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Agricultural Systems 96 (2008) 95–107
Agricultural Systems
www.elsevier.com/locate/agsy

Life cycle assessment of conventional and organic milk production in the Netherlands

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Received 12 July 2006; received in revised form 7 March 2007; accepted 13 June 2007
Available online 6 August 2007

Abstract

Production of milk causes environmental side effects, such as emission of greenhouse gases and nutrient enrichment in surface water. Scientific evidence that shows differences in integral environmental impact between milk production systems in the Netherlands was underexposed. In this paper, two Dutch milk production systems, i.e. a conventional and an organic, were compared on their integral environmental impact and hotspots were identified in the conventional and organic milk production chains. Identification of a hotspot provides insight into mitigation options for conventional and organic milk production. Data of commercial farms that participated in two pilot-studies were used and refer to the year 2003. For each farm, a detailed cradle-to-farm-gate life cycle assessment, including on and off farm pollution was performed. Results showed better environmental performance concerning energy use and eutrophication potential per kilogram of milk for organic farms than for conventional farms. Furthermore, higher on-farm acidification potential and global warming potential per kilogram organic milk implies that higher ammonia, methane, and nitrous oxide emissions occur on farm per kilogram organic milk than for conventional milk. Total acidification potential and global warming potential per kilogram milk did not differ between the selected conventional and organic farms. In addition, results showed lower land use per kilogram conventional milk compared with organic milk. In the selected conventional farms, purchased concentrates was found to be the hotspot in off farm and total impact for all impact categories, whereas in the selected organic farms, both purchased concentrates and roughage were found to be the hotspots in off farm impact.

We recommend to improve integral environmental performance of milk production by: (1) reducing the use of concentrates ingredients with a high environmental impact, (2) decreasing the use of concentrates per kilogram of milk, and (3) reducing nutrient surpluses by improving farm nutrient flows.

Keywords: Life cycle assessment; Integral environmental impact; Milk production system; Organic; Conventional; Hotspot identification; Dairy farming

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1. Introduction

An agricultural activity is considered to be ecologically sustainable if its polluting emissions and its use of natural resources can be supported in the long term by the natural environment. The first step in the assessment of ecological sustainability is assessment of its environmental impact (Payraudeau and Van der Werf, 2005). Assessing the environmental impact is a well-investigated issue in the Netherlands (Oenema et al., 1998). Most research, however, has focused on eutrophication and acidification at farm level, whereas there has been little research on the integral assessment of the environmental impact (Van den Brandt and Smit, 1998; Erisman et al., 2001; Schröder et al., 2003; Van Calker et al., 2004). An integral assessment means that several environmental burdens (e.g. use of natural resources or climate change) and the environmental burden

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doi:10.1016/j.agsy.2007.06.001

of purchased inputs can be addressed together. Life cycle assessment (LCA) is a method for integral assessment of the environmental impact of products, processes or services by including all phases of the life cycle. In recent years, LCA has proven to be an internationally accepted method, used widely in the agricultural sector for integral assessment of the environmental impact and for identification of a hotspot[1] (Cederberg and Mattson, 2000; Haas et al., 2001; Berlin, 2002; Basset-Mens and Van der Werf, 2005; Halberg et al., 2005; Thomassen and De Boer, 2005).

Production of milk is an example of an agricultural activity that causes environmental side effects, such as emission of greenhouse gases and nutrient enrichment in surface water (Van Calker, 2005). In the Netherlands, milk production at farm level contributes nationally around 50% to the NH_3 emission, 15% to the CO_2 emission, 48% to the CH_4 emission, around 37% to the N_2O emission and around 45% to the nutrient enrichment in surface and groundwater (Velthof and Oenema, 1997; Van Egmond, 2004; Van der Schans et al., 2005). To improve the environmental impact of agricultural activities, such as milk production, the Dutch Government and European Union introduced several environmental policies (Oenema, 2004). Dairy farmers are forced to look for different ways to address these environmental policies that focuses mostly on eutrophication and acidification at farm level (Oenema et al., 2001; Baars et al., 2002). One way to comply with future environmental policies may be to convert from a conventional milk production system to an organic one. In 2003, about 1.4% of the total milk sector consisted of organic dairy farms (Binternet, 2003). A comparison between the integral assessment of the environmental impact of conventional and organic systems is needed to address advantages or disadvantages of each system. In addition, identification of a hotspot provides insight into mitigation options for conventional and organic systems.

The objective of this study was to compare the integral assessment of the environmental impact of conventional and organic milk production systems and to identify hotspots in the conventional and organic milk production chains. The LCA of conventional and organic milk production systems was based on data of 21 commercial dairy farms in the Netherlands.

2. Material and methods

2.1. Data

Data from 10 conventional commercial dairy farms were collected in 2003, when these farms were considered to be conventional, complying with current environmental legislation. In 2004, the farms started to participate in a sustainability project ‘Caring Dairy’, which is an initiative of ice cream company Ben & Jerry’s to develop guidelines for sustainable dairy farming practices (Van Calker et al., 2005).

Data were also collected from 11 organic commercial dairy farms in 2003 that participated in a demonstration project of Dutch organic dairy farmers, the so-called BIO-VEEM project (Baars, 2002; Baars et al., 2002). This BIO-VEEM project was started to broaden and strengthen organic dairy farming. Farmers worked together with researchers on themes, such as soil and fertilisation, animal health, economics, and production of fodder crops. The farms differed in management styles, scale, and soils. Every farmer had the intention, furthermore, to search for solutions or new developments within the boundaries of organic dairy farming. The ecological principle of organic farming is that farming should fit the cycles and ecological balances in nature to improve environmental quality and conserve resources (IFOAM, 2006). Some important aspects of organic dairy farming include: promoting natural behaviour of cows by having them spend most of the grazing period outdoors, forbidding use of synthetic fertilizer and pesticides during production of crops, and requiring at least 60% of cows’ daily ration consist of roughage, produced organically preferably on farm (EEG, 1992). In 2003, at least 90% of concentrates must consist of organic ingredients (Ter Veer, 2005).

General characteristics of the farms in addition to average characteristics of typical Dutch conventional and organic farms are in Table 1 (Binternet, 2003; CBS, 2003). Compared with a typical conventional farm, participating conventional farms had more land, more milking cows, and higher milk production per cow. Furthermore, participating farms were less intensive (in Dutch Livestock Units per ha) and had a similar milk fat and lower milk protein percentage. Conventional farms were situated in the Northern region of the Netherlands.

