Greener pastures 7 - A fresh look at nutrient losses from intensively managed pastures

Don Bennett
Bill Russell
Martin Staines
Richard Morris
Mike Bolland

See next page for additional authors

Follow this and additional works at: https://researchlibrary.agric.wa.gov.au/bulletins

Part of the Plant Sciences Commons, and the Soil Science Commons

Recommended Citation

This bulletin is brought to you for free and open access by the Research Publications at Research Library. It has been accepted for inclusion in Bulletins 4000 - by an authorized administrator of Research Library. For more information, please contact jennifer.heathcote@agric.wa.gov.au, sandra.papenfus@agric.wa.gov.au, paul.orange@dpird.wa.gov.au.
Greener Pastures

A fresh look at nutrient losses from intensively managed pastures
Introduction

Dairy farmers in Western Australia have a long history of being concerned for the environment in which they live and work, from early involvement with Landcare District Committees through to participating in the various programs run in DairyCatch.

They have planted trees, organised soil testing programs, carried out salinity surveys and, more recently, have signed up for effluent, nutrient and irrigation water management programs. Many of these programs produce benefits both on and off the farm—they can improve the farm environment, increase farm productivity and reduce nutrient losses to surface and ground water. The wider community has supported farmers with funding from both State and National landcare programs.

Farmers who have implemented an Effluent Management Plan can demonstrate that they are able to contain their dairy effluent on farm without contaminating surface or ground water. On-farm water supplies are protected and a potential point source of pollution is removed. On most farms, the nutrients in effluent can be recycled through pasture, potentially replacing some bought-in nutrients.

The pressure on farmers to demonstrate good environmental management can only increase. Regular algal blooms in some of our major waterways focus the community’s attention on water quality. This leads to demands that land—urban and rural—is managed to reduce nutrient loss.

In some ways, the easy targets have been tackled. These are the point sources of both urban and rural nutrient loss—operations which produce small volumes of effluent containing a high concentration of nutrients. A larger and more difficult source is the diffuse nutrients that leach and runoff from paddocks—as a consequence of the necessary application of fertilisers to produce food.
Increasing use of N by agriculture brings significant environmental risks. The United Nations Millennium Ecosystems Assessment identified fertiliser N as the world’s second worst source of ecosystem decline. The New Zealand Parliamentary Commissioner for the Environment has suggested that New Zealand needs to fundamentally redesign its dairy production system to reduce dependence on N fertilisers.

The increased use of N fertiliser to intensify pasture production is a worldwide trend, as farmers respond to the persistent cost-price squeeze, and has led to strict nutrient regulation in the EU and parts of the US and New Zealand.

As more governments look at regulation to manage environmental problems caused by nutrient leaching and runoff, it is important that their policies and regulations are based on sound, locally-based science.
An important aim of the *Greener Pastures* project was to generate scientifically sound data which would ensure that regulation, if thought necessary, would be appropriate for the soils, rainfall pattern and pasture systems found in the south west of Western Australia.

Farmers in other regions should satisfy themselves that policies and regulations proposed for their industries are likewise based on locally valid data.

From an environmental perspective, all grazing industries are being increasingly challenged to manage intensive pasture systems that meet the expectations of a community that is increasingly sensitive to environmental issues.

The grazing animal complicates things

The rapid and perhaps extreme increase in N use (up to 3 kg/ha/day of applied N) on Australian dairy farms since 1990 was based on the assumption that more N equates to more pasture, which results in more milk, and consequently more profit. While plant growth responses to N are well documented and relatively easy to predict, the introduction of the grazing animal makes the assumption that more N leads to greater profitability much less predictable. Other grazing industries are adopting common dairy practices—controlled/rotational grazing as a means of making better use of home grown feed—as beef and sheep producers start to use fertiliser N to grow more grass.

The grazing animal is a very inefficient user of the N it harvests from plant material. Ruminants typically excrete 70-80% of their total N intake in urine and dung. Urine patches in dairy pasture contain N concentrations of up to 1,000 kg/ha,
greatly exceeding the uptake capacity of pasture plants. Surplus N which escapes use by plants can be not just a major cost to livestock farmers but also an environmental hazard.

