Whole farm modeling to evaluate economic and production implications of BMPs designed to reduce greenhouse gas emissions:

Case Study of Dairy Production in Coastal British Columbia

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EXECUTIVE SUMMARY

Agricultural production is recognized as a significant contributor to greenhouse gas (GHG) production (Amon et al., 2006; Monteny et al., 2006). Intensive dairy production in particular, contributes significant quantities of methane (CH_4) and several forms of nitrogen (N) which can contribute to nitrous oxide (N_2O) production (Casey et al., 2005; Jarvis et al., 1994). Dairy production is a complex system involving inputs such as feed and fertilizer, animals with inherent physiological structures for fermentation of feedstuffs, and the production of manure, storage systems, cropping systems and export of meat and milk (Figure 1). Therefore, it is probable that management changes proposed to reduce emissions of GHG or NH_3 in one area of the cycle will most certainly have long term effects on other parts of the system.

Common sense would dictate that attempting to design and conduct research trials to ascertain the effect of one or multiple changes on a production, economics and GHG emissions from a dairy production system in North America would be, prohibitive from an expense and a time standpoint. Therefore, the use of whole farm models, with short-term studies for validation, is an attractive alternative.

The Integrated Farm System Model (IFSM) was developed as a research and teaching tool to evaluate farm production systems over a long period of time. The model was originally released in 1989 as a dairy and forage system evaluation tool called DAFOSYM (Rotz et al. 1999). Over the last decade, it has been expanded to include beef and crop production systems. In simulating the whole farm production process, IFSM allows for the evaluation and comparison of alternative agronomic, feeding, manure storage and disposal strategies in terms of production, profitability and nutrient cycling. The model also accounts for the use of fossil fuels used in the production process. The model does not predict production of GHG but does provide the basic information required to predict GHG (methane and nitrous oxide) emissions using factors published in the scientific literature.

This project will extend the current body of information already available on nutrient management for dairy production units by investigating the single and additive effects of BMP's linked to reducing GHG emissions. Specifically, this project evaluated six different BMP's, namely, cover cropping, sawdust versus sand bedding, covered versus non-covered manure storage, manure injection versus surface application and lastly, milk production. The case study was based on unit of 870 lactating cattle housed in the south coastal region of British Columbia.

A comparison of BMP's showed little difference in the amount of imported or exported N except for the last BMP of 12,200L milk cow^{-1} year^{-1} where both import and export of N was decreased. The model showed a reduction in volatilization of N when sand bedding is used. However, this N is lost through leaching when manure is applied to cropland. Covering manure storage lagoons showed a decrease in the amount of volatilized N in comparison to non-covered lagoons. However, this N was lost through leaching and denitrification once manure was applied to cropland via an injection system. Likewise, leaving crop land bare over the winter (no cover crop) resulted in higher volatilization and dentrification losses of N.

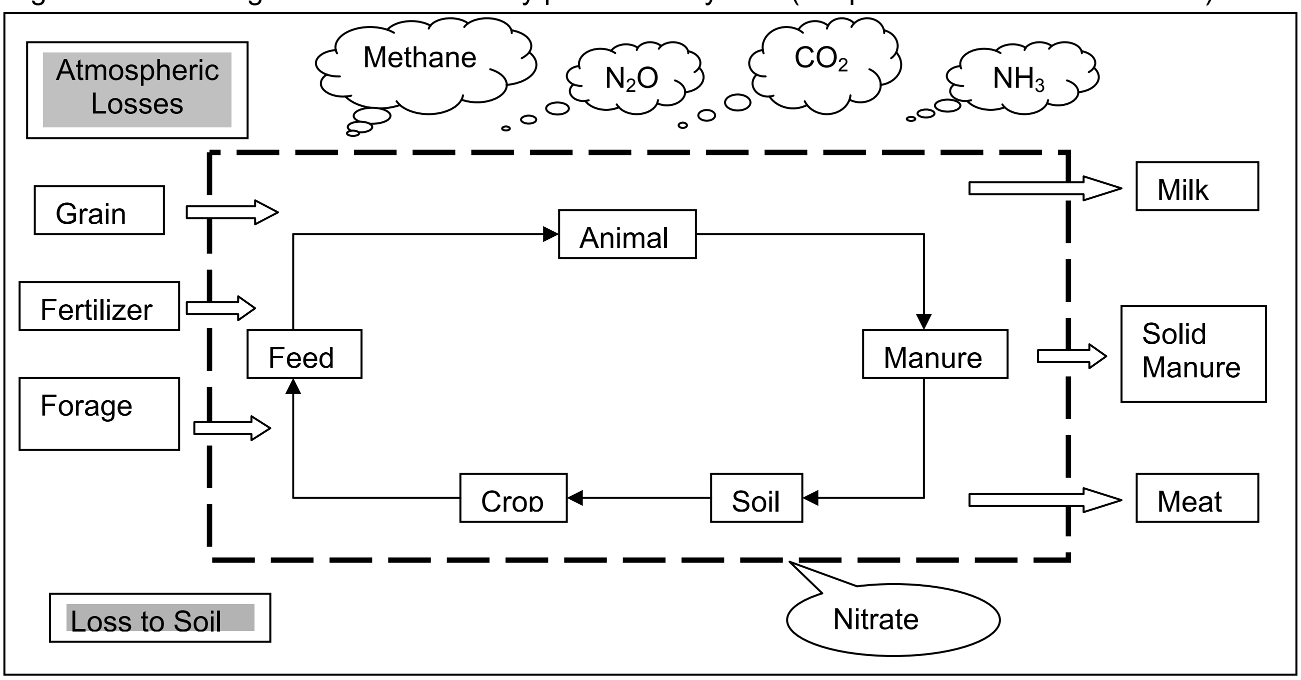
A strength of the IFMS model is its ability to calculate economic return thereby allowing the producer to consider the cost or benefit of implementing a BMP. Evaluation for FarmBC showed that sand bedding, covered manure storage, surface spreading, absence of cover crop and 12,200L milk production yielded economic returns of 99.4, 95.3, 98.8, 97.7 and 74.4 % of their current revenue.

2. INTRODUCTION

Agricultural production is recognized as a significant contributor to greenhouse gas (GHG) production (Amon et al., 2006; Monteny et al., 2006). Intensive dairy production in particular, contributes significant quantities of methane (CH_4) and several forms of nitrogen (N) which can contribute to nitrous oxide (N_2O) production (Casey et al., 2005; Jarvis et al., 1994).