Compared with a typical organic farm, participating organic farms had more land, more milking cows and lower milk production per cow. The organic farms had similar intensity (in Dutch Livestock Units per ha) and higher milk fat and similar milk protein percentages. Organic farms were situated throughout the Netherlands.

2.2. Life cycle assessment (LCA)

LCA is a collection and evaluation of the inputs and outputs and the potential environmental impacts of a production system throughout its life cycle (Guinée et al., 2002). Stages of LCA methodology include: goal and scope definition, inventory analysis (LCI), impact assessment (LCIA) and interpretation of results (ISO, 2006). For each dairy farm, a detailed “cradle-to-farm-gate” LCA was performed.

2.2.1. Goal and scope definition

The goal and scope definition is the stage in which initial choices are made that determine the working plan of the

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[1] A hotspot is an element that has a high contribution to the environmental burden of a product (Guinée et al., 2002).

Table 1
General characteristics of the participating farms in the two pilot studies in 2003

Parameters	Units[a]	Conventional	Typical NL[b]	Organic	Typical NL[b]
Farms	n	10		11[c]	
Grassland	ha	35.5 (10.9)	29.9	40.7 (19.4)	36.1
Arable land	ha	11.2 (6.8)	8.6	11.5 (11.4)	10.8
Milking cows	n	81 (24.9)	63	71 (32.4)	56
Milk production[d]	kg/cow	7991 (800)	7630	6138 (980)	6390
Milk fat	%	4.41 (0.11)	4.42	4.45 (0.66)	4.40
Milk protein	%	3.44 (0.08)	3.49	3.44 (0.30)	3.45
Density	LU/ha[e]	2.13 (0.3)	2.31	1.70 (0.4)	1.76
Intensity	kg FPCM/ha	14713 (2342)		8937 (2655)	
Soil type		100% sand		45% sand 36% clay	
Diesel use on farm	L	4868 (2741)		5026 (3681)	
Electricity use on farm	kWh	27113[f] (12733)		28738[f] (18984)	
Purchased pesticides	kg active matter/ha	0.25 (0.10)			

[a] Units of parameters are given. Numbers for participating farms are means with standard deviation.
[b] Average values of a typical conventional and organic dairy farm in the Netherlands (Binternet, 2003; CBS, 2003).
[c] Four farms were bio-dynamic.
[d] Milk with an economic value (e.g. delivered milk to the factory). Due to lack of data of private use of milk of some farms.
[e] LU = Dutch Livestock Units. 1 LU = the yearly phosphate excretion of one milking cow. Other animal categories are related to this LU.
[f] Five farms used renewable electricity.

entire LCA. One aim of this study was to compare the integral assessment of the environmental impact of conventional and organic milk production systems. In order to compare systems, you need a functional unit (FU). The FU describes the primary function fulfilled by a product system and enables different systems to be treated as functionally equivalent (Guinée et al., 2002). The primary function of dairy systems is milk production. The FU chosen

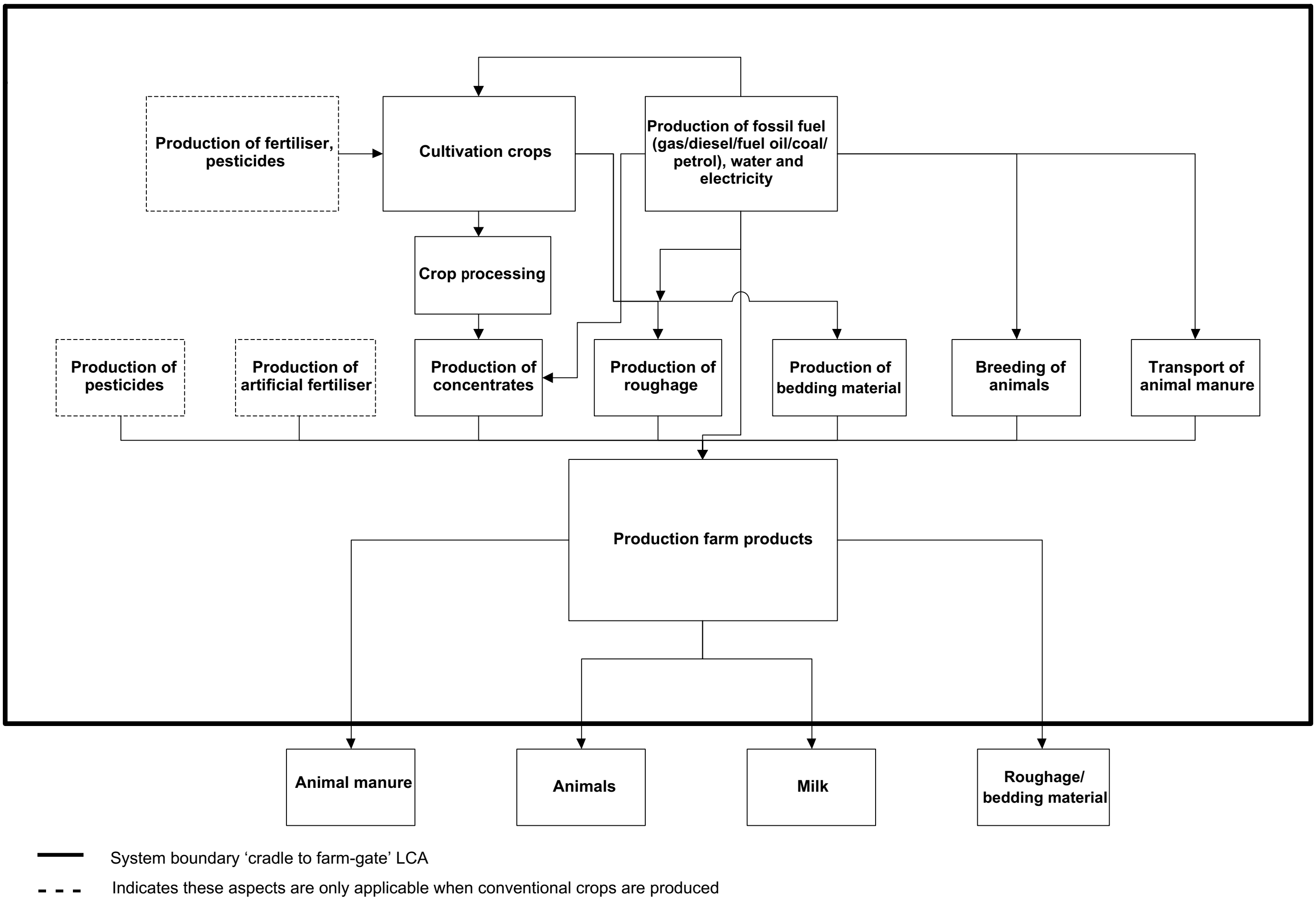

Fig. 1. System boundaries 'cradle to farm-gate' LCA.