N balances for intensive irrigated dairy farms indicate unproductive surpluses can reach over 650 kg/ha/year (worth more than $800 /ha/year). Reducing this surplus through reduced fertiliser input or techniques that allow better use by plants or animals represents an opportunity for both productivity and sustainability improvements.

Preliminary investigations of shallow groundwater between 2003 and 2005 during the Vasse Milk Farmlet grazing systems project found extreme concentrations of N beneath high intensity dairy systems (Staines et al, 2007). This raised serious concerns about the fate of this N—would it end up contaminating deeper aquifers and the environment?

These concerns, and the obvious potential to increase N use efficiency, led to the development of the Greener Pastures project, to see if reducing this surplus through reduced fertiliser input or techniques that allow better use by plants or animals, could improve both productivity and sustainability.

The main issues

The natural resource management activities of the Greener Pastures project focussed on three main issues:

- N budget — how much applied N is productively used in the farming system and how much is surplus or eventually ‘lost’ from the system.
- The fate of the surplus N in our soils—does increasing N use increase the risk of either waterway pollution or deep groundwater resource pollution.
- How N is lost from our grazing systems—leaching through the soil, surface runoff or lost as gas to the atmosphere.
What is a typical N budget?

At Vasse Research Centre (VRC), five independent dairy farmlet herds (five rates of N ranging from 0 to 2 kg/ha/day) were continuously monitored for pasture and milk solids production, as well as nutrient leaching and runoff. In addition, two large ‘innovation’ herds (Dryland and Irrigation Innovation Farms) were monitored, as were two different grazing intensity beef farmlets on VRC. Similar data was also available from the Vasse Milk Farmlet project which was carried out at VRC between 2000 and 2004. The Department of Agriculture and Food, WA (DAFWA) publication “The Greener Pastures Project: Managing Nutrients in Dairy Pastures” describes the research and extension methods of the Greener Pastures project in more detail.

By calculating and adding up all of the N and P contained in imports to the farm—fertiliser, forage and supplements—and subtracting that contained in exports—milk, sold forage and stock—we can determine the N and P ‘surplus’.

An example annual N budget for the five N Response Farmlets (NRF1 to NRF5) and the Irrigation Innovation Farm (IIF) in 2007 shows large surpluses and poor N use efficiency (less than 20%) under high rates of N fertiliser application.
Table 1. Annual N budget for the dryland Nitrogen Response Farmlets (NRF) and the Irrigation Innovation Farm (IIF) in 2007.

<table>
<thead>
<tr>
<th>Source (kg/ha/yr)</th>
<th>NRF1</th>
<th>NRF2</th>
<th>NRF3</th>
<th>NRF4</th>
<th>NRF5</th>
<th>IIF</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>IMPORT</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fertiliser</td>
<td>0</td>
<td>100</td>
<td>210</td>
<td>304</td>
<td>403</td>
<td>503</td>
</tr>
<tr>
<td>N fixation</td>
<td>63</td>
<td>32</td>
<td>25</td>
<td>39</td>
<td>23</td>
<td>85</td>
</tr>
<tr>
<td>Concentrate</td>
<td>66</td>
<td>78</td>
<td>86</td>
<td>101</td>
<td>110</td>
<td>149</td>
</tr>
<tr>
<td>Net forage import</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>9</td>
<td>11</td>
<td>46</td>
</tr>
<tr>
<td>New livestock</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>11</td>
</tr>
<tr>
<td><strong>Import total</strong></td>
<td>134</td>
<td>217</td>
<td>326</td>
<td>460</td>
<td>555</td>
<td>793</td>
</tr>
<tr>
<td><strong>EXPORT</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Milk</td>
<td>51</td>
<td>59</td>
<td>67</td>
<td>77</td>
<td>80</td>
<td>130</td>
</tr>
<tr>
<td>Net forage export</td>
<td>9</td>
<td>0</td>
<td>20</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Livestock sold</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>13</td>
</tr>
<tr>
<td><strong>Export total</strong></td>
<td>66</td>
<td>65</td>
<td>94</td>
<td>85</td>
<td>89</td>
<td>142</td>
</tr>
<tr>
<td><strong>SURPLUS (Import - Export)</strong></td>
<td>68</td>
<td>152</td>
<td>232</td>
<td>375</td>
<td>466</td>
<td>650</td>
</tr>
<tr>
<td>N use efficiency (%)</td>
<td>49</td>
<td>30</td>
<td>29</td>
<td>19</td>
<td>16</td>
<td>18</td>
</tr>
</tbody>
</table>
When we do this calculation on a per-hectare basis for a wide range of N inputs, such as from the different *Greener Pastures* N-Farmlets, Innovation Farms, beef farmlets and Vasse Milk Farmlets, we find a statistically very significant relationship between imported and surplus N (Figure 1).

