3.1 Nutrient budgeting

Dairy production systems typically require regular nutrient applications, especially of the macronutrients nitrogen (N), phosphorus (P), potassium (K) and sulphur (S), to meet nutrient removal rates of pastures and crops (DPI 2004, Gourley *et al.* 2007a). When nutrients are used in excess, they have the potential to significantly degrade air and water quality. The risk of nutrient pollution from a dairy farm increases when nutrient inputs exceed the amount leaving the farm in products (Gourley *et al.* 2007b). Total P and N inputs onto dairy farms, mainly in the forms of feed, fertiliser and N fixation by legumes, are usually much greater than the outputs in milk, animals and crops, so the surpluses tend to increase as farms intensify and stocking rates increase. In addition to off-farm environmental impacts, nutrient accumulation on dairy farms can result in unnecessary expenditure on feed supplements and fertiliser, and may reduce animal health and production (Gourley *et al.* 2007b).

A significant proportion of nutrients on a dairy farm can end up in the effluent (Gourley *et al.* 2007b). These nutrients provide a valuable resource and should, where possible, be used to replace nutrients removed from pastures and crops and to replace fertiliser (Gourley *et al.* 2007a, McDonald *et al.* 2005). The quantification of nutrients in effluent and their subsequent fate are important considerations in dairy effluent management. Farm nutrient budgeting tools are important tools to assess the risks associated with adverse environmental or production impacts that could result from nutrient deficiency or excess.

A nutrient budget, defined as an accounting approach to nutrient inputs, stores and outputs, can help manage nutrients by identifying production goals and opportunities for improvements in nutrient use efficiency, and thus reduce the risk of off-farm nutrient impacts (Gourley *et al.* 2007b). Nutrient budgeting for a dairy effluent management system is more specific than a whole-farm or farm-gate nutrient budget, as only the components of the effluent management system are assessed, such as manure collection and storage, nutrient redistribution, and crop or pasture nutrient uptake. This simple nutrient budget is a common and easy-to-calculate method that use readily available data at the farm scale and from sources that are likely to be fairly accurate. The nutrient budgeting allows for nutrients to be distributed in appropriate quantities for particular crops or pastures over sufficient areas of the farm. This provides a basis for minimising off-farm environmental impacts and efficient nutrient management (which reduces expenditure on feed supplements and fertiliser), and adverse impacts on animal health and production.

A farm nutrient budget does not normally try to directly quantify environmental losses such as P and N runoff, P and N leaching, denitrification or N volatilisation, as these are difficult to measure and are highly variable in space and time. The budgeting assesses nutrient accumulation and loadings and therefore environmental risks associated with the internal transformations, storages and distribution of nutrients across a farm. Nutrient budgets have also been found to be useful tools in improving farmer knowledge about nutrient flows and potential losses from their farms, and can influence fertiliser and manure management decisions. A detailed account of the advantages and limitations of nutrient budgeting is provided in Gourley *et al.* (2007b).

Nutrient importation

Nutrients are imported onto dairy farms principally through fertilisers and stock feeds, but can also be imported in animals, by nitrogen fixation, in bedding, in manure and in irrigation and rain water (Gourley *et al.* 2007b). The rate of nutrient importation will vary depending on the type of system; for example, a dairy farm which has an appropriate stocking rate, cuts its own hay and reuses all nutrients on farm would require lower imports of nutrients (in both feed and fertiliser), whereas a dairy farm with very high stocking rates would be more likely to require higher rates of feed import and fertiliser application and thus will have a higher import of nutrients (McDonald *et al.* 2005).

The amount of nutrients imported through fertilisers can readily be quantified from the proportion of nutrients in the fertiliser and the fertiliser application rate. Although the amount of nutrients imported in stock feeds is often more difficult to quantify, Table 1 provides an indication of macronutrient concentrations typically imported onto a dairy farm in various feed types.