Over the past ten years, research studies have attempted to address various sources of GHG emissions within the dairy production system. These sources have included housing (Amon et al. 2001; Ellis et al. 2001), manure removal, storage and treatment systems (Amon et al., 2006; Berg et al., 2006; Clemens et al., 2006; Külling et al. 2003; Yamulki, 2006). Others have compared GHG emissions from conventional farming practises to those employed in organic production (Olesen et al. 2006; Sneath et al. 2006; Weiske et al. 2006). Many of these studies have looked at one section of the production chain in isolation; for example, Berg et al. (2006) found that covering manure storage lagoons reduced the amount of ammonia (NH_3) lost to the atmosphere but had little effect on GHG emissions. However, the study stops short of telling the whole story in that reduction of NH_x volatilization from storage results in more N being applied to the land. Extra N loading could result in increased leaching loss or increased denitrification and N_2O production. Dairy production is a complex system involving inputs such as feed and fertilizer, animals with inherent physiological structures for fermentation of feedstuffs, and the production of manure, storage systems, cropping systems and export of meat and milk (Figure 1). Therefore, it is probable that management changes proposed to reduce emissions of GHG or NH_3 in one area of the cycle will most certainly have long term effects on other parts of the system.

Figure 1. Flow diagram of FarmBC dairy production system (adapted from Schils et al. 2005)



Common sense would dictate that attempting to design and conduct research trials to ascertain the effect of one or multiple changes on a production, economics and GHG emissions from a dairy production system in North America would be, prohibitive from an expense and a time standpoint. Therefore, the use of whole farm models, with short-term studies for validation, is an attractive alternative. This has been recognized by several authors including Phetteplace et al. (2001), Casey and Holden (2005), Hutchings et al. (1996) and Schils et al. (2005). It could be assumed that non-legislated farmer participation in GHG mitigation or nutrient management programs would be increased if a production or economic benefit resulting from the program could be demonstrated. In Canada, income for a dairy production unit is determined by a quota system. Economic return to a dairy producer is defined by his/her ability to manage costs.

The Integrated Farm System Model (IFSM) was developed as a research and teaching tool to evaluate farm production systems over a long period of time. The model was originally released in 1989 as a dairy and forage system evaluation tool called DAFOSYM (Rotz et al. 1999). Over the last decade, it has been expanded to include beef and crop production systems. In simulating the whole farm production process, IFSM allows for the evaluation and comparison of alternative agronomic, feeding, manure storage and disposal strategies in terms of production, profitability and nutrient cycling. The model also accounts for the use of fossil fuels used in the production process. The model does not predict production of GHG but does provide the basic information required to predict GHG (methane and nitrous oxide) emissions using factors published in the scientific literature.

Agronomic, feeding and manure management practises routinely used on Canadian dairy farms must be reviewed for soundness in terms of environmental and economic sustainability. In the same way, best management practises (BMP's) advocated under the National Farm Stewardship Program (Agriculture and Agri-Food Canada) should be evaluated not only for their impact on long term sustainability, but also on the cost advantage or disadvantage of their implementation. Best management practises are defined as those that 1) minimize and mitigate impacts and risks to the environment by maintaining or improving quality of soil, water, air and biodiversity; 2) ensure the health and sustainability of natural resources used for agriculture production and 3) support long term economic and environmental viability of the agriculture industry. With respect to animal production (meat or milk), BMP's could include new agronomic practises such as no till or cover cropping, modifications to manure collection, storage or application systems, or improved feed/forage evaluation to decrease nitrogen/phosphorus excretion. Evaluation of BMP implementation will require a whole farm modelling system capable of evaluating the effects of the management change over a long period of time.

Recently, the IFSM was evaluated against eight other models as part of an exercise to evaluate nutrient management tools (Cornell, 2004). The study was undertaken because the National Center for Manure and Animal Waste Management concluded that "although a large body of knowledge exists about livestock manure and nutrient management, the development and implementation of best management practises continues to be limited by lack of dissemination and integration of research and extension information". The IFSM was the only model to provide complete economic analysis including income, manure, fertilizer and feed costs. Five of the nine models evaluated, including the IFSM, were able to prove field validation of their system. IFSM was one of the few models to include production parameters such as crop and animal production, as well as feed and labour requirements.

This project will extend the current body of information already available on nutrient management for dairy production units by investigating the single and additive effects of BMP's linked to reducing GHG emissions. Specifically, this project will evaluate six different BMP's, namely, cover cropping, sawdust versus sand bedding, covered versus non-covered manure storage, manure injection versus surface application and lastly, milk production. The case study was based on farm of 870 lactating cattle housed in the south coastal region of British Columbia.

3. MATERIALS and METHODS

FarmBC, located in the south coastal region of British Columbia currently milks 870 cows with an average annual (365d) production of 13,200 L cow^{-1}. The farm site, which is 35.2 ha in size, houses the lactating cows and dry cows within three weeks of freshening. Heifers and the remaining dry cows are housed off site at a feedlot facility and are not considered in this study. The unit rents an additional 153.8 ha of land which together with the land around the dairy unit grows corn for silage. A small grain cover crop is grown over the winter months and harvested as silage the following spring, prior to replanting corn on the same fields.

Cattle are housed in open-sided free stall facilities. High-producing and two-year-old cows are housed in a building using a flush system for manure collection. Mid- and low-producing cows are housed in older barns using scraper systems for manure collection. Bedding used is primarily sand but some stalls receive sawdust; the pre-fresh cows are housed on sawdust packs. Solids are separated from the manure and approximately 85% of the collected solids are exported off the farm to facilities not connected to farm production. Manure handling regulations in British Columbia require storage of manure for a period of approximately four months, usually from the first of November to the end of the following February. Liquid manure on FarmBC is applied to land three to four times per year depending on weather. Liquid manure is stored in four lagoons, each 3.6 m deep but varying in length and width. The lagoons are lined but not covered.

A portion of the rented land (133.2 ha) is located too far from the farm to support the cost of transporting the liquid manure. Nutrient fertilization for this land depends on chemical fertilizer. Using a pipeline system, FarmBC transports approximately 47% of its liquid manure output to neighbouring farms which in turn grow crops (corn or grass silage), which is sold back to the farm for use in the dairy unit. Manure is applied to all land associated with growing crops for FarmBC by an injection system attached to a dragline which receives manure from underground pipes..

In addition to the forage purchased from the surrounding farms, FarmBC purchases high quality alfalfa hay from Washington, a commercial grain mix which is fed according to production, and cottonseed. At the present time, two diets are formulated for the lactating cows. The first is a high energy total mixed ration (TMR) for high-producing cows and first lactation heifers. This samediet is mixed and then diluted with extra forage for the fresh cow group to avoid transition problems such as displaced abomasum. The second diet is a lower energy TMR for the mid and low lactation groups. Cows within three weeks of freshening are fed alfalfa, corn silage and a commercial grain formulation for pre-partum cows. Diets are formulated to attain maximum milk production keeping in mind the health of the cow. In addition, requirements set by the milk marketing system in terms of shipping milk containing a minimum butterfat percentage determine diet composition. The farm does purchase by-products such as condensed molasses solubles, whey permeate and tofu residue. However, IFSM cannot accommodate these ingredients; for the purpose of this project, diets were reformulated to approximate these ingredients with the commercial grain mix. Tillage, planting and harvesting is done by custom operators. Soil type is a shallow sandy loam. For this project, composition and soil characteristics in the model were verified by Ms. Elizabeth Kenney, a Land Resource Officer based at Pacific Agri-Food Research Center in Agassiz, B.C. Based on soil mapping of the south coastal region in B.C., the composition was changed in the model from 50% silt to 25%, 6% clay to 10% and from 44% sand to 65%. Moist bulk density was revised from 1.5 to 1.2 g cm^{-3} and organic carbon content changed from 0.5 to 1.8% to more accurately reflect soil composition at FarmBC. Corn is planted at a density of 79080 plant ha^{-1} and a relative maturity index of 83 days.. Silage yield was entered as 125% to achieve the expected 18 tonne DM ha^{-1} . According to the sales representative from the fertilizer company, FarmBC applies nitrogen, phosphate and potash fertilizer, at rates of 139, 60 and 90 kg ha^{-1}, respectively to corn land pre-planting. This fertilizer is applied in addition to manure application. It is estimated that 60% of the available liquid manure is applied to the small grain cover crop in fall before planting and in early spring (spring application has residual benefit to the corn) and 40% directly to corn land before planting. Corn silage is processed at the chopper during harvesting. Corn, small grain and purchased grass silage is stored on concrete slabs and covered with plastic. Expenses and revenue values used in this exercise where those supplied by FarmBC. In respect for the FarmBC's privacy, revenue comparisons will be presented in relation to a "control" scenario where sawdust is used as the bedding source.

