



Chapter 10

Keeping nutrients on farm

CONTENTS

10	Keeping nutrients on farm.....	10-2
10.1	Introduction.....	10-2
10.1.1	Importance	10-2
10.1.2	Management principles.....	10-5
10.2	Understand nutrients in the environment.....	10-6
10.2.1	Know the sources of nutrients	10-6
10.2.2	Understand nutrient stores and transformations	10-7
10.2.3	Know how nutrients are lost	10-9
10.3	Plan to retain nutrients	10-13
10.3.1	Analyse farm nutrient status	10-14
10.3.2	Determine production potentials	10-14
10.3.3	Assess risks and critical source areas	10-15
10.3.4	Document a plan.....	10-17
10.3.5	Monitor and evaluate	10-17
10.4	Optimise production	10-18
10.4.1	Get top value from low-risk areas.....	10-18
10.4.2	Recycle nutrients	10-18
10.4.3	Optimise irrigation efficiency.....	10-18
10.4.4	Consider stock as a management tool	10-18
10.5	Minimise losses	10-19
10.5.1	Avoid direct loss from fertilisers, effluent and livestock.....	10-19
10.5.2	Reduce and reuse run-off	10-21
10.5.3	Lock-up excess nutrients	10-22
10.6	Summary	10-23
10.6.1	Significance.....	10-23
10.6.2	Best practice checklist	10-23
10.7	References	10-26



10 Keeping nutrients on farm

10.1 Introduction

In this section;

[Importance](#)

[Management principles](#)

10.1.1 Importance

Keeping nutrients on dairy farms is important for several reasons including:

[Cost of production](#)

[Environmental impacts](#)

[Sustainable use](#)

[Community responses.](#)

Nutrients drive dairy production, so excess nutrients lost from a farm are literally ‘money down the drain’ and a lost opportunity for higher yields. Compounding the loss, the nutrients may then have a negative impact on the off-farm environment. Keeping nutrients on the farm makes financial and environmental sense.

‘Only a quarter of the nutrients brought onto a dairy farm leave it in product’

Considering the bigger picture of nutrient use in agriculture, there are questions about the sustainability of current nutrient applications and management. Will farmers in the future have the same access to nutrients as those of today? Keeping nutrients on farm will help ensure they do.

Along with the question of sustainable use, the possibility of adverse environmental impacts also attracts the interest of community groups. Hence, both have the potential to result in regulations on fertiliser use and / or consumer action to demand improved management.

Studies of dairy farms across Australia in the ‘Accounting for Nutrients’ project, have shown that;

- There is large variation in the nutrient status of soils on dairy farms, between farms and within and between paddocks on individual farms.
- On average, there are excess nutrients available, implying low efficiency in converting nutrients to milk and potentially, subsequent losses to the environment – which confirms the results of other research.
- There is a wide variation in nutrient efficiencies between farms, indicating that improvements are feasible in many situations.

For more information on Accounting for Nutrients, see: <http://www.accounting4nutrients.com.au/>

10.1.1.1 Cost of production

Some paddocks on dairy farms may be under-fertilised, but many are not. The Accounting for Nutrients project revealed that of the 37 conventional dairy farms studied around Australia:

- 20% of pasture paddocks had more than three times the required level of phosphorus (Olsen P of 20 mg/kg). Phosphorus levels in paddocks close to the dairy were often two to three times those 2km from the dairy and four times higher than those 4km away.
- All dairy farms are likely to have surplus nitrogen due to conversion inefficiencies, high concentrations in urine, and poor storage in soils. Nitrogen is lost with water run-off, leaching, or to the atmosphere. Nitrogen surpluses rise in proportion to milk production.



- The average soil test levels for sulphur were twice the recommended level for pasture (KCI-40 of 10 mg/kg).
- The average soil test levels for potassium were twice the recommended level for pasture (Colwell K of 140 mg/kg) and three times the level in 20% of cases.

Phosphorus and sulphur levels were substantially lower on organically farmed properties, but not below levels required for productive pastures. If no further phosphorus or sulphur was applied to the high level conventional paddocks for several years, it is unlikely that pasture productivity would suffer. Soil potassium levels were similar between conventional and organic dairy farms (Department of Primary Industries Victoria (n.d.)a).

There are clear opportunities for many dairy farmers to reduce fertiliser applications to high nutrient level paddocks; thereby reducing costs without compromising production, and hence resulting in higher net profit. The value of lost nutrient inputs will increase as do fertiliser costs.

For some case studies, highlighting the savings to be made, see:

<http://www.dairyingfortomorrow.com/index.php?id=16>

<http://www.dairyaustralia.com.au/Levy-investment/Case-studies/Cutting-fertiliser-costs.aspx>

Detrimental influences on the cost of production can also come about due to animal health and productivity impacts due to excessive nutrient intake. High potassium levels can contribute to metabolic disorders such as grass tetany and milk fever, while high nitrate content in pastures can trigger nitrate poisoning (see [Chapter 12.6.1](#) for more information). Excessive calcium and magnesium have also been associated with poor stock health.

10.1.1.2 Environmental impacts

Many excess nutrients are removed in water – either in surface flows or groundwater.

In surface waters, nutrients can stimulate the growth of algae, some of which can be poisonous like types of nitrogen-fixing 'blue-green algae'. Surges in the growth of aquatic plants and algae can also leave an unwanted legacy. As they die, they are decomposed by microorganisms such as bacteria, which use up the available oxygen in the water – and lead to fish deaths as a consequence (Carpenter *et al*, 1998). The availability of excess nutrients can also change the ecology of a water body, leading to the replacement of aquatic plants or macro-algae by micro-algae (Harris, 2002).

In groundwater, high concentrations of nutrients, particularly nitrogen, can lead to human health risks. Excess levels of nitrate have been associated with 'blue baby syndrome', although the relationship is not clear. When introduced to waterways, pathogens from dairy cows can also pose a public health risk and, in some situations, a risk to young stock. As pathogens often follow similar pathways to those of excess nutrients, some practices that reduce nutrient losses will also help reduce the risk of water contamination by dairy pathogens. Nitrogen leaching may also increase the acidity of soil, necessitating treatment with lime.



Minimise trade-offs

Agronomic optimal nutrient concentrations are often greater than safe environmental limits but, as the following graph indicates, it is possible to obtain optimal production without challenging aspects of the environment. In this case, soil phosphorus levels for optimal pasture production are below the level at which there is a significant increase in the risk of phosphorus being lost in sub-surface drainage. The key message is to consider the impact of nutrient levels on the environment as well as on production and to avoid exceeding agronomic requirements to minimise impacts on the environment.

