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LIFE CYCLE ENVIRONMENTAL IMPACTS OF FUTURE DAIRY FARMING INTENSIFICATION SCENARIOS: A COMPARISON OF INTENSIFIED SYSTEMS BASED ON NITROGEN FERTILISER VERSUS MAIZE SILAGE

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Abstract

This study compared multiple life cycle environmental impacts derived from two prospective farm intensification methods to support potential increased milk production in the Waikato region of New Zealand in 2025: (i) extra nitrogen (N) fertiliser at 137 kg N per ha (N scenario), and (ii) extra brought-in maize silage at 2,275 kg dry matter per ha (MS scenario). The cradle-to-farm gate perspective (i.e. environmental emissions starting from an extraction of raw material through to production of milk at the farm gate were accounted for) was used as a system boundary with 1 kg of fat- and protein-corrected milk as a functional unit. Allocation of environmental burdens between co-products of the inflows were based on an economic relationship, and for the outflow (i.e. milk and dairy meat), allocation was based on biophysical relationship (i.e. relative feed requirement for each of co-products). The results demonstrate environmental trade-offs between the two farm intensification methods, highlighting the relevance to assess a wide range of environmental impact indicators when doing an environmental assessment. The environmentally preferable intensification method will depend on priority and scale of environmental indicators of concern.

Introduction

Increased global population and wealth drive increased demand for food, including dairy products (Tilman and Clark 2014). It has been reported that global demand for food products will double over the next few decades (Smith et al. 2013). To support this, the global dairy sector needs to increase its production capacity. Increased production capacity in agricultural systems is usually associated with farm intensification (Tilman et al. 2011). New Zealand is the single largest dairy exporting nation (OECD/FAO 2015), and its dairy production capacity is expected to increase in order to support a vision of doubling export revenue (by 2025) set out by the New Zealand Government (New Zealand Government 2012). Dairy farming systems in New Zealand are usually intensified through increased stocking rate (number of animals per hectare), coupled with increased feed supply to support greater feed demand by these larger number of animals. Increased feed supply in New Zealand dairy systems can be achieved by a range of factors, including increased on-farm pasture production through use of nitrogen (N) fertilisers, or increased use of brought-in (produced off-farm) feed, e.g. maize silage (Pinares-Patiño et al. 2009). Even though these intensification methods generally result in increased milk production per hectare, they also generate additional environmental impacts (MacLeod and Moller 2006). Life Cycle Assessment (LCA) is one of the most effective approaches used to assess environmental impacts over the life cycle of products (Finnveden et al. 2009). Generally, LCA accounts for comprehensive environmental emissions, and transforms them into a range of more understandable environmental indicators based on environmental cause-effect mechanisms (International Standard Organization 2006). As a result, problems associated with shifting environmental burdens between impact categories, between life cycle stages or between interrelated businesses are effectively prevented (Hellweg and Milà i Canals 2014). Over years, LCA is becoming an important tool for evaluating the environmental performance of dairy farming systems worldwide (de Vries and de Boer 2010; Yan et al. 2011).

Therefore, the LCA approach is relevant in this study to assess environmental impacts of different dairy farming intensification methods.

Methods

Multiple environmental impacts were modelled using SimaPro v8 software (Pré Consultants 2013). All material flows in the background systems were derived from the ecoinvent v3 database (ecoinvent Centre 2013), except for palm kernel expeller which was derived from the Agri-Footprint database (Agri-Footprint 2014).

Goal and Scope Definition

The main goals of the present study were to: (i) assess multiple environmental impacts, and (ii) evaluate environmental trade-offs for the cradle-to-farm gate life cycle of milk derived from intensified dairy farming systems (Figure 1). The two scenarios involved increased stocking rate, supported by either: (i) greater on-farm pasture production through increased use of N fertilisers (N scenario), or (ii) greater use of brought-in maize silage (MS scenario). These scenarios were assumed to produce an extra 2,840 kg of fat-and protein-corrected milk (FPCM) per hectare, leading to a total milk production of 21,296 kg FPCM per hectare, which is 50% more production compared to the Waikato region in 2012 (DairyNZ 2013).

