layer, to approximate natural soil stata. These soils were obtained from similar depths in a field at the University of Alberta Farm. A coarse gravel layer to facilitate leachate collection supported the subsoil.

The topsoil was a clay loam, with average sand content of 31.4% and average clay content of 32.3%. The subsoil was a loam, with average sand content of 48.2% and average clay content of 11.4%. In the process of filling in the soil columns, a weight balance and steel tamper were used to control the weight of air-dried soils in each layer. The aim was to get similar densities in corresponding layers in each column.

Partially treated swine manure was applied to the test columns during July and August of 2004 at three nominal application rates: 12, 25, and 50 mm/d over an eight-week period. The 9 columns were divided into 3 groups (triads), with each group being dosed at one of these three application rates. One column within each group served as a control and received only dechlorinated tap water. Kentucky bluegrass sod was applied over the soil columns and irrigated with water for three weeks prior to the application of liquid swine manure, to determine if vegetation of the NOPA apron area would be viable. The plan was to apply partially treated swine manure daily over soil columns, but this frequency had to be modified to allow standing liquid time to penetrate the soil following heavy rainfalls. The effective application rates and recommendations arising from the application procedures are discussed later.

During the application period, the swine manure and leachate were sampled and analyzed every two weeks. The following analyses of liquid samples were performed: pH, EC, TDS, TP, TKN, Ammonia-N, Nitrate-N, Nitrite-N, TOC, and COD.

RESULTS AND DISCUSSION

Water balance and average application rates

The cumulative volumes of applied manure, collected leachate, and rainfall were calculated after the 8-week application, and are shown in Fig. 3. The volumes of leachate through the control columns are also indicated in Fig. 3. Because these columns were located in the open, rainfall was also measured and is shown in Fig. 3. A heavy rainfall at the end of the fifth week caused water to pool in the columns, and manure application was suspended until the pool had dissipated. Some of the rainwater was removed, as indicated in Table 2.

The water balance for each nominal application rate is shown in Table 2. These data indicate that a 20-mm/d-application rate can be applied (including rainfall). The losses indicated in Table 2 represent those due to evaporation and storage in soil columns.

Based on an effective manure application rate of approximately 16 mm/d and the 1,496 mg/L TKN concentration in the applied swine manure, the mean TKN application rate was 24 g N/day/m^2. Compared to the recommended 0.03 g N/day/m^2 supply of nitrogen for crop fertilization (AOPA, 2001), this actual application rate is considerable higher than agronomic requirements.

Nitrogen in leachate

Leachate samples were collected and analyzed every two weeks. Figure 4 shows the variation of TKN and NH_4-N with time under the three application rates. TKN and NH_4-N concentrations in leachate samples were not detected in lechate at the second week from any of the columns. Nitrite and nitrate were also below the detection limit in all leachates except those from the columns receiving 12 mm/d. These leachates contained nitrite and nitrate concentrations of 15.5 and 2.8 mg/L (data not shown). This is significantly higher than that in the applied swine manure. This indicates that some nitrification did occur within these columns during the first two weeks. No nitrate or nitrite was detected in the leachate from any column at any other time during the 8-week test. This may be due to either denitrification being established or to anaerobic conditions existing throughout the Colums preventing nitrification. The latter is more likely, given that the high organic loadings applied to the columns would lead to anaerobic conditions throughout the column depth. These results suggest a need to aerate the topsoil periodically.

Figure 5 shows the cumulative mass of TKN under the three application rates as functions of time. The vast majority of the applied mass of TKN was retained or removed within the soil matrix. Over the course of the 8-week trial, 98.4 and 99.6 percent (by mass) of the TKN and NH_4-N were removed, respectively.

