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Assessment of environmental effects, animal welfare and milk quality among organic dairy farms

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ABSTRACT

Within the organic dairy farming sector in Germany, traditional mixed farms with relatively low yearly milk yields of around 6000 kg per cow exist beside highly specialised grassland based farms with more than 9000 kg milk yield per cow and year. Specialisation and intensification are discussed critically within the organic sector as negative environmental effects are expected. In this study the potential environmental impacts of four different types of organic dairy farms are compared, based on a survey of 27 organic dairy farms classified by a percentage of grassland on total farm area and feeding intensity. The analysed environmental impact categories were energy consumption, climate impact, land demand, ammonia emissions, nitrate leaching, conservation of soil fertility, biodiversity, animal welfare and milk quality. Farms with a high feeding intensity tended to show ecological advantages in the impact categories climate impact and land demand. In contrast, low-input farm types showed positive environmental effects in the impact categories animal welfare, milk quality and ammonia losses. In an overall environmental index, the farm type "low-input mixed farming" showed the best results. The hypothesis that farms orientated on the traditional principles of organic farming tend to have less negative environmental effects even within the range of organic dairy farms is hereby confirmed. However, further research is needed to affirm the methodology used to quantify the environmental effects in the categories of animal welfare and milk quality. The results show that focussing only on the classical environmental impact categories, e.g. energy consumption and climate impact, may lead to different results than a more complex system approach that considers a broader range of relevant impacts and ecological benefits.

1. Introduction

While an ecological advantage of organic compared to conventional milk production has already been shown by several studies (e.g. Cederberg, 1998; Bockisch, 2000; Haas et al., 2001; Stonehouse et al., 2001; de Boer, 2003), there are only few studies concerning different dairy farm types within the organic sector (Weller & Bowling, 2004; Olesen et al., 2006; Mogensen et al., 2007; King et al., 2007). The high variability of farm characteristics within the organic dairy sector in Germany raises the question whether relevant differences in the environmental impact of organic dairy farms with different production structure and feeding intensity can be detected. The objective of this study was a systemic comparison of different dairy farm types within the organic dairy sector in Germany considering intra-farm interactions and all relevant environmental impact categories. The methodology of agricultural life cycle assessment (LCA) was applied and improved for the specific needs of this study.

2. Materials and methods

2.1. Farm survey and definition of farm types

The presented study was based on a survey of 27 organic dairy farms in the German Bundesland North Rhine–Westphalia (NRW). All analysed farms were certified organic

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Table 1
Classification of survey farms to farm types.

	Farm types			
Production structure	Grassland		Mixed farming/tilth	
Intensity	Low	High	Low	High
Number of farms	7	6	7	7
Abbreviation	EXT_GL	INT_GL	EXT_TL	INT_TL

according to EU regulation 2092/91 and produced milk as main product. The farms were classified into four groups according to the percentage of grassland on the total farm area and further by the feeding intensity determined by the amount of concentrate used per cow and year (Table 1). At all farms, data concerning climate and soil, crop rotation, grassland management, ration, milk yield, herd performance, upbringing of heifers for replacement, purchases and sales as well as working methods were collected through interviews with the farmers and bookkeeping data from a minimum of two years from each farm. Additionally, fodder quality of roughage was analysed (e.g. dry matter, net energy content for lactation, crude protein, rumen degradable protein, crude fiber, crude lipid, phosphorus, potassium). Data from the economic years 1999/2000 to 2005/2006 were used. All collected data were checked for consistency. A single data set for each farm was defined based on the available year data sets. In a second step, a model farm type for each of the four farm groups was defined. These model farm types represent the common features within each group and the characteristic differences between the groups and provide consistent datasets that can be used for model calculations. For best achieving the two aims — consistency of data sets and representation of group characteristics — most important properties were defined by group means or by choosing values that occur exclusively or most frequently in the specific group. Remaining characteristics were set by consistent completion (e.g. amounts of purchased fodder depending on herd size, performance, on farm production and type of ration). This approach is necessary because simple averaging of all parameters does not necessarily lead to consistent data sets.