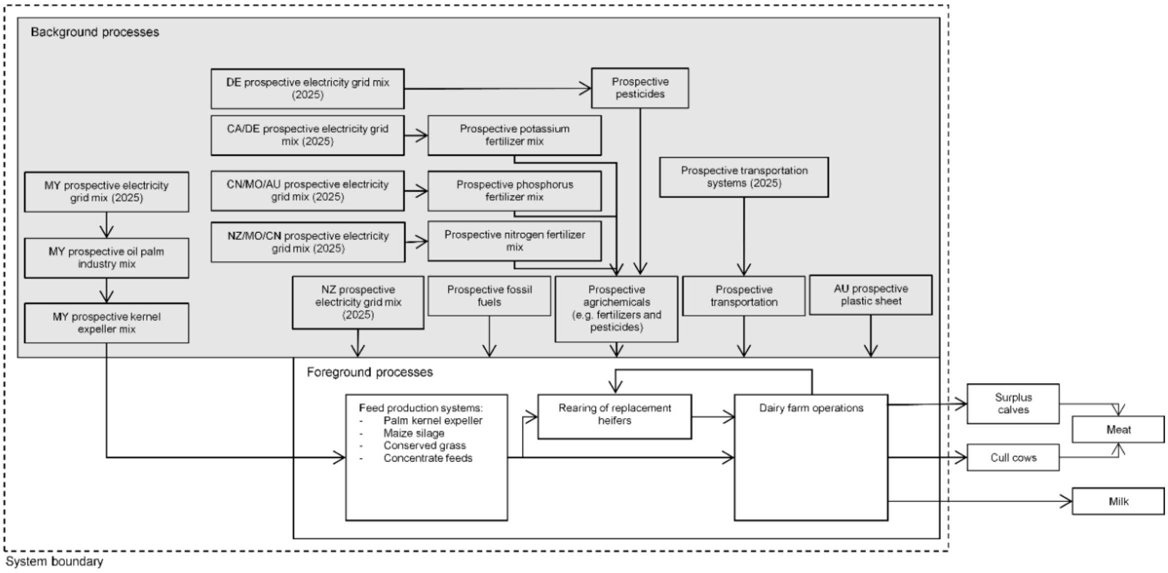

Figure 1 System boundary and simplified flows.

For the N scenario, the amount of extra N fertiliser required was calculated based on the level of feed demand and the response rate of pasture to fertiliser N (Li et al. 2011). An extra 137 kg N (as urea) per hectare was estimated to be required.

For the MS scenario where the net additional feed demand was similar to the N scenario, on a dry matter (DM) basis (assuming the same feed conversion efficiency), 2,275 kg DM per hectare of MS was derived from an off-farm source.

These two intensification methods were applied on the reference dairy farm, i.e. an average dairy farm in the Waikato in 2010/11 (Chobtang et al. 2016).

Note that environmental emissions associated with farm infrastructure, production of farm machinery and veterinary services were excluded.

Life Cycle Inventory Analysis

The inventory for environmental emissions were calculated according to Chobtang et al. (2016), except that all electricity flows were replaced by prospective (future) electricity mix for 2025 (International Energy Agency 2015). Prospective road transport systems were assumed to be EURO 5 specifications. Estimated inputs and outputs for the two scenarios are presented in Table 1.

Table 1 Farm inputs and outputs of the two Waikato dairy farm scenarios (increased use of N fertiliser [N scenario], or greater use of brought-in maize silage [MS scenario]); data are presented on a per-hectare of dairy farmland basis.

Farm traits	Units	Intensification methods	
		N scenario	MS scenario
General farm traits			
• Total farmland	ha/herd	165	165
• Total milking cows	cow/herd	639	639
• Replacement rate	%	23	23
• Culling rate	%	23	23
• Calving rate	%	80	80
• Stocking rate	cow/ha	3.87	3.87
• Animal productivity	kg FPCM*/cow	5,508	5,508
Farm inputs			
• Chemical fertilisers			
○ Nitrogen (N)	kg N/ha	279	142
○ Phosphorus (P)	kg P/ha	49	49
○ Potassium (K)	kg K/ha	45	45
• Fossil energy			
○ Diesel	MJ/kg FPCM	0.158	0.158
○ Petrol	MJ/kg FPCM	0.074	0.074
○ Lubricant oil	MJ/kg FPCM	0.002	0.002
• Electricity	MJ/kg FPCM	0.244	0.244
Total feed intake	kg DM**/ha	18,608	18,608
• Estimated pasture intake	kg DM/ha	11,275	9,000
• Intake of brought-in feeds	kg DM/ha	7,333	9,608
○ Palm kernel expeller	kg DM/ha	4,400	4,400
○ Maize silage	kg DM/ha	2,420	4,695
○ Conserved pasture	kg DM/ha	440	440
○ Concentrate	kg DM/ha	73	73
Farm outputs			
• Milk production	kg FPCM/ha	21,296	21,296
• Culled cows	cow/ha	0.89	0.89
• Surplus calves	#/ha	2.74	2.74

