Variations in Nitrogen Utilisation on Conventional and Organic Dairy Farms in Norway

Matthias Koesling[a,b,*], Sissel Hansen[c], Marina Azzaroli Bleken[d]

[a] NIBIO-Norwegian Institute of Bioeconomy Research, Department of Agricultural Technology and Systems Analysis, Gunnars veg 6, 6630 Tingvoll, Norway. E-mail address: matthias.koesling@nibio.no

[b] Thünen Institute of Organic Farming, 23847 Westerau, Germany

[c] NORSØK-Norwegian Centre for Organic Agriculture, Gunnars veg 6, 6630 Tingvoll, Norway. E-mail address: sissel.hansen@norsok.no

[d] Norwegian University of Life Sciences, Faculty of Environmental Sciences and Natural Resource Management, Fougnerbakken 3, 1432 Ås, Norway. E-mail address: marina.bleken@nmbu.no.

[*] Corresponding author: NIBIO, Department of Agricultural Technology and Systems Analysis, Gunnars veg 6, 6630 Tingvoll, Norway. Tel.: +47 943 74 616.

E-mail address: matthias.koesling@nibio.no

Abstract

Reduced N-surpluses in dairy farming is a strategy to reduce the environmental pollution from this production. This study was designed to analyse the important variables influencing nitrogen (N) surplus per hectare and per unit of N in produce for dairy farms and dairy systems across 10 certified organic and 10 conventional commercial dairy farms in Møre og Romsdal County, Norway, between 2010 and 2012. The N-surplus per hectare was calculated as N-input (net N-purchase and inputs from biological N-fixation, atmospheric deposition and free rangeland) minus N in produce (sold milk and meat gain), and the N-surplus per unit of N-produce as N-input / divided by N in produce. On average, the organic farms produced milk and meat with lower N-surplus per hectare (88 ± 25 kg N·ha^{-1}) than did conventional farms (220 ± 56 kg N·ha^{-1}). Also, the N-surplus per unit of N-produce was on average lower on organic than on conventional farms, 4.2 ± 1.2 kg N·kg N^{-1} and 6.3 ± 0.9 kg N·kg N^{-1}, respectively. All farms included both fully-cultivated land and native grassland. N-surplus was found to be higher on the fully cultivated land than on native grassland. N-fertilisers (43 %) and concentrates (30 %) accounted for most of the N input on conventional farms. On organic farms, biological N- fixation and concentrates contributed to 32 % and 36 % of the N-input (43 ± 18 N·kg N^{-1} and 48 ± 11 N·kg N^{-1}), respectively. An increase in N-input per hectare increased the amount of N-produce in milk and meat per hectare, but, on average for all farms, only 11 % of the N-input was utilised as N-output; however, the N-surplus per unit of N in produce (delivered milk and meat gain) was not correlated to total N-input. This surplus was calculated for the dairy system, which also included the N-surplus on the off-farm area. Only 16 % and 18 % of this surplus on conventional and organic farms, respectively, was attributed to surplus derived from off-farm production of purchased feed and animals. Since the dairy farm area of conventional and organic farms comprised 52 % and 60 % of the dairy system area, respectively, it is crucial to relate production not only to dairy farm area but also to the dairy system area. On conventional dairy farms, the N-surplus per unit of N in produce decreased with increasing milk yield per cow. Organic farms tended to have lower N-surpluses than conventional farms with no correlation between the milk yield and the N-surplus. For both dairy farm and dairy system area, N-surpluses increased with increasing use of fertilizer N per hectare, biological N- fixation, imported concentrates and roughages and decreased with higher production per area. This highlights the importance of good agronomy that well utilize available nitrogen.

Keywords

Efficiency; N-surplus; N-balance; nitrogen intensity; meat; milk

1 Introduction

Livestock accounts for approximately 34 % of human protein supply worldwide (Schader et al., 2015); however, N losses from the livestock sector also contributes to local- and global-scale environmental pollution (Steinfeld et al., 2006). Nitrogen, in particular, contributes to both eutrophication and greenhouse gas emissions. Reducing N-losses is a strategy designed to address these problems and represents an important approach for improving efficiency and productivity in agriculture (Gerber et al., 2013). Depending on the chosen system boundaries, the environmental impact of N can be assessed in relation to unit of product or hectare of agricultural area used, which can include only the farm or the entire system area (Halberg et al., 2005; Oudshoorn et al., 2011).

In the last 20 years, many studies on N-balances, N-efficiencies, and life cycle assessments have been performed on dairy farming in Europe. Some of these studies have compared organic and conventional farms (Cederberg and Flysjö, 2004; Cederberg and Mattsson, 2000; Dalgaard et al., 1998; Haas et al., 2001; Nielsen and Kristensen, 2005; Thomassen et al., 2008; Werf et al., 2009) and have found differences in N-efficiencies, which were invariably higher on organic farms than on conventional farms.

In this study, we aimed to determine the most important variables that influence the N-surplus per hectare and per produced unit, for organic and conventional commercial dairy farms at both the dairy farm and dairy

This is the post-peer review, pre-copyedit version of an article published in Agricultural Systems.
The final authenticated version is available online at: http://dx.doi.org/10.1016/j.agsy.2017.06.001.

system level. N-surplus per hectare at the farm level and N-surplus per produced unit at the dairy system level were considered as the main nitrogen indicators (Bleken et al., 2005). In the dairy system, all the N-inputs for the off-farm production of feed and heifers were also included. The amount of nitrogen used in inputs for the production of 1 kg of N for human consumption (Bleken et al., 2005) was used to identify how well the different inputs are utilised.

At the dairy farm level, we also calculated the N-surpluses per hectare for fully-cultivated land, as well as for native grassland. Local effects can be expressed as impact per hectare and global effects as impact per product (Haas et al., 2000), with N-surplus per hectare being closely related to nitrate leaching to groundwater (Verloop et al., 2006). On the basis of the studies by Thomassen et al. (2008), Huysveld et al. (2015), and Marton et al. (2016), we propose the hypothesis that when evaluating the utilization of nitrogen and the area demand for producing milk, it is crucial to take into consideration not only the dairy farm but also the entire dairy system area.