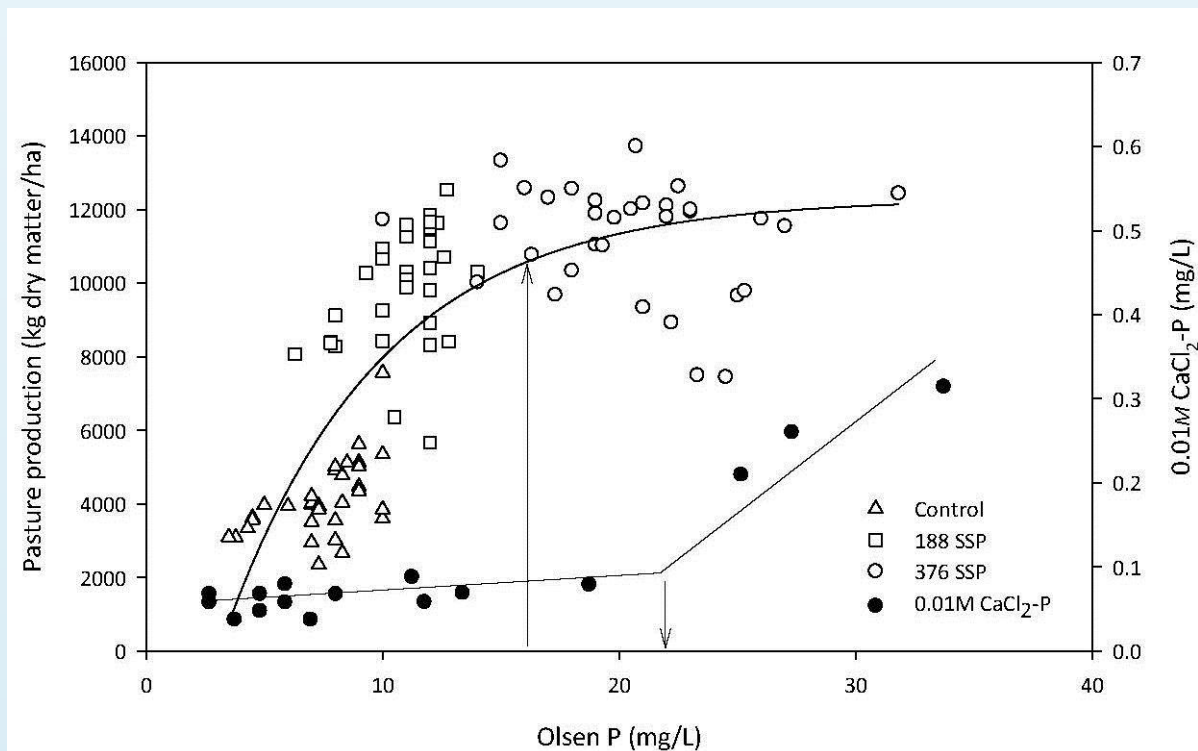


Figure 10.1 Agricultural optimum (up arrow) versus environmental impact (down arrow) for P loss in subsurface drainage (as estimated by 0.01M CaCl₂-P). Data are from plots receiving different rates of superphosphate (SSP; kg ha⁻¹ yr⁻¹) at Canterbury, NZ (McDowell, 2012).

Not all areas are of equal risk of losing nutrients to the environment. Some sites, referred to as 'Critical Source Areas' or 'Hot Spots', are more liable to pose a risk. These areas are typically wet and have high nutrient levels. Identifying and managing critical source areas are important ways to keep nutrients on farms. See [Section 10.3.3](#) for more information.

Gaseous losses (e.g. nitrous oxide from soils, methane from cows and effluent and ammonia from ammonium-based fertilisers) are increasingly important in a carbon economy that is designed to reduce greenhouse gas emissions.

10.1.1.3 Sustainable use

Nutrients are a critical factor driving dairy production. Global populations and their requirements for food are increasing yet, in some cases, questions are being raised about how much access producers will have to nutrients in the future. In that scenario, nutrients will be increasingly important and valuable.



- The Global Phosphorus Research Initiative is one example of a response to concerns that reliable, good quality phosphorous resources are fast diminishing. Global TraPs aims to engage differing viewpoints in better understanding the current and future availability of phosphorous for optimal use; see <http://phosphorusfutures.net/> and <http://www.globaltraps.ch/about-us.html>
- Concerns have also been raised about the sustainability of increasing the amounts of reactive nitrogen within the environment; see <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1247398/>

As a generalisation, Australian soils tend to be very old and low in nutrients, making nutrient inputs an important contributor to high levels of productivity. Modern farming systems tend to import nutrients, such as feeds and fertilisers, to boost production, with relatively little recycling. Many nutrients are shipped out in produce, ultimately entering urban waste treatment systems and then oceans, or lost to the off-farm environment (Cribb, 2006; and Gourley & Weaver, 2012).

10.1.1.4 Community responses

Communities around the world, through organisations and consumer reactions, have pressured governments and food producers in response to environmental and sustainability issues, as outlined previously. The responses range from local to multi-national in scale and include:

- Regulations on nutrient applications – e.g. capping fertiliser application rates or stocking rates, limiting the types of fertiliser to be applied, or requiring nutrient management plans or budgets and capping the ‘loss’ component.
- Public campaigns – e.g. detracting from the credentials and image of the dairy industry to invite regulations, consumer backlash, or additional barriers to trade.

Some regulations are now evident in Australia, with controls on fertiliser use being introduced to protect the Great Barrier Reef (Qld) and Peel Harvey Inlet (WA). For more information, see Gourley & Weaver (2012). There are also ‘softer’ options occurring, involving combinations of research, extension, incentives and regulation, affecting both fertiliser and milk supply-chains. Wise use of nutrients, and demonstration of that management, will be required to reduce the risk of increased regulation of farming activities.

10.1.2 Management principles

Research has shown there are areas on dairy farms with an oversupply of nutrients. There are opportunities for dairy farmers to improve the efficiency at which nutrients are converted to produce, to redistribute nutrients on-farm and to curtail off-farm losses.

The key management principles for dairy farmers to follow are to:

- [Understand nutrients](#) – know about nutrient cycles; where nutrients come from, the transformations they undergo and the pathways they follow.
- [Plan to retain nutrients on-farm](#) – apply the understanding of nutrients to plan for optimal productive efficiency and to contain losses; and check to see the plan is followed and succeeding.
- [Optimise production](#) – get as much production from applied nutrients as possible by focusing on the ‘4Rs’ (the right sources of nutrients, in the right place, at the right rate and right time), and recycle and redistribute nutrients within that framework; especially in the more resilient areas of a farm.
- [Minimise losses](#) – take special care to avoid direct losses and to lock-up or re-use excess nutrients; especially in areas more prone to environmental loss (critical source areas).

These principles, along with the key strategies to address them, are discussed in the following sections.



10.2 Understand nutrients in the environment

The keys to understanding nutrients are:

[Know the sources of nutrients.](#)

[Understand nutrient stores and transformations.](#)

[Know how nutrients are lost.](#)

As summarised in the following diagram, nutrient stores, transformations and pathways are complex, especially for nitrogen. For more information on the nitrogen cycle, see [Chapter 12.1.1](#) and the Nitrogen Cycle Animation:

http://vro.dpi.vic.gov.au/dpi/vro/vrosite.nsf/pages/soilhealth_nitrogen-cycle

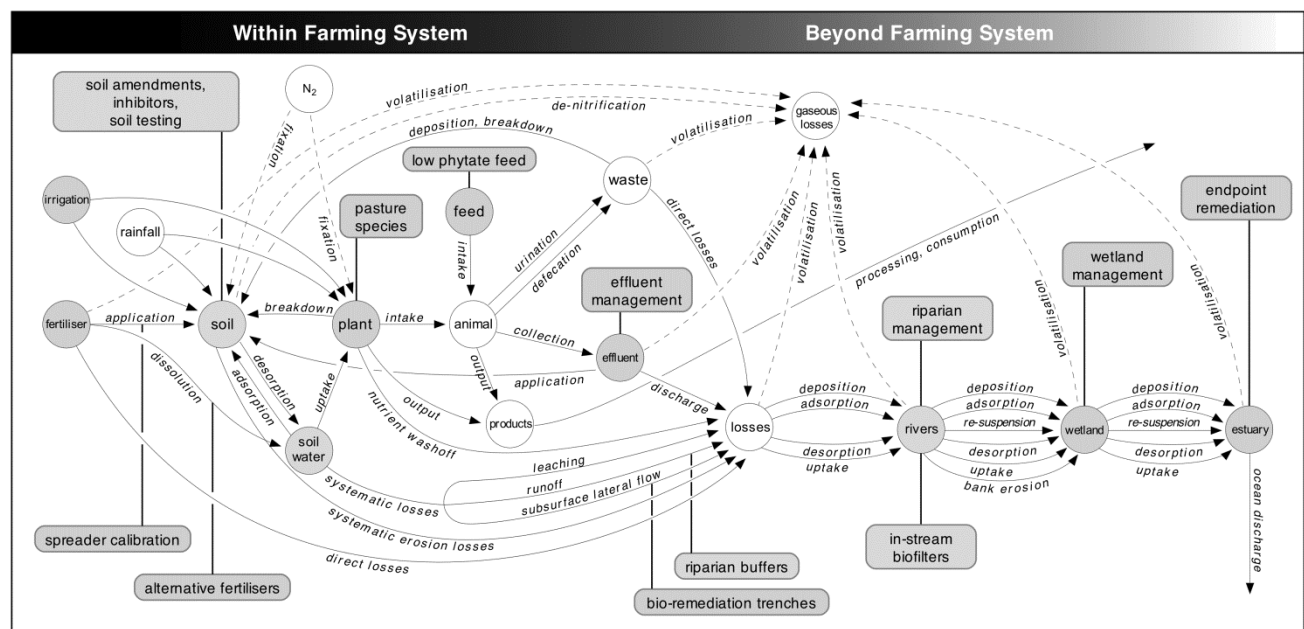


Figure 10.2 Phosphorus and nitrogen stores, transformations and pathways - nitrogen specific pathways shown by dashed lines (Gourley & Weaver, 2012).

