ABILITY OF YARD TRIMMINGS COMPOST TO MITIGATE ENVIRONMENTAL IMPACTS OF OVER-WINTER FIELD STORED POULTRY LITTER

by

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Abstract

Incorporation of poultry litter (PL) into crop production on British Columbia's Fraser River delta is an important means of recycling this over-abundant agricultural waste product. However, environmental and ecological concerns associated with over-winter field storage of PL should be addressed. To mitigate these concerns some farmers have been storing the PL on a 30 cm thick base pad of City of Vancouver yard trimmings compost (YTC) and further covering the pile with a 15 cm thick layer of YTC.

A column study was conducted on the UBC, Vancouver campus to assess the effects of the YTC base pad and cover on the quality of leachate emanating from the PL. The YTC layer under the PL decreased ($P<0.05$) the cumulative Cu, Zn and P leached as compared to the PL alone by 50%, 54% and 30%, but had little ability to retain N or soluble salts. Concentrations in the first flush of leachate out of the PL were reduced by the YTC pad from 25 to 1.3 mg Cu L^{-1}, 11 to 0.95 mg Zn L^{-1}, and 430 to 40 mg P L^{-1}. A key finding was that the YTC cover increased ($P<0.05$) the leaching of N, Cu and Zn from the underlying PL.

A complementary field study was conducted over the same winter in Delta, BC. Three PL storage piles were constructed with and without an YTC pad and/or YTC cover. Soil samples from under and around the piles (0-15 and 15-30cm depths) as well as samples from the YTC base pad were analyzed. Crop development the following spring was negatively impacted under all piles. The YTC pad protected the soil below the core of the pile from leaching due to water table rise however it was less effective under the highly leached outer regions of the piles. Delta farmers are advised to not store PL directly on the soil and to consider the use of an YTC base pad thicker than 30cm. The

YTC cover apparently increases leaching, likely due to increased infiltration of precipitation, yet it reduces run-off, and isolates the PL from wildlife.

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Abbreviations

PL - Poultry litter

YTC - Yard trimmings compost

Y/PL - Column treatment: yard trimmings compost over poultry litter

PL/Y - Column treatment: poultry litter over yard trimmings compost

S - Column treatment: "sandwich" ie. yard trimmings compost over poultry litter over yard trimmings compost

1U - Pile 1 uncovered section

1C - Pile 1 YTC covered section

2U - Pile 2 uncovered section

2C - Pile 2 YTC covered section

EC - Electrical conductivity

D_b - Dry bulk density

D_p - Particle density

WHC - Water holding capacity

CEC - Cation exchange capacity

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1. General introduction and literature review

1.1 Introduction

The lower Fraser Valley extends from Hope to the estuary of the Fraser River. It is characterized by a river delta to the West, a low land plain to the Southeast, and a flood plain extending along the length of the river to the Eastern end of the valley (Figure 1.1). The Fraser Valley consists of diverse wildlife, including many species of migratory birds, and an economically and culturally important salmon run, increasing urban settlement, and some of British Columbia's most productive agricultural land. The Fraser Valley accounts for more than half of the province's gross farm receipts on a small portion of the total agricultural land (Fraser Basin Council (FBC) 2001). Point sources of pollutants in the region are generally well constrained, however it is the non-point sources, such as nutrient overloading in agricultural fields that have become a greater concern. In 2001 the FBC released a document entitled "Nutrient Management Planning Strategies for the Fraser Valley". This document outlined the need to control nutrient inputs (nitrogen (N), phosphorus (P), and potassium (K)) to agricultural fields. These inputs come in the forms of animal manures and chemical fertilizers, and need to be controlled in terms of both quantity and timing of application.

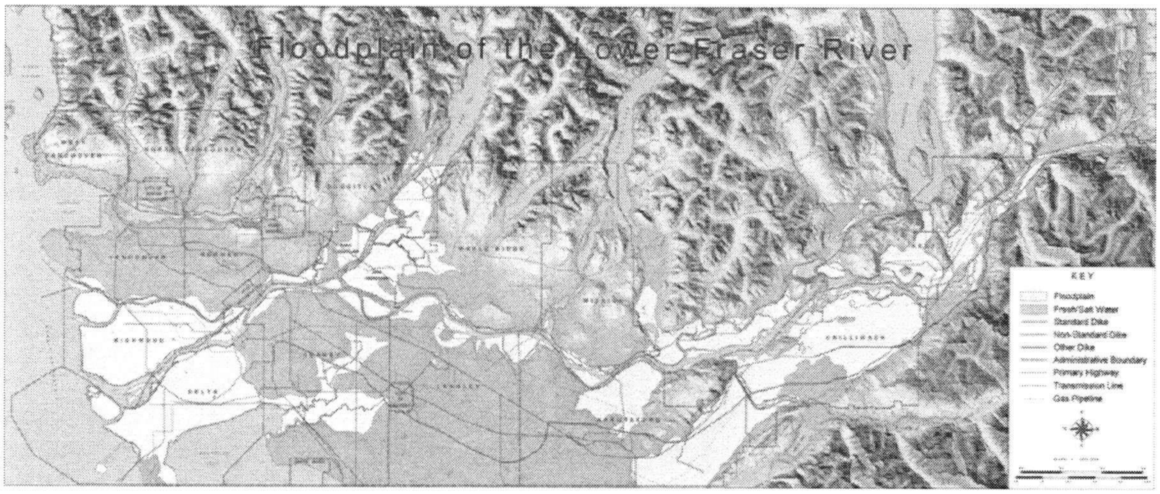


Figure 1.1 Map of the Fraser Valley (Fraser Basin Council, 2004)

Due to the increased intensity of livestock farming in the Surrey to Chilliwack region over the past twenty years, the incorporation of animal manures into crop production throughout the entire Fraser Valley has become a necessary means of disposal of an abundant agricultural waste. However, this raises questions as to the application rates and timing, food safety and wildlife safety with regards to the spread of pathogens, as well as environmental concerns related to over-winter field storage of the manure.

The Corporation of Delta receives on average 712 mm of precipitation from October 1st to April 1st (Environment Canada 2004). These high levels of precipitation can lead to leaching, run-off and overland flow of nutrients, salts, and heavy metals from the stored litter. Furthermore, agricultural fields in Delta are subject to a fluctuating water table which commonly causes soil saturation. In the spring there is often an area of stunted or non-existent crop growth where the poultry litter was stored over-winter. In order to mitigate these concerns some farmers have been building a 30 cm thick base pad out of City of Vancouver yard trimmings compost (YTC) on which the manure is stored, and additionally covering the pile with a 15 cm thick layer of YTC. Preliminary observations indicate that this pad and covering protect the soil below from excessive nutrients and salinity (Bomke and

Temple 2004). In the spring, the compost base pad and covering are thoroughly mixed with the poultry litter and spread evenly over the field. Thus any nutrients lost from the manure and trapped in the YTC remain available for crop growth.

1.2 Background

1.2.1 Poultry litter resource and nutrient management

Since the mid-1980s the intensity of poultry farming in the lower Fraser Valley, particularly the Surrey to Chilliwack region, has increased dramatically. From 1986 to 1996 the chicken and hen production increased from 6.9 million to 10.7 million birds, while the number of these farms decreased by 5% from 1454 to 1380 (FBC 2001). From 1991 to 1996 the turkey production increased from 646 000 to 795 000 birds (Schreier *et al.* 2000). This increase in the number of poultry in the region has forced farmers to import more feed from Alberta and Saskatchewan, thus increasing the region's nutrient surplus. Furthermore, in the Abbotsford region, where crop cultivation occurs over the Abbotsford-Sumas aquifer there has been a shift away from the production of high N demanding forage crops to low nutrient requiring raspberries. The combination of the over application of poultry manure and the cultivation of low nutrient requiring crops has led to very high N levels in the Abbotsford-Sumas aquifer, and nitrate (NO_3) concentrations which are commonly above drinking water standards (Table 1.1) (FBC 2001). This has also led to aquatic habitat degradation, thus putting at risk economically and socially important salmon runs (FBC 2001). Because of this, over the past 10 years there has been a concerted effort to control the amount of manure applied to agricultural fields, and to move excess poultry manure to more manure poor regions (i.e. less livestock production) of the Fraser Valley, such as the Fraser River delta.

In 2000-2001 the Fraser Valley produced approximately 240 000 tonnes of poultry manure, 17 175 tonnes of which were moved via the Sustainable Poultry Farming Group to markets distant from the poultry producing regions of the Fraser Valley (Timmenga and Associates Inc 2003). Forty-nine percent of this was shipped to the Corporation of Delta. In 2004-2005 the total manure production in the Fraser Valley had continued to increase however the amount shipped to Delta had decreased to 2330 tonnes (Chipperfield 2005). The main reasons for this decline in poultry litter use cited by Delta farmers were the environmental regulations (discussed in the literature study) associated with the storage of the manure, and increasing food safety concerns related to pathogens (Chipperfield 2005).

Poultry litter is a mixture of poultry manure, feathers, and bedding material, usually wood shavings or sawdust, which is removed from poultry barns upon clean-out. It is generally high in N, P and salts, as compared to other manures. The exact nutrient content depends on the type of poultry litter (i.e. chicken broiler, commercial egg, hatching egg, or turkey), however in general on a dry weight basis the P_2O_5 equivalent is 2.5 - 3.0% or 11–13 g P kg^{-1} poultry litter, the K_2O content is 1.2 – 1.6% or 10-13 g K kg^{-1} poultry litter, and the ammonium-N (NH_4-N) content is 0.4 – 0.7% or 3-6 g NH_4-N kg^{-1} poultry litter (SPFG 1996).

The major environmental concerns surrounding the use of poultry litter are volatilization of ammonia and nitrous oxides which are harmful atmospheric pollutants, nitrate leaching especially into groundwater used for drinking which can cause methaemoglobinaemia or blue baby syndrome, P build up in soils, unpleasant odors, and the spread of pathogens. In 2004 avian influenza broke out in the Fraser Valley. Since then, public perception surrounding the use and storage of poultry manure has become increasingly important. .

In addition to high levels of nutrients poultry litter contains heavy metals (on average 35 mg kg^{-1} Pb, 150-390 mg kg^{-1} Cu, 400-850 mg kg^{-1} Zn on a dry weight basis), antibiotics, antioxidants, mould inhibitors, hormones, and other organic compounds (Gupta *et al.* 1992; Gupta et al. 2005; Brock *et al.* 2006). Poultry litter leachate at concentrations of 2.9 g L^{-1} aqueous extract has been shown to be toxic to many organisms. This toxicity has been largely attributed to the presence of ammonia and heavy metals (Gupta *et al.* 1992). For these reasons it is extremely important that poultry litter is stored in such a way as to prevent any leachate from flowing directly into nearby waterways or seeping into groundwater.

1.2.2 Water quality standards for British Columbia

The British Columbia Ministry of Environment water quality guidelines for some nutrients and metals present in poultry litter leachate are listed in Table 1.1. The acceptable limits for drinking water for human consumption, freshwater aquatic organisms, marine aquatic organisms, and wildlife are tabulated.

TABLE 1.1
British Columbia water quality guidelines for some leachable nutrients present in poultry litter

Water Type	NO_3-N	NO_2-N	NH_3-N^z	Cu	Zn
		(mg L^{-1})			(μg L^{-1})
Drinking water	10	1	None	500	5000
Freshwater aquatic life	40	0.02	1.84	2	7.5-240^y
Marine life	None	None	1.0	3	10
Wildlife	100	10	None	300	None

(Government of British Columbia 2006)
^{z}At pH 7.0 and 10.0°C; ^{y}Depends upon hardness of water.

1.2.3 Yard trimmings compost resource

In 1995 the City of Vancouver Landfill began collecting yard trimmings from residents of Vancouver, Delta, Richmond, White Rock and parts of Surrey. Over 37, 000 tonnes of yard trimmings, including grass clippings, leaves, plant remains, trees and branches are collected and composted each year (City of Vancouver Landfill 2005). The composting process begins with grinding the yard trimmings into maximum 7 cm long pieces. These are windrowed and turned by a front end loader approximately 5 times over a period of 3 months. This turning of the pile ensures that aeration is complete, and that all portions of the windrow reach temperatures of 55-60°C. After the 5 turns are complete, the compost is formed into a new windrow which is left to cure for 9 months. After the 9 months have passed, the compost is passed through a 1.25 cm screen. The coarse fraction is re-composted with poultry litter, and the fine fraction is the finished yard trimmings compost (YTC).

The finished YTC is much lower in N, P, salts and heavy metals than poultry litter (Refer to Tables 2.2 and 2.3 for analysis of the materials used in this study). Furthermore, the levels of organochlorine, carbamate, and organonitrogen pesticides were all below the detection limits according to analyses performed by Cantest Ltd. in Burnaby, BC for the City of Vancouver Landfill in March 2006.

In order to foster good relations between the City of Vancouver and the Delta farmers, the City has funded some research into the incorporation of YTC into agricultural practices. It has been used as a carbon (C) source in the composting of poultry litter for organic agricultural uses, as a filler in the spreading of manure for low N requiring crops, and as a base pad and cover material for the over winter storage of poultry litter in agricultural fields (Bomke and Temple 2004). This thesis is focused on a more detailed study of this last application.

1.3 Literature study

The literature study will cover the issues and regulations surrounding the field storage of poultry litter, as well as the capacity of compost to act as a filter.

1.3.1 Poultry litter storage

There are many concerns associated with the storage of livestock manures in agricultural fields. Among these are the leaching of nutrients, such as NO_3 and PO_4 which are responsible for the eutrophication of streams and rivers, volatilization of N compounds especially NH_3, and the spread of pathogens such as *Escherichia Coli*, *Campylobacter*, and *Salmonella*. These concerns are exacerbated by high levels of precipitation. Ideally animal manures in regions of high precipitation should be stored on an impermeable surface far from any water ways, completely covered with a roof, and surrounded by a leachate collection ditch followed by some level of treatment. Precipitation running off of the roof should be managed in such a way that it does not come into contact with the manure (Government of British Columbia 1995). Unfortunately, this is not always possible due to the huge amounts of manure being produced in certain regions coupled with the high cost of such manure storage facilities.

On-farm storage of poultry litter is regulated by the British Columbia "Agricultural Waste Control Regulation" (BC reg. 131/92) (Government of British Columbia 1992). This regulation states that animal manures, including poultry litter, can be stored in an agricultural field given that certain conditions are met. First, the material must not be stored on the field for more than 9 months. Second, the material must be located at least 30 meters from any water way or any source of water used for domestic purposes in a manner which prevents the escape of agricultural waste that causes pollution. This might require dykes, berms, or other measures which isolate the material from nearby water ways. Finally, in regions that receive more than 600 mm of precipitation from October 1^{st} to April 1^{st}, such as the Fraser River delta, the regulation requires that the material be covered for this time period, however, there is no indication as to what the cover material should be (Government of British Columbia 1992).

In the Fraser Valley it is common practice to make late summer and early fall deliveries of poultry litter which will be field applied the following spring. This removes the poultry litter from the poultry producing region and transfers the storage responsibilities to the crop producer. For over-winter field storage, the British Columbia Ministry of Agriculture and Lands factsheet suggests shaping the poultry litter pile into a windrow (ie. triangular cross-section), and covering with a tarpaulin weighted down using tires (Government of British Columbia 1995). The goal of the cover is to prevent precipitation from entering into the pile, thus preventing leaching and run-off from the manure. Conversely, the Ontario Ministry of Agriculture, Food and Rural Affairs suggests piling the manure with a broad, flat top, to encourage infiltration of precipitation, and thus discouraging run-off (Government of Ontario 2005). They further suggest covering the pile with a breathable or partial tarpaulin cover, although this is not legislated.

A wide range of options for covering manure piles exist. These include impermeable covers, such as tarpaulins and roofs, and permeable covers such as geotextile fabrics, straw, peat moss, and cornstalks. Permeable covers act as biofilters, and aim to decrease NH_3 volatilization, provide thermal insulation, control run-off, and essentially isolate the manure from the surrounding environment. In field experiments, Berg *et al.* (2005) found that a 7 cm thick layer of straw over pig slurry decreased NH_3 volatilization by up to 75%. However, Rodhe and Karlsson (2002) found that a straw cover on stored poultry litter had no effect on NH_3 losses due to volatilization, and that the positive effects of the straw cover were thermal insulation and control of run-off and leaching. Puumala (2001) found that a peat cover on stored poultry litter decreased NH_3 volatilization by 80 – 90%.

Initially, Delta farmers attempted to cover their poultry litter windrows with tarpaulins. However, these were expensive, blew off during frequent winter wind storms, and were stolen. This led them to the unique idea of using the City of Vancouver YTC as a cover.

1.3.2 Compost as a filter

1.3.2.1 Compost defined

Compost is defined as "a solid mature product resulting from composting, which is a managed process of bio-oxidation of a solid heterogeneous organic substrate including a thermophilic phase" (Composting Council of Canada 2000). According to the Composting Council of Canada, the compost should be left to cure for at least 21 days, and it is deemed mature once the following conditions are met: C:N is <25, upon standing the pile does not heat up to more than 20°C above ambient temperature, the reduction in organic matter is greater than 60% by weight, and the oxygen uptake rate is less than 125 mg O_2 kg^{-1} volatile solids per hour.

1.3.2.2 Chemistry and sorption capacity of compost

Compost consists mainly of humus-like organic materials resulting from aerobic decomposition (Brady and Weil 2002). Humus can be divided into humic and non-humic substances, with the humic substances being further divided into humin, humic acids and fulvic acids. Humic substances are complex, resistant, polymeric compounds with many functional groups (Brady and Weil 2002). These functional groups can lose or gain protons, and thus have the capacity to sorb other compounds.

Due to the complex chemical structure of organic matter, the pH dependent cation exchange capacity (CEC) is high, with CEC increasing with increasing pH (Lax *et al.* 1986). Saharinen *et al.* (1998) have shown that CEC increases with composting because as composting progresses the degree of humification increases, thus producing a greater number of functional groups for cation adsorption and exchange. In this study, the elevated pH of the poultry litter leachate should serve to increase the CEC of the YTC base pad in both the column and field experiments, thus improving the CEC and overall retention capacity of the YTC material. Brewer and Sullivan (2003) found that mature, cured YTC had a CEC of 400 $cmol_c\ kg^{-1}$ of compost C at pH 7.0.

The mineral fraction of compost also possesses negatively charged sites, e.g. OH^-, which can bind metals and nutrients (Grimes *et al.* 1999). In this study, cations such as NH_4, Zn and Cu should be attracted to the negatively charged sites present in the YTC base pad, while anions such as NO_3, PO_4, and sulphate (SO_4) should flow through freely. However, other P compounds could be retained through reaction with Ca and Mg under alkaline conditions. The pH of the YTC is about 7.0 while the pH of the leachate emanating from the poultry litter is 8.0. For this reason it is to be expected that Ca complexation will be an important mechanism for P retention in the YTC base pad.

1.3.2.3 Current applications of compost as a filter

Since the 1950s, compost has commonly been used as the filter medium in the biofiltration of gas streams containing low concentrations of volatile organic compounds, pollutants, reduced N and sulfur (S) compounds, and odorous compounds (Haug 1993).

Furthermore, there is a wide body of literature on the use of peat, wetlands and constructed wetlands for the removal of heavy metals from wastewaters (Karathanasis and Thompson 1993; Couillard 1994; Manios *et al.* 2003). The mechanisms by which metals are removed from wastewaters in wetlands include ion exchange, and adsorption onto clay, organic and inorganic compounds (Manios *et al.* 2003). Metal removal efficiencies of these systems have been found to increase with increasing organic matter content, and substrates high in Ca, Mg, and fulvic acids were shown to retain heavy metals most efficiently (Karathanasis and Thompson 1993). It follows then that compost, with its high organic matter content, should behave in a similar manner as peat in the uptake of metals. To examine this Manios *et al.* (2003) used mature sewage sludge compost mixed with straw as the substrate in pot experiments, irrigated with solutions of increasing metal concentrations. They found that the compost retained up to 100% of the added Cu and Zn, and that the percent retention of the metal increased as the metal concentration in solution increased from 10 mg L^{-1} up to 80 mg L^{-1}.

Recently, there has been some research into the ability of compost to act as a filter for storm and waste waters. Mature compost storm water filter systems have been shown to be effective at treating non-point source pollution by removing P, nutrients, solvents, pesticides, herbicides, silt, Zn, Pb, Cd and Cu (Garland 1995). One system uses high grade mature leaf compost as the filter material (Conrad 1995). The leaf compost acts as a physical filter to sediment, it binds ionic pollutants (mainly metals) through cation exchange, and it adsorbs and degrades organic compounds such as oil and grease. The properties of the leaf compost include high permeability, high humic acid content, low nutrient levels, and high stability.

Compost filter berms as well as compost blankets are being applied to roadsides, construction sites, and other disturbed sites in the United States to prevent soil erosion (United States Environmental Protection Agency (USEPA) 2006). Compost blankets, which are comparable to the YTC covering layer on field stored poultry litter windrows, focus first on reducing erosion through improved infiltration rates and thus reduced run-off. Faucette *et al.* (2005) found that compost blankets of 3.75 cm thickness delayed the onset of run-off by 15 minutes under intense rainfall (i.e. 77.5 mm h^{-1}) conditions, and reduced the total solids in the run-off by up to 99% as compared to bare soil. However, compost blankets high in inorganic forms of N and P were found to release significant quantities of these nutrients in run-off waters. These were greatly reduced in composts with a high percentage of organic N, organic C and Ca (Faucette *et al.* 2005).

Compost filter berms are generally placed across a hillside, and serve to retain and filter run-off water moving downslope. According to an USEPA fact sheet, these filter berms have been shown to remove sediment, motor oil, and other pollutants from stormwater (USEPA 2006). A study commissioned by the Department of Environmental Quality for the State of Oregon found that yard waste compost filter berms reduced total solids and turbidity in run-off waters by 83% and 67%, respectively (Jurries 2004). This is an important finding, as most pollutants enter waterways sorbed onto the surfaces of suspended particles such as clays and organic matter.

1.4 Objectives

This thesis is a portion of a larger project. The broad goal of the entire project is to facilitate the use of poultry litter as an organic fertilizer in crop rotations of both conventional and organic producers in the more nutrient poor region of the Fraser Valley, namely the Fraser River delta, in a precise manner with minimal harm to the surrounding environment.

The objective of this thesis was to examine the capacity of the City of Vancouver yard trimmings compost to mitigate the environmental impacts of over-winter field stored poultry litter.

A column study, including a detailed laboratory characterization of the YTC and poultry litter materials, and a field study of three poultry litter storage piles were conducted in order to answer the following questions (sub-objectives):

1) What are the physical characteristics of the YTC and poultry litter?
2) What effect do the YTC base pad and/or cover have on the quality of leachate emanating from the poultry litter and how does this change over the storage period?
3) If the YTC base pad is improving the quality of leachate coming from the poultry litter, through what mechanisms is this occurring?
4) What are the soil characteristics directly under and surrounding poultry litter field storage piles in the presence or absence of the YTC base pad and/or cover as compared to the rest of the agricultural field after over-winter storage?

1.5 Hypotheses to be tested

1) In the experimental piles and columns, the YTC base pad will sorb metals, salts, and nutrients being leached from the poultry litter layers above, thus improving the quality of the leachate reaching the surrounding environment. The cation exchange capacity of the YTC material will be an integral part of this sorption.
2) The soil quality directly underneath the poultry litter storage piles lacking an YTC base pad will be degraded and crop growth the following spring will be stunted, as

compared to the rest of the field and to the site where the poultry litter storage pile was built on an YTC base pad.

3) The soil surrounding the stored poultry litter which is covered by the YTC will be less affected by run-off from the poultry litter storage pile (i.e. lower in salts and ammonium) as compared to the soil surrounding the uncovered poultry litter storage piles.

1.6 Thesis organization

The thesis describes two experiments; a column study and a field study. Chapters 2 and 3 address the methods, results, discussions and conclusions of the two experiments separately. This was done for clarity as the two experiments were performed entirely separately. Chapter 2 specifically addresses sub-objectives one through three, while Chapter 3 addresses sub-objectives two and four. Chapter 4 synthesizes the results from the two experiments, discusses the broader perspective, draws conclusions and suggests future work.

The thesis and citations are formatted according to the journal Compost Science and Utilization, as the column study chapter will be submitted to this journal in the future.

2. Compost layering effects on poultry litter leaching: A column study

In order to assess the effectiveness of the YTC base pad and covering in protecting soil and water quality from field stored poultry litter, an outdoor column experiment was initiated at the University of British Columbia - Vancouver. The objective was to monitor the leachate quality emanating from the YTC, PL, and combinations thereof in a controlled manner which mimicked manure storage conditions in the field.

2.1 Materials and Methods

2.1.1 Experimental design

The experiment was set up at the Totem Field site on the University of British Columbia, Vancouver campus. Sixteen columns constructed out of tapered 12 L and 19 L food grade rigid plastic pails, measuring 30 cm across the top and 26 cm across the bottom, were placed into a wooden table. It has been proven that if the ratio of the column diameter to the effective particle diameter is greater than eight, then the channeling effect near the column wall is negligible (Sheikhzadeh *et al.* 2004). It is further recommended that a ratio of 15:1 be used for precautionary reasons. As the particle size in the poultry litter and YTC is variable and sometimes quite large (>25 mm), a column diameter of 30 cm was chosen for this experiment. The columns were cut and packed so that the materials were flush with the top of the pail.

For drainage purposes the bottom surface of each column had thirty-one 6.35 mm holes drilled in three concentric circles radiating out at 3, 6 and 12 cm from a central hole. The bottom of each pail was lined with a piece of 18 x 16 mesh fiberglass window screen, covered with a 2 cm thick layer of 1.3 cm diameter gravel, and another piece of window screen. The YTC and poultry litter were packed on top of this drainage layer, which was based on the design used by Dr. Sietan Chieng in his column experiments used to study soil water movement (Chieng, 2003).

Each layer of YTC or poultry litter was 14 cm thick, as this was deemed to be the maximum amount which could be supported by the pails and table without any breakage once saturated with rain water, particularly in the three layered treatments. Field bulk density (D_b) measurements were made on the YTC base pad, YTC cover material and poultry litter in an experimental field storage pile using a modified rubber balloon method with four replications. This method consists of removing and weighing a volume of material, placing a plastic bag in the hole and filling it with water in order to determine the mass per unit volume (Blake 1965). The masses of poultry litter and YTC were packed into the columns in an attempt to replicate the field D_b. Values were 279, 477, and 300 kg m^{-3} for the poultry litter, YTC base pad, and YTC covering layers. The column treatments are listed in Table 2.1.

TABLE 2.1
Column treatments.

Treatment description	Abbreviation
14 cm YTC	YTC
14 cm poultry litter	PL
14 cm YTC over 14 cm poultry litter	Y/PL
14 cm poultry litter over 14 cm YTC	PL/Y
14 cm YTC over 14 cm poultry litter over 14 cm YTC	S

There were five main treatments with three replicates each for a total of 15 experimental units. Additionally, there was an empty column which served as a rain gauge. The treatments, including the rain gauge were randomly assigned to positions on the table. The columns were set up on November 8, 2005 and were left exposed to the weather until March 29, 2006.

To catch the leachate, 19 L inverted water jugs with their bottoms sawn off were attached flush to the bottom of the pails. Number 10 rubber bungs were used to plug the spout. Two holes were drilled into each bung, one for drainage and one as an air inlet. A 10 cm long piece of rigid PVC pipe was inserted into one of the holes. A 10 cm piece of amber latex tubing (9.5 mm o.d. x 6.4 mm i.d.) was attached to the pipe and closed with a hose clamp. To prevent an airlock during drainage another piece of rigid PVC pipe was inserted into the second hole in the bung pointing up into the water jug. A stiff portion of food grade PVC tubing (11.1 mm o.d. x 7.9 mm i.d.) was attached to the pipe inside the water jug and looped around. This allowed for air to enter, while preventing the leakage of any leachate (Refer to Appendix A for photographs of column construction).

The YTC used in the columns was obtained directly from the City of Vancouver Landfill in clean plastic garbage pails. The poultry litter was also collected in plastic garbage pails from a pile of freshly delivered turkey litter. These pails were sealed with plastic lids and stored outside under cover at the Totem Field site until the columns were ready for packing (approximately 2 weeks).

2.1.2 Time domain reflectometry

In two of the columns time domain reflectometry (TDR) was used to monitor the moisture content of different layers, and thus the movement of water through the columns. The two selected columns were a PL column and an S column. The TDR probes consisted of three steel welding rods, 26cm in length, passed through three parallel holes drilled into a number nine rubber bung which was inserted into a hole cut into the side of the pail. This insured that the rods remained parallel and in one single plane in the medium. Two probes were inserted horizontally at two depths in the PL column, and four probes were inserted horizontally into the different layers in the S column. Due to the high salinity of the poultry litter and subsequent high electrical conductivity (EC) of the media, there was often no signal reflection and thus no moisture content could be obtained. This was a problem in all layers at some point throughout the experiment and thus these data have been omitted from this paper. (These data are tabulated in Appendix B.)

2.1.3 Leachate Collection and Analysis

The leachate was collected from the columns on a weekly or bi-weekly basis contingent on the amount of precipitation received. Upon collection, the volume, pH and EC were determined. These were the only determinations made on the samples collected from the rain gauge. EC was determined directly on a Beckman Solu-Bridge conductivity meter, while pH was measured using an Orion Research analogue pH meter model 300. Depending on the colour of the leachate, 20 to 100 mL from each column was dried at 60°C for 72 hours to determine the total solids (TS). The solids were subsequently heated in a muffle furnace at 425°C for 3 hours in order to determine the ash content and the volatile fraction of the solids.