2 Materials and Methods

2.1 Location and farms

Data were collected from 10 certified organic and 10 conventional commercial dairy farms in the county of Møre og Romsdal, central Norway, between 2010 and 2012. This county is mainly located in a coastal area at approximately 63°N and is characterised by a considerably humid climate.

The annual precipitation varies from 1,000 to 2,000 mm and is fairly evenly distributed throughout the year, with the highest amounts falling in coastal areas (Dannevig, 2009). The farmlands are spread from the coast to the valleys further inland. In January, the mean temperature near the coast and in the valleys is 2 °C and -5 °C, respectively, whereas in July, the corresponding temperatures are 14 °C and 15 °C, respectively. The selected farms differed in dairy cow numbers, milking yield, farm area per cow, fertilisation, and forage to concentrate ratio, which reflect the variations across the county (Table 1).

The grazing period for dairy cows and heifers is typically up to three months and four months, respectively. They graze on fully cultivated and surface-cultivated land, native grassland, and free rangeland (Fig. 1 and 2.1.1 Farm areas). During the indoor season, the animals are mainly fed farm-grown roughage and imported concentrates. On cultivated areas, only grass and grass-clover leys are grown. Cereals can be used as a cover crop when establishing new leys and are harvested as silage.

2.1.1 Farm areas

The Norwegian Agriculture Agency distinguishes between three categories of utilised agricultural area: fully-cultivated land, surface-cultivated land, and native grassland (Fig. 1). On *fully-cultivated land*, ploughing, use of manure and mineral fertilisers, and harvesting with machines are all possible, and thus high yields are achieved. On *surface-cultivated land*, ploughing is not possible, and yields are lower than those on cultivated lands. *Native grassland* can only be used for grazing and has the lowest yields among the three categories. Because of the differences in potential management practices and yields in these three area categories, we weighted the farm area by multiplying the fully cultivated land by 1, the surface-cultivated land by 0.6, and the native grassland by 0.3. The weighting of surface-cultivated land followed the guidelines of the Norwegian Agricultural Authority (2011); the factor for native grassland was set to represent an average of the potential grazing (Rekdal, 2008; Samuelsen, 2004). Only some farms had surface-cultivated land and the contribution to the entire dairy farm area was less than 1 %. When we refer to areas without weighting, we mention these areas as cartographic area.

In addition to their own land, most farms have access to *free rangeland*, which consists mainly of native woodland or alpine vegetation and can only be used for grazing. Thus, the free rangeland is a part of the dairy farm, but not a part of the defined dairy farm area. To indicate the contribution of this land to the feed supply, we calculated the energy uptake on free rangeland as a proportion of the entire feed uptake (Table 1).

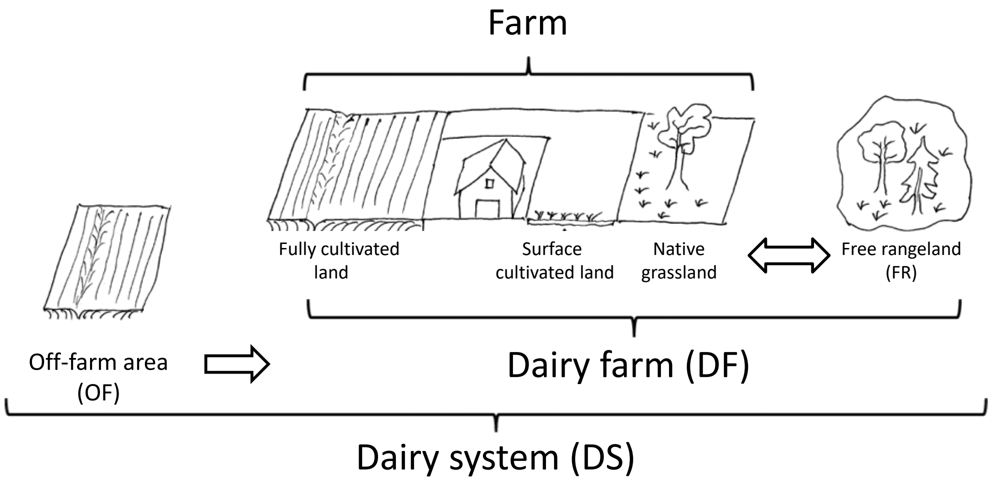


Fig. 1. Different categories of areas for the dairy farm and dairy system.

2.1.2 Choice of system boundaries and functional unit

We identified two system levels as indicated by Bleken et al. (2005): the *dairy farm* and *dairy system***.** The latter includes areas used to raise purchased calves and heifers and to produce purchased fodder outside the farm, and was designated off-farm area. Such areas can be located in the vicinity of the farm, in other parts of the country, or in other countries. In this study, only farms with dairy production as their main enterprise were selected. However, several farms had some non-dairy animals (sheep or horses), or they sold roughage; the area and nutrients used for this were not included as part of the dairy farm (DF).

The N-produce is defined as the nitrogen in sold milk and in meat gain. To calculate the nitrogen content of milk and meat, we divided the protein content of the farms' milk by a conversion factor of 6.38 for milk and 6.25 for meat (FAO, 1986). For cattle, on average, 2.4 % of live weight was estimated to be N (Andrew et al., 1994). This value was multiplied by 53 % of live weight (Olesen et al., 1999) to obtain an estimate of the amount of N in lean tissues in the carcass and edible by-products (Bleken and Bakken, 1997), which we refer to as N in meat in this article.

The functional unit used in this study for human consumption in terms of milk and meat gain is 1.0 kg N, which corresponds to approximately 193 kg milk with 3.3 % protein or approximately 30 kg of meat with 21 % protein. To compare milk from different farms based on its energy content, the amount of milk mass was standardized to a kilogram of energy-corrected milk (ECM) (Sjaunja et al., 1991) based on the fat and protein content of milk on each farm. The method of dealing with co-products (in our case, livestock increment) influences the results (Cederberg and Stadig, 2003; Kraatz, 2009). In the life assessment analysis, we used system expansion rather than allocation.

The farmers in our study sold milk and animals for slaughter or as live animals. Some farms enlarged their herd during the study period, retaining the calves that otherwise could have been sold. To account for this strategy, we used weight gain for the herd instead of the weight of sold animals. To calculate the weight increase of the dairy herd, we multiplied the animal days in each feeding group by the expected average daily weight gain for the group (Table 2; Olesen et al., 1999).

