Surface irrigation adapted to the land spreading of dairy farm effluent

by

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ABSTRACT

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SURFACE IRRIGATION ADAPTED TO THE LAND SPREADING OF DAIRY FARM EFFLUENT

An important number of Canadian dairy farms manage their manure as solids and in doing so, must handle large volumes of manure seepages and milk house wastewater (dairy farm effluent-DFE). The present project adapted surface irrigation as a more economical and sustainable method of disposing of this large volume of DFE on cropped land near their storage facility. The experimental surface irrigation system consisted of a gated pipe installed perpendicular to the slope of the field allowing the discharged DFE to run down the slope.

The adaptation of the system and the measurement of its environmental impact were conducted on two dairy farms, A and B, in the region South West of Montréal where their DFE were characterized. In 2003 and 2004, DFE was applied on one of two 0.5 and 0.3ha plots, on each farm, to observe losses through the subsurface drainage system, by means of sampling wells, and effects on soil nutrient levels.

The DFE collected in 2002 and 2003 had a lower nutrient content than that collected in 2004 because of higher precipitations. The DFE generally contained between 150-500 mg/L of TKN, 15 to 40 mg/L of TP and 500 to 700 mg/L of TK.

DFE losses through the subsurface drainage system were observed on both farms during each irrigation test. Nevertheless, outlet losses were observed only when irrigating under wet soil conditions or when applying more than 50mm of DFE. Outlet losses represented at the most 1.2% of the total DFE volume applied and 0.32% of the nutrient and bacterial loads.

Although only 65 to 75% of the soil surface was covered by the applied DFE, the irrigation sessions did provide some additional soil moisture for crops, increasing yield

by 31% in 2004. Once absorbed by the soil, the applied DFE did not increase the soil nutrient level and variability in the presence of crop. Thus, the DFE contributed to the irrigation and fertilization of the plots.

Surface irrigation to spread low nutrient DFE, as compared to the conventional tanker system reduced the application costs from \$3.05/m^3, to \$0.95/m^3.

RESUME

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Un pourcentage important des exploitations laitières canadiennes gèrent le fumier de leur troupeau sous forme solide et doivent donc manipuler en parallèle un volume important d'eaux usées de laiterie et de purin. Le but du présent projet était de d'adapter l'irrigation superficielle à l'épandage des eaux usées sur les terres en culture situées tout près du réservoir d'entreposage de ces mêmes eaux. Dans ce projet, le système expérimental d'irrigation superficielle était constitué d'une pompe sous vide alimentant un tuyau flexible de 100m à 200m de longueur, qui à son tour transférait l'eau usée dans un tuyau d'irrigation perforé de 45m de longueur. Le tuyau d'irrigation était installé perpendiculairement à la pente du champ pour que les eaux usées puissent ruisseler avec la pente du terrain, une fois relâchées.

L'essai du système s'effectuait sur deux fermes laitières de la région du Sud Ouest de Montréal. Sur chaque ferme, A et B, les eaux usées étaient appliquée sur une parcelle mesurant respectivement 0,5 et 0,3ha, et l'impact comparé à une parcelle semblable servant de témoin. Pour débuter, les eaux usées produites par les deux fermes furent caractérisées annuellement et pendant trois ans. Ensuite, et lors d'essai d'application d'eaux usées, les pertes par drainage souterrain furent évaluées à l'aide de puits d'échantillonnage installés sur le système de drainage souterrain de chaque parcelle. Sur la Ferme A, le volume d'eau usée perdu pouvait aussi être mesuré à la sortie du système de drainage souterrain drainant un grand champ comprenant la parcelle irriguée et la parcelle témoin. En 2004, les sols de chaque parcelle furent échantillonnés de façon systématique, et à deux profondeurs, 0-200mm et 200-400mm, avant, pendant et après l'application des eaux usées.

Les eaux usées caractérisées en 2002 et 2003 étaient plus diluées comparativement à celle de 2004, puisque l'hiver 2004 apportait plus de neige. Les eaux usées de la Ferme A étaient plus diluées que celles de la Ferme B parce que la plateforme d'entreposage des fumiers de la Ferme A était relativement plus grande et qu'elle recevait aussi les eaux usées de laiterie.

En 2003 et sur la Ferme A, de 0.04 à 0.5% de l'eau usée appliquée percolait jusqu'au système de drainage souterrain ce qui représentait 0.25% du taux de nutriments et de la charge en bactéries des eaux usées irriguées. Les eaux de drainage prélevées des puits d'échantillonnage contenait 80% du NTK, 40% du PT, 80% du KT et 100% du taux de bactériens des eaux usées irriguées. En 2004 et toujours sur la Ferme A, $4m^3$ d'eau usée furent perdus à la

sortie de drainage souterrain, ce qui représente 1.2% du volume total appliqué et 0.32% des nutriments totales et de la charge bactériennes. En 2004, le sol offrait une meilleure capacité d'infiltration et l'eau de drainage des puits d'échantillonnage contenait 20% de NTK, 15% de PT et 20% de KT contenu dans les eaux usées appliquées.

En 2003 et 2004, sur la Ferme B, les eaux des puits d'échantillonnage contenaient 80% de NTK, 40% de PT et 80% de KT contenu dans les eaux usées appliquées. Le niveau bactérien dans l'eau des puits d'échantillonnage était identique à celui des eaux usées appliquées, sauf pour la dernière session d'irrigation en 2004, où les comptes des coliformes totaux et fécaux étaient 10 fois plus élevés que celui des eaux usées appliquées.

En général, l'application d'eaux usées par irrigation de surface produit peu de perte par drainage souterrain lorsque appliquées sur sol sec et en quantité respectant la capacité d'absorption des eaux du sol.

Pour les deux fermes, l'application d'eau usagée a eu un effet significatif sur le niveau des sols en Mehlich III P et K, à une profondeur de 0-200mm mais non plus profondément. À cette profondeur et sur la parcelle irriguée de la Ferme A, l'application d'eaux usées et la date d'application avaient un effet significatif sur le taux de tous les éléments nutritifs du sol alors que la distance du tuyau d'irrigation n'avait pas d'effet. Sur la Ferme B, l'application d'eaux usées avait un effet significatif sur le pH et le K du sol à une profondeur de 0-200mm, alors que la distance du tuyau d'irrigation n'avait un impact que sur le pH, le Ca et le Mg du sol. La date d'application avait un impact significatif sur le P du sol.

Bien que 65 à 75% de la surface de sol était couverte par les eaux usées irriguées, leur application n'augmentait pas la variabilité du contenu en éléments nutritifs du sol. Néanmoins, la teneur élevée en K des eaux usées exige la rotation de la parcelle d'irrigation sur une base annuelle.

Sur la ferme B et en 2004, l'application d'eau usée augmentait de façon significative le rendement d'une culture de céréales mélangées de 31%, comparativement la parcelle témoin. De plus, la récolte de la parcelle irriguée contenait plus de protéine et moins de fibre, donc était de meilleure qualité.

L'utilisation d'un système d'irrigation pour appliquer les eaux usées réduisait le coût d'épandage de 3,05\$/m^3 à \$0.95/m^3, comparativement à l'utilisation d'une citerne conventionnelle.

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SYMBOLS AND ABBREVIATIONS

A	Area
ADF	Acid Detergent Fiber
Al	Aluminum
ANOVA	Analysis of variance
BOD	Biological Oxygen demand
C	Control
Ca	Calcium
CE	Eastern plot as control
COD	Chemical Oxygen Demand
C_p	Crop Phosphorous requirement
DFE	Dairy Farm Effluent
E	Thickness of wastewater over soil
EPA	Environmental Protection Agency
FC	Fecal Coliform
FO	Flow from field subsurface outlet
FS	Fecal Streptococci
HA	Holding Area
HRT	Hydraulic Retention Time
I	Irrigated
I	Soil infiltration rate
IE	Irrigation on eastern plot
IW	Irrigation on western plot
kW	kilowatt
L_{pipe}	Length of gated pipe
Mg	Magnesium
MH	Milkhouse
MP	Milking parlor
MS	Manure Seepages

n	Manning's coefficient
NDF	Neutral Detergent Fiber
NH_3-N	Ammonia nitrogen
NH_4-N	Ammonium nitrogen
NO_2^-	Nitrite
NO_3	Nitrate
NO_3-N	Nitrate nitrogen
pH	Concentration of hydrogen ion
Q	Wastewater pumping rate
R	Hydraulic radius
RO	Reverse Osmosis
S	Average field slope
SAS	Statistical Analysis Software
SBR	Sequential Batch Reactor
Sett. S	Settleable Solids
TC	Total Coliform
TDS	Total Dissolved Solids
TK	Total potassium
TKN	Total Kjedahl Nitrogen
TN	Total Nitrogen
TP	Total phosphorus
TS	Total Solids
TSS	Total Suspended Solids
TW	Application with tanker on western plot
UASB	Upflow Anaerobic Sludge Blankets
v	Runoff speed
VIA	Vegetated Infiltrated Areas
VS	Volatile Solids
WW_p	Dairy farm effluent (DFE) phosphorous content

Chapter 1

1. Introduction

1.1 Problem statement

The dairy sector is a significant contributor to Canada's agro-food economy. It is composed of approximately 21,500 producers with a net annual farm income over $4 billion. About 81% of Canada's dairy farms are in Ontario and Quebec, with 14% in the Western provinces, and 5% in the Atlantic Provinces.

The Canadian dairy industry is expected to devise strategies to maintain a high and efficient production while preserving or improving the quality of natural resources, such as water, air and soils. As a result industry is responsible for the management of wastewater generated from its activities (Willer et al. 1999).

Dairy farms typically produce large volumes of milkhouse wastewaters and manure seepage (dairy farm effluent-DFE). In Quebec, the average dairy farm has a herd of 50 cows and about an equal number of replacement animals (FPPLQ 2004). Most farmers store manure on a concrete platform without a roof. This storage system produces large volumes of seepage especially as a result of precipitation falling on the solid manure pile. The platform of a typical Quebec dairy farm can generate 500m^3 of manure seepages annually. In addition to this manure seepage, all dairy farms must manage the milkhouse wash waters, which are estimated at 15 to 20L/cow/day. Thus, the typical Quebec dairy farm generates an additional milkhouse wastewater volume of 250 to 400m^3, depending on the frequency and volume of water used to sanitize milking equipment (Urgel Delisle and Ass 1992; 1994). Consequently, the average dairy farm in Quebec generates DFE volume totaling 750 to 900m^3 each year, and most of these are disposed through land application.

Disposing of this large volume of DFE is challenge for most dairy farmers in Quebec. Two manure spreading systems are required, one for the solids and the second for the liquids. As a consequence, most farms hire a custom operator to spread the DFE at a cost of \$3.10 to \$4.50/m^3 (Barrington 2002). The DFE spreading cannot be carried out at any time of the growing season, but rather before seeding, between hay crops or after harvesting. Spreading these low nutrient DFE with conventional tankers at a maximum rate of $100m^3/ha$ never meets the crop requirements, so additional fertilizers must be applied. Finally, the use of large DFE tankers compact the soil and, when traveling on hay fields between cuts, tanker can damage the hay crop.

Surface irrigation is an option concept which could help spread dairy DFE with more flexibility and at a lower cost than current method, which uses conventional tankers. The irrigation system could consist of a pump and tubing system feeding a gated irrigation pipe, which delivers DFE along its length and lets them run down the slope of a field. Because of the low nutrient content of such DFE, only 0.5 to 1.0 ha of land is required to spread the DFE produced by a herd of 50 cows.

This proposed irrigation system could offer the following advantages over traditional manure application systems including :

1. Lower investment costs, since only a pump and some piping are required;
2. Less time spent spreading the DFE, since surface irrigation is very fast;
3. More flexible spreading schedules, since surface irrigation can be practices without damaging the crop and therefore with vegetation in place;
4. Higher nutrient application than tanker method, since 700 to $1000m^3/ha$ of DFE could easily be applied over one season;
5. Less soil compaction, since no equipment needs to move over the field;
6. Higher crop yields as a result of applying 70 to 100mm of water during the growing season.

1.2 Objectives

The goal of this study is to develop a surface irrigation technique to quickly, economically and efficiently land apply DFE. The present surface irrigation technique bypasses the difficulties experienced with applying DFE with a tanker system. The primary objective in developing this type of system is to meet the needs of the typical dairy farm in Quebec, but it could be adopted by any small Canadian dairy farmer or any other producer of organic wastewaters.

The general goals of this study are to:

1. Develop a surface irrigation system for agricultural wastewaters; and
2. Demonstrate the speed, economics and efficiency of spreading DFE on land using surface irrigation.

The scientific objectives of the study are:

1. Develop an economical DFE land disposal technique by examining the theory explaining the distribution of water on the soil surface, as it runs down a slope;
2. Develop an application method using surface irrigation equipment and evaluate the cost of such equipment;
3. Measure the impact of this technique on the drainage water quality;
4. Measure the impact of this disposal method on crop yield and quality; and
5. Measure the impact of this dairy DFE on the nutrient loading of the soil

1.3 Scope

The dairy farms used in the study have sandy and silty soils. Therefore, the results of this study apply to regions with sandy and silty soils with alfalfa, corn and mixed cereals.

1.4 References

Barrington, S. 2002. Reducing manure odors and surplus nutrients at the Macdonald Campus farm of McGill University. ASAE/CSAE 2002 Annual International Meeting. July 14-17, 2002 Saskatoon, Saskatchewan Canada

FPPLQ. 2004. Annual report. Fédération des producteurs de lait du Québec. Longueuil, Québec.

Urgel Delisle et Ass. Inc. 1992. Épuration des eaux usées de la laiterie et de ruissellement à la ferme. Document produit pour le Ministère de l'Environnement du Québec sous le programme PARDE-PAAGF. Envirodoq EN 930427. MENV, Québec, Canada.

Urgel Delisle et Ass. Inc. 1994. Évaluation de systèmes de fosse septique- champ d'épuration pour l'épuration des eaux usées de laiterie de ferme. Document produit pour le Ministère de l'Environnement du Québec sous le programme PARDE-PAAGF. Envirodoq EN 940584. MENV, Québec, Canada.

Willer, H.C., X.N. Karamanlis and D.D. Schulte. 1999. Potential of closed water systems on dairy farms. Water Science and Technology 39: 113-119.

Chapter 2

2. Literature Review

2.1 Introduction

Dairy farms handling their herd's manure as solid must manage three fractions: (a) a solid fraction collected behind the cows or scraped from the barns, stored, and then loaded into a solid manure spreader and spread on cropland; (b) a liquid fraction produced as seepage as a result of manure decomposition and as a result of precipitation falling on the solid manure stored outside and (c) a second liquid fraction resulting from the washing of milking equipment, milking parlor and milk room. The liquid fraction can create a environmental problem, especially if released without treatment in the proximity of water supplies and populated areas.

2.2 Management practices for milkhouse wastewater

Milkhouse wastewater are contaminated enough to require special disposal measures. Canada's milk quality is one of the highest in the world, but it also requires the washing of all milking equipment and their holding facilities. These wastewaters are rich enough with phosphorus to cause eutrophication in surface waters (Sharpley et al. 1994) and restrict fishing, recreational and drinking practices.

Milkhouse wastewaters are generally stored along with the manure seepage to be later on spread on land as fertilizer (NRAES 1998). Other treatment avenues must be used when the dairy farms uses a solid manure system without the storage capacity to accommodate milkhouse wastewaters. The use of septic system to dispose of milkhouse wastewater has been attempted but with limited success (Miller et al. 1987). Milk fats may not be completely degraded in the septic tank, clogging soil pores in the leachfield and causing hydraulic failure in the system (NRAES 1998).

2.3 Treatments of milkhouse wastewater

Several techniques are available to treat milkhouse wastewater before it is released into the environment. Although the treatment of milkhouse wastewater with physical, chemical or biological processes has a clear role in the overall management scheme, only some treatment systems have been found practical, effective and affordable at the farm level.

The physical treatment of livestock waste is usually accomplished by sedimentation, various methods of screening or centrifuging. Other physical treatments such as drying and incineration are not suitable because the high water content in milkhouse wastewater (generally exceeding 98%) would lead to extremely high fuel costs. Physically treating dairy farm wastewaters does not ensure that they may be discharged safely into the environment because the effluent may not meet water quality criteria. Although some phosphorus is removed from the wastewaters, physical treatments have little impact on any dissolved solids such as ammonium and potassium.

Biological treatment systems for the treatment of solids and liquid wastes use anaerobic, aerobic or facultative fermentation conducted within a structure or in an unconfined manner in soils. Examples of biological treatment systems are anaerobic digesters, septic tanks, oxidation ponds, aerated lagoons, and oxidation ditches. Biological treatment systems rely on microorganisms to degrade and decontaminate wastes, while chemical treatment systems add chemicals to disinfect and precipitate undesirable compounds.

Some of the common systems used to treat livestock wastes and milkhouse wastewater are discussed in the following sections.

2.3.1 Constructed wetland

Constructed wetlands consist of series of basins filled with crushed stone, sand and/or gravel. The basins are lined with an impermeable liner to prevent any waste from leaching into the ground water. Native wetland plants are generally grown to adsorb the nutrients contained in the wastewater. These constructed wetlands simulate natural wetlands, and may offer additional treatment through mechanical filtration and chemical treatment of that waste. The plants grown in the constructed wetland are specifically chosen for their ability to assist in the biological treatment of the wastewater. Performance of the constructed wetlands for wastewater treatment influence contaminant removal efficiencies and treatment effectiveness. The performance of any wetland depends upon the hydraulic retention time and the type and variety of flora, fauna and microbes present.

Constructed wetlands provide an opportunity for treating agricultural wastewaters (Cronk 1996) such as dairy farm wastewater produced from confined animal operations, sewage, surface runoff, and milkhouse wastewater. In a preliminary study conducted by the US EPA, constructed wetlands were found to provide a high level of treatment when the wastewater was initially treated by a lagoon. Constructed wetlands occupy large surfaces compared to other treatment systems, but their construction and maintenance costs are relatively low.

Newman et al. (2000) have used a constructed wetland to treat 2.65 m^3/day of milkhouse wastewater, at the Storrs Campus of the University of Connecticut. This wetland removed 94% of the TS (total solids) and 85% of the BOD_5, while only 68% of the TP (total phosphorous), 60% of the NO_2^-/NO_3^- and 53% of the TKN (total Kjeldahl nitrogen) were removed. Except for fecal coliforms, all contaminants were more effectively removed in the summer than the winter.

Though constructed wetlands have been widely used in hot climates, their performance for cold climates still needs investigation. The Gulf of Mexico Program reviewed the performance of 135 pilot and full scale constructed wetlands for treating livestock wastewaters. The types of wastewater treated by these constructed wetlands included dairy manure and milkhouse wastewater, poultry manure and pig manure. Over 1300 operational data records were summarized in the data base, which showed that BOD_5, TS, ammonium nitrogen, TN (total nitrogen), TP and fecal coliforms could be effectively removed by constructed wetlands (Knight et al. 2000). Average reduction efficiencies were in the range of 65% for BOD_5, 53% for TSS (total suspended solid), 48% for ammonium nitrogen, 42% for TN and 42% for TP.

Mantovi et. al (2003) used a $75m^2$ horizontal subsurface flow reed bed to treat dairy parlor milking wastewater and domestic sewage. The influent wastewater contained 0.7g/L of TS, 1200mg/L of COD (chemical oxygen demand) and 450 mg/L BOD_5. Suspended solids were reduced by 90%, while TN and TP were reduced by 50% and 60%, respectively. After treatment, the population of FC (fecal coliforms) and FS (fecal streptococci) were reduced by 99 and 98%, respectively. The organic load and nutrient contents of the milkhouse wastewater were higher than those of typical wastewater, suggesting that this system was quite effective in removing solids, TP and pathogens. The horizontal subsurface flow reed bed could not efficiently reduced total and ammonical nitrogen due to insufficient oxygen supply.

