Nitrogen footprint of Taupo Beef produced in a nitrogen-constrained lake catchment and marketed for a price premium based on low environmental impact

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Abstract
Farms in the Lake Taupo catchment of New Zealand have a farm-specific nitrogen (N) leaching limit per hectare. A beef cattle finishing farm in the catchment was used as a case study to compare optimised scenarios with and without N constraints and with flexible supply to meat processing companies or a requirement for regular supply to restaurants based on a premium price for beef with a low N footprint. Scenario analyses included evaluation of sourcing surplus young beef cattle from breeding farms or from dairy farms. A life cycle assessment method was used to estimate all reactive N emissions through the life cycle of beef. Leaching of N from the finishing farm was <20 kg N/ha/year from N-constrained scenarios and 43 kg N/ha/year with no N constraint. Profitability decreased with N constraints and with regular beef supply requirements, which could be countered by a price premium. The N footprint from beef production ranged from 95 to 156 g N/kg meat, being least from the N-constrained scenarios. It was lower from dairy-derived beef and higher with regular beef supply requirements. The farm stage dominated the life-cycle N footprint (78% of total emissions) with the only other significant contributor being the final waste (sewage) stage at 21% of the total, based on a traditional urban waste water treatment system. Preliminary analysis indicated that the Taupo town sewage system of land application to pasture for silage production and feeding back to cattle can further decrease the N footprint over the life cycle of beef.

Key Words
Nitrogen footprint, beef, nitrogen constraints, price premium, life cycle assessment

Introduction
Nitrogen (N) input to surface waterways can lead to undesirable plant and algal growth. Lake Taupo is the largest lake in New Zealand and research has shown that while it is currently a pristine lake with very high visibility, there is a very slow decline in water quality associated with increased N inputs and increased growth of phytoplankton (Vant and Huser 2000). Local government regulations are currently in place (since 2011) that have set a maximum farm-specific N leaching value for farms within the catchment. Thus, a farm must manage its farm system and N inputs so that it's N leaching remains at or below the farm's N leaching limit or 'cap' (set according to farm system practices in 2001-2005). The N leaching is calculated using a nationally-accepted and validated model (OVERSEER® nutrient budgets model, hereafter called OVERSEER; Wheeler et al. 2003, 2007).

In practice, these regulations mean that farmers are greatly restricted in their farming options for increasing production in the catchment. One enterprising farmer group have set up a company (Taupo Beef) that produces, processes and markets beef from a low environmental impact system and charge a price premium for the beef in local restaurants and national retail outlets (Taupo Beef 2016).

This project evaluated the implications of the farm constraints by assessing the effects of a range of beef production scenarios on N leaching at the farm level and on the N footprint throughout the value chain. This included sourcing beef animals from dairy farms instead of traditional beef systems. The economic implications of a price premium were evaluated in relation to the farm costs of meeting N leaching limits relative to non-N-constrained farm options.

Methods
The case-study farm system in the Lake Taupo catchment was based on a real cattle finishing farm (120 ha flat-rolling grassland) that purchases yearling beef cattle and sells them prime at about 2-years-old. It has long-term pastures of perennial grasses and white clover on a coarse-textured pumice soil under relatively high rainfall (c.1300 mm/year) and is prone to significant N leaching.

A life cycle assessment (LCA) method was used to evaluate a supply chain based on the finishing farm, which purchased yearling cattle from either a traditional beef farm or a dairy farm. Four finishing farm scenarios were assessed. Three scenarios were optimised for profitability based on the farm remaining within the N leaching cap (< 20 kg N/ha/year); 1. a base farm with traditional flexible beef supply, 2. a farm with a 25 cents/kg beef (carcass weight) premium and flexible beef supply, and 3. a farm with a 25 cents/kg premium and a system requiring steady supply of beef to meet retail requirements. Scenario 4 was based on no N leaching constraints, optimised for profitability (e.g. permitting higher production through the use of N fertiliser to increase pasture growth) and with traditional flexible supply of finished beef cattle to processors.

A life cycle scenario analysis assessed the fate of the 'waste N' after consumption of the beef via a traditional urban sewage system or via land application of sewage and use of the nutrients for pasture silage production on farms. The latter was based on the actual sewage processing system used by the Taupo town.