The rest of the analyses were carried out by Maxxam Analytics Inc. in Burnaby, BC. Quality assurance reports were issued with each batch of samples which included data on matrix spikes, spikes, and blanks. The first leachate sample collected from each treatment was composited and analyzed for total metals, and nutrients (NH_4, NO_3, nitrite (NO_2), dissolved-P, ortho-P, total N, and total P). Each subsequent leachate sample was analyzed individually (three replicates for each treatment) for nutrients and total metals until the eighth collection date by which time the metal concentrations had become very low (near zero). After this collection date leachates were analyzed only for nutrients.

Samples to be analyzed for nutrients were stored on ice packs in a cooler within one hour of collection. Samples to be analyzed for total metals were preserved with 2 mL of

HNO_3 and then stored on ice packs. All samples were taken to Maxxam Analytics in a cooler on ice packs and analyzed within 48 hours of collection.

Maxxam Analytics determined the total metals using inductively coupled plasma mass spectrometry (ICPMS) following EPA SW846 Method 6020A (United States Environmental Protection Agency 2006). All nutrients were analyzed using automated colorimetric techniques, following the Standard Methods for the Examination of Water and Wastewater 19th and 20th editions (American Public Health Association 1995 and 1998).

2.1.4 Physical and Chemical Analyses of Initial and Final Column Materials

The properties determined for both the YTC and poultry litter were gravimetric moisture content, particle size distribution, percent ash and organic matter (OM), pH, EC, particle density (D_p), D_b, total porosity, water holding capacity (WHC), CEC, water extractable P and metals, and total and available nutrients. These properties were determined for the starting materials used to pack the columns. Total and available nutrients, OM, and ash content were also determined on each layer in each of the columns at the completion of the leaching experiment.

The gravimetric moisture content was determined on four replicate samples used in the column experiment immediately upon collection of the materials. These were dried in moisture cans at 60°C for 72 hours due to their organic natures. The moisture content, θ, was then calculated using the following equation, where W_w is the wet weight and W_d is the dry weight:

$$\theta = (W_w - W_d)\, W_w^{-1} \times 100\% \qquad \text{Eq. (1)}$$

Particle size analysis was carried out on four replicate 200 g samples of air dried material. Sieve sizes used were 25, 16, 9.5, 6.3, 4.75, and 2 mm, similar to what was suggested by the Test Methods for the Examination of Composting and Compost (TMECC) manual method 02.02 (Thompson *et al.* 2001). The 2 mm sieve was added due to the large fraction of small particles in both the poultry litter and YTC. Sieves were shaken on an Eberbach shaker for 2 minutes, and the size fractions weighed. Size fractions were determined as follows, where f is a particular size fraction, M_f is the weight of the size fraction, and M_o is the initial weight of the total sample:

$$\%f = (M_f)M_o^{-1} \times 100\% \qquad \text{Eq. (2)}$$

Ash and OM were determined in a muffle furnace on four replicates of a 5 g oven dried sample following the TMECC manual method 03.02B (Thompson *et al.* 2001). This method suggested a temperature of 550°C for 2 hours. Percent loss on ignition or percent OM was calculated as follows:

$$\%OM = (\text{Initial weight} - \text{Final weight})\ (\text{Initial weight})^{-1} \times 100\% \qquad \text{Eq. (3)}$$

$$\%Ash = 100 - \%OM \qquad \text{Eq. (4)}$$

EC and pH of the YTC and PL samples were determined in accordance with the TMECC manual method 04.10A (Thompson *et al.* 2001). This method recommended extracting a 9.5 mm sieved moist sample, however only air dried material was available. The extraction ratio was 1:5 compost: water (mass basis) with twenty minutes of shaking on an Eberbach shaker. The slurry was decanted prior to measurement of EC and pH. A Beckman Solu-Bridge conductivity meter was used to measure EC, while an Orion Research analogue pH meter model 300 was used for determination of pH.

Particle density in kg m^{-3} (D_p) was calculated using percent ash and OM as described by Agnew, et al (2003).

$$D_p = [\%OM(1550)^{-1} + \%Ash(2650)^{-1}]^{-1} \qquad \text{Eq. (5)}$$

This equation assumes a specific gravity of 1.55 for volatile solids or OM, and 2.65 for ash.

Total porosity (TP) was calculated based on the D_b packed into the column, and the particle density (D_p) calculated above.

$$TP = [1 - D_b D_p^{-1}] \times 100\% \qquad \text{Eq. (6)}$$

Water holding capacity (WHC) was determined by packing a sample at known density into a pail with a perforated bottom. The pail was then placed into a tub of water and the level of the water was slowly raised up over a period of four hours. Once the sample was saturated the pail was removed from the tub and allowed to drain freely for a period of 24 hours, as recommended by the TMECC method 03.01C (Thompson *et al.* 2001). At the end of the draining period the samples were weighed again and the WHC on a weight basis (kg water kg^{-1} material) was calculated as follows:

$$WHC = (\text{Wt. wet material after drain 24h} - \text{Wt. dry})\,(\text{Wt. dry})^{-1} \qquad \text{Eq. (7)}$$

The CEC was determined for the YTC only using the ammonium acetate method, buffered to pH 7.0 as described by Chapman (1965) in Methods of Soil Analysis. This method was selected because the pH values of both the YTC and the leachate emanating from the YTC material were approximately seven. A sample of air-dried YTC material was ground using a Wiley Mill with a 1 mm screen. Three replicates of a 5 g sample were shaken with ammonium acetate (buffered to pH 7.0) and filtered. The exchangeable cations Ca, Mg, K, and Na were determined in the filtrate using atomic absorption spectroscopy (AAS). The sample was then washed with iso-propanol, leached with 1M KCl, and re-filtered. The filtrate was analyzed for NH_4 using a semi-micro Kjeldahl digest on a Lachat QuikChem FIA 8000 series.

In order to correct the exchangeable cations for soluble salts a method for the determination of water extractable P and metals was adapted from Wolf *et al.* (2005). This method consisted of shaking a 1:200 moist as received manure or compost to distilled water slurry for 60 minutes and then filtering through a Whatman no. 40 filter paper. This method was carried out on an air-dried sample ground to pass a 1 mm sieve, as was used for the CEC determination. All extracts were analyzed for P, Ca, Mg, Na, K, Cu and Zn by ICP.

Available NH_4-N, NO_3–N, Bray-P_1, K, Ca, Mg, Na, Cu, Zn, Fe, and Mn, as well as total C, S, N, P, K, Ca, Mg, Na, Cu, Zn, Fe, Mn, and B were determined by Pacific Soil Analysis Inc, in Richmond, BC for the initial YTC and PL materials, as well as for each layer from each of the column treatments after leaching. Available NH_4-N and NO_3-N were determined using a K_2SO_4 extract. The NH_4-N was determined colorimetrically on a Technicon Autoanalyzer, and the NO_3-N was determined by the CTA colour development method and measured on a Turner colorimeter (Lavkulich 1978). Available P (Bray-P_1) was determined colorimetrically using the ascorbic acid colour development method on a 1:10 YTC or PL to Bray-P_1 (0.03 N NH_4F in 0.025 N HCl) extract (McKeague 1978). Available Ca, Mg, Na, and K were determined on a Perkin-Elmer AAS using a 1:5 YTC or PL to 1M ammonium acetate extract buffered to pH 7.0 (McKeague 1978). Available Cu, Zn, Fe, and Mn were determined by Perkin-Elmer AAS on a 1:5 YTC or PL to 0.1N HCl extract (McKeague 1978). Available SO_4-S was determined using the Hi-Bismuth Reducible method on a 1:2 YTC or PL to $CaCl_2$ extract (Kowalenko 1993). Total C was determined directly on a LECO CR 12 Carbon Analyzer (McKeague 1978). Total S was determined directly on a LECO Sulfur Analyzer (Lavkulich 1978). Total N, P, K, Ca, Mg, and Na were determined using the Parkinson and Allen digest analyzed on a Perkin-Elmer AAS (Lavkulich 1978).

Total Cu, Zn, Fe, Mn, and B were determined by dry-ashing the sample for four hours at 480°C, dissolving the ash in 5.0N HCl and analyzing on a Perkin-Elmer AAS (Lavkulich 1978).

2.1.5 Statistical Analysis

All data were subjected to a one-way Analysis of Variance (ANOVA) using SAS Institute Inc. "JMPIN" statistical package, version 4.0.4 (JMP 2001). Upon a significant F-value for treatment, mean comparisons were performed using Tukey's Honestly Significant Difference at an alpha level of 0.05.

2.2 Results and Discussion

2.2.1 Weather

November 2005 was drier than average, and the first half of December was very dry, with the City of Vancouver receiving only 7.8 mm of precipitation prior to December 19th (Environment Canada 2005-2006). January 2006 was extremely wet, receiving 284 mm of precipitation compared to the average of 154 mm (Environment Canada 2004). In contrast February was a particularly dry month receiving less than half of that month's average precipitation (57 mm compared to 123 mm). The result of this was that most of the nutrients and metals were leached out by the end of January. These unusual weather patterns raise questions as to the leachability of nutrients and metals in both the poultry litter and YTC, and how this is affected by the time between piling these materials in the field and the first notable precipitation event, as well as the intensity of those precipitation events. The series of intense rainfall events which occurred over a short period of time in January resulted in short contact times between the leachate emanating from the poultry litter and the YTC base pad material through which it flowed. More evenly distributed rainfall events would have likely led to slower flow of leachate through the YTC base pad, and consequently longer contact times resulting in an increased likelihood of retention of nutrients and metals.

2.2.2 Physical and Chemical Properties of YTC and PL

The physical and chemical properties of the YTC and PL materials prior to leaching are listed in Tables 2.2 through 2.6. The YTC from the City of Vancouver Landfill typically has a much lower NH_4-N (average 500-600 mg kg^{-1}) and total N (average 10-15 g kg^{-1}) content than the YTC obtained for this study (City of Vancouver 2005). The high NH_4-N values in the YTC used in this study probably resulted from an insufficient curing time after composting. Brewer and Sullivan (2003) found that an NH_4-N: NO_3-N ratio of less than four indicated that yard waste compost was mature. The ratio of NH_4-N: NO_3-N in the initial YTC used in this study was 4.2, thus signaling that it was not completely mature or stabilized. All other properties of the YTC compared well with average values reported by the City of Vancouver Landfill.

TABLE 2.2
Chemical properties of initial column materials.
Dry weight basis; n = 3

Property	YTC	PL
EC (dS m^{-1})	2.9 ± 0.1	12 ± 0.01
pH	7.1 ± 0.1	7.2 ± 0.06
C/N (mass basis)	13 ± 2	10 ± 0.6
Total C (g kg^{-1})	263 ± 20	360 ± 6
Total N (g kg^{-1})	21 ± 4	35 ± 2
Total P (g kg^{-1})	3.1 ± 0.2	22 ± 2
Total S (g kg^{-1})	3.0 ± 0.3	5.0 ± 0.9
NH_4-N – available (mg kg^{-1})	1250 ± 130	4950 ± 340
NO_3-N– available (mg kg^{-1})	295 ± 13	710 ± 37
P – available (mg kg^{-1})	1490 ± 103	10 390 ± 530
P – water extractable (mg kg^{-1})	380 ± 7	7240 ± 110

*Error bars indicate one standard deviation from the mean.

TABLE 2.3

Concentrations of metals in poultry litter and YTC prior to leaching. Dry weight basis; n = 3

Metal (mg kg^{-1})	YTC	PL
Cu - available	3 ± 1	110 ± 5
Cu - total	47 ± 3	390 ± 20
Zn – available	76 ± 4	380 ± 31
Zn - total	190 ± 12	470 ± 19
K - available	10 940 ± 315	15 000 ± 410
K - total	12 030 ± 1180	16 880 ± 620
Ca - available	4830 ± 134	875 ± 158
Ca - total	18 300 ± 600	35 700 ± 2500
Mg – available	1560 ± 72	750 ± 35
Mg - total	2800 ± 330	4900 ± 360
Na – available	425 ± 20	2860 ± 180
Na - total	930 ± 50	3300 ± 160
Fe – available	1240 ± 214	170 ± 18
Fe – total	9830 ± 849	1160 ± 64
Mn – available	185 ± 13	380 ± 23
Mn - total	280 ± 3	440 ± 13

TABLE 2.4

Particle size distribution of initial column materials. n = 4

Sample	Fraction of material within size interval						
	>25 mm	25-16 mm	16-9.5 mm	9.5-6.3 mm	6.3-4.75 mm	4.75-2 mm	< 2 mm
	(%)						
YTC	0.3 ± 0.3	0.9 ± 0.5	9.1 ± 5.3	9.9 ± 3.7	4.3 ± 1.2	52 ± 7.4	24 ± 1.0
PL	17 ± 11	4.3 ± 2.9	3.7 ± 0.6	4.1 ± 1.1	3.1 ± 0.8	19 ± 4.3	49 ± 8.7

TABLE 2.5

Physical properties of initial column materials. n = 4

Sample	Mass (kg)	D_b (kg m^{-3})	OM (%)	Ash (%)	D_p (kg m^{-3})	^{z}TP (%)	WHC (kg kg^{-1})
YTC p^y	3.82	477	48.8 ± 1.8	51.3 ± 1.8	1970 ± 19	75.8 ± 0.2	0.4 ± 0.007
YTC c^y	2.80	300	48.8 ± 1.8	51.3 ± 1.8	1970 ± 19	84.8 ± 0.1	-
PL	2.32	279	79.2 ± 0.6	20.8 ± 0.6	1700 ± 5	83.6 ± 0.04	1.7 ± 0.09

^{z}TP indicates total porosity. ^{y}p– indicates base pad, c-indicates cover.

TABLE 2.6

Cation exchange capacity and % base saturation corrected for soluble salts of YTC. n = 3

	Ca	Mg	K	Na	CEC	CEC^z	% Base
	cmolc kg^{-1} dry YTC					(cmolc kg^{-1} C)	Saturation
YTC avg	51.4	17.2	24.9	1.28	57.5	220	94.8
Std dev.	2.2	0.01	3.3	0.07	1.6	2.3	1.1

[z]CEC calculated based on the total carbon content of the YTC.

The nutrient analysis of the poultry litter used in this study was characteristic of turkey litter produced in the Fraser Valley (Chipperfield 1996). An important characteristic of turkey litter is its variable particle size which includes large clumps, fine dust, and feathers. This fact makes obtaining a representative sample for analysis challenging.

The density of the YTC base pad measured on the experimental storage pile in the field was extremely high (711 ± 30 kg m^{-3}), because it had been driven on several times by a front end loader. It was very challenging to re-create this density in the columns. It was deemed to be not critical and a lower density was used. The D_b of the YTC base pad layer in the columns was 1.6 times higher than the YTC covering layer. In the field the D_b of the YTC base pad was actually 2.4 times higher than the YTC covering layer. The result of this would be a decrease in total porosity and an increase in WHC, and nutrient and metal retention potentials per unit volume by the YTC base pad layer in the field as compared to the experimental columns. The D_b values of each of the poultry litter layers in the various column treatments were the same as was measured in the field.

The CEC of the YTC was 57.5 ± 1.6 cmolc kg^{-1} dry matter, or 220 ± 2.3 cmolc kg^{-1} C. This value is much lower than the 400 cmolc kg^{-1} C measured by Brewer and Sullivan (2003) on Washington State yard waste compost. However, it fits well into the range reported by Garcia et al (1992) of 41.4 – 123 cmolc kg^{-1} dry matter for mature municipal waste compost. Nonetheless, the measured CEC of the City of Vancouver YTC suggests a significant capacity for cation exchange in the YTC base pad, with Ca being the dominant exchangeable cation.

The leaching losses of the major plant nutrients from the YTC and PL alone columns are listed in Table 2.7. These values are considered to be the maximum leaching losses which could occur in the field over the winter storage period in the outermost wet regions of the field storage piles. Potassium losses were notable from both the YTC and PL, due to the high mobility of this cation, which is not tightly bound by either material. Sodium was also highly leachable, especially from the PL. Extremely high amounts of N were leached from the PL, mainly in the NH_4 form. This is a reflection of the high levels of organic-N present mainly as urea and proteins in PL (Kelleher *et al* 2001). The percentage of NH_4 leached from the PL indicates that conversion of organic-N to NH_4-N was occurring and thus the PL was microbially active. The lack of NO_3 leaching indicates that NO_3 was either taken up by microbes in the PL, or it underwent denitrification. The water saturated conditions in the columns would have been conducive to denitrification (Brady and Weil 2002). The PL experienced much higher losses of N, P and S ($P < 0.05$) than did the YTC. This was likely because the YTC had previously undergone composting during which these elements were converted into more stable and thus less available forms.

TABLE 2.7

Leaching losses of major nutrients from YTC and PL alone columns [z]. n = 3

Nutrient	Total leached from YTC (mg kg^{-1} dry YTC)	% of initial nutrient leached from YTC	Total leached from PL (mg kg^{-1} dry PL)	% of initial nutrient leached from PL
NH_4	730 ± 30^a	59 ± 12	12 300 ± 2450^b	250 ± 70
NO_3	95 ± 40^b	33 ± 20	2.5 ± 0.9^a	0.4 ± 0.1
Total N	1430 ± 50^a	7.2 ± 2.1	16 430 ± 2940^b	48 ± 16
Ortho-P^y	120 ± 10^a	N/A	2460 ± 340^b	N/A
Total P	160 ± 4^a	5.2 ± 0.6	2810 ± 250^b	13 ± 3
Total K	6850 ± 70^a	58 ± 9	13 050 ± 780^b	78 ± 11
Total Na	220 ± 4^a	24 ± 2	2620 ± 160^b	80 ± 10
Total Ca	750 ± 8^b	4.1 ± 0.3	640 ± 40^a	1.8 ± 0.3
Total Mg	330 ± 4^b	12 ± 2	150 ± 9^a	3.1 ± 0.6
Total S	150 ± 5^a	6.3 ± 0.8	2080 ± 120^b	43 ± 10
Total Cu	0.5 ± 0.01^a	1.0 ± 0.1	40 ± 2^b	10 ± 2
Total Zn	1.5 ± 0.04^a	0.8 ± 0.1	19 ± 1^b	4.1 ± 0.6
Total Fe	17 ± 0.2^a	0.2 ± 0.02	40 ± 2^b	3.4 ± 0.5
Total Mn	3 ± 0.04^a	1.1 ± 0.04	20 ± 2^b	4.5 ± 0.7

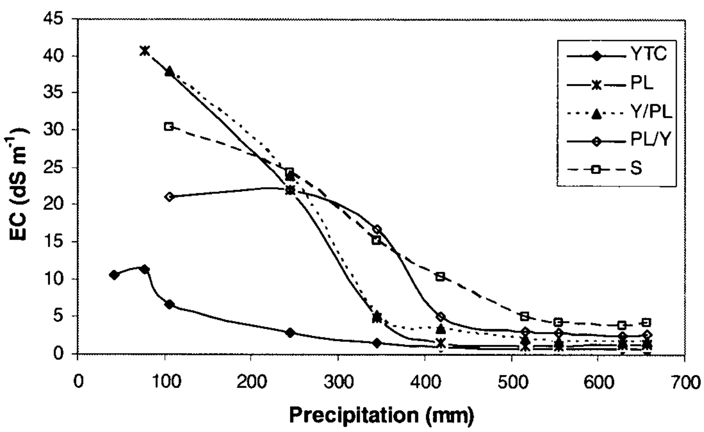
[z]Mean separations performed using a t-test at $\alpha = 0.05$.

[y]Percent initial ortho-P leached calculation was not possible because ortho-P was not measured in the intial YTC and PL materials.

Based on the initial Ca and Mg concentrations in the materials, the YTC leached 2.3 and 3.1 times more of its total Ca and Mg, than did the PL. This may be attributed to the high initial P concentration of the PL, which served to immobilize Ca and Mg. Leaching losses of the heavy metals Cu, Zn, and Mn were almost negligible from the YTC. This is consistent with the work of Grimes *et al.* (1999), who found that the maximum leachability of metals from household waste compost in distilled water, 1 M KCl, and acetic acid at pH 5 was 1%, 2% and 1% of the total for Cu, and 1% of the total for each treatment for Zn. Conversely, leaching losses of these heavy metals from the PL were significantly higher ($P < 0.05$) with 40 mg Cu kg^{-1} dry PL (i.e. 10% of initial) and 19 mg Zn kg^{-1} dry PL (i.e. 4% of initial) being lost to leaching. This is a concern given that PL is high in these metals as a result of poultry feed supplementation (Leeson and Summers 2005). Leachate and run-off waters from field stored poultry litter that reach ditches and other waterways via overland or subsurface flow can negatively impact aquatic life if they are high in N, P and/or heavy metals. (See Appendix C for all data).

2.2.3 Electrical Conductivity

All treatments containing poultry litter had initially very high ECs (Figure 2.1). The YTC base pad in the PL/Y treatment served to decrease the EC of the first sample collected by 50% as compared to the PL alone, from 41 dS m^{-1} to 21 dS m^{-1}. However, the EC of the PL/Y treatment remained elevated for longer than the PL or Y/PL treatments. It appears that the YTC base pad serves to regulate the EC in the leachate by decreasing the initial very high dissolved salt levels and releasing them more slowly over time. It does not appear that the YTC base pad retains any significant portion of these salts.

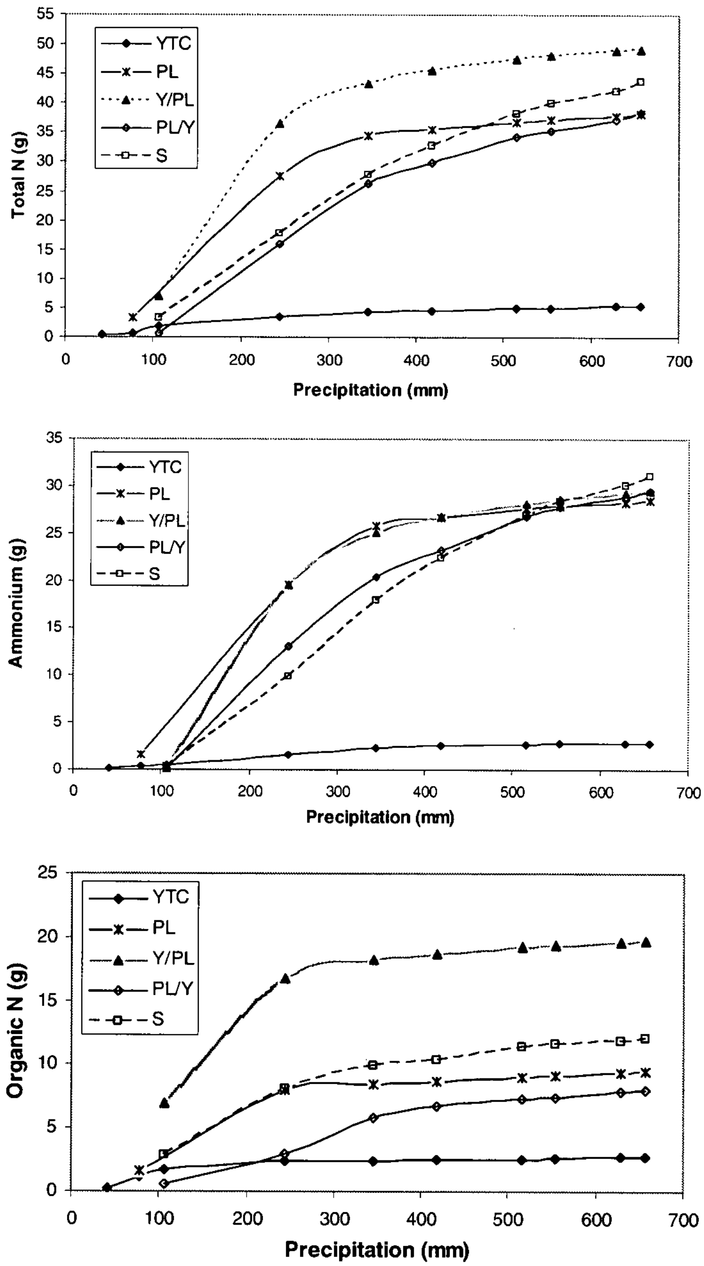


Treatment	Differences at $\alpha = 0.05$ by cumulative precipitation (mm)		
	106	345	657
YTC	a	a	a
PL	c	ab	b
Y/PL	c	b	b
PL/Y	b	c	c
S	c	c	d

Figure 2.1 Electrical conductivities of leachates.

2.2.4 Nitrogen

Organic-N and NH_4 leached readily from all poultry litter containing treatments until after approximately 275 mm of precipitation had occurred (Figure 2.2). Beyond this point there was very little N of any species in the leachate. The levels of NO_3 and NO_2 in the leachates were below the detection limits for all treatments, except for the last two sampling dates, at which time NO_3 was detected in the YTC, PL/Y and S leachates, and NO_2 was detected in the PL/Y and S leachates. The last two sampling events took place in the middle of March and beginning of April. By this time the constant rains had tapered off and temperatures had increased. This led to the warming, drying, and re-oxygenation of the column materials, which allowed for nitrification to proceed.



(a)

(b)

(c)

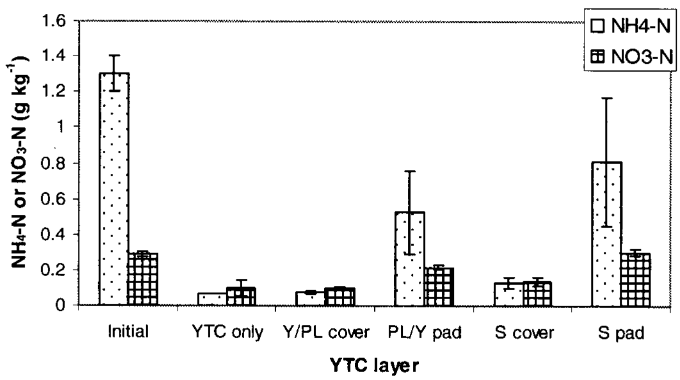
Treatment	Differences (α = 0.05) in total cumulative masses leached		
	Total N	NH_4	Org-N
YTC	a	a	a
PL	b	b	b
Y/PL	c	b	c
PL/Y	b	b	ab
S	bc	b	b

Figure 2.2 Cumulative masses of (a) total N, (b) NH_4, and (c) organic-N leached during column experiment.

There were no differences observed in the cumulative amounts of NH_4 leached from the treatments except the YTC alone. The two treatments with the YTC base pad (i.e. PL/Y and S) leached NH_4 in an approximately continuous manner over the entire period of study. Conversely, the two treatments lacking the YTC base pad (i.e. Y/PL and PL) leached initially very high concentrations of NH_4 until approximately 275 mm of precipitation occurred, after which time the NH_4 concentrations of the leachates decreased to almost zero.

The Y/PL and S treatments lost the largest amounts of total N. It appears that the YTC cover increases the leaching of N from the PL layer below. This was confirmed upon examining the total N concentrations of the poultry litter materials after leaching as compared to the initial materials packed into the columns. The poultry litter in the PL alone column showed a decrease in total N of 10 g N kg^{-1} dry poultry litter after leaching, while the poultry litter layers in the two treatments with the YTC cover, namely Y/PL and S lost 14 and 17 g kg^{-1} of their initial total N, respectively ($P < 0.05$). As the poultry litter wetted and dried over the study a crust was observed on the surface. It was moderately impervious and likely limited gas exchange. It appears that the YTC cover protected the surface of the poultry litter layer below from forming this crust and thus helped to maintain aeration and consequently the microbial activity in the poultry litter layer, resulting in increased mineralization and leaching of N. In addition, significant quantities of Ca were leached from the YTC material. These Ca cations could have displaced NH_4 ions on exchange sites in the poultry litter layer below, thus increasing N leaching.

The forms of available N in the initial YTC material compared to each of the YTC layers after leaching are shown in Figure 2.3. The base pads in the S and PL/Y treatments contained elevated concentrations of both NH_4-N and NO_3-N as compared to the other leached layers. However, there were no overall losses or gains of total N in any of the YTC layers in any of the treatments as compared to the initial YTC, which had a total N concentration of 22.2 ± 0.8 g kg^{-1}. Therefore, the YTC base pad did not retain or immobilize any significant amount of N leached from the PL layer above. These elevated levels of NH_4-N and NO_3-N in the S and PL/Y base pads are leachate species which came from the poultry litter layers above and were not completely flushed out at the completion of the study.

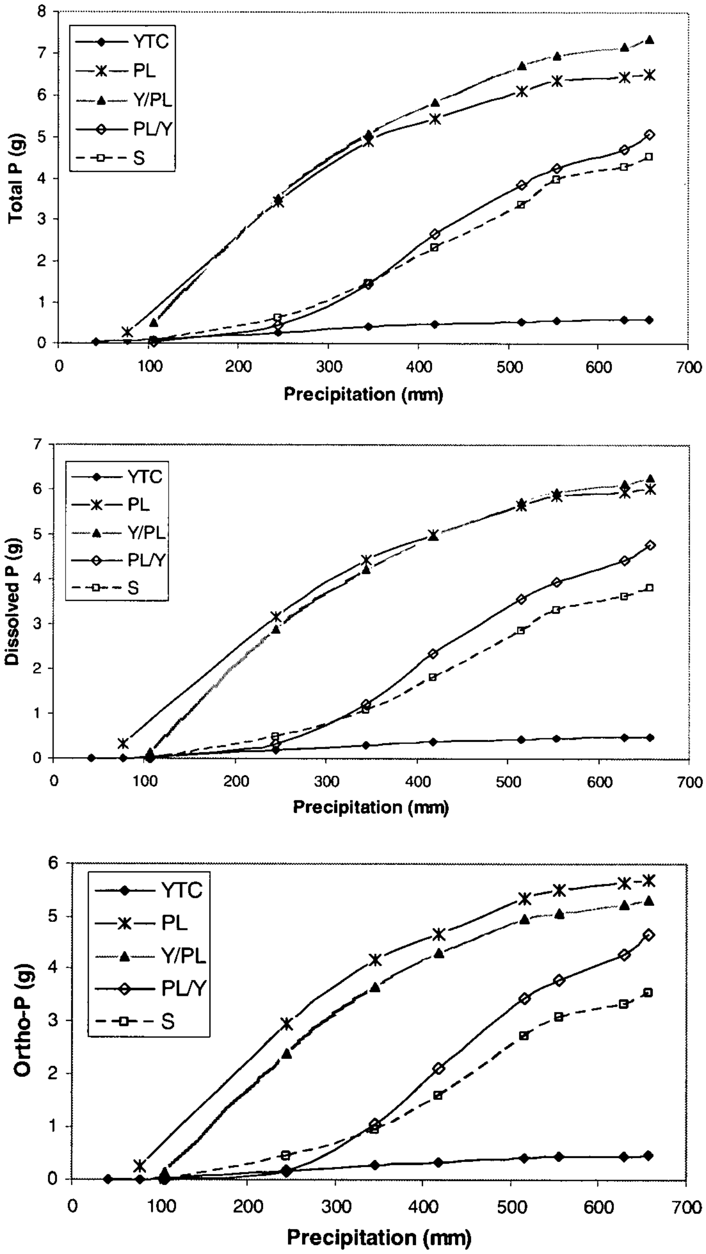


Treatment	Differences ($\alpha = 0.05$) in total cumulative masses leached	
	NH_4-N	NO_3-N
Initial	c	c
YTC	a	a
Y/PL cover	a	a
PL/Y pad	ab	b
S cover	a	a
S pad	bc	c

Figure 2.3 Available NH_4-N and NO_3-N in initial YTC material packed into columns and in YTC layers after leaching.
Note: Y/PL cover indicates the YTC covering layer from the Y/PL treatment; S pad indicates the YTC pad from the S treatment.

