Whole Farm Nitrogen and Phosphorus Management

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Take Home Message

- The aim of nutrient management is to maintain agronomic productivity, reduce environmental impact, and increase profitability.
- Nutrient cycles of wild Prairie ecosystems have been split open into flow-through agricultural systems that concentrate nutrients into commodities.
- Cropping and confined animal feeding operations are increasingly separated, and nutrients move between crop and animal operations as feed and manure.
- A dairy includes a confined animal feeding operation in which the stocks and flows of nutrients can be managed for maximum advantage.
- Animal and crop genetics, feed additives and supplements, and accurate nutrient information can be used to match feed nutrients with animal requirements, thereby reducing the excretion of excess nutrients in manure.
- Good farm management practices for manure removal, transfer, and storage align with good nutrient conservation. Closed or covered systems in which leaks, spills, and leaching are minimized will conserve nutrients.
- Manure processing can remove water, concentrate and stabilize nutrients, and extract value from manure as marketable fertilizers, soil amendments, and energy.
- Land application of manure should be planned based on actual nutrient values of manure and soil, and expected crop requirements.
- Technologies are being developed to improve the uniformity and precision of manure application and optimize crop uptake of nutrients.

WCDS Advances in Dairy Technology (2007) Volume 19: 351-362

Introduction

I have been invited to talk today about whole farm management of nitrogen and phosphorus. Nutrient management on any farm is about agronomic productivity, profitability, and environmental stewardship. This topic is also a small part of the much broader issue of nutrient transport through food supply and waste management systems generally. I would first like to take a few minutes to explore that larger context and explain why I think it is extremely important. I will talk mostly about the Canadian Prairies, but the issues that are illustrated are of global relevance. I will then narrow the focus and talk about the flow of nutrients through a typical dairy operation, the stages in the operation at which those flows might be managed, and some options that are available to do this. So, first I will talk about saving civilization and the environment, and then I will talk about saving money.

The Sustainability of Agriculture

Food production is taken for granted by many people in today's urbanized, Western societies. The great majority of us are city dwellers and are so far removed from agriculture in our daily lives that we rarely give a second thought as to where our food comes from. We spend even less time, if any, thinking about whether our descendents will enjoy a similar safe, secure, and abundant food supply. This question, however, is obviously of great importance. Of course I hope that the answer is "yes", but that is by no means assured.

The integrity of our food supply rests on the foundation of sufficient water, an agreeable climate, the robust genetics of our food crops and animals, and good quality soil. Sustained fertility of the soil, of course, depends on how well we manage nutrients. Traditional wisdom in every agrarian culture teaches that how we manage these resources determines whether our grandchildren will eat well or not.

In Western Canada, we have been blessed with an abundance of all of these resources. William Butler, a British Army office who traveled to the Prairies in 1870 during the Red River Rebellion, referred to the watershed of the North Saskatchewan as a "fertile belt", writing that "the Saskatchewan offers at present… a magnificent soil and a fine climate" (Butler, 1872). Indeed, much of the region is covered with rich chernozemic soils, developed over ten thousand years as part of a productive grassland ecology continually grazed by millions of bison. Further south, the glacier-fed rivers of the South Saskatchewan basin supply water to regions where rainfall is not always adequate for agriculture. The temperate climate and long, mild summer days at these northern latitudes are well-suited to many crops of European origin, which the local agricultural community has worked hard to improve and diversify. These resources, together with advances in science and technology, have made the Prairies one of the world's most productive and labour-efficient agricultural ecosystems. Farmers, though relatively few in number, are able to produce an abundance of inexpensive, high-quality food to support a highly urbanized and industrialized society. In return, industrial agriculture is made possible by the machinery, energy, and other inputs that only such a sophisticated economy can provide. We might ask ourselves, however: is a productive and labour-efficient production system necessarily sustainable? This question is intimately tied to nutrient management practices and soil fertility.