Table 1. Typical nutrient concentrations of stock feeds on a dairy farm (Helyar and Price 1999)**.**

Feed type	Nitrogen ($kg \cdot t^{-1}$ DM)	Phosphorus ($kg \cdot t^{-1}$ DM)	Potassium ($kg \cdot t^{-1}$ DM)	Sulphur ($kg \cdot t^{-1}$ DM)
Fodder				
Hay (cereal)	20	2	12	1.5
Hay (legume)	30	3	22	2
Hay (mixed pasture)	25	2.5	17	2.5
Grains				
Wheat and barley	17.5–21	2.8	4	2.2
Oats	19.8	3	4	2
Lupins	48–57	3.0–4.0	8.5–9.5	3.5
Other pulses	35–45	3.0–4.0	8.0–11.0	1.8–2.5

Nutrient concentrations in grains and forages can vary substantially and may have a large impact on the resultant nutrient budget outcomes (Gourley *et al.* 2007b).

Dairy effluent is often shandied with other water sources (such as irrigation or bore water). In this case, the quality of these other water sources, especially the impacts of salts and sodium, needs to be considered along with the effluent.

Nutrient distribution

Although uniform grazing management aims at an even distribution of manure across a farm, this is rarely achieved. Nutrients are concentrated in some areas when dairy cows are grazed in specific areas during day and night, when feedpads are used for part of the day, or when grazing regimes change with feed importation. Effluent and manure management systems should, as much as possible, manage the build-up of nutrients associated with any location where manure is concentrated, such as within laneways, the dairy shed and yards, on feedpads or in sacrifice paddocks. See chapter 1.2 'Characteristics of effluent and manure' for details on the proportion of time that cows spend at the dairy.

Where significant amounts of nutrients are collected in dairy effluent, it is beneficial and more environmentally benevolent to spread these nutrients over areas that require nutrient increase (as based on soils analysis) rather than just over convenient paddocks adjacent to the effluent storage site. Effluent spread on convenient paddocks that are already high in nutrients will not increase pasture production and could therefore be regarded as a cost rather than a benefit. Where significant amounts of nutrients are collected in dairy effluent, it is beneficial to identify low-nutrient-status paddocks and apply the effluent there. The nutrients in the effluent can then be used to offset fertiliser costs. A sound nutrient budgeting system takes into consideration not only the nutrients being imported and exported on a whole-farm basis, but also the nutrients being transported within a farm (McDonald *et al.* 2005).

Effluent nutrient concentrations

The first step in nutrient budgeting is the quantification of the volume of effluent generated and collected and the concentration of nutrients in the effluent. The most accurate method of quantifying effluent nutrient concentrations is site-specific data, however, as such data are rarely available, nutrient concentrations should be based on the information in chapter 1.2 'Characteristics of effluent and manure'. The nutrient concentrations shown in Table 2 (after Nennich *et al.* (2005) and based on a milk yield of 16.5 L·day^{-1}) have been used for the nutrient budgeting in this chapter.

Table 2. Nutrient concentrations in dairy cow manure used for nutrient budgeting (Nennich et al. 2005).

Nutrient	Nitrogen (g per cow day^{-1})	Phosphorus (g per cow day^{-1})	Potassium (g per cow day^{-1})
	393	63	178

Sulphur

Although S is an important macronutrient, data on S concentrations in dairy cow manure and on S removal rates in crops are limited. As a result, nutrient budgeting for S without site-specific data is inaccurate and can be misleading. This area requires more research (Reuter and Robinson 1997).

Trace elements

The impact of trace elements from dairy effluent is marginal. McBride and Spiers (2001) found that trace element levels in both liquid and solid dairy manures were typically low, except where feed additives were used. Feed additives generally increased levels of copper and zinc. Trace elements are discussed further in chapter 3.5 'Trace elements'.

Nutrient quantification

In quantifying the nutrients collected in a dairy effluent system, you need to apportion the data in Table 2 according to the time the cattle spend on areas from where the effluent is collected. Ideally the time spent on those areas should be estimated to support future management. Alternatively, a less accurate estimate can be obtained from the rough rule of thumb that dairy cattle spend 10% to 15% of their day on an area from which the effluent is collected (see chapter 1.2 'Characteristics of effluent and manure'). An example is provided in Table 4.

The concentrations of nutrients within the effluent system can change. Although the magnitude of change is variable and depends on a range of factors, only N is generally lost throughout collection and conveyance. Other than N nitrogen, if storage ponds are correctly lined, there should be no loss of nutrients from the pond even after stirring. Nutrient locations and losses within an effluent pond system are shown in Table 3.

N within effluent is highly mobile and is lost to the atmosphere through volatilisation and denitrification at all times (Kruger *et al.* 1995). About half of the N typically lost through volatilisation. More information on N conversions and losses from the effluent system is discussed in chapter 3.2 'Nitrogen'.