This is the post-peer review, pre-copyedit version of an article published in Agricultural Systems.
The final authenticated version is available online at: http://dx.doi.org/10.1016/j.agsy.2017.06.001.

2.1.3 Calculation of N-surpluses

We calculated the farm-gate N-surplus of purchased N as the difference between bought inputs (net purchase) and N-produce (sold milk and meat gain), with all products calculated in terms of kilogram N per hectare. The farm-gate N-surplus included also N-input from Biological Nitrogen-fixation (BNF) on fully cultivated land and atmospheric N-deposition deposition on the dairy farm area.

Because nearly all purchased fertilizer and cattle manure, that was not dropped by grazing, were spread on fully cultivated area, rough estimates were made to distinguish between the N-surplus per ha on fully cultivated land and on native grassland. Because only a negligible part of the area on the farms was surface cultivated grassland, no calculations were done for this area. On native grassland, N-input was assumed to mainly consist of concentrates given to the cattle herd and atmospheric deposition, whereas on cultivated land stored cattle manure, purchased fertilizer and BNF were additional N-input. The share of the weighted farm area of respectively fully cultivated area and native- grassland were used to roughly estimate share of concentrates used, and the milk and meat gain from these two types of farm area. The amount of concentrates used and production of milk and meat gain on grassland, was estimated on basis of grazing days on these areas.

This is the post-peer review, pre-copyedit version of an article published in Agricultural Systems.
The final authenticated version is available online at: http://dx.doi.org/10.1016/j.agsy.2017.06.001.

Unfortunately, we did not have data available to calculate field level nitrogen balances as N-input (fertilizer, manure and N-fixation) minus harvested N, neither for the whole farm area nor for the different area types. Our estimates are therefore rough and do not give an exact figure of the N-surplus of the given area. The N-surplus of the dairy system is defined as the total net N-input to the dairy farm plus the N-surplus at the site of production of imported feed minus N-produce. N-surplus per unit of N-produce is the total N-surplus of the dairy system divided by N-produce. The N-surplus from off-farm roughage-producing area, including atmospheric N deposition and N-fixation by clover, was estimated to be 80 kg N·ha^{-1} for conventional farms and 0 kg N·ha^{-1} for organic farms, based on local field trials, fertilisation data, and information from the local extension service. Roughage is normally purchased from stockless farms with no or low input of animal manure, and thus N-surpluses are lower than those on dairy farms. In this study, the area needed for the production of purchased roughage was estimated assuming the average yield as harvested on the farms (4,200 kg DM·ha^{-1} for conventional farms and 2,940 kg DM·ha^{-1} for organic farms). The off-farm area needed (ha) was multiplied by the estimated N-surplus (kg N·ha^{-1}) to obtain the N-surplus from off-farm roughage production.

The further approach for calculating the N-surpluses for conventional and organic production of the ingredients in concentrates is described by Koesling (2017).

The N-surplus associated with raising bought animals off-farm was calculated by multiplying the estimated surplus per kg N in produce, allocated to weight gain, with the nitrogen content of live weight in bought animals. This surplus estimate was based on the results from the farms in the present study and calculated as the average of the conventional or organic dairy farms, respectively. The off- farm area associated with rearing bought animals was calculated by multiplying the estimated N-intensity on off-farm area associated with rearing bought animals on a farm with the average area needed on the dairy farm and off -farm for plant production to produce 1 kg N in produce, using separate averages for the group of conventional or organic dairy farms in the study, respectively.

The N-surpluses (kg N) derived from growing off-farm roughage and concentrates, and raising purchased animals, were summed and then divided by the dairy farm area to yield the N-surplus for off-farm area (I_g).

Nitrogen intake on free rangeland was calculated based on feed energy demand, divided by the energy content (0.85 $\text{FEm}\cdot\text{kg}^{-1}$ DM) and multiplied by the estimated N content for free rangeland (0.011 $\text{kg N}\cdot\text{kg}^{-1}$ DM[1]).

[1] Gustav Fystro personal communication, based on findings from previous investigations.

2.1.4 Farm data and sources

Data from the 20 farms were collected between 2010 and 2012, and the average annual values per farm were used to reduce the influence of weather variations. Farm visits were used to introduce the data collection forms to farmers and to prepare farm maps. Each year, data were collected after spring cultivation, first and second cut, and after the growing season. The information collected included farm area, livestock numbers, milk yield, purchased and sold livestock, number of grazing days on different areas, amount and type of purchased concentrates, bedding material, fertilisers, pesticides, and import and export of roughage and manure. Other information, such as tillage operation and silage yields, was also registered. Farmers also estimated the percentage of clover in grass-clover mixtures before the first and second cuts. Photographs of grassland for which the proportion of clover had been determined were used to improve estimates. The farmers registered the number of animals within each group, grazing area, and grazing period. Farmers reported whether the dairy cows were on the grazing area day and night or only during daytime between milking periods. Changes in stock for each calendar year were also recorded. Details of seeds and medicines were excluded because of their low relevance to the present study (Cederberg and Mattsson, 2000). The amount of atmospheric N deposition was calculated by multiplying the regional average of annual atmospheric N deposition (Aas et al., 2011), 2.94 kg N·ha^{-1}, with the total area of the farm. Therefore, the atmospheric N deposition per weighted dairy farm hectare (Table 2) was larger than the deposit in each area of farmland. The process used to estimate N-fixation is explained later.

Production of N in milk and meat gain on free rangeland was calculated and shown separately as input to the farm. Only one of the 20 farms had no access to free rangeland.

In order to estimate the amount of purchased N, we used the declaration of contents when available, or a standard nutrient content (NORSØK, 2001). For concentrates, we used the specific formulations for the different concentrates given by the Norwegian Agricultural Purchasing and Marketing Cooperation. The average N concentration in farm silage was estimated based on near infrared spectroscopy analysis of 12 silage samples on each farm (three fields, two harvests, two years). The average values for organic or conventional farms were used as the estimates for the N-content in imported silage.