2.2.5 Phosphorus

The cumulative masses of total P, dissolved P, and ortho-P leached from the columns showed the same trends over time (Figure 2.4). Ortho-P and dissolved P were positively correlated ($P < 0.01$, $R^2 = 0.88$). Total P and dissolved P were similarly correlated ($P < 0.01$, $R^2 = 0.97$). This indicates that the majority of the total P leached out of the columns was in the inorganic form. The initial poultry litter packed into the columns had seven times more total P than the YTC (Table 2.2). Therefore, the majority of the P contained in the leachates originated in the poultry litter, for all treatments except the YTC alone.



Treatment	Differences ($\alpha = 0.05$) in total cumulative masses leached		
	Total P	Diss. P	Ortho-P
YTC	a	a	a
PL	cd	c	c
Y/PL	d	c	c
PL/Y	bc	bc	bc
S	b	b	b

Figure 2.4 Cumulative masses of (a) total P, (b) dissolved P, and (c) ortho-P leached during column experiment.

The PL alone and Y/PL columns leached P very quickly and at high concentrations, until approximately 350 mm of cumulative precipitation had occurred, at which time the concentrations dropped off. These two treatments exhibited no significant differences over the length of the experiment beyond the first sampling date. There is a clear inflection point at 350 mm precipitation for all treatments (except the YTC alone) in the graphs of cumulative masses (Figure 2.4), which corresponds to the point on the graph of concentration (Figure 2.5) where the slopes of the two curves containing the YTC base pad (i.e. PL/Y and S) steepen while the slopes of the two curves lacking the YTC base pad (i.e. PL and Y/PL) flatten. This can be explained by the YTC base pad retaining P leached from the poultry litter layers above, until the accumulation of 350 mm of precipitation, at which time the P retention capacity of the YTC apparently became saturated and leachate P concentration increased.

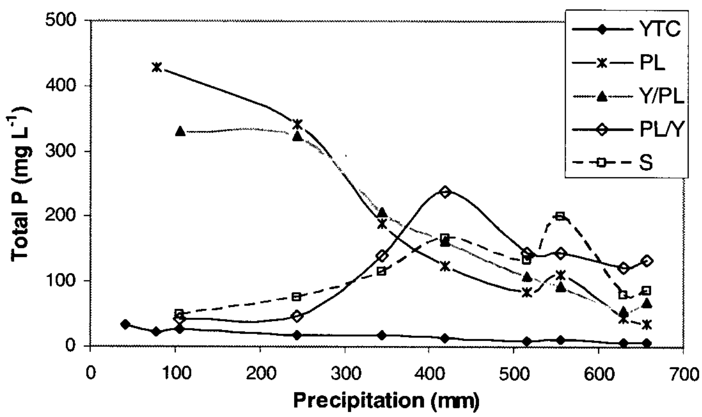
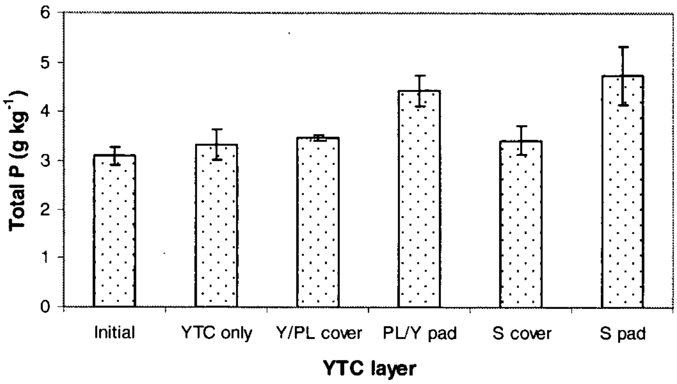


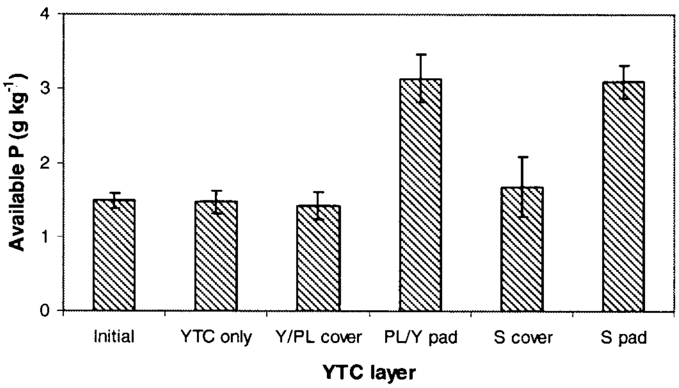
Figure 2.5 Variations in concentration of total P in leachates over experiment.

At the end of the experiment the PL alone treatment leached 1975 ± 1120 mg more total P than did the S treatment ($P < 0.05$). Additionally, the PL/Y column leached 2275 ± 500 mg less total P than the Y/PL column ($P < 0.05$), thus indicating that the YTC base pad was retaining P. Total P increased by an average of 1280 ± 660 mg P kg^{-1} dry YTC in the YTC base pad materials present in the PL/Y and S treatments as compared to the initial YTC total P concentration ($P < 0.05$) (Figure 2.6). Conversely, the YTC alone and YTC covering layers showed no significant changes in total P concentration over the leaching period. From the leachate data it has been calculated that the YTC base pad has the capacity to retain at least 375 ± 339 mg P kg^{-1} dry YTC. The above suggests a significant capacity for P sorption by the YTC base pad.



(a)

Treatment	Differences (α = 0.05) in total cumulative masses leached	
	Total P	Available P
Initial	a	a
YTC	a	a
Y/PL cover	a	a
PL/Y pad	b	b
S cover	a	a
S pad	b	b



(b)

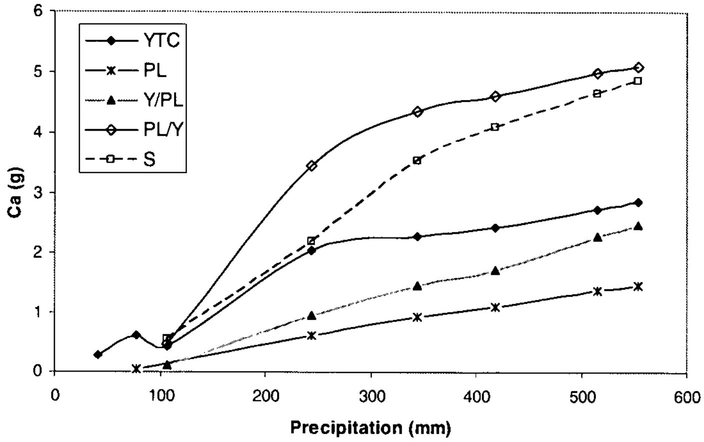
Figure 2.6 Comparison of (a) total P, and (b) available P in the initial YTC material packed into the columns and YTC layers after leaching.

The possible mechanisms of P retention in the YTC base pad are cation bridging with organic matter, microbial uptake and immobilization (Reddy *et al.* 1999), and complexation with hydroxyoxides of Fe and aluminum (Al) at acidic pH, and Ca and Mg compounds at alkaline pH (Beauchemin *et al.* 2003; Moore and Miller 1994; Khalid *et al.* 1977). Cation bridging occurs when $H_2PO_4^-$ binds to a metal cation, often Ca, which itself is bound to humic or fulvic acids. As compost is biologically active there is the opportunity for microbial P uptake and immobilization of the P species present in the poultry litter leachate. However, high levels of precipitation, rapid leaching, and cold temperatures likely reduced the significance of this pathway. Due to the neutral to basic pH of the YTC and PL leachates, complexation with Ca and Mg rather than Fe or Al was probably the dominant form of chemical immobilization of P in this system.

2.2.6 Calcium

The two treatments with an YTC base pad (i.e. S and PL/Y) both leached significantly higher ($P < 0.05$) concentrations of Ca than the other three treatments throughout the leaching period (Figure 2.7). Upon subtracting the cumulative Ca leached from the YTC and PL alone treatments from the PL/Y treatment there was an extra 778 mg of Ca leached when the poultry litter was placed over top of the YTC. This was likely caused by cation exchange occurring in the YTC base pad stimulated by cations in the leachate flowing from the poultry litter layer above. Ammonium and K were likely the most dominant such cations, with Zn and Cu having a smaller impact. Grimes *et al.* (1999), in controlled batch sorption experiments using household waste compost, found that Ca was most likely being replaced by metals in both the organic and inorganic fractions of the compost.

Additionally, the Ca leached from the Y/PL treatment did not prove to be simply the sum of the Ca leached from the YTC and PL treatments. In fact it was 1860 ± 160 mg Ca or 43% lower than expected. One possible explanation for this could be the very high concentration of P contained in the poultry litter. Calcium forms insoluble precipitates with P under alkaline conditions. Thus, as Ca leached out of the YTC covering layer it was immobilized through reaction with P in the poultry litter layer below. The Ca concentration in the PL under the YTC in the Y/PL treatment at the end of the study was significantly higher than the Ca concentration in the initial PL packed into the columns ($P < 0.1$). Furthermore, the ratio of total to available Ca in the poultry litter prior to leaching was 33, while this same ratio for the YTC was about three.



Treatment	Differences (α = 0.05) in total cumulative masses leached
	Ca
YTC	b
PL	a
Y/PL	b
PL/Y	c
S	c

Figure 2.7 Cumulative masses of Ca leached from columns.

2.2.7 Copper and Zinc

After the first major rainfall event, the concentrations of Cu and Zn in the leachates emanating from the PL and Y/PL treatments were 25 and 17 mg Cu L^{-1}, and 11 and 7 mg Zn L^{-1}, respectively. In comparison, the BC Ministry of Environment drinking water quality standards are 0.5 mg Cu L^{-1} and 5 mg Zn L^{-1} (Refer to Table 1.1) (Government of British Columbia 2006). These high leachate concentrations are a reflection of the high concentrations of these two metals in the initial poultry litter packed into the columns (Table 2.3). The YTC base pad was very effective at retaining both Cu and Zn throughout the entire leaching period. The extreme Cu and Zn concentrations in the first flush of leachate from the PL alone treatment were reduced from 25 to 1.3 mg Cu L^{-1} and from 11 to 0.95 mg Zn L^{-1} ($P < 0.05$), equal to over 90% for both metals when the YTC base pad was present in the PL/Y treatment (Figure 2.8).

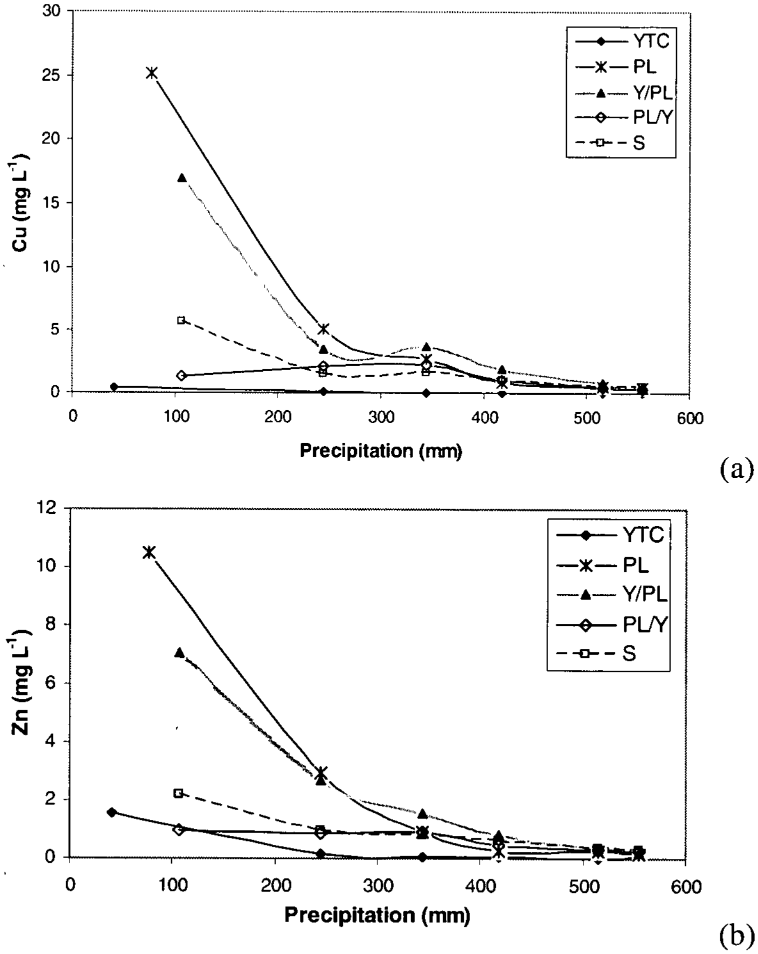
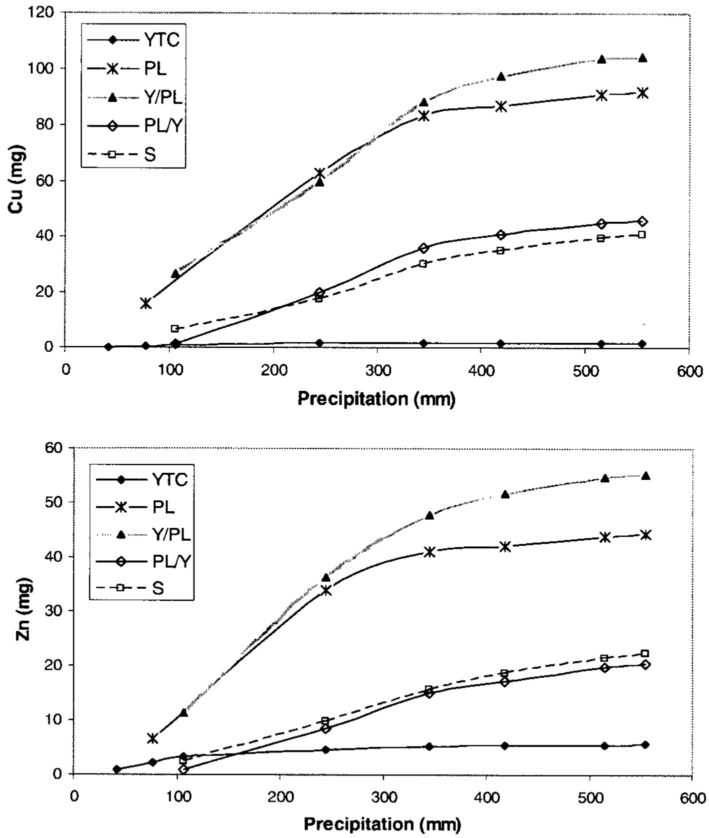


Figure 2.8 Variations in concentrations of (a) Cu and (b) Zn in leachates over study period.

The cumulative masses of Cu and Zn leached from the PL alone column were reduced by 46 ± 6 mg Cu and 24 ± 3 mg Zn ($P < 0.05$) when the YTC base pad was present in the PL/Y treatment (Figure 2.9). The total Cu concentrations of the YTC base pads in the S and PL/Y treatments had increased by an average of 53 ± 10 mg Cu ($P < 0.05$), equal to 102% over the initial Cu concentration in the YTC material packed into the columns. No significant increases in Zn concentration were observed in the YTC base pad material. This was possibly because the initial concentration of Zn in the YTC was high (470 mg Zn kg^{-1} dry YTC) and thus the added 20-30 mg of Zn to the YTC material was not detectable within error.



(a)

(b)

Treatment	Differences ($\alpha = 0.05$) in total cumulative masses leached	
	Cu	Zn
YTC	a	a
PL	c	c
Y/PL	d	d
PL/Y	b	b
S	b	b

Figure 2.9 Cumulative masses of (a) Cu and (b) Zn leached from columns.

The YTC cover in the Y/PL treatment increased the Cu and Zn leaching from the poultry litter below by 13 ± 6 mg Cu or12% and by 11 ± 3 mg Zn or 20% ($P < 0.05$) over the PL alone treatment. Two possible explanations for this exist. First, Ca in the leachate from the YTC covering layer could have displaced Cu and Zn from the exchange sites in the poultry litter. Second, dissolved organic matter in the leachate emanating from the YTC layer above could have been chelating the metals in the poultry litter layer below, thus increasing their solubility. Lindsay (1979) found that for a variety of organic molecules Zn-ligand chelates were more soluble than Cu-ligand chelates. Therefore the relative increase in Zn leached from the poultry litter layer due to the YTC cover was greater than the increase in Cu. The S treatment, which also had an YTC cover, did not show an increase in cumulative masses of Zn or Cu leached as compared to the PL/Y treatment. This could be due to the YTC base pad in the S treatment retaining the extra metals leached from the poultry litter layer above.

Three mechanisms for the retention of Cu and Zn by the YTC base pad are cation exchange, sorption, and precipitation. The elevated pH of the poultry litter leachate (approximately 8.0) would have served to increase the negative charge on the YTC, thus increasing the sorption capacity. These elevated pHs would have also led to the precipitation of Cu and Zn, as these metals are most soluble below pH 7.0 (Brady and Weil 2002). At the end of the study the overall cumulative masses of Cu and Zn leached from the columns were both negatively correlated with the cumulative mass of Ca leached ($P < 0.1$). This negative relationship was even stronger when Cu or Zn was correlated with the cumulative mass of Ca plus Mg ($P < 0.05$). This suggests that Ca and Mg were being displaced from the exchange sites on the humic substances in the YTC base pad by Cu and Zn ions. The overall effect of sorption, cation exchange, and precipitation in the YTC base pad resulted in 12 ± 3 mg of Cu and 6 ± 2 mg of Zn being retained per kg of dry YTC material.

2.3 Conclusions

Nitrogen, Na, K, S, and P leached readily from the poultry litter. The YTC was more stable in terms of leachable nutrients however notable quantities of K, Na, Mg, N, and S were lost due to leaching. The YTC base pad in the PL/Y treatment decreased the cumulative Cu, Zn and P leached as compared to the PL alone by 46 ± 6 mg Cu, 24 ± 3 mg Zn, and 1975 ± 1120 mg P ($P < 0.05$), but appeared to have little ability to retain N or soluble salts. Furthermore, the YTC base pad materials in the PL/Y and S treatments contained on average an extra 1280 ± 660 mg P kg^{-1} dry YTC than the initial YTC prior to leaching ($P < 0.05$).

Cation exchange, mainly via Ca displacement was credited for much of the metal retention, while complexation with Ca and Mg was credited with much of the retention of P. An important scientific finding was that the YTC cover served to increase the leaching of metals and N from the poultry litter layers below.

3. Use of yard trimmings compost to mitigate effects of over-winter field storage of poultry litter on soil quality

The objective of this study was to determine the effects of the YTC base pad, YTC covering, and combinations of the two on selected soil properties under and around three poultry litter field storage piles. Additionally, observational data was collected to assess the overall effects of the piles on run-off quality, and crop development.

3.1 Materials and Methods

3.1.1 Site and pile descriptions

Three experimental poultry litter storage piles were located at two farms near Ladner, BC. The soils are medium to moderately fine textured deltaic deposits of the Gleysolic order. The fields are flat, poorly drained, and there is a fluctuating water table. Piles 1 and 2 were located on a Guichon soil while Pile 3 was located on a Delta soil (Luttmerding 1980). The exact locations and characteristics of the piles are listed in Table 3.1.

TABLE 3.1
Descriptions of experimental poultry litter field storage piles

Pile #	Location	Height (m)	Width (m)	Length (m)	Mass (tonnes)	YTC base pad	YTC cover
1	49° 02' 39.1 N 123° 03' 17.8 W	4.5 - 5	10	70	450	Yes	2/3 covered
2	49° 02' 56.1 N 123° 03' 14.4W	3 – 3.5	10	40	600[z]	No	1/3 covered
3	49° 04' 34.5 N 123° 02' 50.5 W	3	7	20	100	No	Full cover

[z]Estimated by assuming a 60% reduction in volume after composting a combined mass of poultry litter and horse manure of 1480 tonnes (60:40 mix poultry litter: horse manure).

All piles were formed into windrows for the storage period. A windrow is a long pile of triangular cross-sectional area. This shape allows precipitation to be shed, thus preventing pooling, and the creation of saturated, anoxic zones which give off unpleasant odors.

The experimental Piles 1 and 2 were located at opposite ends of the same field on 64th Street, near Ladner, and were located approximately 50 m and 100 m, respectively from the nearest ditch. Pile 1 had a mass of 450 tonnes and was a mixture of broiler litter and turkey litter. The entire windrow was stored on a 30 cm thick base pad of YTC (dry bulk density, D_b = 711 kg/m^3). The manure was covered at both ends by a 15-20 cm thick layer of YTC (D_b = 290 kg/m^3), while a 30 m long section of the middle was left uncovered. The result was that there were two treatments at Pile 1: 1) Uncovered with a base pad (i.e. 1U) and 2) Covered with a base pad (i.e. 1C).

Pile 2 was made up of a composted mixture of 60% poultry litter and 40% barnyard horse manure (volume basis), with a total final mass of 600 tonnes. This mixture was actively composted off site, with four turns to ensure that the entire pile reached temperatures of 55 – 60°C. The middle portion of this windrow (18 m long) had a 15-30 cm thick YTC cover while the two end sections had no cover. This pile had no YTC base pad and was thus stored directly on the soil. The two treatments at this pile were: 1) Uncovered with no base pad (i.e. 2U), and 2) Covered with no base pad (i.e. 2C).

Pile 3 was located further north on 64th Street on a different field. This pile was made up of approximately 100 tonnes of straight poultry litter, had no YTC base pad, was completely covered with a 15-20 cm thick layer of YTC, and was located about 35 m from the nearest ditch. The treatment at this pile was; Covered with no base pad.

3.1.2 Soil sampling and analysis

Soil sampling was carried out in the fall to determine background levels of nutrients at all four sites. Ten soil samples were collected at two depths (0-15 cm and 15-30 cm) from each site at 5 m intervals along a transect 5 m away from the pile and parallel to it. The ten samples from each depth were composited for each particular site, and analyzed by the methods described below for electrical conductivity (EC), pH, and the following available nutrients: NH_4-N, NO_3-N, P, K, Ca, Mg, Na, Cu, Zn, Fe, Mn, and SO_4-S.

In the spring, when the fields had dried and prior to spreading of the manure, soil samples were collected at two depths from the regions around and under the piles. Soil samples were collected from three locations around the pile, namely 0 m or directly beside the pile, 2.5 m, and 5 m away from the pile. Three replicates of these samples were collected for each treatment at each pile. The soil under the piles was sampled in two or three regions depending on the presence or absence of the YTC base pad. Samples were collected from under the wet outer edges and dry inner cores of all three piles. Samples were also collected from under the wet middle region (i.e. wet mid) of Pile 1. Each sample site was replicated three times for each treatment.

Soil samples were also collected at the end of July 2006 under where Piles 1 and 2 had been, as well as from the bulk field around these piles. Soil samples were collected from areas formerly under the uncovered and covered sections of Pile 1 where the wet edge and dry core had been. Also, a composite of ten samples from the bulk field surrounding Pile 1 was collected. For Pile 2 composites of ten samples were collected from both under the former pile location and from the field surrounding it. These samples were analyzed only for pH, EC, and available NH_4-N and NO_3-N.

All soil samples were collected using an Oakfield Probe at 0-15 cm and 15-30 cm depths. Five cores were collected at each site and composited. Upon collection the samples were transferred to plastic bags, sealed and stored on ice packs in a cooler for transport to the laboratory. The NH_4-N and NO_3-N were extracted within 24 hours with a 1M KCl extraction solution using a 10:1 KCl: soil extract as described by McKeague (1978). Extracts were analyzed using a Lachat QuikChem FIA, 8000 series. The remainder of the sample was air dried at room temperature, and ground using a hammer mill with a 2 mm sieve. EC and pH were determined using a 2:1 water to soil extract, on a mass basis. A Beckman Solu-Bridge conductivity meter was used to analyze the EC, while an Orion Research analogue pH meter model 300 was used for determination of pH. The EC results were converted to saturation paste values using the following relationship determined on a Westham Island soil by Wolterson (1993):

$$y = 2.61x + 0.030 \qquad R^2 = 0.97 \qquad \text{Eq. (8)}$$

For the remainder of the chemical analyses samples were sent to Pacific Soil Analysis Inc (PSAI) in Richmond, BC. Available P (Bray-P_1) was determined colorimetrically using the ascorbic acid color development method on a 1:10 soil to Bray (0.03N NH_4F in 0.025N HCl) extract (McKeague 1978). Available Ca, Mg, Na, and K were determined on a Perkin-Elmer Atomic Absorption Spectrophotometer (AAS) using a 1:5 soil to 1M ammonium acetate extract buffered to pH 7.0 (McKeague 1978). Available Cu, Zn, Fe, and Mn were determined by Perkin-Elmer AAS on a 1:5 soil to 0.1N HCl extract (McKeague 1978). Available SO_4-S was determined using the Hi-Bismuth Reducible method on a 1:2 soil to $CaCl_2$ extract (Kowalenko 1993).

3.1.3 Poultry litter and yard trimmings compost sampling and analysis

Temperature measurements within each pile were taken several times throughout the storage period, as an indicator of composting and pathogen reduction. These measurements were taken along a horizontal transect at 1.5 m above the soil surface, at five depths within the pile: 20, 40, 60, 100, and 140 cm from the poultry litter surface.

Samples of the poultry litter and YTC from each pile were collected in the fall as a reference for initial nutrient, moisture, and salt contents. These samples were air dried at room temperature for a minimum of 120 h and then stored in sealed plastic bags until analysis.

In early April 2006, samples of the poultry litter and YTC materials were collected from several locations within each pile. First, an excavator was used to make two large cuts in each treatment at each pile (Refer to Appendix D). The cuts were approximately 2 m wide and they extended from the apex of the pile, straight down to the soil surface and out to one edge. This resulted in complete profiles on four walls from which to collect three replicate samples. The YTC cover was sampled at the apex, the middle and bottom, and the base pad was sampled at the wet outer edge, wet middle region, and dry core. The poultry litter was sampled from the dry inner core, as well as from the wet outer layer at the bottom, middle, and top of the pile. Approximately 10 L of sample from each location were scraped into a pail and thoroughly mixed with a trowel. Samples of 0.5-1 kg were transferred to plastic bags and transported to the laboratory. Samples were laid out to air-dry at room temperature for a minimum of 120 h.

Moisture content, EC, and pH were determined on all samples as described in Chapter 2 (p. 20-21). The YTC and PL materials sampled from each of the regions in Pile 1 only were subjected to a detailed chemical analysis by PSAI. This included ash, available NH_4-N, NO_3-N, and Bray-P_1, as well as total C, N, P, K, Ca, Mg, Na, Cu, Zn, Fe, Mn, and S. The methods are the same as those described in Chapter 2 (p. 23-24).

3.1.4 Statistical analysis

Due to the challenges of on-farm research there was no true replication in this study. Samples were collected from three locations within each treatment at each pile as pseudo-replicates. For each individual pile the pseudo-replicates were subjected to a one-way Analysis of Variance (ANOVA) using SAS Institute Inc. "JMPIN" statistical package, version 4.0.4 (SAS, 2001). Upon a significant F-value for treatment, mean comparisons were performed using Tukey's Honestly Significant Difference at an alpha level of 0.05. Qualitative comparisons only were made between piles.

3.2 Results and Discussion

3.2.1 Climate

The monthly precipitation received at the Vancouver International Airport located approximately 14 km northwest of the study sites is compared to the monthly climate normals calculated from 1971 to 2000 in Figure 3.1 (Environment Canada 2004). The elevation and weather patterns at the airport are comparable to those of the study sites. This figure indicates that January 2006 was an unusually wet month while February was a very dry month. The result of this was that the agricultural fields in Delta in January were completely saturated, there was standing water covering much of the fields, and there was considerable overland flow.

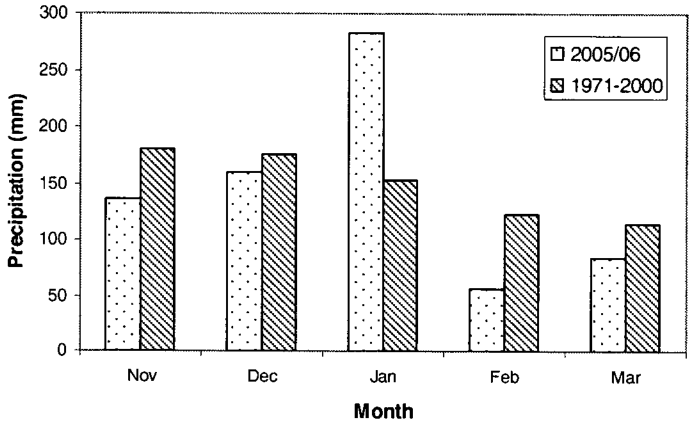


Figure 3.1 Monthly precipitation at Vancouver International Airport 2005-2006 compared to Environment Canada normals.