Solids, sludge and liquid effluent

Nutrient budgeting assumes that solids from separation and sludge from effluent ponds are applied to land along with effluent. Although effluent from all of these sources may not be applied simultaneously, it is assumed that these sources are all applied to the same sites. This would typically occur over a number of years.

Paddock-specific nutrient budgeting can be based on the application of solids from a solids separator or of liquid effluent from a storage pond. Site-specific data yielded from analysis of effluent samples provide the most accurate way of quantifying nutrient levels for this type of budgeting. However, in the absence of such data, the proportions detailed in Table 3 can be used. Pond stirring can redistribute nutrients throughout the storage, but these nutrients soon settle over time, and some become locked up in sludge (NSW Dairy Effluent Subcommittee 1999). More information on sludge management is discussed in chapter 2.8 'Desludging and pond closure'.

Table 3. Nutrient locations and losses within an effluent pond system (NSW Dairy Effluent Subcommittee 1999).

	N (%)	P (%)	K (%)
Effluent	30	40	90
Sludge	20	60	10
Loss	50	–	–

Table 3 shows that the 50% of the N excreted will be available for reuse on land. The calculations in Table 4 allow for this.

Table 4. Quantity of nutrients generated and collected per year for a 300-cow dairy herd, milked twice a day and supplementary-fed on a feedpad.

Nutrient	Nitrogen	Phosphorus	Potassium
Nutrient produced in manure from Table 2 (g per cow day^{-1})	393	63	178
Hours spent per day on areas from which effluent is collected			
Laneways	0.5		
Dairy shed and yards	3.0		
Feedpad	3.0		
Total hours	6.5		
Proportion of day effluent collected	0.271		
Nutrient collected (g per cow day^{-1})	107	17	48
Nutrient available for reuse from Table 3 (g per cow day^{-1})	53	17	48
Total nutrient (kg) per day [a]	15.9	5.1	14.4
Total nutrient (t) per year [b]	4.85	1.56	4.39

a: Based on 300 cows.
b: Based on 305-day lactation.

Nutrient use and export

Nutrients are utilised on dairy farms in the production of pastures and crops. The level nutrient removal will vary with crop type, yield and growing conditions. Table 5 indicates the amounts of N, P and K removed by a range of crops.

Table 5. Nutrient removal (where product is removed from the site) in particular crops.

Crop (yield, wet t·ha^{-1})*	N removal (kg·ha^{-1}·y^{-1})	P removal (kg·ha^{-1}·y^{-1})	K removal (kg·ha^{-1}·y^{-1})
Barley (3.5 t)	168	27	140
Lucerne hay (7.5 t)	209	19	141
Maize silage (50 t)	165	65	206
Millet (9 t)	280	45	186
Oats (3.5 t)	168	27	140
Perennial pasture for hay (15 t)	150	18	80
Perennial ryegrass for hay (15 t)	200–250	25–40	200
Wheat (2.8 t)	208	27	150
Sorghum grain (9 t)	280	45	186
Triticale (2.8 t)	168	27	140
Dairy pasture (10 t DM ha^{-1})	400	40	200

*Adjust according to anticipated or measured yields.

3.1 Nutrient budgeting

Nutrients can be exported from a dairy farm through products (milk, meat, animals, manure, crops) and through losses such as runoff, leaching and N volatilisation (Gourley *et al.* 2007b). However, effluent nutrient budgeting typically does not consider the whole-farm nutrient cycle and thus does not assess nutrients exported off farm. Rather, effluent nutrient budgeting is usually limited to determining the appropriate quantities of nutrients to be distributed for particular crops or pastures, and indicates an area of land sufficient to assimilate the collected nutrients.

For those interested in undertaking whole-farm nutrient budgeting that takes into account nutrients exported as milk, Table 6 indicates average quantities of macronutrients found in milk.

Table 6. Macronutrients in milk (Helyar and Price 1999).