was "1 kg of Fat and Protein Corrected Milk leaving the farm-gate" (CVB, 2000). In accordance with Guinée et al. (2002), we chose the baseline impact categories: land use, energy use, climate change, acidification, and eutrophication. Other baseline impact categories, such as terrestrial or aquatic ecotoxicity, human toxicity, or stratospheric ozone depletion (ODP) were not chosen. Necessary detailed data on pesticides and heavy metals were not available in order to include the impact categories ecotoxicity and human toxicity quantitatively, whereas in case of ODP, other studies showed milk production did not contribute significantly to this impact category (Berlin, 2002; Hospido et al., 2003). The system under study included the whole life cycle required for the production of raw milk, from the production of inputs to products leaving the farm-gate, i.e. excluding transport or processing of raw milk (see Fig. 1). Related transport associated with the production of purchased inputs was included. Medicines, seeds, and machinery were excluded because of their small impact (Cederberg, 1998). Buildings were excluded because we recovered similarity in buildings of the different farm types (Erzinger et al., 2003).

2.2.2. Inventory analysis

The inventory analysis consists of the collection of data concerning resource use, energy consumption, emissions, and products resulting from each activity in the production system. In this stage, each process was further analysed, and factors to be included were defined (Table 2). Subsequently, data of each process were collected, allocation steps for multifunctional processes were performed, and final calculations were completed.

Choice of allocation implies partitioning the environmental impact of a multifunctional process. Several multifunctional processes were present: the production of ingredients for concentrates, of roughage, and bedding material; and the joint production of milk, meat, roughage, and manure leaving the farm-gate. Economic allocation based on shares in proceeds of the products was performed for multifunctional processes (Guinée et al., 2004). For joint production of conventional milk, on average 91% was ascribed to milk, 8.2% to animals, and 0.8% to exported crops. For joint production of organic milk, on average 90% was ascribed to milk, 6.6% to animals, and 3.4% to exported crops and manure.

Table 2
Overview inventory data used in inventory analysis

	Element	Computation method[a]	Included factors	References[b]
Off farm[c]	Purchased pesticides	$Q*$ LCI/kg active matter	Production/ transport	Brand and Melman (1993)
	Purchased artificial fertilizer	$Q*$ LCI/kg artificial fertilizer	Production/ transport	Davis and Haglund (1999)
	Purchased concentrates	$Q*$ LCI/kg concentrates	Crop cultivation[d]	FAO (2002/2003), Cederberg (1998), CVB (2000)
			Crop processing	Brand and Melman (1993), Cederberg (1998)
			Transport	Cederberg (1998), Michaelis (1998), WPD (2003)
	Purchased roughage and bedding material	$Q*$ LCI/kg roughage	Crop cultivation	Dekkers (2001), LEI (2004), Koroneos et al. (2005)
			Transport	Cederberg (1998), Michaelis (1998)
	Purchased animals	$Q*$ LCI/animal	Breeding[e]	Tamminga et al. (2000), Oenema et al. (2000)
			Transport	Cederberg (1998), Michaelis (1998)
	Purchased animal manure	$Q*$ LCI/kg manure	Transport	Brand and Melman (1993)
	Contract work	$Q*$ LCI/litre diesel	Diesel use	Brand and Melman (1993), Hanegraaf et al. (1996)
On farm	Use of diesel	$Q*$ LCI/litre diesel	Supply and use	Michaelis (1998)
	Use of electricity	$Q*$ LCI/kW h electricity	Supply and use	Michaelis (1998), EnergieNed (2002), CertiQ (2003)
	Use of gas	$Q*$ LCI/m^3 gas	Supply and use	Michaelis (1998)
	Use of water	$Q*$ LCI/m^3 water	Electricity supply	Michaelis (1998), EnergieNed (2002)
On/off	Emissions of CH_4	Fixed values animals	Enteric + manure	Schils et al. (2006)
	Emissions of NH_3 and NO_x	Fixed values animals[f] and spreading of fertilizer	Stable/pasture/ deposit/spreading	Oenema et al., 2000, Van Geel (2004), Van der Hoek (2002), Mosier et al. (1998)
	Emissions of N_2O	Fixed values animals/soil	Direct and indirect	Mosier et al. (1998), Oenema et al. (2000)
	Leaching of NO_3 and PO_4	Farm-gate balance and soil surface balance	Net N-leaching factors	Schröder et al. (2005)
			Inputs and outputs	Van Eerdt and Fong (1998)

[a] Q is actual amount of product obtained from technical farm data. LCI is life cycle inventory, which is in most cases end values of a computation procedure.

[b] Most important sources used for the assessment of the life cycle inventory are given.

[c] Off farm includes upstream processes given in Fig. 1 until production farm products.

[d] For estimating related emissions and resource use for cultivation and processing of concentrates ingredients, more references were used than given in this table. For a detailed description we refer to Jansen (2005) and 's Gravendijk (2006).

[e] Breeding includes all aspects of growing-up: feed intake, emissions during stable period and pasturing.

[f] For milking cows ammonia emission and nitrogen excretion were related to milk urea (Van Duinkerken et al., 2005; Schröder et al., 2006).

The computation method used and the most important references for data used in the inventory analysis are in Table 2, in addition to included factors for each element. Collected farm data augmented with feed supplier data were used to assess actual amount (*Q*), whereas data from the literature and use of expert knowledge were used to assess and compute life cycle inventories (LCIs).

