First Life Cycle Assessment of Milk Production from New Zealand Dairy Farm Systems

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ABSTRACT

A first picture of the total environmental performance of milk production from a typical NZ dairy farm system, using Life Cycle Assessment (LCA) was produced and compare to European LCA studies. Five potential impacts have been assessed. Results were expressed per kg of milk produced at the farm gate and per ha of land use. In this first assessment, compared to Swedish and German conventional dairy farm systems, the NZ system had three fold lower eutrophication potential and acidification potential per kg of milk, two fold lower energy use and land use, and 50% to 80% lower global warming potential. Even compared to Swedish and German organic farm systems, its potential impacts per kg of milk were similar or most often lower. This can be explained by a farming system almost entirely based on high-producing perennial pastures and all-year grazing compared to European farming systems with high supplementary feed use.

1. Introduction

On the milk world market, NZ represents one of the most important exporters and is also the third cheapest milk producer after Argentine and Chile. This leadership places a high requirement on the NZ milk sector concerning both, the amount of milk produced and its overall quality, including environmental aspects. Furthermore, over the last decade, NZ dairy farm systems have shown rapid intensification which has raised uncertainty about the sustainability of current and future dairy farm systems. Life cycle assessment (LCA) has been shown to be a valuable tool for the environmental evaluation of whole farm systems (van der Werf and Petit, 2002) and has been applied to a range of agricultural products particularly in Europe (Audsley et al., 1997; Brentrup, 2003; Cederberg and Mattsson, 2000; Haas et al., 2001, Basset-Mens and van der Werf, 2005). With this tool, the potential environmental impacts of a product are assessed by quantifying and evaluating the resources consumed and the emissions to the environment at all stages of its life cycle, usually for agricultural products, “from cradle to gate”, i.e.: from the extraction of resources, through the production of materials, product parts and the product itself at the farm level.

The objectives of this study were to:

• Produce an LCA for milk production from an average NZ dairy farm system
• Compare this assessment with European LCA studies for milk production.

2. Materials and methods

2.1. NZ milk production system

A NZ average milk production system was defined based on national statistics for dairy farms for the year 2002/2003 (see table 1). The studied system included the processes up to the farm (production and delivery of crop and pasture inputs, production of feed supplement, off-farm pasture production for the replacement of cows), as well as the production of milk on the farm.
including on-farm pasture production, herd management and milk extraction (Ledgard et al., 2003). Less than 10% of the feed requirement of cows was provided by feed supplements (maize silage and forage), assumed to be produced on a forage cropping block off the farm. The technical data for maize forage and silage production was provided by a large Waikato contracting company. The replacement animals (25%) were assumed to be grazed off-farm. An average beef farm was assumed to be used for grazing replacements, based on MAF intensive Beef Monitor Farm (Ledgard et al., 2003). Current practices were assumed for the use of inputs for the production of pastures and crops. Fuel and electricity use on the dairy farm was based on average NZ dairy farm data from Wells (2001).

| Table 1. Technical description of the NZ average dairy farm system (year 2002/2003) |
|---------------------------------------------|-------------------|-------------------|
| **Dairy farm**                             | **Data**          | **References**    |
| Area (ha)                                   | 111               | LIC, 2003         |
| Cows                                        | 285               | LIC, 2003         |
| Stocking rate (max cow/ha/year)             | 2.7               | Dexcel, 2004      |
| Milk solids (kg/ha/year)                    | 828               | LIC, 2003         |
| N fertilizer use (kg/ha/year)               | 110               | Dexcel, 2004      |
| P fertilizer use (kg/ha/year)               | 51                | Dexcel, 2004      |
| Feed supplements (maize silage and forage)  | 931               | Dexcel, 2004      |
| (kg DM/ha/year)                             |                    |                   |

<table>
<thead>
<tr>
<th><strong>Off-farm pastures for replacement animals</strong></th>
<th><strong>Area (ha)</strong></th>
<th><strong>References</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>33</td>
<td>MAF monitor farms</td>
</tr>
</tbody>
</table>

2.2. Inventory data

The OVERSEER® nutrient budget model (Wheeler et al., 2003) was used to estimate N leaching and P emissions to waterways (Mc Dowell et al., 2005) as well as to estimate emissions of the greenhouse gases, methane from the digestion of cows and nitrous oxide from soils, with IPCC-based NZ emission factors (De Klein et al., 2001; Clark, 2001). Ammonia emissions from excreta were estimated according to Ledgard (2001). For maize forage and silage production the same emission factors were used except for nitrate leaching which corresponded to an average of measurement data throughout NZ. Inventory data for fertilizers were based on industry data and on literature, particularly from Wells (2001). Energy data for machines and diesel consumption, used for agricultural operations were based on Wells (2001). Emission data for diesel combustion were according to MED (2000). Specific energy processes for the NZ context were developed based on a survey of the main companies and literature references. Finally, the inventory analysis of the project was based on the SIMAPRO database for the early stages of the life cycle of milk production.