The scientific study of sustainability in agriculture is widely considered to have been founded by Gabrielle and Sir Albert Howard, British agronomists who studied traditional agricultural systems in Southeast Asia during the early 1900s. There, farming practices have maintained soil fertility during 40 centuries of intensive cultivation. The Howards asked themselves whether the industrialized agriculture then emerging in the British Empire, including the Canadian Prairies, was similarly sustainable. The couple's work is summarized in a book called "An Agricultural Testament", in which they ask: "Can mankind regulate its affairs so that its chief possession – the fertility of the soil – is preserved? On the answer to this question the future of civilization lies" (Howard, 1943). The Howards' work demonstrates that the general answer to their question is 'yes', but do current agricultural practices on the Canadian Prairies assure the same kind of long-term sustainability? Nutrient management is an integral part of this challenge.

▪ Nutrient Flow Patterns in Prairie Agriculture

Nutrient flows on the Canadian Prairies, as in much of the populated world, have changed radically in the last century. This shift has occurred as wild ecosystems have given way to commodity agriculture. Before Europeans settled on the Prairies, nutrient flows were primarily cyclical. Carbon and nitrogen were captured from the atmosphere, and phosphorus, potassium, and micronutrients were drawn from the soil by the plants and microbes of a diverse, complex, and well-established ecosystem. Enormous populations of herbivores such the American bison and the Rocky Mountain locust consumed the plants and the nutrients returned to the soil with their manure and with their bodies upon their death. The Prairies were also a fire ecosystem, and regular burning played a dominant role in the release of nutrients and renewal of the vegetation.

During the 19th century the Prairies were depopulated of bison, largely by hunting to supply the fur trade with buffalo robes and pemmican (prepared, dried meat which was a staple food of the time). Cattle herds were established in their stead and, in the early 20th century, much of the Parkland, tall-grass, and mid-grass regions were ploughed up as cropland. Even at that time, the production of commodities such as cattle and wheat was already the mainstay of the agricultural economy. With the establishment of commodity agriculture, the mechanisms of nutrient dispersal and cycling that had dominated the wild ecosystems of the plains were gradually suppressed. Today, a substantial fraction of nutrients is instead concentrated into commodity products and transported from to large urban centers. The constituent nutrients of an agricultural commodity rarely return to agricultural soils. Instead, the nutrients are usually discharged through a municipal sewage treatment plant, often into a water body, possibly on the opposite side of the world from their point of origin. It is therefore necessary to use commercial fertilizers to replenish the soil nutrients.

Is our current management of agronomic resources sustainable? Important lessons have been learned during the short history of agriculture on the Prairies. The Dirty Thirties, for instance, were a harsh reminder that when we dominate an ecosystem, we are also responsible for its stewardship. Soil tillage practices have improved dramatically as a result. Many challenges still confront us, however. Today, we are faced with issues of water management on the Canadian Prairies as water use increases and the mountain glaciers at the headwaters of the Prairie rivers recede (Schindler, 2006). Domination of agricultural sectors by a few strains of crops or breeds of animals has serious implications for the robustness of the agricultural gene pool. Even the climate is now considered by many to be corruptible by human activities, and thus something over which we must exercise responsible stewardship. The rapid growth of local and global populations and the accompanying demand on resources will continue to exacerbate these challenges.

Considering nutrient management in particular, there are some important issues to consider. On the input side, modern agriculture is heavily dependent on commercial fertilizers. Nitrogen, for instance, can now be fixed directly from the atmosphere, so we no longer have to rely on natural reserves of organic nitrogen such as guano. The Haber-Bosch process, however, is very energy intensive, and so the cost of nitrogen fertilizer will rise with the expected upward trend in energy prices. Phosphorus is still derived from non-renewable mineral reserves. The most easily accessible of these reserves are rapidly being depleted, and so we can expect phosphorous prices to rise as well. On the output side, our growing population's demand for cheap agricultural products is driving increased specialization and compartmentalization of agriculture. Monoculture crops have long been the rule in North American production systems. In recent decades, livestock are increasingly raised in isolation from crop production in ever larger confined feeding operations. Feed crops are shipped to the feeding operations, where nutrients are further concentrated in animal products and transported to cities.