Mass removals from leachate

Figure 6 illustrates the mass removals of various parameters over the course of the 8-week trial. Some washout of COD and TDS was evident in the control columns. In fact TDS was washed out of all columns other than those that received the 12 mm/d manure applications. The results shown in Fig. 6 indicate that all of the applied TDS was recovered in the leachate, as well as some washout of salts from the soil matrix. The total phosphorus concentration in leachate remained below 1 mg/L at all times under all application rates (data not shown). The phosphorus mass removals shown in Fig. 6 represent approximately 95% of the mass of phosphorus applied to the columns. Phosphorus was probably adsorbed by soil, and should not be seen as a long term method for total phosphorus removal. Rather, this is one of the goals of the preliminary treatment.

TKN was removed very well, with the mass removals exceeding 95% over the 8-week period in all columns. Soil columns that received the 12 mm/d manure applications removed up to 80% of the applied mass of COD. However, the columns that received 25 or 50 mm/d applications achieved approximately 50% COD mass removals.

Recovery of soil

An essential aspect of the proposed land-based treatment system is the ability of the soil to recover after a set of manure applications. Ideally, this would be facilitated by soil tilling to aerate the topsoil. However, to simulate a "worst case scenario" (e.g. the soil is too wet to support machinery), the following was done without tilling. The three columns that had received the nominal 25 mm/d applications were allowed to rest for 6 weeks (no irrigation other than rainfall), and then were irrigated with 10 mm/d of tap water for 10 weeks from September 14 to November 23. Figure 7a illustrates that the ammonium content of the top-most layer of soil (0 to 15 cm) was markedly diminished during the irrigation with tap water, while the combined nitrite and nitrate increased substantially within the layer (Fig. 7b). The concomitant increase in the combined nitrite and nitrate concentrations in this soil horizon shown in Fig. 7b confirms that microbial activity was involved in the decrease in ammonium. The decrease of the combined nitrite and nitrate with depth can be attributed to denitrification within the subsoil. The increase in the combined nitrite and nitrate in the 70 to 90 cm soil layer is attributed to experimental error, and perhaps to non-steady state conditions prevailing in the soil profile. Less than 1% of the mass of nitrogen removed from the soil was recovered in the leachate (data not shown).

While the 16-week recovery period was not sufficient to return the soil to its original characteristics, this trial suggests the ability of natural soil micro flora to assimilate and convert nutrient inputs.

CONCLUSIONS AND RECOMMENDATIONS

An 8-week trial was undertaken to determine (1) the maximum effective rate at which partially treated swine manure can be applied to a natural soil; (2) the ability of the soil to remove contaminants from the applied manure. This was followed by a 16-week period during which the recovery of the soil was observed. Experience gained during the 8-week manure application trial indicates that the maximum effective application rate was 20 mm/d (including rainfall). However, a crust formed on the soil surface that limited infiltration. Periodic tilling of the soil is recommended to break-up the surface crust and aerate the topsoil to promote microbial activity.

The overall mass reductions of TP, TKN and COD in the leachate were 95%, 98%, and 50 to 80%, respectively. TDS in the applied manure was not retained in the soil. Nitrate and Nitrite were not detected in leachate samples, other than those obtained after the first two-weeks of 12 mm/d manure application. This suggests that nitrification did not occur during most of the application period due to inadequate aeration.

Changes in the ammonia and nitrate concentration profiles in the soil during a 16-week recovery period indicate that nitrification was established in the topsoil (0 to 30 cm depth), and that denitrification occurred in the subsoil (30 to 90 cm depth) during this period. This suggests the ability of the soil to recover following manure applications.

ACKNOWLEDGEMENTS

Special thanks are extended to Maria Demeter; Garry Solonynko, and Nick Chernuka of the Environmental Engineering and Science Program at the University of Alberta for their technical support. Funding for this project was provided by David Bromley Engineering Ltd. and the Natural Sciences and Engineering Research Council of Canada (NSERC) Collaborative Research

and Development Programme.

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Table 1. Partially treated swine manure characteristics.