3. RESULTS

Greenhouse gas emissions from dairy production units include methane (CH_4,), nitrous oxide (N_2O) and carbon dioxide (CO_2). Casey and Holden (2005) estimate that enteric fermentation, fertilizer, imported grains, manure management and electricity/fuel consumption are responsible for 49, 21, 13, 11 and 5% of GHG emissions from a dairy production unit, measured as CO_2 equivalents (kg^{-1} $year^{-1}$), respectively.

3.1 Methane

The main source of CH_4 is from enteric fermentation in the rumen with a minor contribution from anaerobic fermentation of manure stored in piles or anaerobic lagoons. Statistics estimating CH_4 emissions from Canadian industries show that GHG emissions (measured as CO_2 equivalents) from enteric fermentation in livestock and from manure management increased some 20 and 76%, respectively between 1990 and 2003 (Environment Canada, 2003).

Methane is generated in the rumen by bacterial fermentation of structural carbohydrates found primarily in forages, but also in concentrates such as barley, beet pulp and cottonseed. Methane generation represents a loss of energy to the animal of between 2 and 12% of gross energy intake (Hindricksen et al. 2006; Jarvis and Pain, 1994). Measurement of methane emission from the ruminant animal is a time consuming, expensive process. Therefore, as reviewed by Benchaar et al. (1998), methane production has been predicted using regression equations and mechanistic models. One such regression equation is that of Moe and Tyrell (1979) which relates methane production to the intake of soluble carbohydrates, cellulose and hemicellulose. The equation is:

$$\text{Methane (Mcal day}^{-1}) = 0.814 + 0.122\ (\text{non-structural carbohydrate}) + 0.415\ (\text{hemicellulose}) + 0.633\ \text{cellulose.}$$

In this exercise, diet characteristics (fiber, protein, non structural carbohydrates) were not modified in relation to the BMP's evaluated. However, the IFMS model is capable of producing a report detailing these components and although it does not currently do so, a prediction equation such as that of Moe and Tyrell's could be incorporated into the program and methane production estimated. Scenarios in which cropping strategies are revised could then be evaluated in term of methane production. For example, a strategy where corn silage is replaced by grass silage could well facilitate increased frequency of manure application but would, in all probability, result in increased methane production as grass silage in coastal region of British Columbia typically contains some 10% more fiber than corn silage (Swift, 2005).

3.2 Nitrogen Compounds

Worldwide, agriculture is responsible for some 60% of total anthropogenic N_2O emissions (Weiske and Petersen, 2006). In Canada, direct and indirect sources of N_2O from agricultural sources accounted for 3.4 and 0.95%, respectively of the total GHG emissions estimated for 2003 (Environment Canada, 2003).

Direct sources of N_2O emissions are linked to denitrification of N-containing compounds applied as fertilizer or manure, or urine patches from grazing animals. Indirect sources of N_2O involve escape of N-containing compounds (such as NH_3)) from manure storage facilities. Best management practises that decrease the amount of N applied to soil and/or decrease the amount of N lost to the atmosphere would serve to decrease GHG emissions.

To that end, six BMP's were tested for their ability to decrease N loss from FarmBC. These BMP's were the type of bedding used in freestalls, covering manure storage structures, injection versus surface spreading of manure applied to crop land, winter cover crop versus no cover crop and level of milk production. In order to relate emissions to milk production, results will be reported as kg N hL^{-1} annual milk production. Annual N lost from the system through volatilization, leaching and denitrification (kg yr^{-1}) are presented in Appendix 1.

***3.2.*1 Type of bedding used in freestalls.**

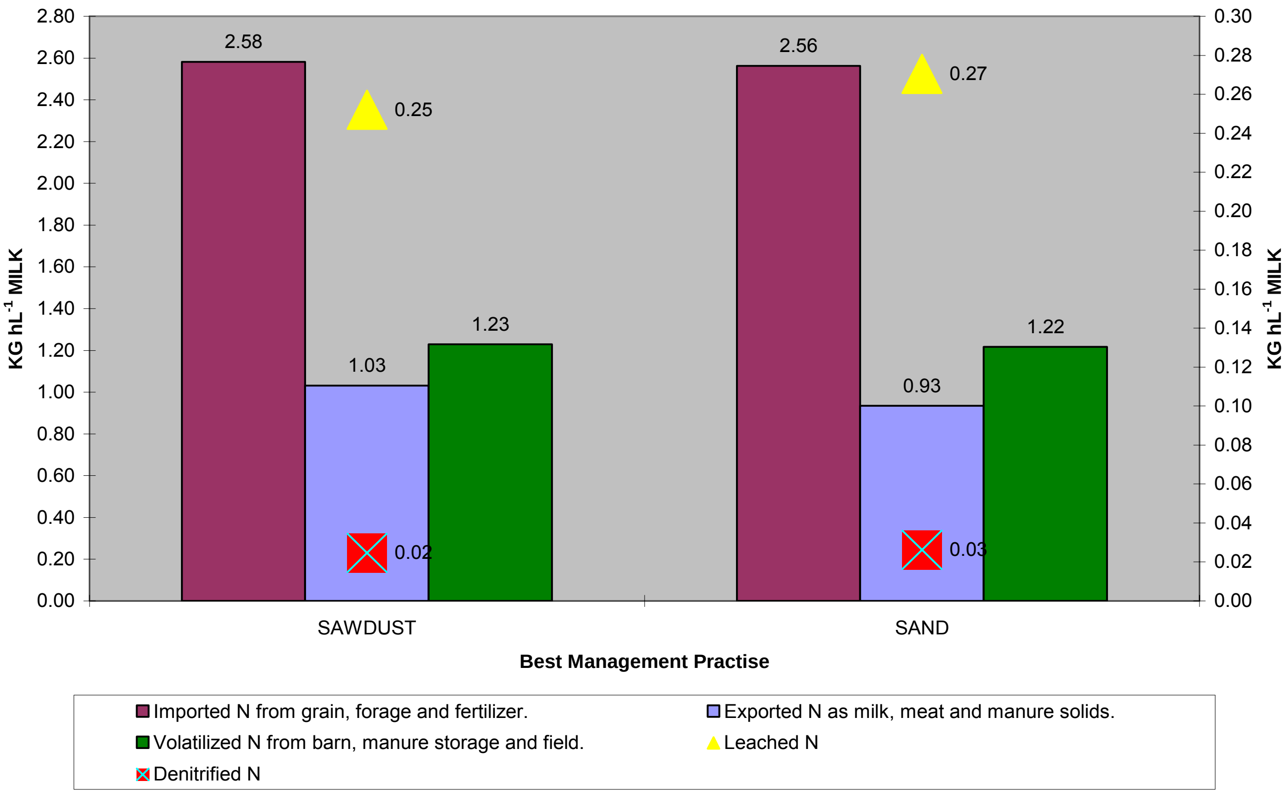
Ruminant animals are inefficient users of intake N in that approximately 30% is converted to meat or milk and the remainder is lost through urine and feces. Approximately 75% of N found in urine is in the form of urea which is converted to ammonium-N by the urease enzyme found in feces and soil. Ammonium-N is converted to NH_3 which escapes through volatilization (Powell et al. 2004). Fecal N is found within compounds that are largely non-volatile (Pinder et al. 2004).