3.2.2 Field Observations

3.2.2.1 Winter

The effects of the YTC covering and base pad on manure storage Piles 1 and 2 were evident in January 2006. There was standing and flowing water surrounding both piles due to the intense levels of precipitation, water table rise, and resulting soil saturation. Directly beside Pile 1 the puddles were a transparent dark brown color. Around Pile 2 (i.e. no YTC base pad) the puddles were opaque and had a black tarry appearance. It was possible to observe this leachate and run-off flowing directly from Pile 2, across the field and into the ditch, despite the fact that this pile was located approximately 100 m away, well in accordance with the Government of British Columbia's Agricultural Waste Control Regulation (Government of British Columbia 1992). When comparing Piles 1 and 2 it appeared that the YTC base pad under Pile 1 helped to regulate the water running-off of and leaching through the PL layers above, acting like a sponge and resulting in less overall water accumulation around the pile. The leachate which did accumulate around Pile 1 was cleaner and clearer looking than the leachate pooling around Pile 2.

Around Pile 2 there were two black, tarry puddles directly beside the two uncovered portions of the pile. This suggested that the YTC covering layer was reducing the leaching and run-off from the wet outer layer of the stored PL. This was not observed around Pile 1 likely because the YTC base pad decreased the effect.

Despite the lack of YTC base pad under Pile 3, the standing water around this pile was a light brown colour comparable to what was observed around Pile 1. This suggests that the YTC cover was inhibiting the leaching and run-off from the outer layers of the PL. Pile 3 seemed to be located in a slight depression, as there was a considerable amount of water pooling around it, but little flowing overland.

The temperatures measured in the piles over the winter indicate that the YTC cover insulates the poultry litter and helps to maintain elevated temperatures (Figure 3.2). Pile 2, which was composted off-site, remained the warmest over the storage period in both the covered and uncovered sections indicating that composting was continuing. The uncovered section of Pile 1 cooled off quickly and remained cool. Pile 3 and the covered section of Pile 1 remained relatively warm indicating that microbial activity was occurring, which could have led to increased rates of mineralization of nutrients resulting in higher levels of leachable nutrients, as well as possible pathogen reduction.

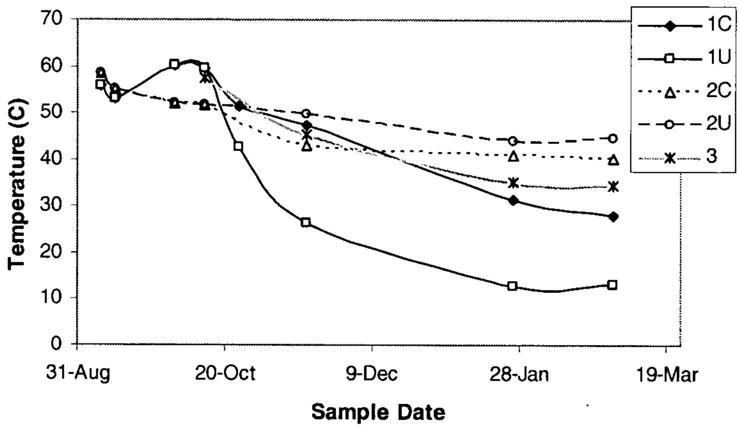


Figure 3.2 Average temperatures measured in piles over the winter storage period. Temperatures are averages of measurements taken at 5 depths within each pile.

3.2.2.2 Summer

Impacts of the manure storage piles on crops were evident in August 2006. The effects of each pile on the subsequent crop at that site are described in Table 3.2. Generally, the negative impacts on crop development are likely attributable to a combination of ammonia toxicity and excessive salinity on seed germination. The symptoms observed on the crops growing under where Pile 2 had been stored, are characteristic of plants growing under excessively high N conditions. These include vigorous dark green vegetative growth, coupled with delayed or absent flowering, fruit set and fruit development (Mills and Jones, 1979). Total available soil N levels measured where Pile 2 had been in August 2006 were approximately 1200 mg kg^{-1}.

TABLE 3.2

Field observations of the effects on crop development the summer following over-winter storage of poultry litter

Pile – Treatment	Crop	Observations
1 Covered, YTC pad	Corn	Approximately half the plants appeared unaffected, half were stunted and showed purpling and curling of the leaves; effects visible under the pile only. Plants growing beside the pile were healthy.
1 Uncovered, YTC pad	Corn	Large area of no crop (20 m x 5 m), strip of healthy plants down centre (under core of pile), stunted plants mixed with no plants extended out to 3 m away from pile.
2 Covered, no pad	Potatoes	Complete plant cover, foliage dark green, no tubers; effects covered area under the pile and out to approximately 1 m away.
2 Uncovered, no pad	Potatoes	Complete plant cover, foliage dark green, no tubers; effects covered area under the pile and out to approximately 1 m away.
3 Covered, no pad	Peas	No crop production under pile or around pile to a distance of approximately 1 m away in all directions.

3.2.3 Soil Quality Under and Around Piles

3.2.3.1 All Piles

Positive correlations ($P < 0.01$) existed under all piles at the 0–15 cm depth between EC and pH, pH and NH_4-N, and NH_4–N and EC. This indicates that leached NH_4^+ was controlling the soil pH under the pile, and that the majority of the leached salts were NH_4-salts. These same positive correlations existed under the piles at the 15–30 cm depth however they were not as strong ($P < 0.1$). (See Appendix E for raw data).

Electrical conductivity, pH and NH_4-N were not correlated for the soil samples taken at 2.5 m and 5 m away from the piles suggesting that the stored manure had little effect on the surrounding field. However, the soil directly beside the piles (i.e. 0 m) exhibited positive correlations ($P < 0.05$) between EC and NH_4-N, as well as between pH and NH_4-N. There was no correlation between EC and pH. Thus, directly beside the piles run-off of NH_4-N was driving the soil pH, however leaching of salts was not a significant factor.

There was a negative correlation ($P < 0.05$) between available P and EC for the soils under and around Pile 1. This was likely an indication that the YTC base pad was retaining P, while the salts were leaching through. The soils below Pile 3 showed a positive correlation ($P < 0.01$) between available P and EC. This substantiates the fact that the YTC base pad in Pile 1 was retaining P, whereas Pile 3 lacked an YTC base pad and thus impacted both soil available P and EC levels. The soils under Pile 2 showed no correlation between EC and available P despite the lack of YTC base pad. This was likely due to the dilution of the poultry litter with barnyard horse manure and pre-composting of Pile 2 offsite, which resulted in less available P for leaching (Table 3.3).

TABLE 3.3

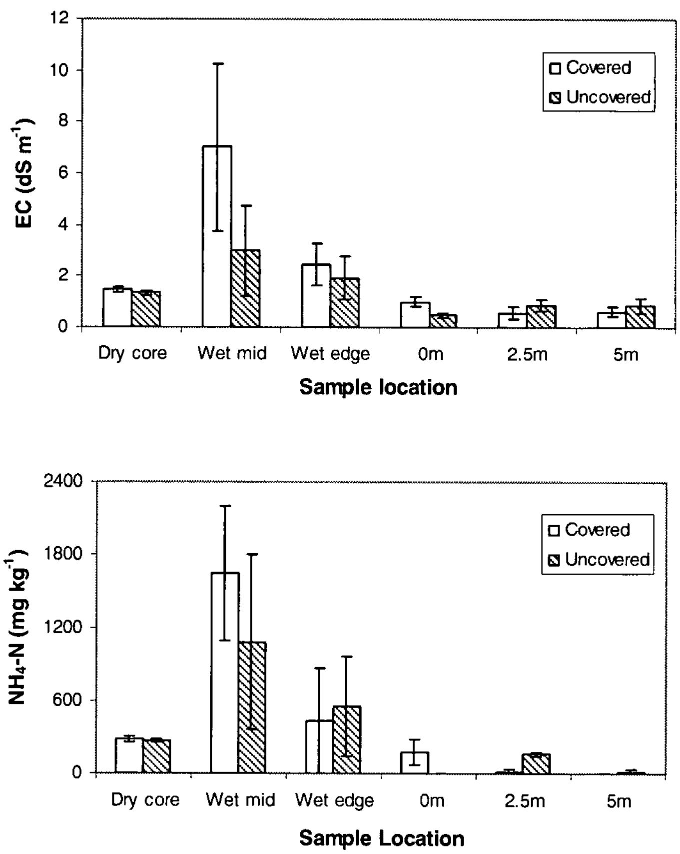
Initial fall nutrient concentrations of the stored poultry litter. n = 4

Initial concentration of nutrient – dry weight basis	Piles 1 and 3 - poultry litter[z]	Pile 2 - poultry litter composted with horse manure
EC	10 ± 1^a	13 ± 0.4^b
pH	6.2 ± 0.2^a	6.4 ± 0.1^a
%C	39 ± 0.7^b	33 ± 2^a
%Ash	15 ± 0.7^a	27 ± 4^b
Total N (g kg^{-1})	51 ± 2^b	37 ± 3^a
Total P (g kg^{-1})	22 ± 0.6^a	22 ± 5^a
Total K (g kg^{-1})	16 ± 1^a	16 ± 2^a
Total Ca (g kg^{-1})	24 ± 0.9^a	42 ± 1^b
Available N (mg kg^{-1})	5160 ± 620^a	5310 ± 510^a
Available P (mg kg^{-1})	5850 ± 520^b	4630 ± 130^a
Available K (mg kg^{-1})	$12\,380 \pm 600^a$	$13\,940 \pm 2200^a$
Available Ca (mg kg^{-1})	531 ± 120^a	531 ± 290^a
Available Na (mg kg^{-1})	3420 ± 250^b	2640 ± 240^a
Available Cu (mg kg^{-1})	65 ± 20^b	17 ± 13^a
Available Zn (mg kg^{-1})	380 ± 13^b	250 ± 35^a

[z]Piles 1 and 3 were made up of the same type of poultry litter.

3.2.3.2 Pile 1

Pile 1 (i.e. full YTC base pad; partial YTC cover) increased soluble salt levels at the 0-15 cm depth only under the pile's two wet regions, namely the wet middle and wet edge as compared to the background EC of 2 dS m^{-1} measured in the fall 2005 (Figure 3.3a). However, the only significantly high EC ($P < 0.05$) was measured under the YTC covered section of the wet middle region, suggesting that the YTC cover increased leaching from the stored poultry litter. Soluble salts under the dry core, as well as at 0 m, 2.5 m and 5 m away from the pile were all below the background level. There was no significant effect at 15-30 cm depth.

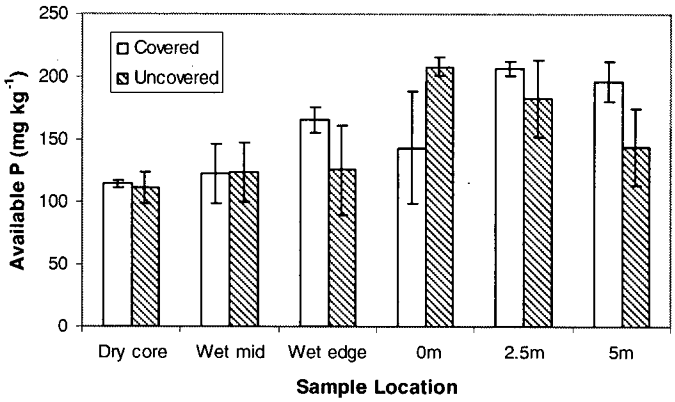


(a)

(b)

Sample Location	Differences at α = 0.05		
	EC	NH_4-N	P
C[z] Dry core	a	ab	ab
U[x] Dry core	a	ab	a
C Wet mid	b	c	ab
U Wet mid	a	bc	ab
C Wet edge	a	ab	abcd
U Wet edge	a	ab	bc
C 0 m	a	ab	abcd
U 0 m	a	a	d
C 2.5 m	a	a	d
U 2.5 m	a	a	bcd
C 5 m	a	a	cd
U 5 m	a	a	abcd

[z]YTC covered section; [x]Uncovered section



(c)

Figure 3.3 Effect of Pile 1 on soil (a) EC, (b) NH_4-N, and (c) available P at 0-15 cm depth, sampled April 2006.

The highest soil NH_4-N concentrations were detected in the wet middle region followed by the wet edge (Figure 3.3b). However, elevated soil NH_4-N levels were also detected at the 0-15 cm depth under the covered and uncovered sections of the dry core, directly beside the covered section of the pile (i.e. 0 m), and 2.5 m away from the uncovered section of the pile. A similar pattern was observed at the 15–30 cm depth with reduced concentrations.

The 0-15 cm depth samples taken from the covered wet middle region apparently exhibited the highest NH_4-N, possibly indicating that the YTC cover increases leaching from the poultry litter although this was not significantly higher than the uncovered wet middle and wet edge samples. Soil NH_4-N levels detected at 2.5 m away from the uncovered section were apparently higher than those 2.5 m away from the covered section of the pile, although these differences were not significant. Nonetheless this data suggests that the YTC cover increases leaching and decreases run-off. As poultry litter wets and dries a crust forms on the surface, which limits the infiltration of precipitation. This was observed in the uncovered poultry litter sections of both Piles 1 and 2. The YTC layer appears to protect the poultry litter surface from forming this crust, and thus allows improved infiltration of precipitation and consequently more leaching and less run-off.

The elevated NH_4-N levels under the dry core of Pile 1 are a reflection of the fluctuating water table and soil saturation which commonly occur over-winter in this region. Once there was water under the pile it would have moved up into the YTC base pad through capillary rise, allowing for leaching or lateral diffusion to occur. It is unlikely that this water could have risen up as high as the PL, as the YTC base pad was 30 cm thick. Also, upon sampling in the spring the upper portion of the YTC base pad and overlying poultry litter in this region were both very dry. Therefore, the elevated NH_4-N detected under the dry cores is hypothesized to have originated in the YTC base pad itself.

Soil available P concentrations under the dry core and wet middle regions of Pile 1 were unaffected by the overlying PL (Figure 3.3c). Background levels of soil available P measured in the fall of 2005 were 129 mg kg^{-1} at 0-15 cm depth and 71 mg kg^{-1} at 15–30 cm depth. This suggests that the YTC base pad under the wet middle region was effective at retaining P leached from the poultry litter above. Some P leaching apparently occurred under the covered wet edge, though this was not significantly higher than any other sample location. Little leaching was expected under the wet edge because this region of the pile mostly consisted of the YTC base pad and cover, with only a small amount of poultry litter, and the maximum leachability of P from the YTC over the entire study period was found through the column study to be only 160 ± 4 mg P kg^{-1} dry YTC. The high available P levels detected in the soil under the covered wet edge might be attributable to field variability. All soil available P concentrations determined on the 0-15 cm depth samples from this site were in the very high risk of P pollution potential as proposed by in the Fraser Valley Soil Nutrient Study 2005 (Kowalenko *et al.* 2007).

Phosphorus run-off from the covered section of Pile 1 had an effect out to 5 m away from the pile at the 0-15 cm depth, but no significant effect at 15-30 cm. The effect of P run-off from the uncovered section extended out to 2.5 m away from the pile at both the 0-15 cm and 15-30 cm depths.

The concentrations of other soil available macro and micro nutrients as well as the pH at the 0-15 cm soil depth under and around Pile 1 after over-winter storage are listed in Table 3.4. Available K and Na concentrations correlated positively with EC ($P < 0.01$) indicating that these species are the dominant salt forming cations present in the PL, they are highly soluble, and loosely sorbed to the poultry litter. Sodium concentrations under the covered wet middle region were significantly higher ($P < 0.05$) than all other Na levels, indicating that the YTC cover increased Na leaching from the poultry litter below.

TABLE 3.4

Soil pH and concentrations of available nutrients under and around Pile 1 at the end of the storage period. n = 3

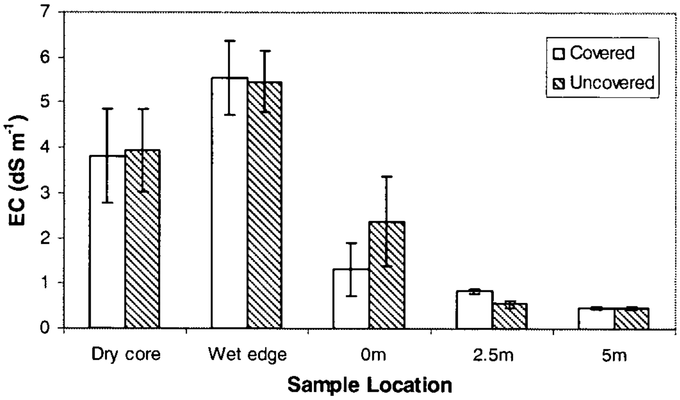
Sample Location	pH	Ca	Mg^{z}	K	Na	Cu	Zn^{z}	Fe	Mn	SO_4-S
					($mg\ kg^{-1}$) dry weight basis					
C Dry Core	5.9 ± 0.1^{d}	1350 ± 50^{bc}	483 ± 3	1040 ± 96^{bc}	62 ± 3^{ab}	6.8 ± 1^{bc}	12 ± 2	533 ± 29^{abcd}	48 ± 4^{e}	26 ± 7^{bcd}
U Dry Core	5.2 ± 0.1^{c}	1150 ± 0^{ab}	393 ± 23	1030 ± 76^{bc}	82 ± 8^{abc}	8.9 ± 0.2^{c}	12 ± 3	673 ± 21^{cd}	37 ± 1^{e}	30 ± 6^{bcd}
C Wet mid	7.1 ± 0.5^{d}	1280 ± 225^{bc}	410 ± 132	1810 ± 1120^{bc}	360 ± 20^{d}	4.1 ± 1^{bc}	14 ± 3	717 ± 58^{d}	48 ± 3^{e}	55 ± 3^{cd}
U Wet mid	6.4 ± 0.4^{d}	1120 ± 29^{ab}	355 ± 13	1920 ± 987^{c}	188 ± 127^{bc}	6.8 ± 0.9^{ab}	15 ± 3	660 ± 26^{cd}	39 ± 2^{e}	35 ± 29^{bcd}
C Wet edge	6.3 ± 0.8^{d}	1300 ± 132^{bc}	413 ± 48	960 ± 476^{bc}	198 ± 78^{c}	7.3 ± 3^{bc}	13 ± 1	443 ± 179^{abcd}	41 ± 1^{e}	49 ± 20^{cd}
U Wet edge	6.3 ± 0.5^{d}	1130 ± 126^{ab}	368 ± 74	1530 ± 306^{bc}	132 ± 38^{abc}	5.6 ± 0.4^{bc}	14 ± 4	492 ± 74^{abcd}	36 ± 2^{abcd}	29 ± 17^{bcd}
C 0 m	5.3 ± 0.4^{c}	1320 ± 29^{bc}	403 ± 25	645 ± 196^{bc}	58 ± 3^{ab}	4.9 ± 2^{bc}	12 ± 3	402 ± 178^{bc}	33 ± 8^{abcd}	29 ± 9^{bcd}
U 0 m	4.6 ± 0.1^{abc}	1270 ± 104^{bc}	348 ± 39	633 ± 57^{ab}	28 ± 3^{a}	4.3 ± 0.8^{bc}	17 ± 2	328 ± 25^{ab}	30 ± 4^{abc}	11 ± 3^{bc}
C 2.5 m	5.6 ± 1.2^{d}	1550 ± 260^{c}	392 ± 7	687 ± 42^{bc}	35 ± 5^{a}	3.9 ± 2^{ab}	16 ± 1	222 ± 84^{ab}	33 ± 3^{abcd}	7 ± 2^{ab}
U 2.5 m	5.3 ± 0.3^{c}	1330 ± 29^{bc}	428 ± 8	849 ± 306^{bc}	57 ± 13^{ab}	6 ± 2^{bc}	16 ± 3	428 ± 149^{bc}	44 ± 3^{de}	30 ± 12^{bcd}
C 5 m	$4.8\ 0.1^{abc}$	1250 ± 173^{bc}	357 ± 60	623 ± 40^{ab}	35 ± 9^{a}	5.9 ± 2^{bc}	14 ± 2	312 ± 39^{ab}	28 ± 4^{ab}	22 ± 7^{bcd}
U 5 m	4.9 ± 0.2^{bc}	1220 ± 29^{bc}	365 ± 20	903 ± 194^{bc}	65 ± 9^{ab}	4.6 ± 2^{bc}	15 ± 4	350 ± 83^{ab}	27 ± 7^{a}	30 ± 17^{bcd}

^{z}F-test not significant at $\alpha = 0.05$

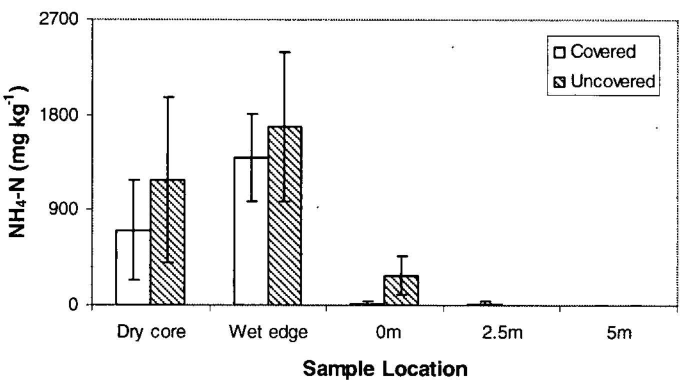
Available Ca concentrations away from the pile were generally higher than those detected under the pile. This is most likely due to Ca run-off from the YTC cover and base pad materials. No significant effects on soil Mg or Zn were detected. The only elevated Cu concentrations were detected under one core sample where leaching was due to water table rise contacting the YTC base pad. Through the column study the leachability of Cu from YTC was determined to be 0.5 ± 0.01 mg Cu kg^{-1} dry YTC, thus it is unlikely that the YTC base pad would have significantly impacted soil available Cu levels, and this anomalous concentration is probably due to field variability. Iron and Mn showed elevated concentrations similarly under the highly leached covered and uncovered wet middle regions of the pile as well as under some of the dry core samples. The YTC base pad does not appear to retain either of these metals.

3.2.3.3 Pile 2

Pile 2 (i.e. no YTC base pad; partial YTC cover) caused elevated soluble salt and NH_4-N levels in the soil under the wet edge and dry core down to 30 cm depth (Figure 3.4). The elevated soil EC and NH_4-N concentrations under the dry core of the pile suggest that during the winter storage season the water table rose up to the soil surface and drew down salts and nutrients from the manure pile above. Both EC and NH_4-N concentrations directly beside the uncovered section of the pile were higher than beside the YTC covered section, though these differences were not significant. This nonetheless suggests that the YTC cover prevents run-off thus limiting the effect of the stored manure on the surrounding field.

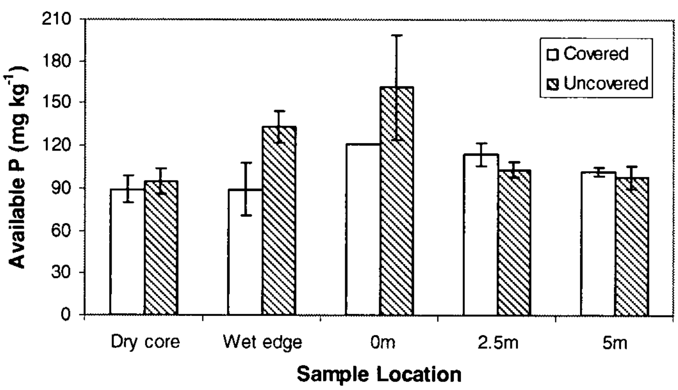


(a)



(b)

Sample Location	Differences at $\alpha = 0.05$		
	EC	NH_4-N	P
C Dry core	bc	abc	a
U Dry core	bc	bc	ab
C Wet edge	c	c	a
U Wet edge	c	c	bc
C 0 m	a	a	ab
U 0 m	ab	ab	c
C 2.5 m	a	a	ab
U 2.5 m	a	a	ab
C 5 m	a	a	ab
U 5 m	a	a	ab



(c)

Figure 3.4 Effect of Pile 2 on soil (a) EC, (b) NH_4-N, and (c) available P at 0-15 cm depth, sampled April 2006.

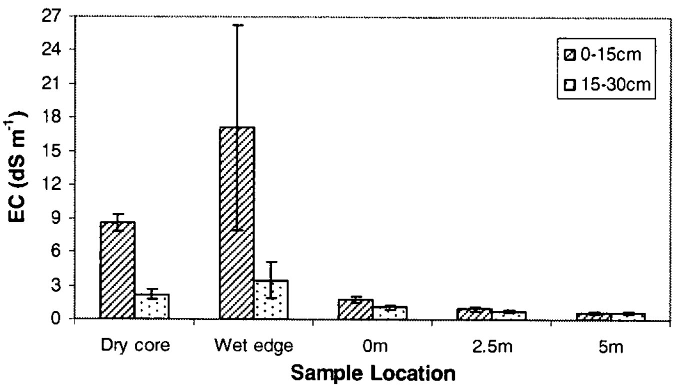
Pile 2 had little effect on soil available P levels at the 0-15 cm depth, and no measurable effect at 15-30 cm. At 0 m away from the uncovered section of the pile the available P concentrations were the highest reaching up to almost 200 mg kg^{-1}, whereas the soil at 0 m away from the YTC covered section had significantly lower soil available P levels of only 121 mg kg^{-1} ($P < 0.05$), equal to the background levels measured the previous fall.

This further substantiates the fact that the YTC cover prevents run-off from the stored poultry litter.

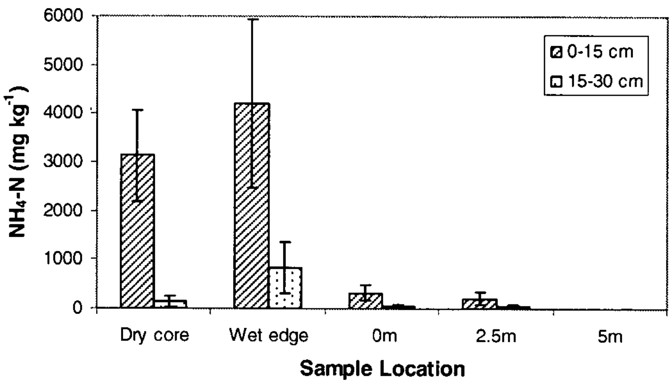
The only other elevated available soil P levels measured near Pile 2 were under the uncovered wet edge. A possible explanation why there was more P leaching from the uncovered poultry litter than there was from the YTC covered poultry litter ($P < 0.05$), is that the YTC is relatively high in Ca. Calcium leached at a rate of 750 ± 11 mg Ca kg^{-1} dry YTC in the column experiment conducted over the same winter. As Ca leached out of Pile 2's YTC covering layer it could have reacted with some of the P present in the poultry litter, immobilizing it and thus reducing the leachability of the P.

3.2.3.4 Pile 3

Pile 3 (i.e. no YTC base pad; complete YTC cover) had a severe effect on soluble salt and NH_4-N levels under the entire pile down to 30 cm depth (Figure 3.5). This pile was much smaller than Piles 1 and 2, thus leaching which occurred under the core of the pile might have come from lateral movement of water under the pile as well as through water table rise. There was no effect on soil EC around the pile however NH_4-N concentrations were apparently elevated out to 2.5 m away at both 0-15 cm and 15-30 cm depths. This NH_4-N run-off likely originated mostly in the YTC cover itself.

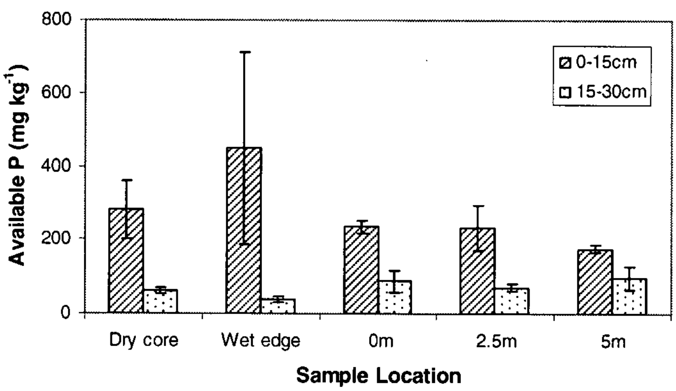


(a)



(b)

Sample Location	Differences at $\alpha = 0.05$		
0-15 cm	EC	NH_4-N	P
Dry core	ab	b	a
Wet edge	b	b	a
0 m	a	a	a
2.5 m	a	a	a
5 m	a	a	a



(c)

Sample Location	Differences at $\alpha = 0.05$		
15-30 cm	EC	NH_4-N	P
Dry core	ab	a	a
Wet edge	b	b	a
0 m	a	a	a
2.5 m	a	a	a
5 m	a	a	a

Figure 3.5 Effect of Pile 3 on soil (a) EC, (b) NH_4-N, and (c) available P, sampled April 2006.

The 0-15 cm soil depth under the wet edge apparently experienced the most P leaching however there were no significant differences between sample locations. Available P levels for all samples at the 0-15 cm depth appeared to be above the background level of 181 mg kg^{-1}, and all values exceeded the 100 mg P kg^{-1} (Kelowna extractable P) limit proposed by the Fraser Valley Soil Nutrient Survey 2005 putting these soils in the very high environmental risk class for P pollution (Kowalenko *et al.* 2007).