Parameter	Mean	Standard Deviation
pH	8.2	0.2
EC (dS/m)	11.0	1.0
TS (mg/L)	4,527	396.2
TDS (mg/L)	4,337	445.2
TSS (mg/L)	190	84.8
TP (P mg/L)	13	1.4
TKN (N mg/L)	1,496	53.0
NH_4-N (mg/L)	1,405	36.1
NO_3-N (mg/L)	0.4	0.1
NO_2-N (mg/L)	0.2	0.2
TOC (mg/L)	1,611	60.0
COD (mg/L)	8,118	556.9

Table 2. Water balance through columns.

Nominal Application Rate	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 (L)	96.8	96.8	175.9	175.9	185.5	185.5
Precipitation (L)	43.2	43.2	43.2	43.2	43.2	43.2
Removal (L)	0	10.9	0	6.0	0	10.5
Leachate (L)	111.0	107.1	185.6	167.5	193.1	168.3
Loss (L)	29.0	22.0	33.4	45.6	35.5	49.8
Manure application rate (mm/d)	8.8	7.8	16.0	15.5	16.9	15.9
Total application rate (mm/d)	12.7	11.7	19.9	19.4	20.8	19.8

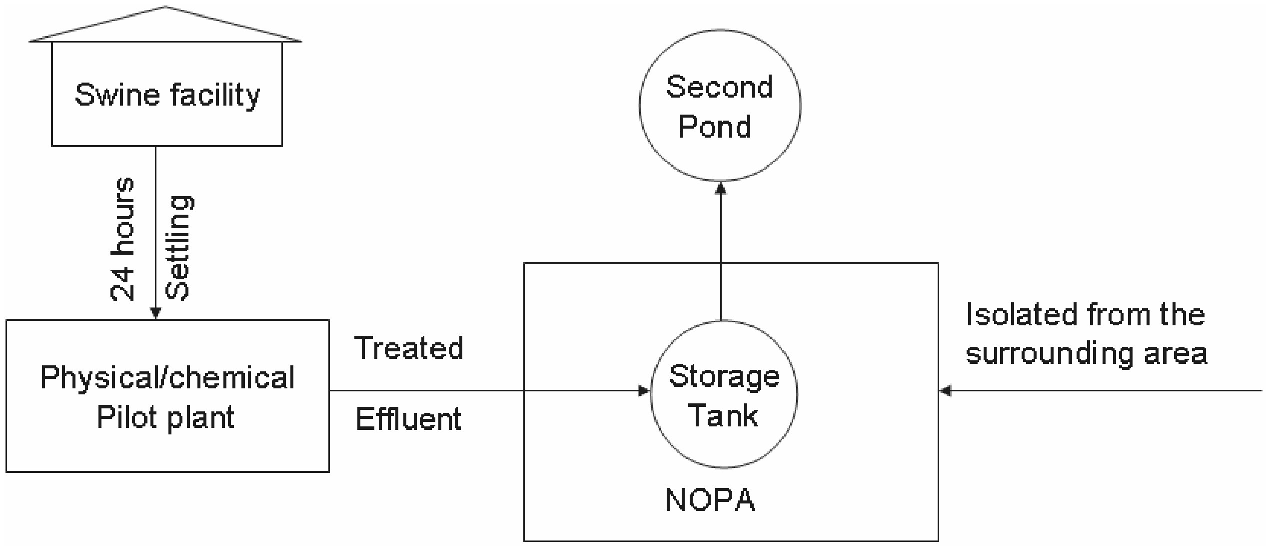


Fig. 1. Integrated swine manure treatment system.