Table 1

Characteristics of the dairy farms

Parameters	Units[a]	Conventional	Standard deviation	Organic	Standard deviation
Number of farms	n	10		10	
Dairy farm area (DF); weighted[b]	ha	31.1	19.6	36.5	26.3
Fully cultivated land	ha	26.8	13.6	33.0	23.7
Surface-cultivated land	ha	0.3	0.4	0.2	0.5
Native grassland	ha	13.6	22.7	11.3	14.7
Estimated utilized dry matter (DM) yield DF	$t\ DM \cdot ha^{-1}$	3.5	0.9	2.7	0.6

Cows per farm[c]	cows·farm^{-1}	29.5	16.4	29.4	17.3
Live weight milking cow	Kg	570	40	545	75
Milk yield per milking cow	t ECM·cow^{-1}	8.3	0.7	6.0	1.2
Milk delivered per DF area	t ECM·ha^{-1}	7.2	2.2	4.6	1.1
Milk fat	%	4.09	0.25	3.89	0.22
Milk protein	%	3.39	0.08	3.28	0.12
Replacement rate	%	41.4	10.0	33.6	8.0

[a] Units of parameters are given. Numbers for participating farms are the means for average of calendar years 2010–12 with standard deviation.
[b] Weighted area = Fully cultivated land + 0.6 Surface-cultivated land + 0.3 Native grassland
[c] The number of cows per year is defined as the number of cows per 365 days, independent of live weight.

Table 2

Energy demand for cattle and energy concentration in feed

	Energy demand/day		Average daily weight gain	Energy content	
			Norwegian Red	conventional	organic
	FEm·(kg milk)$^{-1}$	FEm[f)]	kg·animal^{-1}	FEm·(kg DM)$^{-1}$	FEm·(kg DM)$^{-1}$
milking cows[a]					
maintenance		5.10[b]			
milk yield [kg·day^{-1}] < 20	0.44[b]				
20–30	0.45[b]				
> 30	0.47[b]				
dry cows[a]		6.60[b]			
calves < 6 month		2.22[b]	0.6[b]		
calves 6–12 month		3.85[b]	0.6[b]		
bulls > 12 month		6.53[b]	0.9[b]		
heifers 12–18 month		4.49[b]	0.6[b]		
heifers > 18 month		5.38[b]	0.6[b]		
On-farm roughage (average for group)				0.86[c]	0.83[c]
Concentrates (average for group)				0.91[d]	0.88[d]
Grazing farm area				0.90[e]	0.90[e]
Grazing free rangeland				0.85[e]	0.85[e]

[a] Values for 580 kg liveweight (Norwegian Red). To adjust for other liveweight, we multiplied the demand of FEm·day^{-1} by the average liveweight of cows on farm [kg] and divided this value by 580 [kg].

[b] Olesen et al., 1999.

[c] Calculated on feed samples from farm.

[d] Calculated on declaration from concentrates, purchased by a group.

[e] Based on results from earlier grazing trials and investigations in outlying fields (Gustav Fystro personal communication).

[f] FEm is defined as the net energy of 1 kg barley and corresponds to 6.9 MJ.

2.1.5 Nitrogen fixation and atmospheric deposition

The BNF on harvested and grazed farm area was calculated as follows:

$$BNF = (DM_{TAG} + DM_{BG}) \times Cl\,\% \times N\,\% \times P_{fix}\,\%, \tag{1}$$

where

DM_{TAG} total above-ground DM [kg] is estimated as the harvested yield multiplied by 1.4. The harvested yield is estimated from the assumed feed demand for the production of milk and meat gain on the dairy farm. We assumed that the intake corresponded to the calculated feed demand. The feed demand from harvested roughage was calculated as total energy demand minus the energy taken up from purchased feed, grazing on free rangeland and on-farm and assuming 40% losses from harvest to feed uptake. Further description is given by Koesling (2017).

DM_{BG} below-ground DM = $DM_{TAG} \times 0.5$ [kg]. This value is in line with the IPCC (Paustian et al., 2006)

Cl % percentage of clover in grass-clover yield

N % 3 % N-content, according to Høgh-Jensen et al. (2004) and in line with the findings of Hansen et al. (2014).

P_{fix} % 95 %. Percentage of N in plants calculated using BNF. We used a high value (Høgh-Jensen et al., 2004), because the farms with a higher proportion of clover had a low fertilisation rate.

As the calculation of BNF is based on different assumptions and information from the farms, it has an inherent degree of uncertainty. To investigate if there were still significant differences in N-surpluses between conventional and organic farms (Table 4) if the values for BNF were 20 % lower or higher, all results were recalculated and new t-tests were conducted. Lower values for N-fixation did slightly increase the difference in N-surpluses between conventional and organic farms. When the estimated N-fixation was increased by 20%, difference in N-surplus per ha DF were reduced from a significant level of below 0.001 to below 0.01.

2.2 Statistics

The factors contributing most to N-surplus and the correlations among them were determined by calculating the correlation matrices for 60 variables describing the farm, dairy herd, and plant production. The results were used to preselect variables used in regression analysis, and the most interesting variables for inclusion in the model were selected in a stepwise manner by using forward regression. For statistical analysis and for *t*-tests, R[2] software was used in combination with RStudio[3].

For descriptive statistics, such as means and standard deviations, and production of figures, Microsoft® Excel® 2013 was used.

To analyse the independent variables that influenced N-surpluses and the correlations among them, correlation matrices were calculated. The variables tested (*n* = *80*) represent general information about the farms (area and number of animals), the number of working hours, economic results, dairy production, plant production, imports, calculated N-surpluses, and numbers in relation to the dairy farm and dairy system. The variables were selected based on the results in the literature. The correlation matrices were used to preselect the variables for regression to identify key variables influencing the N-surpluses calculated on N-purchase and all N-inputs response variables for each farm.

3 Results

3.1 Expanding from the dairy farm scale to the dairy system scale

Although the average farm area of the conventional and organic farms was approximately the same (ca. 60 ha), there were large variations within each of the two modes of production. On average, however, conventional farms

[2] R®, version 3.2.4; www.r-project.org
[3] RStudio®, version 0.99.893; www.rstudio.com

used more off-farm area (approximately 48 % of the DF area) than did the organic farms (approximately 40 %; Table 3). We used the proportion of energy in the feed obtained from grazing on free rangeland as a proxy for cultivated land that would have been needed if a farm did not have any access to free rangeland. The averages for the two groups were comparable, at 6 % and 8 % for conventional and organic farms, respectively (Table 3). There was however, a large variation among the farms in each group.