2.2. Assessment methodology

The analysis of environmental effects was based on the methodology developed for agricultural life cycle assessment by Wetterich, Haas and Geier (Geier et al., 1999; Haas et al., 2000; Geier, 2000; Wetterich, 2004), which was adopted to the specific needs of this study. The analysed impact categories are described in Table 2. The standard categories of organic lifecycle assessment have been complemented by the category "milk quality" as different feeding patterns are expected to have effects on the content of conjugated linoleic acids and omega-3-fatty acids in milk, which have positive health effects (Jiang et al., 1996; Kelly et al., 1998; Dhiman et al., 1999; Chouinard et al., 2001; Collomb et al., 2001; Ward et al., 2003; Havemose et al., 2004). Since one of the main objectives in organic farming is to produce particularly healthy food (IFOAM, 2002), milk quality is a suitable indicator in the assessment of organic dairy farm types.

Table 2
Assessed impact categories: units, indicators and most important references.

Impact category	Unit	Indicators	References
Global impact categories			
Energy consumption	MJ/kg milk	Direct energy: fuels, electricity. Indirect energy: primary energy for Machinery, purchased fodder and fuel supply	Arman, 2003; Borken et al., 1999; Cederberg, 1998; Gaillard et al., 1997; Gemis 4.3, 2006; KTBL, 2002, 2004
Climate impact	g CO_2-Equiv./kg milk	CH_4 from enteric fermentation and manure N_2O from manure and fields CO_2 from energy consumption	Anger, 2001, Hayer, 1994; Hüther, 1999; IPCC, 2007; Kirchgessner et al., 1991; Kirchgessner, 1997; Mosier et al., 1998; Velthof & Oenema, 1995
Land demand	ha/1000 kg MILK	Farm land demand for fodder production (farms own land and estimated land demand for production of purchased fodder compounds)	(Own calculations)
Regional and local impact categories			
Nitrogen emissions	kg NO_3/ha	NO_3	Anger, 2001; Arman, 2003; Wolfensberger & Dinkel, 1997; Köpke, 1996
	kg NH_3 /ha	NH_3	Anger, 2001; Dewes & Hünsche, 1998; Döhler et al., 2002; Ferm, 1998; Mannheim, 1996
Soil fertility conservation	Rating [0–10 points]	Humus	Leithold et al. (1997)
		Compaction	Agriview, 2000; KTBL, 2004; Wolfensberger & Dinkel, 1997
		Erosion	Billen et al., 2002; Sauerborn, 1994; Schwertmann et al., 1987
Biodiversity	Rating [0–10 points]	Driving forces: nitrogen supply, time and frequency of cuts in grasslands, habitat quality of crop rotation, diversity of cultivated plants	Deittert et al., 2008; Frieben, 1998; Schumacher, 1995
Animal welfare	Rating [0–10 points]	Pasturing, access to free range, fiber content of ration, milk cells, horn amputation	Alroe et al., 2001; de Brabander et al., 1999; Emmert, 2001; GfE, 2001; Kielwein, 1994; Hoffmann, 1990; Lund & Algers, 2003; Lund, 2006; Sundrum et al., 1994; Rollin, 1993
Milk quality	Rating [0–10 points]	Ration composition and its assumed effects on milk content of omega-3-acids, CLAs and antioxidatives	Dhiman et al., 1999; Dewhurst et al., 2003; de Wit et al., 2006; Havemose et al., 2004; Kelly et al., 1998; Morel et al., 2005; Schaeren et al., 2005; Ward et al., 2003,

Table 3
Standard yields for purchased fodder and assumed transport distances.

Fodder	Main product yield [dt DM/ha]	Transport distance
Compound fodder [a]	32	Farm to retailer: see below, 100 km from retailer to farm
Wheat	40	100 km
Rye, barley, oat	35	100 km
Potatos	105	100 km
Lupines	25	100 km
Field beans	35	100 km
Rapeseed (for rapeseed cake)	15	50 km seed from farm to oil mill, 50 km cake from oil mile to farm or retailer
Sunflower	20	50 km seed from farm to oil mill, 50 km cake from oil mile to farm or retailer
Bran (oat bran, wheat bran)	37	100 km from farm to mill, 100 km from mill to farm
Soybeans	25	10.000 km farm (Brazil) to factory, 100 km factory to farm
Sugar beets (for molasses)	150	20 km sugar beets from farm to factory, 50 km molasses from factory to farm

[a] 40% wheat, 20% field beans, 15% oat bran, 25% sunflower cake.