In British Columbia, good quality sawdust has been readily available to be used as bedding in dairy operations. Over the last five years, some farms have switched to using fine river sand for bedding as the incidence of environmental mastitis is decreased, thereby improving the health of the cows and the quality of the milk. The type of bedding used influences the loss of N through volatilization. Misselbrook and Powell (2005) found that pine shavings retained significantly more urinary N 48h after application than did sand bedding (10 versus 0.7 mg g^{-1} of bedding). They also reported that rate of NH_3 emission from sand bedding was 33% less versus NH_3 emission from sawdust bedding (Misselbrook and Powell, 2005).

As shown in Figure 2, there were small differences between sawdust and sand bedding in terms of the amount of N imported onto and exported from FarmBC. Increased amounts of feed N were imported when sawdust bedding is used. Yields of corn and small grain silage were decreased some 3 and 10%, respectively when sawdust is compared to sand bedding. Due to its physical nature more sawdust than sand bedding is collected with the solids portion of the manure and is exported from the farm. The increased loss in NH_3 from sawdust bedding as shown by Misselbrook and Powell (2005), leaves less N available for support maximum yields of forage crops. This volatilization loss is reflected by the model (Figure 2).

The model predicted increased loss of N through leaching for sand versus sawdust bedding. Manure is applied through injection at FarmBC, a method which may lead to increased N loss through leaching.

Figure 2. Effect of bedding on imported, exported, volatilized, leached and denitrified N.



Increased loss of NH_3 for sawdyst versus sand bedding can be linked to indirect emissions of N_2O. A portion of this NH_3 lost through volatilization can be deposited on land around FarmBC or further afield and undergo denitrification to produce N_2O. Therefore, the BMP of using sand bedding can be seen as beneficial for decreasing GHG emissions. However, sand bedding may promote greater leaching loss of N, thereby negatively impacting water quality in local aquifers.

3.2.2 Covered manure storage.

A significant amount of N in various chemical forms may be lost from manure storage facilities (Amon et al. 2006; Berg et al. 2006; Oenema et al. 2001). The magnitude of the loss is related to manure composition, temperature, air movement, storage surface area and storage structure in terms of manure addition (top versus bottom loading). Research has shown that covering the manure storage structure can decrease N loss in the form of NH_3 (Sommer et al. 1993; Oenema et al. 2001; Williams et al. 2005). Therefore, covering or enclosing manure storage facilities would be a BMP that could be implemented to reduce potential GHG emissions.

Covering the manure storage facility had no effect on import or export of N on FarmBC (Figure 3). The model predicted large differences between covered and non-covered storage in terms of the amount of N lost through volatilization and leaching. Covering the manure storage facility decreased the amount of N lost through volatilization by some 77% (1.22 versus 0.28 kg N hL^{-1} milk). Berg et al. (2006) reported a 75% reduction in NH_3 concentration using straw as a cover on lagoons holding pig slurry. However covering lagoons with straw can increase the amount of CH_4 loss as shown by Amon et al. (2006). Williams et al. (2005) investigated ten types of floating covers including an oil layer,

plastic sheeting and bubble film. They found that the most suitable floating covers were plastic film and Leca, a type of mineral granule. Ammonia emissions were reduced by some 80% (Williams et al. 2005). Direct N_2O emissions from manure storage vary depending on the type of manure (solid versus slurry versus liquid), length of storage, presence of type of cover (Amon et al. 2006; Külling et al. 2003).
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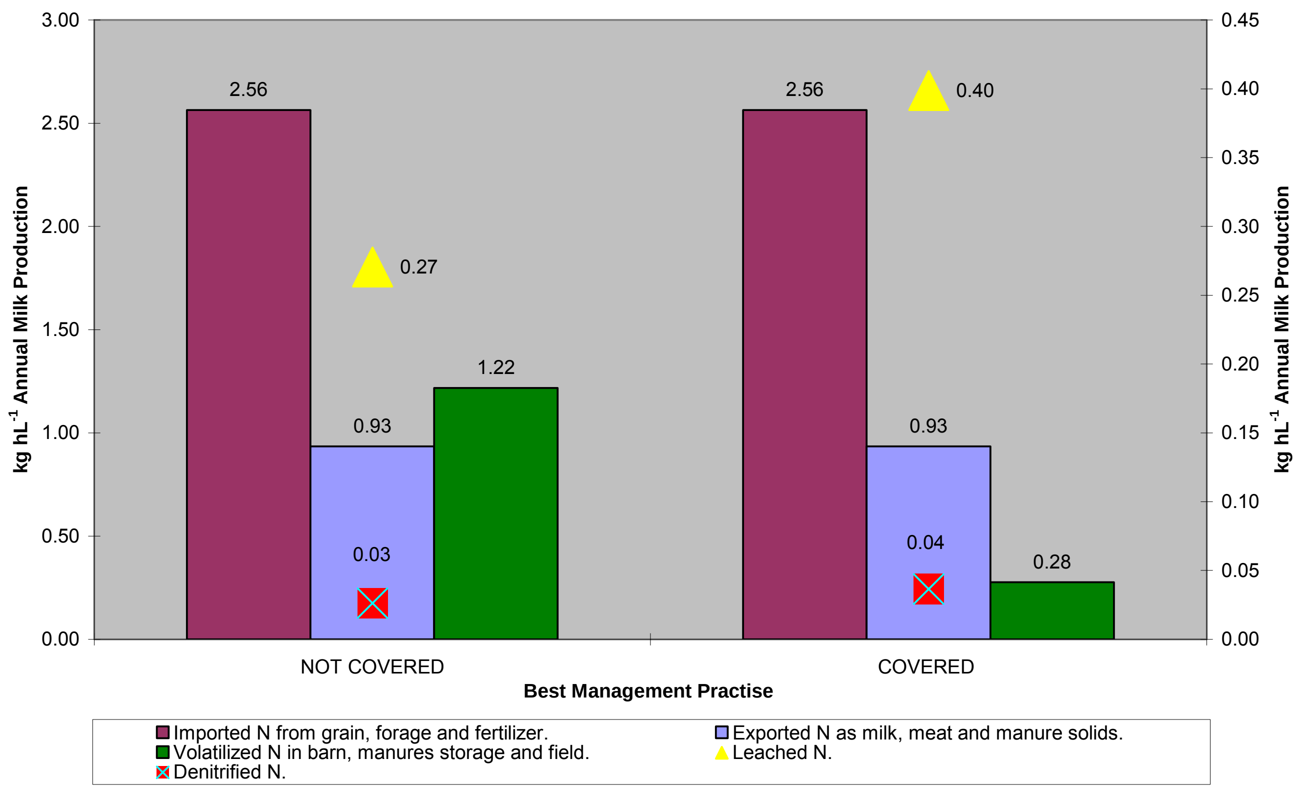
Figure 3. Effect of covering manure storage on imported, exported, volatilized, leached and denitrified N.



