NITROGEN AND PHOSPHORUS BALANCES AND EFFICIENCIES ON CONTRASTING DAIRY FARMS IN AUSTRALIA

Cameron J P Gourley[1], Sharon R Aarons[1], Warwick J Dougherty[2], and David M Weaver[3]

[1]Future Farming Systems Research Division, Ellinbank Centre, Department of Primary Industries, Ellinbank, Victoria 3821 AUSTRALIA
[2]NSW Department of Industry and Innovation, Richmond, NSW, 2753 AUSTRALIA
[3]Centre for Ecohydrology, Department of Agriculture and Food, Albany, Western Australia 6330 AUSTRALIA
E-mail: cameron.gourley@dpi.vic.gov.au

Abstract

Nitrogen (N) and phosphorus (P) imports, exports and within-farm flows were measured during a standardised production year on 41 contrasting Australian dairy farms, representing a broad range of geographic locations, productivity, herd and farm size, reliance on irrigation, and soil types. The amount of N and P imported varied markedly, with feed and fertiliser generally the most significant contributors and principally determined by stocking rate and type of imported feed. Whole-farm N surplus ranged from 47 to 600 kg N/ha/year and was strongly ($P < 0.01$) and linearly related to the level of milk production. Whole-farm N use efficiency ranged from 14 to 50%, with a median of 26%. Whole-farm P surplus ranged from -7 to + 133 kg P/ha/year, with a median of 28 kg/ha. Phosphorus use efficiencies ranged from 6 to 158%, with a median of 35%. The poor relationship between P fertiliser inputs and milk production from home-grown pasture and crops reflected the high soil P levels measured on these farms.

The N and P intakes of each dairy herd, the locations the cows visited and the time they spent there, were also determined during five visits throughout the year. As N and P intakes increased so did excreted N and P, with use efficiencies generally less than 20%. On average 432 g N and 61 g P were excreted by each lactating dairy cow/day. Overall, cows spent a small proportion of their time in the milking parlour (2%) and yards (9%) where dung and urine were generally collected; however, greater time was spent on feedpads (11%) and holding areas (26%) where manure was not routinely collected. The largest amounts of excreted N and P were deposited by cows in grazed paddocks but particularly those closest to the milking parlour.

Key opportunities to improve N and P use efficiency within grazed dairy systems include reducing unnecessary nutrient intake; improved spatial and temporal movement of animals within dairy farms to reduce heterogeneous N and P deposition; increasing the capture, storage and redistribution of excreted N and P in non-productive areas, and more strategic fertiliser and effluent applications.

1. Introduction

Australia is the third largest milk exporter after Europe and New Zealand and is one of the most cost efficient milk producers on a per litre basis (Martin and Puangsumahe 2004). Along with most other dairy producing countries, the Australian dairy industry continues to undergo significant change. The number of dairy farms has declined over the last 30 years, from over 22,000 in 1980 to around 8,000 in 2010. Over the same period, average farm herd size has increased from 77 cows in 1980 to 258 in 2010 whilst average annual milk production per cow has increased from 2,750 to 5,500 L. A key driver of increased per cow productivity has been the increase in supplementary feeding (Doyle and Fulkerson 2001; ABARE 2006) and increasing forage yields and quality due to fertiliser use, particularly N (Eckard et al., 2004).

While nitrogen (N) and phosphorus (P) inputs are required for most dairy operations, when used in excess they can significantly degrade air (N) and water quality (P & N). Total N and P inputs onto dairy farms, mainly in the forms of feed, fertiliser and N fixation by legumes, are usually much greater than the outputs of P and N in milk, animals, and crops (Satter 2001; VandeHaar and St-Pierre 2006). These surpluses tend to increase as farms intensify and stocking rates increase (Halberg et al., 2005a).

Excess P on dairy farms can result in increasing soil P levels beyond agronomic requirements (Gourley 2005; Weaver and Reed, 1998; Mekken et al., 2006), which may also increase the concentration of dissolved P in surface runoff (Sharpley 1995), and leachate (Fortune et al., 2005). Unlike P, N is not significantly buffered by soils, and where N is applied in high concentrations such as in dung, urine or fertiliser, losses through volatilization and leaching can be high (Rotz et al., 2005).

The changing nature of Australian dairy operations, the increasing societal pressure on the farming community to reduce nutrient losses to water and air, and the need to provide evidence that farm practises are meeting environmental standards, justifies the need for the development and implementation of a nutrient budgeting approach to improve nutrient management practices on Australian dairy farms. Nutrient budgeting may assist farmers to meet production goals and identify opportunities for improvements in nutrient use efficiencies, decrease nutrient surplus and accumulation on dairy farms and reduce the risk of off-farm nutrient losses.

The objective of this paper is to report on the results from a detailed nutrient accounting study which quantified N and P flows and transformations on a diverse array of dairy farms across Australia, and discuss opportunities to improve nutrient management at the animal, paddock, and farm scale.

2. Methods

2.1 Characteristics of participating dairy farms

The selected 44 dairy farms involved in this study represented the range of farm sizes, regions locations, livestock densities and manure recycling capacities typical of the Australian dairy industry (Figure 1). Herd size across the farms ranged from 51 to 1263 cows, with an average of 296. The major breed of dairy cattle was Holstein-Friesian, with a smaller number of cross-bred herds, Jersey, Illawara and Australian Reds herd. All dairy farms imported had effluent management systems; 16 farms used feed pads, and 19 used sacrifice paddocks for feeding. All dairy farms used fertiliser, 8 used organic fertilisers, and 40 used inorganic fertilisers. All but three dairy farms milked twice a day, two milked once a day, and the remaining farm milked three times per day. Fifteen of the dairy farms had different feeding strategies for different milking groups. Only 12 of the 44 dairy farms did not use irrigation as a means of increasing pasture or crop production. The proportional area irrigated on each dairy farm ranged from 0 to 95% of the contact area, with a mean value of 34%. The reliance on imported feed ranged from 3 to 66%, with an overall mean of 35%.

