Nutrient Recycling – What Happens to the Excreted Nutrients?

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▪ Take Home Messages

- Most of the nutrients that are fed to dairy cattle end up in the manure.
- Much of the nitrogen in manure can be lost to the air during storage and after application to land.
- Other nutrients accumulate in soil because they have no other loss pathways.
- Excess potassium accumulation is a potential herd health risk.
- Accumulation of other nutrients including nitrogen may pose increased risk of ground or surface water pollution.
- The best strategy to more sustainable dairy production is to improve the diets to reduce nitrogen excretion.

▪ Introduction

The most unfortunate thing about dairy production is that animals produce manure. Although this manure has some nutrient value, it adds to the net cost of animal production. The smell of manure sometimes annoys some our non-farming neighbors. If not managed carefully, manure or components of it gets into waterways, killing fish and encouraging disease organisms. It contains nutrients that accumulate in soil, which may cause soil and/or water pollution.

The most important environmental issue facing dairy producers is manure management. As part the agricultural community, we are becoming more aware of this. The public of Canada is also becoming aware of the potential negative impacts of manure mismanagement. As stewards of the land and of the resources put within our control, we have the responsibility to not only understand the potentially harmful effects of agriculture, but minimize the potential harmful impacts on soil, air and water. Free enterprise is not sustainable if we do not take responsibility for the well-being of our soil, air and water.

Our Canadian laws also encourage stewardship of our resources. Section 98 of the Alberta Environmental Protection and Enhancement Act specifies that “no person shall release or permit the release into the environment a substance in an amount, concentration or level or at a rate of release that causes or may cause a significant adverse effect.” We need to understand how our manure management may affect our air, soil and water. We also need to work towards minimizing the risk of pollution, for our own protection and the protection of future generations.

In this presentation, I will follow the three major nutrients of manure; nitrogen, phosphorus and potassium. I will explain what happens to them and what impact they have on and off the farm.

▪ Most of the Nutrients in the Diet are Excreted and Stay on the Farm

The majority of the nutrients that are imported onto the farm as feed or fertilizer are not exported as animal products, but stay on the farm because they are excreted in the manure. The efficiency of nutrient utilization by animals is poor. Dinn et al. (5) reported that 25 to 33% of the dietary nitrogen fed to lactating dairy cattle was found in the milk. This is similar to most reports of nitrogen use efficiency in dairy cattle in North America. Fisher et al. (6) reported that 5 to 14% of the dietary potassium fed to lactating dairy cattle was found in the milk, depending on the level of potassium in the diet.

A nutrient balance for individual farms reflects the poor utilization of nutrients by dairy cattle. Nutrient balances support what the soil tests are telling us, that phosphorus and potassium are accumulating on most dairy farms. Analysis of three dairy farms in the Fraser Valley of BC show that 77, 76, and 78% of the nitrogen, phosphorus and potassium that comes onto the farm does not leave the farm (Table 1). Comparatively, nutrient balances for two dairy farms in New York state showed that 74, 67 and 78% of the nitrogen, phosphorus and potassium that was imported to these farms was not exported (8). Nitrogen utilization on dairy farms in Europe and North America ranged from 16% to 35% (11). On 350 dairy farms in the Netherlands between 1983 and 1992, 70 to 84% of the potassium brought onto the farm was not exported as animal products (17).

Table 1. Nitrogen, phosphorus and potassium imports and exports on three dairy farms - Fraser Valley, BC (average 80 cows, 40 ha)

	Nitrogen	Phosphorus	Potassium
		kg per year	
Imports			
Feed	10409	2386	3551
Fertilizer	8856	1217	1451
Total Imports	19265	3603	5002
Exports			
Milk	3805	646	1077
Meat	639	214	47
Total Exports	4444	860	1124
Efficiency of nutrient use (%)	23	24	22

Nutrient excess on the farm has implications for a geographic region as well. In the Abbotsford and Chilliwack area of the Fraser Valley, where one of the major agricultural activities is dairy production, nutrient excess was observed. The amount of nitrogen, phosphorus, and potassium that was applied to the fields was 170, 97, and 168 kg ha^{-1} greater than the amount of the nutrients removed by the crop (4).

The efficiency of nitrogen use by dairy cattle can be improved by changes in the diet. Aarts et al. (1) suggested that nitrogen utilization in the animal component of a Dutch dairy farm could increase from the current level of 17% up to 26% with technology now available. This includes the use of a protein evaluation system in which the supply of absorbed amino acids is related to the supply of energy (16). Dinn et al. (5) showed that balancing protein concentrations using the Cornell Net Carbohydrate and Protein System increased the nitrogen utilization of the diet from 26% to 33% with only a slight reduction in milk yield.