Because of the slightly lower stocking rate on organic farms (Table 3) and lower milk yield per cow (Table 1), the milk yield per area of organic DF was only 64 % of that achieved on conventional farms. However, taking into consideration the area of the entire dairy system improved the performance of the organic farms to 76 % of the milk yield per area obtained on conventional farms. Therefore, compared with conventional farms, organic production needed 62 % more on-farm land, to produce a litre of milk, but only 36 % more dairy system (DS) land. Again, however, the variation within the two groups was very large (Table 3).

On all farms, there were an N-surplus per hectare (Table 4, Fig. 2). The calculated surpluses were, nevertheless, significantly lower on organic dairy farms than on conventional farms.

Table 3

Total area and indicators of dairy farm (DF) and of the whole dairy system (DS)

Parameters	Units[a]	Conventional	Standard deviation	Organic	Standard deviation
Dairy farm area (DF); weighted	ha	31.1	19.6	36.5	26.3
Dairy system area (DS)	ha	60.5	36.8	62.8	48.0
Share DF area of DS	%	52.1	8.5	60.4	6.3
Share off-farm area (OF) for bought concentrates of DS	%	44.0	7.9	28.2	6.3
Share OF for bought roughages of DS	%	2.4	3.2	9.7	6.1
Share OF for bought animals of DS	%	1.5	1.8	1.7	2.9
Share of energy uptake on free rangeland in relation to entire feed uptake	%	5.9	3.9	8.1	8.2
DF Stocking rate	cows·ha^{-1}	0.95	0.35	0.81	0.17
DS Stocking rate	cows·ha^{-1}	0.48	0.09	0.53	0.12
Output (milk and meat gain) on DF	kg N·ha^{-1} DF	42.5	12.1	26.4	5.7
Equivalent of milk[b] for N-produce on DF[b]	kg·ha^{-1} DF	8,203	2,466	5,095	1,151
Equivalent of milk[b] for N-produce on DS	kg·ha^{-1} DS	4,095	654	3,033	538
DF Area per kg milk-equivalent[b]	m^2·kg^{-1} DF	1.3	0.5	2.1	0.5
DS Area per kg milk-equivalent[b]	m^2·kg^{-1} DF	2.5	0.5	3.4	0.6

[a] Units of parameters are given. Numbers for participating farms are means for the average of calendar years 2010–12 with standard deviation.
[b] Calculating the equivalent for N-produce as kg milk, using Norwegian full-cream milk, sold with 3.9 % fat and 3.3 % protein (Norwegian Food Safety Authority, 2015).

3.2 Nitrogen surplus on DF

The N-surplus per hectare was, on average, 4.5 times larger on conventional farms than on organic farms for purchased N, and 2.5 times larger for total N-input, in which N from BNF, atmospheric deposition, and produce on free rangeland were included (Table 4). The lower value for the latter was mainly because of the higher N-fixation by clover on organic farms than on conventional farms. For both conventional and organic farms, a close correlation was noted between N-input at the farm level and the N-surplus per hectare (Fig. 3). The input from N-fertilizer was the main factor contributing to the increased N-surplus per hectare on conventional farms. Although the surplus per unit N in produce (delivered milk and meat produce) showed less difference between conventional and organic farms than the surplus per hectare because of the higher production on conventional farms, the difference was still significant. The surplus per kg N produce in sold milk and meat gain at the farm level for purchased N (con 5.3 ± 0.9 kg N·ha^{-1}, org 3.4 ± 1.2 kg N·ha^{-1}) and total N-input (con 6.3 ± 0.9 kg N·ha^{-1}, org 4.2 ± 1.2 kg N·ha^{-1}) was, on average, 1.55 times and 1.51 times larger, respectively, on conventional farms than on organic farms (Table 4).

Among all inputs, the proportion of purchased inputs was 88 % on the conventional farms and 59 % for organic farms (Table 4). Fertiliser accounted for the largest proportion (56 %) of the purchased N-input on conventional farms. Concentrates represented a significant proportion of the nitrogen input, with an average amount of 93 ± 36 kg N·ha^{-1} DF and 48 ± 11 kg N·ha^{-1} DF on conventional and organic farms, respectively.

Table 4

Amount of nitrogen per dairy farm (DF) hectare in annual inputs and outputs

		Conventional		Organic		
	Index and formula	average	std. dev.	average	std. dev.	*t*-test[a]
N-inputs		[kg N·ha^{-1} DF]				

This is the post-peer review, pre-copyedit version of an article published in Agricultural Systems.
The final authenticated version is available online at: http://dx.doi.org/10.1016/j.agsy.2017.06.001.

N-purchase dairy farm (DF)	$I_a = \sum_{n=a}^{f} I_{an}$	234.54	67.72	68.61	19.06	***
Concentrates	I_{aa}	93.14	36.19	47.79	11.28	**
Roughage	I_{ab}	6.18	9.18	11.34	7.10	n. s.
Fertiliser	I_{ac}	131.14	33.01	3.29	9.88	***
Imported manure	I_{ad}	2.87	8.60	4.51	7.27	n. s.
Bought animals	I_{ae}	0.57	0.68	0.49	0.84	n. s.
Sawdust and straw	I_{af}	0.65	0.95	1.19	1.44	n. s.
Biological N-fixation	I_b	26.55	22.73	42.97	17.93	n. s.
Atmospheric N-deposition	I_c	3.75	0.71	3.58	0.50	n. s.
Free rangeland, N in milk, and meat gain	I_d	1.62	1.48	1.35	1.67	n. s.
Sum N-inputs DF	$I_{DF} = sI_a + I_b + I_c + I_d$	266.47	92.64	116.51	39.15	***
N-surplus on off-farm area purchased feed	I_g	39.16	16.15	17.65	4.57	**
N-surplus animal prod. on off-farm area	I_h	1.88	2.25	1.07	1.84	n. s.
Sum N-inputs DS	$I_{DS} = I_{DF} + I_g + I_h$	307.51	81.42	135.23	27.22	***
N-Produce		[kg N·ha^{-1} DF]				
Delivered milk and private use	P_{milk}	38.47	11.35	23.74	5.86	**
Meat gain	$P_{meat} = Weight\ gain \times 0.53$	4.03	1.18	2.66	0.51	**
Sum N produce (milk and meat gain)	$P = P_{milk} + P_{meat}$	42.50	12.12	26.40	5.66	**
Net produce without production free rangeland	$nP = P - I_d$	40.88	11.54	25.05	6.52	**
Other export						
Manure export	O_a	0.23	0.68	0.00	0.00	n. s.
Slaughter waste	$O_b = Weight\ gain \times 0.47$	3.58	1.04	2.36	0.45	**
Sum other export	O	3.80	1.27	2.36	0.45	***
N-surplus per hectare		[kg N·ha^{-1} DF]				
N-surplus, purchased N-inputs DF	$B_p = I_a - P - O$	191.81	58.13	42.21	17.78	***
N-surplus, all N-inputs on DF	$B_{DF} = I_{DF} - P - O$	220.16	55.72	87.75	25.47	***
		[kg N·ha^{-1} DS]				
N-surplus, all N-inputs DS	$B_{DS} = I_{DS} - P - O$	130.47	17.12	62.31	14.64	***
N-surplus per produce		[kg N·(kg N)$^{-1}$]				