To determine the LCI of purchased concentrates, three types of concentrates were distinguished: $\text{DVE} \leqslant 95$, $95 < \text{DVE} \leqslant 110$, and $\text{DVE} > 110$, based on their intestine digestible protein content, using the Dutch DVE-system (Van Straalen, 1995), because DVE-content of the different purchased concentrates related to feeding strategy and milk urea content, and it could be detected relatively easy. After dividing concentrates, general ingredient composition, based on annual data (>95% of its main feed ingredients), of the three types of concentrates were recovered (Doppenberg and De Groot, 2003; Heuven, 2005). Table 3 shows the concentrate ingredients by system, their average share within the three types of concentrates, economic allocation, and their origins. The most common concentrate ingredients used in the conventional system, which account for 60%, were maize gluten meal, beet pulp, and palm kernel meal. The most common concentrate ingredients used in the organic system, which account for 65%, were palm kernel meal, organic wheat grain, organic triticale grain, organic lucerne, and organic lupines. For each ingredient, a life cycle inventory (LCI) was computed. The potential leaching of nitrate and phosphate were calculated by means of a soil surface balance (Van Eerdt and Fong, 1998).

The amount of diesel used for contract work (*Q*) was computed based on expenses of contract work (Table 2). Conversion factors were used to convert expenses into energy content and subsequently into diesel use (Brand and Melman, 1993; Hageman and Mandersloot, 1994; Hanegraaf et al., 1996).

Table 3
Concentrates ingredients by system

Ingredient	Average share in concentrates[a]	Economic allocation (%)	Origin
Conventional system			
Maize gluten meal	28	8	France
Beet pulp	15	11	The Netherlands
Palm kernel meal	17	3	Malaysia
Triticale	9	71	The Netherlands
Wheat hulls	8	9	France/Germany
Soybeans	6	100	Brazil
Soymeal	4	72	Brazil
Organic system			
Palm kernel meal	17	3	Malaysia
Wheat grain[b]	13	83	The Netherlands
Triticale[b]	12	77	The Netherlands
Lucerne[b]	12	100	The Netherlands
Lupines[b]	11	100	Australia
Maize gluten meal	8	8	France
Rape seed meal	8	33	Germany
Soy hulls[b]	5	1	Brazil

[a] Average of the three types of concentrates according to their DVE-content.

[b] Produced organically.

With respect to LCI of electricity, a mixture for conventional and renewable electricity was used (EnergieNed, 2002; CertiQ, 2003).

Emission of methane occurs in two ways: during enteric fermentation of a cow and from manure management. For the organic system, an emission during fermentation of 128 kg CH_4/dairy cow per year was assumed, whereas for the conventional system 113 kg CH_4/dairy cow per year (Schils et al., 2006). This higher enteric emission in an organic production system compared to the conventional system, was due to the larger intake of roughage per cow and the lower content of starch in the roughage which theoretically gives lower fermentation rapidity in the rumen (Jongbloed et al., 2004). Emission from manure management was 0.0018 kg CH_4/kg manure per year for liquid manure and 0.00037 kg CH_4/kg manure per year for solid manure production in animal houses (Van der Hoek and Van Schijndel, 2006).

When a surplus of nitrogen or phosphorus exists, leaching of nitrate or phosphate may occur. Potential leaching of nitrate and phosphate on farm was calculated by means of a farm-gate balance approach. The farm-gate balance represents the amount of nutrients either lost to the environment or accumulated within the soil pools (Nielsen and Kristensen, 2005). Oenema et al. (2005) clarify that nutrient surpluses are an indicator for the potential nutrient loss, but not for the actual nutrient loss. To compute the leached fraction of the calculated farm-gate surpluses, we incorporated a soil specific net N-leaching factor, derived from a National Monitoring Program where soil N surpluses of farms were linked to corresponding nitrate N-concentrations in groundwater and surface water (Schröder et al., 2005). Most agricultural soils in the Netherlands have a ‘‘high’’ to ‘‘very high’’ soil P status, and therefore it is assumed that the soils of the farms are saturated for P and that all surplus P is leached to groundwater and surface waters (Oenema et al., 2005).

On farm, ammonia volatilizes mainly in four ways: from manure in the stable, from the inside and outside manure storage, during grazing, and during application of manure and of artificial fertilizer. For milking cows, estimated emission in stable (including inside manure storage) was related to milk urea (Van Duinkerken et al., 2005). For non-producing cows, heifers and calves, fixed emissions were used based on the national regulation of animal husbandry (Van Geel, 2004). For milking cows, estimated nitrogen excretion was also related to milk urea (Schröder et al., 2006). For non-producing cows, heifers and calves, fixed nitrogen excretions were used (Tamminga et al., 2005). Subsequently, the nitrogen excretion of each animal was divided into nitrogen excretion during grazing and in stable, based on the grazing management and the number of days on pasture. Volatilization during grazing was computed as 8% of the amount of nitrogen excreted during grazing (Oenema et al., 2000). When an outside storage was present, we assumed that 55% of total excreted nitrogen in stable was stored outside (Oenema et al., 2000). Volatilization in the outside manure storage was computed as 4.8% for an open storage and 0.96% for a covered storage of the amount of nitrogen stored (Van der Hoek, 2002). Volatilization during application of manure was computed as a fixed fraction of total amount of nitrogen applied, dependent on: standard techniques to apply manure in the Netherlands according to manure type (solid/semi-liquid) and land type (grassland/arable land) (Van der Hoek, 2002). Volatilization during application of artificial fertilizer was computed as 2.6% of total amount of nitrogen applied (Van der Hoek, 2002).

Emission of nitrous oxide occurs directly from manure and from managed soils, and indirectly after nitrate leaching and after runoff of N and after redeposition of volatilized gasses to soils and waters (IPCC, 2006). Emission of nitrous oxide in stable, from outside manure storage and during grazing, was computed in case of milking cows, as 0.1% for semi-liquid manure in stable and outside storage, 2% for solid manure in stable and outside storage, and 2% during grazing of total amount of excreted nitrogen (Velthof and Oenema, 1997; Oenema et al., 2000). On farm, direct nitrous oxide emission from managed soils was calculated taking into account fertilizer application, nitrogen fixation, crop residues, and background emission (Mosier et al., 1998; IPCC, 2006). Indirect nitrous oxide emission was calculated taking into account nitrate leaching and N-deposition (Mosier et al., 1998; IPCC, 2006).