Phosphorus and potassium utilization is more difficult to alter with diet. Utilization by the animal is somewhat dependent on the amount of the nutrients in the diet, but the concentration of phosphorus and potassium in the milk does not change significantly with changes in the concentration in the diet.

Potassium excretion by the animal is highly dependent on the potassium concentration of the diet. Fisher et al. (6) calculated that 5, 7, and 14% of the dietary potassium was exported in the milk with dietary potassium levels of 1.6, 3.1 and 4.6%, respectively. Because forages accumulate potassium relative to the potassium concentration in the soil, it is sometimes difficult to control the potassium level in the diet.

Where do all the nutrients go that are not exported as animal products? It is our responsibility to understand and manage the nutrient excesses. In some cases such as with nitrogen and phosphorus, excesses may present an environmental risk. In the case of potassium, excesses may pose a dairy herd health risk, and may therefore be a net cost to the dairy producer.

▪ Much of the Nitrogen is Lost to the Air

Nitrogen is the only nutrient that does not accumulate on the farm. Although 70-80% of the nitrogen is found in the manure, there is usually no net accumulation in the soil. What happens to it? On an Ontario dairy farm having liquid manure storage, 35% was lost through ammonia volatilization in the barn and during storage (11). Most of the ammonia loss happens in the barn, before the manure goes to storage. Paul et al. (12) measured ammonia losses of 22-30% of the total excreted nitrogen from the barn floor in a 24 hour period. Muck and Steenhuis (9) measured volatilization losses of up to 40% of the excreted N during the first 24 hr. after excretion.

Ammonia loss to the air depends on the exposure time of the manure to the air, the urea concentration in the manure, and the climatic conditions. Ammonia losses increase with longer exposure time to the air. Therefore a manure management system that minimizes exposure of the manure to the air (particularly the urine) reduces ammonia loss. Smits et al. (15) reported ammonia emission rates of less than 10% of the excreted nitrogen from a barn designed to reduce ammonia emissions by separating the urine from the feces using a urine channel. The urea concentration of the manure is contributed by the urine fraction, which is directly proportional to the protein level in the diet. The greater the amount of excess protein, the higher the urea concentration in the urine, and the higher the ammonia emission rate (12). Ammonia emission also increases with increasing temperature, therefore we can expect higher losses during the summer than during the winter.

Storage of manure in a liquid form results in lower ammonia emission losses than with solid storage of manure, primarily because the exposure to the air is minimized. Bottom loading of manure into a storage tank or lagoon also reduces ammonia emission compared to top loading because of reduced exposure to the air. A surface crust on a manure pit or lagoon significantly reduces ammonia emission.

Nitrogen is also lost to the air as ammonia following land application of manure. Ammonium nitrogen makes up about 50% of the total N in liquid manure. The ammonia loss to the air ranges from 10 to 100% of the ammonium in the manure, depending on management and climatic conditions. If the manure is immediately incorporated on a cloudy day with little air movement, we may expect low ammonia emission. If the manure was surface applied on a warm sunny day with a breeze, we could expect almost 100% loss of the ammonium fraction of the manure. The ammonium fraction in the manure is what provides most of the plant available nitrogen in the year of application.

In a model of nutrient flows in the districts having mostly dairy cattle in the Fraser Valley, 44% of the excreted nitrogen was volatilized as ammonia from the barn, during manure storage, or following manure application to land (4). These estimates assume good manure management. In some cases, nitrogen losses could be as high as 75% of the excreted manure.

Much of the ammonia comes back to the ground near the source of emission, either as dry deposition or in rainfall. There is no way to account for input of nitrogen with fertilizer management, and much of it may be deposited at a time of year that plant growth may not benefit from it. There is also no guarantee that this ammonia will not enter watercourses. In North Carolina, for example, ammonia originating from hog manure lagoons has caused massive damage to the coastal estuaries. Whose responsibility is this? We need to understand where the losses of nitrogen are coming from and what impact this has on the environment.

There is another form of nitrogen that is emitted into the air during manure management. This form of nitrogen is nitrous oxide, more affectionately known as laughing gas. Nitrous oxide is a powerful greenhouse gas, one molecule of nitrous oxide has the same effect on global warming as 300 molecules of carbon dioxide. Nitrous oxide is a very stable molecule and is also thought to cause ozone depletion in the stratosphere. Nitrous oxide is emitted during aerobic decomposition of manure, in the semi-solid manure heap, or following manure application to the field. We are still learning more about the dynamics of nitrous oxide during manure management.