N-surplus, all N-inputs DF per N-produce	$S_{DF} = B_{DF} / P$	5.33	0.90	3.45	1.21	**
N-surplus, all N-inputs DS per N-produce	$S_{DS} = B_{DS} / P$	6.28	0.93	4.16	1.21	***
N-efficiencies		[kg N·(kg N)$^{-1}$]				
N-efficiency purchase DF	$E_{Ia} = P / (I_a - O_a)$	0.18	0.04	0.39	0.09	***
N-efficiency DF	$E_{DF} = P / (I_{DF} - O_a)$	0.16	0.02	0.24	0.06	**
N-efficiency DS	$E_{DS} = P / (I_{DS} - O_a)$	0.14	0.02	0.20	0.04	***
N-input per kg N-produce		[kg N·(kg N)$^{-1}$]				
N-intensity on purchase DF	$N_a = (I_a - O_a) / P$	5.67	1.11	2.65	0.74	***
N-intensity on all inputs DF	$N_{DF} = (I_{DF} - O_a) / P$	6.42	0.91	4.55	1.22	**
N-intensity on all inputs DS	$N_{DS} = (I_{DS} - O_a) / P$	7.38	0.97	5.26	1.21	***

Average values and standard deviations are shown for the groups of conventional and organic farms. For surpluses per hectare (B), surpluses per produce (S), and N-efficiencies (N), the formulas are given.

[a] significant at level *** < 0.001; ** < 0.01; * < 0.05

3.3 Nitrogen surplus per hectare on the different dairy farm areas

The fully cultivated area and the native grassland on farms were fertilized very differently. The N-input for fully cultivated land was considerably higher than that on the native grassland (Table 5). Since only a part of the N-input was utilized, the N-surplus for fully cultivated land was also considerably higher than that for native grassland. All the average estimated surpluses for fully cultivated land presented in Table 5 are higher than those for the dairy farm area in Table 4.

Table 5

Estimated amount of annual nitrogen inputs and outputs per hectare on different cartographic dairy farm areas

	Index and formula[b]	Conventional average	Conventional std. dev.	Organic average	Organic std. dev.	*t*-test[a]
		[kg N·ha^{-1} cartographic area]				
N-purchase dairy farm (DF)	$I_a = \sum_{n=a}^{f} I_{an}$					
Fully cultivated land		272	118	76	25	***
Native grassland		21	15	16	15	n. s.
Biological N-fixation	I_b					
Fully cultivated land		28	24	47	20	n. s.
Native grassland		0	0	0	0	n. s.
Atmospheric N-deposition	I_c					
Equal for all land		3	0	3	0	n. s.
N-Produce (milk and meat gain)	$P = P_{milk} + P_{meat}$	[kg N·ha^{-1} cartographic area]				
Fully cultivated land		46	16	27	9	**
Native grassland		11	6	9	9	n. s.
N-surplus		[kg N·ha^{-1} cartographic area]				
Surplus, purchased N-inputs DF	$B_p = I_a – P - O$					
Fully cultivated land		225	103	49	22	***
Native grassland		12	117	7	7	n. s.
Surplus, all N-inputs on DF	$B_{DF} = I_{DF} – P - O$					
Fully cultivated land		252	95	96	30	***
Native grassland		14	10	10	7	n. s.

Average values and standard deviations are shown for the groups of conventional and organic farms.

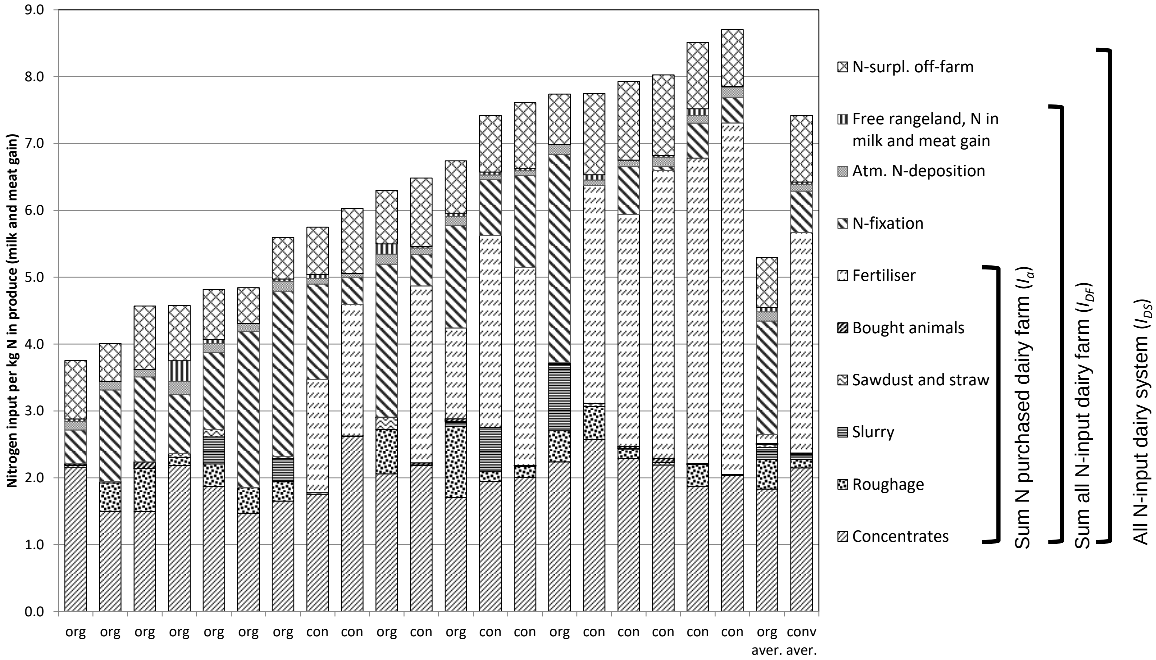
[a] significant at level *** < 0.001; ** < 0.01; * < 0.05