Off farm, ammonia volatilizes mainly in two ways: during application of manure and of artificial fertilizer for production of feed. Volatilization during application of manure was computed as a fixed fraction (domestic 4.8% for grassland and 13.8% for arable land; foreign 20%) of total amount of nitrogen applied (Mosier et al., 1998; Van der Hoek, 2002). In foreign countries volatilization is higher due to applying more manure above-ground and to applying more manure combined with straw. Volatilization during application of artificial fertilizer was computed as a fixed fraction (domestic 2.6% and foreign 10%) of total amount of nitrogen applied (Mosier et al., 1998; Van der Hoek, 2002). In foreign countries, volatilization during application of artificial fertilizer is assumed to be higher due to the lower bounding of ammonium in the artificial fertilizers used.

Off farm, direct and indirect nitrous oxide emissions of managed soils were calculated based on Mosier et al. (1998) and IPCC (2006).

2.2.3. Impact assessment (LCIA)

The LCIA is the stage in which data collected during the inventory analysis are processed, and environmental impacts are computed. Furthermore, environmental effects were assigned qualitatively to the selected impact categories, and environmental effects were quantified in terms of a common unit for that category (characterization). Table 4 shows selected impact categories with related units, contributing elements and characterization factors. Characterization factors for land use, energy use and climate change were chosen according to the Dutch LCA handbook (Guinée et al., 2002). According to the Dutch handbook, no site or regional dependent characterization factors for eutrophication and acidification were used (Huijbregts, 1999). Characterization factors for acidification were chosen from Heijungs et al. (1992).

2.2.4. Interpretation

In this stage results are analysed and evaluated, and conclusions and recommendations of the study are formulated. A contribution check in the interpretation phase identified elements that contributed most to a certain impact category, the so-called hotspots.

Table 4
Selected impact categories with related units, contributing elements and characterization factors[a]

Impact category	Unit	Contributing elements	Characterization factors	References
Land use	m^2	Land occupation	1 for all types of land use	Guinée et al. (2002)
Energy use	MJ	Energy consumption	1	
Acidification	kg SO_2-equivalents	SO_2	1	Heijungs et al. (1992)
		NH_3	1.88	
		NO_x[b]	0.70	
Climate change	kg CO_2-equivalents	CO_2	1	Houghton et al. (1994)[c]
		CH_4	21	
		N_2O	310	
Eutrophication	kg NO_3^--equivalents	NO_x[b]	1.35	Heijungs et al. (1992)
		P_2O_5	14.09	
		NH_3	3.64	
		NO_3^-	1	
		PO_4^{3-}	10.45	
		NH_4^+	3.6	
		COD[d]	0.22	

[a] Based on the Dutch LCA handbook (Guinée et al., 2002).

[b] NO and NO_2.

[c] Assuming a 100-year time horizon.

[d] Chemical oxygen demand; the amount of oxygen required to oxidize organic compounds in a water sample to carbon dioxide and water.

2.2.5. Statistical analyses

For statistical analyses we used SAS (SAS, 2002). Shapiro–Wilk test showed that data had a normal distribution. Data were further analysed with an analysis of variance (GLM procedure). The following analysis of variance model was used for the milk production systems:

$$Y_i = \mu + F_i + \varepsilon_i$$

where μ is the overall mean, F_i the overall effect of the farms and ε_i the error term.

3. Results

3.1. Land use

Table 5 shows results of this LCA study of the conventional and organic milk production system given by impact category. Total land use was less ($p < 0.001$) for the conventional system (1.3 m^2/kg FPCM, 7% Coefficient of Variation, CV) than for the organic system (1.8 m^2/kg FPCM, 22% CV). On-farm land use of the organic system (1.1 m^2/kg FPCM) was higher ($p < 0.01$) compared with the conventional system (0.64 m^2/kg FPCM), which was due mainly to lower yields (no use of artificial fertilizer and pesticides) and lower density (less animals per hectare) in the organic system. No differences were found in off-farm land use (about 0.7 m^2/kg FPCM) between the two systems. Off-farm land use of the conventional system consisted mainly (94%) of land required for production of purchased concentrates. Off-farm land use of the organic system consisted of land required for production of purchased concentrates (51%), and of purchased roughage (42%).

3.2. Energy use

Table 5 shows that total energy use was higher ($p < 0.001$) for the conventional system (5.0 MJ/kg FPCM, 13% CV) than for the organic system (3.1 MJ/kg FPCM, 28% CV). This higher use was due to a higher indirect energy use ($p < 0.001$) of the conventional system compared with the organic system. Direct energy use was lower ($p < 0.05$) for the conventional system (0.6 MJ/kg FPCM) than for the organic system (0.96 MJ/kg FPCM). Indirect energy use of both systems consisted mainly (83% conventional; 67% organic) of energy required for the production and transport of purchased concentrates.

3.3. Eutrophication

Table 5 shows that total eutrophication (in eutrophication potential) was higher ($p < 0.001$) for the conventional system (0.11 kg NO_3-equivalents/kg FPCM, 11% CV) than for the organic system (0.07 kg NO_3-equivalents/kg FPCM, 44% CV). This higher total eutrophication was due to a higher off-farm eutrophication of the conventional system compared with the organic system ($p < 0.001$) and a higher on-farm eutrophication of the conventional system compared with the organic system ($p < 0.05$). The contributions of the elements to total eutrophication were different: nitrate accounted for 32% in the conventional and for 40% in the organic system, phosphate accounted for 53% in the conventional and for 31% in the organic system, and ammonia accounted for 12% in the conventional and for 25% in the organic system.