	N	P	K	S
kg of nutrient per 10 000 L milk	42	10	14	3.2

Nutrient budgeting calculations

Once the total annual quantity of nutrients collected by the effluent management system has been calculated (as in Table 4), the next step is to calculate how these nutrients can be utilised in appropriate quantities on crops or pastures. The effluent nutrient budget sets a minimum area of land required to utilise the collected nutrients while minimising the risk of excess nutrient loss through runoff, leaching or volatilisation. The process of land application should be governed by a limiting constituent analysis (Midwest Plan Service 1985), which determines the limiting nutrient to ensure that it is not over-applied to land; that is, the limiting nutrient loading stays at or below the maximum requirements for a particular crop or pasture. This is done by determining the typical expected yield of the intended crop or pasture and calculating the nutrient removal by this crop or pasture at that yield from data such as that provided in Table 5. This information is then compared with the total annual quantity of nutrients collected by the effluent management system (as calculated in Table 4) to determine the area of land required to utilise the nutrients collected. This process is detailed in the worked examples below. A further calculation will then determine the required effluent loadings as nutrient load: kg·ha^{-1} for solids or ML·ha^{-1} for liquid.

Nutrient budgeting inputs and considerations

The simple effluent nutrient budgeting described above needs as inputs:

- the nutrient levels within the effluent (Table 2)
- the fate of the collected nutrients to determine availability (Table 3)
- the total annual quantity of nutrients generated (Table 4)
- the proposed or existing crop on the land application area
- estimated crop yield (district average or from past experience)
- crop nutrient removal rate (such as data in Table 5).

We also need to consider:

- crop water requirement (typically determined from climatic water budgeting as detailed in chapter 3.9 'Hydraulic application rate and scheduling')
- the proposed dilution or shandying rate (if any)
- achievable effluent loadings (e.g. kg·ha^{-1} for solids or ML·ha^{-1} for liquid)
- the areas of land over which effluent can realistically be applied (may vary between solids and liquids)

- climatic predictions, landform and soil type and the associated risk of runoff or leaching
- existing soil nutrient concentrations
- type and rate of recent (past 12 months) or proposed fertiliser applications.

Any imbalance in nutrients required for optimum production can be made up through fertiliser applications. Similar techniques can be used with maximum loadings for particular soils. If so, refer to state EPA guidelines for maximum soil nutrient loadings. Where P is the limiting constituent, calculate the P retention capacity of the soil to indicate the lifespan of the reuse area before soil P saturation occurs. This is discussed in chapter 3.3 ‘Phosphorus’.

Keep in mind salt and sodium loadings when applying effluent to land, including any salts present in irrigation or bore water also applied to the land. See chapters 3.6 ‘Salinity’ and 3.7 ‘Sodicity’.

Worked examples

Example 1—Total nutrient budgeting

This nutrient budget is based on the total quantity of nutrients collected per year and on spreading those nutrients over an appropriate area of land as governed by the limiting constituent analysis (Midwest Plan Service 1985) detailed above. This budget requires:

- the quantity of nutrients generated (calculated as in Table 4)
- the proposed or existing crop
- the estimated crop yield (district average or from past experience)
- the crop nutrient removal rate (such as in Table 6).

Table 7 details a nutrient budget for an example dairy farm with effluent nutrient loadings taken from Table 4 and the nutrient removal rate by perennial pasture taken from Table 6 and adjusted for slightly lower yields.

Table 7. Example 1—Total nutrient budget, 300 cows with 27% of manure collected.

	Nitrogen	Phosphorus	Potassium
Total nutrient collected from Table 4 ($t \cdot y^{-1}$)	4.85	1.56	4.39
Proposed crop	Ryegrass clover perennial pasture		
Crop nutrient removal from Table 5 ($kg \cdot ha^{-1} \cdot y^{-1}$)	400	40	200
Crop yield (t DM ha^{-1})	10		
Proposed yield (t DM ha^{-1})	8		
Nutrients removed in proposed crop ($kg \cdot ha^{-1} \cdot y^{-1}$)	320	32	160
Area required to utilise all nutrients (ha)	15.2	48.8	27.4

From Table 7, we can conclude that the effluent generated in 1 year should be applied to 49 ha of land to utilise all of the P collected. For optimum production, top-up applications of K and N will be needed.

Example 2—Liquid effluent nutrient budgeting

This nutrient budgeting example is based on nutrient levels within storage ponds derived from site-specific analysis. Rather than directly determining the area of land required (as in Example 1 above), this budget is based on determining the appropriate volume of effluent to apply per ha of land and includes scenarios for shandying effluent with irrigation water. The volume of effluent to be reused then determines the areas of land required as governed by the limiting constituent analysis (Midwest Plan Service

1985). As this budgeting considers the liquid effluent only, solids and pond sludge would need to be applied on separate land.