2.2.1. Scope definition and functional units

Regional environmental effects (ammonia emissions and nitrate leaching) were assessed based on the area, because negative effects can be compensated only within the same region (Haas et al., 2000; Geier, 2000 S.55; Halberg et al., 2005). Global environmental effects (energy consumption, climate impact and land demand) were assessed product based, because negative environmental effects caused in one place can be compensated elsewhere. The categories soil fertility, biodiversity, animal welfare and milk quality were assessed through a rating scale.

In global and therefore *product related impact categories* (energy consumption, climate impact and land demand), only processes directly linked to milk production were taken into account. These were housing of dairy cows and upbringing of heifers needed for replacement, cultivation or purchase of fodder, and supply of fuels and machinery needed for the related production processes. In categories *with regional or local impact,* the whole farm was assessed. In these categories, environmental effects cannot be attributed to a single production branch. For example, in order to estimate nitrate leaching, the whole crop rotation has to be taken into account as the leaching potential cannot be allocated to a single crop and thus, not to a specific production branch.

2.2.2. Inventory analysis

The assessment of *energy consumption* included fuel and electricity used in dairy production (including fodder production) and the indirect energy used for machinery, fodder and fuel supply. For purchased fodder, standard production methods were assumed.

In the category *climate impact*, the enteric methane emissions from dairy cows were calculated through a detailed method using the following formula (Kirchgessner et al., 1991; Kirchgessner, 1997): $CH_4\,[g] = 63 + 26\,XP + 79\,XF + 10\,NfE - 212\,XL$ (with XP: crude protein [kg]; XF: crude fibre [kg]; NfE: nitrogen free extract [kg]; XL crude lipids [kg]).

For enteric methane emissions from non dairy cattle, the following emission factors have been used: 20 kg methane

Table 4
Ranking system for biodiversity.

	Ranking points			
	0	1	2	3
Intensity of grassland cultivation				
Kg N/ha from organic fertilizers	>=140	<140	<100	<50
Number of harvests	4	3	2	1
Date of first harvesting				
NRW<200 m o. NN	Before May 20.	May 20–May 31	June 1–June 15.	After June 15.
NRW 200–400 m o. NN	Before June 1.	June 1–June 14.	June 15–July 1.	After July 1.
NRW>400 m o. NN	Before June 15.	June 15–June 30.	July 1–July 15.	After July 15.
Achievable ranking points: 9				
Biotope quality of crop rotation	0	1	2	
% of cropland				
Cereals	<30% or >65%	30–45% or 55–65%	45<x−<55%	
Late root crops, vegetables	<10% or >30%	10–15% or 25–30%	15<x<25%	
Green legumes (clover, alfafa) (2 years of cultivation)	<15% or >45%	15–25% or 35–45%	25<x<35%	
Achievable ranking points: 6				
Diversity of cultivated crops	0	1	2	3
Shannon-Index	<1.25	<1.725	<2.2	>=2.2
Achievable ranking points: 3				
Achievable rating points in total [v_r]: 0–18				
Achievable rating point standardized [$v_s = v_r/18*10$]: 0–10				

per animal and year for calves of 0–12 months, 60 kg for heifers of 12–24 months and 100 kg for non dairy cattle of more than 24 months (Hayer, 1994). Methane emissions from manure were calculated using the conversion factor 2.5% for solid manure, 30% for slurry and 1.5% for pasture, assuming maximum emissions of 345 kg per dairy cow and 120 kg per livestock unit for all other cattle (Hayer, 1994; Hüther, 1999).

N_2O emissions were calculated using the emission factors described by Mosier et al. (1998): 1.25% of the N-input to soils, 2.5% of potential nitrate leaching and 1% of the ammonia and NO_x emissions. CO_2 — emissions resulted directly from energy consumption. For conversion from MJ to CO_2-equivalents, the factors published by Borken et al. (1999) and the GEMIS 4.3 database were used.