10.2.1 Know the sources of nutrients

Nutrients on dairy farms come from inputs, such as [feeds and fertilisers](#), [redistribution or recycling](#), and, in the case of nitrogen, from nitrogen fixation by legumes.

10.2.1.1 Feeds, fertilisers and fixation

The relative importance of feeds and fertilisers in nutrient budgets shifts with different farming systems:

- If imported feed is less than 20% of the feed budget, then fertiliser is usually the main source of nitrogen, phosphorus, potassium and sulphur.
- If purchased feeds are more than 40% of the feed budget, then they tend to be the main source of nutrients.
- On low-input farms, with little imported feed or fertiliser application, nitrogen fixation can be the biggest source of nitrogen (Department of Primary Industries Victoria (n.d).b.)

Fertilisers are usually the main source of phosphorus and highly water soluble forms, like superphosphate and Di-Ammonium Phosphate (DAP), are most commonly used in fertilisers. Water soluble phosphorus may be taken up immediately by plants and it may be readily transported by water, but this is dependent on the soil's ability to adsorb phosphorus (measured by its Phosphorus Buffering Index (PBI) – see [Section 10.2.3.3](#)).



The nutrient concentrations in feeds should be tested as they vary within and between different types. Forages and by-products are especially variable, compared to grains and pellets.

Annual fodder crops can 'harvest' surplus nutrients but they may require additional different nutrients and cultivation may increase the risk of losses through leaching or erosion.

10.2.1.2 Redistribution

Nutrients may be redistributed on-farm by stock in urine and dung, by recycling treated effluent and through harvesting and feeding out home-grown feeds such as silage or hay.

The Accounting for Nutrients project showed that cows on conventional farms spend approximately three-quarters of their time in paddocks (especially those close to dairies), 6% in laneways, 9% in yards and 2% in milking sheds. Changing where they spend their time can change where they redistribute nutrients, although cows tend to excrete more in response to certain stimuli, such as entering yards or crossing a creek (Davies-Colley *et al*, 2004).

Urine patches are sites of high nutrient concentration, especially nitrogen and potassium, which can increase pasture yield and the concentration of nitrogen and potassium in the forage. There is, however, an increased risk of ammonia loss and nitrate leaching from these patches.

Dung is another source of nutrients that can be redistributed over the farm via stock or collected and spread as fertiliser.

Recycling treated effluent onto paddocks can effectively re-use and relocate nutrients. Risks occur when effluent is applied to saturated soils resulting in nutrient-rich run-off, and when the same area continuously receives effluent resulting in high soil nutrient levels. An application of 100mm of effluent can equate to 34 kg of phosphorus and 210 kg of nitrogen (Rivers & Dougherty, 2009).

10.2.2 Understand nutrient stores and transformations

To optimise the productive value of nutrients and assess their risk to the environment, it is important to understand how different nutrients cycle through the soil, plants and environment – e.g. whether they are lost, transformed, or stored. In general, phosphorus, potassium and sulphur may be stored, but nitrogen isn't. This section covers:

[Transformations](#)
[Stores.](#)

10.2.2.1 Transformations

Nutrients cycle through the environment. That is, they move through the soil, plants, animals and atmosphere; between inorganic and organic forms; and through soluble, insoluble and sometimes gaseous forms. For more information on nutrient cycles, see [Chapter 3.3](#)

The observed concentrations of nutrients in waterways may vary with 'in-stream processes' such as dilution by high flow rates or deposition in slow-flowing water; or through processes such as adsorption to, or desorption from sediments, and uptake by algae or plants.

Nitrogen is not generally stored in the environment and can be readily lost as water-soluble nitrate through runoff or leaching, or in gaseous forms such as nitrous oxide through denitrification or ammonia through volatilisation. This is one reason why the efficiency with which applied N is converted to produce is relatively low. Nitrogen may also be 'immobilised' or stored as organic nitrogen through incorporation in plants, soil organic matter, fungi and bacteria. Detailed analysis of 11 dairy farms found 50% of the nitrogen lost was via leaching and 48% via volatilisation; with 2% by denitrification (Gourley *et al*, 2011).



As the following graphs show, total nitrogen inputs are related directly to milk production – and to nitrogen surpluses. It cannot be concluded that all surplus N will be uniformly lost to the environment, as an array of factors will influence that including temperature, pH, moisture levels and the amount of organic matter present. However, increasing surpluses do increase the risk of nutrient losses to the environment.

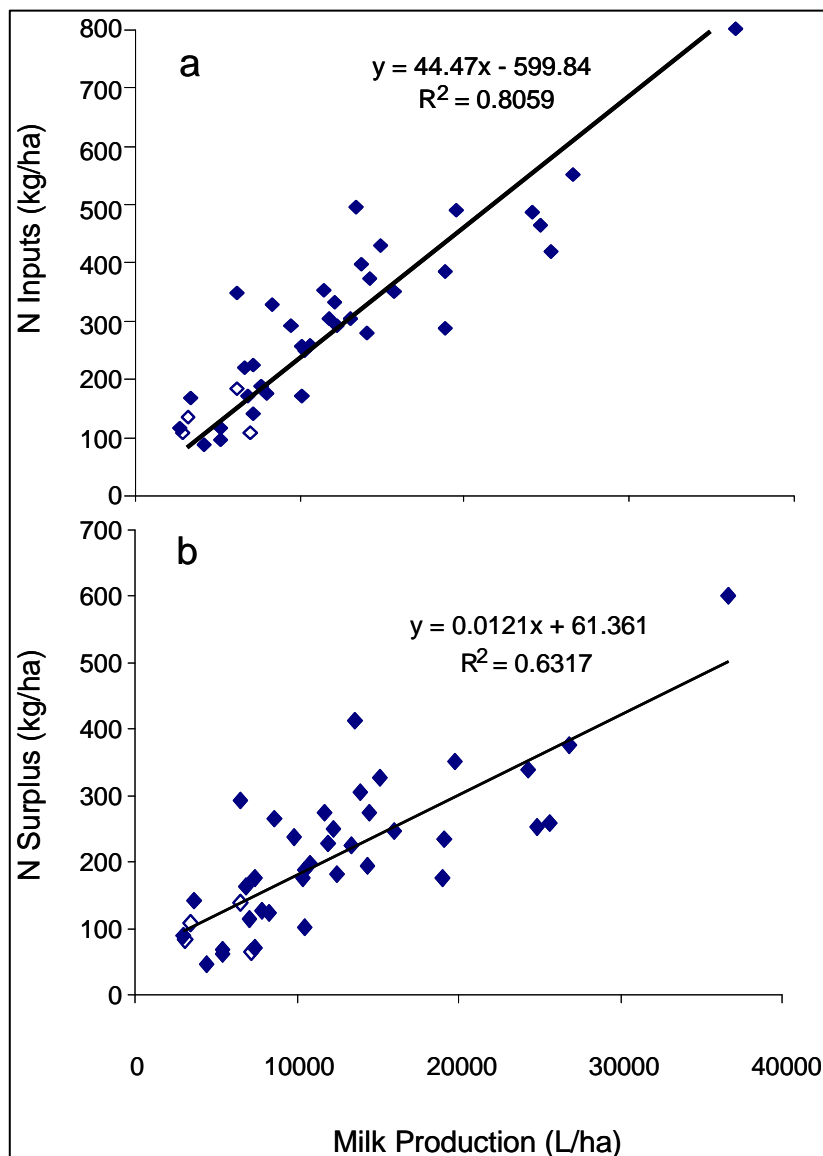


Figure 10.3 Relationship of N inputs to production and surpluses for 41 contrasting dairy farms across Australia - unshaded symbols represent organic dairy farms. (Gourley & Weaver, 2012)

The Accounting for Nutrients project found wide variations in nutrient conversion efficiencies. Conversion efficiencies relate to the proportion of nutrient entering the farm that is converted into saleable product such as milk or meat, or in other words, nutrient outputs divided by nutrient inputs. These wide variations as listed below, suggest that many farmers have scope for improvement:

- Nitrogen surpluses on Australian dairy farms ranged from 47 – 601 kg N/ha/yr and Nitrogen Use Efficiency ranged between 14%-50%.
- Nitrogen surpluses averaged 12 grams of N per litre of milk which is similar to those found overseas in Europe, the US and New Zealand.