Confined feeding operations also concentrate nutrients in animal manure, the amount of which often far exceeds the loading capacity of the feeding operation's land base. The economics of transporting this excess manure dictate that nutrient loading of the soil will be greatest near to the feeding operation. The application of large amounts of nutrients has implications for the health of the soil, the watersheds into which the fields drain, and the water bodies in to which those watersheds discharge. This is a growing concern in many North American watersheds, dramatically illustrated in the context of the Prairies by extensive algal blooms in Lake Winnipeg, through which water from the Saskatchewan River passes on its way to Hudson's Bay. Questions therefore arise as to how appropriate loading capacities should be determined for particular soils.

Commodity agriculture has changed the nature of nutrient transport from a tight cycle between plants and animals in wild ecosystems or subsistence farms to a much more open flow. Nitrogen and phosphorus are exported to urban markets, and soil nutrients must therefore be supplemented with imported nutrients. In confined feeding operations, a substantial fraction of these nutrients is concentrated in large volumes of animal manure, resulting in another set of nutrient management challenges. As mentioned, this evolution of North American agriculture has resulted in unprecedented labour efficiency and abundant, inexpensive food, but the accompanying challenges of stewardship are increasingly complex and far-reaching.

▪ Nutrient Management in Dairy Operations

In this broad context we can now examine the more focused topic of nitrogen and phosphorus management on dairy operations. We should also remind ourselves that responsible nutrient management, aside from saving civilization, also saves money. A sound nutrient management program enables an operator to identify where improvements might be made in managing nutrients to increase profit, reduce environmental impacts, and sustain the agronomic productivity of the farm. Comprehensive measurement and conscientious record-keeping are the basis of a good management program. Some investment is required to measure nutrients at various points in the operation, and computer software is available to help manage the information that is acquired.

A useful way of thinking about the flow of nutrients through any agricultural operation is to consider a mass balance: to examine the flows and stocks of nutrients in the operation, determine whether the inputs and outputs balance, and see where losses might be occurring. The general flow of nutrients in an agricultural operation is illustrated in Figure 1. At the heart of this schematic the conventional nutrient cycle is still apparent, but also evident are the numerous pathways by which nutrients are imported and exported. As recognized previously, with increasing concentration and specialization of agriculture these imports and exports can overwhelm the underlying cycle.

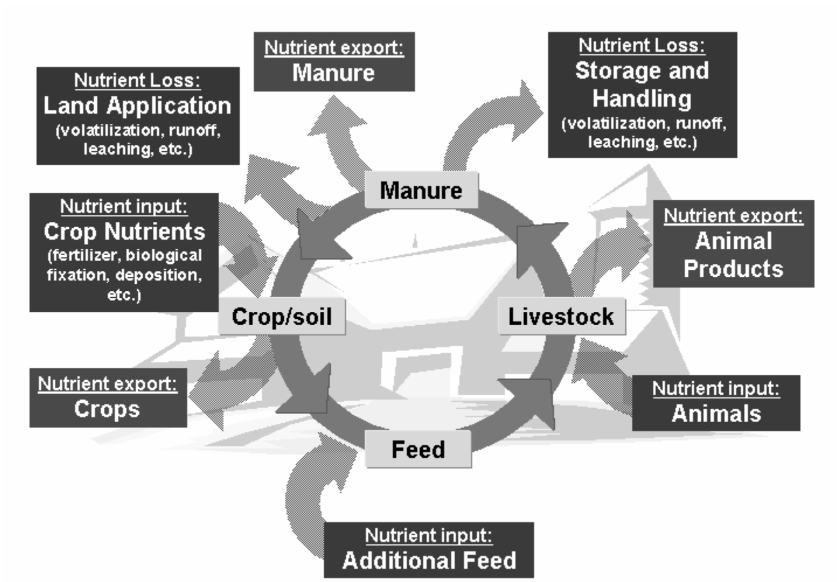

Figure 1. General schematic of nutrient flow through an agricultural operation. Adapted from Oryschak (2005).