Land demand includes the area needed for fodder production on the farm and the assumed area needed for the cultivation of purchased fodder. The latter was calculated based on standard yields (Table 3).

Ammonia emissions were calculated using the following emission factors: For emissions from animal housing 12% (Döhler et al. 2002); for emissions from manure storage, 8% for slurry and 25% for solid manure (Döhler et al. 2002); and for emissions during and after application, 8–23% for arable land and 12–35% for grassland, depending on the application technology (Mannheim, 1996, Anger, 2001). For pasture, the emissions have been calculated using the model of Anger (2001), summing up to an average emission factor of 10%.

Potential *nitrate leaching* was estimated based on nitrogen field balances, taking into account an atmospheric nitrogen deposition of 20 kg per ha, atmospheric nitrogen emissions (NH_3, N_2O), nitrogen fixation in humus (50 kg N per t of humus, using the humus balance factors defined by Leithold et al., 1997) and symbiotic nitrogen fixation (kg N per t harvested green legume dry matter: 30 kg for grassland and 40 kg for temporal fodder legumes (Stein-Bachinger et al., 2004); for grain legumes: nitrogen in harvest of grain (Köpke, 1996)).

Soil fertility conservation, biodiversity, animal welfare and milk quality were assessed with a qualitative approach by defining a ranking scheme. The ranking points of the four ranking schemes were standardized to the 0–10 scale with 10 as the best achievable result.

The ranking of the category *soil fertility* is based on the three indicators humus-balance, erosion and compaction. Humus balance was calculated by using the methodology proposed by Leithold et al. (1997). The scale ranks from humification of >0.005% in 10 years (10 points) to humus losses of more than 0.2% of total soil matter in 10 years (0 points). Compaction was calculated based on the methodology of weighted soil pressure used by Wolfensberger and Dinkel (1997). 10 points are achieved for fields with less than 200 kPa soil pressure and 0 points for more than 800 kPa. The risk of erosion was estimated with the assessment system developed by Billen et al. (2002). The total ranking points in the category soil fertility was the average of the ranking inventories of the three indicators.

Table 5
Ranking system for animal welfare of dairy cows.

		Ranking points and assessment criteria				Weighting
Housing	Indicators	0	1	2	3	1
Food intake	Pasturing [% of ration]	<20%	20%–50%	50%–80%	>80%	
Motion behaviour	Stocking rate [a]	<0.1 ha/cow	0.1–0.2 ha/cow	0.2–0.3 ha/cow	>0.3 ha/cow	
	Pasturing [h per day in summer]	<1 h	1–6 h	6–12 h	>12 h	
	Free range	No	Some hours a day		Always accessible	
Social behaviour	Stocking rate [a]	<0.1 ha/cow	0.1–0.2 ha/cow	0.2–0.3 ha/cow	>0.3 ha/cow	
	Pasturing [h per day in summer]	<1 h	1–6 h	6–12 h	6–12 h	
	Free range	No	Some hours a day		Always accessible	
Resting behaviour	Pasturing [h per day in summer]	<1 h	1–6 h	6–12 h	6–12 h	
Hygiene	Stocking capacity [b]	<0.15 ha/cow	0.15–0.3 ha/cow	0.3–0.5 ha/cow	>0.5 ha/cow	
	Pasturing [h per day in summer]	<1 h	1–6 h	6–12 h	6–12 h	
Achievable rating points: 0–30						
Feeding		0	1	2	3	5
Fibre intake	intake of structural raw fiber (kg per cow and day) [c]	<2.5 kg	2.5–2.75 kg	2.75–3 kg	>3 kg	
Achievable rating points: 0–15						
Health		0	1	2	3	2.5
Amputation of horns		Horns amputated			Horns not amputated	
Somatic cells content		>200,000	150,000–200,000	100,000–150,000	<100,000	
Achievable rating points: 0–15						
Achievable rating points in total $[v]_r$: 0–60						
Achievable rating point standardized $[v_s = v_r/60*10]$: 0–10						

[a] Stocking rate: average pasture area accessible on a specific pasture day per cow.
[b] Stocking capacity: total farm land that is used for pasturing per cow.
[c] Structural raw fibre is defined as 50% of total raw fibre for chopped silage and 100% for non chopped silage, hay and grazing.

