Estimating nitrogen excretion and deposition in Australian grazing dairy systems for improved nutrient management

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Abstract
Current nutrient management approaches in Australian dairy systems largely target the application of fertiliser nutrients. However, increasing animal densities and greater reliance on purchased feeds means that nutrient inputs in feeds have increased. Consequently, the role of grazing animals in nutrient flows and deposition needs to be accounted for in dairy industry nutrient management plans. However, quantifying nutrient intakes and therefore nutrient excretion is difficult, due to challenges in estimating pasture dry matter intake by grazing cattle. To quantify N fluxes through grazing dairy cows we modified an animal performance method for estimating annual dry matter intake to calculate daily N intake and excretion. Using the excretion data, we estimated N loading rates to specific locations visited by the lactating herds within the dairy farms. The results indicated that these herds received a mean of 52% of their energy requirements from supplementary feeds despite the grazing base of the dairy systems. Calculated annual N flows through the lactating herds were 60% of total N inputs onto these farms. Mean N intakes (545 g/cow/day) were well in excess of recommended levels resulting in excretion on average of 433 g N /cow/day in these systems. The resulting deposition of excreted N to pasture paddocks was not uniform, with 30% more N returned to paddocks that were generally closer to the dairyshed. The smallest mean annual load of excreted N was deposited in the dairyshed and yards. However, this N load is typically applied as effluent to paddocks closest to the dairyshed which further exacerbates N accumulation and potential losses in these parts of dairy farms. These results demonstrate that quantifying excreta N loads and spatial nutrient distribution by grazing dairy cows is required for improved N management in grazing system dairy farms.
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Key Words
Metabolisable energy, animal performance, excreta, manure, nutrient recycling, spatial nutrient distribution

Introduction

High N use in agriculture has been linked to atmospheric losses and contamination of ground and surface water systems (Erisman *et al.* 2013). Nitrogen fertiliser use for pasture and fodder production, as well as the importation of a range of purchased feeds has increased on Australian dairy farms over the recent past (Stott and Gourley 2016). The potential for losses of N in these grazing based livestock production systems has therefore increased and is further exacerbated by the excretion and deposition of excess N by dairy cows around farms (Castillo *et al.* 2000). Nitrogen loads deposited on grazing system dairy farms will be influenced by the locations where cows spend time and their duration in those places (Aarons *et al.* 2016). Therefore, accounting for nutrients excreted by cows is required to improve N management on dairy farms.

Current nutrient management approaches for Australian dairy systems largely target the application of fertiliser nutrients with little quantification of the role of the grazing animal in within-farm nutrient flows (Dairy Australia 2016). By contrast, improved nutrient management approaches elsewhere have emphasised quantifying N excretion using strong predictive relationships identified between intake and excretion (for example, Kebreab *et al.* 2001; Nennich *et al.* 2005). Estimating nutrient intakes in grazing systems is more problematic however, due to difficulties in measuring grazed fodder consumption, particularly in commercial settings. Of the number of approaches trialled for calculating fodder intake, the animal metabolic performance method proved the best suited to use on commercial farms (Hellwing *et al.* 2015).

The objective of this research was to quantify N flows using an animal performance method for estimating lactating dairy cow N intake and N excreta and to estimate the spatial distribution of N excreted by these cows, for a broad range of commercial Australian grazing system farms.

Methods

Estimating N intake and excretion on commercial dairy farms

The 'Feed Standards' approach for estimating annual dry matter intake by dairy herds in Australian grazing systems (Heard *et al.* 2011) was modified to calculate daily dry matter and nutrient intake on 43 commercial dairy farms, representative of the range of production systems across all regions nationally (Gourley *et al.* 2012). The input data (i.e. lactating herd size, liveweight, stage and number of lactations, milk production, amount of supplements provided, terrain traversed) were determined from five quarterly interviews with the farmers on each farm over a year. The total metabolisable energy (ME) requirements for the herd 'average lactating cow' was calculated using milk production, maintenance, pregnancy, grazing and activity energy requirements. The ME supplied in supplements was subtracted from the total energy requirements to give the ME gained from pasture. Using N content and ME analytical data, pasture dry matter intake (DMI) as well as total N intake (supplements and pasture) was calculated. Daily N excretion (g/cow/day) was calculated by subtracting from the daily N intake the N produced in milk that day by the lactating herd.