A dairy farm concentrates crop nutrients by feeding animals, whether by grazing, on-farm feed production, or the import of feed onto the farm. Some nutrients are exported from the farm in the milk, which falls under the ‘animal products’ label in Figure 1. Another substantial portion of the nutrients is concentrated in the manure. The management of manure and the concentrated nutrients that it contains can become a considerable challenge as the size of the dairy increases. As the number of animals becomes larger relative to the land base of the dairy operation and more feed is imported, the livestock component of the system as shown in Figure 1 becomes increasingly divorced from the crop/soil component. The nutrient flow between livestock and crop is instead maintained by the import of nutrients in the form of feed, and their return to cropland in the form of manure. The opportunities for nutrient management on a large dairy are therefore most evident as manure management but, if the whole nutrient cycle is considered, there also are other opportunities that can be exploited.

Feed Utilization and Formulation

If we move 'upstream' from manure, we can consider ways by which we might decrease the excretion of nutrients in the cow manure (Okine and Mathison, 2004). The cow herself, her metabolism and utilization of nutrients, is a perpetual target for improvement. The effort to improve the efficiency of milk production has been ongoing for centuries in the form of traditional breeding programs. Now, however, we have new tools to help us in this task. The entire bovine genome has recently been mapped, with a significant contribution to this effort coming from the bovine genetics group at the University of Alberta. An enormous amount of work still lies ahead to understand how the variations in the information contained in the genome translate into physiological differences, such as efficiency of milk production. It is therefore fundamentally important that genetics research, which so often steals the limelight, continue to be complemented by strong basic research in physiology, as well as the cellular biology and biochemistry that links them.

Several other avenues of investigation are also being pursued to improve nutrient utilization by the cow. There is active research ongoing to characterize the microbial population in the cow's rumen and to determine ways in which rumen metabolism might be made more efficient including, for instance, the use of ionophores. The use of hormone implants or supplements, where permissible, is also a very effective means of improving an animal's utilization of nutrients and thereby reducing nutrient excretion.

A bit further 'upstream' from the cow, we can attempt to optimize nutrient utilization by better matching the nutrients in the feed to the requirements of the animal. Nutrient level recommendations are usually quite conservative, and nutrients in the feed can therefore frequently be reduced to, or sometimes even below, recommended levels without affecting production. The hope is that by more precisely formulating feed in this way, fewer nutrients will remain to be excreted in the manure. This match is a moving target, however, since genetic potentials differ between herds and constantly change as breeds are improved, and individual requirements vary daily. Animal nutrition research is therefore an ongoing exercise. Similarly the nutrient content of crops and other ingredients used in animal feed are locally unique and continually change with advances in crop breeding, newly introduced varieties, climate, and production practices. Ideally, we would know precisely the nutrients contained in available feedstuffs in order to accurately formulate a feed that exactly matches the well-understood requirements of a particular group of animals. This ideal is certainly not the reality, however, and nutritionists must often rely on information about crops and animals that is estimated, outdated, or measured in other jurisdictions.

Nutrient use might also be improved with appropriate feed additives or supplements. For instance, phosphorus is more available to the cow's metabolism as sodium phosphate than in most other forms. Apart from increasing nutrient availability and reducing excretion, feed additives can act in other ways to conserve nutrients. Particular types of zeolite, a class of absorptive mineral additives, can be included in the diet to absorb ammonia during manure storage and thus reduce nitrogen loss. Finally, the manner in which a supplement is fed also effects the efficiency of nutrient use: It is recommended, for example, that free choice feeding of phosphorus supplements be avoided where possible, because animals will often over or under-supplement themselves.