2.3. Evaluation methodology

Environmental impacts were evaluated using Life Cycle Assessment (LCA). The following impact categories were considered: Global Warming Potential (GWP), Eutrophication Potential (EP), Acidification Potential (AP). The use of energy and land was also quantified as contributing to the depletion of non-renewable resources. These impacts were related to one production unit (kg of milk produced) and for regional impacts (EP and AP) to one area unit as well (ha of land used).

Impacts were allocated between the co-products milk and meat (85:15) according to a biological causality, using the same equation as Cederberg and Mattsson (2000) but with NZ data.
The indicator result for each impact category was determined by multiplying the aggregated resources used and the aggregated emissions of each individual substance with a characterisation factor for each impact category to which it may potentially contribute. Characterisation factors are substance-specific, quantitative representations of the additional environmental pressure per unit emission of a substance.

Eutrophication covers all potential impacts of high environmental levels of macronutrients, in particular N and P. As recommended by Guinée et al. (2002), Eutrophication Potential (EP) was calculated using the generic EP factors in kg PO$_4$-eq., NH$_3$ 0.35, NO$_3$ 0.1, NO$_2$ 0.13, NO$_x$ 0.13, PO$_4$ 1. GWP was defined here as the impact of emissions on the heat radiation absorption of the atmosphere. As recommended by Guinée et al. (2002), Global Warming Potential for a 100 year time horizon (GWP$_{100}$) was calculated according to the GWP$_{100}$ factors by IPCC in kg CO$_2$-eq., CO$_2$ 1, N$_2$O 310, CH$_4$ 21. Acidifying pollutants have a wide variety of impacts on soil, groundwater, surface waters, biological organisms, ecosystems and materials (buildings). Acidification Potential (AP) was calculated using the generic method proposed by Heijungs et al. (1992) in kg SO$_2$-eq., NH$_3$ 1.88, NO$_2$ 0.7, NO$_x$ 0.7, SO$_2$ 1. Energy use refers to the depletion of energetic resources. Energy use was calculated using the Lower Heating Values proposed in the SimaPro software. Land use refers to the loss of land as a resource, in the sense of being temporarily unavailable for other purposes.

2.4. Comparison with European LCA studies of milk production

Two published studies for LCA of milk production from Sweden (Cederberg and Mattsson, 2000) and from Germany (Haas et al., 2001) were used for the comparison. Cederberg and Mattsson (2000) compared conventional and organic milk productions. Haas et al. (2001) compared conventional intensive with conventional extensive and organic production systems. Haas et al. (2001) assumed meat production to be insignificant compared to milk production so they did not apply any allocation rules between these two co-products while Cederberg and Mattsson (2000) allocated 15% of the impacts on the meat production on the basis of a biological causality. In Cederberg and Mattsson (2000), the functional unit (FU) was 1t of milk corrected to 4% of fat content. Haas et al. (2001) did not take account of the milk quality in the definition of their functional unit but expressed regional impacts per ha of on-farm grasslands which was not possible to compare with our area-related impacts. To facilitate comparison with these studies, the FU of our NZ study was also adjusted from average milk containing 4.7 fat (LIC, 2002) to an energy corrected milk based on 4% fat. Given all the assumptions necessary to implement LCA, the comparison of different LCA studies presents some uncertainties and should be taken with caution.