On-farm eutrophication consisted mainly of leaching of nitrate, and phosphate, and of volatilized ammonia during application of fertilizer during production of on-farm feed and of volatilized ammonia from excreted manure in the stable, manure storage(s), and during grazing. In the conventional system, on-farm feed production contributed 90% and animals contributed 9% to on-farm eutrophication, whereas in the organic system on-farm feed production contributed 75% and animals 23% to on-farm eutrophication. On-farm leaching of nitrate and phosphate

Table 5
Results given in mean (standard deviation) of this LCA study of the conventional and organic milk production system given by impact category

Impact category	Unit		Milk production system		Significance[a]	Hotspot[b]	
			Conventional	Organic		Conventional	Organic
Land use	m^2/kg FPCM	On farm	0.64	1.1	**	Farm area	Farm area
		Off farm	0.64	0.7	–	C	C/R
		Total	1.3 (0.1)	1.8 (0.4)	***	Farm area/C	Farm area
Energy use	MJ/kg FPCM	Direct	0.6	0.96	*	D/G	D/E
		Indirect	4.4	2.17	***	C	C
		Total	5.0 (0.6)	3.1 (0.88)	***	C	C
Eutrophication	kg NO_3-eq/ kg FPCM	On farm	0.06	0.04	*	F	F/A
		Off farm	0.05	0.03	***	C	C/R
		Total	0.11 (0.01)	0.07 (0.03)	***	F/C	F/C/R
Acidification	g SO_2-eq/ kg FPCM	On farm	5.6	7.37	**	A/FA	A/FA
		Off farm	3.9	3.45	–	C	C/R
		Total	9.5 (0.8)	10.8 (1.9)	–	A/C	A/FA
Climate change	kg CO_2-eq/ kg FPCM	On farm	0.7	0.9	***	A/F	A
		Off farm	0.7	0.55	–	C	C/R
		Total	1.4 (0.1)	1.5 (0.3)	–	A/C	A/C/R

[a] $^*p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

[b] A = animals; C = concentrates; D = diesel; E = electricity; F = field; FA = fertilizer application; G = gas; R = roughage.

explain a large part of the results. Therefore, we included outcomes of the nutrient balances to gain more insight in differences between conventional and organic farms. Total N and P_2O_5-surplus per hectare was higher for conventional farms (222.9 N and 36.1 P_2O_5) than for organic farms (103.8 N and 7.0 P_2O_5) (Table 6). These higher values for conventional farms were due mainly to the higher input of concentrates and the input of artificial fertilizer for conventional farms. In addition, the net N-leaching factor was higher for conventional farms (0.37) than for organic farms (0.25), because conventional farms were situated on sandy soils, which have a higher net N-leaching factor whereas organic farms were situated on clay or peat soils and have a lower net N-leaching factor.

Off-farm eutrophication consisted mainly of leaching of nitrate, and phosphate, and volatilized ammonia during application of fertilizer by production of purchased concentrates and purchased roughage. In the conventional system, purchased concentrates contributed 92%, whereas in the organic system purchased concentrates contributed 60% and purchased roughage 36%.

3.4. *Acidification*

Table 5 shows that total acidification (in acidification potential) for the conventional system was 9.5 g SO_2-equivalents/kg FPCM (8% CV), and for the organic system 10.8 g SO_2-equivalents/kg FPCM (17% CV). Total and off-farm acidification did not differ between the systems. On-farm acidification was higher ($p < 0.01$) for the organic system (7.37 g SO_2-equivalents/kg FPCM) than for the conventional system (5.6 g SO_2-equivalents/kg FPCM). Ammonia was the element that accounted for most of total acidification (74% in the conventional and 81% in the organic system). On-farm acidification was caused mainly by: volatilization of ammonia from manure in the stable, from the inside and outside manure storage, during grazing, and during application of fertilizer. In the conventional system, manure in stable, storage, and during pasture contributed 52% and during application of fertilizer 41%, whereas in the organic system manure in stable, storage, and during pasture contributed 62% and during application of fertilizer 30%. Table 6 shows ammonia volatilization of stable, and storage, and during pasture, and during application of fertilizer per hectare of the conventional and organic farms. We expressed the ammonia emissions given in Table 6 per kg FPCM as well, taking into account given intensities of the selected farms (14713 kg FPCM/ha for the conventional and 8937 kg FPCM/ha for the organic farms) (Table 1). Ammonia volatilization of stable, and storage, and during pasture was slightly higher for conventional farms per hectare but lower per kg of milk (20.1 kg N/ha; 1.36×10^{-3} kg N/kg FPCM) compared with organic farms (18.8 kg N/ha; 2.1×10^{-3} kg N/kg FPCM). Ammonia volatilization during application of fertilizer was about twice as high for conventional

Table 6
Mean (standard deviation) nitrogen (N) and phosphate (P_2O_5) surplus in kg/ha per year by production system computed by means of a farm-gate balance

	Conventional		Organic	
	kg N/ha/year	kg P_2O_5/ha/year	kg N/ha/year	kg P_2O_5/ha/year
Input				
Fixation	15.7 (2.2)	–	64.5 (34.2)	–
Deposition	25.9 (0.9)	2.3 (–)	30.1 (7.6)	2.3 (–)
Animals	0.8 (1.7)	0.5 (1.1)	10.8 (28.9)	0.04 (0.1)
Concentrates	126.6 (31.6)	48.6 (10.7)	29.6 (18)	12.7 (8.5)
Artificial fertilizer	130.1 (42.8)	16.7 (11.7)	–	–
Roughage	8.4 (9.7)	2.6 (3.4)	41.2 (34.6)	12.7 (10)
Organic manure	6.4 (10.4)	3.6 (6.3)	9.9 (19.4)	4.5 (8.8)
Total	313.9 (38.9)	74.3 (15.2)	186 (56.8)	32.3 (13.7)
Output				
Animals	11.3 (3.9)	7.4 (2.6)	6.8 (3)	4.5 (2)
Milk	75.1 (12.3)	28.7 (4.6)	45.5 (13.6)	17.5 (5.5)
Roughage	3.5 (5.5)	1.4 (2.3)	10 (8.2)	3.8 (3.2)
Manure	1.2 (3.6)	0.7 (2.1)	19.8 (32.7)	9.1 (14.9)
Total	91 (13.8)	38.2 (6.3)	82.2 (38.6)	34.8 (17.7)
Surplus/ha	222.9 (38.9)	36.1 (11.2)	103.8 (59.6)	7.0 (9.5)
NH_3 volatilization				
Stable/pasture/storage	20.1 (4.5)		18.8 (4.3)	
Fertilizer application	19.6 (3.8)		9.4 (4.5)	
N_2O emission				
Stable/pasture/storage	1.3 (0.4)		1.9 (1)	
Field direct	3.6 (0.6)		1.8 (0.6)	
Indirect	1.9 (0.4)		1.1 (0.9)	
N-leaching factor	0.37 (0.06)		0.25 (0.2)	
Leaching/ha	64.2 (16.3)	36.1 (11.2)	21.1 (29.6)	7.0 (9.5)

farms per hectare but similar per kg of milk (19.6 kg N/ha; 1.33×10^{-3} kg N/kg FPCM) compared with organic farms (9.4 kg N/ha; 1.05×10^{-3} kg N/kg FPCM).