This relationship shows that, across a wide range of N imports, 75% of this N is not turned into a farm product. This is often termed the N ‘surplus’, somewhat of a misnomer because ‘surplus’ usually implies a good thing, such as a build-up that can be used later. This ‘N surplus’ should more accurately be termed ‘lost N’ as, apart from some medium-term small changes in soil N storage, it is actually completely lost from the productive farm system.

Ongoing research aims to refine the input-to-surplus relationships at low levels of N and P import, such as for beef cattle grazing, as it is likely that they will become non-linear at low import levels.

DAFWA publication Managing Nitrogen in Dairy Pastures contains more details about the efficiency of N conversion to pasture dry matter and milk solids. Full and detailed N and P budgets for all seasons/farmlets are still being calculated, so the nutrient budget information presented in this bulletin is still considered to be interim.
Figure 1. The relationship between N imports and N exports shows the N surplus (or loss) to be 75% across a wide range of inputs.

\[ N \text{ surplus} = 75\% \text{ of } N \text{ input} \]
\[ (R^2 = 0.974) \]
Where does the nitrogen go?

Most of the N applied to growing pasture as fertiliser is taken up by plants and—unless fertiliser is applied to waterlogged soils when water is moving over the soil surface—probably very little is lost from the system at this point in time. The problems start when the pasture is grazed by animals which are inherently very inefficient at using the N in their feed. Up to 80% of the N they ingest is excreted in urine and dung and it is this N which potentially causes most of the problems.

Nitrogen not exported from the farm in product can potentially move in a number of directions. It can:

- leach past the generally shallow plant root-zone into the surficial (or shallowest) aquifer
- leach into deep ‘useful’ aquifers (drinking and other water supplies)
- be lost as surface runoff
- be lost to the atmosphere as nitrogen gas, ammonia or nitrous oxide gas

The importance of each of these potential loss pathways will vary with soil type, degree of waterlogging, rainfall and time of year.

Figure 2. Potential N loss pathways in typical south west Australia dairy areas.
Nutrient leaching into surficial aquifers

N and P leaching into the surficial aquifer were measured over four years in a series of 160 shallow bores installed within the *Greener Pastures* farmlets at VRC. These bores, around 1-2 m deep, covered the full range of N fertiliser rates, from nil to 2 kg/ha/day, and included the centre-pivot irrigation paddocks. The layout of the bores is shown in Figure 3. The bores were monitored monthly over four years for depth to watertable and concentration of N and P compounds in the groundwater.

Figure 3. Design of the bore system used to measure N and P in shallow ground water beneath the N farmlets on Vasse Research Centre.
What did we find?

The monitoring found that the amount of N lost by shallow leaching was proportionate to the amount of N applied. This is because increased N fertiliser allows more cows/ha which in turn means more urine and more N lost. There is a statistically significant relationship between the N input of the dairy farming system and the mean annual concentration of N lost into the surficial aquifer (Figure 4).

Figure 4. The relationship between annual N input and the mean annual total nitrogen (TN) concentration of the surficial aquifer beneath the dryland dairy and beef systems.
By regularly measuring the volume (‘thickness’) of the surficial aquifer as well as the concentration of N within it, it is also possible to estimate the amount of N contained in the surficial aquifer—and therefore N lost to the pasture system.