Table 6
Ranking scheme for milk quality. The total ranking is calculated by multiplying the ranking of each fodder compound with the share of dry matter of this compound in the dairy cows ration.

Fodder	Ranking	Reasons for ranking (differences in milk quality compared to standard)
Pasture	3	Higher contents of conjugated linoleic acids (CLAs), tendentially higher contents of Omega-3-fatty acids
Clover/alfalfa hay	2	Significant positive effect of legumes compared to grasses and tendentially positive effects of silage free rations on CLAs and Omega-3-fatty-acids
Clover/alfalfa silage	1	Significant positive effect of legumes compared to grasses on CLAs and Omega-3-fatty- acids
Grassland hay	1	Positive effects of silage free ration
Grassland silage	0	Standard
Grain silage	0	(No results available)
Corn silage	−2	Significant negative effects on content of CLAs, Omega-3-fatty-acids and antioxidatives.
Concentrates	−2	Significant negative effects on CLA- und Omega-3-fatty-acid contents
Achievable rating points in total [v_r]: 0–3		
Achievable rating point standardized [$v_s = v_r/3 * 10$]: 0–10		

In the category *biodiversity*, rather than estimating state indicators such as the total number of species at the assessed farm, driving forces directly related to the farm structure and feeding intensity were included to a ranking scheme. This way, the ranking system expresses how the potential biodiversity of the specific site is influenced by the farm management. State indicators are not suitable to be used because individual side conditions may overlay the effects of production measures. The ranking scheme is described in Table 4.

The assessment of *animal welfare* was oriented on the organic principle of naturalness and integrity (Alroe et al., 2001, Lund & Algers, 2003, Lund, 2006). As in the category biodiversity, a ranking based on driving factors was defined (Table 5).

The potential *milk quality* was deducted from the effects of ration composition on the milk content of conjugated linoleic acids (CLAs), omega-3-fatty acids and antioxidatives. The ranking scheme is described in Table 6. The total ranking was calculated by multiplying the ranking points of each fodder compound by the percentage of this fodder compound within the total ration.

The assessment of environmental effects was carried out for all real farms and for the model farm types. The differences between the farm groups were checked for statistical differences with Mann–Whitney-*U*-Test at $\alpha = 0.05$.

Based on the inventory results, an overall index was calculated by averaging the standardized analysis results of all categories. In order to determine a standardized value v_i of the categories which were not assessed by a ranking, the best result achieved by any practical farm ($\max_i$) was defined as 10 and the lowest one as 0 ($\min_i$). The standardized value v_i is then defined as follows: $v_i = (\max_i - r_i)/(\max_i - \min_i) * 10$.

3. Results

The farm groups defined by region, percentage of grassland and concentrate use differ in multiple farm characteristics. More intensive farms are generally larger, both with respect to farm area and herd size. They achieve significantly higher milk yields per cow. The replacement rate tends to be lower in less intensive farms. Less intensive farms feed a significantly higher percentage of pasture. Low-input tilth farms use very little purchased fodder (Table 7). Intensive farms add soybean cake mostly from overseas soybean production to fulfil the protein requirements of their high performing cows. The overall results of the inventory of environmental indicators are shown in Table 8.

The *energy consumption* of the different farm groups does not differ significantly. Tendentially, intensive grassland based farms and low-input tilth farms have a higher energy demand than low-input grassland farms and intensive tilth farms. The lower energy demand of intensive tilth farms is mainly caused by the use of corn silage as energy efficient fodder compound. The high energy demand of the intensive grassland based dairy system is caused by the high amount of purchased feedstuff.

The *climate impact* of the intensive tilth based farm type INT_TL was significantly lower than the climate impact of the low-input, grassland based farm type EXT_GL and tendentially lower than the climate impact of the intensive grassland based farm type and the low-input tilth farm type. The main source of greenhouse gas emissions are the methane emissions from enteric fermentation. Traditional low-input rations containing more fibre and less protein cause higher

Table 7
Characteristics of farm types. In brackets: range of values in survey farms. Groups marked with different letters differ significantly at $\alpha = 0.05$ in Whitney-*U*-Test.