Moving even further upstream, we can also attempt to alter a crop's nutrient profile to better match the requirements of the animal. The ideal in this work is the creation of a feed crop containing exactly the nutrients required by a particular animal type, thereby reducing feed processing costs and excess nutrients. Traditional crop breeding programs are indispensable in this kind of work. Today's golden child of science – genetics – is also an important tool for the crop breeder as for the animal breeder. Once again, however, it is important to realize that genetics research is of little value without strong complimentary research in crop physiology and related disciplines.

Despite our best efforts to match feed nutrients to the requirements of the animals, and no matter how efficient the animals might be in converting feed into milk, some nutrients will always come out of the back end of a cow as manure. In the next section, therefore, we will consider manure management options in some detail.

Manure Collection, Transfer, and Storage

Manure management options include different practices and technologies for its collection, transfer, storage, treatment, and land application (Amrani, 2004). Since there are limits as to how much nitrogen or phosphorus should be applied to a given area of land, we must consider ways of reducing the cost of transportation to avoid overloading soils near a dairy. There are also some processing steps that could potentially extract some value from, or enhance the value of, manure before application.

Some nutrient management options are more appropriate to a liquid manure system and others to a solid system, and each has implications for the flow of nutrients through the production system. Generally, liquid manure systems are convenient for ease of handling and mechanization, and lend themselves well to many treatment technologies and field injection methods, but they are more prone to nutrient losses through spills, leaching, and gaseous emissions. Solid systems, on the other hand, although less prone to such losses, are often more labour intensive.

Generally, good nutrient conservation aligns with good management practice:

By keeping the operation as clean, dry, and well-managed as possible, you will go a long way to reducing nutrient loss by spills, leaching, and gaseous emissions. This is especially true of nitrogen, which is much more prone than phosphorus to dissolve in water and volatilize from wet surfaces. In collection systems, therefore, more frequent manure removal reduces nutrient loss through volatilization. A bedding system can do the same by absorbing urine. In the case of liquid or semi-solid manure, covered or enclosed transfer systems are likely to retain more nitrogen.

Similarly for storage, good management is equivalent to good nutrient conservation. In liquid systems up to half of the nitrogen in the manure is in the form of ammonia, so covering or containment is also recommended where practical, to minimize the loss of nitrogen as ammonia. Keeping the pH low is also important to keep the ammonia in solution. Chemical additives are also available to precipitate the nitrogen in a solid form. For solid systems, storage areas should be well constructed with surface water diversions and run-off collection.

Manure Processing

Manure processing can be used to advantage where the available land base is limited and where the manure must be transported any appreciable distance for application (Schoenau and Assefa, 2004). Processing can be used to remove water and concentrate nutrients, so that less mass has to be transported and nutrients can be spread more uniformly over a larger area, and to stabilize nutrients so that they are less prone to leaching or volatilization in the field. Each processing option, however, requires some investment in the necessary capital and maintenance, and each involves some operating and labour costs.

Conventional treatment technologies for liquid manure systems include solid-liquid separation by gravity, mechanical, or chemical means. When used upstream of storage, separation can reduce solids loading in storage facilities and improve handling. It may be possible with more advanced systems to effectively separate fine suspended particles and thereby concentrate nutrients in the solid fraction. This increases the volume of liquid that can be spread on a given area, and thereby reduces transportation and handling costs. In areas where water is scarce, it could be worthwhile to invest in the necessary equipment to recycle or reuse the water that is extracted, either in the barn or in manure processing (below).

Composting is an ancient manure treatment method that is becoming increasingly popular with some producers, either for solid manure systems or for managing solids after solid-liquid separation. Composting can reduce manure volumes by up to 50% and stabilizes the nutrient content of the manure in a uniform, potentially marketable soil amendment that is easy to spread. There is the risk of nitrogen loss through volatilization if the process is not well-managed.