- Phosphorus Use Efficiencies averaged 29%, but were very variable, with some exceeding 100% if inputs failed to match losses in product (Gourley & Weaver, 2012 and Gourley *et al*, 2012).

10.2.2.2 Stores

Phosphorus is stored in the soil with higher concentrations in the surface layer of soil, but it may be present in forms which are inaccessible to plants. Soils differ in their ability to hold phosphorus (as measured by their Phosphorus Buffering Index – see [Section 10.2.3.3](#)) and are also affected by their acidity. In acidic soils, phosphorus may become locked up by aluminium and iron, while calcium or magnesium phosphates may form in neutral or alkaline soils.

10.2.3 Know how nutrients are lost

Nutrients are removed from dairy farms via:

- [Produce](#) – milk, hay and livestock,
- [Atmosphere](#) – as gases or as particulate matter (e.g. wind-blown soil),
- [Water and erosion](#) – in surface water or ground-water, and through water erosion from paddocks or stream banks.

Taking action to reduce losses of a certain form can result in increased losses of another form – termed ‘pathway swapping’ – see [Section 10.2.3.3](#). For example, nitrogen may be lost as nitrate, ammonia or nitrous oxides. Restricting one pathway may open another, although the losses may occur at a different rate. Managers may have to set priorities.

10.2.3.1 Produce

Livestock sales usually only account for a small amount of the nutrients exported from a dairy farm in produce. Hay can be a larger source, and it is usually high in potassium and nitrogen. In terms of produce leaving the farm, milk is the largest nutrient exporter on a dairy farm.

10.2.3.2 Atmosphere

Around half the nitrogen present in urine and faeces occurs as ammonia; a form which may be readily lost to the atmosphere. Manure, and effluent treatment, can also result in the release of nitric oxide and nitrous oxide, a potent ‘greenhouse gas’ (Birchall *et al*, 2008). Wet soils can also be sources of nitrous oxides.

Methane, another greenhouse gas, is produced in the rumen of cows and from the biological treatment of effluent. In terms of greenhouse impact from established dairy farms, the two main contributors are methane from the rumen and nitrous oxide from urine and nitrogenous fertilisers.

Wind erosion is not usually a big issue on dairy farms, although dust from yards and feedpads may be; and would carry nutrients with it.

10.2.3.3 Water and water erosion

Water-borne nutrients may be transported via surface water run-off or sub-surface flows (leaching). Spaces between soil particles such as macro-pores, earthworm holes and decayed roots, provide ‘preferred pathways’ for sub-surface flows, but water will also move through the soil matrix itself. Water may also erode soil particles, removing them and the nutrients within. Erosion may occur in paddocks, along tracks or from stream banks.

Understanding these pathways requires consideration of:

- Run-off and drainage
- Nutrient concentrations
- Connectivity



- Effluent ponds
- Pugged soils
- Sealed surfaces
- Surface cover
- Wetlands
- Riparian buffers
- Stream-bank erosion

Run-off and drainage from rainfall or irrigation are key drivers of water-borne nutrient losses. Nutrient movement is proportional to water movement. Episodic events (storms) can be a major force, with studies finding 30% and 69% of annual losses occurring in a single storm (Holz, 1997 and Nash & Halliwell, 1999).

The amount of water moving and the rate at which it moves is affected by many factors besides climate, such as soil type, slope, landform, surface cover and sub-surface geology. Different combinations of factors result in different pathways being important – and in variable losses across farms. Some parts of a farm will lose nutrients more readily than others. Areas of higher potential loss are referred to as ‘**Critical Source Areas**’ or ‘**Hot spots**’.

Nutrient concentrations are also important. The application of fertilisers, defecation by grazing stock and recycling effluent in paddocks, all immediately increase the concentration of nutrients. Run-off or infiltration soon after will consequently have high concentrations. However, the concentrations measured in paddocks decrease rapidly with time. Phosphorus from most fertilisers has a ‘half-life’ (the time for concentrations to halve) of less than 10 days (Nash & Halliwell, 1999) and for N it is less than 2 days (Barlow et al, 2007).

Nutrient concentrations due to effluent recycling will be influenced by the ‘depth’ or volume of effluent and the rate and frequency of application.

Trade-offs: pathway swapping.

Applying nitrogenous fertilisers after rain will reduce the risk of N loss as water-borne nitrate. However, to reduce losses of N as gaseous ammonia from volatilisation, it is recommended that fertilisers be applied within a day before expected rainfall or irrigation (Barlow et al, 2007). Reducing atmospheric losses can require a trade-off; increasing the risk of water-borne losses.

The concentration of phosphorus in surface run-off is proportional to the concentration of phosphorus in the surface layers of soil with which it is in contact – and inversely related to the Phosphorus Buffering Index (PBI) of the soil. That is, soils that are high in available phosphorus and have little capacity to hold additional (or ‘buffer’) phosphorus (low PBI), are most likely to result in high concentrations of phosphorus in surface run-off, as shown in the following graph. The risk of losses occurring increases as soil phosphorus concentrations increase and soil is saturated with phosphorus (Dougherty *et al*, 2010; Weaver & Wong, 2011; Bolland & Russell, 2010).

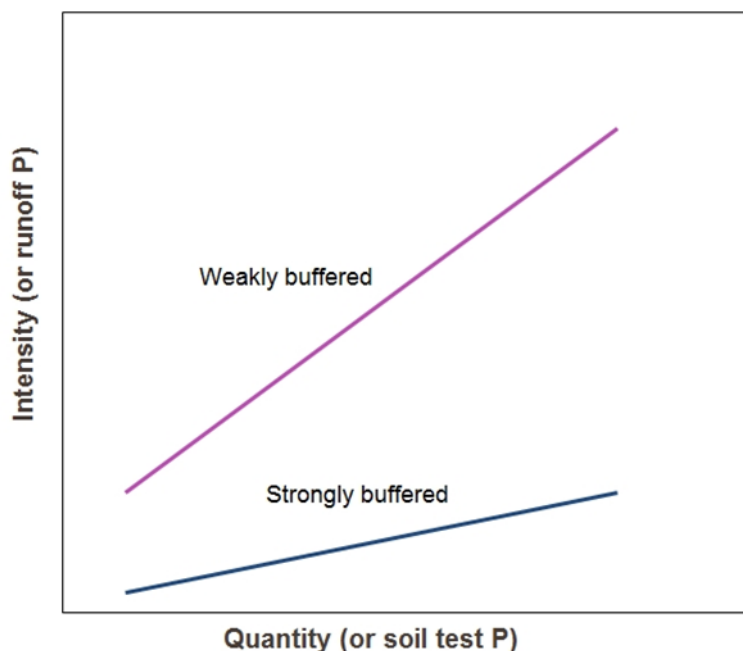


Figure 10.4 Runoff P concentrations (Dougherty *et al*, 2010)

Critical concentrations of phosphorus for maximum pasture production also vary with the Phosphorus Buffering Index of soils, as demonstrated by the following table.

Table 10.1 Critical P levels (DPIV, 2011)

PHOSPHORUS BUFFERING INDEX (Soil type)	CRITICAL COLWELL SOIL TEST P (mg/kg)	
	Pasture performance compared with potential	
	90% - 95%	95% - 98%
PBI 0-15 (Very sandy)	15 - 23	23 - 30
PBI 15-35 (Sand, Sandy loams)	17 - 26	26 - 34
PBI 35-70 (Sandy/Silty loams)	19 - 30	30 - 39
PBI 70-140 (Sandy/Silty clay loams)	22 - 35	35 - 45
PBI 140-280 (Clay loams)	26 - 42	42 - 54
PBI 280-840 (Clay loams & Clay)	37 - 58	58 - 75
PBI >840 (Volcanic clays & Peat)	50 - 90	90 - 120

With regard to environmental impacts, '**connectivity**' is another important factor. If nutrient-carrying water flows from a critical source area directly to a water body, then more nutrients will enter that water body, than if the 'connection' was via considerable overland flow where sedimentation would remove nutrients. However, connectivity is not just a factor of physical location. Soils that are saturated will have stronger connectivity with adjacent sites than will dry soils that hold water with little run-off. Artificial drainage can increase connectivity and larger storms will have more connectivity than small ones.