Character	Unit	EXT_GL	INT_GL	EXT_TL	INT_TL
Farm area	ha	65 ^{c} (29–114)	110 ^{b} (69–222)	65 ^{bc} (34–118)	115 ^{b} (63–318)
Size of herd	Heads (dairy cows)	45 ^{b} (26–67)	75 ^{a} (53–199)	35 ^{b} (26–44)	85 ^{a} (42–158)
Total stocking density	Livestock units per hectare farm area	1.2 ^{ab} (0.9–1.9)	1.4 ^{a} (1.2–1.7)	1.0 ^{b} (0.8–1.5)	1.2 ^{ab} (1.0–1.5)
Replacement rate	%	24% ^{ab} (14–38)	35% ^{a} (28–41)	20% ^{b} (9–32)	29% ^{ab} (24–33)
Milk yield	kg milk/cow and year	6000 ^{b} (5480–6910)	8400 ^{a} (7686–9216)	5600 ^{b} (4500–7158)	7600 a (6631–8553)
Feeding intensity	t DM of concentrates / cow and year	0.9 ^{bc} (0.2–1.4)	2.2 ^{a} (1.6–2.7)	0.4 ^{c} (0–0.7)	1.1 ^{b} (0.9–1.9)
Roughage yield*	t DM per ha	7.5 ^{a} (6.3–8.8)	7.5 ^{a} (6.7–8.7)	8.2 ^{a} (6.0–8.0)	8.6 ^{a} (6.2–9.2)
Share of pasture in dairy cow ration	% of DM in summer half-year	50% ^{a} (29–85)	15% ^{b} (10–25)	60% ^{a} (29–80)	25% ^{b} (17–31)

*Including grass, fodder legumes, corn silage and grain silage.

Table 8
Results of inventory: environmental impact of the model farms. In brackets: Range of results for the underlying group of survey farms. Groups marked with different letters differ significantly at $\alpha=0.05$ in Whitney-*U*-Test.

Category	Unit	EXT_GL	INT_GL	EXT_TL	INT_TL
Energy consumption	MJ/kg milk	1.20 [a] (1.04–1.51)	1.52 [a] (1.17–1.93)	1.32 [a] (0.87–1.97)	1.17 [a] (1.14–1.57)
Climate impact	g CO_2-equiv./kg milk	1172 [b] (753–1264)	1036 [bc] (853–1048)	1082 [abc] (645–1441)	917 [c] (763–1033)
Land demand	ha/1000 kg milk	0.31 [ab] (0.21–0.40)	0.27 [bc] (0.18–0.27)	0.28 [a] (0.19–0.47)	0.22 [c] (0.16–0.23)
Arable land demand	ha/1000 kg milk	0.07 [c] (0.01–0.09)	0.10 [bc] (0.07–0.13)	0.03 [d] (0.03–0.08)	0.10 [b] (0.07–0.12)
Ammonia emissions	kg NH_3/ha	44 [b] (28–70)	48 [a] (40–55)	24 [c] (18–29)	39 [bc] (21–47)
Nitrate leaching	kg NO_3/ha	64 [a] (32–104)	122 [a] (49–270)	86 [a] (19–157)	95 [a] (23–175)
Soil fertility	Ranking [standardized to 0–10 points scale]	8.7 [a] (8.1–8.9)	8.7 [a] (8.0–8.7)	7.7 [b] (6.4–8.2)	7.0 [b] (5.2–8.3)
Biodiversity	Ranking [standardized to 0–10 points scale]	2.2 [ab] (0–3.4)	0 [a] (0–2.2)	2.8 [ab] (1–4.5)	1 [ab] (1–4.1)
Animal welfare	Ranking [standardized to 0–10 points scale]	6.5 [ab] (2.5–8.6)	3.1 [b] (2.0–3.2)	8.4 [a] (3.3–9.0)	3.8 [b] (2.7–4.6)
Milk quality	Ranking [standardized to 0–10 points scale]	4.7 [a] (2.9–7.7)	2.8 [b] (2.0–3.1)	7.1 [a] (4.2–7.7)	3.3 [b] (2.3–3.9)
Overall Index[1]	Ranking [standardized to 0–10 points scale]	6.9 [ab] (5.1–6.9)	5.2 [bc] (4.7–6)	7.9 [a] (5.5–7.9)	5.8 [bc] (5.1–6.7)