Digital mapping of the farms involved aerial photographs and schematics of current farm layouts to generate farm maps for collecting information about paddock boundaries, fence lines, watering points, housing and infrastructure, irrigation systems, utilised and non-utilised areas (i.e. bush, riparian, etc), and other landscape features. Data interpretation included area of individual paddocks, total milking area, laneways and total lengths, and distances walked to each paddock from the dairy. Overall, the average total land, dairy-farm land and contact land areas were 336, 235, 194 ha, respectively, but varied widely, ranging from 67 - 1046, 47 - 612, and 40 - 460 ha, respectively.

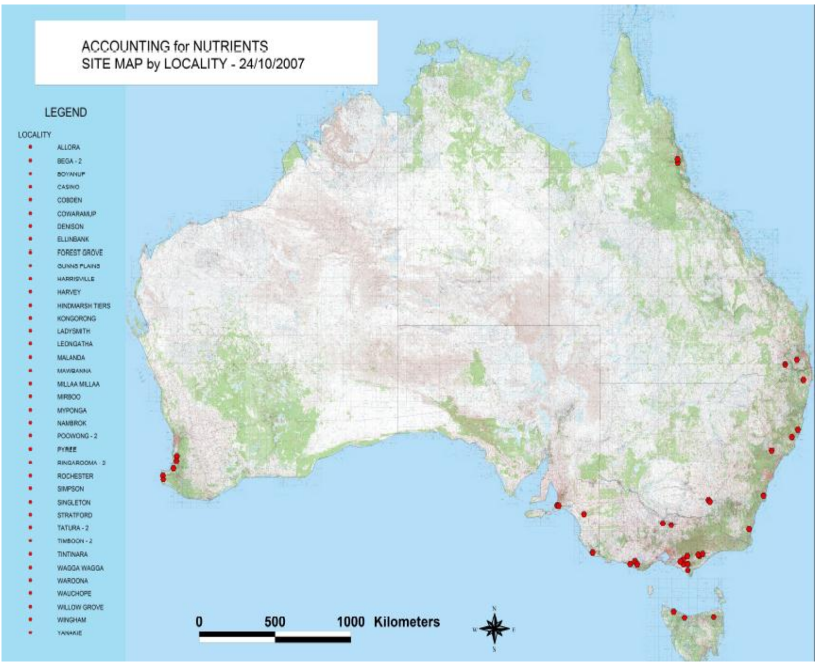

Figure 1. Location of the 44 selected dairy farms participating in the A4N study.

2.2 Farm visits and data collection

An 'on-farm' protocol was developed to provide a comprehensive set of instructions for collecting data from the participating 44 dairy farms. Customised diaries were provided to all farmers at the commencement of the monitoring period to allow them to record farm activities. Standard questionnaires are also during the quarterly farm visits. Detail about sample handling, storage and shipping, are all outlined in the project documentation, available online from the A4N website www.accounting4nutrients.com.au.

The on-farm data collection period ensured a 12 month assessment of nutrient impost and outputs between February 2008 and February 2009. Eight quarterly farm visits during the study included December 2007, February 2008 (beginning of monitoring), May, August, November 2008 and February (2009). A July 2009 farm visit collected any identified information gaps and verifies the compiled data for each farm. A final farm visit (December 2009), was used to provide a comprehensive one-on-one feedback session, including the provision of collated farm-based information.

During quarterly farm visits, information and samples were collected and verified, including herd number and structure, pasture-cropping areas, paddock and infrastructure layouts, feeding practices and milk production, purchases, stores of feed and fertiliser, current feed components, milk and manure samples, and collated farmer diary information. Comprehensive data sets were collected from a total of 41 dairy farms.

The 'Pasture Consumption Calculator' (Pasture calculator) (Heard and Wales, 2009) was modified in conjunction with the developers to enable calculation of pasture consumed by the lactating herds on the day of each quarterly visit. The calculated pasture intakes, in conjunction with supplement nutrients consumed were used to calculate the nutrient excretion rates (grams of nutrients excreted/cow/day) by dairy herds on all farms.

All participating dairy farms were extensively soil sampled to determine the soil fertility levels of individual paddocks and other selected areas. This involved collecting samples from all paddocks used for pasture and crop production as well as areas where stock are confined (sacrifice paddocks, feeding areas, sick paddocks), but not laneways or areas where manure is collected. Collected soil was analysed for pH (in $CaCl_2$ and water), Olsen and Colwell P and K, phosphorus buffering index, KCl_{40} S, organic carbon, and extractable cations (ammonium acetate).

3. Results

3.1 Key sources of nutrient exports and imports

Milk shipped off farm was clearly the major source of nutrients exported, making up more than 90% of the total annual N and P exports. The N and P exports of nutrients in animals was generally small, and although large-scale periodic animal exports do occur, the net exports in animal nutrients relates to removal of culled cows and calves, unless a significant change in the farm system is implemented. The export of nutrients in stockpiled manure or dairy effluent has the potential to remove significant amounts of nutrients but no participating farm shipped off any manure during the study period. Similarly, harvested and exported forages can also result in the net removal of significant amounts of nutrients, particularly N and K, though this occurred infrequently, with almost all harvested forage being consumed by animals within the same home-farm area.

Imported N and P, contained in a variety of products, varied widely between farms. In general, the single largest source of N imported on to dairy farms was inorganic fertiliser, either as a NPKS blends or urea. Imported grain or grain-based concentrates was also an important source of N, while hay, silage and by-products also all contributed very similar N imports on one farm or another. On some farms, particularly those with limited or no N fertiliser applications, N fixation by legumes was a major contribution. In particular cases, poultry manure, and municipal waste water also contribute a significant amount of nitrogen. The most common source of imported P was inorganic fertilisers and alternative fertiliser products, such as rock phosphate and poultry manure. Imported feed was also an important contributor to total P imports, especially grains and grain-based concentrates and specific by-products with relatively high P concentrations.