*FPCM = fat- and protein-corrected milk; **DM = dry matter

The functional unit was 1 kg FPCM (International Dairy Federation 2010). An economic allocation was used to partition environmental emissions for the inflows (e.g. between palm oil and palm kernel expeller), whereas environmental emissions between dairy co-products (e.g. between milk and dairy meat) were partitioned using a biophysical relationship based on relative feed requirements (International Dairy Federation 2010).

The life cycle stages were: (i) on-farm (Onfarm), (ii) rearing of replacement heifers (Replacement), (iii) production of brought-in feed (Feeds), (iv) manufacturing of agrichemicals for use on the dairy farm (Agrichemicals), and (v) transportation of off-farm inputs for use on the dairy farm (Transport).

Life Cycle Impact Assessment

Twelve environmental impact categories were assessed, following the International Reference Life Cycle Data System (ILCD) recommendations (EC-JRC-IES 2011): Climate Change (CC), Ozone Depletion Potential (ODP), Human Health Toxicity - non-cancer effects (Non-cancer), Human Health Toxicity - cancer effects (Cancer), Particulate Matter (PM), Ionizing Radiation - human health effects (IR), Photochemical Ozone Formation Potential (POFP), Acidification Potential (AP), Terrestrial Eutrophication Potential (TEP), Freshwater Eutrophication Potential (FEP), Marine Eutrophication Potential (MEP) and Ecotoxicity for Aquatic Freshwater (Ecotox).

Results and discussion

Environmental impacts

The cradle-to-farm gate life cycle environmental impacts per kg FPCM for the two farm intensification scenarios are shown in Figure 2. The contributions of different life cycle stages to different impact categories varied. The on-farm stage dominated the CC, PM, POFP, AP, TEP and MEP indicators, whereas the remaining indicators were collectively dominated by the off-farm stages.

Environmental trade-offs

Differences in environmental impacts between the two scenarios were less than 2% for four impact indicators: ODP, Cancer, POFP and FEP (Figure 2). The N scenario had six environmental indicators higher than the MS scenario: CC (8%), PM (16%), IR (6%), AP (16%), TEP (16%) and MEP (11%). In contrast, the MS scenario had two environmental indicators higher than the N scenario: Non-cancer (6%) and Ecotox (20%).

The major emissions driving the increased impacts for the N scenario were from manufacturing (e.g. carbon dioxide) (Ledgard et al. 2011; Hasler et al. 2015) and use of N fertiliser (e.g. ammonia, nitrous oxide and nitrate) (Ledgard et al. 2009). However, in the MS scenario, the increased impacts were driven by heavy metals in phosphorus fertiliser and pesticides used in maize silage production.

These findings confirm that focusing on a single environmental indicator (e.g. CC or Carbon Footprint) will not provide a comprehensive assessment of environmental sustainability of pasture-based dairy farming systems (Chobtang et al. 2016).