Analyses covered farm production and economics (using the INFORM farm systems model; Rendel et al. 2013), N leaching from the breeding and finishing farms (using OVERSEER), and LCA-based N footprint and carbon footprint assessment. Profit was calculated as earnings before interest, taxes, depreciation and amortisation (EBITDA). Nitrogen footprint calculations accounted for the loss of all reactive N forms including leached N (dominated by nitrate), ammonia and nitrous oxide (calculated using the NZ GHG Inventory method), and other nitrogen oxides (e.g. from fossil fuel use). The LCA, modelled using SimaPro (version 8.1.0.6), accounted for all direct N emissions from the breeding and finishing farms, and all indirect N emissions including those from production, transport and use of farm inputs including N fertilisers (i.e. cradle-to-farm-gate; using Ecoinvent database version 3.1, modified using NZ-specific data). It also included estimation of all N emissions from meat processing, transport, consumption and waste stages of the life cycle, based on consumption in a restaurant in the Taupo town. The waste stage refers to meat-N excreted into the sewage system after meat consumption (based on Muñoz et al. 2008) and assumed to be processed using a municipal waste water treatment system and N fate factors from the NZ waste water inventory (Hauber 1995) and IPCC (2006), with most emissions as N to water from secondary-treated waste water.

Results

Calculated N leaching per hectare from the finishing farm was 18-19 kg N/ha/year in the N-constrained scenarios and 43 kg N/ha/year for the non-N-constrained base scenario, respectively. Profitability (EBITDA) decreased by 32% for the Base farm in the N-constrained scenario compared to the corresponding unconstrained scenario (Table 1). A premium of 25c/kg carcass weight on the N-constrained farm brought the profit back up to that for the unconstrained base farm. However, profit was much lower when that same farm had to manage a system that required a regular supply of finished cattle to meet the required retail supply (i.e. $457/ha for scenario 3 compared to $738/ha for scenario 2).

Table 1. Description of some farm characteristics for four scenarios for a 120 ha finishing farm in the Lake Taupo catchment with an N leaching constraint or no N constraint, optimised for profitability. Yearling beef cattle were purchased for the finishing farm from either a traditional beef breeding farm or a dairy farm (surplus dairy calves reared off-farm and raised to yearlings on a breeding farm system).

	Constrained N leaching			
	1	**2**	**3**	**4**
	Base	Base + Premium	Base + Premium +Supply	Base (no N constraint)
Finishing farm only:				
Fertiliser N (kg N/ha/yr)	0	0	0	160
t live-weight brought-in	147.3	147.2	232.5	122.8
t live-weight sold	241.5	241.2	302.5	227.3
t net live-weight sold	94.2	94.0	70.0	104.5
Profit ($/ha/yr)	$488	$738	$457	$725
Finishing + Breeding farm:				
Breeding farm area needed (ha)	276	276	461	223
Finishing +Dairy-derived Breeding farm:				
Breeding farm area needed (ha)	148	149	302	105
Dairy farm area needed (ha)[1]	18	18	23	17

[1] Area for production of milk powder used for rearing calves from 4-days-old to weaning

The amount of live-weight (LW) sold from the finishing farm was lower under the N-constrained scenarios within the same conditions than the non-N-constrained scenarios (Table 1). While this was associated with lower N leaching from the N-constrained farm, it resulted in a greater land requirement for production of yearling cattle from the breeding farm. Overall, the land requirement was lower for the more intensive non-N-constrained scenarios.

The losses of reactive N were mainly from N leaching (predominantly nitrate) and ammonia emissions, which were of a similar magnitude (Table 2). For the finishing farm, the N footprint was least for scenario 3, but when the breeding farm component was included there was little difference between all N-constrained scenarios. However, the N footprint per kg LW sold was up to two-fold higher for the non-N-constrained scenario. The N footprint for scenarios where beef was derived from dairy farms was 7-12% lower for the N-constrained scenarios compared to that for beef from traditional breeding farm and was 5% lower for the non-N-constrained scenario.