▪ Nitrogen is Lost to Watercourses

Pollution of surface waters by manure represents the most direct and obvious form of pollution. Manure provides color to the water. Algal blooms are relatively immediate. Fish kills happen soon after pollution of water by manure and are usually obvious.

The ammonium form of nitrogen is the most harmful to fish at low concentrations. Ammonium also encourages growth of algae, which reduce oxygen concentrations in the water, also harming fish. The nitrate form of nitrogen is not directly harmful to fish, but it also encourages growth of algae which reduces the oxygen concentration in the water.

The best way to minimize the nitrogen lost directly to watercourses is to minimize winter application of manure and to keep some distance from watercourses when applying manure. It is difficult to completely eliminate the risk of surface water pollution because heavy rainfall events that may wash soil and manure into watercourses are not always predictable. Applying manure and incorporating it into the soil just before the plant requires the manure nitrogen also reduces the risk of pollution.

▪ Nitrogen Accumulates in the Soil and is Leached to Groundwater

Despite nitrogen losses to the air, there is often a net excess of nitrogen applied to the soil. One of the forms of nitrogen is nitrate. Nitrate accumulates in soil where manure has been applied at high rates for a long period of time. What happens to this nitrate? If it is near the soil surface, plants can take it up. Under warm, wet conditions, it can be lost to the air via a process called denitrification. With this process, most of the nitrate in soil changes to dinitrogen gas; 80% of the air consists of this gas.

Denitrification for the most part, is a harmless process. It is the only process that returns fixed nitrogen back to the air. For example, atmospheric nitrogen is converted to plant nitrogen through nitrogen fixing bacteria. It is also converted to ammonium or nitrate during the manufacturing of fertilizer. The only way that this nitrogen is returned back to the air is through denitrification. This is primarily a bacterial process that occurs under anaerobic conditions (when the oxygen concentration in the soil or water is low). A byproduct of the denitrification process is nitrous oxide, which is a powerful greenhouse gas as mentioned earlier.

Nitrate is very soluble in water, therefore is easily transported downward. This nitrate can cause nitrate pollution of the groundwater. The risk of groundwater pollution is affected by soil type, the amount of water going through the system, and the depth to groundwater. For example, in some areas of the United Kingdom, nitrate from the soil surface has taken 40 years to reach groundwater. Grassland that was ploughed after World War II resulted in a flush of nitrate production, which moved downward to the groundwater over a period of 40 years. In another example, excess nitrate applied on the Abbotsford aquifer is thought to reach the groundwater within 1-2 years.

Groundwater in Alberta is definitely at risk of nitrate pollution. It may be a delayed effect because of the low rainfall. The lower rainfall in Alberta also means that when groundwater is polluted by nitrate, it may take 10s or even

100s of years to reduce the nitrate concentration in the water. In southcoastal British Columbia, groundwater is easily polluted by nitrate because of the high rainfall and gravelly subsoils. The nitrate is also relatively easy to flush out because of the high groundwater recharge rates resulting from high rainfall. Removing nitrate from drinking water is an expensive process. It is much less expensive to prevent the pollution from occurring in the first place.

▪ Phosphorus Accumulates in Soil and is at Risk of Polluting Surface Waters

Phosphorus and potassium do not have the same loss pathways to the air that nitrogen does. This means that excess phosphorus imported onto the farm stays on the farm and accumulates in the soil. Higher phosphorus concentrations in soil become an environmental risk when soil erosion occurs. Many inland lakes and streams are phosphorus limited, which means that additions of phosphorus will encourage growth of algae (13).

It has always been thought that phosphorus does not move with the water in the soil. This idea came about because inorganic phosphorus will bond with calcium and magnesium in soil and become a solid that is not soluble in water. This happens very effectively in high pH soils such as found in the prairies. Phosphorus in manure does not necessarily behave the same way as inorganic phosphorus. Phosphorus in manure is primarily in the organic form, and some of these forms of organic phosphorus are readily soluble in water. Downward movement of phosphorus in manured soils has also been linked with the presence of wormholes (14). It appears that worm holes accelerate the movement of phosphorus and other manure constituents downwards below the root zone.

Soil phosphorus accumulation in areas of intensive livestock production in Quebec has been correlated with elevated concentrations of phosphorus in surface waters (13). The province of Quebec has already responded to this by passing legislation concerning the spreading of manure.