While N loss from volatilization was decreased, loss through leaching was significantly increased (Figure 3). In this simulation, manure was applied to cropland by injection rather than spreading on land surface. Injection would promote greater loss through leaching whereas spreading would result in greater loss through volatilization as shown by Amon et al. (2006). The model predicted an increase in denitrification loss by 0.1 kg hL^{-1} annual milk production for covered manure storage. This seems a small increase but for FarmBC, would result in an approximate increase of one tonne of N lost annually to GHG emissions.

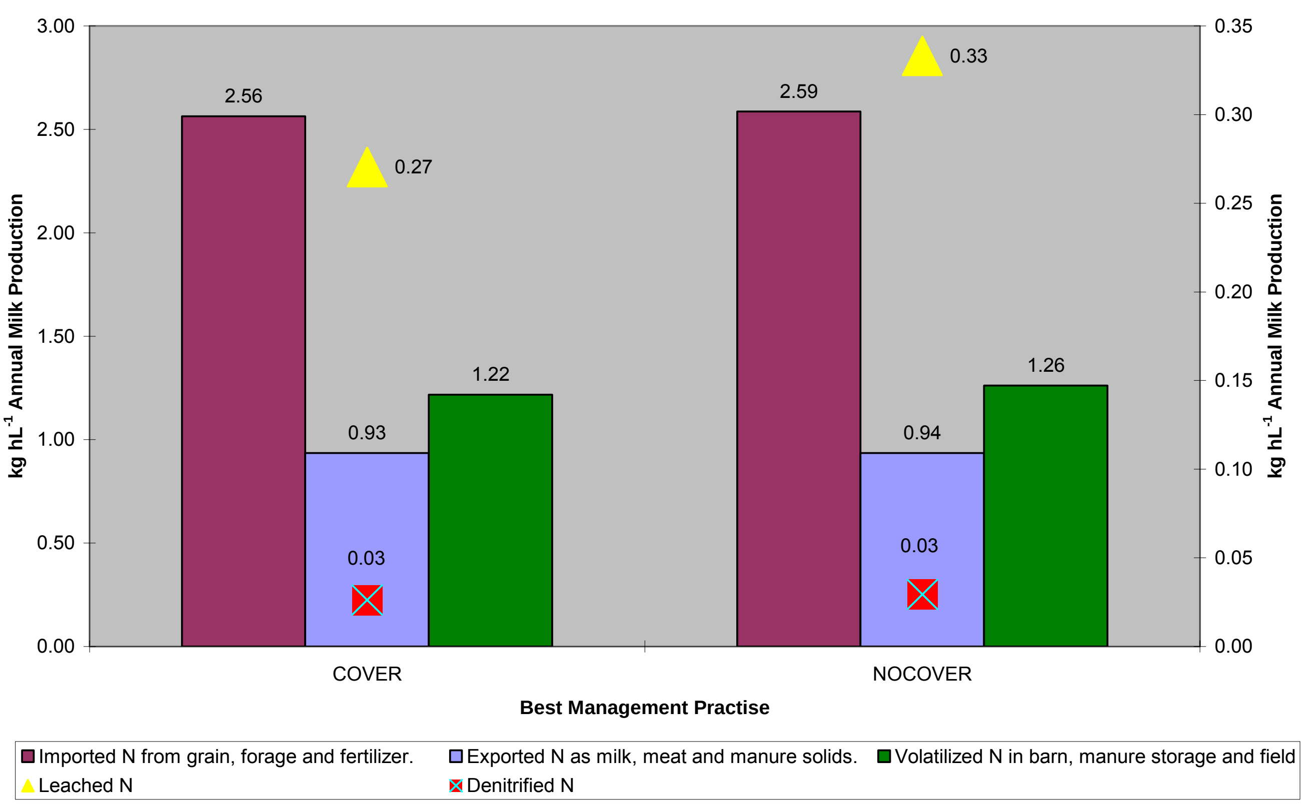
Adoption of the BMP of covering manure storage lagoons would not appear to be beneficial for reducing N-containing GHG emissions. In addition, formation of CH_4, an anaerobic process, may be enhanced depending on the cover used.

3.2.3 Cover cropping.

Cover cropping refers to the practise of planting a small grain or grass immediately after corn silage is harvested. This forage will be harvested as silage the following spring, the residual ploughed under and corn replanted. There are several reasons to plant cover crops including using residual soil N not used by the corn crop, minimizing erosion and increasing the organic matter content of the soil (Roy and Coelho, 2004). FarmBC currently uses the practise of cover cropping to supply grass forage for lactating cows and heifers.

In theory, cover cropping should reduce GHG emissions by using residual N in the soil that could be denitrified. As shown in Figure 4, the model predicts a difference in the amount of N lost

Figure 4. Effect of cover crop on imported, exported, volatilized, leached and denitrified N.



through leaching. The grass or small grain crop uses the N in the ground for growth rather than it being lost through leaching. Van Vliet and Zebarth (2004) showed significant reductions in Nitrate-N (61%), Ammonium-N (33%) and total N load (56%) by using relay cropping on corn land. Relay cropping is a cover crop planted when the corn is very small (Bittman et al. 2004).

Although the model did not predict a difference in denitrification N loss with or without cover crop, reports in the scientific literature would support such a conclusion. Oenema et al. (2001) reported that application of manure N to cropland increases the loss of N_2O via nitrification and denitrification processes. These authors also reported that the magnitude of this loss would differ due to the presence or absence of crops requiring N for growth. In the south coastal region of B.C., regulations prevent application of manure to land between November and March. Therefore, producers, including FarmBC spread manure in the fall. Cover crops would use the N in this manure, in addition to residual N in the soil from the corn crop, thereby reducing/eliminating losses through leaching or denitrification.