Off-farm acidification for the conventional system consisted of 83% of ammonia volatilization during production of purchased concentrates. Off-farm acidification for the organic system consisted of 43% of ammonia volatilization during production of purchased concentrates and of 37% during production of purchased roughage.

3.5. Climate change

Table 5 shows that total climate change (in global warming potential) for the conventional system was 1.4 kg CO_2-equivalents/kg FPCM (6% CV) and for the organic system 1.5 kg CO_2-equivalents/kg FPCM (17% CV). Total and off-farm climate change did not differ between the systems. On-farm climate change was higher ($p < 0.001$) for the organic system (0.9 kg CO_2-equivalents/kg FPCM) than for the conventional system (0.7 kg CO_2-equivalents/kg FPCM). Contributions of the elements to total climate change were different: methane accounted for 34% in the conventional system and for 43% in the organic system, nitrous oxide accounted for 38% in the conventional and for 40% in the organic system, and carbon dioxide accounted for 29% in the conventional and for 17% in the organic system.

On-farm climate change consisted mainly of methane emission during enteric fermentation and manure management, direct nitrous oxide emission of manure and of managed soils, and indirect nitrous oxide emission after leaching and redeposition of volatilized gasses to soils and waters. In the conventional system, animals and manure contributed 68% and managed soils 24%, whereas in the organic system, animals and manure contributed 76% and managed soils 16%. It can be derived from Table 6 that direct and indirect nitrous oxide emissions per kg of milk were higher for the organic farms (5.4×10^{-4} kg N/kg FPCM) than for the conventional farms (4.6×10^{-4} kg N/kg FPCM).

Off-farm climate change consisted mainly of direct and indirect nitrous oxide emissions, carbon dioxide emissions of fossil fuels during production, and transport of purchased concentrates and roughage, in addition to nitrous oxide and carbon dioxide emission during production of artificial fertilizers. In the conventional system, purchased concentrates contributed 87%, whereas in the organic system purchased concentrates contributed 51% and purchased roughage 38%.

4. Discussion

In this study, we used LCA to gain insight into the integral assessment of the environmental impact of conventional and organic milk production systems in the Netherlands, as a case study. The potential environmental impact of a milk production system, as computed with an LCA, differs from the actual environmental impact for several reasons. First, it is difficult when performing an LCA of commercial farms to measure actual emissions or leaching on a farm. Instead, generally recognized standards or formulas based on experiments are used to assess emissions and leaching, using real farm data where possible.

Second, accurate environmental inventory data are not always available. In some cases, for example, data represented economic figures, because they were collected for purposes other than this LCA study. The effect of supply changes should in favour be addressed when assessing milk production. No data, however, were available for changes in supply of roughage, concentrates, and manure on the farms. The literature shows that the effect of change in supply is assumed to be small. Farms can have a negative or positive change in supply. The effect of change in supply on the differences between the systems is decreased by the large variation in integral environmental impact of the farms.

Comparing different systems producing similar products requires a high degree of accuracy for inventory data (Basset-Mens and Van der Werf, 2005). Furthermore, Basset-Mens and Van der Werf (2005) state that a large amount of data needs to be available, representative of the systems to be evaluated. In total, 21 commercial dairy farms were analysed, at least 10 farms representing each production system, which is large compared with earlier LCA studies of milk production systems. Although this sample size is rather large, the farms were not chosen at random, and therefore, do not represent the total Dutch conventional and organic milk production.

In addition to inventory data and sample size, methodological choices affect final results. One choice of methodology, for example, is the question of how to handle co-products. Within attributional LCA of milk production, using economic allocation is justified, assuming a static situation (Guinée et al., 2004). Within consequential LCA of milk production, however, system expansion is preferred assuming a change-oriented situation (Weidema, 2003; Dalgaard et al., 2006). We used economic allocation, because this study was a descriptive attributional LCA. A second choice of methodology is the impact categories. No consensus has been reached yet on how to include land use effects such as soil quality and biodiversity (Milà i Canals et al., 2006). We included only land use impacts in the LCA whereas several land quality issues might be better in organic production. In addition, we did not include the effects of pesticides, because of methodological issues, although another benefit from organic production is that no pesticides are used.

Taking into account the methodological constraints of this LCA-study mentioned above, we will first compare the integral assessment of the environmental impact of the conventional and organic systems, and then we will discuss identification of hotspots. The higher total land use per kg FPCM of the organic farms compared with the conventional farms implies that feeding less concentrates but more roughage, and producing a large part of the feed on farm with lower yields (no use of pesticides and artificial fertilizer), results in a higher use of on-farm land per kg milk produced. The similar off-farm land use for conventional and organic farms is because purchased organic concentrates contain a higher amount of main products compared with conventional concentrates, and main products carry the entire land use. In addition, production of organic concentrate ingredients requires in general more land due to lower yields, compared with conventional concentrate ingredients, because no fertilizer and pesticides are used. Lower indirect energy use and higher direct energy use per kg FPCM for organic farms compared with conventional farms implies that feeding more feed produced at farm level, feeding less concentrates, and using no pesticides and artificial fertilizers results in a lower total energy use per kg FPCM. The higher on-farm acidification potential per kg FPCM of the organic farms compared with conventional farms, can be because more animals were needed per kg milk produced for organic farms. No difference between the conventional and organic farms was found in off-farm acidification potential. Off-farm acidification potential for conventional farms consisted mainly of purchased concentrates, partly produced in foreign countries, whereas off-farm acidification potential for organic farms consisted of purchased roughage, mainly of national origin, in addition to purchased concentrates. On-farm acidification for organic farms, furthermore, was higher than for conventional farms. More ammonia emission occurs nationally on organic farms compared with conventional farms. On-farm global warming potential per kg FPCM for organic farms was higher than for conventional farms, because more animals were needed per kg organic milk produced, and enteric methane emission was assumed to be higher for each organic milking cow. The lower eutrophication potential per kg FPCM for organic farms than for conventional farms implies that feeding less concentrates but more roughage, producing a large part of the feed on farm, and using no artificial fertilizer results in a lower on and off-farm eutrophication potential.