▪ Manure Application to Land May Be Based on Phosphorus Instead of Nitrogen

Manure application recommendations are either based on the amount of animals per hectare, on the nitrogen content of the manure, or the phosphorus content of the manure. Manure application rates based on animal density are usually calculated based on the nitrogen concentration of the manure. There is a risk of excess manure application if low yielding crops are grown. The manure application recommendations for Alberta are based on this system (2).

Manure application recommendations vary with soil type. Although this type of manure recommendation has a lot of merit, and is simple, it does not benefit producers who reduce nitrogen excretion by improving diets, or who are able to grow higher yielding crops.

Manure application recommendations in many areas are now based on balancing manure nitrogen with crop uptake. This means that the amount of nitrogen in manure that is applied to land must be related to the amount of nitrogen removed by the crop. Manure application rates vary depending on the nitrogen content of the manure, the type of crop and the expected yield. For example, forage grass in the Fraser Valley removes up to 400 kg N ha^{-1} annually (3). Crops in the black soil zones of Alberta are expected to remove up to 90 kg N ha^{-1} annually (2). This means that manure application rates for forage grass in the Fraser Valley can be up to 4.4 times higher than manure application rates on the black soils in Alberta. It also means that 4.4 times the amount of land is required in Alberta for a farm with a similar number of animals.

Although manure application recommendations based on nitrogen balancing are better than those based on animal density, there are still some problems. Because the manure application rates are based on the nitrogen content of the manure, it does not always consider nitrogen losses after manure excretion by the animal and before manure application. This could encourage manure management that strips the manure of the nitrogen so that manure can be applied at a higher rate. This is happening with hog manure stored in lagoons in North Carolina. The nitrogen losses from these lagoons can be as high as 90% of the nitrogen excreted by the pigs. This means that only 10% of the manure nitrogen needs to be applied to the field. What happened to the other 90% of the nitrogen? It went into the air and was deposited somewhere. This system doesn’t take full accountability of the nutrients in the manure. It also results in higher application rates of other nutrients, which may lead to greater excesses in soil.

There are already some areas that base manure application recommendations on the phosphorus content of the manure. The Netherlands has been doing this for almost 20 years. Their rationale was that phosphorus in manure is not subject to loss like nitrogen is, and therefore is a more stable element to base recommendations on. There are many areas in North America that are now considering phosphorus based manure application recommendations. There are several reasons for this. With application rates based on nitrogen, more phosphorus is applied than can be taken up by the plant. Phosphorus concentrations in soil are climbing. Because many inland waterways are phosphorus limited, this increases the risk of algae blooms in the water, with the resulting negative impact on fish.

Manure application rates based on phosphorus encourages more stewardly manure management. Usually, the amount of manure applied is less when application recommendations are based on phosphorus. This means that there is more incentive to apply the manure in a manner that allows optimal utilization of nitrogen. It also means that there is less incentive to remove the nitrogen before the manure is applied to the field.

Ideally, manure application rates should be based on both nitrogen and phosphorus. They should be based on nitrogen until the phosphorus levels in soil reach a specified concentration. When the soil phosphorus concentration reaches a designated level, manure application rates should be based such that phosphorus application is balanced with phosphorus removal by the crop. Periodic soil testing will verify how well this is working.

▪ Potassium Accumulates in Soil and May Poison Dairy Cattle

Potassium doesn't have many loss pathways. Potassium is a very soluble nutrient, which means it travels with water. When manure is piled as a semi-solid, significant amounts of potassium may be washed into the ground or down the slope to the creek. The potassium doesn't have negative environmental implications that we are aware of yet, but other components of manure that are washed to the creek with the potassium do have negative environmental impacts.

Improved manure storage also means that more potassium is going back onto the land. Nutrient balances for dairy farms indicate a net surplus of potassium, which means that potassium concentrations in the soil on dairy farms will increase (10). Most soil tests on dairy farms indicate an increase in soil potassium with time. The rate of increase depends on how much manure was applied, how much potassium fertilizer was applied, the crops that are grown, and the soil type.

Potassium is a positively charged nutrient. This means that it is attracted to soil particles because soil particles have a net negative charge. The amount of negative charges that soil has is dependent on soil type. A sandy soil has very little negative attraction to potassium compared with a clay soil, which has a high attraction to potassium. This means that a clay soil can potentially have much higher concentrations of potassium than a sandy soil. The amount of rainfall also influences the amount of potassium in the soil. In high rainfall areas, potassium does move downward with water. This occurs more readily in sandy soils than in clay soils. This is a blessing to the dairy producer, because it means that potassium concentrations in soil do not increase as fast as in areas with lower rainfall. In the prairies, where rainfall is lower, we can expect higher accumulations of potassium in soil.