Inadequate or poorly maintained **effluent ponds** can be sources of direct loss of water-borne nutrients to the environment. Problems can include insufficient free-board to handle input surges or insufficient storage capacity to hold effluent when conditions dictate against it being recycled in paddocks (e.g. saturated soils not suitable for irrigation).



Pugged (saturated and compacted) soils have low infiltration rates and hence high run-off. They are also sites of increased nitrogen loss through denitrification and can be liable to erode. If they occur in low-lying areas, where water and nutrients from adjacent paddocks accumulate, they can be critical source areas for nutrients. Draining such areas will transport nutrients as well as water – making management of the drainage water crucial if environmental risks are to be managed.

Sites of heavy stock use which are **compacted or sealed** (e.g. laneways near milking sheds, yards, feedpads, troughs and gates) have high concentrations of nutrients and run-off rates. Although loaded with nutrients from manure and urine, they are often only a small area of a dairy farm, hence their total contribution to losses may not be as significant as appearances may suggest. Their ‘connectivity’ with vulnerable environments will be another factor in assessing their risk. For more information see; Monaghan & Smith (2012), Lucci *et al* (2012) and Dougherty & Hossain (in-print).

Cultivated paddocks or those with little **surface cover** such as emerging fodder crops, are potential sites for soil erosion, subject to features like slope, length of run, rainfall or irrigation intensity and soil type.

Wetlands can be very effective in ‘mopping up’ excess nutrients and preventing them from leaving a farm, but there are a number of caveats about that. Wetlands can be considered as sinks which work well until they are full or saturated, at which time they can then become sources of nutrient. Constructed wetlands are made in a way to permit their periodic cleaning out to avoid that problem. The other main challenge for wetlands is their ability to take flood waters. If floods (when most nutrient movement occurs) simply flow straight over a wetland or run through it very quickly, then they have minimal impact on reducing peak loss events.

Riparian buffers (‘filter strips’ adjacent to waterways) play a similar role to wetlands and face the same performance issues.

If the riparian areas include vegetated stream banks, then that can help stabilise the banks and reduce **stream-bank erosion** – which can be significant in some soil types. Stream flow-rate is another key factor in stream-bank erosion. Although it is driven by flows and run-off in upstream areas, slowing the flow of water as it leaves farms is one way to help reduce flow-rates in streams; and, in suitable circumstances, reduce stream-bank erosion – see [Section 10.5.2](#).



10.3 Plan to retain nutrients

The keys to nutrient planning are:

- [Analyse farm nutrient status.](#)
- [Determine production potentials.](#)
- [Assess risks and identify critical source areas.](#)
- [Document a plan.](#)
- [Monitor and evaluate.](#)

These steps align with the annual nutrient planning cycle as follows:

NUTRIENT PLANNING	ANNUAL CYCLE	NUTRIENT PLANNING	ANNUAL CYCLE
Analyse	Step 1.	Document a plan	Steps 4 & 5.
Production potential	Step 2.	Monitor & evaluate	Step 7.
Assess risks	Step 3.		
Step 6 (Implement) is covered in the following sections 10.4 & 10.5			

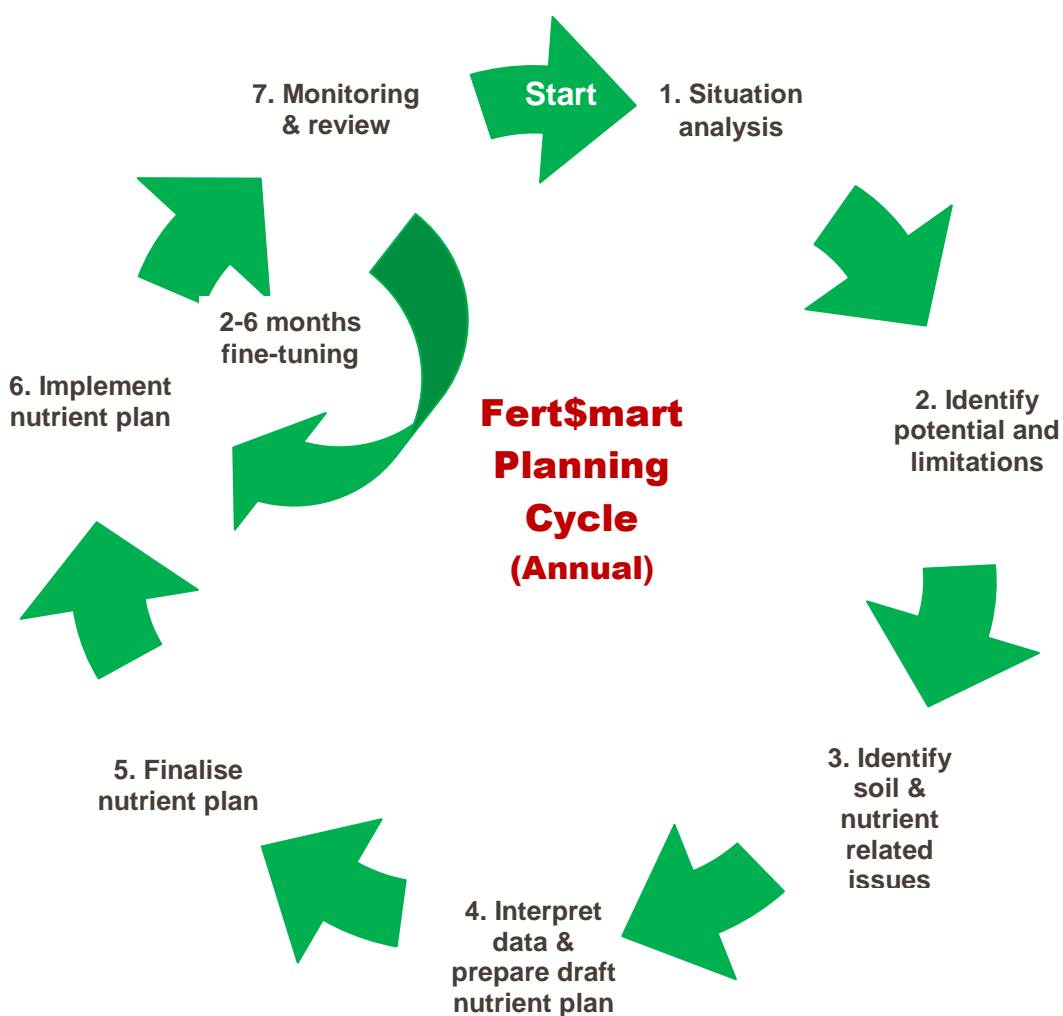


Figure 10.5 Annual nutrient planning cycle.



10.3.1 Analyse farm nutrient status

Important tools to understand a farm's nutrient status are:

- [Soil test and nutrient maps](#)
- [Nutrient budgets.](#)

10.3.1.1 Soil test and nutrient maps

Farm management zones (areas with similar physical features and management) should be soil tested regularly (see [Chapter 15.3.1](#) for more detail). The results should be considered as part of a time series to note any trends.

It is useful if soil nutrient status can be mapped to identify paddocks with high nutrient levels and those with low levels. Maps make it easy to see the paddocks that are potential 'critical source areas' for nutrient loss and where less fertiliser could be applied. Nutrient maps also visually assist in readily identifying where ameliorants such as lime are needed; or where there are opportunities to redistribute excess nutrients, for example in low nutrient status paddocks in which effluent could be recycled.