3.2 Nutrient balances and use-efficiencies on Australian dairy farms

The whole-farm nutrient balances determined for each participating dairy farm provide specific information relating to the various nutrient imports and exports, the potential surplus or deficit of N and P and a measure of the relative conversion of imported nutrients into exported products. As such, they integrate farm-scale information into productivity and environmental performance indicators (Oenema et al., 2003).

It is important to note that the study was designed to describe nutrient flows and transformations across the breadth of the Australian dairy industry and enable the comparison of contrasting Australian dairy systems. We therefore used a stratified-random process to select the participating dairy farms, and not a random sampling approach. Nevertheless, the large number of farms included in this study, the recognition of key farm characteristics, and the diversity of systems selected have provided an industry-wide assessment of current nutrient status and environmental challenges at a range of scales. This is demonstrated by the similar range of dairy farm characteristics and the description of the median farm in this study and those describing the Australian dairy industry as a whole (Dairy 2010 Situation & Outlook - Annual Report 2010, http://www.dairyaustralia.com.au/Situation-and-Outlook).

Overall, nutrient imports onto dairy farms in Australia are generally much higher than those exported in products. Whole-farm nitrogen surplus determined in this study ranged from 47 to 600 kg N/ha (Figure 2) and nitrogen use efficiency ranged from 14 to 50%. While these ranges in N surplus/ha and N use efficiency appear broad, they reflect the varying levels of intensity and inputs present in both Australian and international dairy production systems.

For example, a recent study in Western European titled ‘Green dairy’ involving 130 commercial dairy systems also found a similar range in N surplus/ha, with average regional N surpluses between 93 and 502 kg N/ha and nitrogen use efficiencies ranging between 19 and 40% (Raison et al., 2006). Similar ranges in N surpluses and N use efficiencies have been measured in more regionally focused studies in the USA (Rotz et al., 2006; Histov et al., 2006), The Netherlands (van der Meer, 2001), New Zealand (Ledgard et al., 2004) and in Western Australia (Ovens et al., 2008).

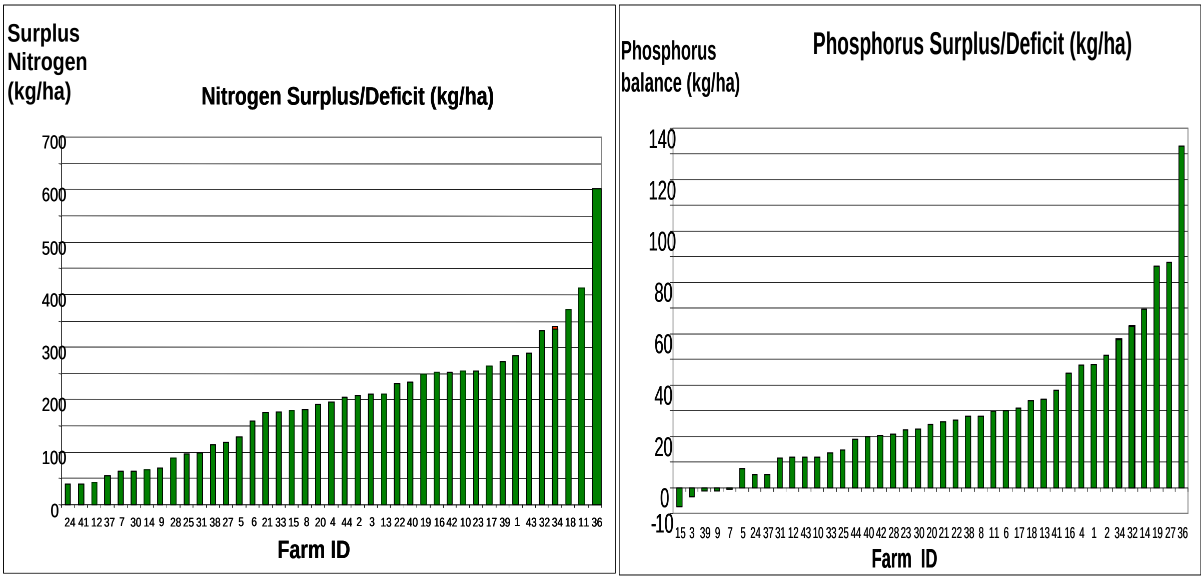

Figure 2. Whole-farm n and P balances (kg P/ha) for 41 participating dairy farms.

Whole-farm **phosphorus** surplus across the 41 independent dairy farms ranged from -7 to + 133 kg P/ha. Five of the 41 farms were in net P deficit, while 8 farms had high P surpluses of > 50 kg P/ha (Figure 2). Interestingly, 3 of the high P surplus farms were ‘organic’, with high P surpluses reflecting a relatively low P export and high P import, primarily in the form of rock phosphate. The overall phosphorus use efficiencies across the 41 dairy farms ranged from 6 to 158%. When the five high P surplus farms were excluded, the range of P surpluses determined in this study were again similar to the 4 - 36 kg P/ha range determined within the Green Dairy project (Raison et al., 2006).

It is clear from these balances that P inputs are very different between farms. Negative P balance farms have greater exports of P than imports (in any form), and are subsequently 'mining' P from the system, presumably the soil. This approach appears to be warranted in some systems where existing soil test levels were above recommended thresholds of adequacy (Gourley et al., 2006), and existing nutrient reserves can be utilised without affecting potential production. However, other farms were also continuing to mine P, but the low soil P reserves were likely to be limiting potential pasture production and therefore milk production. In contrast, most farms had a net P surplus.