So who cares about high potassium in soil? The cows do. Forage grasses are luxury consumers of potassium, which means the higher the potassium concentration in the soil, the higher the potassium uptake by the grasses. Potassium is taken into the root through the same pathway as magnesium, which means that less magnesium is likely to be taken up by the plant when there is an excess of potassium in the soil.

Excess potassium in forage grasses has several effects on the animal. The first effect is a lack of magnesium. Magnesium concentrations in feed tend to be lower because less magnesium is taken up by plant grown in high potassium soils. Less magnesium is absorbed by the animal because potassium and magnesium share the same pathway through the stomach or intestinal lining. Fisher et al. showed that excess potassium in animal diets may have a negative influence on the utilization of calcium and magnesium, and may predispose the cows to both milk fever and grass tetany (7).

The second effect on the animal is that the cow is now ingesting a diet with a higher salt content. In order to compensate for this, the cow drinks more in order to flush out the excess potassium. Fisher et al. (7) found that cows on a 4.6% potassium diet produced 3 times more urine than cows on a 1.6% potassium diet. This not only produced a lot more manure, but altered the normal function of the kidney and had long term implications for the cows.

The third effect of high potassium is that it presents a severe problem for dry cows.

> “It is generally accepted that a ration with a negative dietary cation-anion difference fed pre-partum (3-4 weeks) will decrease the incidence of milk fever, and improve a cow’s subsequent productivity and reproductive performance. If the pre-partum diet is based on a home grown forage containing in excess of 2.5% K, it is impossible to formulate a palatable supplement that would result in a negative cation-anion difference in the total diet.” (7)

It is best to measure potassium concentrations on forage grasses, especially those that are grown near the barn, or are purchased from neighbors having hog or poultry farms. Poultry manure contributes a very high amount of potassium to the soil. If forages are high in potassium, don’t feed them to the dry cows. Dilute them with other lower potassium feedstuffs for feeding with the milking herd.

Good manure management is the best way to manage potassium concentrations in soil. If manure application rates were based on the phosphorus concentration in the manure, it is not likely that potassium concentrations in the soil would increase dramatically.

▪ Summary

We in the agriculture industry need to take responsibility for understanding the fate of excreted manure nutrients, and for managing them in a sustainable manner.

Most of the nutrients that are fed to the animals are excreted in the manure. Nitrogen can be lost to the air as ammonia or nitrous oxide. This emission may have a negative impact to the environment beyond the farm boundaries. Nitrogen can also enter surface water as either ammonium or nitrate, and can result in excess algal growth and fish kills. Nitrogen can enter groundwater as nitrate. In the prairies, groundwater that is polluted with nitrate will take a long time to become clean again. Nitrate is expensive to remove from groundwater. Phosphorus doesn't have many loss pathways, and therefore tends to accumulate in the soil on dairy farms. This puts surface water at risk through phosphorus pollution. It may be more environmentally sustainable to base manure applications on phosphorus than on nitrogen. Phosphorus based manure management also encourages more stewardly management of nitrogen. Potassium also doesn't have many loss pathways and accumulates in the soil. Forages take up potassium relative to the potassium level in the soil. Excess potassium in soil may have dramatic animal health effects, on milk fever and reproduction.

Manure must be:

- stored in a manner that minimizes ammonia loss (minimize exposure to air)
- stored in a manner that prevents rainwater from washing nutrients out, causing pollution to soil or surface water
- applied to the field at rates that allow the crop to utilize the nutrients
- applied to the field close to the time of optimal uptake by crops

It is in the dairy producers best interest to understand the fate of their manure nutrients. Poor nutrient management can have serious health implications for the dairy herd. This translates into a significant economic cost to the dairy producer.

Managing dairy manure as a liquid can be the best method of conserving and recycling manure nutrients during storage. It can also be the best method for recycling the nutrients for crop production, if the manure is applied properly. Managing the manure as a solid or semi-solid often results in nitrogen losses during storage, and it generally is more difficult to conserve the nitrogen after application to the field.

There are farms that do not have enough land to apply manure nutrients in a sustainable manner. These farms need to have good neighbors that are willing to utilize the manure, or the manure needs to be processed so that the nutrients can be exported. Composting is one way of doing this. Composting may also be an option for very large farms where it is very costly to transport manure long distances.

One of the most important and effective strategies for minimizing the negative environmental impacts of manure is to reduce the amount of nutrients that are excreted. This is most effective for nitrogen, where up to a 25% reduction in nitrogen excreted is possible with ration balancing.

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