[b] indexes and formulas are given in Table 4

This is the post-peer review, pre-copyedit version of an article published in Agricultural Systems.
The final authenticated version is available online at: http://dx.doi.org/10.1016/j.agsy.2017.06.001.

3.4 Nitrogen surplus on DS

The ratio of all N-inputs/N in produce was 7.4 and 5.3 for conventional and for organic farms. High inputs on the organic farms is mainly because of the higher N-fixation by clover and use of concentrates. The N-surplus per hectare was higher on the dairy farms than on the off-farm areas, because off-farm area is mainly on farms without animals, where N-inputs are generally lower than found on the dairy farms. The contribution of the off-farm N-surplus to the total N-surplus on DS was not significantly different between the two modes of production, and was, on average, only 14 % and 15 % for conventional and organic production, respectively.



Milk yield 7.5 8.3 4.4 3.0 7.3 7.1 5.1 8.6 9.2 4.1 8.3 7.7 9.4 8.2 5.5 7.9 8.4 7.8 7.1 7.7 6.0 8.3
[t ECM·cow·year^{-1}]

Fig. 2. Nitrogen amount by input per kilogram N in produce (milk and meat gain, left axis) on conventional (con) and organic (org) farms. The legend shows the inputs and their grouping. The farms are sorted by increasing total N-input per kg N in produce. Beneath the table, the annual milk yield per cow for each farm is shown as metric ton ECM·cow·year^{-1}. (For indices and calculations, see Table 4.)

Organic farms had milk yields of between 3.0 and 8.4 metric ton ECM·cow^{-1}·year^{-1} (Fig. 3). The conventional farm with the lowest ratio N-input/N-produce (3.5) had a milk yield above the average and an N-fixation per hectare (63 kg N·ha^{-1} DF), which was more than twice the average of that on conventional farms (27 kg N·ha^{-1} DF), and used the lowest amount of fertiliser (75 kg N·ha^{-1} DF) among the conventional farms. Some farms utilised more feed from free rangeland. This N-input from free rangeland contributed to the N-produce without increasing N-purchased.
Increased N-input in the dairy system (I_{DS}) increased N-output of the delivered milk and meat gain (P) on conventional farms (R^2 = 0.77; Fig. 3). On conventional farms, the amounts of all N-inputs (I_{DS}) and N-purchase (I_a) were found to be highly correlated (I_a = (0.97 I_{DS}) - 22.80; R^2 = 0.89). For both conventional and organic farms, a significant trend of increased N-surplus per hectare (balance) with increasing N-inputs (I_{DF}) was noted. However, no correlation was found between increased N-inputs (I_{DS}) and N-surplus per unit of N-produce for the dairy system (S_{DS}).

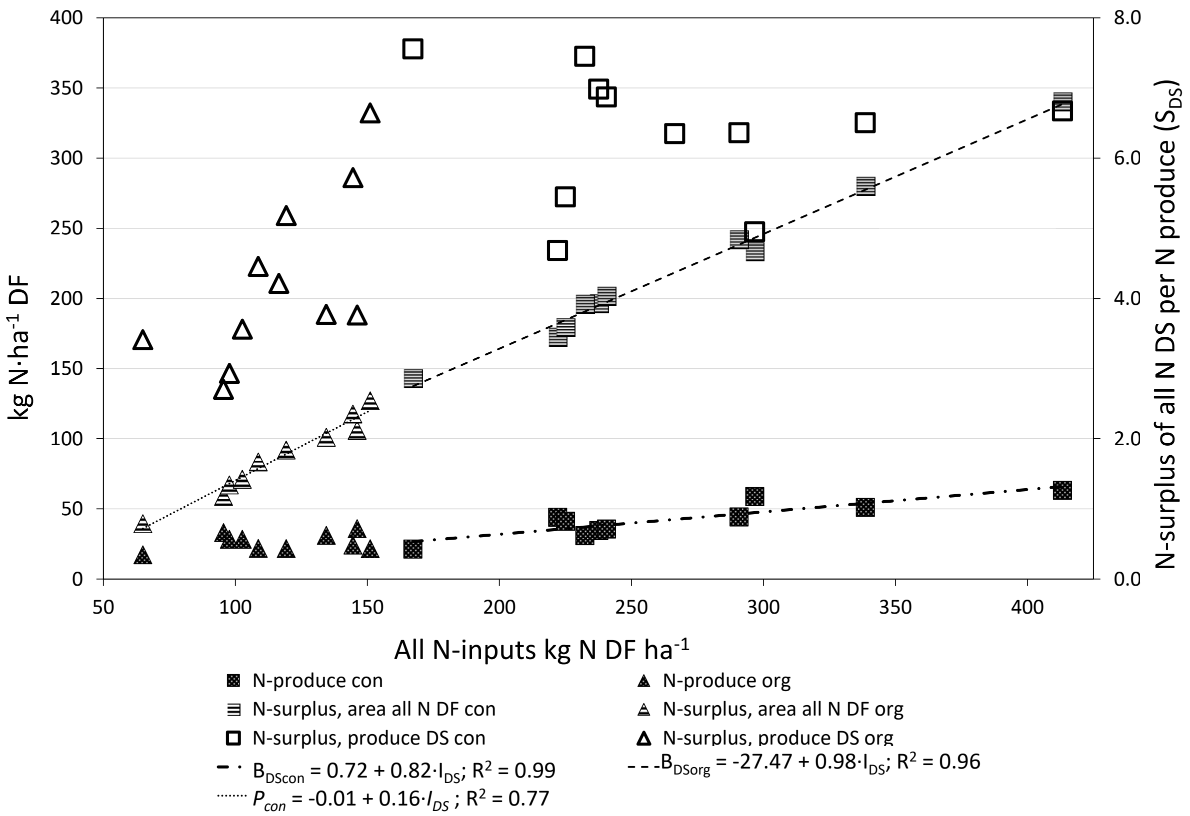


Fig. 3. Nitrogen in produce (milk and meat gain), N-purchase (left axis), and N-surplus per produce for the dairy system (S_{DS}; right vertical axis) versus the total N-input per hectare on the dairy farms. con: conventional; org: organic.