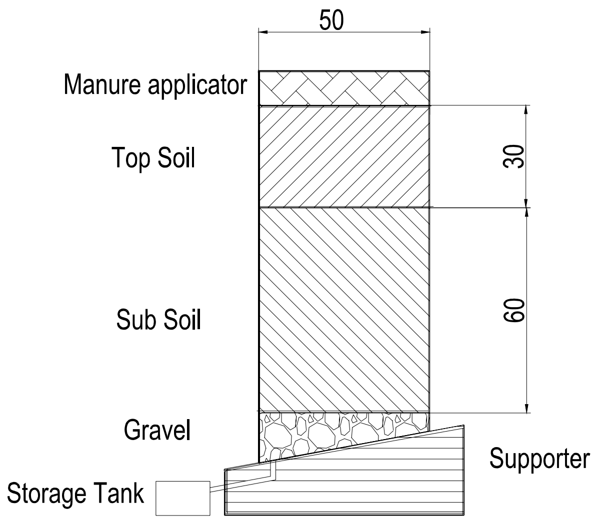


Fig. 2. Soil column profile (Unit: cm).

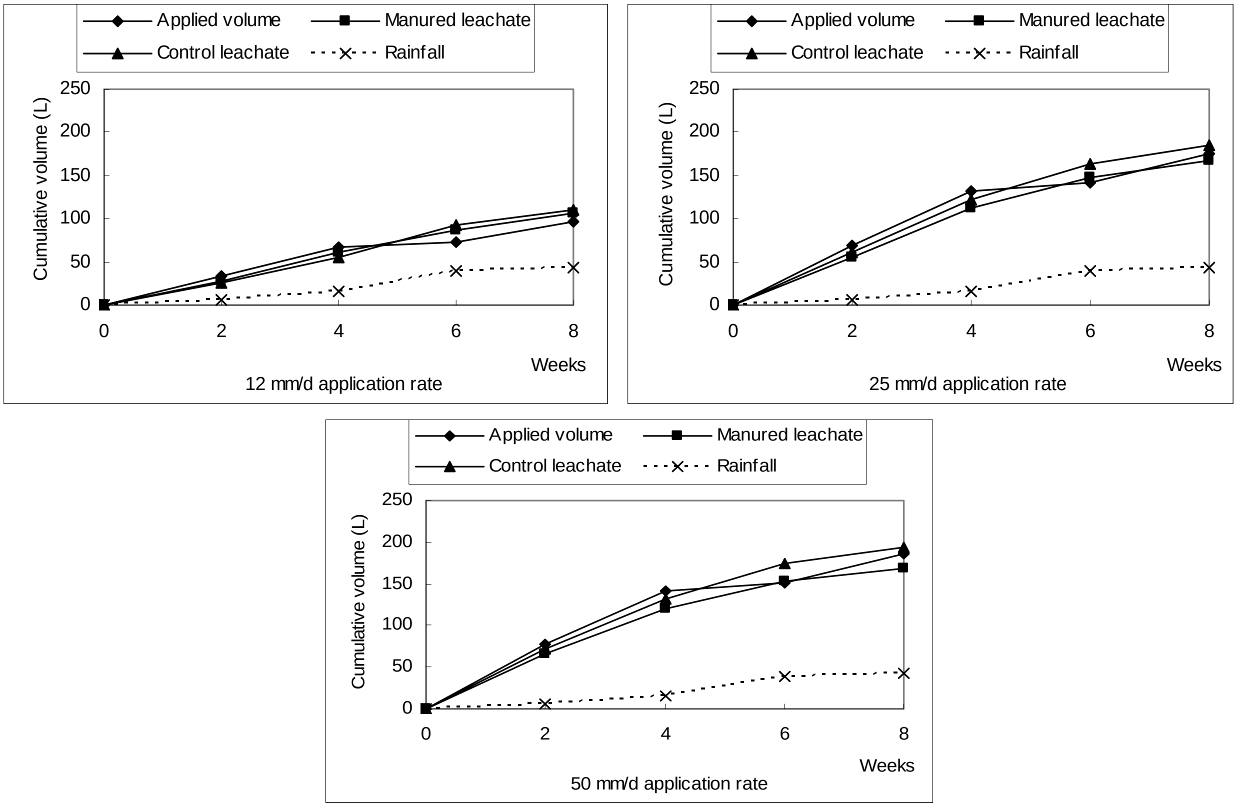


Fig. 3. Cumulative volumes of the applied manure and leachate.