The concentrations of other soil available macro and micro nutrients as well as the pH at the 0-15 cm soil depth under and around Pile 3 after over-winter storage are listed in Table 3.5. Similar to Pile 1 EC was positively correlated with K and Na ($P < 0.05$) indicating that these are the dominant salt forming cations in the poultry litter. Available Ca concentrations under the core and edge of Pile 3 were significantly lower ($P < 0.05$) than at 5 m away. This could be the result of high levels of P leaching out of the stored poultry litter and forming insoluble precipitates with Ca thus reducing its availability under the pile. Also Ca run-off from the YTC cover could have increased the concentrations at 5 m away. Concentrations of Cu, Fe and SO_4-S were all significantly higher ($P < 0.05$) under the wet edge of the pile than at 5 m away, indicating that these species leached out of the poultry litter but did not run-off and re-enforcing the notion that the YTC cover protects the surrounding field from poultry litter run-off. Zinc concentrations under the wet edge were high but due to large variability no significant differences were observed. Soil available Mn and Mg levels were apparently unaffected by the stored poultry litter.

TABLE 3.5

Soil pH and concentrations of available nutrients under and around Pile 3 at the end of the storage period. n = 3

Sample Location	pH	Ca	Mg^{z}	K	Na	Cu	Zn^{z}	Fe	Mn^{z}	SO_4-S
		(mg kg^{-1})								
Dry Core	6.9 ± 0.1^{d}	1200 ± 220^{a}	303 ± 78	2470 ± 1240^{ab}	510 ± 215^{b}	5.3 ± 0.9^{b}	9.7 ± 1	740 ± 32^{b}	37 ± 2	55 ± 21^{ab}
Wet edge	6.1 ± 0.1^{c}	1130 ± 210^{a}	375 ± 18	3020 ± 930^{b}	520 ± 160^{b}	4.9 ± 0.7^{ab}	13 ± 5	700 ± 23^{b}	33 ± 5	120 ± 54^{b}
0 m	5.2 ± 0.2^{b}	ND^{y}	ND	ND	ND	ND	ND	ND	ND	ND
2.5 m	4.8 ± 0.2^{b}	ND	ND	ND	ND	ND	ND	ND	ND	ND
5 m	4.4 ± 0.1^{a}	1900 ± 130^{b}	440 ± 42	303 ± 13^{a}	62 ± 13^{a}	3.5 ± 0.1^{a}	8 ± 0.6	180 ± 15^{a}	32 ± 0.6	20 ± 11^{a}

^{z}F-test not significant at $\alpha = 0.05$.

^{y}ND – no data available.

3.2.4 Assessment of YTC base pad and covering

Despite the obvious differences between each of the three piles, such as pile size and type of poultry litter/prior composting, qualitative comparisons were made with the broader goal of determining on-farm best management practices regarding over-winter field storage of poultry litter on British Columbia's Fraser River delta.

The intensity of leaching and run-off which occurred under and around the piles was used to assess the effectiveness of the YTC base pad and covering layer at protecting soil quality and mitigating other environmental concerns. Leaching was most severe everywhere under Pile 3 as compared to the other piles. Pile 3 was made up of less than one quarter and one sixth of the volumes of poultry litter present in Piles 1 and 2, respectively, yet it had up to thirteen times the impact on soil quality based on ECs and available N levels. Soluble salt and NH_4-N concentrations under the wet regions of Piles 1 and 2 were very similar (Figure 3.6). High levels of leaching under Pile 1 were expected due to its large size compared to Pile 3, as well as its composition, specifically fresh poultry litter. However, the hypothesis was that the YTC base pad would protect the soil below. Pile 2, though very large, was made up of a pre-composted mixture of PL and barnyard horse manure. As horse manure is much lower in N and salts than poultry litter and due to the stabilizing effect of composting, a reduced amount of leaching from this pile was expected (Table 3.3).

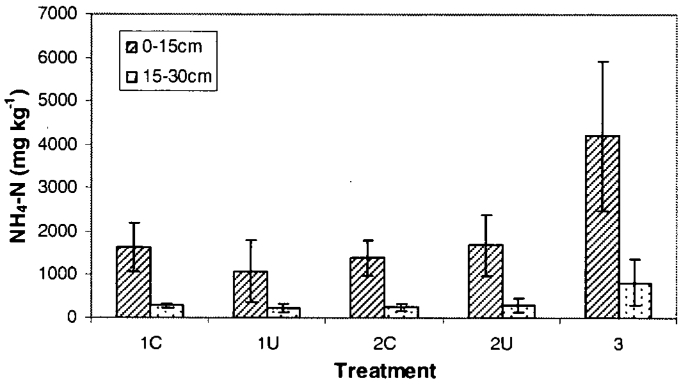


Figure 3.6 Soil NH_4-N concentrations under highly leached wet regions of all piles at end of storage period, sampled April 2006. Qualitative comparisons only.

Ammonium and soluble salt concentrations under the dry cores of the piles clearly indicate that the YTC base pad in Pile 1 was effective at protecting the soil from leaching caused by water table rise (Figure 3.7). Pile 3 had the biggest effect on soil salinity under its core compared to the soils under the cores of the other piles. The smaller impact on soil quality of Pile 2 as compared to Pile 3 was likely a result of the pre-composting of the poultry litter with horse manure in Pile 2, which resulted in significantly lower total N concentrations as compared to the straight poultry litter in Pile 3 (Table 3.3). Furthermore, Pile 3 appeared to be in a low spot on the field, thus water was unable to run-off and more leaching occurred.

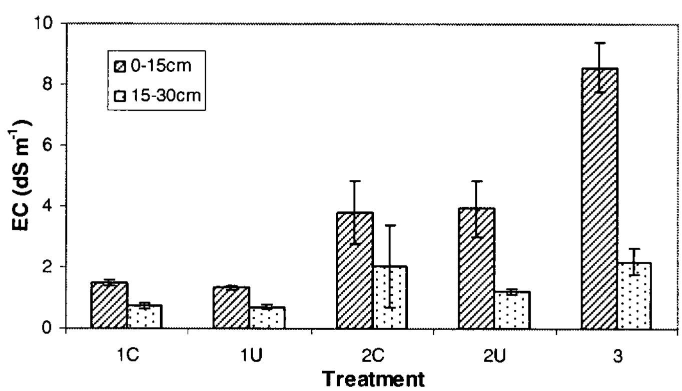


Figure 3.7 Soil ECs measured under the cores of the piles at the end of the storage period, sampled April 2006.

The YTC cover on Pile 1 appeared to increase leaching of salts in the wet middle region, while it had no effect on leaching in Pile 2. Again this could be a result of the pre-composting of the poultry litter in Pile 2. When uncovered poultry litter wets and dries it tends to form a crust, which limits gas exchange. Perhaps the composting of the poultry litter with horse manure in Pile 2 improved the structure of the manure, thus improving the aeration and infiltration of precipitation. The YTC cover in Pile 1 apparently protected the poultry litter surface below from sealing off, thus allowing for increased infiltration and leaching as compared to the uncovered portion. At both Piles 1 and 2 the YTC cover appeared to protect the surrounding soil by decreasing run-off.

The YTC cover has added benefits apart from the mitigation of nutrient run-off. These are pathogen reduction within the poultry litter as a result of increased temperatures caused by the YTC insulation, as well as the isolation of the poultry litter from wildlife. Birds are often seen on field stored poultry litter piles, feeding on insects living inside the pile. This is a possible pathway for disease transmission from caged livestock to wild bird populations, which is apparently mitigated with a layer of YTC.

An analysis of the nutrient content of the YTC base pad materials after storage compared to the initial fall nutrient content revealed that the YTC base pad retained to some degree Cu, K, Na, P and NH_4^+ leached from the poultry litter. However due to large variability these increases were not always significant (See Appendix F for complete data set). The wet middle region under the YTC covered and uncovered sections of the pile, where leaching was most intense, contained elevated levels of Na and K ($P < 0.01$), as well as NH_4-N and P (not significant at $\alpha = 0.05$ due to extreme variability). The wet middle region under the uncovered section showed elevated levels of Cu ($P < 0.1$).

The 30 cm thickness of the YTC base pad was appropriate under the core of Pile 1, however the soil under the highly leached wet edges of the pile would have likely benefited from a thicker base pad.

3.3 Conclusions

Crop development the spring following over-winter poultry litter storage was negatively impacted at all sites. The crop growing where Pile 1 had been stored showed the fewest negative effects, while no crop development occurred where Pile 3 had been stored.

Pile 3 had the largest impact on soil quality under and around the pile. This was attributed to the lack of YTC base pad, and the uncomposted nature of the stored poultry litter. The YTC base pad in Pile 1 protected the soil below from leaching due to water table rise under the core of the pile, and to a lesser extent under the intensely leached wet outer regions of the pile. The YTC base pad was found to contain significantly elevated levels of Cu ($P < 0.1$), and Na and K ($P < 0.05$). The YTC cover on Piles 1 and 2 reduced run-off of nutrients by increasing infiltration of precipitation, and consequently increasing leaching. The off-site pre-composting of the poultry litter with barnyard horse manure in Pile 2 resulted in a more stable, less leachable product which appeared to have a smaller effect on soil quality over the storage period than the fresh poultry litter in Piles 1 and 3.

Delta farmers should not store poultry litter directly on the soil, and would be well advised to examine the potential of an YTC base pad of greater than 30 cm thickness. The YTC base pad is not perfectly effective at mitigating environmental impacts of field stored poultry litter, and thus requires some modification.

The YTC cover plays the important role of isolating the poultry litter from wildlife whereby mitigating the spread of pathogens from caged livestock to wild bird and other animal populations. Regarding nutrients the YTC cover decreases run-off, and increases infiltration and consequently leaching. Pre-composting the manure off-site also protects soil quality.

4. General discussion and conclusions

4.1 Introduction

This thesis employed a controlled column experiment and a field study to examine the ability of the City of Vancouver YTC to act as a filter and to mitigate environmental impacts of over-winter field stored poultry litter. The column study provided a controlled setting in which to examine the quality of leachate emanating from the poultry litter and YTC materials alone, as well as the effects of the YTC cover and base pad on the quality of the poultry litter leachate. In conjunction with the laboratory characterization of the materials, the column study provided an arena in which to form hypotheses regarding the retention of species by the YTC base pad, and increased solubility of certain species by the YTC cover. Upon scaling up to the field study where the challenges of on-farm research were present and true replication was absent, many of the processes observed in the column study were apparent, although often obscured by variability. This chapter seeks to make the connections between the column study and the field study in order to assess the YTC in its ability to mitigate environmental impacts of poultry litter field storage, and to suggest beneficial management practices (BMPs) for the over-winter field storage of poultry litter on British Columbia's Fraser River delta. Significance, potential applications, strengths and weaknesses of the research, and suggestions for future work will also be discussed.

4.2 Comparisons and interpretations of column and field studies

The leachabilities of nutrients, metals and total solids from the YTC and PL materials determined through the column study are a useful indicator of the potential impacts that these materials could have on the environment in which they are stored over-winter. The poultry litter leached extremely high concentrations of NH_4, P, K and Na, as well as moderately high concentrations of Cu, Zn, Fe, Mn and S. This data confirmed the necessity of isolating the poultry litter from the surrounding environment during over-winter field storage in regions of high precipitation.

In order for the YTC base pad to be an effective filter/barrier between the poultry litter and the surrounding environment the YTC itself must not be a significant source of potentially harmful leachate species, such as N, P, and heavy metals. This was the case for Cu, Zn, Mn and P however 1430 mg of total N were leached per kilogram of dry YTC material over the entire storage period. This is a moderate amount that had little effect on the soil under the core of Pile 1 in the field study, but could have negative effects if the leachate were to flow directly into a water body.

The United States Environmental Protection Agency (USEPA) outlines quality standards for compost used in filter berms for erosion control (USEPA 2006). The USEPA parameters are compared with the City of Vancouver YTC used in this study in Table 4.1. The YTC meets the criteria for pH, EC and organic matter content however the percentage of small sized particles is considerably higher than recommended. This small particle size was reflected in the 25 g total solids per kilogram dry YTC leached over the column study. Leaching and run-off of solids is a concern due to nutrients and metals which are sorbed onto the particle surfaces. This would likely not be a substantial problem for the YTC base pad as it lies flat on the soil surface. Solids run-off from the YTC cover could be a moderate concern however the field study showed that due to increased infiltration rates caused by the YTC cover run-off did not have a significant impact on the soil surrounding the covered poultry litter piles.

TABLE 4.1

Comparison of YTC quality with USEPA standards for compost used in erosion control filter berms

Parameter	USEPA standard	YTC (n = 4)
pH	5.0 – 8.5	7.1 ± 0.1
Maximum EC (dS m^{-1})	5.0	2.9 ± 0.1
Organic matter (%)	25 - 65	49 ± 0.8
Particle size	No more than 50% passing a 6.5 mm sieve	80% passing a 6.5 mm sieve

(USEPA 2006)

The effects of the YTC base pad in the column and field studies are compared in Table 4.2. At times in the column study nutrient reductions in the leachate by the YTC base pad were observed while enrichments of the same nutrient were not detected in the YTC base pad material. This could be attributable to the increased sensitivity of leachate analysis as compared to analysis of the YTC material. High initial levels of a given nutrient in the YTC material could have obscured small increases in concentration of these nutrients measured at the end of the study.

TABLE 4.2

Comparison of YTC base pad effects ($P < 0.05$) in column and field studies. n = 3

	Column study		Field Study
Nutrient	Concentration in base pad at completion of study	Cumulative mass detected in leachate	Concentration in base pad under highly leached wet regions at completion of study
EC	Enriched	N/A	No effect
NH_4	Enriched	No effect	No effect
P	Enriched	Reduced	No effect
K	Enriched	No effect	Enriched
Ca	Depleted	Increased	Depleted
Na	Enriched	No effect	Enriched
Cu	Enriched	Reduced	Enriched
Zn	No effect	Reduced	No effect

Copper was consistently retained and calcium (Ca) was consistently depleted in the YTC base pads. These were the only consistencies observed across the three methods of analysis in the two studies. In the column study P was clearly reduced in the leachate and enriched in the YTC base pad, however due to large variability in P concentrations of the Pile 1 YTC base pad no significant retention of P was detected in the field study. The EC, K, Na and NH_4 were enriched in the YTC base pad after leaching in the column study however the leachate samples did not indicate significant reductions of these species in the treatments containing the YTC base pad. The YTC base pad in the field study was enriched in K and Na, whereas the variability in the NH_4 and EC measurements was very large which obscured any significant enrichment of these species. Overall the data indicates that the YTC base pad sorbs soluble salts and releases them slowly over time, with no permanent immobilization of the ions. The quantity of these loosely held ions present in the base pad at the end of the storage period depends largely on the thickness and density of the YTC base pad as well as the amount and intensity of precipitation received. The YTC clearly immobilized Cu in both experiments, and likely retained P and Zn as well.

The YTC cover in the column study increased the leaching of Cu, Zn, and N from the poultry litter below. In the highly leached wet regions of the field stored poultry litter the YTC cover significantly ($P < 0.05$) increased the leaching of salts and appeared to increase the leaching of NH_4-N. Furthermore, in the field study the YTC cover increased infiltration of precipitation into the stored poultry litter, thus increasing leaching overall and decreasing run-off. The result of this was a larger impact on the soil directly below the pile with a smaller overall footprint of the stored manure on the surrounding field.

4.3 Potential of YTC base pad and assessment of appropriate thickness for over-winter field storage of poultry litter

Given the metal and P retention capabilities of the YTC base pad determined through the column study using the leachate data (Table 4.3), potential retention capacities were calculated to be used for assessment of the required YTC base pad thickness in the field

(Table 4.4). These calculations were performed assuming the same YTC base pad dry bulk density as was used in the column study although this density is typically 1.5 times higher in the field. The higher density in the field would lead to longer contact times between the leachate and the YTC, as well as an increased mass of YTC material within a given base pad thickness, and thus would likely result in increased retention capacities.

TABLE 4.3

P, Cu and Zn retention capacities of YTC base pad determined through column study

Element	YTC Retention Capacity (mg element kg^{-1} dry YTC)
P	375 ± 339
Cu	12 ± 3
Zn	6 ± 2

TABLE 4.4

Potential P, Cu, and Zn retention capacities of a cylindrical section of an YTC base pad of 30 cm diameter and increasing thickness

Element		Mass retained in 14 cm thickness	Mass to be retained by 30 cm thickness	Mass to be retained by 45 cm thickness
			(mg)	
P	Max	2350	5040	7550
	Min	520	1110	1670
Cu	Max	55	117	175
	Min	38	80	121
Zn	Max	28	60	90
	Min	20	43	64

*All calculations assume an YTC base pad dry bulk density of 477 kg m^{-3}, as was used in the column study.

The amount of P retained by the YTC base pad was substantial yet highly variable. The amounts of Cu and Zn retained were more consistent however the total masses were much lower. These values are the maxima achieved in the column study but are not necessarily the absolute maxima, as the YTC was only subjected to the concentrations of these elements present in the leachate emanating from a 14 cm thick layer of poultry litter leached with 660 mm of precipitation. The calculated range of Cu and Zn retention capacities for the 30 cm thick YTC base pad would have been sufficient to retain the total cumulative masses of these metals leached from the PL over the column study (Table 4.5). The high concentration of P leached from the PL coupled with the large variability in the YTC retention capacity of this element suggest that an YTC base pad of 45 cm thickness might not have been sufficient to retain the cumulative mass of P leached from the PL over the column study. However, there would have been a significant reduction in the extreme P concentrations in the poultry litter leachate which could serve to protect surrounding fresh and coastal waters from eutrophication caused by overland or subsurface flow of this leachate.

TABLE 4.5

Cumulative masses of P, Cu and Zn leached from PL alone column over study period

Element	Cumulative mass leached from 2.32 kg dry PL over column study (mg)
P	6510 ± 570
Cu	92 ± 5
Zn	44 ± 3

Scaling up the thickness of the YTC base pad from the column study to field situations is very difficult due to the triangular shape of the windrows compared to the simple flat layered, gravity driven geometry of the columns. Regarding elements such as N, K, and Na, which were not conclusively retained by the YTC material, yet were enriched in the YTC base pads in the column and/or the field study, it would seem that a thicker base pad would provide a greater barrier to the leaching of these elements. Determining the appropriate depth would be highly subjective as the results for these elements were variable between treatments and experiments.

Another important factor in the filtering capacity of the YTC base pad is the amount and intensity of cumulative precipitation to which the materials are exposed over the storage period, and the timing of these events. The column study indicated extremely high concentrations of nutrients, metals and salts leaching from the PL alone and Y/PL columns until approximately 350 mm of precipitation had occurred. The columns with the YTC base pad conversely leached low to moderate concentrations until 350 mm of precipitation at which time three different effects occurred. First, as was the case for Cu and Zn, the concentrations remained low and then decreased to nearly zero. Second, as in the case of P, the concentration in the leachate increased, indicating the probable saturation of the YTC retention capacity for this element. Third, as in the cases of N and soluble salts, the concentrations remained moderate and continued to decrease slowly over time. In all cases the YTC base pad was effective at improving the leachate quality emanating from the poultry litter until 350 mm of precipitation. Therefore, whether the YTC is retaining the leachate species or simply acting as a physical barrier to them, one can hypothesize that the 30 cm thick base pad used in the field study, compared to the 14 cm thick base pad present in the column study, would be an effective barrier for more than 350 mm of cumulative precipitation and a 45 cm thick base pad would be even better.

The significantly larger volume of manure stored on the YTC base pad in the field relative to the column study clearly puts greater pressure on the YTC filtering capacity, however the triangular shape of the windrow allows for some run-off. Also, the internal heating of the poultry litter pile gives rise to evaporation, which acts to counter leaching. The effect of this is mostly felt in the centre of the pile, thus leaching is kept to the bottom wet outer rim. In this region the maximum depth of saturated poultry litter overlying the YTC base pad observed in the field study was less than 1 m.

The 30 cm thick base pad currently used in Delta proved to be deep enough to keep the manure raised off the soil surface and prevent leaching due to water table rise under the core of the pile. In terms of leaching in the wet outer regions however this 30 cm thickness was not enough. Taking into account the metal and P retention capacities of the YTC, along with the buffering effect the YTC provides by acting as a physical barrier to soluble salts and NH_4, I propose that a 45 cm thick YTC base pad would be a more appropriate thickness under field stored poultry litter for protecting soil and water quality in the Delta region while not exceeding a practical quantity of YTC in terms of shipping and handling.

4.4 Further applications of YTC material as a filter and/or environmental buffer

Many Delta farmers have small dedicated manure storage areas consisting of a cement base pad with three cement walls. Generally, the manure is left uncovered in these facilities, and thus the leachate is free to run-off due to the lack of absorption by the cement pad. Essentially the leachate is funneled in one direction by the three walls, concentrating it and potentially leading to overland flow or seepage into groundwater. A densely packed berm of YTC across the open side of such manure storage facilities could filter this leachate, removing heavy metals, some P, and moderating the soluble salt levels.

As previously mentioned, similar berm type applications are currently being endorsed for use in erosion control by the USEPA. Compost is credited with retaining large volumes of water, sediment, heavy metals and other pollutants, providing a medium for vegetation establishment, and containing beneficial organisms which can degrade pollutants (USEPA 2006). The USEPA also recommends using a series of filter berms for maximum performance. This idea could be applied to field stored manure in which a windrow of poultry litter is stored on a base pad of YTC, and then at a distance away (e.g. 1 m) a berm of YTC could be built surrounding the pile. This could filter the leachate and run-off emanating from the stored manure which is flowing overland due to soil saturation.

As reaction with Ca and Mg was credited with much of the P retention by the YTC in the column study, it is hypothesized that a layer of calcium carbonate lime spread over the top surface of the YTC base pad prior to windrowing the poultry litter could improve this retention. Moore and Miller (1994) found that the addition of slaked lime ($Ca(OH)_2$) to poultry litter at a rate of 43 g Ca kg^{-1} litter decreased soluble P levels from 2000 mg P kg^{-1} to < 1 mg P kg^{-1}. Mixing lime into the poultry litter prior to windrowing would have the negative impact of encouraging NH_3 volatilization due to the increased pH, and it would likely be too expensive and labour intensive to be practical. Conversely, spreading a layer of lime over the surface of the YTC base pad would be relatively simple and inexpensive. Furthermore, the soils in the Delta region are acidic (pH range for the two fields used in this study was 4.4 to 4.7) and would thus be positively impacted by the addition of a liming material. The pH of the YTC base pad would likely increase as leachate flowed through the lime layer, which would serve to increase the pH dependent CEC of the YTC material and thus also improve the metal retention capacity.

4.5 Broader perspective

4.5.1 Poultry litter storage options

The Delta farmers have been shaping manure piles into windrows (i.e. triangular cross-sectional area) for the storage period at the recommendation of the Government of British Columbia (1995). This shape helps to maintain elevated temperatures within the pile, and it encourages run-off, thereby reducing pooling and the creation of saturated anoxic zones which produce offensive odors. Conversely, the Government of Ontario recommends building a pile which is "as flat as possible" on top in order to encourage infiltration and decrease run-off (Government of Ontario 2005). This appears to be a reasonable method of reducing the impact of nutrient run-off on the surrounding soil. A layer of YTC over a flat topped pile could help to reduce odors and improve infiltration, thus decreasing run-off as well as leaching in the wet bottom region of the pile.

Ideally, manure piles should be covered with tarpaulins, however the Delta farmers found that these were expensive, blew off in the wind, and were stolen. Thus, they tried covering the piles with YTC. Tarpaulins are impermeable and thus prevent leaching and run-off if they completely cover the pile and remain in place, but they provide no thermal insulation, and they contribute to the waste stream. Conversely, YTC is permeable and thus leaching is a factor. However, the YTC helps to insulate the poultry litter pile, which keeps the temperatures high, deactivating pathogens, and thus increasing food safety (Bomke and Temple 2004).

Manure storage responsibility is another important issue. Currently, few poultry producers in the Fraser Valley have the capacity to store their poultry litter beyond one production cycle. Thus, the manure is shipped at all times of the year to crop producers who must then bear the storage burden. This shifts the potentially negative ecological impacts of manure storage from the region which is experiencing the economic benefits of poultry production, to a separate region which receives no compensation from the intensive poultry industry. In the Netherlands it is legislated that livestock producers have the capacity to store all manure produced in the fall and winter, while in Denmark similar legislation states that livestock producers must have sufficient storage capacity for all the manure produced annually (Brandjes *et al.* 1996). Similar legislation in British Columbia would serve to protect the ecology of the Fraser River delta from the harmful effects of over-winter poultry litter field storage.

4.5.2 Use of poultry litter in crop production on BC's Fraser delta

Field application of poultry litter is an important means of nutrient recycling for this over-abundant agricultural waste product. A report prepared for the Sustainable Poultry Farming Group (SPFG) found that in 2001 the poultry industry was the largest producer of manure based N and P in BC's lower Fraser Valley, where there was a manure nutrient surplus of 4 000 tonnes of N and 5 700 tonnes of P (Timmenga and Associates Inc. 2003). A report put out by Agriculture and Agri-food Canada and the BC Ministry of Agriculture and Lands on the soil nutrient status of agricultural fields in the Lower Fraser Valley in 2005 found that 31% of the 172 fields sampled had fall residual soil N levels of greater than 99 kg ha^{-1} (Kowalenko *et al.* 2007). Furthermore, 91% of the fields sampled in Delta were in the high to very high risk category of P pollution potential. As most farmers apply poultry litter based on crop N requirements, P is typically over-applied and thus builds up in the soil. In the United States the P-index is used to identify fields vulnerable to P losses and to limit the application of manure once a threshold is reached (Lemunyon and Gilbert 1993). Brock *et al.* (2006) studied Cu and Zn accumulations in soils receiving repeated applications of livestock manures. They concluded that although Cu and Zn did accumulate significantly in soils, the P-index would limit manure applications before Cu and Zn reached toxic levels. No such index exists in BC, thus the repeated application of poultry litter to agricultural fields in Delta is cause for concern, especially given the already commonly high P levels.

Several studies have found that the most effective way to control odors and nutrient run-off/leaching from stored manure is through dietary adjustments (Mikesell 2002; Brandjes *et al.* 1996). In intensive livestock production animals are fed an excess of nutrients, as well as metals, antimicrobials, and hormones (Gupta *et al.* 2005) much of which are excreted undigested. Nicholson *et al.* (1999) found that the concentrations of Cu and Zn in poultry litter were up to five times higher than those in poultry feeds, indicating a low efficiency of utilization of these metals by the birds. The necessity of such feed supplementation is questionable, though the impact on the ecosystem when such poultry litter is used in crop production is clearly negative. There are also food safety concerns related to the uptake of these heavy metals and antimicrobials by crops for human consumption, as well as ecological concerns related to anti-microbial resistant bacteria. The above concerns suggest a need for better regulation of the use of poultry litter in crop production in ecologically sensitive regions subject to intensive winter leaching, such as Delta.

4.6 Risk Assessment

The effects of field stored poultry litter on the soil are dramatic. To walk onto an agricultural field in August which is fully covered in a healthy pea crop and then to see a 150 m^2 bald patch is startling. But the larger question remains; what percentage of the total cultivated land area in Delta is affected by excessive nutrients and salinity from field stored poultry litter? In this research the three stored manure piles were located on two fields with a total area of approximately 36 ha. The maximum footprint of these piles, including a 1 m halo of run-off around each pile, totaled 0.19 ha, which is equivalent to 0.5% of the cultivated land area over which the stored manure was spread.

From the above assessment it is clear that though the visual affects of the stored manure on the soil are dramatic, the overall affects in terms of crop production are small. It is likely then, that the most significant impact that these piles have on the surrounding environment is through direct contact with wildlife, and run-off and leachate waters which travel either over-land or as subsurface flow eventually reaching groundwater, ditches, streams, and coastal waters. On the south and west sides of the Fraser Delta lies an internationally important estuary. It is the largest estuary on the Pacific coast of North America, home to millions of waterfowl, shore birds, and birds of prey, and it is an important crossroads on the Pacific flyway where migratory birds from three continents converge (British Columbia Waterfowl Society 2006). Protecting these waters from pollutants from agricultural practices is of the utmost importance. Furthermore, ensuring that wild birds do not congregate on manure piles for warmth or feeding purposes is critical.

4.6.1 Beneficial management practices

- Store poultry litter in a different location on a given field each year to avoid long term damage to soil quality, and to avoid saturation of the soil P and heavy metal retention capacities as well as the capacity to retain other chemicals such as anti-microbial compounds and hormones.
- If possible, store poultry litter on a slightly elevated place on the field to avoid pooling of water. Low spots should be avoided.
- Store poultry litter on an YTC base pad of at least 30 cm, or preferably 45 cm thickness, in order to protect soil and water quality from leaching due to water table rise, as well as to mitigate some of the negative effects on the soil under the highly leached wet outer regions of the pile.
- Thoroughly mix the YTC base pad and cover in with the poultry litter prior to field application in order to ensure even application of the nutrients retained by the YTC base pad for crop production, and also to amend the soil with organic matter.
- Cover field stored poultry litter with a 15 cm thick layer of YTC to protect wildlife such as, migratory birds, coyotes, and rodents from pathogens and anti-microbial

compounds present in the poultry litter. The cover also insulates the pile, thus leading to pathogen reduction and increased food safety.

- If possible, pre-compost the poultry litter off-site to create a more stable product for over-winter storage.

4.7 Assessment of thesis research

4.7.1 Strengths of research

One of the clear strengths of this thesis was the combination of a controlled experiment and an on-farm field study. Although the experimental design in the field study did not permit a precise statistical model for comparing the piles, the study was nonetheless very informative in terms of comparing the processes observed in the column study to a practical situation. The column study provided a controlled setting in which to examine precise concentrations of nutrients and metals present in the leachate. This allowed for detailed analysis of the effects of the YTC cover and base pad on the quality of leachate emanating from the poultry litter. Detecting increases in metal or P concentrations in soils under poultry litter piles was troublesome due to the variable background levels of these elements. The variability of nutrients measured within the YTC base pad at the end of the storage period was also very large. Therefore, determining if the YTC base pad retained metals or P based on the field stored poultry litter piles was inconclusive. However, from the column study it is logical to assume that the leachate and run-off waters leaving Pile 1, which was built on an YTC base pad, had lower P, Cu and Zn concentrations than those leaving the other two piles which lacked YTC base pads.