Impact categories acidification and eutrophication also have a local and regional impact. These two impact categories, therefore, were also expressed in on-farm impact per ha farm area (Thomassen and De Boer, 2005). Although on-farm acidification potential per kg FPCM was higher for organic farms than for conventional farms, the on-farm acidification potentials per ha farm area were similar. An explanation for this result is that organic farms produced less milk per hectare than conventional farms. The on-farm eutrophication potential per ha farm area was lower for organic farms than for conventional farms. This result was the same for the product-related eutrophication (in kilogram milk).

A contribution analysis for the hotspot identification showed of all impact categories that purchased concentrates contributed most to the off-farm impact for conventional farms. Purchased concentrates contributed most to the indirect impact of energy use for organic farms, whereas for the other impact categories both purchased concentrates and purchased roughage contributed most to the off-farm impact for organic farms. Farmers, however, can only influence purchased amount of concentrates, but hardly composition, when purchased. Subsequently, farmers can hardly change the environmental impact of one kilogram of purchased concentrates. The environmental impact of concentrates consists mainly of transport and processing of certain ingredients in addition to cultivation of the crops.

We compared our hotspot identification with outcomes of a Dutch study in which 12 conventional farms that aim at efficient use of nitrogen and phosphorus were analysed using the LCA methodology with reference year 2002 (Werkman, 2005). Concentrates contributed around 70% to the off-farm impact of all impact categories in that study, which is similar to our hotspot identification for conventional farms.

We also compared our LCA outcomes with results of two Swedish studies and one German study (see Table 7). The Swedish ('96) study compared conventional and organic systems based on data of two specialised experimental farms (Cederberg and Mattson, 2000). Differences in environmental impact between the two systems could not be analysed statistically in this Swedish LCA case study because only two farms were analysed. The Swedish ('01/'02) study compared conventional high-production, conventional medium-production, and organic system based on data of 23 commercial farms (Cederberg and Flysjö, 2004). The German ('98) study compared conventional intensive, conventional extensive, and organic systems based on data of 18 commercial farms (Haas et al., 2001). Only differences and not actual numbers between the different systems in the studies can be compared, because of differences in computational methods (De Boer, 2003).

Our results on land use (organic higher) and energy use (conventional higher) agree with all three studies (Table 7). The similar climate change of conventional and organic milk production agrees with the German ('98) study and the Swedish ('01/'02) study. Our result for product-related acidification (in tonnes milk) agrees with the German ('98) study and agrees with the Swedish ('01/'02) study. Our result for product-related eutrophication (in tonnes milk) was lower for organic production and agrees with the German ('98) study. In the Swedish ('01/'02) study, organic production had the highest emission of ammonia and highest leaching of nitrate per kg milk, which resulted in a 25% higher product-related eutrophication, but this increase was not significant compared with conventional production. In the German ('98) study, the conventional production had a higher area-related acidification (136 and 119 kg SO_2-equivalents/farm ha) and eutrophication (566 and 326 kg NO_3-equivalents/farm ha) compared with organic production (107 kg SO_2-equivalents/farm ha;

Table 7
Results of two Swedish (Cederberg and Mattson, 2000; Cederberg and Flysjö, 2004) and one German (Haas et al., 2001) LCA studies compared with results of this Dutch study (Dutch$^{'03}$) rounded to two digits

Case and year of data	Number of farms	Production system	Land use	Energy use	Climate change	Acidification		Eutrophication	
			m^2/t milk	GJ/t milk	kg CO_2-equivalents/t milk	kg SO_2-equivalents/		kg NO_3-equivalents/	
						t milk	farm ha	t milk	farm ha
Swedish$^{'96}$	1	Conventional	1900	3.6	1080	18	130	61[a]	450
	1	Organic	3500	2.5	950	16	50	68	220
German$^{'98}$	6	Conventional intensive	–	2.7	1300	19	140	78[b]	570
	6	Conventional extensive	–	1.3	1000	17	120	47	330
	6	Organic	–	1.2	1300	22	100	29	140
Swedish$^{'01/'02}$	9	Conventional high	1500	2.6	900	10	–	39	–
	8	Conventional medium	1900	2.7	1040	10	–	43	–
	6	Organic	2900	2.1	940	12	–	52	–
Dutch$^{'03}$	10	Conventional	1300	5.0	1400	10	140	108	1600
	11	Organic	1800	3.1	1500	11	100	67	600

[a] Eutrophication potential was given in O_2-equivalents and is transformed to NO_3-equivalents.
[b] Eutrophication potential was given in PO_4-equivalents and is transformed to NO_3-equivalents.

141 kg NO_3-equivalents/farm ha) which agrees with our results.

5. Conclusion

This LCA case study, based on 10 conventional and 11 organic farms showed better environmental performance concerning energy use and eutrophication potential per kilogram of milk for organic farms than for conventional farms. Furthermore, higher on-farm acidification potential and global warming potential per kilogram organic milk implies that higher ammonia, methane, and nitrous oxide emissions occur on farm per kilogram organic milk than for conventional milk. Total acidification potential and global warming potential per kilogram milk did not differ between the selected conventional and organic farms. In addition, results showed lower land use per kilogram conventional milk compared with organic milk. Purchased concentrates was found to be the hotspot in the selected conventional farms in off farm and total impact for all impact categories. Whereas in the selected organic farms, concentrates was found to be the hotspot in off farm impact besides roughage.

Based on this LCA case study, we recommend to improve integral environmental performance of milk production by: (1) reducing the use of concentrates ingredients with a high environmental impact, (2) decreasing the use of concentrates per kilogram of milk, and (3) reducing nutrient surpluses by improving farm nutrient flows. In addition, we recommend further studies to focus on performing LCA's of concentrates ingredients in collaboration with Dutch feed suppliers. Environmental aspects should be taken into account together with cost price and nutritional aspects, for selecting concentrates components. We recommend also to enlarge integral assessment of the environmental impact of milk production systems by increasing the number of farms over several years.

Acknowledgements

The authors express their gratitude to the Dutch Ministry of Agriculture, Nature Conservation and Food Quality for financial support (Programme 415). The authors are also grateful to Roelien Werkman, Jolanda Jansen, Leonie 's Gravendijk, Théo Viets, Eddie Bokkers, the farmers and researchers participating in the projects Koeien en Kansen, Caring Dairy and Bioveem II for their contribution to this research. Valuable suggestions from Reinout Heijungs of CML, Leiden University and Mike Grossman, University of Illinois, are gratefully acknowledged.

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