Less N is imported as forage-N onto FarmBC when a cover crop is grown, resulting in less N entering the N cycle on farm (56% retained versus 63% when no cover crop is grown). FarmBC uses the majority of the cover crop tonnage for feeding to heifers and dry cows. Inclusion of cover crops into the diets of lactating cattle, at the expense of commercial grains, good quality alfalfa and/or corn silage, would, in theory, result in greater CH_4 emissions due to the higher content of structural carbohydrates (cellulose and hemicellulose). A recent survey detailing the nutrient content of B.C. grown forages reports mean neutral detergent fiber contents of corn silage and cover crop as 46 and 60%, respectively (Swift, 2005).

Cover cropping can be viewed as a beneficial BMP providing the crop is harvested and fed. Ploughing under the cover crop would only serve to add N into the system, thereby increasing the total amount of N that could be lost through volatilization, leaching or denitrification.

3.2.4 Injection versus surface spreading of manure.

Smell associated with manure application can be a contentious issue between rural and city populations in south coastal B.C. FarmBC is located in close proximity to a village as well as a town of some 70,000 people.

FarmBC has designed a system where manure is sent, via underground pipes, to surrounding cropland. Manure is applied to the land via an injection system attached to a dragline. Injection systems reduce the amount of NH_3 loss (Bittman et al. 1999), thereby reducing the smell. Therefore, manure incorporation would appear to be a BMP in terms of reduced N loss and relationships with the public.

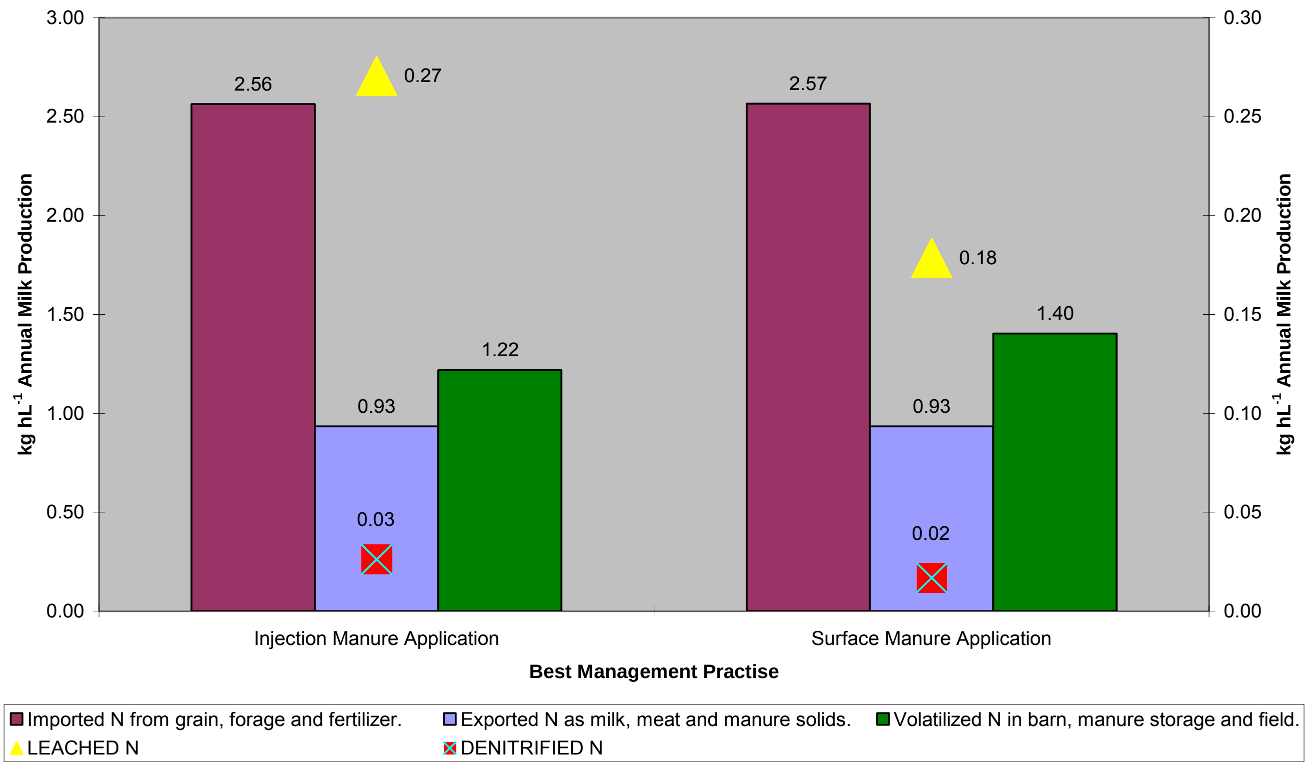
Method of application had no effect on the amount of N imported or exported from FarmBC (Figure 5). As expected, injection of manure decreased the amount of N lost through volatilization as compared to surface-applied manure (Figure 5). For FarmBC, this decrease equates to 20,671 kg annually (0.18 kg hL^{-1} annual milk production). However, approximately 50% of the N saved from volatilization is lost through increased leaching when manure is applied by injection. As shown in Figure 5, leaching loss increased from 0.18 (surface application) to 0.27 (injection application) kg hL^{-1} annual milk production. Dentrification loss of N was predicted to increase slightly (0.03 versus 0.2 kg hL^{-1} annual milk production) when manure was injected instead of surface applied. Therefore, application of manure by injection would appear to be a beneficial BMP in terms of GHG emission as less N is volatilized which may directly or indirectly incorporated into N_2O. However, manure injection may result in increased leaching loss, thereby affecting the water quality in surround aquifers.

3.2.5 Milk Production

The amount of milk produced is usually related to the implementation of BMP's and not necessarily considered a BMP. Milk provides a vehicle to move N out of the farm system. It is reasonable to assume if N can be exported as milk protein, then it is not available to be converted into N_2O or NH_3 . The N content of milk produced in B.C. falls 0.48 to 0.56, depending on breed and feeding program. Therefore, the amount of milk production will determine how much N is exported from the system.

Currently, the average milk production at FarmBC is 13,200L cow^{-1} $year^{-1}$. Weekly component analysis provided by the B.C. Milk Marketing Board, shows an average composition of 3.5% butterfat and 3.2% protein (0.52%N). Therefore, some 60 tonnes (59,717kg) of N is moved off farm annually via milk production. Decreasing milk production by 1000L cow^{-1} $year^{-1}$ while maintaining the same N input