Despite several advantages offered by constructed wetlands, such as low construction and maintenance costs and a highly efficient removal of some contaminant loads, it is not used in Canada. During the winter, when temperature drops below 0°C, the treatment process slows or even stops. Thus, it is not perceived as efficient due to climatic constraints. Secondly, wetlands require a large surface area: to treat milkhouse and manure seepages for a 50 cow dairy herd, more than 0.5 ha of land is required for the constructed wetland. Yin and Weiran (1995) report that surface flow wetlands have an investment cost of $\$20/m^2$ and an operating cost of $\$0.025/m^2$.

2.3.2 Anaerobic treatment

Anaerobic treatment is a naturally occurring biological process carried out by a large variety of bacteria working together in the absence of oxygen. These bacteria grow by converting organic matter into methane and carbon dioxide through several steps. These bacteria operate over temperatures ranging from 10 to 50°C. The process of anaerobic digestion is completed in three steps: 1) hydrolysis of organic matter takes place, 2) decomposed organic matter is converted into organic acid, and 3) the organic acids are converted into methane and carbon dioxide.

Anaerobic lagoons are the most common treatment system for processing dairy manure. A regional research project on animal waste as nutrient and energy resources in warm, humid climates summarized many experiments utilizing anaerobic lagoons to animal wastes. Hill et al. (1990) evaluated lagoon management systems thatrecycle dairy wastewater. Other factors evaluated were:

1) estimate of sludge accumulation;
2) crystal accumulation in water recycle systems;
3) potential use of lagoons to produce CH_4 for biogas (energy) uses, and;
4) lagoon overland flow treatment.

Overall, the anaerobic treatment system reduced the COD by 75%, TVS (total volatile solids) by 48%, TS by 46% and TN by 69%. Reductions in total plate count for TC (total coliforms), FC and FS in the three pond systems were 99, 98, and 99% respectively (Hill et al. 1990).

Biogas production varied widely for several anaerobic lagoons, ranging from 0.2 to $0.5m^3/m^2/d$ with a methane concentration of 60% (Hill et al. 1990). Some research indicates that dairy manure does not breakdown into methane as readily as other animal wastes (Hill 1990). Cogeneration is not cost effective as flushed manure wastewater is too dilute for conventional anaerobic digestion system. Although a fixed bed reactor is capable of treating larger volumes of dilute wastewater per unit time, compared to conventional systems, this technology has been applied most successfully to treat swine wastes, not dilute dairy manures or dairy wastewater.

Solid loading rates and hydraulic as well as solid retention time are important design criteria in anaerobic digestion. Warburton et al. (1981) studied the performance of the anaerobic phase when dairy wastewater was fed to anaerobic tanks at loading rates of 0.14-0.30 kg BOD/m/d and 0.67-1.36 kg of TS at three hydraulic retention times of 5, 7.5

and 10 days. Little variations in BOD and TS removal were observed with changes in loading rate. BOD_5 reduction increased from 48 to 77% when the hydraulic retention times was increased from 5 to 10d.

According to Vetter et al. (1990), the conventional sludge digester is not well suited to treat the relatively dilute dairy wastewaters because of the long hydraulic retention time required to prevent microbial wash out. Moreover, the relatively dilute natures of the milkhouse wastewaters result in poor gas yield.

Alternative anaerobic configurations such as anaerobic filters, upflow anaerobic sludge blankets (UASB) reactors and fluidized beds can overcome these problems and have been successfully used in the past to treat a variety of organic wastes (Lettinga 1984; Wheately et al. 1997). However, efficient operation normally requires digestion temperatures in the range of 30-37 °C (Wheately et al. 1997), requiring some of the biogas produced to be burned to heat the digester contents. In addition, to reduce biogas consumption, systems may be needed to recover the heat from the treated effluent as it leaves the digester. These factors add to the overall complexity of the process.

Anaerobic digestion can be applied for treating milkhouse wastewater. The process requires a lower capital investment than aeration but a much greater commitment to managing the system. Nevertheless, the effluent is still highly loaded with organic matter and cannot be discharged directly into the environment without further treatment. Anaerobic digesters remove very little of the nitrogen contained in the wastewater. Indeed, instances have been reported where the anaerobic process increased the ammonium concentration as a result of protein degradation and carbon losses. A tertiary treatment following anaerobic digestion is required to safely discharge the effluent into water courses. Thus anaerobic digestion is not suitable as a stand alone process for treating milkhouse wastewater.

Despite its low running cost, the energy produced and the elimination of odors, anaerobic process requires an additional tertiary treatment before the wastewater can be disposed.

2.3.3 Aerobic digestion

Aerobic (naturally oxygenated) lagoons are shallow basins that serve as both treatment and storage units for milkhouse wastewater. During the 6 months (or longer that) organic wastes are retained lagoon, microorganisms break down the organic contaminants to simpler compounds such as carbon dioxide and water. As long as the system remains oxygenated, objectionable odors are not produced. To maintain sufficient oxygen levels, lagoons must be shallow and the surface should be free of scum and other floating materials. Such systems require minimum capital cost, are simple to operation, and offer good reduction levels in BOD_5 and TS reduction, but decomposition slows down under cold temperatures. A laboratory study showed that decomposition in aerobic drop greatly below 4°C (Day and Funk 1998).

Aerobic lagoons function most effectively if the wastewater is pretreated to remove solids by settling. A common pretreatment system consists of two settling tanks, connected in series, or a single tank separated into two compartments. Mechanical separation of coarse solids from wastewater prior to aeration can significantly improve the efficiency of the process by reducing power requirement for mixing. However, separation may not be necessary when the wastewater contains less than 3% TS.

In the recent years, sequencing batch reactors (SBR) have become more common. The SBR is modern version of the fill and draw process, consisting of one or more tanks, each capable of waste stabilization and solid separation. SBR are more dynamic and flexible in terms of operation and are kinetically more advantageous than activated sludge systems. Although, the application of SBR for the treatment of industrial wastewater has been widely reported, few studies have treated agricultural wastewater. Lo et al. (1988) worked on the treatment of milking center wastewater using a 5L bench SBR operating at different temperatures and under different cycles. High BOD_5, COD, ammonia nitrogen and TSS removal were achieved. Despite this high performance, SBR are generally too expensive for the treatment of milking center wastewater.

Although they are relatively simple to operate and effective at reducing nutrient loads contaminants, aerobic digestion have high energy requirement and regular maintenance costs that can increase the overall cost of this treatment option.

2.3.4 Reverse Osmosis

Reverse osmosis (RO) works by increasing pressure on the side of higher salt concentration, thus forcing the permeate (water fraction) back through the membrane and retaining the mineral and salts. RO has been mainly applied for drinking water preparation and is now used to treat wastes from the food sector, the galvanic industry and the dairy industry. Fouling problems of nano-filtration and reverse osmosis membranes used for the treatment of the effluent from chemical-biological plants and dairy industry effluents have been noted, and remain to be solved. However, some researches have applied this technique to the treatment of milkhouse wastewater and liquid manure.

Van Gastel and Thelosen (1995) treated dilute dairy manure using a pilot plant with $8m^2$ of membrane surface exposed to swine slurry with 1.7% TS. Increasing the temperature from 10 to 20°C in combination with a settling treatment, improved the efficiency of the system but increased treatment cost. From their study and for a 500 animal herd, the cost of RO with a prior settling treatment was estimated at 15 Euro/m^3 (\$23/m^3).

A farm study conducted in France, used RO to treat swine slurry, and compared this technique with several others based on separation efficiencies, economic costs, quality and ease of disposing the end product. Pieters et al. (1999) reported that separation techniques based on natural settling followed by sieving, microfiltration and

RO for swine slurry eliminates 77% of the volume. The effluent (permeate) obtained after these steps contained TSS and COD levels low enough to be spread safely on the land or discharged into a stream. The cost of treating slurry from 1100 sows was assessed at $8 US/m^3.

These few studies indicate that RO and nano-filtration techniques produce good quality effluent, but they are not affordable for the treatment of dilute manure seepages and milkhouse wastewaters.

2.3.5 Land Treatment

The application of wastewater to land, often called land treatment, soil treatment or land application, has been practiced for hundreds of years throughout the world. Sewage farming was first introduced in the United States in the 1870's (Rafter 1899). Land treatment systems for wastewater fall into three categories, namely (a) slow rate irrigation (b) high rate and (c) over land flow

Slow rate systems at 10 to 100 mm/week, provide an intermediate and direct reuse of wastewater for crop production at rates lower than those commonly used for surface or sprinkler irrigation. Plants play a dominant role in the adsorption of nutrients such as nitrogen and phosphorus. Physical and chemical interactions in the soil are less important in achieving desired performance because of relatively low loading rates.

In rapid infiltration using high rates of 100 to 3 000 mm/week, wastewater moves downward through the soil for treatment (Pound and Crites 1973). In high rate systems physical, chemical and biochemical interactions with wastewater in the soil are quite important and contribute to the treatment of the wastewater. Biological and chemical contaminants may be degraded or adsorbed to soil surface, which detoxifies the water that moves through the soil profile and eventually enters the ground water.

Over land flow is especially suited for use on impermeable soils as it offers intermediate soil infiltration rates. Over land flow systems are the least developed land treatment systems. They were used to some extent to apply industrial wastes and specifically food processing wastes, but have never been used to apply municipal wastewaters because large runoff volumes can transport wastewater directly to surface waters. The application of lagoon effluent to land via irrigation or overland flow requires a crop capable of assimilating large amount of nutrients. Liu et al. (1997) studied the effect swine lagoon effluent on dry matter yield and N and P uptake by crops using overland flow technique. They found that with the addition of NH_4-NO_3 and swine lagoon effluent, dry matter yield was significantly increased, however increasing the effluent rates increased TP and TN concentrations in the forage.

Keeney (1982) and Sims (1995) reported that land application of dairy waste can recycle the nutrients back onto farm land and reduce the need for fertilizer but excessive quantities can cause environmental pollution and have a negative impact on ground water quality. Application organic nitrogen fertilizers through waste disposal at rates exceeding crop N requirements can lead to nitrate leaching below plants roots and into the groundwater (Vetter and Steffens 1981).

Land application has provided the most cost-effective treatment method for all farm wastewaters because most farms have land available to receive wastewater and other organic wastes. Combining milkhouse wastewater with manure allows the use of a common disposal system for both types of wastes. A liquid manure storage facility, properly constructed and sized, provides the flexibility of both storing the milkhouse wastewater and using them to dilute manures and ease their handling. While this method of land application by tankers results in increased transportation and application costs, the milkhouse wastewater supplies nutrients for crop production. The risk of groundwater contamination is low from land application of manures containing milkhouse wastewater if nitrogen application rates do not exceed crop needs.

In the New Zealand, permanent pastures were used for the removal of nitrogen and phosphorus from untreated milkhouse wastewater. Soil uptake and drainage losses of TN and TP were measured during three years of application. Approximately 90% of TP was retained in top 50mm of soil profile while only 15% of TN was retained (Macgregor et al. 1982). There was no increase of soil TN content probably because most of it was adsorbed by the pasture crop.

Using a vegetative soil filter system to treat dairy wastewater, Paterson et al. (1980) measured its effectiveness in reducing milkhouse wastewater contaminants over a 2yr period. For a wet vegetative filter area, 4.5 L/m^3/d was found to be a safe loading rate, except during events of rain and snow melt. Considerable emphasis was given on the practical operation and the layout, the rotation of application sites and the proper maintenance of the system for satisfactory performance.

Working with wastewater generated from milkhouse cleaning activities, Jamieson et al. (2002) recommended the use of vegetated infiltrated areas (VIA) as a possible treatment option for milking center wastewater for a commercial dairy farm of 50 cows. The VIA was built on loam soil and the system was loaded during two growing seasons. A valve was installed to divert the first rinse of milk pipe wash water to the manure storage, resulting in a 76% drop in TSS. The vegetated infiltrated areas proved to be cost effective if properly managed, but long term effects of this technique on ground water quality merit further investigation.

In land application, the method of application affects nutrient uptake and the magnitude of losses. In a pasture, a lysimeter study measured the fate of nutrients following the surface application and subsurface injection of dairy pond sludge (Cameron et al. 1996). Surface application of dairy pond wastewater at a rate of 300 Kg N/ha was found to impose minimum environmental risk in terms of ground water contamination.

In a study conducted in Spain, swine slurry was applied to calcareous soil at rates of 200, 400, 600, 800 and 1000 m^3/ha/yr to measure the effect on exchangeable potassium (Bernal et al 1993). Soils with a higher clay content retained more exchangeable potassium than those with a low clay content.

Toyama et al. (1990) measured the effects of applying secondary effluent on plant yield and soil bacterial population. Land application proved to be satisfactory and just as economical when compared to techniques of advanced wastewater treatment. No impact on the ground water quality was observed. A soil column study measured the effects applying swine slurries to the biological and chemical properties of soils (Lam et al. 1993). The soil effectively decontaminated the swine slurries as long as the soil's hydraulic permeability was not exceeded. Also, less permeable soils were found to be more efficient in removing nutrient than more permeable soils (Lam et al. 1993).

Land application of agricultural wastewaters is therefore one of the best option for their disposal where land is not limiting factor.

2.3.5a Transport cost for the land application

Transportation and land spreading of manure imposes an initial investment cost and a high running cost which increases with distance. Transportation and land spreading costs for manure spreading are influenced by the following factors

1. tank capacity;
2. soil bearing capacity;
3. spreading periods between crops;
4. transportation distance.

For small transportation distances, limited differences in cost are encountered between the various equipment options but, for long transportation distances, the spreading cost is influenced by the size of tanker. Solid wastes might more easily be accommodated on farms; however milkhouse wastewater and manure seepages contain more than 98% water and cost a lot to transport. The transport of liquid manure by pipeline is used in many countries where there is a centralized wastewater treatment plant. The relatively low TS in most slurry enable their transport by means of pipelines. If the TS levels are high, some pre-screening is necessary to remove suspended matter that may lead to blockage. This systems works well within a 3 km range or when there is need to transport large volumes of manure.

2.4 Conclusion

In conclusion, the choice of land spreading equipment for the disposal of dairy wastewater depends upon several factors. If land is scarce, the treatment of such wastewater through physical, biological or chemical means could be first option. In Canada, land is usually abundant and these wastewaters contain nutrients essential to crops. The cost of treating, storing, transporting and disposing of wastewater is a major issue for the farmers. This cost is even higher when the wastewaters contain low levels of nutrients. The conventional tanker system is not well suited to spread such wastewaters because wastewater spreading can only be carried out before and after the growing season. The tanker can spread at the very most 100 m^3/ha, and such limited rate does not meet the crop requirements. Finally, using a tanker to apply large volumes of wastewaters leads to soil compaction and crop damage.

To give farmers a better, cost effective system for the application of wastewaters with a low nutrient content, a study is planned to adopt surface irrigation for such application.

CONNECTING STATEMENT

The following chapters (3 and 4) present two papers prepared for publication. Chapter 3 deals with the impact of surface irrigation on drainage water quality and on dairy farm wastewater spreading costs. In order to develop a surface irrigation system for the agricultural wastewaters, surface irrigation flow theories were developed. Surface irrigation system was tested on two farms for efficient and economical spreading of wastewaters over a period of three years. The project also measured the system's area and percentage of land coverage and the effect of its application rate on drainage water quality.

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Chapter 3

SURFACE IRRIGATION ADOPTED TO THE LAND SPREADING OF DAIRY FARM EFFLUENT

3.1 INTRODUCTION

The dairy sector is a significant contributor to Canada's agricultural and agro-food economy. Among all agricultural sectors, the dairy sector is the fourth most important commodity group after grains, red meats and horticulture, with a net annual farm income of over 4 billion dollars (Agriculture and Agro-Food Canada 2003). About 81% of Canada's dairy farms are located in Ontario and Quebec, while 14% and 5% are located in the Western and Atlantic Provinces, respectively (Holstein Canada 2005).

Dairy farm effluents consist of several types (Willer et al. 1999), such as wash water from cleaning the milking equipment and seepage from manure piles stored outside without protection from precipitation. For large dairy operations handling manures as liquids, this DFE is used to dilute the semi-liquid excretions produced by the herd. For small dairy farms with a solid manure storage system, the volume of DFE produced annually is expensive to store and spread because it is relatively large and requires a second type of manure storage and handling system.

In Quebec, the average dairy farm with a herd of 50 cows and an equal number of replacement animals (FPPLQ 2004) must generally manage 500m^3/yr of manure seepage, which represents approximately half the volume of the solid manure pile itself. This seepage is made up of contaminated precipitation and liquid resulting from the decomposition of the solid manure pile. Besides, an additional 275 to 350m^3/yr of milk house wash waters must also be handled and this volume depends on the type of milking equipment washing system and its management (Urgel Delisle and Ass. 1992; 1994). Consequently, the average Quebec dairy farm handles from 775 to 850m^3/yr of DFE.

For the small dairy farm, this large volume of DFE is expensive to store and spread on land because it requires a second type of manure handling equipment, besides that used for the solids, and this material contains limited amounts of nutrients (Table 3.1). Most farms hire a custom operator to dispose of DFE at cost of \$3.10 to \$4.50/m^3 using a conventional tanker pulled by a tractor or installed on a truck (Barrington 2002). Spreading of DFE with such tankers can only be carried out before planting or after the crop harvest in row cropped systems, or between hay cuttings, can lead to soil compaction and is limited to 100 m^3/ha. To meet crop requirement for any major nutrient (N, P or K), DFE should be applied at a rate of 700 m^3/ha.

The adaptation of surface irrigation for land spreading of such DFE would offer several advantages such as applying as much as 500m^3/ha at any one time during the growing season, regardless of the crop stage and without the risk of soil compaction. Furthermore, the large volume of DFE applied should provide water to promote crop production during the dry summer months. Nevertheless, surface irrigation is known to lead to groundwater seepage (Fleming et al. 1990). Because wastewaters are applied in this case, any groundwater seepage can have a negative impact on the water resource.

The objectives of this study were therefore to select and test surface irrigation equipment for the efficient land application of DFE at rates of 250 to 500m^3/ha; characterize DFE during three consecutive years on two farms and for one year on four additional farms with a different manure handling system; observe the amount and contaminant load of subsurface seepage resulting from surface irrigation and recommend ways to minimize this phenomenon, and; conduct an economic assessment of the cost of surface irrigation versus that of a conventional tanker pulled by a farm tractor.

3.2 SYSTEM DESIGN

The design of a surface irrigation system for the application of DFE requires the computation of:

1. The plot size: this ensures that the nutrients provided by DFE do not exceed those required by the crop; generally, this calculation is based on the most limiting nutrient, from an environmental point of view. In North America, environmental authorities recommend the application of organic wastes in quantities respecting the phosphorous crop uptake, especially for soils rich in this element (Converse et al. 2000; Simard et al. 1995).
2. The length of gated or perforated pipe required to irrigate the plot. This value is governed by the length of slope below the pipe position in the field;
3. The DFE pumping rate, to avoid surface tail waters; this rate must not exceed the soil infiltration rate of the plot.

The size of the irrigation plot can be simply calculated as:

$$A = \frac{V_w}{\left(\frac{C_P}{WW_P}\right)} \tag{3.1}$$

where

A = surface area of crop to be irrigated, ha;

C_p = crop phosphorous requirement, kg/ha of P_2O_5;

WW_p = DFE phosphorous content, kg/m^3 of P_2O_5;

V_w = irrigation volume of DFE, m^3.

For example, if a corn silage crop requires 62kg/ha of P_2O_5, and the DFE contain 55mg/L or 0.055kg/m^3 of P_2O_5, then 1127m^3/ha of DFE should be applied to meet the crop phosphorous requirements. If the farm pit holds 750m^3 of DFE, then the plot or receiving area measures 0.67ha.

The length of irrigation pipe must respect the application area, A, and the length of slope below the gated pipe position in the field :

$$L_{pipe} = \frac{A}{L_{slope}} \tag{3.2}$$

where

L_{pipe} = length of gated pipe required, m;

L_{slope} = the length of consistent slope below the gated pipe position in the field, m.

The value of L_{pipe} should also be limited to ensure the even distribution of DFE over its full length.