Figure 5 shows how the amount of N lost into the surficial aquifer varies with N applied and how it varies throughout each growing season.
When these measurements were related to the N surplus, it was found that

- At N fertiliser rates up to 0.5 kg/ha/day, leaching losses are similar to those where no N fertiliser is applied.
- At rates above 0.5 kg/ha/day, annual leaching losses are large at around 78% of additional N applied and are directly proportional to the additional application rate.
- These represent large economic losses—for example, in some years up to $1000/ha worth of N lies beyond the reach of the pasture system in the surficial aquifer at an application rate of 2 kg N/ha/day (NRF5).
- The data suggests that there is scope to reduce leaching losses—and improve the efficiency of N use—by varying the application rates and, perhaps, the timing of application following grazing—during the growing season, however this requires further analysis of the data.

The results also indicate that a ‘breakthrough’ response occurs at rates above 0.5-1 kg/ha/day, which also corresponds to the optimum levels in terms of N budget efficiency and pasture productivity. Grazing management may also play a significant role here, as described in DAFWA publications Managing Nitrogen in Dairy Pastures and Grazing Management of Dairy Pastures.

**What about phosphorus?**

Levels of soluble reactive P (SRP) in the surficial aquifer were below the limit of detection (< 0.01 mg/L) in 86% of all samples analysed (412 in total) from the farmlets and the dryland and irrigation innovation farms during 2006-2008. Furthermore, 98% of samples recorded SRP levels below 0.1 mg/L. The low levels were recorded despite the area having an extended history of high fertiliser P application.
The farmlet paddocks had a mean Phosphorus Retention Index (PRI) of 32 and a mean Phosphorus Buffer Index (PBI) of 69 in 2007, indicating only a moderate capacity to adsorb P. However, the low levels of soluble P detected in the surficial aquifer indicate that the total P retention capacity of the profile is large enough to have sorbed (retained) most of the P applied and leached. The profile would need to become ‘saturated’ with P before any soluble P can be detected in the groundwater and this has clearly not yet been reached.

This is likely to be the typical situation for most ‘dairy’ soils, as they tend to be the ‘better’ soil types, having moderate to high P retention capacity.

This does not mean, however, that there is no risk of P leaching in the future as, in the long-term, excessive rates of P will ultimately lead to a leaching ‘breakthrough’ level of P in the soil that can no longer be sorbed. For this reason, despite the results which indicate low vertical P leaching, application should be based on pasture requirement (as described in DAFWA publication Managing Phosphorus in Dairy Pastures) with consideration also given to paddock-scale P budgets.

**Nutrient leaching into deeper aquifers**

Both the potential for vertical movement of groundwater and the actual movement of nutrients from the surficial aquifer into underlying aquifers were the focus of a major study in 2006/2007 (Bennett et al., 2007).

Two scales of research were undertaken in this study.

At the Greener Pastures research site at VRC, leakage below the surficial aquifer into the
deeper aquifers was determined to be negligible using a number of hydrological techniques. The principal reason for the lack of deep leaching was determined as being the presence of extremely low hydraulic conductivity clay sediments (or other hydrogeological discontinuities) within the upper 30 m of the profile. This means that there is negligible drainage of water from the shallow surficial aquifer into deeper aquifers.

In 2006, a much more extensive examination was also undertaken across the main dairy areas from Pinjarra to the Scott River.

Two hundred and fifty existing deep bores installed into the main aquifers under a range of land uses at 130 sites were chosen for the study. These bores had all been sampled for salinity and major nutrients in 1991, allowing a comparison over time to be undertaken. The 1991 study proposed that agricultural land use was affecting groundwater quality in some areas—mainly the Southern Swan Coastal Plain and the Scott Coastal Plain—through an increase in N compounds, mainly where fertiliser use was heavy and the watertable was shallow (Hirschberg and Appleyard, 1996). However, it reported that P levels were low and that nitrate levels were insignificant. The location of the bore sites is shown in Figure 6.
Figure 6. Groundwater study area showing bore sites sampled in 2006.
In the 2006 study, 130 shallow bores were installed near the existing deep bore sites so that the top of the watertable—which is most likely to be influenced by broad-scale agricultural activities—could also be sampled. These shallow bores were installed on-farm in areas/land uses that were most likely to be impacting on the existing, deeper bores. They were installed as close as practical, usually within 10 m—but up to 100 m in a few cases where there were accessibility problems—of the existing sites. Installation depth was to a maximum of 2 m, or to the depth of any major change in soil texture. This was mostly a boundary between sand and clayey-textured soils but sand/iron-organic hardpan and sand/massive laterite boundaries were also encountered.