Nitrogen deposition over a lactation on grazing system dairy farms

Nitrogen deposition by lactating herds was estimated by identifying the locations the herds visited (as reported by Aarons *et al.* 2016) and apportioning daily and annual N loads (kg) based the length of time (as a proportion of 24 hours) the animals spent there. These areas included grazed paddocks, feeding pads, laneways, holding areas, the yards and the dairyshed where the cows were milked. Annual N loads were estimated by weighting the five calculated daily N excretion rates for each quarter and standardising to a 305 day lactation.

Nitrogen imports and exports

Annual N inputs and exports were calculated as described by Gourley et al. (2012). Farm data were collected during the interviews that described all supplement (fodder, concentrates etc), animal, irrigation and fertiliser imports as well as milk and livestock exports. Nitrogen inputs from fixation were assessed using the clover contents of pastures with atmospheric N inputs based on distance from the coast.

Sample collection and analysis

Samples of all feeds and pasture, as well as bulk tank milk were collected on the day of each interview, immediately placed on ice and promptly returned to the laboratory. Pasture and fodder samples were collected from paddocks representative of the cows' diet on the day of the interview. Samples of supplements fed were collected from all sources; including hay, silage and concentrates. Samples of bulk tank milk, representative of all milkings for the day and collected after the vat contents were thoroughly agitated, were stored frozen until analysis. Pasture and feed samples were sub-sampled for dry matter estimation (dried 105^{o}C for 48 hours) and for chemical analysis (dried 65^{o}C and ground <2mm). All samples were analysed at Westons Laboratories for N concentration (method LTM168) and metabolisable energy (method LTM193).

Results

The mean daily ME expended on maintenance (55 MJ), pregnancy (9 MJ), milk production (125 MJ) and walking (9 MJ) was supplied by a variety of grazed pasture and a range of supplementary feeds (Rugoho *et al.* in press). Despite the importance of grazing pasture in these systems, the herds received on average 52% (median=51%) of their energy requirements from supplements across the five interview dates (Table 1).

Table 1. Summary statistics for daily estimated pasture DMI and N intake calculated using metabolisable energy requirement data collected on 43 commercial dairy farms across five separate assessment periods.

	Metabolisable energy[a]			Dry matter intake		Pasture N
	Required	Supplement	Pasture	Supplement	Pasture[d]	intake
	MJ/cow/day	MJ/kg DM/cow/day	MJ/cow/day	kg/cow/day	kg/cow/day	g/cow/day
Minimum	116	13	0.4	1.05	0.04	1.2
Mean	195	104	98	9.17	9	336
Median	194	97	97	8.64	9	320
Maximum	289	251	236	25.35	22	787
SD	33.4	52.2	45.4	4.91	4.7	165.9

[a]Metabolisable energy required by the lactating cow and supplied by either supplement or pasture

Calculated pasture DMI intakes were highly concordant (Lin's concordance correlation = 0.6582, C_b = 0.9935) with farmer estimates of pasture allocations indicating that the methodology used represented pasture offered to the herds on these farms. The range (maximum – minimum) of total N intake by these herds was 1.3 times that for 90 experiments analysed by Castillo et al. (2000). The mean N intake in these grazing systems was greater than the recommended level of 400 g/cow/day, above which there is likely to be an exponential increase in urinary compared with faecal N output. Consequently, N excretion was high with lower associated feed N use efficiencies (Table 2) than had been previously reported (Powell *et al.* 2010).

Table 2. Summary statistics for N intake, milk N secretion, N excretion and N use efficiencies (NUE) for commercial grazing system dairy farms across five separate assessment periods, as well as annual excreted N loads and N imports.

	Intake	Secretion	Excretion	NUE	Excreted N load	Total N imports
		g/cow/day		%	(t/year/farm)	
Minimum	268	48	199	11	6.8	8.8
Mean	545	112	433	21	34.4	55.1
Median	543	110	429	21	24.3	37.4
Maximum	983	190	793	39	154.9	245.2
SD	129.4	29.0	110.3	4.3	29.6	49.0

The amount of N excreted over the lactation was 60% of total N imports (i.e. feeds, fertiliser, livestock, N fixation, irrigation water), indicating the importance of N deposited by lactating cattle on these farms. As expected, N deposition was greatest in grazed paddocks where the animals spent most time (data not presented). However, deposition of nutrients to paddocks varied dependent on farmer herd management. Paddocks where the lactating herd were placed overnight had greater loads deposited over the lactation and were on average 142 m closer to the dairyshed than paddocks primarily grazed during the day (Figure 1A). Feedpads and holding areas (located within 100 m of the dairyshed) received similar N loads to that collected in the dairyshed and yards. However, only excreta deposited in the latter were always collected as effluent for re-use (Aarons et al. 2016).