4.7.2 Weaknesses of research

The most obvious weakness of this research was the lack of replication in the field pile treatments. Ideally Piles 1 and 2 would have been comprised of the same poultry litter materials. Fully half of both piles would have been covered with YTC and the other half would have been left uncovered. This would have provided four distinct yet comparable treatments. Two replications each of these piles on other fields would have provided four clear treatments with three replications. This however was not possible due to the quantity of manure required by the participating farmer, the variable sizes of his fields, and the requirement to compost some of the manure due to certain fields being under certified organic production. Sample replication was useful for indicating the variability within each pile. This variability was often very large, especially when sampling the YTC base pad material. This indicated that true replication was needed in order to make broad conclusions.

Some of the variability in sampling the YTC base pad might have been mitigated through a different sampling protocol. For sampling, an excavator made a large cut in the pile from the apex to the soil surface and out to one side. This provided two walls from which to scrape the desired layer. The YTC base pad was extremely compacted and difficult to sample, and thus the actual sample collected might have been biased towards the more easily removed sections. For sampling the YTC base pad, it would have been preferable to have the excavator scrape off the stored poultry litter, leaving the base pad exposed. Then a 30 cm deep core of the YTC base pad could have been collected in each of the desired sampling locations. This would have been a more precise sampling method.

Another weakness of the research was the lack of soil microbial analyses. It would have been useful to know whether the soil microbial ecosystem was affected by the stored poultry litter, and if these effects were mitigated by the presence of the YTC base pad and/or cover.

4.7.3 Status of hypotheses and current state knowledge

The first hypothesis listed in the introductory chapter regarding the YTC base pad "sorbing metals, salts, and nutrients being leached from the poultry litter layers above" has been confirmed to some degree. The column study proved that the YTC base pad retains Cu, Zn and some P. The determination of the CEC of the YTC material in the laboratory (equal to 57.5 cmolc kg^{-1} dry YTC), combined with the Ca and Mg leaching dynamics in the column study proved that cation exchange was an integral part of the metal retention. Salts and N were not retained by the YTC base pad, however the base pad did serve to moderate their concentrations in the leachate by decreasing the initially very high concentrations and releasing them more slowly over time.

The second hypothesis stated that "the soil directly underneath the poultry litter storage piles lacking an YTC base pad will be degraded and crop growth the following spring will be stunted, as compared to the rest of the field and to the site where the poultry litter storage pile was built on an YTC base pad". This was partially incorrect. The soil below each of the piles was degraded and crop growth was affected the following summer, including under Pile 1 which was built entirely on a 30 cm thick YTC base pad. However, the crop health under Pile 1 was more variable than under the other piles, with some regions showing negative effects and other regions showing lush growth.

The final hypothesis referred to the soil surrounding the YTC covered sections being less affected by nutrients and salinity than the soil surrounding the uncovered sections. This was observed in both Piles 1 and 2 however the increases in soil nutrients beside the uncovered sections were not always significantly higher than those beside the covered sections. Crop development around the covered sections of Pile 1 was clearly improved as compared to the crop development around the uncovered sections of that pile. The increased infiltration and thus leaching caused by the YTC cover was not predicted, but it served to decrease run-off and thus protect the soil surrounding the piles.

4.8 Suggestions for future research

The suggestions for future research can be grouped into five sections: 1) assessment of a thicker YTC base pad, 2) assessment of an YTC berm, 3) assessment of a flat-topped pile, 4) application of a lime layer to the YTC base pad, and 5) effects of field stored poultry litter on the soil microbial community. The assessment of a thicker YTC base pad would be best accomplished in the field, through the comparison of a few piles with no base pad, 30 cm thick and 45 cm thick pads. The assessment of the YTC berm could be carried out around a cement manure storage pad as well as around a field stored poultry litter pile with or without an YTC base pad. Collection of leachate and run-off samples in the field would be required. The assessment of a flat-topped pile would need to be carried out in the field. Two flat-topped treatments, one with an YTC cover and one with no cover, as well as two piles of triangular cross-section, one with an YTC cover and one with no cover, could be compared. Piles of equal mass would be a necessity. Nutrients found in soil samples under and around the piles could be used as indicators of leaching and run-off. The application of lime to the YTC base pad could be studied in a column experiment in order to closely observe the leaching dynamics. This might also give indications as to the quantity of lime required to be effective. A complimentary or subsequent field study would also be required. An analysis of the soil microbial communities using phospholipid fatty acid profiling (PLFA) under and around some poultry litter piles in the fall, spring, summer and following fall could give an indication of the effects that the stored poultry litter had on the soil microbes and the length of time required for these communities to recover. PLFA provides the structure of the microbial community in proportions of fungi, gram positive bacteria, gram negative bacteria, and actinomycetes.

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Appendix A: Column construction

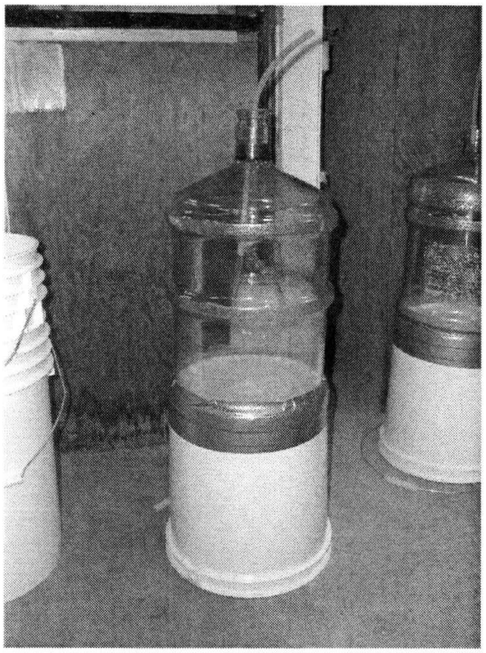

Figure A.1 Photo of upside down column showing the amber tubing used for leachate collection, and the air inlet loop inside the jug.

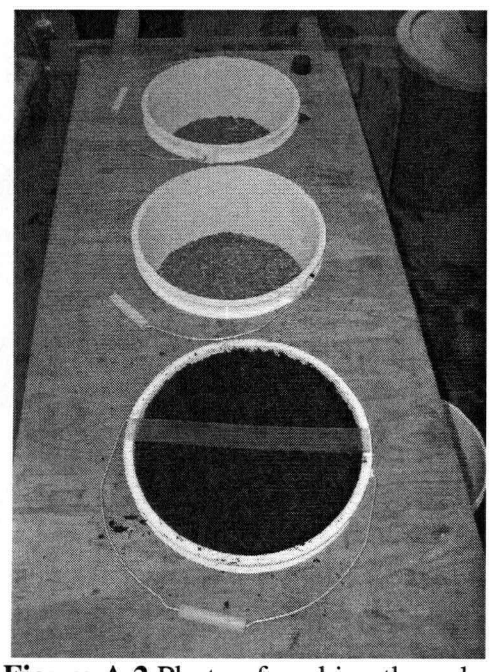

Figure A.2 Photo of packing the columns.
The light brown layer is the poultry litter and the dark brown is the YTC.

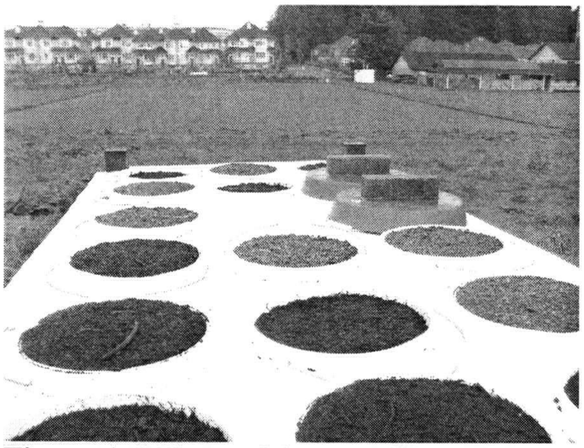

Figure A.3 Photo of the top of the column table at Totem field, UBC, Vancouver. Dark brown circles are treatments in which the YTC is on top. Light brown circles are treatments where the poultry litter is on top. The two green lids are sandwich treatments that were covered for the duration of the experiment. The data was not used in this thesis.

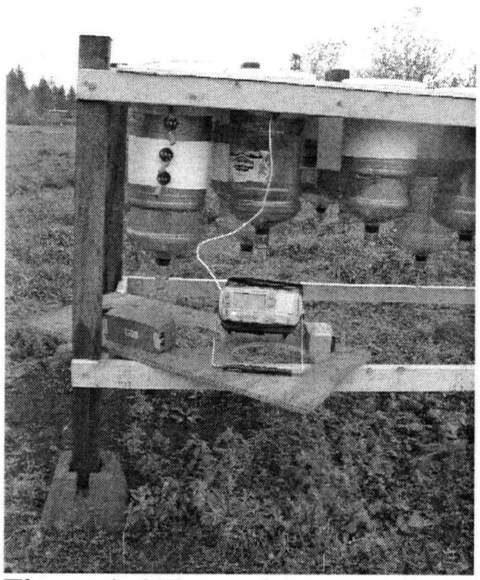

Figure A.4 Photo of the two columns used for TDR data collection. The probes were left in place for the duration of the experiment and the TDR instrument was brought out regularly for readings. The treatment on the far left was a sandwich treatment, and the treatment on the right was a PL alone treatment.

Appendix B: Time domain reflectrometry data

Table B.1 Descriptions of locations of TDR probes in columns

Probe no.	Column	Description
1	S	34 cm below column surface, i.e. 6 cm into YTC base pad layer
2	S	26 cm below column surface, i.e. 12 cm into PL layer
3	S	16 cm below column surface, i.e. 2 cm into PL layer
4	S	8 cm below column surface, i.e. 8 cm into YTC cover layer
5	PL	12 cm into PL
6	PL	5 cm into PL

Table B.2 Raw data from TDR measurements over column study

Date	Probe 1	Probe 2	Probe 3	Probe 4	Probe 5	Probe 6
			Ka[z]			
11/8/2005	12.66	3.94	3.1	5.22	2.36	2.36
11/10/2005	11.36	4.09	4.09	6.11	2.03	2.2
11/15/2005	11.36	3.94	5.04	9.2	2.13	7.07
11/18/2005	12.13	4.56	10.62	9.66	2.24	N/A
11/24/2005	14.9	4.4	N/A	10.9	2.02	N/A
12/1/2005	16.97	9.66	N/A	12.66	N/A	N/A
12/5/2005	20.2	16.97	N/A	14.03	N/A	N/A
12/12/2005	N/A	16.97	N/A	10.9	N/A	N/A
1/3/2006	N/A	N/A	23.7	8.98	N/A	N/A
1/18/2006	N/A	N/A	25.56	16.97	N/A	17.91
2/1/2006	N/A	18.55	23.7	8.43	31.56	14.88
2/14/2006	N/A	17.28	20.2	14.03	27.49	14.03
2/24/2006	N/A	16.36	18.55	6.49	20.2	13.47

[z]Ka – apparent dielectric constant, no units.

Appendix C: Column study data

Table C.1 Total solids content, EC and pH of leachates.

Treatment Name	Sample Date	Precipitation	Replicate	Leachate Volume	TSS	Ash	DOM	Ash	Volatile Fraction	EC	pH
		(mm)		(mL)	(mg L^{-1})			(%)		(dS m^{-1})	
YTC	Nov-15	41.4	1	582	12500	9000	3500	64	36	10	7.2
YTC	Nov-15	41.4	2	613	14000	8500	5500	61	39	11	7.1
YTC	Nov-15	41.4	3	454	14000	8500	5500	55	45	11	7.1
YTC	Dec-05	77.2	1	1150	12000	4500	7500	38	62	10	7.2
YTC	Dec-05	77.2	2	1300	13500	5000	8500	37	63	12	7.2
YTC	Dec-05	77.2	3	1220	13500	5500	8000	41	59	12	7.1
PL	Dec-05	77.2	1	712	38000	20500	17500	54	46	48	8.1
PL	Dec-05	77.2	2	720	20500	11500	9000	56	44	32	8.2
PL	Dec-05	77.2	3	460	29500	16500	13000	56	44	42	8.1
YTC	Dec-20	106.2	1	1680	6333	4333	2000	68	32	6.5	7.7
YTC	Dec-20	106.2	2	1655	7667	5000	2667	65	35	6.4	7.8
YTC	Dec-20	106.2	3	1650	9000	6000	3000	67	33	6.8	7.6
YTC/PL	Dec-20	106.2	1	1795	19500	10000	9500	58	42	35	7.7
YTC/PL	Dec-20	106.2	2	1443	21000	11000	10000	63	37	37	7.7
YTC/PL	Dec-20	106.2	3	1520	30000	14500	15500	57	43	42	7.7
PL/YTC	Dec-20	106.2	1	597	16500	10500	6000	51	49	21	7.0
PL/YTC	Dec-20	106.2	2	1024	15000	10000	5000	52	48	21	7.0
PL/YTC	Dec-20	106.2	3	928	18000	11000	7000	48	52	21	7.0
YTC/PL/YTC	Dec-20	106.2	1	1223	25000	14500	10500	64	36	34	7.6
YTC/PL/YTC	Dec-20	106.2	2	1022	20000	12500	7500	67	33	27	7.6
YTC/PL/YTC	Dec-20	106.2	3	1210	21000	12000	9000	61	39	30	7.7
YTC	Jan 3/4	245	1	10600	3333	1667	1666	50	50	2.9	7.2
YTC	Jan 3/4	245	2	10260	4000	2333	1667	58	42	2.7	7.2
YTC	Jan 3/4	245	3	10450	3333	2000	1333	60	40	3.0	7.0
PL	Jan 3/4	245	1	9775	8500	4000	4500	61	39	20	7.4
PL	Jan 3/4	245	2	8415	16500	8000	8500	68	32	21	7.8

Treatment Name	Sample Date	Precipitation (mm)	Replicate	Leachate Volume (mL)	TSS (mg L^{-1})	Ash (mg L^{-1})	DOM (mg L^{-1})	Ash (%)	Volatile Fraction (%)	EC (dS m^{-1})	pH
PL	Jan 3/4	245	3	9500	12500	6500	6000	68	32	25	7.6
YTC/PL	Jan 3/4	245	1	8355	17000	7500	9500	47	53	25	7.2
YTC/PL	Jan 3/4	245	2	10400	17000	8000	9000	49	52	24	7.1
YTC/PL	Jan 3/4	245	3	9080	12000	6000	6000	52	48	24	7.2
PL/YTC	Jan 3/4	245	1	8220	17000	11000	6000	65	35	21	7.4
PL/YTC	Jan 3/4	245	2	10430	15500	10500	5000	68	32	22	7.2
PL/YTC	Jan 3/4	245	3	7610	18000	12500	5500	69	31	23	8.1
YTC/PL/YTC	Jan 3/4	245	1	7930	15500	9500	6000	44	56	22	7.6
YTC/PL/YTC	Jan 3/4	245	2	7265	15500	10500	5000	47	53	24	7.4
YTC/PL/YTC	Jan 3/4	245	3	7795	19000	1300	17700	50	50	26	7.6
YTC	Jan 11/06	344.6	1	8190	1667	1000	667	60	40	1.7	7.5
YTC	Jan 11/06	344.6	2	8050	1000	333	667	33	67	1.2	7.4
YTC	Jan 11/06	344.6	3	8295	1000	333	667	33	67	1.5	7.4
PL	Jan 11/06	344.6	1	7710	5000	2000	3000	40	60	2.8	7.3
PL	Jan 11/06	344.6	2	7005	3500	1500	2000	43	57	6.0	8.0
PL	Jan 11/06	344.6	3	8270	5000	2000	3000	40	60	6.0	7.8
YTC/PL	Jan 11/06	344.6	1	7740	6667	3000	3667	62	39	4.8	7.5
YTC/PL	Jan 11/06	344.6	2	7750	4667	2000	2667	59	41	3.6	7.3
YTC/PL	Jan 11/06	344.6	3	6980	7333	3000	4333	57	44	7.5	7.7
PL/YTC	Jan 11/06	344.6	1	7350	8333	4667	3666	56	44	17	7.7
PL/YTC	Jan 11/06	344.6	2	7328	7000	3834	3166	55	45	17	7.8
PL/YTC	Jan 11/06	344.6	3	7305	5667	3000	2667	53	47	17	7.8
YTC/PL/YTC	Jan 11/06	344.6	1	7180	6500	4000	2500	45	55	16	7.5
YTC/PL/YTC	Jan 11/06	344.6	2	7400	11000	6500	4500	43	57	17	7.7
YTC/PL/YTC	Jan 11/06	344.6	3	7690	11500	6500	5000	41	59	14	7.8
YTC	Jan 18/06	418.2	1	4840	1000	500	500	50	50	0.9	7.0
YTC	Jan 18/06	418.2	2	4765	750	500	250	67	33	1.0	7.0
YTC	Jan 18/06	418.2	3	4940	750	500	250	67	33	0.9	7.0
PL	Jan 18/06	418.2	1	4610	750	250	500	33	67	1.6	7.0
PL	Jan 18/06	418.2	2	4180	1250	500	750	40	60	1.8	7.4

Treatment Name	Sample Date	Precipitation (mm)	Replicate	Leachate Volume (mL)	TSS	Ash (mg L^{-1})	DOM	Ash	Volatile Fraction (%)	EC (dS m^{-1})	pH
PL	Jan 18/06	418.2	3	4750	1000	250	750	25	75	1.6	7.1
YTC/PL	Jan 18/06	418.2	1	5080	2333	1333	1000	57	43	7.3	7.4
YTC/PL	Jan 18/06	418.2	2	5005	2000	1000	1000	50	50	16	7.4
YTC/PL	Jan 18/06	418.2	3	4540	3667	1667	2000	46	55	8.0	7.4
PL/YTC	Jan 18/06	418.2	1	4900	3667	1667	2000	46	55	5.8	7.7
PL/YTC	Jan 18/06	418.2	2	5160	2667	1333	1334	50	50	4.3	7.6
PL/YTC	Jan 18/06	418.2	3	4890	3000	1000	2000	33	67	5.0	7.6
YTC/PL/YTC	Jan 18/06	418.2	1	4840	5667	3667	2000	65	35	3.4	7.3
YTC/PL/YTC	Jan 18/06	418.2	2	4900	7000	4333	2667	62	38	2.5	7.2
YTC/PL/YTC	Jan 18/06	418.2	3	5240	5000	3000	2000	60	40	4.4	7.4
YTC	Feb. 1/06	515.2	1	7595	750	375	375	50	50	0.8	7.0
YTC	Feb. 1/06	515.2	2	7350	500	250	250	50	50	0.9	7.0
YTC	Feb. 1/06	515.2	3	7880	750	375	375	50	50	0.7	7.1
PL	Feb. 1/06	515.2	1	7890	1000	500	500	50	50	1.2	7.2
PL	Feb. 1/06	515.2	2	7090	1500	750	750	50	50	1.3	7.6
PL	Feb. 1/06	515.2	3	8005	1250	500	750	40	60	1.2	7.3
YTC/PL	Feb. 1/06	515.2	1	8250	2000	1000	1000	50	50	2.2	7.5
YTC/PL	Feb. 1/06	515.2	2	8300	1750	750	1000	43	57	1.9	7.2
YTC/PL	Feb. 1/06	515.2	3	7595	1750	1000	750	57	43	2.4	7.3
PL/YTC	Feb. 1/06	515.2	1	8250	2000	750	1250	50	50	2.8	7.7
PL/YTC	Feb. 1/06	515.2	2	8730	2000	750	1250	50	50	2.8	7.6
PL/YTC	Feb. 1/06	515.2	3	7875	2333	750	1583	43	57	3.6	7.7
YTC/PL/YTC	Feb. 1/06	515.2	1	7825	4000	1250	2750	42	58	4.3	7.6
YTC/PL/YTC	Feb. 1/06	515.2	2	7995	3667	1500	2167	55	45	6.0	7.6
YTC/PL/YTC	Feb. 1/06	515.2	3	7815	4000	1500	2500	50	50	5.0	7.8
YTC	Feb. 14/06	554.2	1	2160	600	300	300	50	50	0.8	7.4
YTC	Feb. 14/06	554.2	2	2130	700	400	300	57	43	0.9	7.3
YTC	Feb. 14/06	554.2	3	2115	700	400	300	57	43	0.7	7.4
PL	Feb. 14/06	554.2	1	2180	1100	600	500	55	46	1.1	7.3
PL	Feb. 14/06	554.2	2	2005	800	400	400	50	50	1.3	7.6

Treatment Name	Sample Date	Precipitation (mm)	Replicate	Leachate Volume (mL)	TSS (mg L^{-1})	Ash (mg L^{-1})	DOM (mg L^{-1})	Ash (%)	Volatile Fraction (%)	EC (dS m^{-1})	pH
PL	Feb. 14/06	554.2	3	2125	900	500	400	56	44	1.2	7.4
YTC/PL	Feb. 14/06	554.2	1	2755	1250	750	500	60	40	1.5	7.4
YTC/PL	Feb. 14/06	554.2	2	2490	1500	750	750	50	50	1.7	7.4
YTC/PL	Feb. 14/06	554.2	3	2405	1500	750	750	50	50	2.1	7.5
PL/YTC	Feb. 14/06	554.2	1	2650	1750	750	1000	43	57	2.8	7.5
PL/YTC	Feb. 14/06	554.2	2	2560	2000	1000	1000	50	50	2.7	7.5
PL/YTC	Feb. 14/06	554.2	3	2610	2250	1000	1250	44	56	3.3	7.5
YTC/PL/YTC	Feb. 14/06	554.2	1	3045	3500	1750	1750	50	50	4.5	7.5
YTC/PL/YTC	Feb. 14/06	554.2	2	3000	2500	1250	1250	50	50	3.6	7.3
YTC/PL/YTC	Feb. 14/06	554.2	3	3005	3500	2000	1500	57	43	4.7	7.6
YTC	Mar. 15/06	628.6	1	3520	700	400	300	57	43	0.8	7.0
YTC	Mar. 15/06	628.6	2	3575	800	500	300	63	38	0.7	7.2
YTC	Mar. 15/06	628.6	3	3720	600	500	100	67	33	0.6	7.5
PL	Mar. 15/06	628.6	1	3385	1100	500	600	45	55	1.0	7.8
PL	Mar. 15/06	628.6	2	2972	1100	500	600	45	55	1.2	8.0
PL	Mar. 15/06	628.6	3	3178.5	1100	500	600	45	55	1.1	7.9
YTC/PL	Mar. 15/06	628.6	1	3925	1400	800	600	57	43	1.9	7.7
YTC/PL	Mar. 15/06	628.6	2	3880	1500	800	700	53	47	1.8	7.2
YTC/PL	Mar. 15/06	628.6	3	3325	1400	700	700	50	50	1.8	8.0
PL/YTC	Mar. 15/06	628.6	1	3745	1750	1000	750	57	43	2.6	7.4
PL/YTC	Mar. 15/06	628.6	2	3990	2000	500	1500	25	75	2.4	7.3
PL/YTC	Mar. 15/06	628.6	3	3867.5	2000	750	1250	38	63	2.5	7.2
YTC/PL/YTC	Mar. 15/06	628.6	1	3805	3000	1500	1500	50	50	4.0	8.0
YTC/PL/YTC	Mar. 15/06	628.6	2	3590	2250	1000	1250	44	56	3.5	7.4
YTC/PL/YTC	Mar. 15/06	628.6	3	3697.5	3250	1500	1750	46	54	4.4	8.1
YTC	April 5/06	656.6	1	2160	545	181.8	363.2	33	67	0.7	7.4
YTC	April 5/06	656.6	2	2195	700	300	400	43	57	0.6	7.0
YTC	April 5/06	656.6	3	2275	500	200	300	40	60	0.5	8.0
PL	April 5/06	656.6	1	2243	1200	400	800	33	67	1.4	7.7
PL	April 5/06	656.6	2	1618	1200	400	800	33	67	1.6	8.0

Treatment Name	Sample Date	Precipitation (mm)	Replicate	Leachate Volume (mL)	TSS (mg L^{-1})	Ash (mg L^{-1})	DOM (mg L^{-1})	Ash (%)	Volatile Fraction (%)	EC (dS m^{-1})	pH
PL	April 5/06	656.6	3	2260	1000	200	800	20	80	1.2	7.8
YTC/PL	April 5/06	656.6	1	2615	1200	700	500	58	42	1.4	7.7
YTC/PL	April 5/06	656.6	2	2610	1500	900	600	60	40	1.8	7.2
YTC/PL	April 5/06	656.6	3	2155	1600	700	900	44	56	2.0	7.6
PL/YTC	April 5/06	656.6	1	2630	2750	1000	1750	36	64	2.9	6.9
PL/YTC	April 5/06	656.6	2	2675	2000	1000	1000	50	50	2.4	6.5
PL/YTC	April 5/06	656.6	3	2727	2500	1250	1250	50	50	2.9	6.6
YTC/PL/YTC	April 5/06	656.6	1	2652	3500	2250	1250	64	36	4.4	7.6
YTC/PL/YTC	April 5/06	656.6	2	2670	2250	1250	1000	56	44	3.8	7.4
YTC/PL/YTC	April 5/06	656.6	3	2950	3250	2250	1000	69	31	4.4	7.2

Numbers in orange were averaged due to missing data (ie. leaked columns, lost samples) or anomalous values.

Table C.2 Concentrations of nutrients in leachates.