[1]Mean of all standardized values. For the quantitative assessed categories the standardized value v_i is defined as follows: $v_i=(\max_i-r_i)/(\max_i-\min_i)*10$, with $\max_i$ and $\min_i$ as the highest and lowest value achieved by any farm.

methane emissions per kilogram milk. Additionally, for the farm type EXT_TL, solid dung systems are typical, which show lower methane emissions compared to slurry systems. Within the low-input farm groups, there is a high variability of inventory values. The variability in emissions is mostly caused by differences in roughage quality. Other reasons for a high variability are differences in milk yield and housing system within the farm group.

The *land demand* per t of milk is lowest in the farm type INT_TL. The difference between low-input and high-input systems is significant for tilth farms but not for grassland farms. The difference in area demand between tilth system and grassland system is not significant neither for high-input nor for low-input management. The higher land use efficiency of the intensive tilth farm type compared to the low-input tilth farm type is caused by higher energy yields per hectare in corn silage production. Low-input tilth farms scarcely use this potential.

The land needed for the production of milk should be distinguished between arable land and grassland. Arable land has a higher agricultural value than grassland because productivity is higher and there are more alternatives for the land use. The *arable land demand* of the farm type EXT_TL is significantly lower than in the other farm types. This farm type follows most consistently the traditional idea of using cows for "refinement" of grassland and the clover needed for nitrogen supply (Table 8).

Ammonia emissions were significantly lower in low-input tilth farms compared to low-input grassland based farms. On grassland sites, low-input farms differed significantly from high-input farms. The critical load for sensible ecosystems of 20 kg N/ha deposition per year (Ferm, 1998, equivalent to an average emission rate of 48 kg NH_3/ha in cultivated land for this region) was exceeded by some of the individual farms of the grassland based farm groups INT_GL and EXT_GL. For the intensive grassland-based farm group, the emission values for all farms are very close to this limit, while in the low-input group the average is below the critical value.

The *nitrate leaching potential* did not differ significantly between farm groups because of very high variation in stable- and field-nitrogen-balances within all groups. The calculated values are comparable to those from other studies using similar methodology (Wetterich et al., 1999; Cederberg, 1998). Predominantly, the potential nitrate emissions do not pose a risk for eco- or human toxicity. On an average site with 900 mm precipitation and average soil quality, the potential nitrate concentration in leakage exceeds the drinking water limit of 50 mg NO_3/l at a nitrate surplus of above 200 kg NO_3/ha (leakage calculated by the model of Dyck & Chardabellas, 1963). Only one individual farm exceeds this limit.

The differences between the farm types in *soil fertility* and *biodiversity* were small. None of the farms showed a remarkable risk of soil degradation. Farming intensity had no significant effect. Concerning the impact category *biodiversity*, the achieved rating points ranged only up to 5 points. In none of the farm types, the productive area gave a considerable contribution to botanical biodiversity. Nature conservation measures beside the productive area, which can be conducted by all farm types, generally have a higher positive effect on biodiversity.

The *animal welfare* rating showed significantly higher rating values for the group EXT_TL compared with the high-input groups INT_GL and INT_TL. The variability within the low-input groups of farms was very high: Not all members of these groups achieved the high rating of the model farm. But on the other hand none of the high-input farms achieved high values.

In the category *milk quality*, the ratings of the two intensive farm groups are significantly lower compared to those of the low-input farms (EXT_GL and EXT_TL). As in the category animal welfare, the variation within the low-input farm groups was high. Nevertheless, the data sets were still disjoint to the data sets of the intensive farm types.

The overall *environmental index* was highest for the farm type EXT_TL and significantly higher than for the intensive farm groups (Table 8). The other groups did not differ significantly.

4. Discussion

Despite the broad range of environmental inventory values within the farm groups, considerable differences between the farm types were identified.