10.3.1.2 Nutrient budgets

Nutrient budgets (see [Chapter 15.5](#) for more information) provide additional perspectives on nutrient status. They provide insight into the efficiency with which nutrients are converted to produce and highlight potential risks and opportunities for improvement, such as striving to better match inputs against losses. As indicated in the following table, as farm productivity rises due to additional inputs (such as imported feeds) so too may the nutrient surplus.

Table 10.2 Potassium and phosphorus budgets. (Gourley *et al*, 2007).

Potassium and phosphorus inputs in feed, outputs in milk, and difference, for three stocking rates (2, 3 or 4 cows/ha) in a wet (1998-99) and dry (2000-01) season in Victoria.						
	1998-99			2000-01		
	2 cows/ha	3 cows/ha	4 cows/ha	2 cows/ha	3 cows/ha	4 cows/ha
<i>Potassium (kg/ha)</i>						
Feed	28	52	74	39	107	184
Milk	19	29	36	20	30	36
Difference	+9	+23	+38	+19	+77	+148
<i>Phosphorus (kg/ha)</i>						
Feed	7	15	23	9	22	38
Milk	10	15	19	10	16	21
Difference	-3	0	+4	-1	+6	+17

For more information on nutrient budgets, see Gourley *et al*, 2007.

10.3.2 Determine production potentials

Unlocking the productive potential of a farm involves:

- [Nutrient targets](#)
- [Soil limitations](#)
- [Redistribution options](#)

10.3.2.1 Nutrient targets

Nutrient budgets combined with feed budgets are a first step to ensuring adequate nutrition for pastures and livestock. Setting nutrient targets for soils – to optimise production yet minimise risks of environmental loss – is another important step. Areas where nutrient targets have already been



achieved for phosphorus may be prioritised as locations in which P applications may be reduced or halted.

10.3.2.2 Soil limitations

In some situations, plants are not able to make use of the nutrients that are present due to other limiting factors. As examples, soil pH may not be suitable and the nutrients may be bound to other elements or the soil may be saturated and plant roots unable to function due to a lack of oxygen, curtailing nutrient uptake. In such situations, simply adding more nutrients will do little to improve productivity but much to increase the risk of nutrient loss, whereas rebalancing the pH or improving soil structure will unlock existing potential.

10.3.2.3 Redistribution options

Options for redistributing nutrients should also be assessed from a cost:benefit perspective. Nutrient budgets for farm management zones and farm nutrient maps may identify some options (e.g. cutting hay in high nutrient (especially potassium) paddocks for feeding out in low nutrient paddocks, applying effluent to low nutrient areas, or changing grazing pressures between paddocks), but management factors and costs must be considered to determine which options are realistic.

10.3.3 Assess risks and critical source areas

Assessing risks involves identifying hazards then considering the likelihood of them occurring and the potential consequences or effects, should the hazard eventuate.

Risk = **Likelihood** X **Consequence**.

For dairy farms, water-borne nutrients often pose the major risk to the local off-farm environment. As such, water movement either above or below the surface, is a key driver and a big influence on risk. Identifying critical source areas is an important step in assessing the risk of nutrients being lost from a farm.

Dairy farmers are used to managing nutrients as a fundamental input to controlling economic and productivity risks. For efficiency and sustainability reasons, farmers will increasingly have to also assess the environmental risks of nutrient inputs.

10.3.3.1 Hazards

'Cracking the Nutrient Code' (FIFA, 2001) was developed by Fertilizer Australia and presents a framework for assessing hazards, likelihoods and consequences at a farm scale, including practices checklists. It includes questions to help assess the likelihood and consequences of risks concerning nutrient stores or imbalances and losses, grouped as:

- **Load** – excess nutrients, e.g. exceeding optimal soil concentrations.
- **Mine** – depleting nutrient stores, e.g. downward trending soil nutrient concentrations that are below optimal levels.
- **Run** – losing nutrients in surface run-off, e.g. steep, high rainfall country which is high in nutrients.
- **Leach** – losing nutrients in sub-surface water movement; e.g. shallow water tables in permeable soils.
- **Blow** – losing nutrients to the atmosphere, e.g. wind erosion of dry, exposed soils.

When considering hazards associated with water-borne nutrients it is often useful to also consider the hazards associated with water-borne dairy pathogens. Pathogens can travel via similar pathways to nutrients and some management innovations to contain nutrient losses will also reduce the risk of pathogens entering waterways.



10.3.3.2 Likelihood

The dairy industry has developed several tools to help assess risks.

The **Farm Nutrient Loss Index** (FNLI) considers management practices, climate and the physical characteristics of different farm management zones likely to be at risk of losing nutrients to the environment. The tool can provide detail to help apply the Fertilizer Australia framework and identify potential 'critical source areas' on individual farms. It can remove some subjectivity from an assessment. Coupled with the Dairy Self Assessment Tool (**Dairy SAT**) – a best practices checklist – the FNLI provides some quantitative input to qualitative assessments such as '**Cracking the Nutrient Code**'.

For more information on the FNLI and DairySAT see the 'tools and guidelines' at:

www.dairyingfortomorrow.com.au.

For more information on Cracking the Nutrient Code, see:

http://www.fifa.asn.au/default.asp?V_DOC_ID=840

It is essential that risk assessments consider:

- those areas of a farm likely to pose most risk (critical source areas),
- management practices likely to be a hazard, and
- the location of individual farms in their catchment context (e.g. degrees of connectivity).

'**Understanding Dairy Catchments**' is a tool to help assess risks for dairying in a catchment context. It helps users understand the critical links between the management of different areas and the likelihood of negative impacts for a catchment. For more information see:

<http://www.dairyingfortomorrow.com.au/index.php?id=55>.

10.3.3.3 Potential consequences

The significance of an impact on the environment can be considered in light of the value of the environmental asset in question and the vulnerability of the asset. In this context, environmental assets are things like lakes, rivers, estuaries and wetlands, and the plants and animals they support.

The Commonwealth Government's Environment Protection and Biodiversity Conservation Act and associated website (<http://www.environment.gov.au/epbc/>) provide a good place to begin to assess the significance of an asset. It includes lists of threatened flora and fauna including migratory birds, ecological communities and critical habitats. Internationally important wetlands listed under the Ramsar Convention are also recorded along with information on nationally important wetlands. Similar lists and protection measures may also be relevant from a State or regional level.

The vulnerability of the asset to an impact is affected by the asset itself – e.g. whether the asset is able to recover from an impact or if it will suffer permanent, irreversible change – and the impact; e.g. its severity and extent, and whether it is a sudden impact or a cumulative one in response to gradual changes. Characteristics of the local environment (or 'receiving waters') will help determine some of those aspects. For example, a high energy coast with strong flushing coastal currents (an 'open' system) will usually be more resilient than a shallow, low energy terminal lake into which streams drain (a 'closed' system). The social characteristics of local communities may also be relevant, with some communities being highly aware and concerned regarding the environment.

When considering nutrients, concentrations are often important in assessing immediate threats but loads (the amount of nutrient in the water-body over time) and budgets are important in understanding how concentrations may change over time, and if systems are on the verge of being overloaded or saturated. Once saturated, wetland ecosystems may become much more sensitive to small additional loads of nutrients which may trigger major, irreversible changes in the environment.



When assessing potential consequences, it is useful to know whether short term nutrient concentrations or long term loads pose the greatest threat to the environment (Kleinman et al, 2011). Catchment management officers may be able to help work this out and provide directions to programs with support for on-farm change.

10.3.4 Document a plan

The nutrient management plan, (including the recycling of effluent, redistribution of nutrients between paddocks and rebalancing soil chemistry) should fit within a whole farm management plan. In regard to fertilisers, its focus will be on determining which fertilisers to use, where, when and in what amount (see the '[4Rs](#)' Framework - the right sources of nutrients, in the right place, at the right rate and right time).

Considerations in a whole-farm context include:

- **Nutrient balance.** Inputs need to replace outputs in produce plus unavoidable losses. For phosphorus, inputs must also provide for the buffering capacity (PBI) of the soil (Weaver & Wong, 2011).
- **Critical levels.** Inputs should achieve critical soil concentrations to optimise production but not exceed them or any known critical levels that increase the risk of loss to the environment.

For more information see [Chapter 16](#).