Sampling of 385 bores in total occurred between August and September 2006, with all samples analysed by the Chemistry Centre of WA. We looked for a relationship between the nutrient concentration—and other factors such as pH and electrical conductivity—and a range of factors including sample depth, soil profile, aquifer type, land use, soil type, landform and time. Analysis of groundwater from various depth intervals indicated no agriculture-related N or P contamination of water supply aquifers under dairy areas.

Results are summarised in Figure 7 which shows the mean nitrate-N and SRP concentrations found in the main aquifers beneath the southern Perth Basin. Only the concentrations of N and P found within the surficial aquifer are considered to be related to human activity, with all other deeper aquifers (Superficial, Yoganup and Leederville, in order of increasing depth) exhibiting very low levels, with no apparent agriculture-related influence on nutrient concentration.
Figure 7. Mean nitrate-N and soluble P concentrations in bores screened adjacent to the main aquifer types (see text for detail).
No nutrient leaching into deeper aquifers

In summary, the study found that N and P do not progress through deeper soil layers into aquifers, which is in contrast to the situation in countries such as New Zealand and The Netherlands. There are a number of reasons for this:

• There is poor vertical connectivity between the surficial and deeper aquifers.

• There are only small downward (or sometimes even upward) groundwater potentials over much of the area.

• Most recharge to the aquifers beneath the coastal plain is derived from the largely forested Blackwood Plateau and along the Darling Scarp.

• There is a high probability of P-fixing material within the Superficial aquifer.

• The groundwater conditions greatly favour gaseous losses following denitrification.

• The groundwater in the Superficial and deeper aquifers is ancient.

This data, together with analysis of published hydrological data, land capability mapping and a soil map unit database, allowed a spatial risk of leaching analysis to be developed for the soil units of the southern Perth Basin. This analysis also showed that discharge of groundwater from the surficial aquifer to surface streams, drains and ecosystems in dairy areas is a very minor component and has low environmental risk. This matrix is reported in Table 2, with Figure 8 showing the location of the landscape units.

The study also concluded that there had been no change in any groundwater factors since the 1991 sampling, in either the superficial or deeper aquifers, but that intensification in land use does increase the risk of (particularly N) enrichment of the surficial aquifer.
<table>
<thead>
<tr>
<th>Soil-Landscape System</th>
<th>Watertable*</th>
<th>Local discharge**</th>
<th>Deep aquifers***</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abba Plain#</td>
<td>M</td>
<td>H</td>
<td>L</td>
</tr>
<tr>
<td>Bassendean Dune</td>
<td>H</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>Bassendean Flat#</td>
<td>H</td>
<td>H</td>
<td>L</td>
</tr>
<tr>
<td>D’Entrecasteaux</td>
<td>M</td>
<td>H</td>
<td>M</td>
</tr>
<tr>
<td>Forrestfield</td>
<td>M</td>
<td>H</td>
<td>M</td>
</tr>
<tr>
<td>Ludlow Plain</td>
<td>M</td>
<td>H</td>
<td>L</td>
</tr>
<tr>
<td>Nillup Plain#</td>
<td>L</td>
<td>H</td>
<td>L</td>
</tr>
<tr>
<td>Pinjarra Plain#</td>
<td>L</td>
<td>M</td>
<td>L</td>
</tr>
<tr>
<td>Quindalup Dune</td>
<td>M</td>
<td>H</td>
<td>M</td>
</tr>
<tr>
<td>Scott River#</td>
<td>M</td>
<td>H</td>
<td>L</td>
</tr>
<tr>
<td>Spearwood Dune</td>
<td>M</td>
<td>H</td>
<td>M</td>
</tr>
<tr>
<td>Treeton Hills</td>
<td>L</td>
<td>H</td>
<td>L</td>
</tr>
<tr>
<td>Vasse</td>
<td>M</td>
<td>M</td>
<td>L</td>
</tr>
<tr>
<td>Whiccher Scarp</td>
<td>L</td>
<td>H</td>
<td>L</td>
</tr>
<tr>
<td>Yelverton Shelf</td>
<td>L</td>
<td>H</td>
<td>L</td>
</tr>
</tbody>
</table>

Table 2. Risk matrix for shallow leaching, lateral discharge and deep leaching of N and P derived from intensive broadscale agriculture for the main soil-landscape systems south of Pinjarra.