New technologies are becoming available for use alone in or combination to extract value from manure by generating marketable fertilizers, soil amendments, or energy. Anaerobic digestion is one technology that is getting a lot of press, and so deserves mention. Although digesters do not directly impact nutrient flow, they do produce a uniform liquid product that can be easily spread or further processed. If the digester is used to produce energy in conjunction with a cogeneration set, for instance, then the energy and combustion heat can also be used in further processing. Digester technology is already well-developed for liquid manure, and digester systems that incorporate water recycling are being developed for higher-solids manure, as from feedlots.

Other emerging technologies include processes for removing specific nutrients and concentrating them as marketable fertilizers. Such concentrates are economical to transport and are advantageous for uniform and precise application. Precipitation of phosphorus in a crystalline form called struvite from the liquid fraction of manure slurries is a process that is being successfully used to treat municipal waste water. Microwave technology and chemical treatments are also being assessed for solubilising phosphorus, to make more available in the liquid fraction for precipitation (Pan et al., 2006). Other technologies used in municipal waste treatment, such as sequencing batch reactors for biological nutrient removal, might also be adapted for use in treating liquid manure slurries. These processes are capital intensive, and will be more cost effective for large operations or cooperative or regional treatment plants.

Land Application

Nutrients which are not lost from the production system or exported as commodities are eventually returned to the farmland in the form of manure. Land application is therefore an important part of a nutrient management program, and deserves some careful planning (Schoenau and Assefa, 2004). Ideally, the amount of manure produced by an operation should be estimated and its nutrient content determined by direct testing. Adequate soil tests should also be conducted regularly to determine actual soil nutrient content. If a field history has already been accumulated, then residual N and P from previous applications can be determined. Based on the soil test results, the planned crop, and the expected yield, supplemental nutrient requirements can then be estimated, and manure application rates determined from the manure nutrient tests. Manure applicators or spreaders should be calibrated, and consideration should be given during application to the topography of the field, proximity to water, setback distances, etc.

Reality is never as clean-cut as the ideal, and some challenges in manure application must be confronted. When applying agronomic rates of nitrogen in the form of animal manure, phosphorus is very likely to be over-applied. Applying manure according to phosphorus requirements, if at all practical, might require the use of supplemental commercial nitrogen fertilizer. Another challenge is that even a well calibrated applicator does not guarantee uniform distribution of manure. Application invariably begins at the same edge of the field every time, and a heavy initial dump can be expected, especially with solid manure spreaders. There will be overlap between passes and at the end of the field where the machinery turns. With any application technique, there will also be some nutrient loss, especially of ammonia.

Research is ongoing to attempt to address these challenges. The nutrient extraction technologies mentioned earlier could help to address the imbalance between nitrogen and phosphorus concentrations. Field equipment with global positioning systems (GPS), precision application technology, and field mapping software could help to spread nutrients more uniformly and to improve and automate record keeping. Controlled traffic farming, which is attracting interest in Australia and Europe, can now use GPS and auto-steer technologies to guide field machinery with identical wheel bases down the same tracks on each pass (Tullberg, 2006). Nutrient placement is much more precise, compaction is eliminated on the cropped area of the field, and traction and fuel efficiency is increased because machinery always operates on hard surfaces. Technology for the reduction of nutrient loss through volatilization and leaching includes direct injection of liquid manure into the root zone, which is already very popular on the Canadian Prairies. The Prairie Agricultural Machinery Institute in Humboldt, SK, is developing equipment for the injection of semisolid and solid manure.

■ Conclusions

Nutrient management is an important aspect of good farming practice from the perspective of agronomic sustainability, environmental stewardship, and economic viability. Dairymen manage very nutrient-intensive animal feeding operations, and so the challenges and opportunities posed by nutrient management are especially relevant to them. An awareness and understanding of nutrient flows and of existing and emerging practices and technologies for managing them can help to make a dairy operation more profitable, environmentally sound, and sustainable over the long term.

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