The DFE pumping rate, Q (m^3/h), must then be regulated not to exceed the infiltration rate of the soil over the plot surface. This ensures the infiltration of all DFE by the time the DFE reach the distance L_{slope}. The required pumping rate can be calculated from the following equation, where f_s is a safety factor:

$$Q = A \times I \times f_s \times 10 \qquad (3.3)$$

where

I = soil infiltration rate, mm/h;

f_s = a safety factor accounting for the fact that irregularities in the ground surface will lead to its incomplete coverage by the DFE;

A = surface area, ha;

Q = pumping rate, m^3/h.

One objective of the present project is to recommend values for (I * fs) and compare these to the irrigation water application rate (I') suggested by Schwab et al. (1986) as summarized in Table 3.2. The design should ensure that L_{pipe} is long enough for all the DFE to be infiltrated by the time they reach the end of the plot. This value is simply calculated from equations (3.1) and (3.2) and a reasonable (I * fs) value, irrespective of the ground slope.

3.3 METHODOLOGY

3.3.1 Equipment selection and plot testing

To conduct DFE surface applications, the equipment selected consisted of a liquid manure vacuum pump with a capacity of 60 to 600m^3/hr, powered by the PTO of a standard 50 to 70 kW farm tractor. The pump delivered DFE to a flexible non perforated plastic tubing measuring 100 to 200m in length and 150mm in internal diameter. This flexible tubing was connected to a 45m gated irrigation pipe installed perpendicular to the field's slope with enough down slope distance to irrigate a 0.5-1.0ha size plot. The ground slope below the gated pipe offered no counter slope, since this would stop the spreading of DFE.

To gauge the pump's flow rate, a flow meter was installed on a section of aluminum tubing, 300mm long, located between two sections of flexible pipe, about 15m from the pump. The flow meter reading was checked by monitoring the drop in DFE level in the storage pit. In 2002, the equipment selected was tested for clogging and flow performance only.

In 2002, and to measure the infiltration rate of the soils, three soil cores, 10cm high by 10cm in diameter, were collected from each plot and subjected in the laboratory to a constant head of 10mm to reproduce field infiltration conditions (Klute 1965). The results were used to calculate the surface area required for irrigation (equation 3.1). Also performed in 2004 but not reported in this paper are the plot grid design and the soil and crop sampling for nutrient applications and yield, respectively (Chapter 4).

3.3.2 DFE characteristics

During the first year, annual DFE production and characteristics were monitored on six farms with a slightly different DFE handling method (Tables 3.3a) and only on Farm A and B during the two consecutive years. All farms were located in the Saint Anicet region, some 75km South West of Montreal, Canada. Selected to conduct the surface irrigation tests during 2003 and 2004, Farm A collected DFE consisting of milk house wash waters and manure seepages while Farm B collected only manure seepages. Farm A and B managed a herd of 42 and 24 dairy cows respectively, with a similar number of replacement animals (Table 3.3b).

The DFE characteristics were monitored by sampling storage pits in May of each year. For all pits sampled, DFE was collected from the bottom, center and top of the storage, using a long collection pole holding at its lower end a bottle with a removable cap. Before sampling, the DFE depth in the storage was measured to obtain its mid value. Then, the collection pole was lowered down to the floor of the pit and the cap removed to collect a DFE sample at 200mm from the bottom of the storage. Once the sample was removed from the collection bottle and this bottle washed, the procedure was repeated at mid depth and at 100mm from the top of the DFE in storage.

3.3.3 The experimental plots

On both Farms A and B, two plots were selected to conduct the tests: the first plot received the irrigated DFE while the other was the control receiving no DFE. On Farm A, the soils of the experimental plots were loamy in texture, and slopped northwards at a rate of 1.0% over a distance of 150m. Each plot measured 50m in width, where the Eastern plot served as control plot (non-irrigated) while the Western plot received the irrigated DFE (Fig. 3.1a). On Farm A, irrigated DFE were applied to cover a plot length of 100m representing an application area of 0.5ha.

On Farm B, both 50m wide experimental plots consisted of gravely sandy soils with a southern slope of 2.5 to 3.5% over a distance of 60m, and soils with higher clay content at the bottom of this slope. The Western plot of 0.3ha served as control (non-irrigated) and the Eastern plot also of 0.3ha received the irrigated DFE (Figure 3.1b). Corn (*Zeamays*) and mixed cereals (*Tritucum aestivum, Hordeum vulgare and Avena sativa*) were grown in 2003 and 2004 on both experimental farms.

The monitoring of ground seepage losses on Farms A and B was achieved using the already installed systematic and minimal subsurface drainage systems, respectively. On Farm A, two drains under each experimental plot were intercepted and linked by a 100mm subsurface drain leading into a sampling well (Fig. 3.1a). These sampling wells drained into the field subsurface drainage system which had an outlet some 850m down slope into a drainage ditch. The seepage losses could be measured on Farm A at this ditch outlet. On Farm B, each experimental plot was drained by a single subsurface drain (Fig. 3.1b). Therefore, a subsurface drainage sampling well could be installed at the edge of each plot. On Farm B, the outlet of each subsurface drain downstream from the sampling wells was below the ditch water level, and no water course seepage losses could be observed and measured. At the sampling well, the seepage loss was estimated by observing the depth of liquid in the drain, flowing into the sampling well.

Although the bottom of each sampling well was 600mm deeper than the level at which drains entered the structure, a limited amount of water was found in the well before the irrigation sessions. Therefore, this feature had limited dilution effect on the load of samples collected.

3.3.4 Seepage losses and DFE distribution

Irrigation trials were conducted in the summers of 2003 and 2004 (Tables 3.4a and 3.4b) and DFE application rates varied from 200 to 800m^3/ha, to test the effect of different levels of applications on the volume and contaminant load of groundwater seepage losses. For each irrigation application, the method consisted in measuring the volume applied by irrigation and the extent of ground coverage and monitoring subsurface drainage losses at the sampling wells and at the Farm A field outlet. During each DFE application session, samples were collected from the sampling wells of both the irrigation and control plots, at the irrigation pipe and also at the Farm A drainage outlet when losses did occur. On Farm B, the field drainage outlet pipe was below the ditch water level and the volume of DFE loss was estimated from the flow observed in the sampling well. Samples were collected from the wells before, during and for some three days the application session.

In July 2003, the labor and equipment required and the resulting cost of operating the irrigation system were compared to that of using a conventional tanker. A time study was conducted while applying DFE at a rate of $70m^3/ha$, on the control plot of Farm A using a conventional tanker. A time study was similarly conducted while irrigating $250m^3/ha$ of DFE on the irrigated plot of Farm A. The cost of both operations was compared on the basis of disposing of all $1000m^3$ of DFE found on Farms A and B, assuming that these two farms could share the equipment.

In 2004 and based on the 2003 measurements, two piezometers were installed on Farm A (Fig. 3.1a), to observe the fluctuations in groundwater table with irrigation application and better explain the results. Piezometers could not be installed on Farm B because of stony ground conditions. Thus, in 2004, before and after each irrigation sessions, soil moisture was monitored by sampling the surface 100mm depth at 20 points/ plot using a distribution grid and the groundwater depth was observed where and when possible.

During all application sessions, the percentage of ground surface coverage and the surface runoff speed was observed, by walking around in the irrigated field and measuring the extent of DFE distribution.

3.3.5 Analytical procedure

Soil particle size distribution was determined using sieves and the hydrometer method (Sheldrick and Wang 1993). Soil moisture content was determined by drying at 60°C for 48h.

All DFE samples were analyzed for TN (total nitrogen), total phosphorous (TP), total potassium (TK) and total, suspended and dissolved solids (TS, SS, DS), pH, Total and Fecal Coliforms and Fecal Streptococci, according to standard methods (APHA et al. 1998). All solids (TS, SS, DS) were determined by drying at 103°C for 24h. All DFE samples were digested with sulfuric acid and hydrogen peroxide at 500°C before being analyzed for TKN using an ammonia selective probe connected to a pH meter and for TP and TK using a colorimetric method and a spectrophotometer. Because of the low levels of nitrate and nitrite in the DFE measured using a selective probe attached to a pH meter (results not shown), TN was assumed equal to TKN. All microbial counts were determined by filtration and the proper incubation of the filter for a colony count.

The water nutrient and bacterial loads observed in the sampling well of the irrigated and control plots were compared statistically by means of the student-t method (Steel and Torrie 1986). All significant differences are based on a 95% confidence level.

3.4 RESULTS and DISCUSSION

3.4.1 Equipment selection and performance

The equipment was tested for pump capacity and pipe blockage. When DFE were collected in a pit separate from that of the manure storage, no large solid particles were present to clog the pipes. The system worked well even when the TS content of the DFE reached 1.3%, as on Farm B. The applications resulted in a limited amount of odor being released, as observed but not measured, because the DFE were applied under the crop canopy.

During the field tests, a uniform distribution of DFE was achieved over the full length of the gated pipe, by simply adjusting the gates over the openings. The gated openings could be closed when in line with path of preferential runoff flow, such as a field lane with no vegetation or besides a field ditch.

When using up to 200m of flexible-150mm diameter polyvinyl tubing and 45m of gated irrigation pipe, the selected manure pump could easily deliver up to 600m^3/hr, which meant that 250m^3 of DFE could be applied in less than 30 minutes. The higher rate of application required a farm tractor with a minimum power of 70kW.

During all applications, the DFE runoff covered from 65 to 80% of the soil surface but had no effect on soil nutrient fluctuation levels of the irrigated plot, as compared to that of the control plot (Chapter 4). Higher coverage was obtained with dryer soils as the surface DFE runoff velocity was slower due to the higher infiltration rate. The average surface runoff velocity was of the order of 1m/minute on Farm A and 3 to 5m/minute on Farm B, because of the higher slopes. For all applications, the runoff DFE would cover the full plot length and some accumulation regularly occurred at the bottom of the slope, especially on Farm B where the plot was only 60m long.

3.4.2 Infiltration capacity of the experimental plots

In the laboratory, the loamy soils of Farm A gave an infiltration rate 270 mm/h initially which dropped within 0.5h to a stable value of 50mm/h +/- 10mm/h. On Farm B, the gravelly sandy (top of the slope) and clay soils (bottom of the slope) gave an initial infiltration rate of 900 and 200 mm/h which respectively dropped to a constant value of 840 +/- 50mm/h and 50 +/- 10mm/h after 0.5h. The irrigation rates generally recommended (Schwab et al. 1986) are conservative values when compared with those measured in the laboratory (Table 3.2), and are therefore considered to represent a value for ($I * f_s$) rather than just the infiltration rate (I).

3.4.3 DFE characteristics

The DFE characterized on the six dairy farms in 2002 are presented in Tables 3.5a and 3.5b. In general and for the DFE stored separately from the solid manure (all farms except C-1 and C-2), the TS values were below 1.0% and the DFE contained 50 to 600mg/L of TN and 15 to 60mg/L of TP. The DFE had TK values ranged from 218 to 1075 mg/L. Higher TS, TN and TP values were observed on farms storing their DFE along with the solid manure, as TS exceeded 2%, and TN and TP exceeded 1000 and 130mg/L, respectively. Levels of TC, FC and FS (total coliforms, fecal coliforms and fecal streptococci) and the ratio of CF/FS varied widely from farm to farm, but tended to increase with TS content.

On Farms A and B, the 2002 DFE were similar to those of 2003, but more heavily loaded in 2004 because of the ore intensive rainfalls observed during the winter of 2003-04 (Tables 3.5c and 3.5d). The DFE of Farm A were more diluted than those of Farm B, because of the larger plat-form area used per unit solid manure mass and the fact that Farm A collected milk house wash waters while Farm B did not. The DFE characteristics of Farm A and B are within the range described in the scientific literature (Table 3.1).

Table 3.6 calculates the land DFE application rate based on crop nutrient uptake for both Farms A and B and for the characteristics observed during all three years. The DFE application rate must be adjusted from year to year, as their nutrient content is variable. Also, if TP is used to calculate DFE application rates, K will be over applied, requiring the rotation of the application plot from one year to the next. In general, DFE nutrient loads are much higher than that of typical dairy manures (Westerman et al 1985).

3.4.4 Seepage losses on Farm A

During all irrigation sessions, summarized in Table 3.4a, seepage was observed to flow into the plot sampling well some 30 minutes after starting the DFE application, but not into that of the control. This seepage would stop flowing some 90 minutes after stopping the irrigation applications. During the August 2003 and 2004 irrigation sessions, 1.6 and $4.0m^3$ of seepage losses occurred at the field outlet, respectively. This field outlet started to flow some 140 minutes after starting the irrigation session and would stop running some 90 minutes later. As observed by other researchers, irrigation leads to seepage losses (Fleming et al. 1990).

For the 2003 applications, the samples collected from the sampling well of the irrigated plot were similar in loading as compared to those collected from the well of the control plot (Fig. 3.2a). Also, during the first irrigation session, the control plot received $70m^3$ of DFE applied using a conventional tanker. The sampling well samples demonstrated some contamination 3 days after this application, as a result of 30mm of rainfall. Nevertheless, the samples from both sampling wells demonstrated TN, TP and bacterial load equivalent to only 10% of that of the DFE. On July 11^{th} and 14^{th}, a volume of less than 500L of subsurface seepage flowed into the sampling well, following applications of 450 and $230m^3$/ha. On August 29th, the application of $630m^3$/ha of DFE, following 20mm of rainfall, lead to the subsurface loss of $1.6m^3$ at the field outlet and into the water course. This seepage offered on the average, 30% of the TN, TP and TK and 50% of the Coliforms (Total and Fecal) but the same Fecal Streptococci load contained by the applied DFE.

In 2004, the control plot received no DFE and its samples of water were significantly less loaded that those collected from the irrigated plot sampling well (Fig.

3.2b). Nevertheless, the samples collected from the irrigated plot sampling well offered on the average only 25% of the load contained in the irrigated DFE. For the 15th and 19th of July applications of 538 and 552 m^3/ha, conducted under dry climatic conditions, less than 500L of subsurface seepage was observed. On August 2nd, and after a 100mm rainfall, the application of 682m^3/ha lead to the subsurface seepage loss of 4.0m^3 at the field outlet and into the water course. Although the seepage lost at the field outlet offered on the average, only 20% of the load in TN, TP and TK contained in the irrigated DFE, its bacterial loads, especially in Coliforms (Total and Fecal) where much higher than the irrigated DFE.

The second piezometers readings of 2004 gave a better indication of groundwater table depth than the first piezometers installed on higher grounds, only 10m down slope from the irrigation pipe. The second piezometers indicated a groundwater table deeper than 1.6m before the first irrigation application, and of 1.26m, four days after the second application in the absence of rain. After the second irrigation session, the groundwater table came up to within 0.26m of the surface, but no field outlet seepage was observed. On August 2004, after a 100mm rainfall, the second piezometer indicated a groundwater table at a depth of 1.30m which came within 0.28m of the surface 5h, after the irrigation session. On July 19th, the 1.25 groundwater table depth was equivalent to that of the subsurface drains but only for the irrigated plot which had been irrigated four days earlier, while that of 1.30m of August 2nd, again equivalent to the subsurface drain depth, applied to the entire field which had been exposed to a 100mm rainfall. Therefore, the July 19th seepage losses could be distributed by the subsurface drains to the rest of the much drier field, while on August 2nd, the rest of the field was just as wet.

These observations suggest that when applying reasonable amounts of DFE, for example, at rates under 550m^3/ha on Farm A, seepage losses will not run out of the subsurface drainage outlet of the field in which the small (0.5ha) irrigated plot is located, because of the irrigation phenomenon which occurs over the rest of the field with a deeper groundwater. Furthermore, the seepage which is lost to subsurface drains under the irrigated plot represents less than 0.1% of the total volume applied, with no more than 30% of the load of the applied DFE. Thus, only the soil macro-pores over the subsurface drains contribute to this seepage loss when the soil is relatively dry, and these micro-pores have a filtration effect on the DFE as they seep to the subsurface drainage system.

3.4.5 *Seepage losses on Farm B*

Also on Farm B, seepage was observed to flow into the sampling well of the irrigated plot some 30 to 45 minutes after starting each application and would run for 20 to 30 minutes thereafter. On Farm B, the DFE were applied during two consecutive days at the rate of 367-383 and 130-217 m^3/ha, respectively. During the first day of application, the soils were dryer and it would take more time for seepage to start flowing into the sampling well of the irrigation plot; furthermore, this seepage flow would not last as long. On both years, some 30 and 50L of seepage were estimated lost, during the first and second consecutive days of application.

As no DFE was applied to the control plot, on both years, the samples obtained from the sampling well corresponding to the irrigated plot were significantly more loaded in nutrients and bacteria than those obtain from the sampling well corresponding to the control plot (Fig. 3.3a and 3.3b).

In 2003, the seepage collected from the sampling well had a TP load equivalent to that of the DFE applied by irrigation, but the TKN, TK and bacterial loads offered only 10% of the load, except for the sample collected after 2h of irrigation on the second day. In 2004, the seepage collected from the sampling well had a nutrient load equivalent to that of the DFE applied, and a bacterial load which tended to be as large on the first day and larger on the second day of irrigation, and as compared to the DFE applied. Both in 2003 and 2004, the volume of seepage lost amounted to 50L, representing again less than 0.1% of the total volume of DFE applied.

Because of the gravely soil texture found on Farm A, less DFE filtration occurred inside the soil macro-pores and the seepage contaminant load was just as high as that of the DFE.

3.4.6 System's operating costs

On Farm A and during the July 11th 2003 session, a conventional tanker was used to apply 32m^3 of DFE to the control plot. This represents 4 tanker loads of 8m^3 applying a rate of 70m^3/ha. This operation took 40min and used two tractors and one operator besides the tanker and the liquid manure pump. On the same day, the irrigated plot received 225m^3 using the surface irrigation system, which took 55 minutes and only one tractor, one operator and the liquid manure pump. Setting up the tanker loading pipe took 15 minutes as compared to laying the irrigation pipe which took 30 minutes; both setting up operations required 2 persons.

This data was used to compare the cost of spreading DFE using a tanker with that of using a surface irrigation system (Table 3.7). Assuming that the surface irrigation system is shared between the two Farms, A and B, and that the irrigation pipe is left in the field until all DFE is applied, the surface irrigation system can reduce the cost of spreading DFE from \$3.05/m^3, when using a custom operator equipped with a tanker, to \$0.95/m^3 when using the surface irrigation system. The cost of the surface irrigation system could be further reduced if shared among more than two farms and if the increase in crop yield resulting from its irrigation was accounted for.

3.5 Conclusion

The characterization of DFE on six farms with a different handling system indicate that only those DFE stored separately from the solids manure are free of large particles of solids and can be easily pumped and distributed using a gated irrigation pipe. During three consecutive years, DFE were characterized on two farms and their nutrient and bacterial loads were found to vary with winter precipitation.

Subsurface seepage losses occurred during all DFE applications by irrigation, but the nutrient load of these seepages, compared to the DFE applied, was lowered in parallel with the clay content of the receiving soil. No seepage will flow out of the subsurface drainage system outlet if the irrigated plot is much smaller than the field drained by the subsurface drainage system, if the DFE are applied at a rate respecting the irrigation guidelines and if the groundwater table depth of the field is lower than that of the subsurface irrigation system.

Finally, the irrigation system used in this project reduced the DFE land spreading to \$0.95/m^3, compare to the cost of \$3.50/m^3 using a conventional tanker pulled by a farm tractor. Furthermore, the time required to apply the DFE was reduced by 75%.

Acknowledgement

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3.6 References

Agriculture and Agri Food Canada 2003. www.dairyinfo.gc.ca/cdiccdi.htm

Ali, I., S. Barrington and R. Bonnel. 2004. Innovative application of surface irrigation for efficient disposal of farm DFEs. ASAE/CSAE 2004 Annual International Meeting. August 1-4, 3004 Ottawa, Ontario Canada

APHA 1998. Standard Methods for the Examination of water and DFE, 20th ed.; American Public Health Association, American Water Works Association, and water Pollution Control federation: Washington, DC.