Treatment Name	Sample Date	Total N	Nitrate	Nitrite	Ammonium	Kjedahl N	Organic N	Diss. P	Ortho-P	Total P	TOC	COD	BOD
		(mg L^{-1})											
YTC	Nov-15	752	0	4	252		497	8.0	6.0	34.1	2650	10400	1910
YTC	Nov-15												
YTC	Nov-15												
YTC	Dec-05	593	0	0	176	590	417	7.8	5.0	24.6			
YTC	Dec-05	574	0	0	159	570	415	7.0	5.0	22.7			
YTC	Dec-05	501	0	0	156	500	345	5.7	5.0	22.4			
PL	Dec-05	5190	0	0	2720	5200	2470	497		429	6150	15700	3800
PL	Dec-05												
PL	Dec-05												
YTC	Dec-20	415	0	1.2	83	410	331	5.3	4.0				
YTC	Dec-20	401	0	1	61	400	340	4.9	3.7				
YTC	Dec-20	397	0	1	72	400	324	7.9	6.4				
YTC/PL	Dec-20	4480	0.14	2.3	115	4500	4360	79.0	78.9	330	2980	21900	2710

Treatment Name	Sample Date	Total N	Nitrate	Nitrite	Ammonium	Kjedahl N	Organic N	Diss. P	Ortho-P	Total P	TOC	COD	BOD
		(mg L^{-1})											
YTC/PL	Dec-20												
YTC/PL	Dec-20												
PL/YTC	Dec-20	833	0	1.3	148	830	686	7.7	3.5	41.4	1940	7810	426
PL/YTC	Dec-20												
PL/YTC	Dec-20												
YTC/PL/YTC	Dec-20	2810	0	3	365	2800	2450	5.3	1.5	49.6	2460	17200	1430
YTC/PL/YTC	Dec-20												
YTC/PL/YTC	Dec-20												
YTC	Jan 3/4	155	0.42	2.2	113	150	40	14.7	12.8	18			
YTC	Jan 3/4	158	0.51	2.2	111	160	44	14.5	11.8	18			
YTC	Jan 3/4	205	0.57	2.2	109	200	94	18.4	15.0	18			
PL	Jan 3/4	3250	0.82	3.1	2500	3200	745	365	345	342			
PL	Jan 3/4	2640	0.66	2.6	1780	4100	857	317	283	342			
PL	Jan 3/4	2030	0.42	2.4	1530	2000	502	246	241	342			
YTC/PL	Jan 3/4	3660	0.41	3	1990	3700	1670	308	263	323			
YTC/PL	Jan 3/4	2880	0	2.6	2190	2900	687	339	305	323			
YTC/PL	Jan 3/4	3030	0.46	2.5	2090	3000	937	246	159	323			
PL/YTC	Jan 3/4	1760	0.6	2.6	1160	2900	597	42.7	19.9	47			
PL/YTC	Jan 3/4	1660	0.21	2.6	1485	1700	172	32.5	22.1	47			
PL/YTC	Jan 3/4	1860	0.09	2.6	1810	1900	47	29.4	16.5	47			
YTC/PL/YTC	Jan 3/4	1680	1.32	2.3	1090	1700	589	73.0	86.0	76			
YTC/PL/YTC	Jan 3/4	2160	0.86	2.8	1570	2200	587	77.0	58.0	76			
YTC/PL/YTC	Jan 3/4	1940	1.32	2.2	1079	1900	868	37.1	24.8	76			
YTC	Jan 11/06	116	0	0.7	92	120	25	14	15.6	17			
YTC	Jan 11/06	109	0	0.5	106	110	2	13	14.5	16			
YTC	Jan 11/06	81	4.76	0	83	76	0	15	16.1	18			
PL	Jan 11/06	872	0	0.7	808	650	63	153	157	181			
PL	Jan 11/06	890	0	0.9	827	890	63	164	159	190			
PL	Jan 11/06	854	0	0.7	789	850	65	179	173	201			
YTC/PL	Jan 11/06	827	0	1	772	830	56	151	147	184			

Treatment Name	Sample Date	Total N	Nitrate	Nitrite	Ammonium	Kjedahl N	Organic N	Diss. P	Ortho-P	Total P	TOC	COD	BOD
							(mg L^{-1})						
YTC/PL	Jan 11/06	581	0	0.8	412	580	168	164	152	187			
YTC/PL	Jan 11/06	1410	0	1.4	1040	1400	367	218	202	253			
PL/YTC	Jan 11/06	1280	0	1.1	1090	1300	197	141	135	154			
PL/YTC	Jan 11/06	1400	0	1.1	1012	1400	387	125	117	140			
PL/YTC	Jan 11/06	1520	0	1.1	935	1500	583	108	98	125			
YTC/PL/YTC	Jan 11/06	1110	0	0.9	924	1100	189	67	39.1	99			
YTC/PL/YTC	Jan 11/06	1460	0	1.2	1250	1500	207	86	77	120			
YTC/PL/YTC	Jan 11/06	1440	0	1.2	1100	1400	340	86	79	127			
YTC	Jan 18/06	38	0	0	31	38	7	13	11.5	14			
YTC	Jan 18/06	48	0	0	35	48	13	12	10.9	12			
YTC	Jan 18/06	45	0	0	33	45	12	14	13.1	15			
PL	Jan 18/06	225	0	0	194	230	32	131	115	133			
PL	Jan 18/06	251	0	0	218	250	34	105	95	113			
PL	Jan 18/06	223	0	0	184	220	39	127	115	131			
YTC/PL	Jan 18/06	445	0	0	335	450	110	153	130	151			
YTC/PL	Jan 18/06	317	0	0	240	320	77	150	129	154			
YTC/PL	Jan 18/06	599	0	0	455	600	145	163	148	181			
PL/YTC	Jan 18/06	803	0	0	548	800	256	200	192	224			
PL/YTC	Jan 18/06	628	0	0	485	630	143	276	262	276			
PL/YTC	Jan 18/06	762	0	0.8	604	760	158	202	192	215			
YTC/PL/YTC	Jan 18/06	846	0	0	740	850	106	113	101	142			
YTC/PL/YTC	Jan 18/06	1130	0	0.8	970	1100	155	149	136	172			
YTC/PL/YTC	Jan 18/06	987	0	0.7	920	990	67	175	163	185			
YTC	Feb. 1/06	47	5.45	3.1	18	39	21	8	8.3	8.1			
YTC	Feb. 1/06	43	2.73	1.1	33	39	6	8.8	8.8	8.6			
YTC	Feb. 1/06	36	0	0.7	28	36	8	9.8	10	9.8			
PL	Feb. 1/06	153	0	0	116	150	37	98	98	93			
PL	Feb. 1/06	182	0	0	138	180	44	68	75	70			
PL	Feb. 1/06	190	0	0	107	6	83	91	90	90			
YTC/PL	Feb. 1/06	232	0	0	163	230	69	93	91	127			

Treatment Name	Sample Date	Total N	Nitrate	Nitrite	Ammonium	Kjedahl N	Organic N	Diss. P	Ortho-P	Total P	TOC	COD	BOD
		(mg L^{-1})											
YTC/PL	Feb. 1/06	223	0	0	143	220	80	87	69	102			
YTC/PL	Feb. 1/06	295	0	0	229	300	67	96	82	98			
PL/YTC	Feb. 1/06	515	0	0.6	438	350	76	142	148	130			
PL/YTC	Feb. 1/06	468	0	0.6	401	470	67	154	168	162			
PL/YTC	Feb. 1/06	561	0	0.7	474	560	87	146	156	143			
YTC/PL/YTC	Feb. 1/06	601	0	0.7	500	600	101	92	98	95			
YTC/PL/YTC	Feb. 1/06	690	0	0.8	532	690	158	151	167	156			
YTC/PL/YTC	Feb. 1/06	783	0	0.7	676	780	108	155	162	151			
YTC	Feb. 14/06	62	9.3	0	17	52	35	7.1	7.1	7.5			
YTC	Feb. 14/06	50	3.4	0	25	47	22	8.6	8.3	13.5			
YTC	Feb. 14/06	41	0	0	25	41	16	9.1	9.2	10.2			
PL	Feb. 14/06	149	0	0	138	150	11	108	91	116			
PL	Feb. 14/06	174	0	0	148	170	26	86	69	80			
PL	Feb. 14/06	136	0	0	116	140	21	98	81	136			
YTC/PL	Feb. 14/06	171	0	0	153	170	18	109	52	89			
YTC/PL	Feb. 14/06	187	0	0	166	190	21	76	42.1	98			
YTC/PL	Feb. 14/06	246	0	0	223	250	24	83	57	96			
PL/YTC	Feb. 14/06	428	0	0	376	430	52	138	142	137			
PL/YTC	Feb. 14/06	414	2.07	0	361	410	51	132	132	135			
PL/YTC	Feb. 14/06	481	0	0	432	480	49	163	162	165			
YTC/PL/YTC	Feb. 14/06	594	0	0	482	590	112	90	81	107			
YTC/PL/YTC	Feb. 14/06	476	0	0	435	480	41	230	127	299			
YTC/PL/YTC	Feb. 14/06	670	0	0	577	670	93	154	141	194			
YTC	Mar. 15/06	98	83.4	0	1.1	14	13	7	6.2	7.4			
YTC	Mar. 15/06	111	78.8	0	3.2	32	29	7.9	6.9	7.6			
YTC	Mar. 15/06	50	35.5	0	0.0	14	14	7.5	6.7	6.1			
PL	Mar. 15/06	173	0	0	96	170	77	47.2	39.4	44			
PL	Mar. 15/06	226	0	0	146	230	80	48.3	39.7	46.2			
PL	Mar. 15/06	200	0	0	121	0	79	0	39.6	45.1			
YTC/PL	Mar. 15/06	254	0	0	165	250	90	49.3	33	46.5			

Treatment Name	Sample Date	Total N	Nitrate	Nitrite	Ammonium	Kjedahl N	Organic N	Diss. P	Ortho-P	Total P	TOC	COD	BOD
							$(mg\ L^{-1})$						
YTC/PL	Mar. 15/06	146	0	0	120	150	26	71	68	87			
YTC/PL	Mar. 15/06	280	0	0	180	280	100	32.2	20.5	31.2			
PL/YTC	Mar. 15/06	513	28.4	46	313	440	126	113	102	105			
PL/YTC	Mar. 15/06	497	46.2	50	264	400	137	120	137	116			
PL/YTC	Mar. 15/06	416	32.5	48	262	260	74	147	135	145			
YTC/PL/YTC	Mar. 15/06	486	6.46	1.2	449	480	30	41.3	40.2	40.9			
YTC/PL/YTC	Mar. 15/06	549	6.61	0.8	415	380	127	99	85	105			
YTC/PL/YTC	Mar. 15/06	612	49.3	37.6	498	520	27	105	90	97			
YTC	April 5/06	67	55.3	0	1.2	12	11	5.6	5.7	5.7			
YTC	April 5/06	70	52.3	0	0.9	18	17	7.1	8	7.1			
YTC	April 5/06	19	2.98	0	1.0	16	15	6	5.2	5.9			
PL	April 5/06	199	0	0	137	200	62	34.1	36.9	35.6			
PL	April 5/06	221	0	0	171	220	50	38.4	40.7	39.3			
PL	April 5/06	196	0	0.7	118	200	78	28.9	31.6	29.6			
YTC/PL	April 5/06	132	0	0	85	130	47	41.3	41.3	47.9			
YTC/PL	April 5/06	147	0	0	80	150	68	67	47.9	106			
YTC/PL	April 5/06	142	0	0	137	140	6	36.2	28.5	51			
PL/YTC	April 5/06	473	53.5	162	217	260	41	112	139	139			
PL/YTC	April 5/06	420	66.8	173	168	180	13	101	111	98			
PL/YTC	April 5/06	493	57.2	197	203	240	36	163	178	163			
YTC/PL/YTC	April 5/06	548	22.4	1.8	412	520	112	42	36.8	53			
YTC/PL/YTC	April 5/06	585	29.6	0.9	414	550	141	61	52	85			
YTC/PL/YTC	April 5/06	753	160	219	308	370	66	105	122	126			

Data was averaged due to missing sample points (ie. leaked columns, lost samples) or anomalous values.
Data was extrapolated (using previous and subsequent data) due to missed analysis by Maxxam Analytics.

Table C.3 Concentrations of metals in leachates.

Treatment Name	Sample Date	K	Na	Ca	Mg	S	Fe	Cu	Zn	Mn	B	Mo	Ni
		(mg L^{-1})											
YTC	15-Nov-05	4220	168	505	228	183	10.4	0.4	1.6	2.3	0.4	0.1	0.2
PL	5-Dec-05	5340	1010	57	5	1070	21.6	25.2	10.5	1.2	3.1	0.9	0.8
YTC/PL	20-Dec-05	4910	757	67	7	749	17.6	17.0	7.1	1.3	2.5	0.7	0.6
PL/YTC	20-Dec-05	4270	218	560	260	349	4.1	1.3	1.0	1.1	0.3	0.1	0.2
YTC/PL/YTC	20-Dec-05	4820	489	485	192	561	10.9	5.7	2.2	1.9	0.7	0.2	0.4
YTC	3-Jan-06	1020	33	91	38	14	2.2	0.1	0.1	0.4	0.3	0	0
PL	3-Jan-06	2300	456	63	4	383	5.8	5.1	3.0	0.4	2.0	0.2	0.3
YTC/PL	3-Jan-06	2730	414	93	8	300	5.5	3.6	2.7	0.7	2.0	0.2	0.2
PL/YTC	3-Jan-06	3370	343	341	117	334	5.3	2.2	0.9	0.8	0.4	0.1	0.2
YTC/PL/YTC	3-Jan-06	3410	342	213	66	286	5.2	1.5	1.0	0.8	0.7	0.1	0.2
YTC	11-Jan-06	343	8	30	13	3	1.3	0	0.1	0.2	0.3	0	0
PL	11-Jan-06	554	118	43	5	67	2.3	2.7	0.9	5.0	1.2	0.1	0.1
YTC/PL	11-Jan-06	1080	146	66	11	111	4.4	3.8	1.6	11.2	1.1	0.1	0.1
PL/YTC	11-Jan-06	1650	259	121	14	198	8.3	2.2	0.9	14.0	0.6	0.2	0.2
YTC/PL/YTC	11-Jan-06	2260	239	181	13	219	5.7	1.7	0.8	13.1	0.8	0.1	0.2
YTC	18-Jan-06	237	4.8	28	12	2	0.7	0	0.1	0.1	0.2	0	0
PL	18-Jan-06	114	30	35	0.18	10	0.6	0.8	0.3	0.2	0.6	0	0
YTC/PL	18-Jan-06	562	61	55	0.37	37	2.4	1.9	0.8	0.4	0.9	0.1	0
PL/YTC	18-Jan-06	701	111	55	0.43	60	5.4	1.0	0.5	0.4	0.8	0.2	0
YTC/PL/YTC	18-Jan-06	1490	166	113	0.54	123	5.6	1.1	0.6	0.5	0.8	0.1	0.2
YTC	1-Feb-06	198	2	41.7	18.9	2	0.4	0	0	0.1	0.3	0	0
PL	1-Feb-06	97	20.4	36.9	28.2	6	0.5	0.5	0.2	0.2	0.4	0	0
YTC/PL	1-Feb-06	321	25.6	67.8	40.6	12	1.3	0.8	0.4	0.4	0.6	0	0
PL/YTC	1-Feb-06	394	63.8	45	9.9	30	4.3	0.5	0.3	0.4	0.8	0	0
YTC/PL/YTC	1-Feb-06	842	88.7	70.6	16.7	54	4.8	0.6	0.4	0.5	0.8	0	0
YTC	14-Feb-06	160	1.7	52.5	23.3	2	0.3	0	0.1	0.2	0.3	0	0
PL	14-Feb-06	79	14.9	41.1	27	5	0.3	0.4	0.2	0.2	0.4	0	0
YTC/PL	14-Feb-06	236	12.8	76.7	31.6	7	0.7	0.3	0.2	0.2	0.5	0	0

Treatment Name	Sample Date	K	Na	Ca	Mg	S	Fe	Cu	Zn	Mn	B	Mo	Ni
		(mg L^{-1})											
PL/YTC	14-Feb-06	343	53.5	43.2	13.5	20	3.3	0.4	0.3	0.4	0.8	0	0
YTC/PL/YTC	14-Feb-06	704	69.7	73.8	20	44	4.8	0.5	0.3	0.5	0.8	0.1	0

Concentrations of cadmium, selenium, and lead were below the detection limits for all samples for each sampling date.

Table C.4 Macro and micro nutrient concentrations of initial YTC packed into columns and YTC layers after leaching.

				-------- Available-------			---Total---												
		Ash	Total C	NH4-N	NO3-N	Bray-P_1	N	P	K	Ca	Mg	Cu	Zn	Fe	Mn	S	Na	pH	EC
Treatment	Rep	(%)		(mg kg^{-1})			(%)					(mg kg^{-1})				(%)			(dS m^{-1})
YTC	1	44	24.7	72	143	1333	2.21	0.36	0.31	1.90	0.25	50	185	8061	294	0.27	0.13	6.4	0.37
YTC	2	41	26.8	68	100	1641	2.28	0.34	0.29	1.84	0.26	55	195	8894	271	0.25	0.15	6.4	0.32
YTC	3	44	28.7	68	49	1436	1.91	0.30	0.29	1.98	0.26	67	191	9574	245	0.26	0.16	6.4	0.28
YPL - Yc	1	42	25.9	84	103	1231	2.04	0.35	0.20	1.67	0.38	52	171	10042	262	0.23	0.13	6.6	0.36
YPL - Yc	2	37	27.2	80	103	1415	2.05	0.35	0.22	1.68	0.31	45	163	8193	273	0.19	0.16	6.6	0.32
YPL - Yc	3	43	23.9	72	104	1600	2.08	0.34	0.24	1.60	0.37	43	154	8849	267	0.19	0.16	6.6	0.38
PLY - Yp	1	45	25.7	792	227	2769	2.22	0.47	0.37	1.53	0.32	95	179	7260	266	0.22	0.18	6.4	1.25
PLY - Yp	2	48	24.3	408	218	3323	2.06	0.41	0.38	1.58	0.46	93	192	8966	253	0.24	0.19	6.2	1.1
PLY - Yp	3	38	31.3	376	209	3323	2.06	0.45	0.36	1.69	0.30	98	194	7911	285	0.21	0.18	6.2	1.0
S - Yc	1	46	30.3	96	166	1231	2.06	0.35	0.33	1.69	0.28	50	182	7219	282	0.25	0.13	6.6	0.43
S - Yc	2	38	29.9	144	118	2031	2.00	0.37	0.32	1.82	0.34	54	174	8654	267	0.18	0.17	6.5	0.38
S - Yc	3	40	26.9	152	132	1785	1.83	0.31	0.30	1.69	0.32	49	154	8157	265	0.17	0.14	6.5	0.37
S - Yp	1	42	30.7	1204	310	2892	2.33	0.54	0.66	1.69	0.37	116	204	7189	300	0.22	0.23	7.2	2.0
S - Yp	2	43	26.6	728	311	3077	1.98	0.45	0.44	2.00	0.38	100	176	9912	295	0.19	0.17	6.5	1.6
S - Yp	3	44	31.4	496	279	3323	1.99	0.43	0.56	1.54	0.41	99	168	8422	254	0.26	0.17	6.4	1.3
Initial	1	43.2	27.00	1300	276	1436	1.91	0.32	1.20	1.90	0.32	51	202	10851	277	0.23	0.09	7.2	2.8
Initial	2	41.8	28.30	1400	300	1436	2.60	0.33	1.35	1.85	0.28	48	174	8785	282	0.26	0.09	7.0	3.0
Initial	3	45.6	24.66	1200	300	1436	1.85	0.30	1.20	1.75	0.27	44	182	9957	278	0.23	0.09	7.1	2.8
Initial	4	49.9	25.18	1100	303	1641	1.90	0.29	1.06	1.83	0.24	44	190	9725	275	0.24	0.10	7.1	2.8

*Yp = YTC base pad, Yc = YTC cover

Table C.5 Macro and micro nutrient concentrations of initial PL packed into columns and PL layers after leaching.

Treatment	Rep	Ash	Total C	Available NH4-N	Available NO3-N	Available Bray-P_1	Total N	Total P	Total K	Total Ca	Total Mg	Total Cu	Total Zn	Total Fe	Total Mn	Total S	Total Na	pH	EC
		%	%	(mg kg^{-1})			(%)					(mg kg^{-1})				(%)			(dS m^{-1})
PL	1	20	36.9	1400	91	10769	2.49	2.41	0.15	4.93	0.61	443	709	1774	798	0.34	0.07	7.1	1.1
PL	2	16	36.8	1200	148	11077	2.43	2.44	0.17	4.92	0.55	470	660	1566	716	0.32	0.17	7.0	1.3
PL	3	17	36.3	1040	127	9538	2.51	2.59	0.12	5.08	0.65	513	748	1786	792	0.31	0.06	7.1	1.2
YPL	1	19	37.3	232	345	10460	2.10	2.45	0.19	3.89	0.70	335	529	1944	648	0.25	0.07	6.5	1.5
YPL	2	17	37.2	344	311	10770	2.02	2.27	0.16	4.41	0.66	376	591	2150	667	0.24	0.06	6.7	1.3
YPL	3	18	37.1	240	364	12000	2.10	2.57	0.23	3.66	0.82	334	528	1940	593	0.25	0.06	6.7	1.4
PLY	1	19	36.8	1240	219	10155	2.32	2.76	0.15	3.97	0.68	320	552	1435	607	0.26	0.07	7.3	1.4
PLY	2	23	35.4	1120	190	10460	2.19	2.28	0.14	3.89	0.73	346	540	3888	583	0.26	0.07	7.1	1.3
PLY	3	17	38.4	1120	150	10155	1.98	1.94	0.10	3.52	0.57	308	527	1319	593	0.33	0.05	7.2	1.3
SPL	1	20	37.4	640	509	11243	2.07	2.94	0.27	4.26	0.73	447	670	1702	755	0.28	0.07	6.8	1.7
SPL	2	16	40.1	408	423	9230	1.75	1.96	0.14	3.60	0.66	350	530	1377	593	0.24	0.05	6.6	1.5
SPL	3	15	39.1	260	426	9846	1.61	1.57	0.12	3.12	0.55	290	473	1290	538	0.23	0.05	6.6	1.4
SDPL	1	18	34.7	3520	421	12310	2.56	2.13	1.68	3.30	0.54	330	469	1173	469	0.46	0.32	7.0	7.5
SDPL	2	19	33.1	3680	379	14460	2.94	2.51	1.63	3.70	0.59	359	490	1307	467	0.53	0.33	6.9	12
Initial	1	19.1	36.0	5400	705	10154	3.64	2.07	1.66	3.30	0.46	375	463	1104	441	0.59	0.35	7.1	12
Initial	2	17.4	34.8	5000	721	9846	3.64	2.24	1.66	3.49	0.51	364	475	1214	419	0.38	0.31	7.2	12
Initial	3	15.5	36.3	4800	745	10461	3.22	2.06	1.65	3.60	0.46	396	451	1101	440	0.54	0.33	7.2	12
Initial	4	13.9	35.8	4600	658	11077	3.47	2.39	1.78	3.89	0.53	407	496	1211	451	0.50	0.33	7.1	12

Appendix D: Sampling Field Piles

Figure D.1 Photograph of excavator cut made for sampling at Pile 1 in the YTC covered section.
The three pegs marked with flagging tape indicate the dry core, wet middle, and wet edge samples. Two such excavator cuts were made in each treatment at each pile.

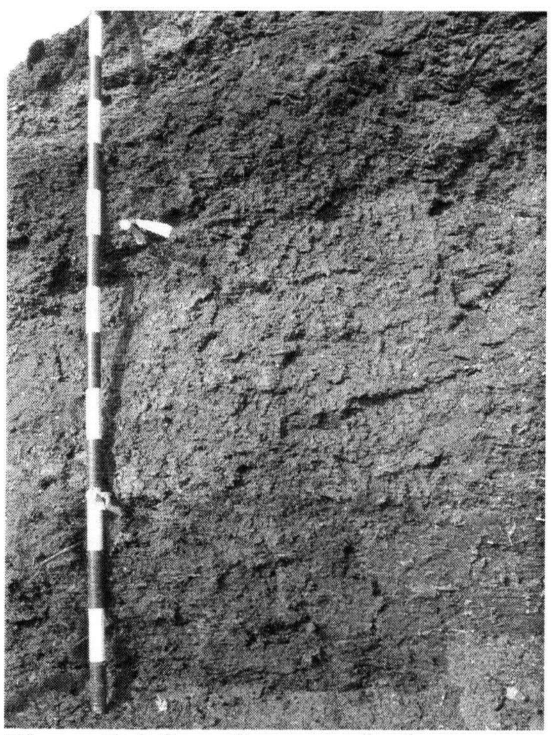

Figure D.2 Sampling spots in the wet outer region of the YTC covered section of Pile 1. Samples were collected from the YTC base pad, wet poultry litter, and YTC cover. Scale: each black bar is 10 cm long.

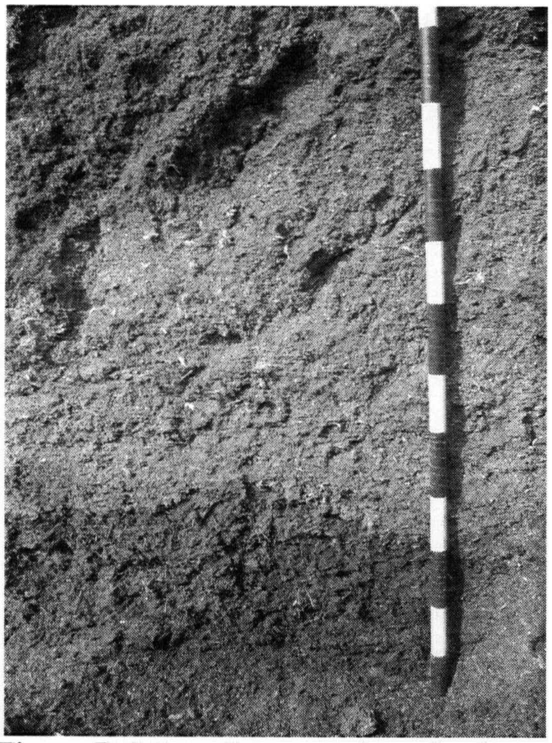

Figure D.3 Sampling spots from the dry core of Pile 1.
Samples were collected from the YTC base pad, dry poultry litter, and wet poultry litter above. Scale: each black bar represents 10 cm.

Appendix E: Field Study Soil Data

Table E.1 Macro and micro nutrients concentrations of soils collected under and around field piles.

Sample	ID*	Depth	NH4-N	NO3-N	Total Available N	P	K	Ca	Mg	Na	Cu	Zn	Fe	Mn	SO-S
			(mg kg^{-1})												
S1	1-C-0-1	0-15cm	246.7	6.4	253.1	123	775	1350	420	60	7.3	13.0	600	42	28
S2	1-C-0-1	15-30cm	170.4	0.0	170.4	87	360	1300	395	65	3.8	5.0	700	26	13
S3	1-C-0-2	0-15cm	48.4	13.3	61.6	195	740	1300	375	55	4.1	14.0	255	28	20
S4	1-C-0-2	15-30cm	8.6	12.7	21.2	103	390	1250	405	40	2.6	8.0	275	16	19
S5	1-C-0-3	0-15cm	226.6	0.2	226.8	113	420	1300	415	60	3.4	8.5	350	30	38
S6	1-C-0-3	15-30cm	170.4	0.0	170.4	179	740	1350	445	65	4.7	13.5	310	37	56
S7	1-C-2-1	0-15cm	3.4	7.4	10.8	210	700	1400	385	35	3.7	15.5	260	32	7.1
S8	1-C-2-1	15-30cm	5.7	8.6	14.3	103	400	1350	375	40	2.2	8.0	290	18	6.8
S9	1-C-2-2	0-15cm	5.0	4.3	9.2	200	720	1400	390	30	5.5	16.5	280	37	5
S10	1-C-2-2	15-30cm	12.0	2.3	14.4	103	420	1200	360	35	2.9	10.0	310	22	13
S11	1-C-2-3	0-15cm	39.3	4.5	43.8	210	640	1850	400	40	2.4	15.5	125	31	8.9
S12	1-C-2-3	15-30cm	5.5	1.6	7.1	92	370	1400	440	50	2.8	8.5	245	19	15
S13	1-C-5-1	0-15cm	3.5	6.8	10.3	185	580	1350	375	40	4.6	14.5	280	27	15
S14	1-C-5-1	15-30cm	3.9	5.3	9.2	97	410	1300	370	35	2.6	7.5	305	13	13.9
S15	1-C-5-2	0-15cm	3.1	15.8	18.9	190	660	1350	405	40	5.5	12.0	355	25	29
S16	1-C-5-2	15-30cm	3.2	17.6	20.8	97	370	1250	410	40	2.3	7.5	295	14	45
S17	1-C-5-3	0-15cm	2.7	16.4	19.1	215	630	1050	290	25	7.6	16.5	300	33	23
S18	1-C-5-3	15-30cm	2.3	19.6	21.9	87	395	1200	430	40	2.6	7.0	285	14	32
S19	1-U-0-1	0-15cm	3.5	7.2	10.7	215	570	1150	305	25	3.9	19.0	300	30	9.3
S20	1-U-0-1	15-30cm	3.7	6.7	10.4	246	755	1250	350	35	4.7	20.0	310	29	17
S21	1-U-0-2	0-15cm	5.4	4.3	9.7	210	680	1350	380	30	5.3	16.5	340	34	8.5
S22	1-U-0-2	15-30cm	75.3	2.4	77.7	179	810	1350	400	40	6.8	17.0	405	41	19
S23	1-U-0-3	0-15cm	2.6	20.8	23.4	200	650	1300	360	30	3.8	16.0	345	26	14
S24	1-U-0-3	15-30cm	6.7	34.0	40.7	200	790	1300	400	50	5.6	19.0	260	35	45
S25	1-U-2-1	0-15cm	179.8	0.9	180.7	149	640	1350	435	55	8.0	14.0	600	48	36
S26	1-U-2-1	15-30cm	154.5	0	154.5	67	490	1150	405	55	3.8	5.0	600	31	14

Sample	ID*	Depth	NH4-N	NO3-N	Total Available N	P	K	Ca	Mg	Na	Cu	Zn	Fe	Mn	SO-S
			$(mg\ kg^{-1})$												
S27	1-U-2-2	0-15cm	161.1	1.0	162.1	190	705	1350	430	45	4.6	15.5	355	43	16
S28	1-U-2-2	15-30cm	174.9	0	174.9	113	730	1150	380	75	6.7	13.0	600	39	21
S29	1-U-2-3	0-15cm	141.9	0.1	142.0	210	1200	1300	420	70	5.5	19.5	330	42	38
S30	1-U-2-3	15-30cm	41.0	0	41.0	164	820	1300	425	75	3.7	17.0	340	31	50
S31	1-U -5-1	0-15cm	2.1	9.4	11.5	152	725	1250	385	60	4.5	15.0	255	27	45
S32	1-U -5-1	15-30cm	1.2	9.0	10.2	52	410	1150	455	75	2.3	6.0	275	11	69
S34	1-U -5-2	0-15cm	1.9	6.4	8.3	110	875	1200	345	60	3.2	11.0	385	20	12
S35	1-U -5-2	15-30cm	0.9	12.4	13.3	43	580	1100	445	90	2.0	5.0	330	9	15
S36	1-U -5-3	0-15cm	43.7	2.0	45.7	171	1110	1200	365	75	6.2	19.0	410	33	33
S37	1-U -5-3	15-30cm	18.7	1.0	19.7	176	790	1200	345	80	4.4	14.5	400	26	54
S38	1-CE-1	0-15cm	944.1	0	944.1	154	600	1150	365	285	10.5	12.5	650	42	68
S39	1-CE-1	15-30cm	286.5	0	286.5	87	730	1150	430	100	5.2	7.0	700	31	14
S40	1-CE-1	30-60cm	60.8	0	60.8	26	285	1550	875	95	3.5	8.0	265	20	22
S41	1-CE-2	0-15cm	193.7	0	193.7	169	780	1400	415	175	6.7	13.5	345	41	28
S42	1-CE-2	15-30cm	140.8	0	140.8	67	550	1350	520	115	2.7	5.5	425	26	37
S43	1-CE-2	30-60cm	14.1	0	14.1	16	190	1200	910	115	4.1	4.5	280	16	39
S44	1-CE-3	0-15cm	166.8	0	166.8	174	1500	1350	460	135	4.7	13.5	335	41	52
S45	1-CE-3	15-30cm	78.7	0	78.7	92	450	1350	565	100	2.8	7.5	295	25	48
S46	1-CE-3	30-60cm	26.9	0	26.9	14	230	1100	940	125	5.4	4.5	310	19	45
S47	1-Cin-1	0-15cm	1115.9	0	1115.9	97	2600	1500	560	380	2.5	11.5	750	44	57
S48	1-Cin-1	15-30cm	242.0	0	242.0	67	425	1200	470	100	3.8	5.5	800	30	13
S49	1-Cin-2	0-15cm	1601.2	0	1601.2	144	535	1050	360	340	5.1	16.0	750	50	52
S50	1-Cin-2	15-30cm	310.6	0	310.6	87	705	1200	435	100	5.6	8.0	650	41	13
S51	1-Cin-3	0-15cm	2216.3	0.7	2217.0	128	2300	1300	310	360	4.7	15.5	650	49	57
S52	1-Cin-3	15-30cm	288.1	0	288.1	87	615	1150	410	80	6.2	9.0	650	41	13
S53	1-CC-1	0-15cm	258.3	0	258.3	113	970	1300	485	60	5.4	10.5	500	44	20
S54	1-CC-1	15-30cm	177.9	0	177.9	77	350	1250	450	45	4.1	6.5	500	34	10
S55	1-CC-2	0-15cm	274.1	0	274.1	113	1000	1350	480	60	7.1	12.5	550	50	24
S56	1-CC-2	15-30cm	172.0	0	172.0	34	380	1250	410	50	6.1	8.0	600	41	11