3. Results

The LCA results obtained for the average NZ dairy farm system appeared to be consistent with other LCA studies of milk production (Table 2).
Table 2  Compared environmental impact assessment of milk production (per kg of milk and per ha of land used for eutrophication and acidification) by Cederberg and Mattsson (2000), Haas et al. (2001) and this study.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>GWP (g CO₂-eq)</th>
<th>Acidification (g SO₂-eq)</th>
<th>Eutrophication (g PO₄-eq)</th>
<th>Energy use (MJ LHV)</th>
<th>Land use (m².a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FU</td>
<td>kg milk</td>
<td>kg milk</td>
<td>ha land</td>
<td>kg milk</td>
<td>ha land</td>
</tr>
<tr>
<td>NZ-conv</td>
<td>718</td>
<td>5.68</td>
<td>60120</td>
<td>2.52</td>
<td>26660</td>
</tr>
<tr>
<td>Sweden-conv</td>
<td>1100</td>
<td>15.8</td>
<td>93510</td>
<td>6.05</td>
<td>31430</td>
</tr>
<tr>
<td>Sweden-organic</td>
<td>950</td>
<td>18.8</td>
<td>-</td>
<td>7.5</td>
<td>-</td>
</tr>
<tr>
<td>German-conv-Int</td>
<td>1300</td>
<td>18.8</td>
<td>-</td>
<td>7.5</td>
<td>-</td>
</tr>
<tr>
<td>German-conv-Ext</td>
<td>1000</td>
<td>17</td>
<td>-</td>
<td>4.5</td>
<td>-</td>
</tr>
<tr>
<td>German-organic</td>
<td>1300</td>
<td>22</td>
<td>-</td>
<td>2.8</td>
<td>-</td>
</tr>
</tbody>
</table>

Per kg of milk, the GWP was 30% to 80% higher for all European systems (950 to 1300 g CO₂-eq/kg of milk) compared to the NZ system (718 g CO₂-eq/kg of milk) (Table 2). In the NZ system, 57% of the GWP was due to the methane emissions during cow digestion (Fig. 1 and 2), the main part being from on-farm pasture digestion (46%). 40% was associated with the production of pastures and crops for feed supplement (Fig. 1), mainly due to nitrous oxide from soils which constituted a total of 34% of GWP (Fig. 2). CO₂ emissions due to the use of fuel and from the conversion of lime in soils accounted for only 9% of the total GWP. In the other LCA studies, the same processes were identified for their contribution to the GWP: mainly methane emission from cows and the emission of N₂O from cropping soils (Cedeberg and Mattsson, 2000; Haas et al., 2001). The breakdown of the three main emissions CH₄, N₂O and CO₂, for the NZ system (Fig. 2) was very close to those obtained for the organic and extensive systems from the Swedish and German studies. In those cases, the CO₂ emissions accounted for around 10% while the CH₄ contribution was around 60% (Cedeberg and Mattsson, 2000; Haas et al., 2001). Conversely, the two conventional systems from Sweden and Germany obtained a contribution to GWP from CH₄ of around 50% and a CO₂ contribution higher than 20%.

The NZ system had a similar EP to German organic production but obtained 1.8 to 3 times less than EP for other scenarios including organic production from Sweden (Table 2). EP was almost entirely due to the production of pasture production, with on-farm pasture production and grazing being the main contributor (86%) (Fig. 1). Nitrate emissions accounted for 55% of EP, while NH₃ emissions accounted for 40% (Fig. 2). The contribution of PO₄ losses to EP was only 4%. In the Swedish and German studies, the losses of nutrients from soils and particularly NH₃ and NO₃, were also identified as the main processes responsible for EP, but these were largely from crop production for feed and not from pasture production. The Swedish organic system showed a similar breakdown between NO₃, NH₄ and PO₄ contributions to EP, to the NZ system: around 53% for NO₃, around 40% for NH₃ and 3% for PO₄. Conversely, the Swedish conventional system obtained a higher contribution from NH₃ (50%) than from NO₃ (45%). No corresponding data were available from the German study.

AP for the European systems was 2.8 to 3.9 times greater than for the NZ system (Table 2). As for EP, almost all the AP was due to pasture productions, with on-farm pasture production and grazing as the main contributor (86%) (Fig. 1). However, NH₃ emission dominated acidification (95%) (Fig. 2). Both organic and conventional Swedish systems had an NH₃ contribution to AP of around 90% while in the German study, this contribution ranged from 95% for intensive conventional to 97% for organic farms.
Concerning land use, only the Swedish study provided figures which allowed expression of EP and AP per total ha of land used. The NZ conventional scenario used very few ha of land per kg of milk produced (0.94 m²/kg of milk) compared to the conventional system from Sweden (1.93) and even less compared to the organic system (3.46) (Table 2). The main stages contributing to the use of land were the on-farm (75%) and off-farm (20%) pasture production (Fig. 1). The relative contribution of pasture production to land use in the NZ average system was very high compared to the relative contribution of grasslands to land use in the Swedish organic system (around 60% against 40% for crops). It was even higher compared to the relative contribution of grasslands to land use in the Swedish conventional system (around 40% against 60% for crops).