3.3 Within-farm nutrient transformations

3.3.1 N and P excretion by dairy cows

Supplementation of pasture-based diets by farmers aiming to increase milk production results in greater dietary crude protein and phosphorus intake. However, as N and P intakes increased, so did excretion of these nutrients, associated with reduced efficiency of use of N and P to produce milk. On average, around 20% of intake N and 25% of P was excreted in milk (Table 1). On some farms N and P intake efficiency was >35%, although these high efficiencies usually occurred only once for each farm. The ranges (minimum to maximum) in N and P use efficiency by these Australian dairy herds are comparable to that cited internationally. Feed N use efficiencies less than 20% is considered to be low, while 30 to 35% is considered above average (Chase 2003).

Table 1. Nutrient use efficiency calculated for herds on 43 farms at 5 visits

	Efficiency of nutrient utilisation (%)					
	N	P	K	S	Ca	Mg
Mean	20.8	25.0	8.8	16.2	23.3	4.3
Median	20.5	24.3	8.3	14.9	21.0	4.1
Minimum	10.5	10.7	2.1	3.0	0.0	1.0
Maximum	35.1	48.5	19.7	47.9	75.5	8.7
s.e.m.[§]	0.28	0.43	0.22	0.48	0.73	0.08

[§]s.e.m. standard error of the mean

Almost half a kilogram of N was excreted daily by each cow, about 7 times that of P (Table 2). Therefore, for an average herd size of 250 cows over a 300-day lactation, 32.4 and 4.6 t of N and P are excreted around a dairy farm.

Table 2. Daily nutrient excretion by lactating cows on 43 farms at 5 visits

	Excreted nutrients (g/cow.day)					
	N	P	K	S	Ca	Mg
Mean	432.3	61.1	339.6	43.8	91.3	52.4
Median	430.9	59.4	329.4	42.1	88.2	49.9
Minimum	199.0	19.9	120.2	18.5	9.6	20.8
Maximum	792.0	131.6	670.8	101.7	210.3	274.2
s.e.m.[§]	7.39	1.39	6.90	0.88	2.69	1.39

[§]s.e.m. standard error of the mean

3.3.2 Cow movement on dairy farms

The locations lactating dairy herds visited over a 24 hour period (paddocks, dairy shed, yards, laneway feed pad, and holding area) and the time the animals spent there were recorded on all farms on each of the 5 quarterly visits (Figure 3), with forty-three farmers providing adequate data for analysis. Cows spent most of their time in paddocks (73.7%) which was significantly greater than time spent elsewhere on dairy farms. Cows spent the least amount of time in dairy sheds with significantly increasing amounts of time spent in feed pads, holding areas, laneways and yards. Cows only spent a mean of 1.7 and 8.6 % of their time in dairy sheds and yards, respectively, where excreted nutrients are routinely collected. The mean time in feed pads (3.9%) and holding areas (6.1%) was low when averaged over all farms, as these management units are not present on all farms. Of the 44 farms, twenty had feed pads, eleven identified holding areas, and seven farms had both.

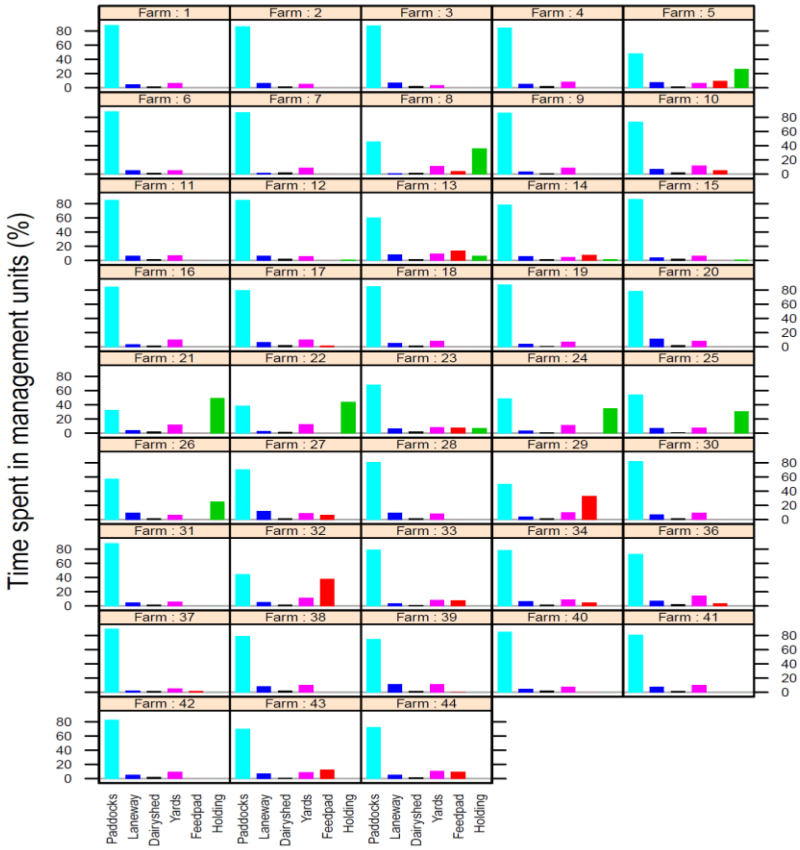

Figure 3. Mean percent time spent by lactating dairy herds in 6 management units (paddocks, laneway, dairy shed, yards, feed pad, holding area) on 43 dairy farms.

3.3.3 Nutrient deposition and loading rates

The calculated nutrient excretion rates for the lactating herds on each farm at each survey visit were combined with farm-specific spatial and temporal cow movement data to determine nutrient deposition loads (kg/day) to locations around dairy farms.

Nitrogen excreted in the yards was significantly greater than that in the dairy shed, feed pads, holding areas, and laneways. Consequently, nutrients deposited in yards need to be managed carefully as, based on project data, some farmers only wash their yards once daily despite collecting excreta deposited in the dairy shed at each milking. Nitrogen excreted in yards is particularly susceptible to volatilisation losses, and could constitute a large contribution to greenhouse gases based on the nutrient loads returned by dairy cows in this location. International research suggests the potential for large losses of gaseous nitrogen from concreted yards and other areas where animal are held for long periods (Kohn et. al., 1997).