In categories with impact on a global scale, which were assessed product based, farm types with higher intensity are tendentially favourable. These results correspond with the results of other studies comparing different organic farms concerning energy demand or greenhouse gas emissions (King et al., 2007; Olesen et al., 2006). With respect to the category land demand, it has to be considered that intensive farm types resulted in needing less land per product unit in total, but in needing significantly more arable land. This way, organic dairy production with rations including higher share of concentrates produced on arable land becomes a direct competitor to human food production.

In area based regional and local categories, intensive farms showed a considerably higher risk of environmental harm compared with low-input farms. The intensive grassland based model farm exceeded the critical load for ammonia emissions. The risk of nitrogen emissions is directly linked to feeding intensity: A high turnover of nitrogen increases the risk of emissions because of inevitable losses in each metabolic step. Considering the limited ability of nitrogen uptake in grassland systems, intensification on grassland based organic farms has to be discussed critically.

The local impact categories of soil fertility and biodiversity did not show large differences between the farm types. In the impact categories of animal welfare and milk quality, the largest differences were detected. Low-input farms showed significantly higher ratings compared to high-input farm types. However, in these categories further research is needed to validate assessment methodology. The ranking used in this study can only give a hint on qualitative, system-related differences of the farming systems. A quantification of environmental impact cannot be deducted.

The farm type EXT_TL showed the highest overall environmental index. This farm type operates with nearly no fodder import and is therefore close to the organic ideal of self-sufficiency. The positive environmental valuation of this farm type supports the hypothesis that farming practices oriented on the traditional guidelines of organic farming lead to positive environmental effects even within the organic farming sector.

The partially broad variation in environmental impact assessment within the individual groups of farms characterized by similar production structures and feeding intensities shows that for most categories it is not possible to draw direct conclusions from farm type to practical farm. There are only the following exceptions: (1) All intensive farms showed lower milk quality than the low-input farms; (2) in the category animal welfare, no high-input farm achieved the high rating which was achieved by some of the extensive farms; (3) Ammonia emissions of low-input tilth farms did not reach the critical loads in any case. This indicates that in all cases where an intensive production was favourable, individual low-input farms achieved the same high results, but in some categories where low-input farms showed advantages, none of the individual intensive farms achieved a high ranking. This may indicate that disadvantages of intensive farms may be more system inherent. Still more research is needed to specify the conditions under which low-input farms could achieve energy and climate efficiency comparable to high-input farm types.

In this study, animal welfare is assessed focussing on the concepts of naturalness and integrity which is not accepted by all organic producers and consumers. Other possible indicators for animal welfare not included in this study — e.g. hygiene and health care — could possibly lead to different assessment results. A statistical proof of interactions between further welfare indicators and farm type was not expected to be possible at the small sample size of this survey. Concerning milk quality, the effects of different rations on the milk contents of CLAs, omega-3-fatty acids and antioxidatives have not yet been quantified, therefore no conclusion on quantitative health effects can be drawn. Nevertheless, the differences in the categories of animal welfare and milk quality should be considered for further research, especially regarding the consumer expectations for organic products (Alvensleben and Bruhn, 2001).

Other authors found partly different ranges of indicator values (Schumacher, 1996; Cederberg, 1998; Bockisch, 2000; Grönroos et al., 2006; King et al., 2007; Thomassen et al., 2008). However, the differences could be generally explained by methodological differences or differences in the characteristics of the analysed farms. Even if a direct comparison of absolute values of environmental impact inventories is not possible due to methodological differences, the relation between different analysed farm types is expected to be similar under different assessment approaches (de Boer, 2003; Bockstaller et al., 2006; Nemecek et al., 2005).

5. Conclusions

Despite a high variability within the farm groups, different farm types show statistically significant and relevant differences in environmental impact. The intensive farm types tend to be advantageous in the global impact categories climate impact and land demand. On the other hand, low-input farm types have significant advantages in the categories ammonia emissions, animal welfare and milk quality. This result shows that an environmental impact assessment analysing only the global impact categories climate impact and energy consumption leads to different conclusion than an overall analysis taking also categories with regional and local impact into account. Regarding the principles of organic farming to produce environmentally friendly while assuring high animal welfare and high product quality, these categories need further observance.

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