Barrington, S. 2002. Reducing manure odors and surplus nutrients at the Macdonald Campus farm of McGill University. ASAE/CSAE 2002 Annual International Meeting. July 14-17, 2002 Saskatoon, Saskatchewan Canada

Converse, J.C., R.G. Koegel and J.H. Staub. 2000. Nutrient separation of dairy manure. In Proceedings of the Eight International Symposium on Agriculture and Food

Processing Wastes: St Joseph, Michigan, American Society of Agricultural Engineering. 259-267.

Fleming, R.J., D.M. Dean and M.E. Foran. 1990. Effect of manure spreading on tile drainage water quality. In: Proceedings of the 6th International Symposium on Agricultural and Food Processing Wastes. ASAE, St Joseph, Michigan, USA. 385-392.

FPPLQ. 2004. Annual report. Fédération des producteurs de lait du Québec. Longueuil, Québec.

Holstein Canada. 2005. www.holstein.ca/english/breed/stats.asp-8k-2005

Klute, A. 1965. Laboratory measurement of hydraulic conductivity of saturated soils; methods of analysis, Part 1. American society of Agronomy, Madison, Wisconsin, USA. 210-221.

Leohr, R.C. 1984. Pollution control for agriculture 2nd edition, Academic Press Inc, New York pp. 450

Schwab, G.O., R.K. Frevert, T.D. Edminster and K.K. Barnes. 1986. Soil and water conservation engineering. Third edition, John Wiley and Sons, New York, USA. 432-472.

Sheldrick, B.H. and C. Wang. 1993. Particle size distribution. In: Carter MR (ed) Soil sampling and methods of analysis. Lewis, Boca Raton, FL. pp. 499-511

Simard, R.R., D. Cluis, G. Gangbazo and S. Beauchemin. 1995. Phosphorous status of forest and agricultural soils from a watershed of high animal density. Journal of Environmental Quality: 24, 1010-1017.

Steel, R.G.D. and J. H. Torrie. 1986. Principles and procedures of statistics, a biometrical approach. McGraw Hill Publishers Inc., New York, USA.

Toyama, T., H. Yokrose, S. Yoshida and M. Kuwahara. 1990. Evaluation of land application using secondary effluent in a forest slope: Estimation of drained water quality and discussion of the effect upon soil or plants and behavior of bacteria. Water Resources 24(3), pp. 275-288.

U.S. Department of Agriculture 1992. Agricultural waste management field handbook, National Engineering Services Part 651, Washington D.C. [Online] Available: www.abe.iastate.edu/Ae573_ast475/AWMFH/awmfh.html

Urgel Delisle et Ass. Inc. 1992. Épuration des eaux usées de la laiterie et de ruissellement à la ferme. Document produit pour le Ministère de l'Environnement du Québec sous le programme PARDE-PAAGF. Envirodoq EN 930427. MENV, Québec, Canada.

Urgel Delisle et Ass. Inc. 1994. Évaluation de systèmes de fosse septique- champ d'épuration pour l'épuration des eaux usées de laiterie de ferme. Document produit pour le Ministère de l'Environnement du Québec sous le programme PARDE-PAAGF. Envirodoq EN 940584. MENV, Québec, Canada.

Westerman P.W., L.M Safely, J.C. Barker, and G.M. Chescheir. 1985. Available nutrients in livestock waste. In: Agricultural waste utilization and management, Proceedings of 5th International Symposium on Agricultural Wastes, Chicago IL.

Willer, H.C., X.N. Karamanlis and D.D. Schulte. 1999. Potential of closed water systems on dairy farms. Water Science and Technology 39: 113-119.

Table 3.1. DFE characteristics from selected references.

Nutrients	Units	Ref. 1 M.H.	Ref. 2 M.S.	Ref. 3 M.H.	Ref. 3 M.H+ M.P.	Ref. 3 M.H+M. P+H.A	Ref. 4 M.H+M.S	Ref. 4 M.S.
Total solids	% wet basis		0.52 ± 0.25	0.28	0.60	1.50	0.26	0.75 0.62-0.95
BOD	mg/L	3200						
COD	mg/L			3036	5004			
TN	mg/L		440 ± 150	86.4	200.4	900	136	311 215-451
NH_3-N	mg/L	132 5-625						
NO_3-N	mg/L	0.3-6.5						
P	mg/L	57.6 6-183	90 ± 40	69.6	99.6	99.6	19.1	20.7 13.8-27
K	mg/L		600 ± 200	180	300	399.6	526	612 595-635

References: 1. Leohr 1984 ; 2. Westerman et al. 1985; 3. U.S.D.A. 1992; 4. Ali et al. 2004 reporting the same values as this paper.
Abbreviations: M.H. = Milk House; M.S. = Manure Seepages; M.P. = Milking Parlor; H.A. = Holding area (manure included).

Table 3.2. Recommended and measured irrigation applications rates (Schwab et al. 1986).

Soil texture	Subsurface	Recommended IR mm/h		Measured IR mm/h	Recommended application soil depth mm/m	m.c. at F.C. (%)
		no vegetation	With vegetation			
Fine sand	Deep	25	43	840*	67-83	12
Fine sand	Compact bed	18	30			
Silt	Deep	13	25	50**	166-208	34
Silt	Compact bed	8	15			
Clay		3	5	34 to 60***	108-125	43

Note: IR – irrigation application rate or infiltration rate
* stabilized value for the gravelly sandy soils on Farm B;
** stabilized value for Farm A;
*** stabilized value for the clay soils of Farm B.

Table 3.3a. Description of the six dairy farms used for DFE characterization.

Parameter	Farm A	Farm A-1	Farm A-2	Farm B	Farm C-1	Farm C-2
Cow Number	44	52	50	24	50	60
Solid storage pad m^2/cow	21.8	13.5	10.1	22.9	14.1	11.2
Effluent storage m^2/cow	9.1	5.9	20.2	4.2	None	None
Total storage area, m^2/cow	30.9	19.4	30.3	27.1	14.1	11.2
Manure storage effluent composition	MH MR	MH	MH MR	MR	MR	MR

MR – manure runoff; MH – milk house wastewater; NA – DFE stored within the manure storage.

Table 3.3b. Additional description of Farms A and B

Characteristics	Farm A	Farm B
Number of cows	42 including 35 in lactation	24 including 20 in lactation
Herd	82 heads	42 heads
Manure storage		
-Solid plate-form surface area	30m X 30 m plus entrance for a total of 960 m^2	21m X 25m plus entrance for a total of 525 m^2
-Seepage collection pit	Earthen 18m in diameter at the bottom, 4.3m deep and side slope of 2 hor: 1 ver	Earthen 10m in diameter at the bottom, 2.1m deep with side slope of 2.5 hor: 1 ver
Herd feeding	Corn silage, hay	Corn silage, hay
Bulk tank size	2220 L	1000 L
Milk pipeline length	61.4 m	30.3 m

Table 3.4a. Irrigation tests conducted on Farm A.

Year	Day	Ir.**	Volume applied		Rain*	Soil moisture ***(STD)		GWT depth		Field Outlet Flow
			m^3	m^3/ha	mm	Before %	After %	Before m	After m	m^3
2003	11th July	1st	225	450	0					
	14th July	2nd	115	230	30					
	29th August	3rd	315	630	20					1.6
Total			**655**							
2004	15th July	1st	269	538	6	26.68 (10.4)	34.3 (4.7)	0h- >1.60 3h->1.60 20hr-1.12	0h->1.6 3h->1.6 20h-1.6	
	19th July	2nd	276	552	12	32.65 (5.46)	40.6 (5.0)	0h->1.60 5h-0.80	0h-1.26 5h-0.26	
	2nd August	3rd	341	682	100	30.97 (3.1)	40.8 (4.9)	0hr-1.37 4hr-0.31 6hr-0.45 72hr-1.1	0h-1.30 4h-0.28 6h-0.38 72h-1.3	4.0
Total			**886**							

* Spanning period of 2 days before irrigation; ** Irrigation session, *** Standard deviation.

Table 3.4b. Irrigation tests conducted on Farm B.

Year	Day	Ir.**	Volume applied		Rain*	Soil moisture ***(STD)	
			m^3	m^3/ha	mm	Before %	After %
2003	Sept 22	1st	110	367	0		
	Sept 25	2nd	40	133	0		
Total			**150**				
2004	July 6	1st	115	383	8	15.1 (6.9)	27.8 (4.9)
	July 9	2nd	65	217	0	29.5 (6.1)	36.0 (6.4)
Total			**180**				

* Spanning period of 2 days before irrigation; ** Irrigation session, *** Standard deviation.

Table 3.5a. DFE characteristics for Farms A, A-1, A-2.

characteristics	units		Mean	
		A	A-1	A-2
TS	%	0.230	1.111	0.857
SS	%	0.196	0.889	0.814
DS	%	0.035	0.222	0.043
pH	mg/L	6.8	7.4	7.1
NH4-N	mg/L	28.9	446.3	304.3
TN	mg/L	54.0	597.1	520.3
TP	mg/L	19.5	58.8	19.6
TK	mg/L	777.0	490.0	218.0
TC	10^3/100ml	20.0	187.0	233.3
FC	10^3/100ml	1.7	160.0	87.0
FS	10^3/100ml	2.2	683.0	545.0
FC/FS ratio		0.77	0.23	0.16

Note : On Farms A, A-1 and A-2, the collection pit receives manure seepages and milk house DFEs.

- TC, FC and FS = Total Coliforms, Fecal Coliforms and Fecal Streptococci.

Table 3.5b. DFE characteristics for Farms B, C-1, C-2

characteristics	units		Mean	
		B	C-1	C-2
TS	%	0.750	2.281	3.290
SS	%	0.675	2.167	2.961
DS	%	0.075	0.114	0.329
pH	mg/L	7.3	6.9	6.7
NH4-N	mg/L	132.0	962.4	1430.5
TN	mg/L	171.9	1061.7	1786.2
TP	mg/L	14.7	134.4	140.8
TK	mg/L	338.0	860	1075
TC	10^3/100ml	4.0	316.7	993
FC	10^3/100ml	1.0	220.0	510
FS	10^3/100ml	28.0	7133.3	6433
FC/FS ratio		0.03	0.03	0.08

Note: On Farm B, the collection pit receives only manure seepages.

On Farms C-1 and C-2, the samples are manure seepages collected from structure used to store both the solid manure and the manure seepages.

- TC, FC and FS = Total Coliforms, Fecal Coliforms and Fecal Streptococci.

Table 3.5c. DFE characteristics for Farm A

Parameter	Units	Characteristics of liquid manure pit					
		2004				Average	Average
		Top	Middle	Bottom	Average	2003	2002
	%	0.28	0.45	0.59	0.44	0.26	0.23
	%	0.27	0.37	0.50	0.37	0.23	0.20
	%	0.04	0.00	0.02	0.02	0.03	0.03
	%	0.02	0.08	0.07	0.05		
pH		7.9	6.9	6.9	7.2	7.1	6.8
TN	mg/L	71	153	231	151	136	54
TP	mg/L	18.6	31.2	40.8	30.2	19.1	19.5
TK	mg/L	382	583	754	573	526	777
COD	mg/L	1292	2106	3200	2199		
TC	10^3/ml	10	87	30	42	84	20
FC	10^3/ml	1.0	13	28	14	3.0	1.7
FS	10^3/ml	0.20	10	110	40	1.1	22
FC/FS ratio		5	1.3	0.25	0.35	2.73	0.08

- TC, FC and FS = Total Coliforms, Fecal Coliforms and Fecal Streptococci.
- Farm A: manure seepages and milk house DFE

Table 3.5d. DFE characteristics for Farm B.

Parameter	Units	Characteristics of liquid manure pit					
		2004				Average	Average
		Top	Middle	Bottom	Average	2003	2002
TS	%	0.89	1.58	1.54	1.32	0.75	0.75
DS	%	0.71	1.28	1.38	1.12	0.70	0.68
SS	%	0.04	0.07	0.05	0.05	0.05	0.07
Sett. S	%	0.09	0.23	0.11	0.14		
pH		7.57	7.02	7.02	7.2	7.4	7.3
TN	mg/L	313	1375	1008	899	311	172
TP	mg/L	34.1	51.8	36.6	40.8	20.7	14.7
TK	mg/L	948	752	713	805	612	338
COD	mg/L	3966	13636	13744	10449		
TC	10^3/ml	12	55	29	32	81	4.0
FC	10^3/ml	1.0	15	29	15	8.3	1.0
FS	10^3/ml	10	300	270	193	150	120
FC/FS ratio		0.1	0.05	0.11	0.08	0.05	0.008

- TC, FC and FS = Total Coliforms, Fecal Coliforms and Fecal Streptococci.
- Farm B: manure seepages only

Table 3.6. DFE application rate to meet crop nutrient requirements.

Farm A	Application to meet crop requirements (m^3/ha)		
Year	N	P_2O_5	K_20
2002	2780	1390	125
2003	1040	1360	185
2004	940	860	170
Farm B			
Year	N	P_2O_5	K_20
2002	870	1800	285
2003	500	1000	160
2004	170	660	120
Crop requirement*	150	62	120

Note: *corn silage nutrient uptake in Kg/ha for a yield of 30 tons/ha at 35% dry matter content.

Table 3.7. Dairy effluent application cost using the surface irrigation system versus a conventional tanker system

Surface irrigation system					
Operation	Time (h)	Manpower needed	Manpower cost (\$)^{z}	Equipment needed	Equipment cost (\$)^{y,x}
Installation & dismantling	2	2	40.00	30kW tractor and wagon	100.00
Application	4	1	40.00	Irrigation pipe, 80kW tractor, manure pump	850.00
Effluent application rate = 250 m^3 h^{-1}; **Cost = \$0.95 m^{-3} of dairy effluent**					
Conventional tanker system					
Operation	Time (h)	Manpower needed	Manpower cost (\$)	Equipment needed	Equipment cost (\$)^{y,x}
Installation & dismantling	1.0	2	20.00	Tanker, pump and loading pipe	50.00
Loading and application	20	1	200.00	2- 80kW tractors, manure pump and tanker	3000.00
Effluent application rate = 50 m^3 h^{-1} ; **Cost = \$3.05 m^{-3} of dairy effluent**					

^{z}Manpower cost \$10 h^{-1}

^{y}Equipment costs include machinery operating, depreciation and investment costs, and were assessed from the following purchasing and rental costs: \$5 000 for the irrigation pump and \$4 000 for the irrigation pipe depreciated over 15 years; \$30 h^{-1} for the 30kW tractor, \$20 h^{-1} for the wagon carrying the irrigation pipe; \$50 h^{-1} for the 80kW tractor; \$50 h^{-1} for a tanker and manure pump.

^{x}Cost computed on the basis that two dairy farms share the equipment and spread 1000m^3 of effluent yr^{-1}.

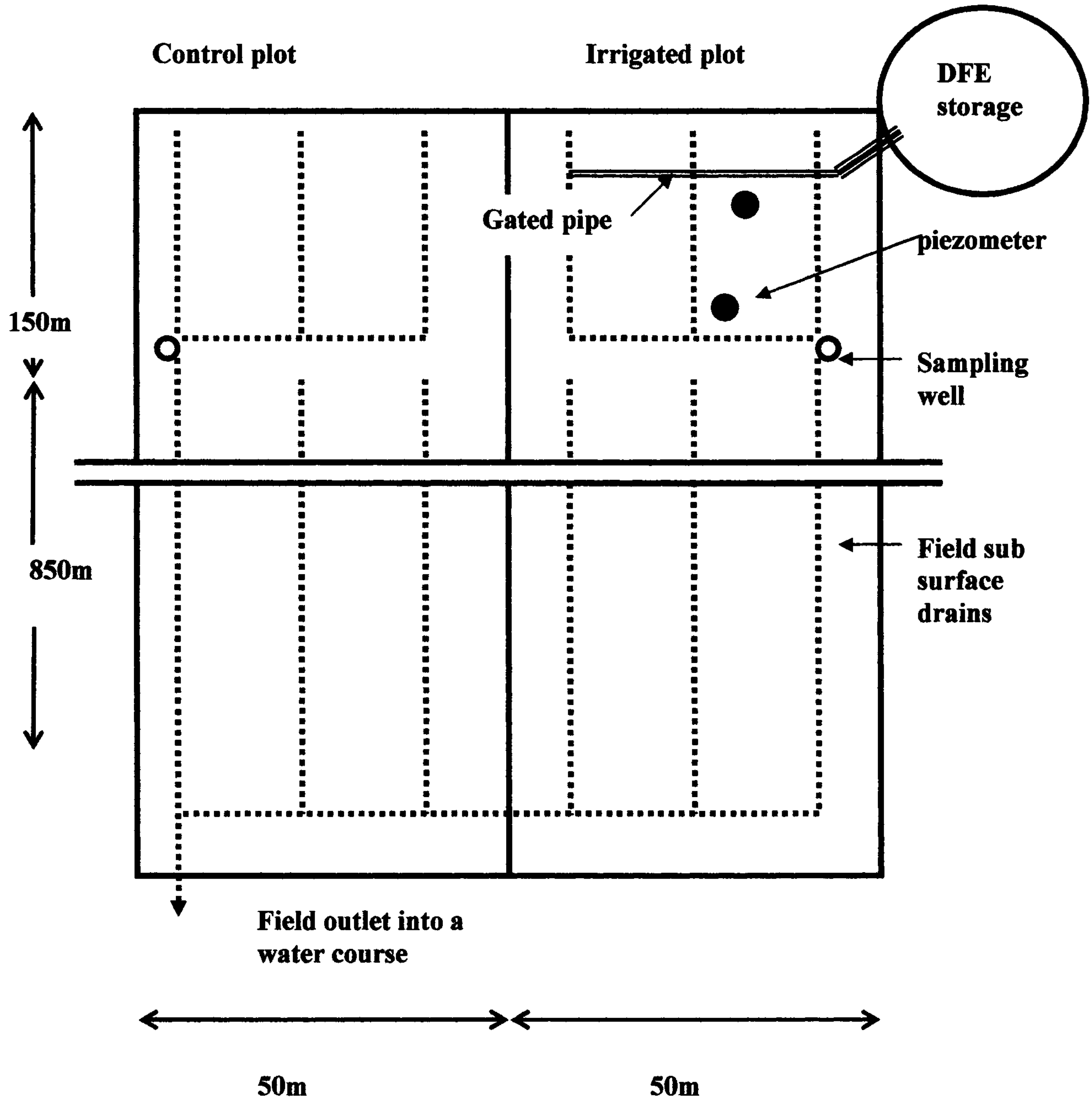


Fig. 3.1a. Experimental plots of Farm A.