Per ha of land use, EP and AP for the NZ system ranged between the Swedish organic system and the Swedish conventional system (Table 2). With a higher productivity per ha than conventional production from Sweden (so less surface used per kg of milk produced), the NZ conventional system had still lower potential impacts for EP and AP, -15% and -35%, respectively. However, the fluxes of eutrophying and acidifying pollutants per ha for the NZ system were relatively close to the fluxes quantified by Cederberg and Mattsson (2000) for the Swedish conventional system.
4. Discussion and conclusion

4.1. Advantages of the NZ dairy farm system

The LCA results obtained in this study for an NZ dairy farm system have shown to be consistent with other LCA studies, highlighting the specific environmental problems due to milk production: the contribution to GWP of methane emissions during pasture and feed digestion by cows and of nitrous oxide from pastures and crops, the contribution of ammonia volatilisation to AP, the contributions of nitrate leaching and ammonia emissions to EP and finally, the land use for pasture and crop production.
However, for the five impact categories considered, the NZ dairy farm system appeared to have important advantages. European conventional systems had three fold greater EP and AP per kg of milk than the NZ dairy farm system, two fold greater energy and land use and 50% to 80% greater GWP. Compared to European organic systems, the potential impacts of the NZ dairy farm system per kg of milk were similar (EP for German organic system) or most often lower (GWP, AP, land use). On the contrary, per ha of land use, EP and AP were lower for the Swedish organic system compared to the NZ conventional system, followed by the Swedish conventional system. In addition, organic and NZ conventional systems appeared to have some common features in terms of environmental performance, linked to their higher self-sufficiency compared to conventional systems.

It is worth noting that the NZ conventional system had lower impacts per kg of milk produced, due first, to its high milk productivity per ha. However, some qualitative features also explained these advantages. The NZ dairy farming system relies essentially on permanent mixed pastures (clover + ryegrass) grazed all year round. In the climatic NZ context (regular rainfall and not extreme soil moisture, moderate temperatures and adequate light), these pastures have a high yield (over 14 t DM/ha/year) which is a key-feature of the efficiency of the whole system. The presence of clover allows reduced use of N fertilizer thanks to its capacity for N$_2$ fixation from the air. In such pasture-based systems, cows ingest their feed from and apply their excreta directly on pastures. This very short cycle reduces the energy consumption and all associated impacts linked with the production and the transport of concentrated feed, and also linked with effluent management.

4.2. Areas of potential improvement for the NZ dairy farm system

Pasture production and associated grazing effects with excreta recycling, especially on the farm, have been identified as the main stage contributing to the impacts over the whole milk life cycle. It concerns primarily eutrophication potential, acidification potential and land use and secondarily the GWP and energy use. NO$_3$, NH$_3$ and N$_2$O have been identified as the main emissions responsible for these potential impacts. The second important process for the environmental performance of the milk life cycle is the methane emission during pasture digestion by cows which contributes largely to the GWP.

These hot spots of the NZ system can also be seen as potential areas of improvement. Research works have been performed on the different opportunities of reducing these losses from the NZ system. An important potential has been identified from mitigation options at different points of the system, from the feed quality through the management of cows, the crop manipulation and the soil manipulation. These mitigation options would need however further quantification on a long-term basis and by considering the whole system (Ledgard and Menneer, 2005). On the basis of these research works, useful scenarios could be analysed by using the LCA methodology.

4.3. Uncertainties and perspectives

The comparison of LCA studies remains a difficult and uncertain exercise (de Boer, 2003) given the different methodologies and assumptions used in each of them. Some of these assumptions could be harmonised and lead to more accurate and useful comparisons. It would require a real partnership between the different teams involved. Additionally, the uncertainty of the final results is generally not assessed in these studies, which makes their comparison even more difficult. Using LCA with nationally averaged information allows a big picture to be drawn but it suffers because of the high variability in direct emissions locally and with soils, and the need to match eutrophication and acidification indicators to the sensitivity of local ecosystems. Important research is needed for improving the accuracy of both LCA results and comparisons between LCA studies.
References