# main dairy farming soil types
* upper (<1.5m) layer of surficial aquifer
** discharge of surficial aquifer to watercourses
*** substantial Superficial and Leederville aquifers
Figure 8. Major soil-landscape systems of the Southern Perth Basin.
Nutrients lost in surface runoff

N and P losses in surface run-off have been measured intensively at the paddock and farm scale on VRC and more widely for the Vasse River catchment.

Research at the farm and paddock scale allowed investigation of nutrient run-off processes and responses to intensification and management changes. Samples were collected automatically at six sites on VRC over a period of six years. In all, 2,800 runoff water samples were collected and analysed.

Nitrogen

At the paddock scale, although analysis of data is continuing to accurately define the N and P budgets for all years, the available data indicates that there is a robust relationship between N surplus (or N input) and N lost in runoff. The relationship suggests that only about 2.5% of the N surplus is lost as runoff across a wide range of N inputs (Figure 9). This represents a small amount in farming terms, yet the concentrations in this runoff are still environmentally significant. About 70% of the N in run-off was in an organic form, indicating that it had been through a productive agricultural ‘cycle’. This indicates that N runoff is a symptom of productive agriculture, rather than a direct response to applying more N fertiliser per se. It follows then that the most productively efficient N fertiliser application rate and timing—in terms of the N level where production per unit of N is maximised—will also be the most environmentally effective in terms of least environmental harm per unit of production.
Figure 9. Relationship between annual total N load in surface runoff and annual total N surplus for paddocks of differing N input intensity.

\[ y = 0.0233x + 3.8 \]
\[ (R^2 = 0.736) \]
Phosphorus

For P, annual median total P concentrations and P loads in runoff were highly variable but always high in terms of environmental thresholds, and were poorly correlated to annual P surplus. Annual median total P concentration and load in runoff were also poorly correlated to paddock soil P concentration and soil PBI. However, annual P runoff load was better correlated with annual runoff volume. There was no relationship between total P concentration and annual runoff volume.

The relationship between annual P load and runoff, in the absence of the other relationships, may indicate that soil P release mechanisms are quite tightly controlled and perhaps based on a gradient between the concentration in the soil and the water moving across its surface. The flat landscape and the observation that the runoff moves slowly in sheets, after the soil becomes waterlogged, are also consistent with this hypothesis.

This implies that the P status of the surface ‘crust’—in combination with the timing and intensity of runoff generation—may be a very important determinant of the amount of P runoff. If this is the case, topdressing of P through the growing season is likely to exacerbate P run-off, especially if the P soil test is above the critical level for that soil.

Around 60% of the P in run-off is an insoluble form and we suspect that much of this may also be organic. The P form is difficult to determine using current methods, yet is crucial to our understanding of loss mechanisms—and therefore management approaches—so further work on this aspect is warranted.

This work to date suggests that, at the paddock scale, significant N and P run-off will be unavoidable in productive agriculture.
Catchment modelling

The N and P runoff response relationships at the farm scale are particularly important to know when looking at the catchment scale impacts of dairying and other agricultural industries. Various ‘catchment models’ are being used to do this. These models generally do not have a reliable farm or paddock scale basis but rely on larger-scale generalisations to achieve apparent calibration at the end of catchment scale—and can (as is the case in the Vasse catchment) greatly over-represent the proportion of N runoff at the farm or paddock scale.

These models are being used to develop policy and targets, guide funding and propose intervention at the farm or paddock scale.

What is clearly needed are catchment models that have the capacity to incorporate farming system scale responses based on models that have an accurate underlying production focus, as well as an environmental focus. Without this, catchment models will continue to have limited direct relevance to farming systems. The production information, together with the runoff response information collected, can provide the required information to develop better farming system models. The onus is on catchment managers to take up the challenge to make their models and policies relevant to farming systems.