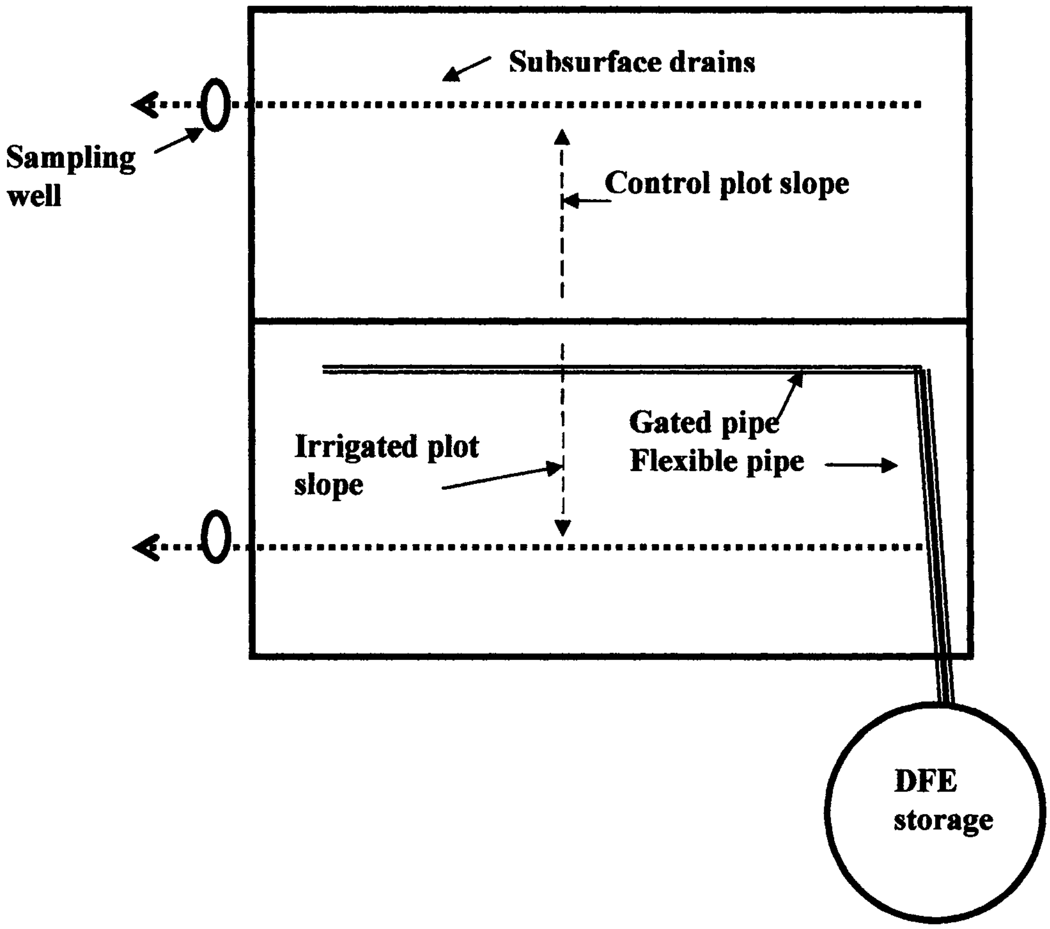
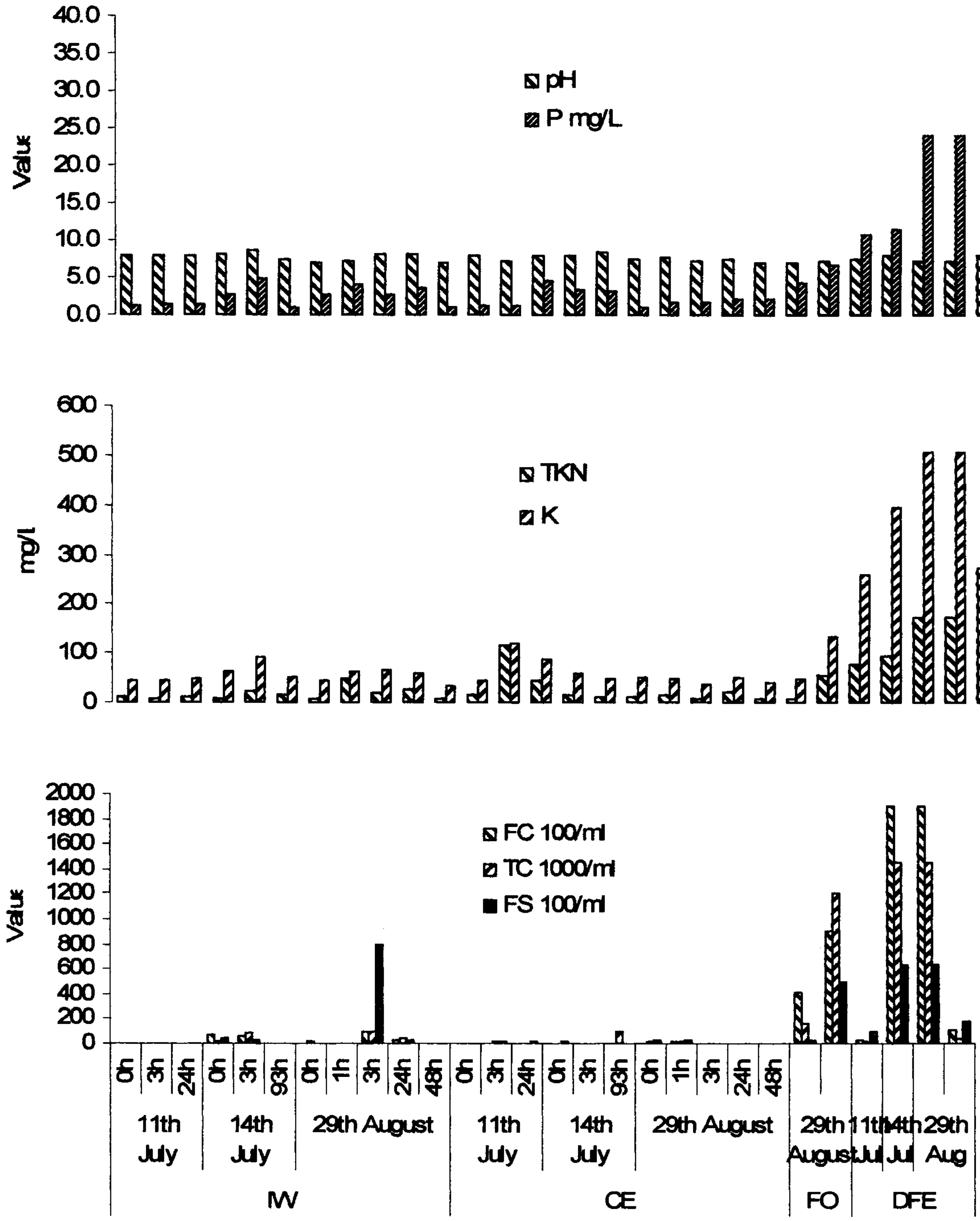
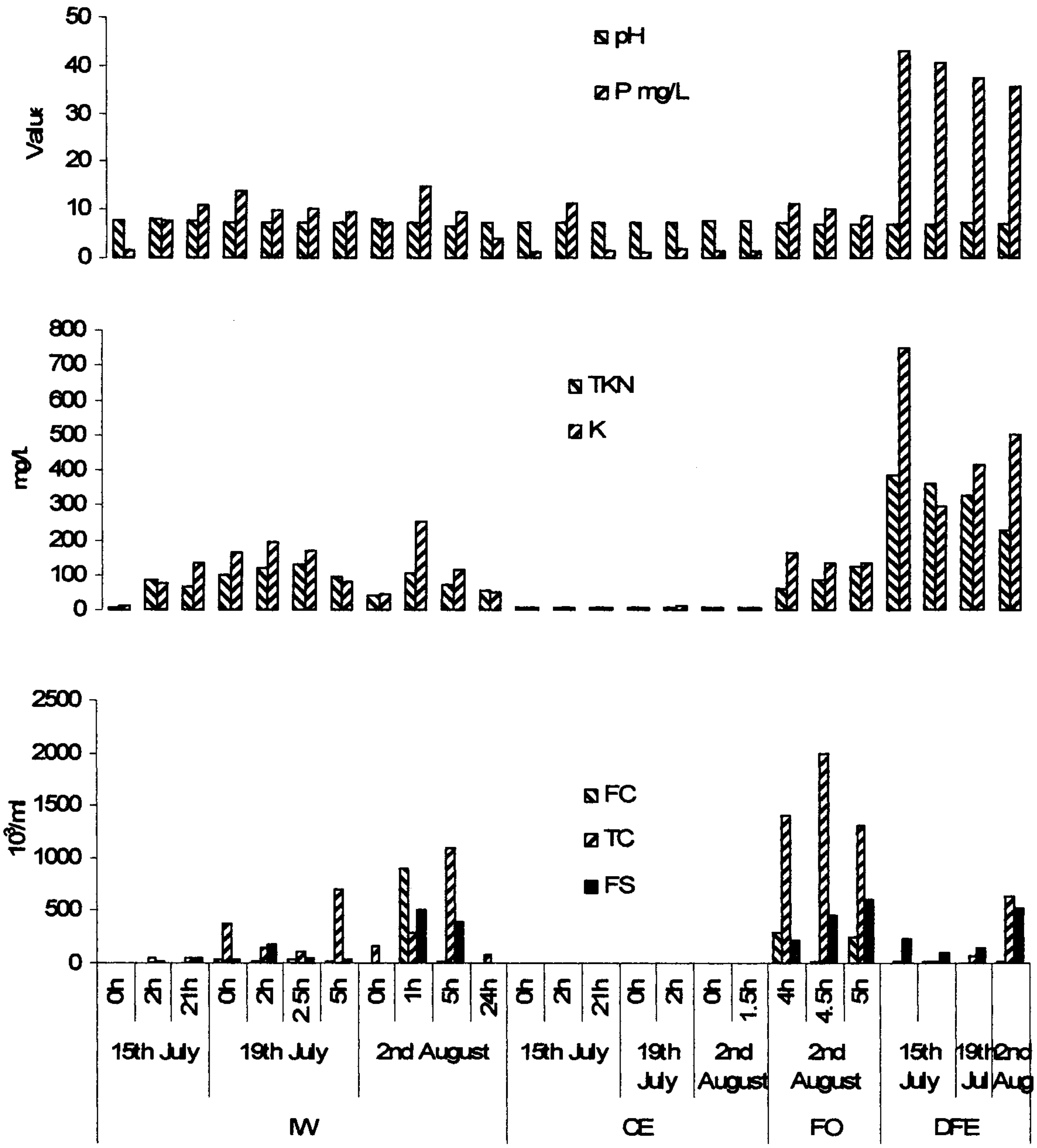


Fig. 3.1b. Experimental plots of Farm B.



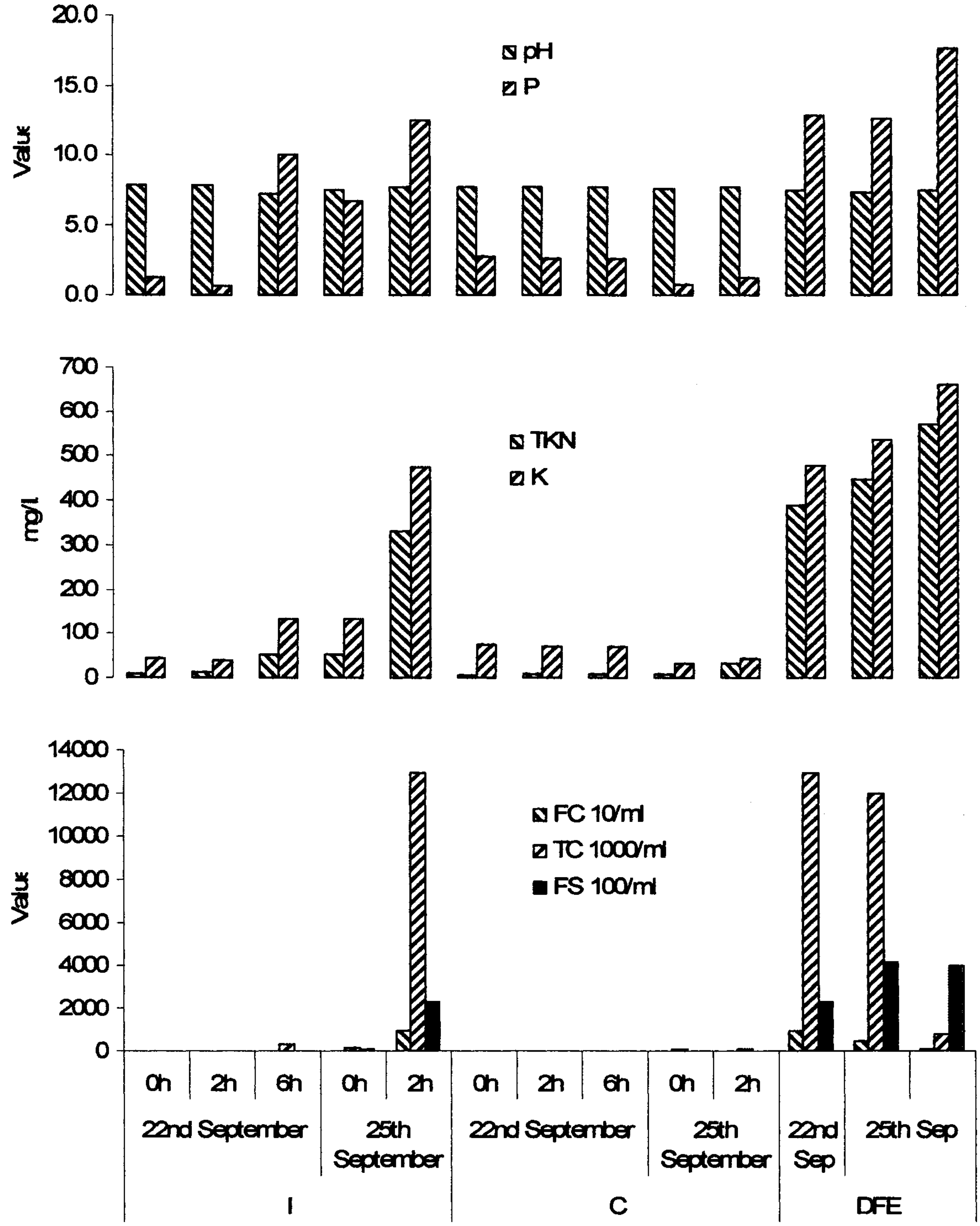
IW: Irrigation on western plot, CE: Control on eastern plot, FO: Flow from subsurface drainage field outlet, DFE: Applied dairy farm effluent and 0h: start of irrigation (representing time of sample taken from irrigated and control sampling wells).

Fig. 3.2a. Water quality of sampled drainage water of Farm A in 2003



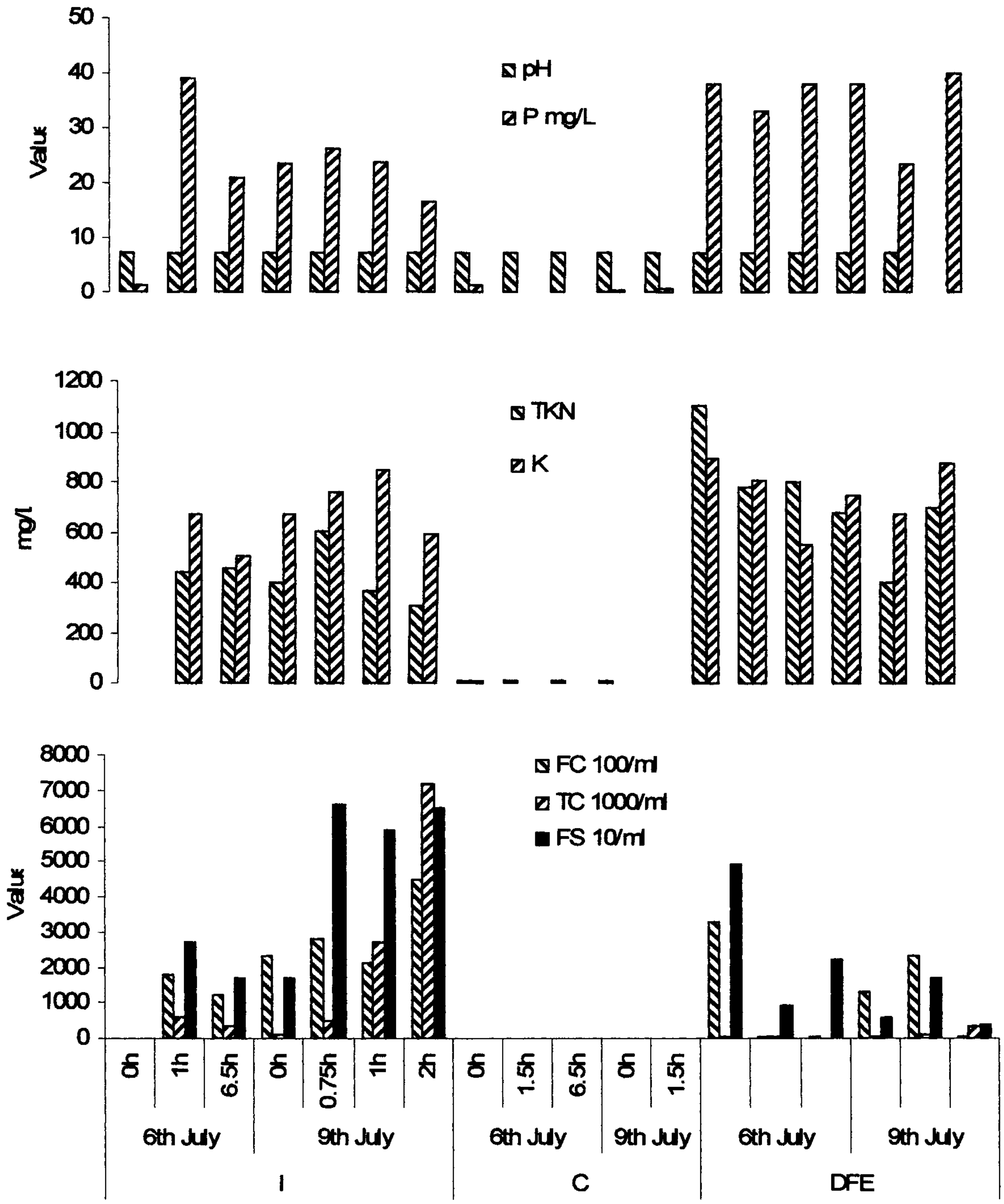
IW: Irrigation on western plot, CE: Control on eastern plot, FO: Flow from subsurface drainage field outlet, DFE: Applied dairy farm effluent and 0h: start of irrigation (representing time of sample taken from irrigated and control sampling wells).

Fig. 3.2b. Water quality of sampled drainage water of Farm A in 2004



I: Irrigated plot, C: Control, DFE: Applied dairy farm effluent and 0h: start of irrigation (representing time of sample taken from irrigated and control sampling wells).

Fig. 3.3a. Water quality of sampled drainage water of Farm B in 2003



I: Irrigated plot, C: Control, DFE: Applied dairy farm effluent and 0h: start of irrigation (representing time of sample taken from irrigated and control sampling wells).

Fig. 3.3b. Water quality of sampled drainage water of Farm B in 2004

CONNECTING STATEMENT

Chapter 4 deals with the impact of heavy application of dairy farm wastewater on soil and crop quality. The study was conducted on two different farms, soil samples were taken at three depths and effect of this wastewater application was seen at these depths and distances from irrigation the irrigation pipe to see the uniformities of irrigation. The project monitored the evolution of nutrient levels and crop yield on experimental sites, each consisting of control and irrigated plot

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The contributions of the authors are: i) First author carried out entire experimental work: field work, analyzed collected samples, and collaborated in the writing of the article. ii) Second author supervised the research, gave scientific advice on the experimental method, and collaborated and corrected in the writing of the article. iii)) Third author edited, collaborated and made critical but crucial suggestions in the writing the article. She also helped the author in statistical analysis. iv) Fourth author gave scientific advice in writing the article and helped in laboratory work. iv) Fifth author helped in field study and data collection.

Chapter 4

Applying dairy effluent by surface irrigation to improve soil fertility and forage production

4.1 INTRODUCTION

Dairy farms produce large volumes of effluent that must be disposed of in an environmental sensitive manner. Dairy effluent is composed of milk house wash water, generated from the cleaning of milk pipelines and bulk storage tanks, and manure seepage from solid manure storages (Willers et al. 1999). In Québec, a dairy farm with 50 milking cows and an equal number of replacement animals generates between 275 and 350 m^3 y^{-1} of milk house wash water, with about 550 m^3 y^{-1} of seepage from manure decomposition mixed with precipitation in roofless solid manure storages. It is estimated that dairy farms generate 500 to 900 m^3 of effluent that must be disposed of in an environmentally sensitive manner each year (FPPLQ 2004).