Table 2. N footprint (i.e. reactive N loss from leaching, ammonia, N_2O and NOx emissions) for four scenarios for a 120 ha finishing farm in the Lake Taupo catchment with an N leaching constraint or no N constraint, optimised for profitability. Yearling beef cattle were purchased for the finishing farm from either a traditional beef breeding farm or a dairy farm (surplus dairy calves reared off-farm and raised to yearlings on a breeding farm system).

	Constrained N leaching			
	1	**2**	**3**	**4**
	Base	Base + Premium	Base + Premium +Supply	Base (no N constraint)
Finishing farm only:				
N leached (g N/kg LW sold)	9.48	9.49	7.17	18.72
Ammonia (g N/kg LW sold)	9.32	9.41	7.75	22.79
N_2O (g N/kg LW sold)	0.84	0.84	0.70	1.87
NOx (g N/kg LW sold)	0.18	0.18	0.14	0.38
N Footprint (g N/kg LW sold)	**19.82**	**19.92**	**15.76**	**43.76**
Finishing + Breeding farm:				
N Footprint (g N/kg LW sold)	**42.10**	**42.08**	**43.49**	**62.36**
Finishing +Dairy-derived Breeding farm:				
N Footprint (g N/kg LW sold)	**39.09**	**38.92**	**37.95**	**59.10**

Application of LCA methods (cradle-to-farm-gate; LEAP 2015) to determine the carbon footprint of LW sold (covering the finishing farm + breeding farm stages) resulted in estimates of 7.3, 7.4, 8.6 and 7.8 kg CO_2-equivalents per kg LW sold for scenarios 1-4, respectively. This illustrates the greater inefficiency and higher carbon footprint for scenario 3 based on regular supply for retail and lowest carbon footprint for the other N-constrained scenarios. However, relative differences between scenarios were not as large as for the N footprint.

The whole life cycle N footprint was calculated using LCA data from all farm stages and from NZ meat processing plants, transportation and consumption of meat (Lieffering et al. 2012), as well as estimates for N emissions from waste (i.e. sewage) from consumed meat. For the N-constrained Premium+Supply scenario the relative contribution from the various life cycle stages was 37% for the breeding farm, 41% for the finishing farm, <1% for meat processing, <1% for transport and consumption (including cooking) stages, and 21% for the waste stage. The latter was based on a generic urban waste water treatment plant.

Discussion and Conclusions

N-constrained farm scenarios resulted in N leaching of <20 kg N/ha/year and aligned to current case farm practices. However, they showed lower profitability compared to that for the non-N-constrained scenario. Beef from the farm is marketed under a low environmental impact brand (Taupo Beef 2016) and receives a price premium. However, the requirement for regular supply of beef to meet retail needs mean that a more complex system with greater purchases and sales of cattle is required. This was associated with a further reduction in profitability compared to that from the traditional farm systems with flexible cattle sales that matched pasture growth patterns and market returns.

The N-constrained scenarios operated with a low N footprint due to a year-round grazing system with no N fertiliser use or annual crops. The lowest N footprint was equivalent to 95-98 g N/kg meat (from dairy-derived calves) and increased to 156 g N/kg meat (non-N-constrained beef originating from breeding cows). This was much lower than the N footprint reported for European beef farm systems at about 700 g N/kg meat (Leip et al. 2014) and, apart from methodological differences, the difference can be attributed to the European cattle systems using N fertiliser, annual crops, and cattle housing systems. These housing systems require manure collection and application, which result in much larger ammonia emissions compared to that for excreta deposited directly onto soil in the grazing systems (e.g. Misselbrook et al. 2000).

The farm stage dominated the life cycle N footprint (>80% of total emissions) with the only other significant contributor being the final waste (sewage) stage at 21% of the total, based on a traditional urban waste water treatment system. Taupo Beef is sold in restaurants in the town of Taupo and sewage from the Taupo town is processed by land application to pasture that is subsequently harvested (after analysis to confirm absence of pathogens) and made into silage. The silage is then used by farms in the area as a feed source. Preliminary analysis of the fate of N from this system and substitution for the fertiliser value from the sewage, indicates that this can substantially decrease the N footprint contribution from the waste (sewage) stage. Thus, this study illustrates that beef production with low N emissions is possible and that attention to farm and waste life cycle stages can potentially result in a low overall N footprint.

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