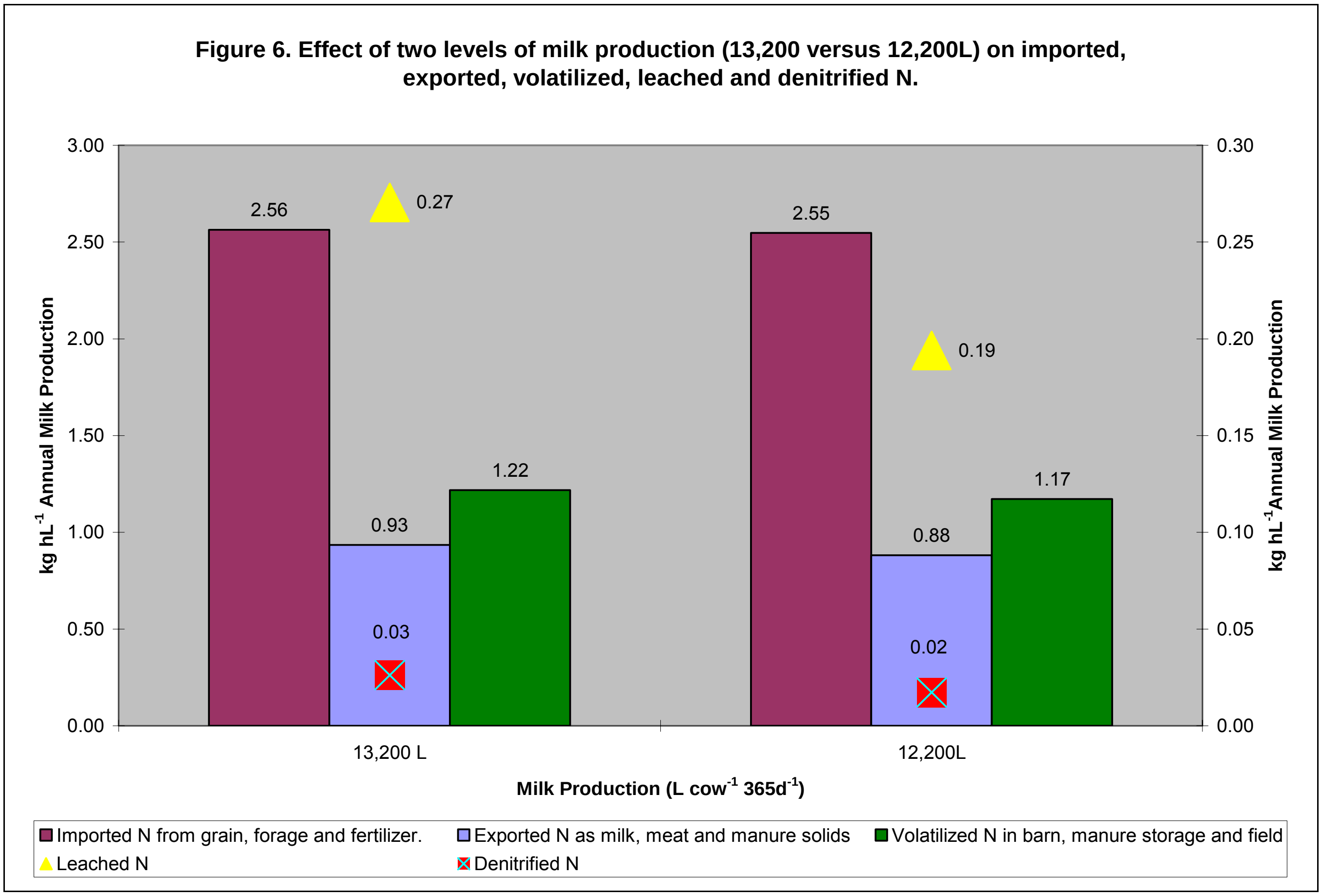
Figure 5. Effect of manure application method on imported, exported, volatilized, leached and dentrified N.



would result in 4,524 kg of N staying within the system.

However, there is a flaw in this assumption in that milk production is driven by dry matter intake. The model shows (Figure 6) increases in forage purchases, which in turn, increases the amount of imported N onto FarmBC. Using an efficiency factor of incorporating feed N into milk N of 30%, the remaining 70% of the extra feed N is added to the system. According to the model, this results in higher volatilization and leaching N within the system. The model assumes a linear relationship between milk production and dry matter intake and ignores the concept of feed efficiency.

Feed efficiency, calculated as kg of feed required to produce one kg of meat has been used to evaluate poultry and swine performance for many years, but is only just now being adopted by the dairy industry (Linn and Salfer, 2006). Presently, the model does not account for feed efficiency when estimating nutrient requirements for milk production. Modifications to the model in terms of ration balancing are required, specifically to incorporate a dynamic formulation system which recognizes forage digestibility, protein fractions and the requirement of the animal for metabolizable energy and protein.



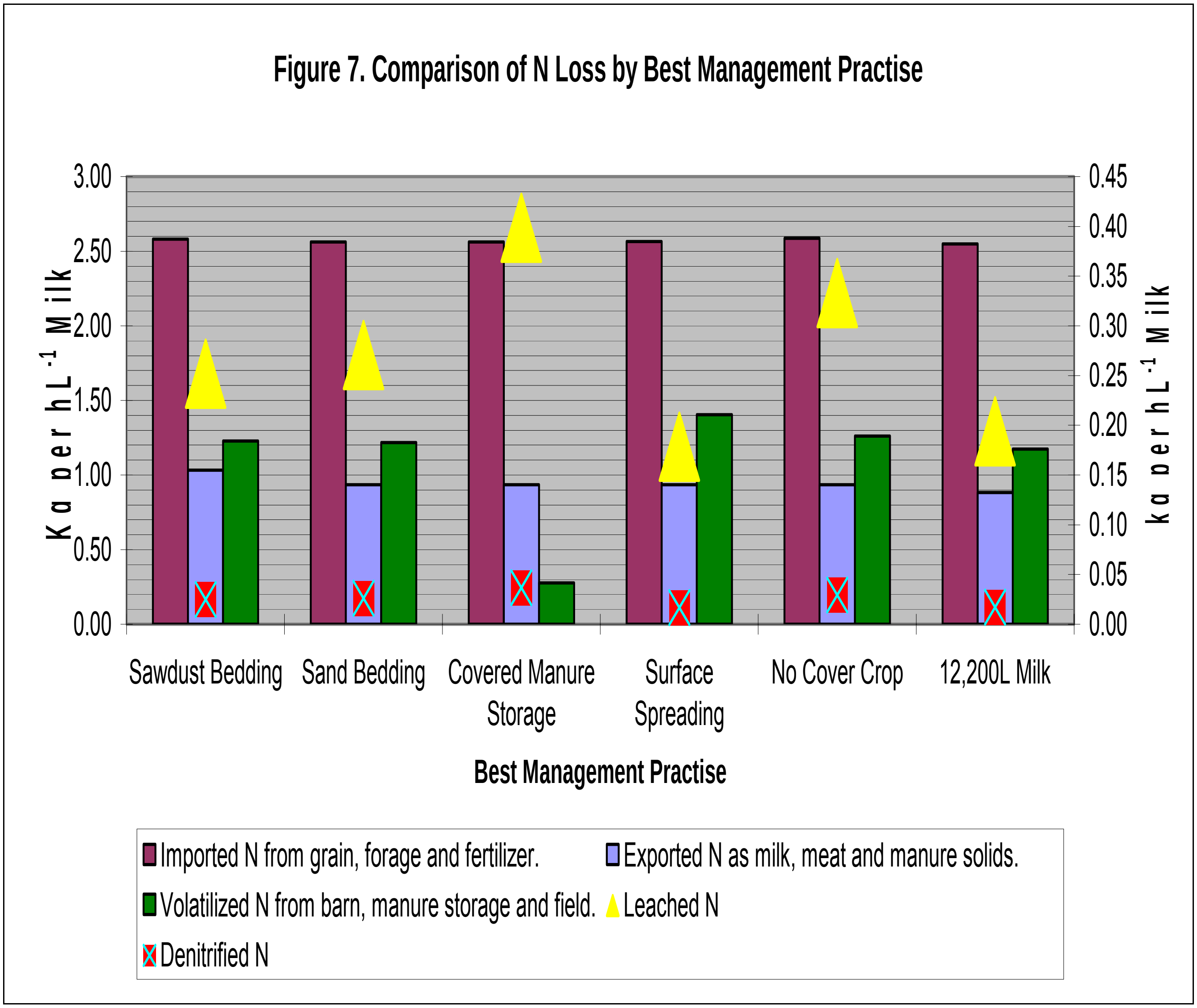
In review, a comparison of BMP's evaluated as to their effect on exit routes for N on FarmBC is shown in Figure 7. As cow numbers and milk production were kept constant to reflect the quota system, there was little difference in imported or exported N except for the last BMP of 12,200L milk cow^{-1} year^{-1} where both import and export of N was decreased.