One general option is to land apply on forages and silage crops, dairy effluent with a tanker pulled by a farm tractor or on a truck (Macoon et al. 2002). Dairy effluent contains about 0.3 to 0.6 g total N L^{-1}, between 0.05 and 0.13 g total P L^{-1} and 0.4 to 0.8 g total K L^{-1}, which is less than 20% of the nutrient content of liquid manure and slurries (Westerman et al. 1985; USDA 1992; Longhurst et al. 2000). The fertilizer value of dairy effluent is therefore relatively low. The application of 100 m^3 of dairy effluent with a tanker would supply about 10 to 15% of the N required in grass-dominated hayfields or for corn silage production (CRAAQ 2003). Repeated trips with the tanker would be needed to meet crop N requirements in such systems, which could lead to soil compaction. At higher effluent application rates, ponding and surface runoff could occur. While dairy effluent can be applied year round in semi-tropical areas (Woodard et al. 2003), producers in temperate regions have less flexibility. Legislation in Québec limits the application period for dairy effluent from April 1 to October 1 (Ministère de l'environnement du Québec 2002). This poses a challenge for producers choosing to spread dairy effluent with a tanker, since such applications can only occur before planting or after harvest in row cropped systems, or between hay crops.

Irrigation systems have been used to apply dairy effluent (Longhurst et al. 2000; Woodward et al. 2003; Houlbrooke et al. 2004). These systems permit larger and more controlled applications of effluent than tanker trucks and can deliver irrigation water and nutrients for crop production throughout the season. Soil fertility can be improved after several years of dairy effluent application (Hawke and Summers 2003). However, dairy effluent is not a balanced nutrient source and applications based on crop N requirements often provide P and K in excess of crop needs (Johnson et al. 2004; Wang et al. 2004). In addition, irrigation can increase soil nitrate and phosphate losses through leaching (Di et al. 1998; Woodard et al. 2003; Toor et al. 2005). Research is needed to determine the economic and environmental consequences for Canadian dairy producers of applying dairy effluent to agricultural land through surface irrigation.

The objective of this research was to determine whether applying dairy effluent through surface irrigation would improve soil fertility on dairy farms in Québec. We also compared the costs of applying dairy effluent with a surface irrigation system and by tanker.

4.2 Materials and Methods

4.2.1 Farm Description

Two farms in Saint Anicet, Québec (45° 10' N, 73° 04' W) were selected for the study. Farm A has a herd of 44 dairy cows and a similar number of replacement animals, while Farm B has 24 milking cows and a similar number of replacement animals. Soils on these farms are light-textured (<30% clay) Humic Gleysols of the Ste. Barbe series (Farm A) and Norton series (Farm B).

4.2.2 Experimental Design

At each farm, two experimental plots were established. One plot was non-irrigated (control) and the other was irrigated with dairy effluent. At Farm A, the plots (each 50 m wide by 100 m long) were located on a north-facing slope (1% slope over a distance of 150 m). Soil texture along the slope was silty loam in the top 30-40 cm underlain by clay. On Farm B, the plots (each 50 m wide by 60 m long) were located on a south-facing slope (3.5% slope over a distance of 60 m). The soil was a shallow sandy loam (about 20-30 cm deep) over gravel at the top- and mid-slope positions, changing to a loam over gravel at the bottom of the slope. A sampling grid was established at each farm (Figs. 41a, 41b) and soils were collected from the 0-20 cm and 20-40 cm depths for plot characterization before treatments were applied (Table 4.1). In mid-May 2004, the plots were cultivated with a disk harrow and seeded with mixed cereals (*Triticum aestivum* L., *Hordeum vulgare* L. and *Avena sativa* L.) for animal forage. No fertilizers were applied to the experimental plots.

Dairy effluent was applied to the irrigated plots during the summer of 2004 using a surface irrigation system. Effluent was transferred from the storage pit by a liquid manure vacuum pump (capacity of 60 to 600 m^3 h^{-1}) attached to a flexible non-perforated plastic tube (150 cm diameter). The plastic tube was 100-200 m long, depending on the distance from the effluent storage pit and the irrigated plot on the farm. The vacuum pump was powered by the power takeoff (PTO) of a standard 80 kW farm tractor. It pumped effluent through the plastic tube to a gated irrigation pipe (45 m long), installed perpendicular to the ground slope so the effluent traveled down the slope by gravity. The irrigation rate was controlled by a flow meter installed about 15 m from the pump, to respect the water infiltration capacity at the site. Flow meter readings were verified by monitoring the effluent level in the storage pit.

Dairy effluent was applied three times to the irrigated plot on Farm A, and twice to the irrigated plot on Farm B during the summer of 2004. The effluent on Farm A consisted of milk house wash water and manure seepage from the solid manure storage, whereas the dairy effluent on Farm B was manure seepage only. Effluent samples were collected from the gated pipe at 5 min intervals during the first hour of irrigation, composited and stored at 4°C until analysis. All analyses were conducted using standard methods (APHA 1998). Total solids were determined gravimetrically after drying for 24h at 103°C. After digesting all samples at 500°C using 18M sulphuric acid and 50% hydrogen peroxide, the TKN was determined using an ammonia sensitive probe connected to an Orion pH meter, and TP and TK were determined colorimetrically. The pH of all samples was determined using a pH probe connected to an Orion meter. Effluent characteristics and the quantity applied at each irrigation event are provided in Tables 4.2a and 4.2b.

4.2.3 Soil Analysis

Before applying dairy effluent, three soil cores (each 10 cm long, 3 cm diameter) were collected at each sampling point in the irrigated plot, composited and oven-dried (60°C for 48 h) to determine the gravimetric moisture content. Three soil cores were also taken from the 0-10 cm layer of the irrigated plot for moisture content and soil nutrient analysis about 24 h after effluent was applied, composited and stored at 4°C. Within one week, the NH_4-N and NO_3-N concentrations on sieved (<2 mm) field-moist soils were determined in 2 M KCl extracts (1:5 soil:solution) using the cadmium reduction-diazotization and salicylate methods (Maynard and Kalra 1993; Lachat Instruments 2000). Extracts were analysed on a Lachat Quik-Chem AE flow injection autoanalyzer (Lachat Instruments, Milwaukee, WI, USA). Then, soils were oven dried (60°C for 48 h) to determine the gravimetric moisture content and analyzed for Mehlich-3 extractable P and K (Tran and Simard 1993). The Mehlich-3 P concentration was determined using the ammonium molybdate-ascorbic acid method (Murphy and Riley 1962) on a Lachat Quik-Chem AE flow injection autoanalyzer (Lachat Instruments, Milwaukee, WI, USA), while the Mehlich-3 K concentration was determined by atomic absorption spectrometry.

About two weeks after the final effluent application (15 August 2004 on Farm A, 30 July 2004 on Farm B), soil was collected from the 0-20 cm and 20-40 cm depths at each sampling point using an auger (4.5 cm diameter), dried (60°C for 48 h) and sieved (<2 mm mesh). Soil pH was determined on 1:2 soils:water slurries (Hendershot et al. 1993). Soil nutrients (P, K, Mg, Ca and Al) were extracted with Mehlich III solution (1:10 soil:solution) for after shaking for 5 min at 130 rpm (Tran and Simard 1993). The P concentration was analyzed by the ammonium molybdate-ascorbic acid method described above, while K, Mg, Ca and Al concentrations were determined by atomic absorption spectrometry. The P/Al ratio was calculated from equation 4.1:

$$\text{P/Al ratio} = (\text{Mehlich III P} / \text{Mehlich III Al}) * 1.12 * 100\% \qquad (4.1)$$

where Mehlich III P and Mehlich III Al are the concentrations (mg kg^{-1}) of P and Al in Mehlich III extracts and the factor 1.12 is used for comparison with plasma emission spectrometry (CRAAQ 2003).

4.2.4 Forage Analysis and Yield

Crop failure occurred on Farm A due to poor stand establishment and inadequate weed control, thus no data were collected on forage characteristics or yield. On Farm B, forage samples were collected from 4 random locations (0.5 m x 0.5 m quadrats) in the irrigated plot and 4 random locations (0.5 m x 0.5 m quadrats) in the non-irrigated plot in August 2004. Samples were oven-dried (60°C for 48 h) and ground (<1 mm mesh) before analysis for total fiber, using the neutral detergent fiber (NDF) technique, and protein content with the acid detergent fiber (ADF) method (AOAC 1990; Van Soest et al. 1991). Yield estimates for the irrigated and non-irrigated plot were expressed on a tonnes (dry matter) of forage ha^{-1} basis.

4.2.5 Statistical Analysis

Data were log transformed to equalize variance, and the effect of irrigation on the soil moisture content and soil fertility parameters was evaluated with pairwise Student *t*-tests (95% confidence level).

4.3 Results and Discussion

About 65 to 75% of the plot area was visibly covered with dairy effluent during irrigation. Soil moisture in the top 10-cm increased from 1.0 to 13.2% (gravimetric moisture basis) after irrigation events on Farm A, and by up to 16.3% after irrigation on Farm B (Table 4.3). There was a significant increase ($P<0.05$, contrast analysis) in soil moisture following all dairy effluent applications at Farm A, and that of July 6th at Farm B (Table 4.3). Soil moisture did not differ before and after irrigation on July 9th at Farm B, as the time between this event and the previous irrigation event (3 days earlier) was too short for the soil to dry. The surface irrigation system provided even distribution of effluent across the plot, as indicated by the similarity in soil moisture content at the pipeline (0 m) and at down slope sampling positions on Farm A and Farm B (Table 4.3). No difference was found in the extractable N (NH_4 + NO_3), extractable P and extractable K concentration between pipeline and down slope sampling positions at Farm A and Farm B (data not shown). These results indicate that the surface irrigation system delivered water and nutrients from dairy effluent evenly over the irrigated plot on these farms, despite the visual 75% soil surface coverage.

After the last effluent application, the irrigated plot had a higher pH than the non-irrigated plot in the 0-20 cm depth of Farm A and Farm B, as well as in the 20-40 cm depth of Farm A (Table 4.4). The apparent liming effect of the dairy effluent may have occurred as H^+ ions were replaced by other cations (e.g., K^+, Ca^{2+}, Mg^{2+}) originating from the dairy effluent or solubilized from soil minerals. More extractable P, K, Ca and a greater P/Al ratio was found in the 0-20 cm depth on Farm A, as well as more K, Ca and Mg in the 20-40 cm depth (Table 4.4). Since there was no forage production on Farm A due to poor stand establishment, it is not surprising that effluent applications increased extractable nutrient concentrations because heavy applications of dairy effluent provide an ample source of water-soluble nutrients (Westerman et al. 1985; Longhurst et al. 2000). Although the P/Al ratio in the 0-20 cm depth at Farm A increased to 0.128 (Table 4.4), this is still below the critical P/Al ratio of 0.131 set for light-textured soils with <30% clay in Québec (Ministère de l'environnement du Québec 2002). The apparent leaching of K, Ca and Mg to the 20-40 cm depth of the irrigated plot on Farm A does not pose an environmental concern because forage crops are still capable of recovering nutrients from this depth, and the underlying marine clay should also readily adsorb these cations.

The application of dairy effluent had a direct, beneficial effect on forage production at Farm B. Yield was estimated at 11.5 Mg dry matter (dm) ha^{-1} in the irrigated plot, which was 22% higher than the 9.0 Mg dm ha^{-1} harvested from the non-irrigated plot. In addition, the irrigated plot produced forage of higher quality, with more protein and less fiber than forage from the non-irrigated plot (data not shown). The increase in forage yield and quality was likely due to the timely application of irrigation water in July, as crops typically experience water stress when evapotranspiration exceeds precipitation.

There was more extractable K and Ca in the 0-20 cm depth of the irrigated plot than the non-irrigated plot on Farm B, suggesting that dairy effluent applications provided these nutrients in excess of forage requirements (Table 4.4). When applied at rates that match the N requirements of crops, the quantities of K supplied by dairy effluent are often in excess of crop nutrient requirements (Hawke and Summers 2003; Wang et al.

2004). While K accumulation is not expected to be negatively affect crop production or lead to environmental pollution, the K/Mg ratio in forages should be monitored, as imbalances are known to cause the physiological disorder hypomagnesemia (grass tetany) in dairy cows (Havlin et al. 1999). Regular soil testing of irrigated farmland is recommended to ensure that dairy effluent applications do not increase the P/Al ratio above the critical levels, and that extractable cation ratios are balanced, particularly in soils that are used to produce forage crops.

4.3.1 Economics of Applying Dairy Effluent with a Surface Irrigation System

It is evident that applying dairy effluent through surface irrigation can improve soil fertility and increase forage production. Yet, producers require information on the costs and ease of operation of surface irrigation before investing in such a system.

On 11 July 2003, a trial was conducted on Farm A to determine the equipment, manpower and time required to load and apply dairy effluent to fields within 1 km of the effluent storage with surface irrigation versus a tanker pulled by a farm tractor. Gated irrigation pipe (45 m) was installed and connected to the effluent storage by two people in 30 min. One tractor was required to power the liquid manure pump, and one operator was needed to monitor the irrigation event that delivered 225 m^3 of dairy effluent to the field in 55 min. To transfer effluent to the tanker, a loading pipe was installed at the effluent storage by two people in 15 min. It took 5 min to load the tanker truck with 8 m^3 of dairy effluent and 5 min to apply the dairy effluent to the field. This system can be managed by one person who operates the tractor and liquid manure pump at the effluent storage to fill the tanker and then hauls the load with a second tractor to the field where effluent is applied. In this trial, the tanker pulled by a tractor applied 32 m^3 of dairy effluent to the field in 40 min. We estimate that it cost \$0.95 to apply 1 m^3 of dairy effluent using the surface irrigation system, which is cheaper than the tanker truck system at \$3.05 m^{-3} of dairy effluent (Table 4.5).

4.4 Conclusions

There are many benefits to using a surface irrigation system to apply dairy effluent. First, it can deliver large quantities of effluent more rapidly and inexpensively than a conventional tanker. The dairy effluent used in this study did not clog the pipelines and odor emissions were negligible as the effluent was released at the ground level, under the crop canopy. Once installed, the irrigation pipeline can be used to make controlled applications of water and nutrients from dairy effluent throughout the growing season, as required by the crop. Applying dairy effluent with a surface irrigation system is simple and economical, and has the potential to improve soil fertility and increase crop production on dairy farms in Québec.

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American Public Health Association. 1998. Standard methods for the examination of water and wastewater. 20th ed. American Public Health Association, American Water Works Association, and Water Pollution Control Federation, Washington, DC.

Association of Official Analytical Chemists. 1990. Official methods of analysis. 15th ed. Association of Official Analytical Chemists, Arlington, VA. 82 p.

Centre de Reférence en Agriculture et Agroalimentaire du Québec (CRRAQ). 2003. Guide de référence en fertilisation, 1re édition. Sainte-Foy, QC. 294 p.

Di, H. J., Cameron, K. C., Moore, S. and Smith, N. P. 1998. Nitrate leaching and pasture yields following the application of dairy shed effluent or ammonium fertilizer under spray or flood irrigation: results of a lysimeter study. Soil Use Manage. **14**: 209-214.

Fédération des producteurs de lait du Québec (FPPLQ). 2004. Rapport de production 2004 du PATLQ – Numéro spécial. Fédération des producteurs de lait du Québec. Longueuil, QC. 41 p.

Havlin, J. L., Beaton, J. D., Tisdale, S. L. and Nelson, W. L. 1999. Soil fertility and fertilizers. 6th ed. Macmillian Publishing Co., NY. 499 p.

Hawke, R. M. and Summers, S. A. 2003. Land application of farm dairy effluent: results from a case study, Wairarapa, New Zealand. New Zealand J. Agr. Res. **46**: 339-346.

Hendershot, W. H., Lalonde, H. and Duquette M. 1993. Soil reaction and exchangeable acidity. Pages 141-145 *in* M.R. Carter, ed. Soil sampling and methods of analysis. Lewis Publishers, Boca Raton, FL.

Houlbrooke, D. J., Horne, D. J., Hedley, M. J. and Hanly, J. A. 2004. The performance of traveling effluent irrigators: assessment, modification, and implications for nutrient loss in drainage water. New Zealand J. Agr. Res. **47**: 587-596.

Johnson, A. F.., Vietor, D. M., Rouquette, F. M. and Haby, V. A. 2004. Fate of phosphorus in dairy wastewater and poultry litter applied on grassland. J. Environ. Qual. **33**: 735-739.

Lachat Instruments. 2000. Methods manual. Lachat Instruments, Milwaukee, WI.

Longhurst, R. D., Roberts, A. H. C. and O'Connor, M. B. 2000. Farm dairy effluent: a review of published data on chemical and physical characteristics in New Zealand. New Zealand J. Agr. Res. **43**: 7-14.

Macoon, B. , Woodard, K. R., Sollenberger, L. E., French, E. C., Portier, K. M., Graetz, D. A., Prine, G. M. and Van Horn, H. H. 2002. Dairy effluent effects on herbage yield and nutritive value of forage cropping systems. Agron. J. **94**: 1043-1049.

Maynard, D. G. and Kalra, Y. P. 1993. Nitrate and exchangeable ammonium nitrogen. Pages 25-38 *in* M.R. Carter, ed. Soil sampling and methods of analysis. Lewis Publishers, Boca Raton, FL.

Ministère de l'Environnement du Québec. 2002. Règlement sur les exploitations agricoles. Loi sur la qualité de l'environnement. Article 35 and Annexe 1.3. Gouvernement du Québec. Québec City, QC.

Murphy, J., and Riley, J. R. 1962. A modified single solution method for the determination of phosphate in natural waters. Anal. Chim. Acta. **27**: 31-36.

Sheldrick, B. H. and Wang C. 1993. Particle size distribution. Pages 499-511 *in* M.R. Carter, ed. Soil sampling and methods of analysis. Lewis Publishers, Boca Raton, FL.

Toor, G.S., Condron, L. M., Cade-Menun, B. J., Di, H. J. and Cameron, K. C. 2005. Preferential phosphorus leaching from an irrigated grassland soil. Eur. J. Soil Sci. **56**: 155-167.

Tran, T. S. and Simard, R. R. 1993. Mehlich-extractable elements. Pages 43-49 *in* M.R. Carter, ed. Soil sampling and methods of analysis. Lewis Publishers, Boca Raton, FL.

United States Department of Agriculture (USDA). 1992. Agricultural waste management field handbook. National Engineering Services, Part 651, Washington, DC. [Online]. Available: www.abe.iastate.edu/Ae573_ast475/AWMFH/awmfh.html

Van Soest, P. J., Robertson, J. B. and Lewis, B. A. 1991. Methods for dietary fiber, neutral detergent fiber and non-starch polysaccharides in relation to animal nutrition. J. Dairy Sci. **74**: 3583-3597.

Wang, H., Magesan, G. N. and Bolan, N. S. 2004. An overview of the environmental effects of land application of farm effluents. New Zealand J. Agr. Res. **47**: 389-403.

Westerman P. W., Safely, L. M., Barker, J. C. and Chescheir, G. M. 1985. Available nutrients in livestock waste. Pages 191-210 *in* Proc. 5th Int. Symp. Agr. Wastes. Chicago, IL. 1985 Dec. 16-17. Am. Soc. Agr. Eng., St. Joseph, MI.

Willers, H. C., Karamanlis, X. N. and Schulte, D. D. 1999. Potential of closed water systems on dairy farms. Wat. Sci. Technol. **39**: 113-119.

Woodard, K. R., French, E. C., Sweat, L. A. Graetz, D. A., Sollenberger, L. E. Macoon, B., Portier, K. M., Rymph, S. J., Wade, B. L., Prine, G. M. and Van Horn, H. H. 2003. Nitrogen removal and nitrate leaching for two perennial, sod-based forage systems receiving dairy effluent. J. Environ. Qual. **32**: 996-1007.