Loss of N as gas

It is clear that the large farm-gate N surpluses cannot be accounted for by leaching and/or surface runoff. While there may be a change in soil storage of N, it is our assumption that most of the unaccounted N is lost in the gaseous form. Some is lost as ammonia over summer, while it is likely that N may also be lost through denitrification in waterlogged soil over winter. This process generates innocuous nitrogen gas and/or the powerful greenhouse gas nitrous oxide, depending on the degree and extent of waterlogging.
The N isotope study

At VRC, Fillery (2009) tracked N applied to pasture in urine and fertiliser using the stable N isotope $^{15}$N. This study found that about 50% of the $^{15}$N applied in urine was lost within 14 days when applied in January and February and about 23% when applied in early April. Less than 1% of the urine N was converted to nitrate—the process of nitrification—within 14 days, suggesting that the N was lost through ammonia volatilisation.

Nitrification remained at low rates up to early May, with only about 2% of applied urine N present in soil as nitrate ahead of winter rainfall.

As the growing season progressed, losses of $^{15}$N from pastures receiving urine (equivalent of 500 kg N/ha) continued, amounting to 53% of N applied in urine in August and 27% applied in September.

For fertiliser applied $^{15}$N (as Urea) up to 40% of N applied in August and around 23% of N applied in September could not be accounted for in pasture and soil sampled in October.

In a related study, Fillery (2009) used direct measurements of ammonia gas loss from grazed pastures. This indicated that the loss of N via ammonia gas was dependent on climatic conditions. While loss was low during periods of frequent rainfall, up to 45% of the N deposited in urine was rapidly lost as ammonia gas at other times.

These studies show that gaseous loss can account for much of the surplus N, with loss as ammonia gas in summer and autumn but nitrogen or nitrous oxide gases being the more dominant mechanism during winter and spring.

While this work clearly indicates that a large proportion of the surplus N is lost as gas emissions, further work is required to better define denitrification losses, particularly in respect to their impact on greenhouse gas emissions.
Summary and application to other dairy areas in Australia

While much of this work is focussed on the south west Australian dairy areas, some important lessons are applicable to other dairy regions in southern Australia.

Shallow leaching loss rates can be very high in high-N input systems. However, unlike some other much publicised areas of the world, deep drainage of N into important aquifers does not occur. Instead, much of this loss is likely to end up as N gas emission. As such, the aquatic environmental risk of high N use systems is much lower than previously expected locally, but they represent serious inefficiencies in farming terms. The collection of robust hydrological leaching and runoff information locally has allowed a more reasoned analysis of the environmental risks of intensive dairying in the region. A similar approach is recommended for farmers elsewhere in Australia.

References and further information


Fillery IRP (2009) Observations on key nitrogen transformations that affect N use efficiency in Western Australian dairy pastures. Report to Dairy Australia, CSIRO, Perth


Acknowledgements

Numerous people have contributed to the Greener Pastures study between 2003 and 2011.

The project would not have been possible without the support, contributions and dedication from the entire team: John Baker, Don Bennett, Mike Bolland, Graham Blincow, Tess Casson, Len Chinnery, John Crosby, Patrick Donnelly, Hamish Downs, Ian Fillery, Kevin Gardiner, Gordon Gibbon, Ian Guthridge, ‘Tex’ Hahn, Peter Jelinek, Kathy Lawson, Andrew Lindsay, John Lucey, Corrine Mack, Nola Mercer, John Milligan, Richard Morris, Peter Needs, Leonarda Paszkudzka-Baizert, Bill Russell, Dennis Russell, Greg Sawyer, Neroli Smith, Martin Staines, Frank Treasure, Judy Wills and David Windsor.

We are grateful for the guidance and support by Michael Blake, Laurie Cransberg, Grant Evans, Peter Evans, Dale Hanks, Brynley Jenkins, David Kemp, Ben Letchford, Ian McGregor, Miles Mottershead, Ian Noakes, Peter Oates, Paul Omodei, Ralph Papalia and Victor Rodwell.

We also thank our interstate colleagues for their support and guidance: Roger Barlow, David Chapman, Tom Cowan, Anne Crawford, Tom Davidson, Richard Eckard, Warren Mason and Mark Paine.

We acknowledge funding and support of this project by the Department of Agriculture and Food WA, Dairy Australia and Western Dairy. Additional funding and/or contributions in kind, were provided by the Chemistry Centre (WA), CSIRO Plant Industry, South West Catchments Council and Land and Water Australia.