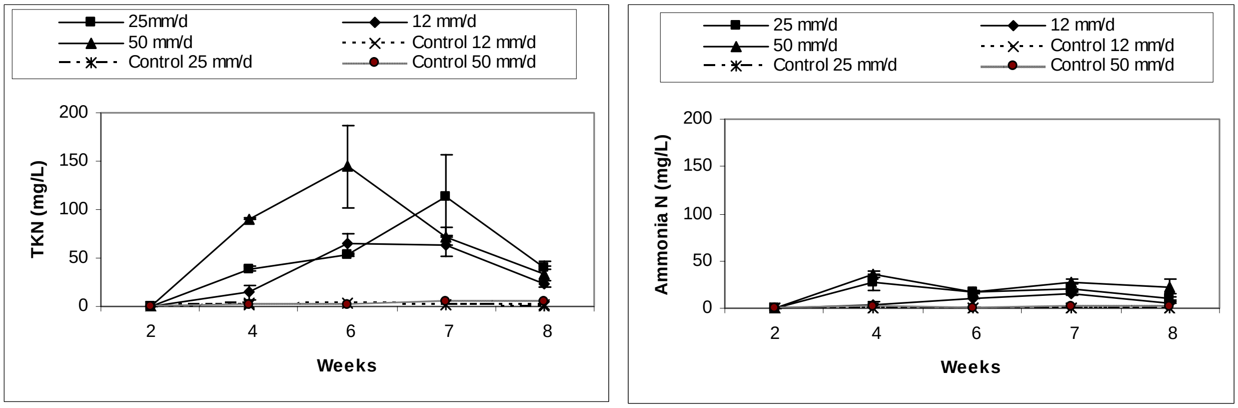


Fig. 4. Leachate TKN and NH_4-N concentrations during the 8-week trial (TKN and NH_4-N concentrations in applied swine manure were 1496 mg/L and 1405 mg/L, respectively).