Although smaller mean nitrogen loads were deposited in feed pads and holding areas, when only those farms with these management units were analysed, the mean depositions were 10.3 and 26.5 kg/day respectively. Like yards, gaseous nitrogen losses from concreted feed pads can be large. For feed pads that are not concreted, as well as holding areas, excreta are very infrequently collected, and nutrients such as nitrogen pose a potential for gaseous as well as run-off and leaching losses.

Night paddocks received N loading rates on average 1.5 times greater than day paddocks, confirming the role of this management practice in contributing to nutrient re-distribution and accumulation on dairy farms.

Table 3. Mean nitrogen loads (kg/day) deposited by lactating cows in locations on 43 farms at 5 visits

Locations	Mean	Minimum	Maximum	Median	s.e.m.§
Day paddocks	32.3	0.0	220.9	24.9	2.08
Laneway	7.1	0.0	168.3	4.2	0.83
Dairyshed	2.0	0.0	16.2	1.4	0.14
Yards	10.1	0.0	101.0	6.3	0.84
Feedpad	6.3	0.0	102.5	0.0	1.17
Holding area	4.1	0.0	79.6	0.0	0.82
Night paddocks	46.9	0.0	308.4	33.6	2.95

§s.e.m. standard error of the mean

3.3.4 Soil fertility and spatial nutrient distribution on dairy farms

In general, the average soil nutrient levels were found to be well above agronomic requirements on the dairy farms involved in this project (Table 4). For example, the average Olsen P level on pasture paddocks from the 37 conventional dairy farms was 36 mg/kg, well above the standard recommendation of 20 mg/kg. There were also substantial differences in soil fertility levels within and between dairy farms. While organic and conventional dairy farms had similar average pH and available K S levels in pasture soils, the organic dairy farms had substantially lower available P and S levels.

Land use had a substantial impact on the existing soil fertility levels. Areas with high animal densities, such as calving paddocks, feed pads, holding area and sick paddocks, had substantially elevated soil nutrient levels when compared to the overall pasture paddocks (Table 4). In contrast, low intensity areas such as ‘other animal’ and treed areas had much lower fertility levels.

Table 4. Mean soil pH, available P, levels of different land uses from 40 conventional and 4 organic dairy farms.

Management/Use	Distance to dairy (m)	pH (CaCl2)	Olsen P (mg/kg)	Colwell P (mg/kg)
Organic				
Pasture n=141*	625.5	5.4 (0.6)^	16.7 (13.8)	65 (62)
Conventional				
Pasture n=1773	881.4	5.3 (0.7)	35.6 (20)	127 (76)
Bull paddock n=6	444.0	5.3 (0.9)	48.8 (26)	169 (82)
Feeding areas n=12	53.1	6.8 (1.2)	319.9 (285)	1151 (1286)
Holding area n=13	400.4	5.8 (0.9)	143.5 (171)	510 (685)
Sick paddock n=16	46.9	5.6 (0.9)	71.4 (61)	280 (282)
Other animal n=104	na	5.1 (0.6)	27.4 (15)	100 (58)

* n= number of areas sampled   ^ Standard Deviation in parenthesis

4. Discussion

4.1 Relationships between farm characteristics, nutrient use efficiency and balances.

4.1.1 Nitrogen

There is a strong relationship between the total milk production and the total amount of nitrogen imported onto the farm (Figure 4). While recognising the potential associative relationship between other important drivers of milk production such as grain importation, this relationship demonstrates the interdependency of milk productivity and N inputs. The majority of this imported N was in imported feed and fertiliser.

The determined nitrogen surplus was also strongly related to the level of milk production for each farm (Figure 5). As milk production increases per ha, so does the N imported and corresponding N surplus. The slope of this linear relationship (0.0145) provides a national industry estimate of the N surplus (kg) per litre of milk produced. This equates to a net N surplus of 14.5 g of nitrogen per litre of milk produced. A very similar linear relationship was described in the EU Green Dairy project (Raison et. al., 2006) with milk production ranging from 3000 to 50,000 L/ha, N surplus ranging from 70 to 745 kg N/ha and a corresponding slope of 0.0122 (12.2 g N/L).

The 41 dairy farms investigated had contrasting feed production systems with the calculated reliance on imported feed ranging from 3 to 66% of the total dietary metabolisable energy. Interestingly there was no significant relationship between the N surplus/ha and the reliance on imported feed. This may be explained by defining the systems and the potential N use efficiencies, loss pathways and potential for N recycling. For example, it would be expected that a major source of N input on farms with low reliance on imported feed would be from N fertiliser used to drive greater home-grown pasture and crop production. Conversely, farms with high feed N inputs would correspond with more complex feeding systems and animals spending a larger proportion of time on feed pads. Each system would initially specific N loss pathways, i.e. leaching and volatilisation losses from fertiliser N; N volatilization losses in urinary deposition on feed pads and effluent storage. However, as the cow consumes this feed, be it imported or home-grown, the issues associated with N intake, the use efficiency in conversion of feed to milk, the places of manure deposition, and the opportunity for recycling of excreted N, are common, and influenced by 'between farm management variation' rather than a single factor such as reliance on imported feed.

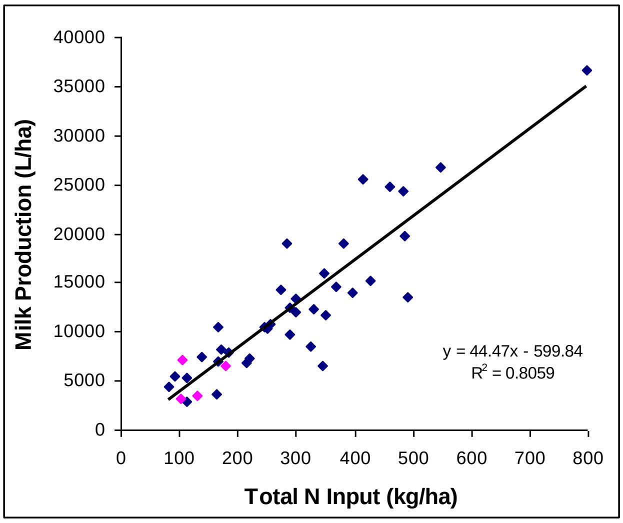

Figure 4. The relationship between total milk production and total nitrogen imports for the 41 participating dairy farms. The 4 organic farms are highlighted.