10.3.5 Monitor and evaluate

Keeping an eye on how the nutrient management plan is being implemented and the impact it is having on production, soil nutrient levels and profit will be an on-going exercise. Observations from that monitoring, and any trends, will help fine-tune the plan for the future (See [Chapter 1.7](#)).

As part of the evaluation it is also worthwhile estimating the savings being generated from improved nutrient management. The simplest measure may be a reduction in fertiliser costs or a reduction in the application of specific nutrients (e.g. phosphorus applications may not be required). Revisiting whole-farm or management zone nutrient budgets may be another way to consider the reductions in nutrient loss due to improved management.



10.4 Optimise production

The keys to optimising production, in terms of converting nutrients into milk, are:

[Get top value from low risk areas](#)

[Recycle nutrients](#)

[Optimise irrigation efficiency](#)

[Consider stock as a management tool](#)

10.4.1 Get top value from low-risk areas

A good way to ensure nutrients are not lost to the environment is to use them in production – converting them to produce. For example, if higher rates of nitrogen are being applied, then higher rates of stocking are needed to make use of extra pasture growth. Optimising production from areas that are more resilient and a lower-risk in terms of nutrient loss is one way to profitably manage risk at a farm scale. That is, strive for peak production in resilient areas, and reduce the pressure on critical source areas.

10.4.2 Recycle nutrients

Effluent can be a valuable source of water and nutrients when treated as an irrigation supply and/or applied in the [4Rs](#) framework. Recycling effluent can reduce risks to the environment and optimise production without additional fertiliser inputs.

Infrastructure is a key to optimising the productive value of effluent. There must be adequate storage capacity for the effluent, the ability to get treated effluent to where it will be useful and an appropriate irrigation or spreading system. Separating solids and liquids can make effluent recycling an easier proposition.

10.4.3 Optimise irrigation efficiency

Excess (lost) water inevitably means lost nutrients on a dairy farm. Optimising water use efficiency to minimise water loss will drive measures of production (yields of dry matter / mega litre) while containing nutrient loss. The approach should be the same when irrigating water and recycled effluent. An irrigation and drainage management plan is a useful tool to help design appropriate infrastructure and to develop a plan for scheduling irrigation, including irrigating with recycled effluent.

10.4.4 Consider stock as a management tool

Options to redistribute nutrients through grazing patterns and feed transfers are discussed in [Section 10.2.1.2](#), and can be an effective aide to optimal productivity. Another practice to reduce nutrient losses and optimise production is by managing grazing pressure to avoid wet-soil pugging by the use of on-off grazing; keeping pastures productive for longer and avoiding higher risks of nutrient loss from compacted, saturated soils.



10.5 Minimise losses

The keys to minimising nutrient losses are:

[Avoid direct losses](#)

[Reduce and reuse run-off](#)

[Lock-up excess nutrients](#)

10.5.1 Avoid direct loss from fertilisers, effluent and livestock

Direct losses are losses of nutrients from the farm system through a pathway with direct off-farm connectivity, e.g. by spreading fertiliser over flowing surface water. These can be almost immediate and come from inadequately managed:

- [fertiliser applications](#),
- [effluent](#) or
- [livestock](#).

10.5.1.1 Avoid direct loss from fertilisers

Some potential fertiliser losses are easy to avoid:

- No applications direct to surface waters such as drains, creeks and dams – maintaining a buffer between fertilised pastures and surface waters or drains.
- No applications to ‘hot spots’ – avoiding critical source areas with strong connectivity; such as pugged paddocks adjacent streams or bare soils, laneways and yards.
- Minimise irrigation run-off – ensuring there is no run-off after applying fertilisers, or not applying fertilisers to a buffer strip at the end of irrigation bays.

Others require some planning:

- No applications of nitrogen within 5 days of an anticipated run-off event.
- Minimise ammonia volatilisation from urea applied during the warmer months by irrigating fertiliser into the soil, but avoid run-off. Where irrigation is not possible, losses can be reduced significantly by applying urea 2-3 days before grazing (Warning: lumps of urea ingested by animals can cause ammonia toxicity). See [Chapter 12.3](#) for further information regarding minimising nitrogen losses.
- No applications of phosphorus within 7 days of an anticipated run-off event or when soils are freely draining after heavy rains.

To reduce nutrient losses from fertilisers it is necessary to consider the ‘4Rs’ framework of:

- [Right source](#),
- [Right place](#),
- [Right rate](#), and
- [Right time](#).

Right source

Stable, slow release, forms of fertiliser pose least risk to the environment, but may not be cost effective or necessary in many situations. Using fertilisers of low solubility can reduce losses by 0-20% depending on the circumstances (McDowell & Nash, 2012). See [Chapter 11](#) and [Chapter 12](#) for information on how to select the right source of fertiliser for different situations and conditions.

Right place

Special attention is needed for critical source areas and to avoid direct applications to water-ways. Following the [Fertcare program guidelines](#) for application will address those concerns. Select areas with low nutrient levels for added applications. In cultivation paddocks, ensure pre-plant fertilisers are incorporated and covered by loose soil.



Right rate

A common goal is to meet the needs of plants by ensuring nutrients, particularly N, K and S, are available at rates to match plant uptake. Nutrient types and rates should be targeted for different areas of the farm based on soil test results, critical levels for plant growth and nutrient budgets. Some 'rules of thumb' are summarised below and can be seen in full at:

<http://www.nitrogen.unimelb.edu.au/> :

- Apply N at 30-50 kg/ha per application to meet plant growth requirements, at intervals of at least 21 – 28 days respectively during periods of active plant growth.
- Where annual N applications exceed 250 kg N/ha/yr, soil testing and applying lime may be required if fertilising at higher rates in high production paddocks.
- Don't apply P if soil test levels are above those where a pasture response is likely. The critical level will vary with the phosphorus buffering capacity (PBI) of the soil and the desired level of production from the paddock – Refer **Error! Reference source not found.**

Ensuring spreading equipment is [Accu-spread](#) accredited will result in an even distribution of fertilisers within the targeted application zone.

Right time

Timing applications to meet plant needs is a priority, for example as needed for Nitrogen. However, consideration must also be given to optimising uptake and minimising losses. Timing activities (e.g. not applying fertilisers when heavy rainfall and run-off is imminent) is a management option to reduce nutrient losses. Seven-day forecasts from the Bureau of Meteorology can be useful guides to help determine the risk of significant run-off occurring. Losses that may be controlled by management are sometimes termed 'incidental losses'. Avoiding run-off from irrigation is another example.

Applying nitrogen on a cool, dry surface, a day prior to adequate 'watering in' rain but not before heavy, run-off inducing rainfall is one way to optimise production and minimise losses through volatilisation and run-off.

10.5.1.2 Avoid direct loss from effluent

Effluent from milking sheds, feedpads and yards should be effectively captured and stored for treatment. Designing, and maintaining, correctly sized pre-treatment systems, ponds and sumps to cope with peak loads (e.g. capturing a 'first flush' in storms but diverting cleaner subsequent water) is the first step. Similarly, laneways (especially those subject to heavy traffic and/or draining direct to a water-body) should be constructed and maintained with adequate shape and crown to disperse nutrient-rich run-off in a low-risk manner. Constructing drainage diversion humps or 'whoa boys' that direct sloping laneway run-off to grassed areas is one way to achieve this.

The rule of thumb that recycled water should be applied as thinly as possible over as large an area as possible is as relevant to recycled dairy effluent as it is to other recycled wastewaters, although opportunities on dairy farms may be limited and require additional irrigation infrastructure. It is particularly important to avoid applying recycled effluent to saturated soils where run-off will occur. Having adequate storage capacity and irrigation capacity are fundamental for that. A soil-water budget can help in planning an appropriate system. If losses remain a risk, then additional treatment may be an option to reduce nutrient loads (e.g. high rate algal ponds, where nutrients from effluent help grow algae which are harvested for use as fertiliser or stock-feed, have been trialled to reduce phosphorus levels) (McDowell et al, 2004).



Effluent irrigation systems may be prone to blockages, which can in turn lead to stoppages or overflows, which result in run-off. Having fail-safe tools like breakdown alerts and automatic shut-downs can help manage that risk (Hanly, 2012).

Refer to [Chapter 13](#) for further information about using dairy effluent.