This budget requires:

- the nutrient levels within the liquid effluent (from analysis)
- the proposed or existing crop
- the estimated crop yield
- the crop water requirement
- the proposed dilution rate(s)
- the crop nutrient removal rate (from Table 5)
- the loadings of nutrients per hectare (kg·ha^{-1} for solids or ML·ha^{-1} liquid).

It is also advantageous to know the existing soil nutrient concentrations. Table 8 details an example nutrient budget for an irrigation farm with measured effluent nutrient concentrations and growing an irrigated maize crop, with the crop nutrient removal rate from Table 5.

Table 8. Example 2—Liquid effluent nutrient budget.

	Nitrogen	Phosphorus	Potassium
Liquid nutrient concentration (measured) (mg·L^{-1})	25.6	14.3	17.8
Proposed crop	Irrigated maize silage		
Crop nutrient removal from Table 5 (kg·ha^{-1}·y^{-1})	165	65	206
Crop yield (t·ha^{-1})	50		
Proposed yield (t·ha^{-1})	60		
Nutrients removed in proposed crop (kg·ha^{-1}·y^{-1})	198	78	247
Crop water requirement (ML·ha^{-1})	10.0		
Proposed dilution rate (ratio)	1 part effluent to 1 part water		
Proposed annual application (ML·ha^{-1})	5.0 ML effluent : 5 ML irrigation water		
Nutrient concentration in irrigation water (mg·L^{-1})	12.8	7.15	8.9
Nutrient applied to crop (kg·ha^{-1})	128	71.5	89
Nutrient excess (+) or deficit (–) (kg·ha^{-1})*	–70	–6.5	–158

*Where an excess occurs, further dilution of the effluent is required. Alternatively, a different crop could be selected that needs less water or removes more nutrients.

From Table 8, we can conclude that the liquid effluent could be applied to the crop at a rate of 5 ML·ha^{-1} (over the growing season) and the maize would still utilise the P applied. In this case P is the limiting constituent, and higher applications of effluent (such as through a lower dilution ratio) would apply P in excess of crop requirements. In this scenario above, for optimum production, top-up applications of K and N would be needed.

Nutrient budgeting computer programs

Various spreadsheets are available to assist with effluent nutrient budgeting. Some are detailed and are more suitable for research, such as DAIRYBAL, from the Queensland DPI (McGahan *et al.* 2004), which determines the manure output of a dairy herd from the rations fed to the cattle and the pastures or forage crops grazed. The model assesses the nutrient mass balance on the effluent application areas to determine whether the proposed cropping or pasture management practices are environmentally sustainable in terms of nutrient loading. However, for a typical farm-based nutrient budget, simpler spreadsheets provide the area of land required over which to apply (and therefore reuse) the nutrients generated and collected in the effluent management system. Such a model has recently been developed by the Victorian DPI (Scott McDonald, pers. comm., DPI Vic., 2007).

When using these models, take care that the inputs are accurate. In addition, interpretation of the outputs, which can be complex, often requires careful consideration to ensure that the outputs are used appropriately and kept in context.

Nutrients and the environment

Nutrient surpluses at the paddock level and the subsequent accumulation and losses to the broader environment are often complex and highly variable in both space and time (Gourley *et al.* 2007b). Details on specific nutrients and environmental issues relating to these are provided in chapters 3.2 'Nitrogen', 3.3 'Phosphorus', 3.4 'Potassium' and 3.5 'Trace elements'.