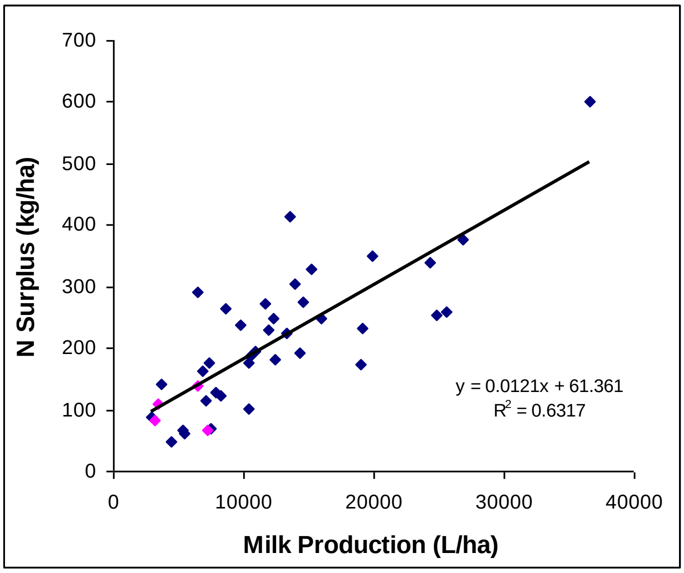

Figure 5. The relationship between total milk production and total nitrogen surplus for the 41 participating dairy farms. The 4 organic farms are highlighted.

Overall, the nitrogen use efficiency determined on the 41 dairy farms ranged from 14 to 50%. Whole-farm nitrogen use efficiency on dairy farms appears to be limited by the biological potential of cows to transform feed N into milk and for pastures and crops to utilise applied fertiliser and recycled nitrogen in manure (Powell et al., 2010). This suggests that within-farm management factors such as the effectiveness of recycling animal excreted nutrients, timing and rate of N fertiliser applications, as well as soil and climatic factors, are more likely to be key drivers of N use efficiency, than prescriptive farm characteristics.

The variability in the N efficiencies determined within this study and internationally, as well as the potential N use efficiencies that have been determined under experimental conditions, suggest that there are substantial opportunities to improve N use, resulting in enhanced productivity and reduced N losses to the broader environment. Figure 6 indicates the major components of N cycling within dairy farms and potential intervention strategies which may impact on N use efficiency. For example, over a six-year period, dairy farms in The Netherlands were able to increase whole-farm N use efficiency (from 15% to 30%) through improved N fertiliser applications and effluent management (Groot et al., 2006). Other successful strategies to improve whole-farm N use efficiency have included feeding more dietary fibre and less crude protein (Kohn et al., 1997), and N losses through ammonia volatilisation (Oenema et al., 2009).

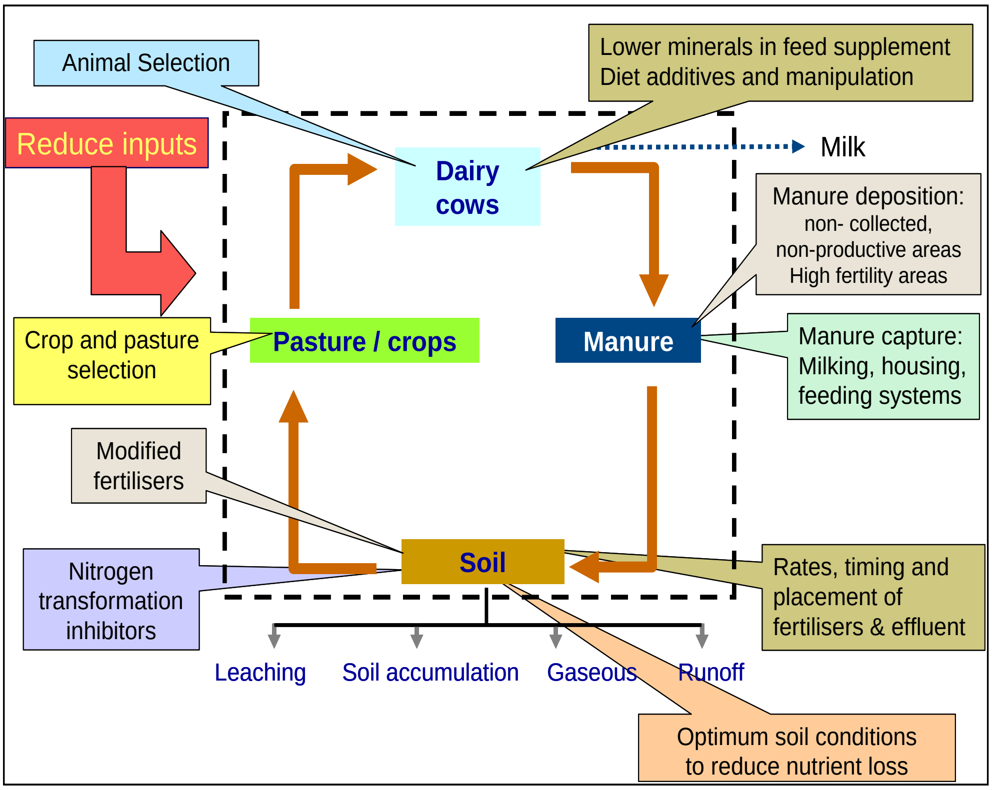

Figure 6. Components of nitrogen cycling within dairy farms and key points of intervention to increase the efficiency of N use

4.1.2 Phosphorus

While whole-farm phosphorus surplus can be impacted significantly by P imported in feeds, notably in by-products, the most common source of imported P was inorganic fertiliser, mainly as highly soluble NPKS blends but also in alternative fertiliser products, such as rock phosphate and poultry manure. In general the farms which did not apply P fertiliser in any form had very low P surpluses (< 10 kg P/ha) or deficits.