Nitrogen applied as fertiliser was less than annual excreted N loading rates to night paddocks but was similar for day paddocks (Figure 1B). As fertiliser N was typically applied uniformly to all paddocks these data indicate that, on average, paddocks visited overnight received at least twice the rate of N from cow excreta that farmers applied in fertiliser. Moreover, the applications to night paddocks of fertiliser and directly deposited N do not include the N applied in effluent collected from the dairyshed and yards, which is usually applied to these same paddocks.

Despite the loads of N returned by grazing dairy cows around these dairy farms, whole-farm N balances and within-farm flows are not currently estimated in industry nutrient management tools, as these tools are primarily used for estimation of P, K and S fertiliser rates in conjunction with soil test data (Dairy Australia 2016). Only N applied in fertiliser and in effluent is calculated in the industry recommended nutrient budget tool. The data from these grazing system farms indicate the importance of excreted N and the role of herd management in the potential for accumulation of N in parts of these farms.

Conclusion

Current nutrient management approaches recommended for the dairy industry account for nutrients imported onto and exported from farms but do not adequately quantify nutrient re-distribution within farms. The method demonstrated in this study enables the quantification of N loads and distribution by lactating herds around grazing system dairy farms. These data indicate the need to account for spatial variability in N deposition on these grazing system dairy farms as part on improved nutrient management programs. By using dietary and lactation information readily sourced on commercial dairy farms, excreted N can be calculated and apportioned within farms to ensure that N loads are appropriately matched to agronomic requirements, fertiliser N applications are more strategic and N losses minimised. Further research to estimate N excretion by dry cows, heifers and calves will add to calculations of N deposition on farms. In addition, estimation of urinary N excretion is warranted as the high N intakes in these grazing systems are likely to lead to excretion of excess protein in urine.

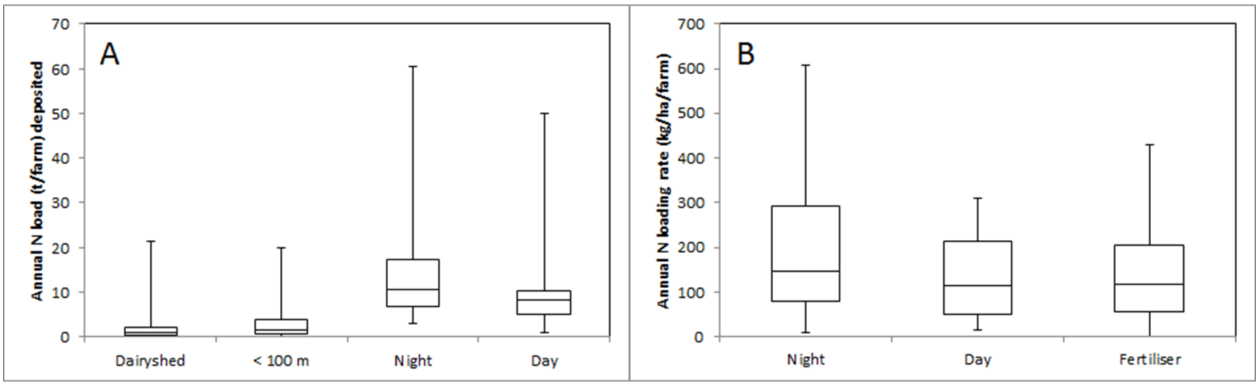

Figure 1. Boxplots of A) annual farm N loads (t/farm) deposited at the dairyshed and yards, within 100 m of the dairyshed and yards, and in paddocks grazed overnight (Night) or during the day (Day), and B) N loading rate (kg/ha) excreted in Night and Day paddocks by the lactating herds over a 305 day lactation as well as fertiliser N applied on 42 grazing system dairy farms.

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