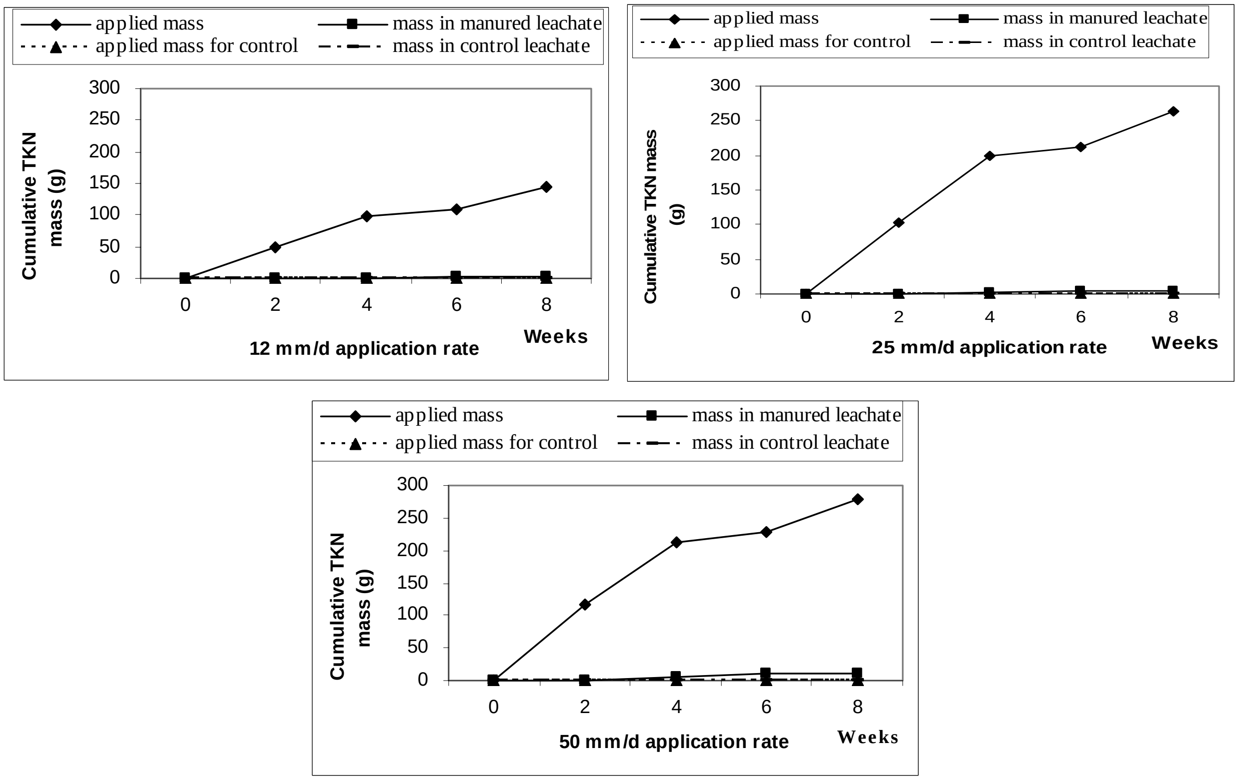
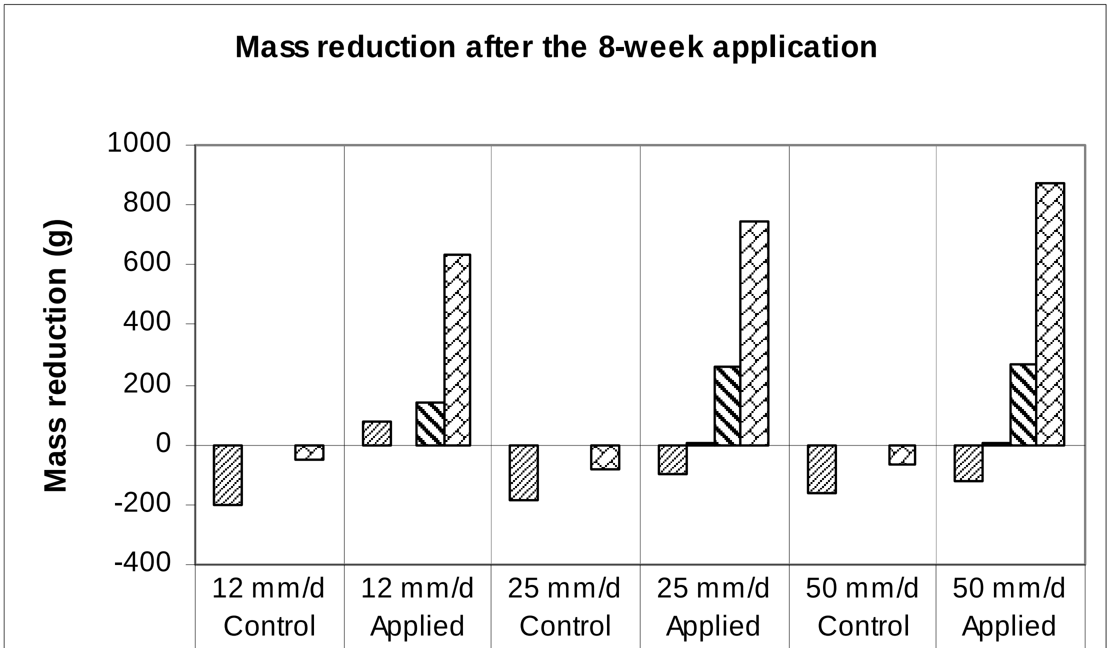