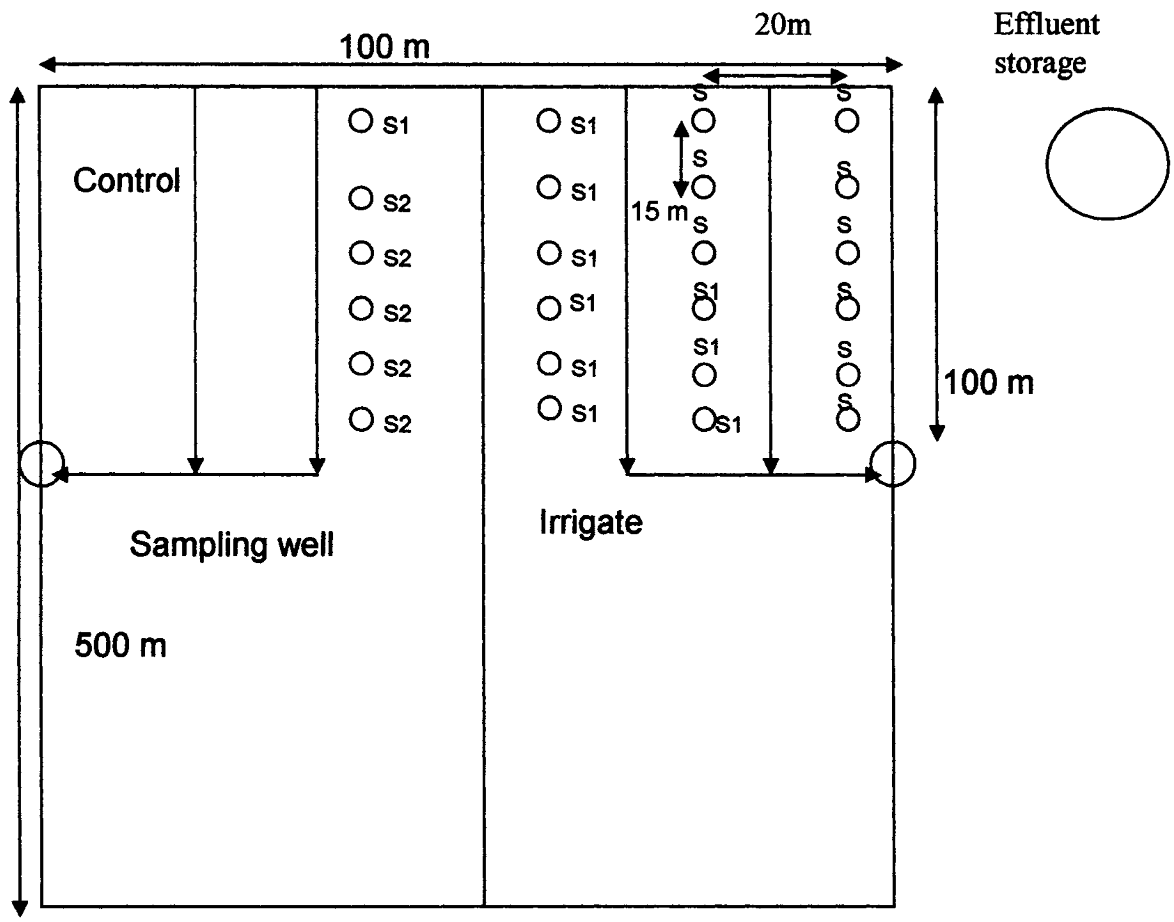


Fig. 1a. Soil sampling grid on Farm A

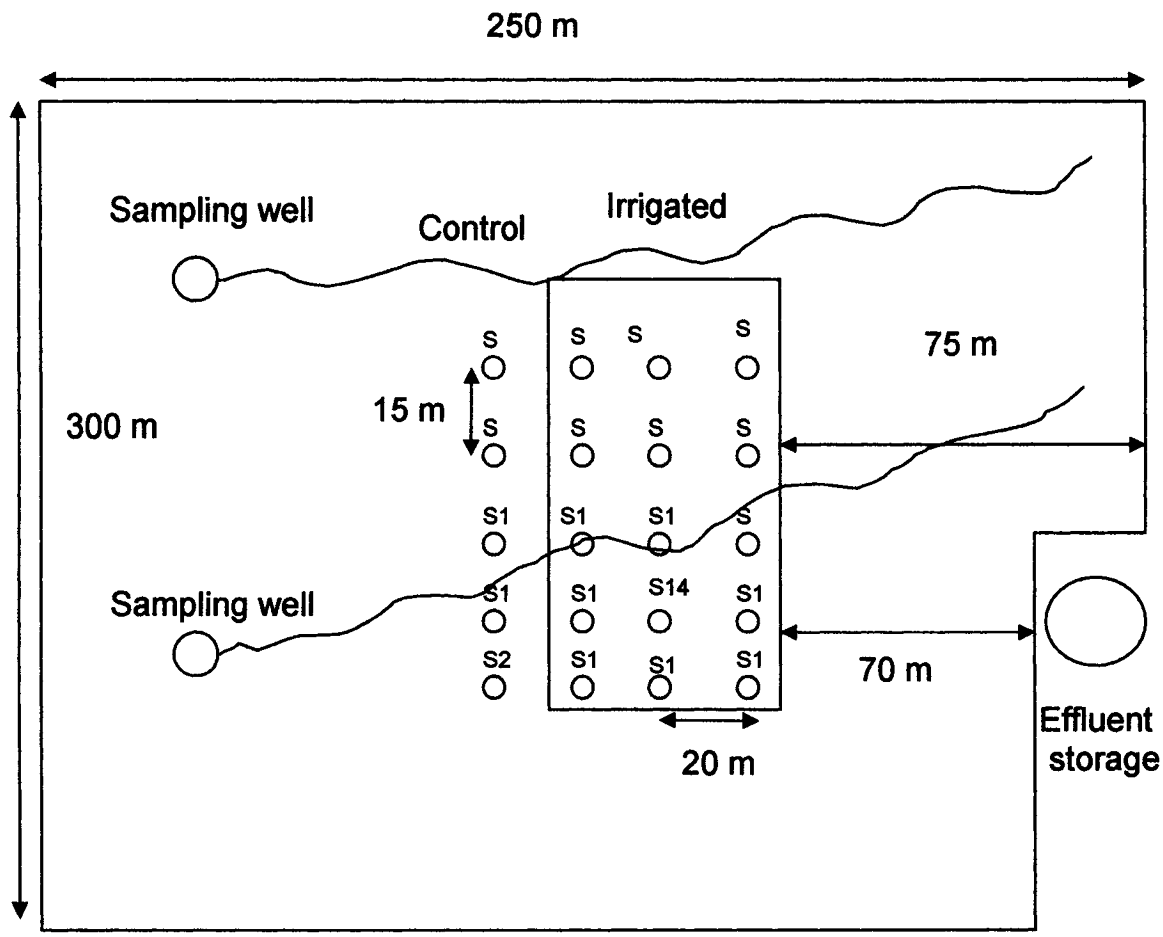


Fig. 1b. Soil sampling grid on Farm B

Table 4.1. Soil characteristics at the experimental plots on Farm A and Farm B prior to irrigation events (May 2004). Values are the mean of at least 19 measurements

Parameter	Farm A	
	0-20 cm	20-40 cm
Sand (g kg^{-1})^z	380	119
Silt (g kg^{-1})^z	396	506
Clay (g kg^{-1})^z	225	375
Total C (g kg^{-1})^y	38.5	34.0
pH^x	6.9	7.3
P_{M3} (mg kg^{-1})^w	52.5	61.5
P/Al ratio^w	0.066	0.081
K_{M3} (mg kg^{-1})^w	155	250
Ca_{M3} (mg kg^{-1})^w	3535	3800
Mg_{M3} (mg kg^{-1})^w	590	589
Parameter	**Farm B**	
	0-20 cm	20-40 cm
Sand (g kg^{-1})^z	245	268
Silt (g kg^{-1})^z	506	458
Clay (g kg^{-1})^z	250	274
Total C (g kg^{-1})^y	25.0	22.4
pH^x	6.7	6.7
P_{M3} (mg kg^{-1})^w	18.5	16.7
P/Al ratio^w	0.020	0.018
K_{M3} (mg kg^{-1})^w	189	170
Ca_{M3} (mg kg^{-1})^w	2594	2566
Mg_{M3} (mg kg^{-1})^w	367	351

^{z}Hydrometer method (Sheldrick and Wang 1993).

^{y}Carlo Erba Flash EA NC Soils Analyzer (Milan, Italy).

^{x}1:2 soil:water slurry (Hendershot et al. 1993).

^{w}Mehlich-3 extracts (Tran and Simard 1993).

Table 4.2a. Characteristics of dairy effluent applied through surface irrigation pipeline on Farm A. The effluent contained milkhouse wash water and seepage from a solid dairy manure storage

Parameter[z]	Farm A		
	15 July 2004	19 July 2004	2 August 2004
Total solids ($g\ L^{-1}$)	6.2	5.5	4.4
Dissolved solids ($g\ L^{-1}$)	5.6	5.2	4.2
Suspended solids ($g\ L^{-1}$)	0.2	0.1	0.1
pH	7.0	7.1	6.9
Total N ($mg\ L^{-1}$)	371	324	229
Total P ($mg\ L^{-1}$)	41.9	37.4	35.6
Total K ($mg\ L^{-1}$)	523	414	502
COD ($mg\ L^{-1}$)[y]	3110	3129	2647
Total coliforms ($10^3\ mL^{-1}$)	15	73	640
Fecal coliforms ($10^3\ mL^{-1}$)	5	4	10
Fecal streptococci ($10^3\ mL^{-1}$)	160	140	520
Quantity applied ($m^3\ ha^{-1}$)	538	552	682

[z]All parameters were determined using the standard methods for wastewater analysis (American Public Health Association 1998).

[y]COD, chemical oxygen demand

Table 4.2b. Characteristics of dairy effluent applied through surface irrigation pipeline on Farm B. Effluent was the seepage from a solid dairy manure storage

Parameter[z]	Farm B	
	6 July 2004	9 July 2004
Total solids (g L^{-1})	16.0	12.7
Dissolved solids (g L^{-1})	14.8	12.5
Suspended solids (g L^{-1})	0.2	0.2
pH	7.1	7.2
Total N (mg L^{-1})	895	687
Total P (mg L^{-1})	36.5	39.1
Total K (mg L^{-1})	752	765
COD (mg L^{-1})[y]	13074	8500
Total coliforms (10^3 mL^{-1})	58	173
Fecal coliforms (10^3 mL^{-1})	15	13
Fecal streptococci (10^3 mL^{-1})	201	115
Quantity applied (m^3 ha^{-1})	380	220

[z]All parameters were determined using the standard methods for wastewater analysis (American Public Health Association 1998).

[y]COD, chemical oxygen demand

Table 4.3. Influence of dairy effluent applications on gravimetric soil moisture content (%) in the 0-10-cm depth at the pipeline (distance = 0m) and at down slope sampling positions. Soil moisture content was determined within 24 h of applying dairy effluent

Farm A				
Treatment	Distance from pipeline (m)	Effluent application date		
		15 July 2004	19 July 2004	2 August 2004
Before irrigation	n/a	26.7	32.7	31.0
After irrigation	0	32.3	34.6	39.6
	15	27.9	33.8	39.1
	30	29.0	33.7	40.0
	45	31.1	34.6	39.1
	60	32.6	39.3	42.8
	75	ND[z]	40.6	44.2
Contrast analysis				
Before irrigation vs after irrigation		P=0.0134	P=0.0037	P<0.0001
Distance = 0m vs Distance > 0m		NS[y]	NS	NS

Farm B			
Treatment	Distance from pipeline (m)	Effluent application date	
		6 July 2004	9 July 2004
Before irrigation	n/a	15.1	29.5
After irrigation	0	24.6	33.7
	15	26.5	31.3
	30	24.4	33.7
	45	21.7	27.9
	60	31.4	36.8
Contrast analysis			
Before irrigation vs after irrigation		P<0.0001	P=0.2567 (NS)
Distance = 0m vs Distance > 0m		NS	NS

[z]ND, not determined

[y]NS, not significant (P>0.05, contrast analysis)

Table 4.4. Soil pH and Mehlich-3 extractable nutrients in the 0-20 cm and 20-40 cm soil depths collected about two weeks after the final dairy effluent application on Farm A and Farm B

Parameter	Farm A					
	0-20 cm			20-40 cm		
	Irrigated[z]	Non-irrigated[z]	*P* value[y]	Irrigated[z]	Non-irrigated[z]	*P* value[y]
pH	6.93	6.58	0.037	7.13	6.58	<0.001
P_{M3} (mg kg^{-1})	98.6	36.0	<0.001	35.1	33.9	NS
P/Al ratio	0.128	0.039	<0.001	0.037	0.035	NS
K_{M3} (mg kg^{-1})	385	110	<0.001	177	108	0.002
Ca_{M3} (mg kg^{-1})	4319	2678	<0.001	3437	2408	<0.001
Mg_{M3} (mg kg^{-1})	524	426	NS	584	469	0.032
Parameter	**Farm B**					
	0-20 cm			20-40 cm		
	Irrigated[x]	Non-irrigated[x]	*P* value[y]	Irrigated[x]	Non-irrigated[x]	*P* value[y]
pH	5.74	5.47	0.028	6.16	5.93	NS
P_{M3} (mg kg^{-1})	38.6	42.7	NS	19.6	22.2	NS
P/Al ratio	0.032	0.032	NS	0.016	0.019	NS
K_{M3} (mg kg^{-1})	288	79.2	0.007	175	162	NS
Ca_{M3} (mg kg^{-1})	2389	2102	0.017	2468	2012	NS
Mg_{M3} (mg kg^{-1})	341	304	NS	334	327	NS

[z]Values are the mean of 18 measurements (irrigated plot) and 6 measurements (non-irrigated plot).

[y]*P* values from pairwise t-test, NS indicates P>0.05.

[x]Values are the mean of 14 measurements (irrigated plot) and 5 measurements (non-irrigated plot).

Table 4.5. Dairy effluent application cost using the surface irrigation system described in this paper versus a conventional tanker system

Surface irrigation system					
Operation	Time (h)	Manpower needed	Manpower cost ($)^{z}	Equipment needed	Equipment cost ($)^{y,x}
Installation & dismantling	2	2	40.00	30kW tractor and wagon	100.00
Application	4	1	40.00	Irrigation pipe, 80kW tractor, manure pump	850.00
Effluent application rate = 250 $m^3 h^{-1}$; **Cost = $0.95 m^{-3} of dairy effluent**					

Conventional tanker system					
Operation	Time (h)	Manpower needed	Manpower cost ($)	Equipment needed	Equipment cost ($)^{y,x}
Installation & dismantling	1.0	2	20.00	Tanker, pump and loading pipe	50.00
Loading and application	20	1	200.00	2- 80kW tractors, manure pump and tanker	3000.00
Effluent application rate = 50 $m^3 h^{-1}$; **Cost = $3.05 m^{-3} of dairy effluent**					

[z] Manpower cost $10 h^{-1}

[y] Equipment costs include machinery operating, depreciation and investment costs, and were assessed from the following purchasing and rental costs: $5 000 for the irrigation pump and $4 000 for the irrigation pipe depreciated over 15 years; $30 h^{-1} for the 30kW tractor, $20 h^{-1} for the wagon carrying the irrigation pipe; $50 h^{-1} for the 80kW tractor; $50 h^{-1} for a tanker and manure pump.

[x] Cost computed on the basis that two dairy farms share the equipment and spread 1000m^3 of effluent yr^{-1}.

Chapter 5

5. SUMMARY

For both Farms A and B, the wastewater collected in 2002 and 2003 had a lower nutrient content than that collected in 2004 because of more dilution from precipitation than in previous years. The wastewater of Farm A was more dilute (lower nutrient content, lower total solids) than wastewater of Farm B (manure seepage only) because Farm A had a larger manure storage and mixed of milkhouse wash waters with its manure seepage. The surface irrigation system worked well and did not block when used to dispose off wastewaters collected in a storage facility separate from that used for the storage of solid manures.

From the irrigation trials conducted in 2003 and 2004 on Farm A and B, wastewater was observed to start flowing in the subsurface drainage system some 30 minutes after starting the irrigation application. In 2003, between 0.04 and 0.5% of the applied wastewater was lost at the outlet and sampling wells, which represented 0.25% of the total nutrient and bacteria load. The drainage water in the irrigated plot sampling well contained 80% of the TKN, 40% of the TP, 80% of the TK and 100% of the bacterial levels of the wastewater. In 2004, $4m^3$ of wastewater was lost at the field outlet, which represented 1.2% of total volume applied and 0.32% of total nutrient and bacterial loads. In 2004, the soil showed better infiltration capacity and the drainage water collected in the sampling well of irrigated plot of Farm A showed 20% of TKN, 15% of TP and 20% of TK of applied wastewater. Sampling well of irrigated plot of Farm B contained 80% of TKN, 40% of TP and 80% of TK of applied wastewater. The bacterial level in drainage water was the same as that in applied wastewater except in last irrigation session in 2004 in which the Total and Fecal Coliform counts were 10 times higher than in applied wastewater.

For both farms, the wastewater application had a significant effect on soil Mehlich III P and K for soil depth of 0-200mm but not for deeper layers. On Farm A, at a 0-200mm soil depth, wastewater application had a significant effect on all soil nutrient levels while distance down the slope from the irrigation pipe did not affect and application date had a significant effect on P, K, Mg and P saturation. On Farm B, wastewater applications had a significant effect on soil pH and K at a soil depth of 0-200mm, while distance down slope from the irrigation pipe had an impact on soil pH, Ca and Mg and application date had a significant effect on soil P and saturated P. Wastewater application significantly increased the yield of mixed cereals by 31% compared to control plot and irrigated crop had more protein and fiber. Applying wastewater with tanker (custom applicator) is estimated to cost $3.05/m^3$, while the surface irrigation system is much lower, at $0.95/m^3$. The cost of application by surface irrigation could be lowered even more if the system is shared among more than two farms.

During the three year study period, wastewater was applied by surface irrigation was conducted under various environmental conditions and at different times during crop development. To minimize losses of wastewater through the subsurface drainage system, wastewater applications should respect the soil's infiltration rate and water holding capacity. The application of wastewater to dry soils lead to small but unacceptable wastewater discharges through subsurface drainage. Application of wastewater from dairy farm to cropped soils should also be rotated every year to minimize K accumulation. The application of wastewater based on crop P requirement is recommended to prevent undesirable nutrient build-up.

5.1 Recommendations for future research

This research project demonstrated that surface irrigation is an efficient method of disposing dairy farm wastewaters during the growing season on farms. It also demonstrated that best management practices for irrigation must be respected to minimize wastewater losses through the subsurface drainage system. Additional research is needed to determine whether dairy farm wastewater can be applied to a broader range of soil types than studied in this project. It seems likely that other types of wastewater could be land applied safely and environmentally using a surface irrigation technique, but this needs to be investigated further.

Chapter 6

REFERENCES

Bernal, M.P., A. Lax and A. Roig. 1993. The effect of pig slurry on exchangeable potassium in calcareous soils. Biology and Fertility of Soils 16: 169-172

Cameron, K.C., A.W. Rate, M.J. Noonan, S. Moore, N.P. Smith and L.E. Kerr. 1996. Lysimeter study of the fate of nutrients following subsurface injection and surface application of dairy pond sludge to pasture. Agriculture, Ecosystems and Environment 58: 187-197.

Cronk, J.K. 1996. Constructed wetlands to treat wastewater from dairy and swine operations: a review. Agricultural Ecosystems and Environment 58: 97-114.

Day, D.L. and T.L. Funk. 1998. Processing manure: Physical, Chemical and Biological treatment. In: Animal waste utilization: Effective use of manure as a soil resource / edited by J.L. Hatfield and B. A. Stewart. Ann Abbor Press 121, Michigan U.S.A. pp. 243-282.

Hill, D. T. 1990. Steady state thermophillic design equation for methane production from livestock wastes. Page 88 in Proc. 6th Int. symp. Agric. Food Proc. Wastes. Am. Soc. Agric. Eng., St Joseph, MI

Hill, D.T., G.L. Newton, R. A. Nordstedt, V.W.E. Payne, D. S. Ramsey, L. M. Safley and P. W. Westerman. 1990. Parameters for the efficient biological treatment of animal wastes. Page 515 in Proc. 6th Int. symp. Agric. Food Proc. Wastes. Am. Soc. Agric. Eng., St Joseph, MI

Jamieson R.C., R.J. Gordan, L.M. Cochrane, A. Madani and J.R. Burney. 2002. Land application of milking centre wastewater. Canadian Biosystems Engineering Volume 44: 6.1-6.10.