Unlike the strong relationship between nitrogen import and milk production, there was a poor correlation between total milk production and total amount of phosphorus imported onto the farm. The wide variation determined between imported P and milk production is well demonstrated at an imported P level of around 50 kg P/ha, where milk production varying between 3000 and 27000 L/ha. Conversely, farms with low milk production per ha, including the 4 organic dairy farms, had varying P imported, ranging between 3 and 93 kg P/ha.

The determined phosphorus surplus was also poorly related to the level of milk production for each farm. While the dairy farmers with the highest milk production had the highest P surplus per ha, the remaining farms had highly variable P surpluses. Of note are three of the low production organic farms, which had P surplus values above 50 kg P/ha. In contrast, farms with milk production around the national average (12,000 - 15,000 L/ha) had P surpluses ranging from -8 to +90 kg P/ha).

Similarly to N fertiliser, the effectiveness of P fertiliser applications was investigated from the relationship between total fertiliser P applied and the 'adjusted' total milk production (Figure 7). In contrast to N fertiliser, however, there was a poor relationship between imported P fertiliser and milk production attributed to home-grown pasture and crops. Of note is the high range in adjusted milk production when P fertiliser inputs were small (< 10 kg P/ha).

The lack of a defined relationship between P imports and productivity is supported by the generally high levels of soil P measured across a broad range of dairy farms. The mean soil level for Colwell P and Olsen P, determined across the conventional dairy farms was 127 and 36 mg/kg respectively, well above the agronomic soil test targets of 45 – 90 mg/kg for Colwell P and 20 mg/kg for Olsen P, recommended for pasture production (Gourley et. al., 2006). Under these high soil P conditions, additional pasture and crop production from the application of P fertiliser would not be expected and therefore neither would an associated increase in milk production from home grown feed. Moreover, the milk production from farms with low or no P imports but with adequate levels of soil P, suggest that these soil P reserves can be utilised without a resulting decline in milk production.

Despite the generally low soil P levels on the organic dairy farms, and the relatively high P surpluses caused by the use of rock phosphate on some of these farms, there did not appear to be a resultant increase in home-grown feed and subsequently in milk production. These results support the low levels of P availability from rock phosphate and the limited pasture (and crop) yield responses that may occur unless soil and climatic conditions favour its use (Bolland et. al, 1988).

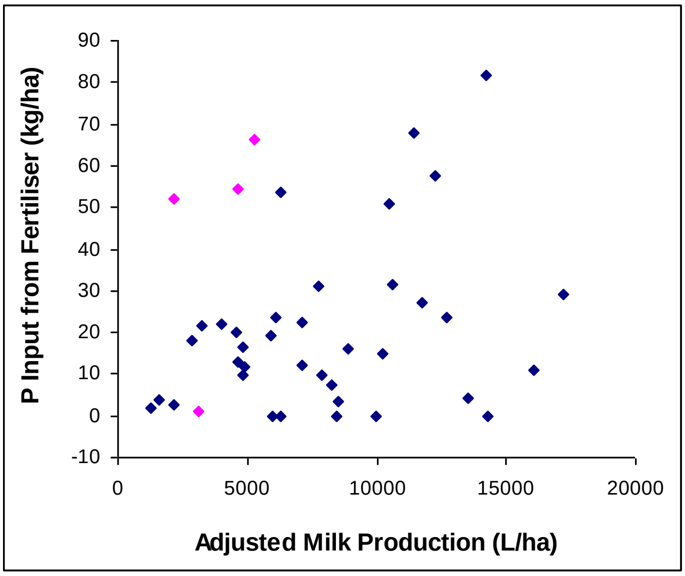

Figure 7. The relationship between adjusted milk production from home-grown feed and total fertiliser P imported for the 41 participating dairy farms. The 4 organic farms are highlighted.

5. Conclusions, implications and opportunities

The intensification of the Australian dairy industry has exacerbated nutrient surplus at the farm scale. This excessive and inefficient use of nutrients, specifically N and P, can significantly degrade air and water quality. Moreover, the dairy industry continues to intensify in the cooler and wetter southern coastal areas which also support important waterways and a rapidly growing urban population. Increasing societal expectations for clean water and air, along with competition for land and water resources is likely to increase the tension between these competing interests.

5.1 Current soil fertility levels on dairy farms

Soil nutrient levels are generally high on Australian dairy farms. The dairy industry is recognised both nationally and internationally as having high levels of nutrient inputs and as a consequence having the potential to accumulate and lose a significant amount of nutrients to the broader environment. If current nutrient management practices persist and dairy farms continue to intensify, soil nutrient levels are likely to further increase with even greater nutrient losses to the broader environment.

More than three quarters of the paddocks sampled had fertility levels above agronomic requirements. At these levels most pastures and crops are very unlikely to produce additional dry matter from fertiliser inputs. An exception to this are specific dairy farm systems, such as organic or biodynamic systems, which are likely to have substantially lower soil phosphorus and sulphur fertility, with pastures and crops potentially responsive to soluble fertiliser inputs. Key indicators of elevated soil fertility are overall milk production, nutrient surplus and stocking rate. These indicators reflect the overall intensity of the dairy operation and the likely higher amounts of nutrients imported in feed and fertiliser.

Within farm nutrient heterogeneity is substantial, irrespective of dairy farm system. Higher soil nutrient levels of P, K and S are driven by paddock stocking density, proximity to the dairy, frequency of effluent applications, and feeding strategies.