The first BMP evaluated was a choice between sawdust and sand bedding. Sawdust is a by-product of the forestry industry in B.C and has been used extensively due to availability. However, sawdust can present challenges in terms of environmental mastitis, a bacterial disease which can severely affect cow health as well as milk quality. Producers such as FarmBC have changed to sand bedding as research has shown lower bacterial counts, hence, reduced incidence of mastitis (Zdanowicz and Shelford, 2001). It should be noted that sand bedding presents unique challenges in terms of physical handling and equipment maintenance, and so has not been widely adopted by the industry. Model output shows a reduction in volatilization of N when sand bedding is used. However, this N is lost through leaching when manure is applied to cropland.

Best management practises were compared to present practises employed at FarmBC, namely, sand bedding, manure application via injection, uncovered lagoons for manure storage, winter cover crop on corn ground and finally, milk production of 13,200L cow^{-1} year^{-1}.

Covering manure storage lagoons showed a decrease in the amount of volatilized N in comparison to present practises. However, this N was lost through leaching and denitrification once manure was applied to cropland via an injection system. Likewise, leaving crop land bare over the winter (no cover crop) resulted in higher volatilization and dentrification losses of N.

The IFMS model can calculate economic return thereby allowing the producer to consider the cost or benefit of implementing a BMP. Evaluation for FarmBC showed that sand bedding, covered manure storage, surface spreading, absence of cover crop and 12,200L milk production yielded economic returns of 99.4, 95.3, 98.8, 97.7 and 74.4 % of their current revenue using sawdust bedding.



4. DISCUSSION

The purpose of this study was to evaluate a whole farm model, the IFMS, for its ability to predict the effect of BMP's on GHG emissions, specifically CH_4 and N_2O. Direct measurement of these compounds on-farm is expensive and time consuming. Therefore, GHG emissions in studies evaluating BMPs are usually estimated using small-scale simulation studies (Berg et al. 2006; Külling et al. 2003) or indirectly using emission factors (EF) published by the Intergovernmental Panel on Climate Change (IPCC, 1996). Emissions of CH_4 published by IPCC (1996) are based on a series of equations using inputs such as dry matter, feed intake, energy digestibility and ash content. Direct emissions of N_2O are derived using an equation of EF(type of manure storage) x (kg N excreted).

Indirect emissions of N_2O are based on equations using factors for NH3 and NO_x volatilization and leaching (IPCC, 1996). Therefore, while IFMS does not directly calculate GHG emissions, it does provide much of the information as required by IPCC (1996) to estimate GHG emissions.

Strengths of the model include:

- Comprehensive evaluation of a farm system including forage systems, manure collection, storage and application systems, machinery use, feeds and nutrition, and economics.
- Information produced can be transferred to estimate GHG emissions
- Model predicts nutrient management of phosphorus and potassium in addition to nitrogen.
- Ease of use in terms of information collection and input.
- Relevance to Canadian dairy, beef and cropping production units.
- Ability to assess agronomic, feeding and management decisions over a number of years.
- Ability to incorporate weather data specific to a geographical region.

Suggested modifications to the model are:

- Revision of the feed/diet formulation system to a dynamic model which incorporates digestibility factors such as metabolizable energy and protein. It would be of benefit to enter actual diets being fed rather than having the system formulate diets based on a requirement for intake of protein, net energy of lactation and so forth. Depending on the prediction equation or model chosen, more detailed information as to feed nutrient content is required predict CH_4 emissions from enteric fermentation. One suggestion would be to link IFMS to the National Research Council's Nutrient Requirements of Dairy Cattle (2001) or to the Cornell Pen Minor (CPM) model.
- Consideration of linkage to a model specifically designed for determination of leaching and denitrification losses in soil.
- Inclusion of sub-model designed to predict GHG emissions.

In conclusion, the IFMS model is a comprehensive model designed to evaluate nutrient management on dairy, beef and cropping production units. The model would be enhanced if the current static feed formulation system was replaced with a dynamic model which will evaluate feeds in terms of their ability to provide digestible energy and protein. It would also be of benefit to be able to enter and evaluate current diets in terms of their affect on GHG emissions

In regards to GHG emissions, the results of this project clearly show that the choice is between prevention and reaction. The BMP's evaluated in this project are all designed to "react" to the amount of N already present in the system through feed and fertilizer importation. A good example is the noted reduction of N loss through volatilization by using covered manure storage. It would appear, therefore, that this BMP is beneficial. However, evaluation of this BMP within the whole farm context shows that covered manure storage results in increased leaching and denitrification losses once the manure containing more N is applied to crop land. Further BMP's would then be required to prevent these losses, namely, ascertaining manure composition pre-spreading and secondly, application rates based on soil composition and crop requirements (precision agriculture). The question then arises as to "What happens to the surplus manure not needed for crop fertilization?"

While there is no question as to the value of mitigation practises in reference to GHG emissions from Canadian agricultural operations, it does beg another question as to the role of "preventative" research. One example would be research programs designed to elucidate and recommend forages or cropping strategies that support milk production but have the potential to decrease GHG emissions through superior energy digestibility, decreased ruminal N escape or a combination of both. With slight modifications, a model such as IFMS could play a key role in the design and evaluation of such research programs. Certainly evaluation of any GHG mitigation strategy demands evaluation within a whole farm model context.

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Appendix A. Predicted annual yields of volatilized, leached and dentrified nitrogen.

	Volatilized N (kg)	Leached N (kg)	Denitrified N (kg)
Sawdust bedding	141,196	28,947	2,833
Sand bedding	139,838	31,064	3,014
Covered manure storage	31,708	45,782	4,197
Surface spreading of manure	161,130	20,504	1,934
No cover crop	144,881	38,253	3,377
12,200L milk production	134,657	22,275	1,986