In general, the impact of effluent reuse practices on farms and their surrounding environment through surface runoff, leaching or volatilisation causes concern. Dalal *et al.* (2003) describe the effect of greenhouse gases derived from losses of N from farms. Eutrophication—the enrichment of nutrients—is caused by a build-up of nutrients and can lead to blue-green algal outbreaks (Drewry *et al.* 2006). Dairy farms can contribute to problems on account of the high levels of nutrients that can run off and leach. Runoff is common after rainfall or irrigation, and carries with it nutrients. Fleming and Cox (2001) state that 98% of total nutrient loss over a 3-year period came from overland flow. Average annual losses from dairies can be as high as 22.8 kg total N ha^{-1}, 10.0 kg total P ha^{-1} and 43.1 kg K ha^{-1} (Holz 2007). Although farm nutrient losses often depend on climate, hydrology, soil and landscape (which are often out of the manger's control), nutrient runoff can be minimised through careful timing and application of effluent and through good soil conservation practices such as contour banks, minimum or zero tillage and strip cropping. As long as these practices are appropriate for the climate or location, they can help to minimise soil and nutrient losses. Although runoff from effluent reuse areas should flow into farm drainage structures and end up in recycling ponds and thus not leave the farm, the construction of runoff collection dams and ponds is currently not permitted in some catchments under water management plans.

Further information on the environmental impacts of dairy nutrient management and nutrient losses can be assessed by using the Farm Nutrient Loss Index (FNLI), developed in the Better Fertiliser Decisions project (Gourley *et al.* 2007a). This project collected comprehensive information to improve fertiliser decisions for grazing industries across Australia. It compiled and interpreted results from pasture fertiliser experiments and information on nutrient loss processes in all pastoral regions in Australia. It revealed the relationship between soil test results and pasture response and gave critical soil test values for P, N and S at regional, state and national scales, and by soil characteristics such as soil texture and P buffering index. The FNLI is a computer-based decision support tool used to assess the risk of nutrient loss from the paddock to the off-farm environment. It predicts the relative risk of P and N loss processes and is designed to assist farm advisors, in conjunction with farmers, to make informed nutrient management decisions. The FNLI takes into account the pathways of nutrient loss relevant to Australian pasture-based industries:

- runoff across the soil surface
- drainage past the root zone
- lateral flow through subsurface layers in the soil profile
- emission of greenhouse gases.

For more details on the FNLI and the Better Fertiliser Decisions project, refer to Gourley *et al.* (2007a).

Further research

More research and model development is required to achieve a more robust and thorough nutrient budgeting tool for Australian dairy farms (Gourley *et al.* 2007b) or an overall farm nutrient management model that considers environmental impacts and farm production, such as the Overseer Nutrient Budgets used in New Zealand (Mathew Redding, pers. comm. QDPI, 2007). Gourley *et al.* (2007b) suggest that a nutrient budgeting tool must cover not only basic input and output of nutrients on dairy farms, but also:

- diets fed to dairy cows
- manure nutrient loads
- manure forms
- manure nutrient collection, storage and redistribution
- productive and non-productive areas
- soil testing data.

Gourley et al. (2007b) argue that this will identify excess accumulation of nutrients within particular management units, quantify relative nutrient efficiencies, and hence identify the opportunities to improve nutrient management decisions by dairy farmers and advisors, and enhance environmental outcomes. Such a nutrient budgeting tool needs to:

- identify and quantify key nutrient inputs, outputs and stores (e.g. feed, manure) and nutrient surplus and efficiencies at both the farm gate and more the farm system levels
- define the uncertainties in nutrient budget calculations and predictions
- identify and quantify nutrient distribution within the dairy farm and nutrient losses off the farm
- integrate nutrient budgets at the field level with recommended Australian soil test targets and use this information to support fertiliser recommendations
- provide an effective assessment of costs and benefits resulting from current nutrient management practices
- establish appropriate targets for permissible surpluses and potential nutrient efficiencies at the whole-farm and component levels
- recommend management practices which will improve nutrient budgets and nutrient use efficiencies.

The results of the dairy farm nutrient budgeting provided above should be used to assess the environmental sustainability of a dairy farm. The area of land required to utilise the limiting nutrient must be available for the intended purpose. On low-intensity dairy farms where no feed is imported, this is typically readily achieved. On high-intensity, high-stocking-rate dairy farms that import significant volumes of feed and often use a feedpad system, the area of land required to reuse the nutrients collected in the effluent management system can be substantial and needs to be available in order for the enterprise to continue or proceed. The option of exporting effluent in liquid or solid forms, such as to surrounding farms, could be considered.

Despite the complexities associated with nutrient management on a dairy farm, effluent nutrient budgeting results in improved nutrient use efficiency and reductions in nutrient surpluses at the farm level; improved environmental performance at the catchment or broader scale; and greater confidence among farmers, advisors and policy makers in the use of nutrient budgeting to enhance nutrient management and environmental performance on dairy farms.

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