High nutrient loading from the deposition of animal excreta is clearly a key driver of elevated soil nutrient levels. Paddocks with high densities of animals per ha can have very high nutrient accumulation while those infrequently visited and with low stock densities will generally have lower soil nutrient levels. These high nutrient areas can also have degraded soil structure and low plant cover, increasing the risk of nutrient losses. An additional negative consequence from high potassium loads, resulting from manure, effluent applications and fertiliser, is high plant K uptake and potential metabolic disorders in livestock.

There are substantial opportunities on dairy farms to reduce or exclude fertiliser inputs. The relatively small costs associated with undertaking a strategic and on-going soil sampling program are likely to be returned many times through the potential savings in unnecessary fertiliser expenditure. In many cases, high levels of soil test P, K and S may supply necessary plant nutrients for a number of years before maintenance nutrient applications may be required.

Where fertiliser applications are warranted for increasing pasture and crop productivity, a more strategic approach should be undertaken. The clear link between spatial distribution of nutrient levels and animal management provides informed guidance on where nutrients are likely to be required.

5.2 Nutrient surpluses and efficiencies

Whole-farm nitrogen surplus is strongly linked to milk production. Whole-farm nitrogen surpluses ranged from 47 to 600 kg N/ha and was strongly related to the level of milk production and the amount of N imported. The overall industry estimate of whole-farm N use efficiency (the proportion of imported N exported in product) was 26%. Based on these findings, an average of 14.5 g of N is lost to the broader environment for each litre of Australian milk produced. This appears to apply irrespective for the intensity of the dairy systems.

Nitrogen losses from Australian dairy farms are comparable to similar systems internationally. While potential N losses appear high, the Australian results are comparable to those measures in other industrialised dairy industries such as New Zealand, the EU and USA. However, two thirds of the farms assessed had annual N surpluses above that acceptable under current European Union compliance standards and this proportion is a likely reflection of the Australian dairy industry as a whole. While no such standards currently exist in Australia, international markets may assign similar standards in the future.

Nutrient use efficiency in dairy production is limited by the biological potential of cows to transform feed nutrients into milk and of crops and pastures to convert applied nutrients into forage and other agronomic products. However, the variability in actual nutrient use efficiencies achieved by dairy producers and the disparity between actual and potential efficiencies determined under experimental conditions indicates that substantial improvements in nutrient use efficiency can be made on many commercial dairy farms.

5.3 Linking nutrient inputs, efficiency and productivity

The link between nitrogen input and milk production is strong. While it is clear that large amounts of nitrogen are imported onto dairy farms, the system does not adequately store available N reserves. It is therefore not surprising that there is a strong correlation between nitrogen inputs and milk production. The correlation may in part be indirectly caused by the link between the energy and nitrogen content of feed, as well as the direct impact of nitrogen in increasing pasture, crop and animal production. The use of nitrogen fertiliser was also strongly related to milk production from home-grown pasture and crops, but on specific farms, the role of N fertiliser was substituted by biological N fixation by legumes.

The link between phosphorus inputs and milk production is weak. Farms that produced greater amount of milk per ha also had increasing levels of imported P. However, this appeared to result from greater importation in feed as well as fertiliser. Unlike nitrogen, there was no definable relationship between P, K and S fertiliser inputs and milk production from home-grown pasture and crops. This is not surprising, given the high soil P, K and S levels and the relative availability and supply capacity that already exist on these dairy farms.

5.4 Productivity gains from increasing nutrient use efficiency.

The range of nutrient use efficiencies on an individual farms indicate that significant increases in efficiency are possible. While general farm characteristics, such as stocking rate, reliance on imported feed, etc, did not directly influence nutrient use efficiency, ‘good management’ rather than fixed farm characteristics are likely to result in greater nutrient use efficiency outcomes.

While decreasing the surplus and increasing the efficiency of P, K and S is likely to result in a cost savings in fertiliser costs, increasing N use efficiency has the potential to significantly increase pasture and crop productivity and milk production, and decrease the amount of purchased feed.

There are some substantial opportunities to improve nutrient cycling; enhancing overall productivity and the proportion of nutrients ending up in product. This has been demonstrated by the quantification of various nutrient pools, fluxes and transformations that occur within Australian dairy farms. Opportunities to improve nutrient cycling and nutrient use efficiency identified within this study include a reduction in dietary nutrient concentrations, increasing the capture, storage and redistribution of excreted nutrients, and more strategic fertiliser and effluent applications.

Simple and effective assessment methods are needed to understand the potential efficiency of N use in our dairy systems and to set realistic goals for improved N efficiencies and N surpluses. A key outcome from this current project has been the blend of scientific and farmer knowledge through collaborative on-farm research. For example, the ‘snap-shot’ assessments of N use during the farm monitoring program have provided important industry-based information which can be used to determine benchmark N use efficiency values. However, further work is needed to better understand how and why on-farm management decisions impact actual N use efficiencies, and to quantify the actual productivity gains from capturing more N in productivity drivers. This information could then be used to develop and apply recommendations that have a high probability of being implemented on dairy farms.

Acknowledgements
The Accounting for Nutrients project has relied extensively on the considerable and broad-ranging efforts of a large number of people and organisations across Australia. We would like to acknowledge the significant financial contributions from Dairy Australia, Incitec-Pivot, Megafert, Impact, Murray Goulburn, Bega Cheese, and a range of State departments.

The A4N project team would also like to acknowledge specialist technical input from the Science leadership team, including Sharon Aarons, Andrew Smith, David Weaver, Nigel Fleming, Richard Eckard, Ian Fillery, and Mark Powell. We also thank Richard Habgood for his significant input into evaluation and communication activities. The relational data base was designed and constructed by Jenny Smith. Data entry and quality assurance was managed by Ivor Awty. The detailed interpretation of project information would not have been possible without the efforts of the project biometrician, Murray Hannah.

We would particularly like to thank the 44 farmers who participated in this project. Their time and effort in collecting and providing farm information was essential to achieve successful project outcomes.

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