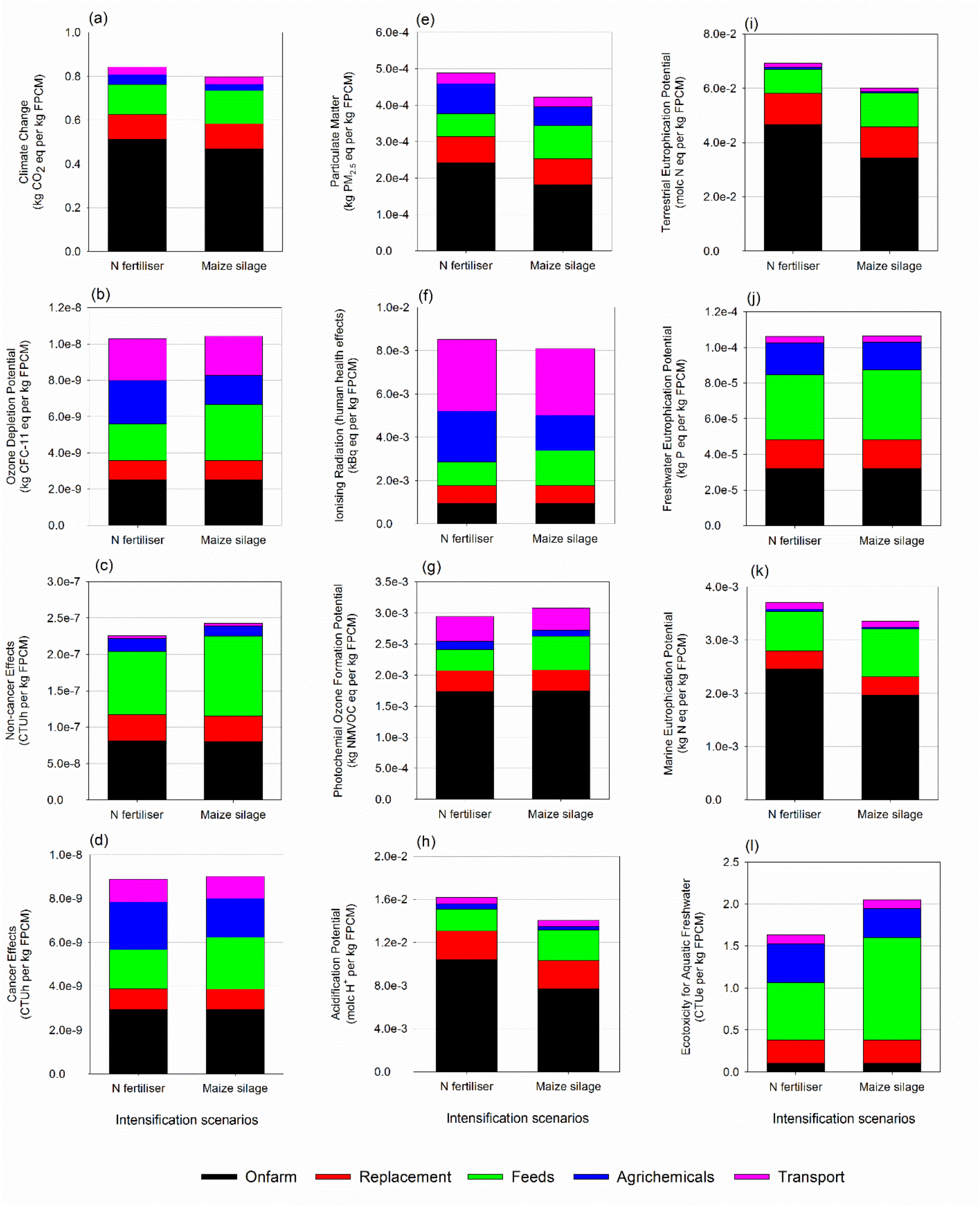

Figure 2 Environmental impacts and contribution of different life cycle stages for the cradle-to-farm life cycle of milk derived from a prospective Waikato dairy farm in 2025 for two different farm intensification methods (use of nitrogen [N] fertiliser or use of brought-in maize silage): (a) Climate Change, (b) Ozone Depletion Potential, (c) Human Health Toxicity (non-cancer effects), (d) Human Health Toxicity (cancer effects), (e) Particulate Matter, (f) Ionizing Radiation (human health effects), (g) Photochemical Ozone Formation Potential, (h) Acidification Potential, (i) Terrestrial Eutrophication Potential, (j) Freshwater Eutrophication Potential, (k) Marine Eutrophication Potential and (l) Ecotoxicity for Aquatic Freshwater. Impacts were expressed per kg FPCM.

Conclusions

There were environmental trade-offs between the two dairy farm intensification methods. Choice of environmentally preferable intensification methods should initially be based on priority and scale (e.g. local versus global) of environmental impacts of concern. For example, if the Climate Change indicator was prioritised (a global indicator), then the increased use of maize silage would be the preferred method of intensification. In contrast, if the Ecotoxicity for Aquatic Freshwater was prioritised (a local indicator), then the increased use of nitrogen fertiliser would be the preferred method of intensification.

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