Sample	ID*	Depth	NH4-N	NO3-N	Total Available N	P	K	Ca	Mg	Na	Cu	Zn	Fe	Mn	SO-S
								(mg kg^{-1})							
S57	1-CC-3	0-15cm	314.7	0	314.7	118	1150	1400	485	65	8.0	13.5	550	51	34
S58	1-CC-3	15-30cm	200.0	0	200.0	97	430	1250	435	50	5.6	8.0	600	40	12
S59	1-UE-1	0-15cm	372.2	0	372.2	100	1200	1250	425	110	5.3	10.5	465	34	14
S60	1-UE-1	15-30cm	220.0	0	220.0	48	690	1100	500	135	2.2	3.5	430	16	34
S61	1-UE-1	30-60cm	11.5	0	11.5										
S62	1-UE-2	0-15cm	1026.6	0	1026.6	110	1800	1000	285	175	5.4	13.5	575	36	47
S63	1-UE-2	15-30cm	489.3	0	489.3	74	1000	1075	415	150	3.9	6.8	530	27	37
S64	1-UE-2	30-60cm	51.3	0	51.3										
S65	1-UE-3	0-15cm	259.5	0	259.5	167	1600	1150	395	110	6.1	17.5	435	37	26
S66	1-UE-3	15-30cm	229.0	0	229.0	110	900	1050	355	90	6.0	11.5	575	27	20
S67	1-UE-3	30-60cm	42.3	0	42.3										
S68	1-Uin-1	0-15cm	533.0	0	533.0	110	1250	1150	365	105	7.7	12.0	675	38	20
S69	1-Uin-1	15-30cm	156.4	0	156.4	44	525	1150	480	95	4.4	4.2	695	25	9
S70	1-Uin-2	0-15cm	815.6	0	815.6	110	1450	1100	360	125	6.0	14.0	675	41	17
S71	1-Uin-2	15-30cm	192.6	0	192.6	62	600	1150	410	85	5.2	6.0	750	26	15
S72	1-Uin-3	0-15cm	1898.2	0	1898.2	152	3050	1100	340	335	6.6	17.5	630	39	68
S73	1-Uin-3	15-30cm	334.2	0	334.2	81	1025	950	470	180	5.8	9.0	650	22	29
S74	1-UC-1	0-15cm	261.2	0	261.2	124	940	1150	415	80	8.8	10.5	650	36	23
S75	1-UC-1	15-30cm	157.4	0	157.4	64	415	1150	380	80	12.5	3.3	600	92	12.3
S76	1-UC-2	0-15cm	263.6	0	263.6	100	1080	1150	370	75	8.7	11.0	690	37	31
S77	1-UC-2	15-30cm	148.8	0	148.8	56	420	1150	480	95	8.8	5.7	550	32	15.6
S78	1-UC-3	0-15cm	278.8	0	278.8	110	1060	1150	395	90	9.1	15.0	680	38	35
S79	1-UC-3	15-30cm	123.8	0	123.8	44	630	1100	500	150	4.5	4.9	550	28	21.3
S80	2-C-0-1	0-15cm	44.5	56.0	100.4	121									
S81	2-C-0-1	15-30cm	110.8	20.9	131.7	68									
S82	2-C-0-2	0-15cm	4.8	14.8	19.5	121									
S83	2-C-0-2	15-30cm	4.5	5.6	10.1	53									
S84	2-C-0-3	0-15cm	2.1	7.4	9.5	121									
S85	2-C-0-3	15-30cm	7.3	1.7	9.0	63									

Sample	ID*	Depth	NH4-N	NO3-N	Total Available N	P	K	Ca	Mg	Na	Cu	Zn	Fe	Mn	SO-S
			(mg kg^{-1})												
S86	2-C-2-1	0-15cm	0.6	24.4	25.0	105									
S87	2-C-2-1	15-30cm	1.0	10.6	11.6	42									
S88	2-C-2-2	0-15cm	12.8	13.5	26.3	121									
S89	2-C-2-2	15-30cm	0.8	21.1	21.8	58									
S90	2-C-2-3	0-15cm	38.9	20.3	59.3	116									
S91	2-C-2-3	15-30cm	6.1	1.9	8.1	63									
S92	2-C-5-1	0-15cm	0.4	9.5	9.9	100									
S93	2-C-5-1	15-30cm	0.7	4.9	5.6	53									
S94	2-C-5-2	0-15cm	1.1	7.1	8.2	100									
S95	2-C-5-2	15-30cm	0.2	6.9	7.1	58									
S96	2-C-5-3	0-15cm	1.0	8.8	9.7	105									
S97	2-C-5-3	15-30cm	0.3	4.7	5.0	53									
S98	2-U-0-1	0-15cm	83.6	51.7	135.2	158									
S99	2-U-0-1	15-30cm	41.5	1.6	43.1	84									
S100	2-U-0-2	0-15cm	376.3	142.4	518.7	200									
S101	2-U-0-2	15-30cm	240.8	3.2	244.0	84									
S102	2-U-0-3	0-15cm	395.1	117.5	512.6	126									
S103	2-U-0-3	15-30cm	299.4	1.8	301.2	74									
S104	2-U-2-1	0-15cm	3.0	5.3	8.2	100									
S105	2-U-2-1	15-30cm	0.7	4.0	4.7	63									
S106	2-U-2-2	0-15cm	1.6	4.6	6.2	100									
S107	2-U-2-2	15-30cm	2.8	1.9	4.7	79									
S108	2-U-2-3	0-15cm	2.4	4.5	7.0	110									
S109	2-U-2-3	15-30cm	5.5	1.5	7.0	63									
S110	2-U-5-1	0-15cm	1.4	5.7	7.1	89									
S111	2-U-5-1	15-30cm	0.3	4.0	4.3	74									
S112	2-U-5-2	0-15cm	0.6	5.7	6.3	105									
S113	2-U-5-2	15-30cm	0.7	3.0	3.6	79									
S114	2-U-5-3	0-15cm	0.7	3.7	4.3	100									

Sample	ID*	Depth	NH4-N	NO3-N	Total Available N	P	K	Ca	Mg	Na	Cu	Zn	Fe	Mn	SO-S
								(mg kg^{-1})							
S115	2-U-5-3	15-30cm	0.5	0	0.5	84									
S116	2-CE-1	0-15cm	928.4	0	928.4	68									
S117	2-CE-1	15-30cm	309.8	0	309.8	39									
S118	2-CE-1	30-60cm	16.0	0	16.0										
S119	2-CE-2	0-15cm	1602.7	0	1602.7	95									
S120	2-CE-2	15-30cm	164.8	0	164.8	58									
S121	2-CE-2	30-60cm	16.5	0	16.5										
S122	2-CE-3	0-15cm	1669.5	0	1669.5	105									
S123	2-CE-3	15-30cm	292.6	0	292.6	74									
S124	2-CE-3	30-60cm	26.0	0	26.0										
S125	2-CC-1	0-15cm	1248.6	0	1248.6	100									
S126	2-CC-1	15-30cm	161.7	0	161.7	58									
S127	2-CC-2	0-15cm	470.7	0	470.7	84									
S128	2-CC-2	15-30cm	58.0	0	58.0	63									
S129	2-CC-3	0-15cm	401.9	0	401.9	84									
S130	2-CC-3	15-30cm	73.1	0	73.1	58									
S131	2-UE-1	0-15cm	2156.1	0	2156.1	142									
S132	2-UE-1	15-30cm	486.8	0	486.8	63									
S133	2-UE-1	30-60cm	26.0	0	26.0										
S134	2-UE-2	0-15cm	873.6	0.3	873.8	121									
S135	2-UE-2	15-30cm	176.8	0	176.8	84									
S136	2-UE-2	30-60cm	36.0	0	36.0										
S137	2-UE-3	0-15cm	2028.3	0	2028.3	137									
S138	2-UE-3	15-30cm	201.9	0	201.9	63									
S139	2-UE-3	30-60cm	33.0	0	33.0										
S140	2-UC-1	0-15cm	2086.4	0	2086.4	100									
S141	2-UC-1	15-30cm	142.0	0	142.0	53									
S142	2-UC-2	0-15cm	734.5	0	734.5	100									
S143	2-UC-2	15-30cm	121.3	0	121.3	74									

Sample	ID*	Depth	NH4-N	NO3-N	Total Available N	P	K	Ca	Mg	Na	Cu	Zn	Fe	Mn	SO-S
								(mg kg^{-1})							
S144	2-UC-3	0-15cm	732.5	0	732.5	84									
S145	2-UC-3	15-30cm	121.0	0	121.0	63									
S146	3-0-1	0-15cm	257.3	10.5	267.8	215									
S147	3-0-1	15-30cm	101.1	0	101.1	118									
S148	3-0-2	0-15cm	519.3	13.5	532.9	241									
S149	3-0-2	15-30cm	44.8	0	44.8	82									
S150	3-0-3	0-15cm	216.7	14.5	231.2	246									
S151	3-0-3	15-30cm	25.4	0	25.4	62									
S152	3-2-1	0-15cm	109.6	0	109.6	185									
S153	3-2-1	15-30cm	21.5	0	21.5	67									
S154	3-2-2	0-15cm	153.0	0	153.0	300									
S155	3-2-2	15-30cm	36.7	0	36.7	82									
S156	3-2-3	0-15cm	364.0	29.7	393.8	210									
S157	3-2-3	15-30cm	82.7	0	82.7	64									
S158	3-5-1	0-15cm	3.8	1.2	5.0	167	315	2000	485	75	3.4	8.5	180	32	32
S159	3-5-1	15-30cm	3.7	0	3.7	114	170	1800	485	75	3.3	7.5	180	28	36
S160	3-5-2	0-15cm	0.6	5.7	6.2	186	290	1950	425	60	3.5	8.5	160	31	17
S161	3-5-2	15-30cm	3.9	0	3.9	114	190	1750	445	70	3.4	7.0	170	28	33
S162	3-5-3	0-15cm	3.6	2.0	5.6	171	305	1750	405	50	3.5	7.5	190	32	11
S163	3-5-3	15-30cm	2.2	0	2.2	62	150	1650	475	55	3.4	6.0	190	24	14
S164	3-E-1	0-15cm	5885.1	0	5885.1	243	2050	1300	390	360	5.6	9.0	690	33	84
S165	3-E-1	15-30cm	368.5	0	368.5	34	360	1400	560	120	5.4	4.5	445	24	10
S166	3-E-1	30-60 cm	60.7	0	60.7	11	145	975	595	90	15.5	4.5	270	13	28
S167	3-E-2	0-15cm	2445.4	0	2445.4	743	3900	900	355	675	4.2	19.0	690	28	185
S168	3-E-2	15-30cm	1406.5	0	1406.5	47	900	1300	555	335	3.5	5.5	480	24	36
S169	3-E-2	30-60 cm	40.6	0	40.6	12	125	1050	680	100	18.0	6.0	335	12	24
S170	3-E-3	0-15cm	4313.6	0	4313.6	357	3100	1200	380	515	4.8	12.0	730	38	101
S171	3-E-3	15-30cm	720.4	0	720.4	37	300	900	300	105	7.7	5.3	680	31	14
S172	3-E-3	30-60 cm	214.8	0	214.8	17	240	1050	560	115	14.5	4.5	300	14	35

Sample	ID*	Depth	NH4-N	NO3-N	Total Available N	P	K	Ca	Mg	Na	Cu	Zn	Fe	Mn	SO-S
			(mg kg^{-1})												
S173	3-C-1	0-15cm	3407.1	0	3407.1	286	1700	950	215	390	4.6	9.0	760	36	66
S174	3-C-1	15-30cm	221.9	0	221.9	71	345	1400	485	140	5.3	5.5	435	26	21
S175	3-C-2	0-15cm	3917.3	0	3917.3	357	3900	1300	330	760	5.1	11.0	750	39	68
S176	3-C-2	15-30cm	5.6	0	5.6	57	255	950	285	80	5.1	5.5	480	25	13
S177	3-C-3	0-15cm	197.7	0	197.7	200	1800	1350	365	385	6.3	9.2	700	37	31
S178	3-C-3	15-30cm	2094.9	0	2094.9	57	185	1400	425	90	5.6	7.0	485	27	14
S179^{z}	4-0-1	0-15cm	0	5.7	5.7	272									
S180	4-0-1	15-30cm	0	0	0										
S181	4-0-2	0-15cm	0.1	1.0	1.1	308									
S182	4-0-2	15-30cm	0	0	0										
S183	4-0-3	0-15cm	0	5.8	5.8	323									
S184	4-0-3	15-30cm	0	0	0										
S185	4-2-1	0-15cm	0	1.9	1.9	272									
S186	4-2-1	15-30cm	0	0	0										
S187	4-2-2	0-15cm	0	0.3	0.3	282									
S188	4-2-2	15-30cm	0	0	0										
S189	4-2-3	0-15cm	0	0.5	0.5	287									
S190	4-2-3	15-30cm	0	0	0										
S191	4-5-1	0-15cm	0	0	0	267									
S192	4-5-1	15-30cm	0	0	0										
S193	4-5-2	0-15cm	0	0.1	0.1	272									
S194	4-5-2	15-30cm	0	0	0										
S195	4-5-3	0-15cm	0	0.7	0.7	333									
S196	4-5-3	15-30cm	0	0	0										
S197	4-E-1	0-15cm	1380.8	68.9	1449.7	297									
S198	4-E-1	15-30cm	349.4	5.2	354.6										
S199	4-E-1	30-60 cm	38.9	0	38.9										
S200	4-E-2	0-15cm	699.7	11.0	710.7	554									
S201	4-E-2	15-30cm	218.6	2.3	221.0										

Sample	ID*	Depth	NH4-N	NO3-N	Total Available N	P	K	Ca	Mg	Na	Cu	Zn	Fe	Mn	SO-S
			(mg kg^{-1})												
S202	4-E-2	30-60 cm	121.0	0	121.0										
S203	4-E-3	0-15cm	492.2	0	492.2	226									
S204	4-E-3	15-30cm	48.3	0	48.3										
S205	4-E-3	30-60 cm	12.7	0	12.7										
S206	4-C-1	0-15cm	2002.3	0	2002.3	133									
S207	4-C-1	15-30cm	97.8	0	97.8										
S208	4-C-2	0-15cm	2787.0	0	2787.0	118									
S209	4-C-2	15-30cm	448.2	0	448.2										
S210	4-C-3	0-15cm	434.0	0	434.0	144									
S211	4-C-3	15-30cm	71.9	0	71.9										
S231	Pile 1 Fall	0-15cm	8.0	77.9	85.9	129	320	600	175	50	4.0	5.5	375	9	68
S232	Pile 1 Fall	15-30cm	4.8	0	4.8	71	240	700	200	45	2.5	6.0	285	11	11
S233	Pile 2 fall	0-15cm	5.5	97.3	102.9	124									
S234	Pile 2 fall	15-30cm	2.3	0	2.3	65									
S235	Pile 3 Fall	0-15cm	11.6	350.2	361.7	181	300	2250	525	95	3.0	9.5	135	33	83
S236	Pile 3 Fall	15-30cm	1.3	0	1.3	86	175	1800	500	90	3.2	7.5	160	26	53
S237	Pile 4 fall	0-15cm	1.5	20.3	21.8	246									
S238	Pile 4 fall	15-30cm	0.3	0	0.3	213									

* First digit indicates the pile number (1-3). For Piles 1 and 2 the first digit is followed by the letter 'C' for YTC covered or 'U' for uncovered. The following letter for all piles indicates 'E' for edge, 'in' for inner, or 'C' for core or if it is a number it indicates the distance away from the pile (0 = beside the pile, 2 = 2.5 m and 5 m away). The final number indicates the replicate number (1-3). Eg. 1-C-2-2 = Pile 1, covered section, 2.5 m away, replicate number 2 or 3-C-1 = Pile 3, core, replicate number 1.

[z]Pile 4 is a case study which was not included in the thesis because it was located on a different soil type, it was not a windrow, and was very small. The data have been included here for future reference.

Appendix F: Field Study YTC and PL Data

Table F.1 Macro and micro nutrient concentrations of initial YTC sampled in the fall and YTC sampled from various locations within Pile 1 after storage.

				-------Available--------			-------------------- Total --------------------												
Sample Location	Rep	Ash	Total C	NH4-N	NO3-N	Bray-P_1	N	P	K	Ca	Mg	Cu	Zn	Fe	Mn	S	Na	pH	EC
		(%)		(mg kg^{-1})			(%)					(mg kg^{-1})				(%)			(dS m^{-1})
1CPE*	1	57	24	104	363	1108	1.42	0.27	0.49	1.99	0.47	50	165	11216	356	0.17	0.19	6.8	1.1
1CPE	2	57	22	52	251	1477	1.35	0.30	0.49	1.91	0.49	53	159	11464	308	0.11	0.23	6.7	0.8
1CPE	3	53	24	52	697	2277	1.68	0.41	0.59	1.81	0.38	65	186	10000	309	0.27	0.29	5.7	2.6
1CPM*	1	45	27	8800	123	4000	2.72	0.66	1.47	1.07	0.26	50	167	7585	243	0.42	0.58	6.0	15
1CPM	2	46	24	880	57	1231	1.50	0.21	0.81	1.58	0.35	46	155	10210	295	0.20	0.26	7.6	2.4
1CPM	3	50	28	2080	100	1600	1.81	0.33	0.99	1.47	0.33	57	150	9873	284	0.25	0.44	8.0	3.0
1CPC*	1	53	28	456	38	1169	1.50	0.25	0.69	1.58	0.36	45	143	9979	284	0.14	0.21	7.4	1.5
1CPC	2	46	26	700	44	1231	1.57	0.26	0.74	1.68	0.35	49	150	11111	325	0.14	0.22	7.5	1.7
1CPC	3	45	25	544	30	923	1.41	0.18	0.64	1.67	0.31	44	146	11250	302	0.13	0.18	7.4	1.5
1CCM*	1	53	22	536	1261	1169	1.51	0.23	0.40	1.59	0.33	50	144	10312	271	0.14	0.20	5.2	2.7
1CCM	2	42	28	88	491	985	1.51	0.24	0.27	1.80	0.32	52	146	6900	254	0.13	0.18	6.3	0.9
1CCM	3	43	28	768	720	2708	1.82	0.64	0.36	2.32	0.41	90	221	8842	389	0.16	0.22	6.8	1.7
1CCT*	1	57	24	52	183	1292	1.43	0.27	0.38	1.70	0.37	58	177	10616	297	0.12	0.20	6.4	0.5
1CCT	2	42	27	136	920	1046	1.74	0.24	0.35	1.69	0.33	45	145	9408	285	0.19	0.17	5.6	2.1
1CCT	3	44	23	56	507	1108	1.44	0.23	0.32	1.70	0.29	47	144	9382	288	0.13	0.14	6.4	0.8
1UPE*	1	60	21	2200	137	1816	1.64	0.33	0.81	1.57	0.34	67	160	10647	270	0.34	0.15	7.2	2.2
1UPE	2	58	22	2200	114	1492	2.19	0.41	0.81	1.46	0.33	67	170	9081	277	0.30	0.15	7.3	1.9
1UPE	3	44	23	200	1100	1816	1.72	0.41	0.70	1.77	0.31	56	202	7188	318	0.23	0.11	5.6	2.4
1UPM*	1	52	26	4600	194	3438	2.04	0.62	1.20	1.05	0.35	132	212	6618	245	0.36	0.19	6.8	6.5
1UPM	2	54	26	880	94	1427	1.56	0.33	1.00	1.46	0.36	75	147	8437	254	0.25	0.15	7.6	2.4
1UPM	3	53	25	640	220	1038	1.57	0.33	0.89	1.57	0.38	54	158	8873	267	0.25	0.14	7.5	2.4
1UPC*	1	47	29	420	97	1038	1.60	0.27	0.78	1.71	0.35	49	256	8742	288	0.21	0.10	7.3	1.5
1UPC	2	52	24	180	80	973	1.36	0.26	0.74	1.68	0.38	51	161	8613	273	0.18	0.10	7.4	1.3

Sample Location	Rep	Ash	Total C	Available NH4-N	Available NO3-N	Available Bray-P_1	Total N	Total P	Total K	Total Ca	Total Mg	Total Cu	Total Zn	Total Fe	Total Mn	Total S	Total Na	pH	EC (dS m^{-1})
		(%)		(mg kg^{-1})			(%)					(mg kg^{-1})				(%)			
1UPC	3	56	23	280	89	973	1.51	0.28	0.70	1.48	0.38	42	148	8792	264	0.20	0.10	7.4	1.2
Initial	1	43	27	1300	276	2092	2.21	0.36	1.39	1.69	0.32	41	161	9388	273	0.30	0.09	7.2	2.8
Initial	2	42	28	1400	300	2123	2.31	0.34	1.43	1.59	0.27	37	157	7856	261	0.33	0.09	7.0	3.0
Initial	3	46	25	1200	300	2000	2.22	0.35	1.33	1.58	0.36	56	158	8544	271	0.27	0.09	7.1	2.8
Initial	4	50	25	1100	303	2123	2.12	0.34	1.29	1.47	0.35	38	164	9539	268	0.28	0.10	7.1	2.8

*Sample location codes: 1 indicates Pile 1 for each sample; CPE = YTC covered section, sample collected from the YTC base pad on the edge; CPM = YTC covered section, sample collected from the YTC base pad in the middle; CPC = YTC covered section, sample collected from the YTC base pad under the core of the pile; CCM = YTC covered section, sample collected from the YTC cover in the middle (eg. halfway up the pile); CCT = YTC covered section, sample collected from the YTC cover at the top of the pile; UPE, UPM and UPC indicate the uncovered section YTC base pad samples collected from the edge, middle and core.

Table F.2 Macro and micro nutrient concentrations of initial poultry litter sampled in the fall and poultry litter after storage sampled from various locations within Piles 1 and 2.

Sample Location*	Rep	Ash	Total C	Available NH4-N	Available NO3-N	Available Bray-P	Total N	Total P	Total K	Total Ca	Total Mg	Total Cu	Total Zn	Total Fe	Total Mn	Total S	Total Na	pH	EC (dS m^{-1})
		(%)		(mg kg^{-1})			(%)					(mg kg^{-1})				(%)			
1C-PLWB	1	16	40	1360	195	7179	2.93	1.96	0.77	2.61	0.83	326	380	761	511	0.35	0.13	7.2	3.3
1C-PLWB	2	15	39	12800	246	7385	4.40	2.21	1.64	2.77	0.63	232	398	885	476	0.50	0.50	6.0	23
1C-PLWB	3	15	41	1280	174	7179	3.21	1.81	0.45	3.32	0.48	257	482	1071	610	0.38	0.97	6.9	2.3
1C-PLWT	1	21	33	4160	1487	15385	3.77	2.69	2.19	3.17	0.82	349	524	1092	568	0.65	0.46	6.5	18
1C-PLWT	2	27	31	2880	790	13846	3.33	3.37	2.03	6.10	1.16	632	854	1663	976	0.53	0.53	6.5	18
1C-PLWT	3	27	30	4400	1077	14461	3.98	3.81	2.26	3.79	1.15	260	530	1353	530	0.80	0.59	6.5	18
1C-PLDC	1	16	38	7120	390	6564	4.35	2.07	1.79	2.64	0.62	327	464	949	475	0.56	0.35	6.2	17
1C-PLDC	2	14	41	3560	174	5538	4.79	1.84	1.39	2.34	0.51	191	404	745	404	0.46	0.40	5.6	12
1C-PLDC	3	13	40	3440	157	5641	4.74	1.98	1.44	2.00	0.52	186	337	632	368	0.45	0.43	5.6	11

Sample Location*	Rep	Ash	Total C	---------Available------ NH4-N	NO3-N	Bray-P	------Total------ N	P	K	Ca	Mg	Cu	Zn	Fe	Mn	S	Na	pH	EC (dS m^{-1})
		(%)		(mg kg^{-1})			(%)					(mg kg^{-1})				(%)			
1U-PLWB	1	15	45	13300	486	5405	5.87	1.85	2.35	2.13	0.47	302	391	1118	360	0.55	0.34	6.0	24
1U-PLWB	2	14	44	14600	371	5189	5.83	1.75	2.23	2.00	0.45	322	433	889	373	0.58	0.37	6.0	25
1U-PLWB	3	20	42	3200	286	5189	4.38	2.96	1.65	3.96	0.84	396	595	1101	771	0.46	0.31	7.2	5.0
1U-PLWT	1	25	36	1620	1200	15892	3.06	3.96	0.37	5.28	1.08	365	899	1634	1024	0.38	0.10	6.4	3.2
1U-PLWT	2	24	38	3300	514	13189	3.97	4.36	1.11	4.75	1.19	287	839	1435	1048	0.44	0.28	7.1	4.4
1U-PLWT	3	24	34	2900	800	11676	3.25	3.25	1.07	4.34	0.86	315	662	1627	792	0.44	0.26	7.0	5.0
1U-PLDC	1	14	43	4100	274	5189	4.77	1.70	1.54	2.37	0.48	313	399	754	431	0.44	0.24	5.5	12
1U-PLDC	2	14	44	3800	231	5405	4.81	1.73	1.60	2.14	0.51	321	406	855	459	0.45	0.27	5.6	11
1U-PLDC	3	15	41	4500	214	6203	5.29	1.90	1.54	2.24	0.51	137	459	962	524	0.43	0.43	5.8	13
1 initial	1	15	38	5000	674	6564	4.89	2.23	1.52	2.28	0.47	174	391	1087	380	0.50	0.42		
1 initial	2	14	40	4200	650	5744	5.33	2.21	1.65	2.48	0.44	131	431	754	402	0.40	0.40		
1 initial	3	15	39	5000	689	5333	5.13	2.11	1.70	2.46	0.46	24	395	962	406	0.38	0.35		
1 initial	4	15	39	3800	639	5744	5.08	2.12	1.50	2.47	0.42	20	387	1075	430	0.43	0.37		
2C-PLWT	1	39	33	2880	1895	7400	3.32	2.76	1.56	4.10	0.71	261	410	3024	551	0.50	0.26	7.0	11
2C-PLWT	2	35	31	3120	2905	10600	3.08	2.75	1.40	4.55	0.58	255	411	3571	476	0.48	0.26	6.5	12
2C-PLWT	3	36	33	1920	2810	8400	3.05	2.31	1.83	4.50	0.74	241	375	4176	482	0.57	0.27	6.8	13
2C-PLWB	1	32	36	1840	347	8400	3.30	3.22	1.85	4.52	0.56	237	418	2753	430	0.43	0.40	7.8	6.4
2C-PLWB	2	45	29	1520	421	7400	2.72	2.21	1.12	5.97	0.58	196	426	6077	544	0.46	0.24	7.6	4.8
2C-PLWB	3	45	32	640	1247	8600	2.70	3.10	0.94	11.4	0.73	302	604	2542	720	0.55	0.22	7.5	4.5
2C-PLDC	1	24	37	4720	179	6400	4.03	2.03	1.44	2.85	0.71	212	316	2321	359	0.42	0.30	5.6	12
2C-PLDC	2	26	40	5360	179	5000	3.93	1.89	1.64	4.71	0.47	223	332	1949	396	0.55	0.29	6.0	16
2C-PLDC	3	26	41	5120	200	5800	3.81	1.91	1.60	4.97	0.47	184	346	1857	400	0.56	0.31	6.2	15
2U-PLWT	1	43	31	400	1698	8400	2.10	2.04	0.39	3.50	0.54	243	403	4237	599	0.26	0.11	5.6	3.4
2U-PLWT	2	34	31	880	3076	11400	2.94	3.43	0.38	3.70	0.72	259	490	2288	588	0.27	0.13	5.8	6.5
2U-PLWT	3	40	36	2960	2801	10000	2.47	3.43	0.25	7.01	0.59	313	531	3822	658	0.24	0.10	6.4	5.5
2U-PLWB	1	38	32	2400	274	8800	3.09	2.67	1.69	5.31	0.55	293	542	4664	607	0.37	0.31	6.7	7.0
2U-PLWB	2	25	34	2000	3000	12200	3.27	3.11	1.58	2.55	0.73	238	340	1915	372	0.41	0.35	5.8	15
2U-PLWB	3	20	30	640	642	8800	2.64	2.54	1.07	2.88	0.82	232	341	1706	352	0.46	0.26	7.0	5.5
2U-PLDC	1	25	37	3360	200	6200	4.43	1.87	1.57	3.90	0.89	190	338	3692	380	0.48	0.28	5.2	12

Sample Location*	Rep	Ash	Total C	NH4-N	NO3-N	Bray-P	N	P	K	Ca	Mg	Cu	Zn	Fe	Mn	S	Na	pH	EC (dS m^{-1})
				---------Available------			---------Total---------												
		(%)		($mg\ kg^{-1}$)			(%)					($mg\ kg^{-1}$)				(%)			
2U-PLDC	2	24	40	4080	210	6200	4.49	1.85	1.65	3.78	0.47	187	347	3046	378	0.50	0.32	5.4	15
2U-PLDC	3	19	40	3600	200	5000	4.30	1.96	1.49	2.87	0.49	226	340	1486	372	0.52	0.37	5.6	15
2 initial	1	23	34	4300	600	4780	3.46	1.95	1.64	4.51	0.45	139	333	1502	424	0.51	0.35		
2 initial	2	24	34	4900	576	4530	4.03	2.04	1.90	4.73	0.52	172	333	1505	435	0.55	0.34		
2 initial	3	29	31	5400	558	4718	3.72	3.00	1.57	5.06	0.51	179	359	2110	485	0.50	0.33		
2 initial	4	32	32	4200	689	4513	3.48	1.83	1.46	2.53	0.52	179	295	6118	454	0.41	0.30		

*Sample location codes: first number indicates Pile 1 or 2; 'C' indicates YTC covered section and 'U' indicates uncovered section; PL indicates poultry litter sample; WB = wet bottom (ie. saturated wet region around bottom of pile); WT = wet top of pile; DC = dry core of pile.