Keeney, D.R. 1982. Nitrogen management for maximum efficiency and minimum pollution. In: F. J. Stevenson (Ed), Nitrogen in Agricultural Soils, American Society of Agronomy, Madison, WI, pp. 605-648.

Knight, R.L., V.W.E. Payne, R. E. Borer, R. A. Clarke and H.P. John. 2000. Constructed wetland for livestock wastewater management. Ecological Engineering 15: 41-55.

Lam, K.C., S. L. Ng and R.J. Neller. 1993. Fate of biological and chemical containments from on site disposal of liquid piggery wastes: Results from soil column study. Water Science and Technology 27: 63-75.

Lettinga, G. 1984. The prospects of anaerobic waste water treatment. In: Anerobic Digestion and Carbohydrate Hydrolysis of Waste, ed. G.L. Ferrero, M.P. Ferranti, and H. Naveau. Elsevier Applied Science Publisher, London, pp. 262-273.

Liu, F., C.C. Mitchell, J.W. Odom, D.T. Hill and E.W. Rochester. 1997. Swine lagoon effluent disposal by overland flow: Effect on forage production and uptake of nitrogen and phosphorus. Agronomy Journal 89: 900-904.

Lo, K.V., J. P. Tam, P.H. Liao and N.R. Bulley. 1988. Treatment of milking center waste in sequencing batch reactors, Biological Wastes 25: 193-208.

Macgregor A. N., D. G. Bowler, T. O. Tan and J. K. Syers. 1982. Removal of nitrogen from untreated milking shed wastes after application to permanent pasture. Agriculture Water Management 5: 181-191.

Mantovi, P., M. Marmiroli, E. Maestri, S. Tagliavini, S. Piccinini and N. Marmiroli. 2003. Application of a horizontal subsurface flow constructed wetland on treatment of dairy parlor wastewater. Bioresource Technology 88: 85-94.

Miller, M.H., D.G. Grieve, P.H. Groenevelt, D.A. Lobb and R. P. Voroney. 1987. An assessment of milkhouse wash water treatment and disposal systems. Guelph, ON: The Center for Soil and Water Conservation, University of Guelph.

Newman, J.M., J. C. Clausen and J. A. Neafsey. 2000. Seasonal performance of a wetland constructed to process dairy milkhouse wastewater in Connecticut. Ecological Engineering 14: 181-198.

NRAES. 1998. Guideline for milking center wastewater. NRAES-115, DPC 15. Ithaca, NY: Northeast Regional Agriculture Engineering Service, Cornell University, Ithaca, NY.

Paterson, J.J., J.H. Jones, F. J. Olsen, and G.C. McCoy 1980 Dairy liquid waste distribution in an overland flow vegetative soil filter system. Transactions of the ASAE 23: 973-977.

Pieters, J.G., G. J. Neukermans and M. B. A. Colanbeen. 1999. Farm-scale membrane filtration of sow slurry. J. Agric. Eng. Res. 73: 403-409.

Pound, C.E. and R.W. Crites. 1973. Wastewater treatment and reuse by land application, Volume I-Summary. Environmental Protection Technology Series EPA-660/2-73-006a. p 13.

Rafter, G.W. 1899. Sewage irrigation, Part II. USGS Water Supply and Irrigation Paper no.22, USDI, Washington, D.C. 41 p.

Sharpley, A.N., S.C. Chapra, R. Wedepohl, J.T. Sims, T.C. Daniel and K.R. Reddy. 1994. Managing agricultural phosphorous for protection of surface wasters: issues and options. Journal of Environmental Quality 23: 437-51.

Sims, J. T. 1995. Organic wastes as alternative nitrogen sources. In: P.E. Bacon (Ed), Nitrogen Fertilization in the Environment, Marcel Dekker, New York, pp. 487-536.

Toyama, T., H. Yokose, S. Yoshida and M. Kuwahara. 1990. Evaluation of land application using secondary effluent in a forest slope: estimation of drained water quality and discussion of the effects upon soil or plant and behavior of bacteria. Water Resources 24: 275-288.

Van Gastel, J.P.B.F and J.G.M. Thelosen. 1995. Reduction of the volume of sow slurry with reverse osmosis. P1.129. Research Institute for Pig Husbandry, The Netherlands.

Vetter, H. and G. Steffens. 1981. Leaching of nitrogen after the spreading of slurry. In: J. C. Brogan (Ed), Nitrogen Losses and Surface Run-off from land spreading of manure. Martinus Nijhoff/Dr W. Junk, The Hague, pp. 251-269.

Vetter, R. L., D.J. Friedrick, P. Huntingdon. 1990. Full scale anaerobic digester and waste management for a 300 cow dairy. Agricultural and Food Processing waste: Proc. 6th Int. Symp. Agric. Food Proc. Wastes. 17-18 December 1990, Chicago. Am. Soc. Agric. Eng., St Joseph, MI, pp. 236-249.

Warburton, D.J., R. M. Clarke and H. Melcer 1981. Anaerobic/aerobic treatment for dairy shed wastewater II Performance of the anaerobic Phase. J. Agric Eng. Res. 26: 509-515.

Wheately, A.D., M.B. Fisher and A.M.W. Grobicki. 1997. Application of anaerobic digestion for the treatment of industrial wastewaters in Europe. Journal of the Charted Institution of Water and Environment Management 11: 39-46.

Yin, H. and S. Weiran. 1995. Using reed beds for winter operation of wetland treatment systems for wastewater. Water Science and Technology 32: 111-117.

APPENDIX

Coefficient of variation for different parameters before and after irrigation for farm A over a depth of 0-200mm

	C.V .before							C.V. after						
Parameter	P	K	Ca	Mg	Al	pH	Psat	P	K	Ca	Mg	Al	pH	Psat
Irrigation	42	31	19	14	9	4	42	30	31	19	25	18	5	34
Control	25	44	18	11	18	5	18	22	26	24	15	6	3	20
Irrigation: control	1.7	0.7	1.1	1.3	0.5	0.8	2.3	1.4	1.2	0.8	1.7	3.0	1.7	1.7
Change: after/before, %								-20	-28	-27	+31	+500	+113	-26

Coefficient of variation for different parameters before and after irrigation for farm A over a depth of 200-400mm

	C.V. before							C.V. after						
Parameter	P	K	Ca	Mg	Al	pH	Psat	P	K	Ca	Mg	Al	pH	Psat
Irrigation	89	49	23	19	11	3	96	46	24	13	21	14	3	41
Control	49	27	36	21	12	3.6	43	37	19	21	11	7	3	38
Irrigation: control	1.8	1.8	0.6	0.9	0.9	0.8	2.2	1.7	1.3	0.6	1.9	2.0	1.0	1.1
Change: after/before, %								-6	-18	0	+111	+122	+20	-50

Coefficient of variation for different parameters before and after irrigation for farm B over a depth of 0-200mm

	C.V. before							C.V. after						
Parameter	P	K	Ca	Mg	Al	pH	Psat	P	K	Ca	Mg	Al	pH	Psat
Irrigation	51	67	30	28	15	7.9	58	32	89	14	18	14	9.4	34
Control	30	12	53	39	22	12	24	21	7.8	6.5	26	12	5	19
Irrigation: control	1.7	5.6	0.6	0.7	0.7	0.7	2.4	1.5	11.4	2.2	0.7	1.2	1.9	1.8
Change: after/before, %								-12	+104	+267	0	+71	+171	-25

Coefficient of variation for different parameters before and after irrigation for farm B over a depth of 200-400 mm

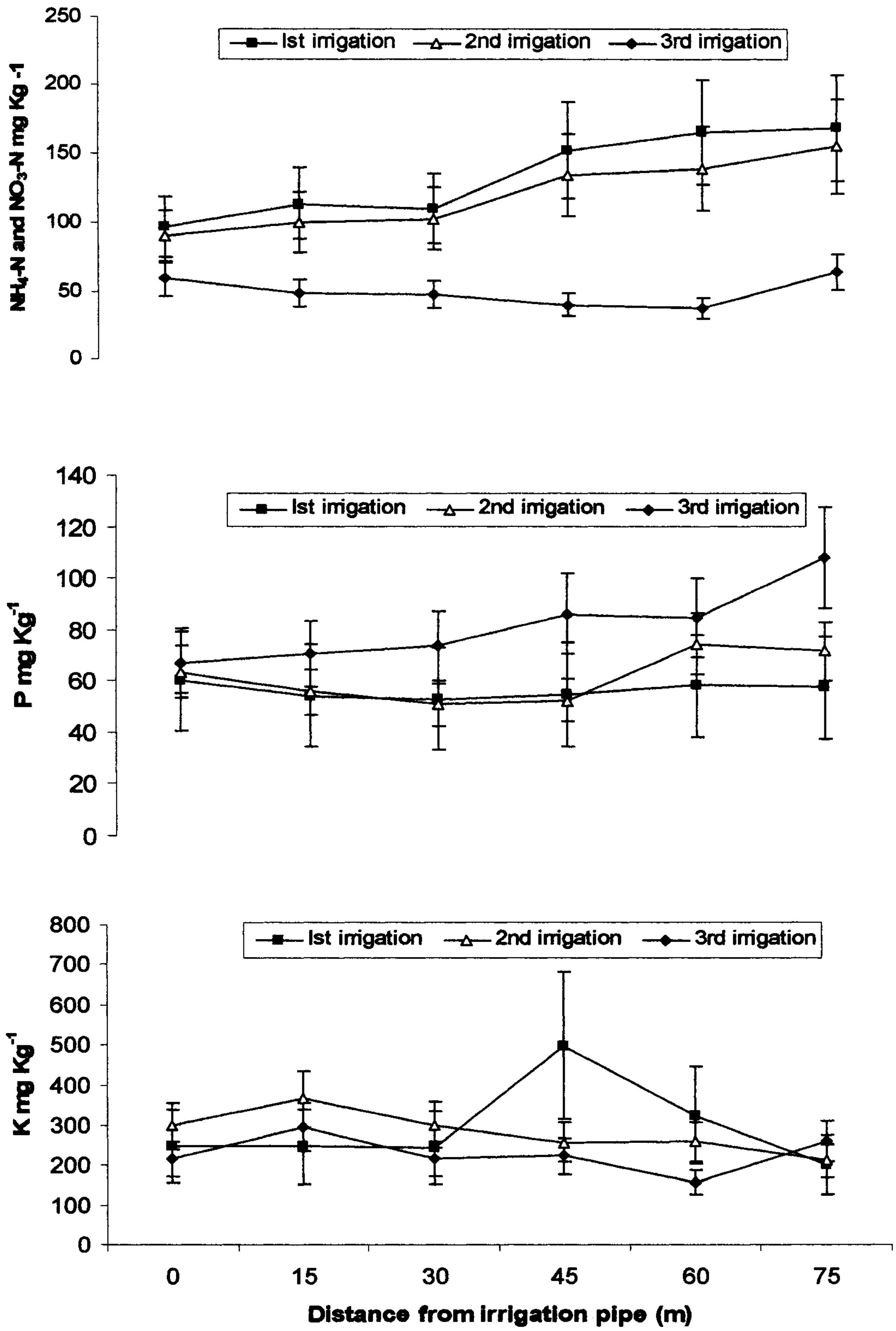
	C.V. before							C.V. after						
Parameter	P	K	Ca	Mg	Al	pH	Psat	P	K	Ca	Mg	Al	pH	Psat
Irrigation	76	73	27	30	18	7.6	75	60	80	27	33	18	11	60
Control	24	24	46	57	27	13	30	38	44	19	35	18	7	44
Irrigation: control	3.2	3.0	0.6	0.5	0.7	0.6	2.5	1.6	1.8	1.4	0.9	1.0	1.6	1.4
Change: after/before, %								-50	-40	+133	+80	+43	+167	-46

ANOVA for Farm A over a depth of 0-200 mm				
Parameter	Treatment	Block	Date	Trt*Date
pH	p<0.0001	N.S.	N.S.	N.S.
P	p<0.0001	N.S.	p=0.0323	p=0.0052
K	p<0.0001	N.S.	p=0.0003	p=0.0002
Ca	p<0.0001	N.S.	N.S.	N.S.
Mg	p=0.0365	N.S.	p=0.0097	N.S.
Al	p=0.0025	N.S.	N.S.	N.S.
Psat	p<0.0001	N.S.	p=0.0409	p=0.0089

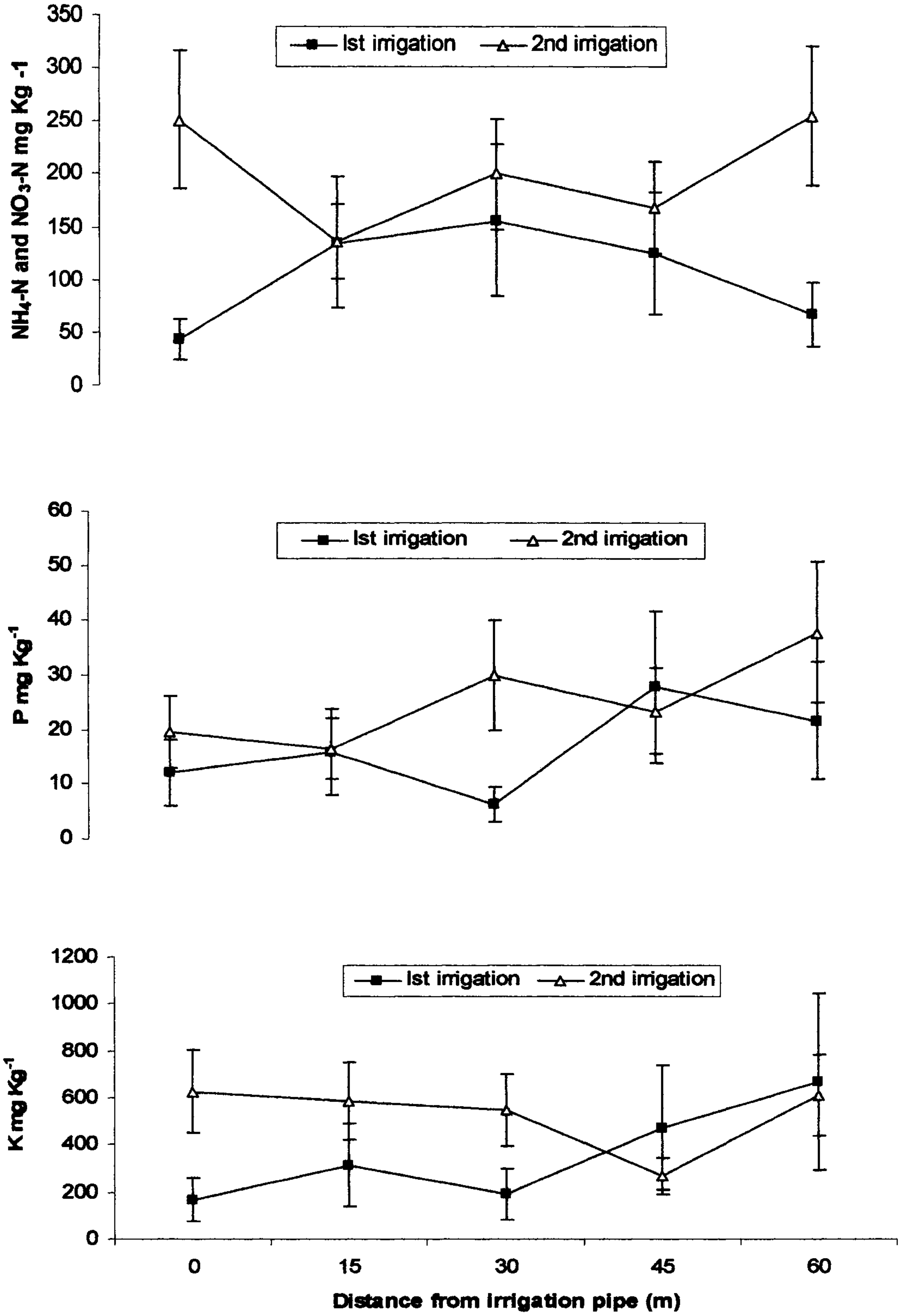
ANOVA for Farm A over a depth of 200-400 mm				
Parameter	Treatment	Block	Date	Trt*Date
pH	p<0.0001	N.S.	p=0.0162	N.S.
P	N.S.	N.S.	N.S.	N.S.
K	p=0.0007	N.S.	N.S.	N.S.
Ca	p<0.0001	N.S.	N.S.	N.S.
Mg	N.S.	N.S.	N.S.	N.S.
Al	N.S.	N.S.	p=0.0324	N.S.
Psat	N.S.	N.S.	N.S.	N.S.

. ANOVA for Farm B over a depth of 0-200 mm				
Parameter	Treatment	Block	Date	Trt*Date
pH	p=0.0229	p<0.0001	p<0.0001	N.S.
P	N.S.	N.S.	p=0.0026	p=0.0111
K	p=0.0116	N.S.	N.S.	N.S.
Ca	N.S.	p<0.0001	N.S.	N.S.
Mg	N.S.	p=0.0019	N.S.	N.S.
Al	N.S.	N.S.	p<0.0001	N.S.
Psat	N.S.	N.S.	N.S.	p=0.0201

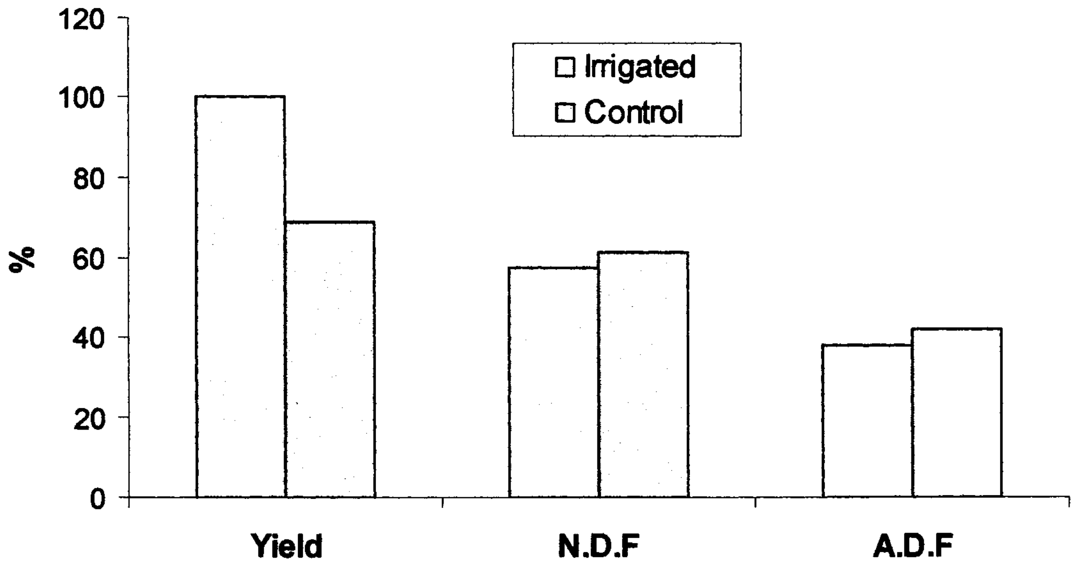
ANOVA for Farm B over a depth of 200-400 mm				
Parameter	Treatment	Block	Date	Trt*Date
pH	N.S.	p<0.0001	p=0.0006	N.S.
P	N.S.	N.S.	N.S.	N.S.
K	p=0.0334	N.S.	N.S.	N.S.
Ca	N.S.	p=0.0020	N.S.	N.S.
Mg	N.S.	N.S.	N.S.	N.S.
Al	N.S.	N.S.	p=0.0031	N.S.
Psat	N.S.	N.S.	N.S.	N.S.



Nutrient levels in soils for Farm A after each irrigation, as affected by the distance down slope from the irrigation pipe.



Nutrient levels in soil for Farm B after each irrigation, as affected by the distance down slope from the irrigation pipe.



Percentage crop yield (dry matter ha^{-1}), NDF (cellulose, hemi cellulose and fiber) and ADF (cellulose and fiber) for the mixed cereal crop grown in the irrigated and non-irrigated plots of Farm B.