10.5.1.3 Avoid direct loss from stock

Keeping stock out of watercourses is a fundamental approach to keep nutrients and pathogens out of waterways. Fencing, creek crossings and alternative watering points are prerequisites. 'Hot spots' like troughs and gates should also be carefully sited.

Pugged areas with strong connectivity to water are a potential 'critical source area' and should not be grazed, to avoid direct losses. For more information on assessing pugging and planning recovery, see [GippsDairy \(2011\)](#). Changed grazing management (e.g. on-off grazing) or feedpads may be necessary.

10.5.2 Reduce and reuse run-off

Water movement is a key driver of risk, so reducing run-off and deep-drainage will help reduce the loss of nutrients from dairy farms. Irrigation should be managed to minimise overwatering and waterlogging and should consider the water holding capacity of the soil type. Irrigation systems that result in good distribution uniformity (low pressure systems) and scheduling based on plant water usage and accurate soil moisture monitoring equipment can assist in this regard.

It is necessary, however, to consider individual farms and sub-catchments in their own right, as general rules do not always apply. For example, while boggy areas on farms may have been drained to increase production, there can be merit from a nutrient management perspective in some locations in slowing the flow of water and reducing run-off. Taking a whole-farm, or even sub-catchment, view can help to identify opportunities to retain water and nutrients in a useful manner (e.g. to maximise water use efficiency as measured by pasture production / mm of rainfall) and to slow the rate of flow in local streams and hence reduce stream-bank erosion.

This may be as simple as retaining thick grass buffers adjacent to water lines, especially small streams in paddocks. At the other extreme, it could be constructing an artificial wetland to take water from low-lying areas or for water drained from boggy areas. Care should be taken with natural wetlands, but there may be opportunities to reduce stock access or reinstate wetland vegetation and increase their capacity as a nutrient sink, without harming their ecology.

An option for flood irrigation is to not fertilise the end of bays, providing a buffer as recommended for waterways, and to avoid run-off. Re-use dams may also be installed, increasing the efficiency of water use and recycling nutrients.

Avoiding water movement that results in erosion will also reduce the loss of nutrients from farms. Permanent pastures and adopting conservation tillage during pasture renovation or the growing of fodder crops will help maintain groundcover (e.g. retaining residues or sowing cover crops), surface roughness and infiltration. Careful periodic deep cultivation can also be beneficial, incorporating nutrient rich top-soil within the deeper soil profile and closing off macro-pores through which P may be lost (McDowell *et al*, 2004). Diversion or contour banks can also slow water movement on sloping grounds.

Rehabilitating any eroding areas (including streambanks in some situations) and ensuring there is good ground-cover will retain soil and reduce the loss of nutrients. As with buffering waterways, it can be relatively easy and very beneficial to work on small order streams within paddocks.



10.5.3 Lock-up excess nutrients

Applying soil ameliorants to 'lock-up' nutrients may be an option for some situations; especially when focused on critical source areas - and when it makes the saved nutrients available for plant uptake.

For example, in Western Australia, bauxite has been applied when available as an economically feasible way to retain phosphorus in sandy, at-risk soils. Research is also showing that nitrification inhibitors can work in the field; although practical, well-tested applications have not been available for conventional Australian dairy farms (Eckard *et al*, 2008) but work is ongoing in this area. The N-inhibitors work by reducing the rate at which ammonium from the main sources, fertilisers and urine, is converted to nitrate and nitrous oxide. The process gives plants more time to take up both ammonium and nitrate ions, meaning more fertiliser is available to, and is used by, pastures; increasing productivity and reducing environmental losses (Cameron *et al*).



10.6 Summary

In this section:

[Significance](#)

[Best practice checklist.](#)

10.6.1 Significance

Losing nutrients from a dairy farm is:

- wasting increasingly expensive inputs, effectively increasing the cost of production per litre of milk, and
- increasing the risk of adverse environmental impacts.

The waste of important nutrient resources and the risk of adverse impacts may trigger community responses which result in increased regulation of farming activities and/or market reactions and trade barriers.

Keeping nutrients on farm can improve gross margins and enable dairy farmers to proudly promote their sound environmental ethics.

10.6.2 Best practice checklist

In this section:

[Management principles and strategies](#)

[Management practices.](#)

10.6.2.1 Management principles and strategies

The key strategies to retain nutrients on dairy farms, and optimise production and profit, are:

Understand nutrients in the environment

- Know the source of nutrients
- Understand nutrient stores and transformations
- Know how nutrients are lost

Plan to retain nutrients on-farm

- Analyse farm nutrient status
- Determine production potentials
- Assess risks and identify critical source areas
- Document a plan
- Monitor and evaluate

Optimise production

- Get top value from low-risk areas
- Recycle nutrients
- Optimise irrigation efficiency
- Consider stock as a management tool

Minimise losses

- Avoid direct losses
- Reduce and re-use run-off
- Lock-up excess nutrients



10.6.2.2 Management practices

Examples of how those principles may be applied, with reference to practices recorded in DairySAT, are:

[Print table>>>](#)

	Understand nutrients	Plan to retain nutrients	Optimise production	Minimise loss
Soils	<ul style="list-style-type: none"> Understand the types of erosion occurring and their causes. 	<ul style="list-style-type: none"> A plan is in place to minimise erosion. 	<ul style="list-style-type: none"> Management minimises compaction and pugging. Irrigation is managed to minimise overwatering and waterlogging. Management avoids soil acidification. 	<ul style="list-style-type: none"> Management minimises erosion.
Fertilisers	<ul style="list-style-type: none"> Understand why soil sampling is needed. 	<ul style="list-style-type: none"> Correctly taken soil samples are regularly collected from representative areas. A farm nutrient management plan guides fertiliser applications. Soil constraints are considered when determining nutrient requirements. 	<ul style="list-style-type: none"> Calibrated or Accuspread-accredited fertiliser spreaders are used. Effluent is used as a fertiliser with rates determined by soil nutrient (and water) requirements. 	<ul style="list-style-type: none"> Buffers are used to protect waterways and drains from fertilisers. Additional nutrients are not applied to critical source areas. Fertiliser applications are timed to avoid run-off.
Effluent	<ul style="list-style-type: none"> 	<ul style="list-style-type: none"> Ponds have been integrated into the farm plan. Ponds are correctly sized and managed. Manure stockpiles are sited away from sensitive areas and are banded. Feedpads are designed for appropriate effluent, 	<ul style="list-style-type: none"> Effluent is retained on-farm and reused for productive gains. Effluent composition is tested and is suitably distributed to match application rates with soil, pasture and crop requirements. 	<ul style="list-style-type: none"> Ponds are emptied regularly. Ponds are desludged when required. Sump/traps have sufficient capacity and spare pumps are on hand. Buffers are used to protect waterways and drains from effluent.



		manure and waste feed management.		
	Understand nutrients	Plan to retain nutrients	Optimise production	Minimise loss
Irrigation	•	<ul style="list-style-type: none"> Seasonal water use is measured. 	<ul style="list-style-type: none"> Irrigation scheduling is based on plant water use or soil moisture. 	<ul style="list-style-type: none"> Management avoids run-off and deep drainage.
Greenhouse gases	•	<ul style="list-style-type: none"> Nitrogenous fertiliser sources are selected to minimise nitrogen losses. Effluent is tested for nitrogen levels. 	<ul style="list-style-type: none"> Nitrogen is applied when pastures are actively growing and can use the N. Nitrogen fertiliser application rates are kept below 50 kgN/ha per application. Effluent application is timed to avoid wet conditions and maximise plant uptake. On/off grazing or stand-off areas are used to minimise pugging of wet soils. 	<ul style="list-style-type: none"> Nitrogen is not applied to water-logged soils, before irrigation/heavy rains and for at least 2-5 days after irrigation/heavy rains. Nitrification inhibitor sprays are applied once or twice in wetter months.
Waterways	•	<ul style="list-style-type: none"> Farm plan seeks to improve native biodiversity and environments; e.g. through grazing management. 	<ul style="list-style-type: none"> Stock are provided with alternative (non-riparian) watering points. 	<ul style="list-style-type: none"> Riparian and wetland areas are fenced for stock control. Bare riparian areas are revegetated.



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