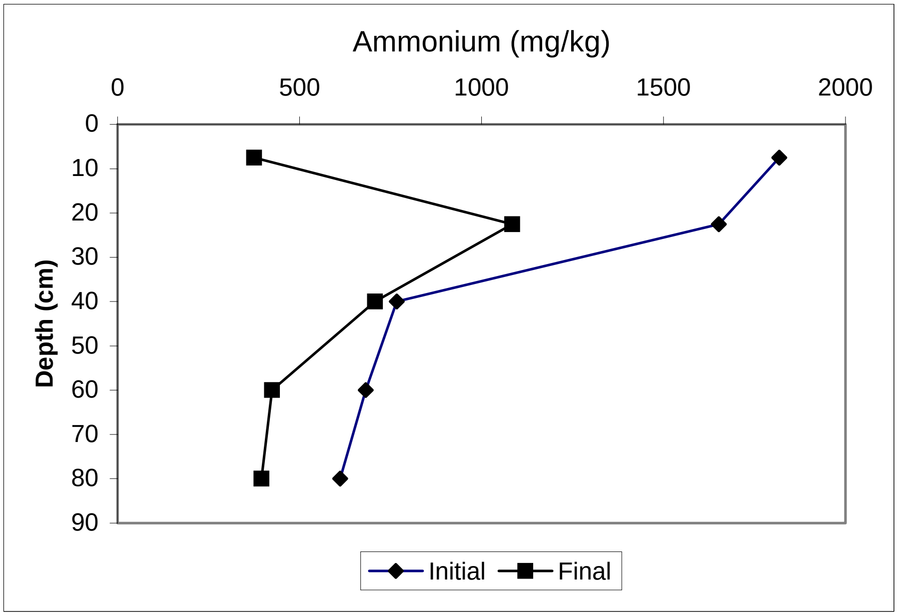
Fig. 5. Cumulative masses of TKN applied and recovered in the leachate over the course of the 8-week trial.



	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

Fig. 6. Cumulative mass removals from manure during the 8-week application period.

a)



b)

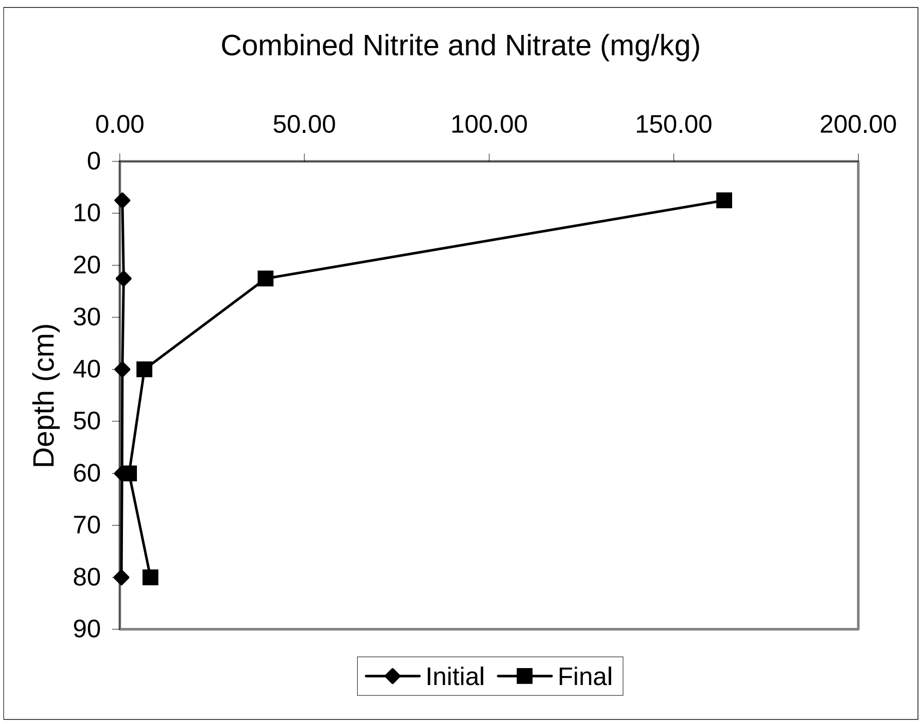


Fig. 7. Nitrogen conversion during the final 10 weeks of the recovery period: (a) ammonium; and (b) combined nitrite and nitrate.