The average N-surplus per unit of N-produce (S_{DS}) on the conventional farms, was approximately 1.5 of that on the organic farms (Table 4).

3.5 Variables influencing N-surpluses

The N-surpluses per unit of N-produce on dairy farm (Eq. 2) and dairy system level (Eq. 3) could be described by four variables in a regression for all 20 farms: imported fertiliser (I_{ac}), BNF (I_b), imported feed ($I_{aa} + I_{ab}$), and the produce (P) of milk and meat gain for both farm and system level. The negative sign for produce of milk and meat indicates that an increased production per area in lower N-surpluses in produce.

$$S_{DF} = 4.941 + 0.031 \cdot I_{ac} + 0.034 \cdot I_b + 0.029 \cdot (I_{aa} + I_{ab}) - 0.175 \cdot P \qquad (2)$$

$R^2 = 0.91, P < 0.001$

$$S_{DS} = 5.624 + 0.032 \cdot I_{ac} + 0.033 \cdot I_b + 0.033 \cdot (I_{aa} + I_{ab}) - 0.182 \cdot P \qquad (3)$$

$R^2 = 0.91, P < 0.001$

There were only small differences in the effect of the different variables between DF and DS; however, intercept for DS was higher than that for DF. This difference can be attributed to differences in N-input, which in DS, in contrast to DF, also includes the N-surplus from production of imported feed and bought animals.

For the group of conventional farms, a high coefficient of determination was obtained, owing only N in fertilizers (I_{ac}) and N in produce (Eq. (4) and (5)).

$$S_{DF} = 5.561 + 0.021 \cdot I_{ac} - 0.069 \cdot P \qquad (4)$$

$R^2 = 0.87, P < 0.001$

$$S_{DS} = 5.954 + 0.024 \cdot I_{ac} - 0.066 \cdot P \qquad (5)$$

$R^2 = 0.86, P < 0.01$

On organic farms, The N-surpluses per unit of N-produce were mainly influenced by BNF (I_b), imported feed (I_{aa} + I_{ab}) and N in produce (Eq. (6) and (7)).

$$S_{DF} = 2.751 + 0.044 \cdot I_b + 0.098 \cdot (I_{aa} + I_{ab}) - 0.260 \cdot P \qquad (6)$$

$R^2 = 0.95, P < 0.001$

$$S_{DS} = 3.554 + 0.041 \cdot I_b + 0.103 \cdot (I_{aa} + I_{ab}) - 0.271 \cdot P \qquad (7)$$

$R^2 = 0.95, P < 0.001$

On conventional farms, the N-surplus per unit of N-produce (S_{DS}) decreased with increasing milk yield per cow (Fig. 4; $R^2 = 0.44$, $P < 0.01$), whereas on organic farms, the S_{DS} was not influenced by the milk yield.

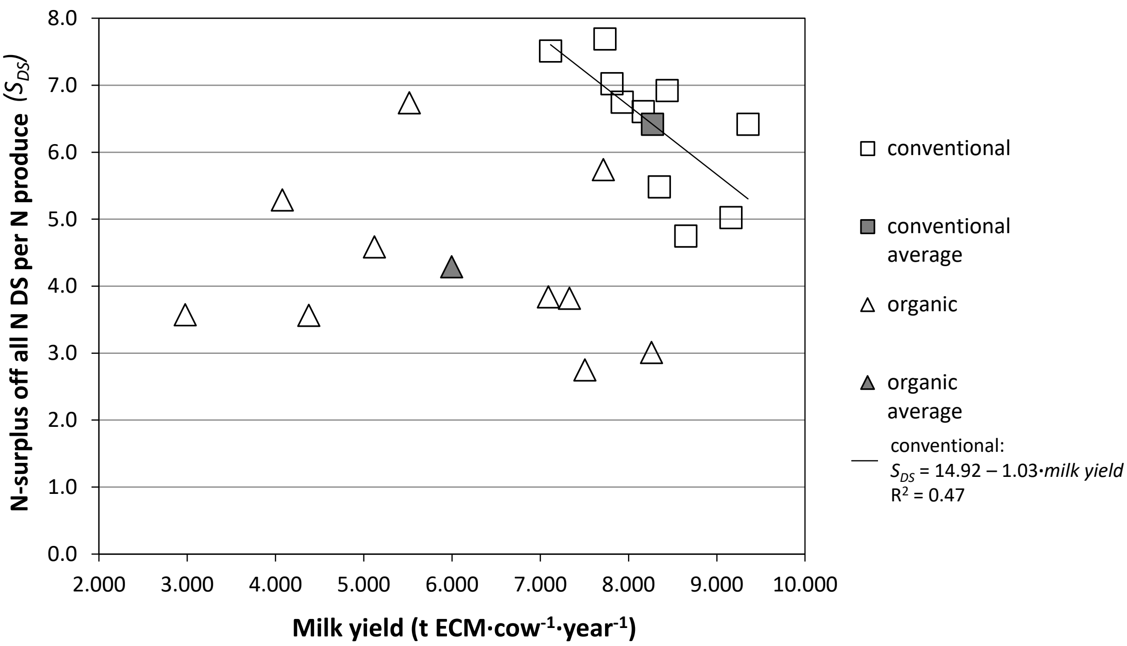


Fig. 4. Nitrogen surplus per unit of produce (S_{DS}, vertical axis) versus annual milk yield per cow (metric ton ECM·cow·year^{-1}) for conventional and organic farms: the average for each group with linear regression for conventional farms. (For indices and calculations, see Table 2)

4 Discussion

Analysing the nitrogen utilisation on 20 dairy farms in regard to the dairy farm and the entire dairy system area, we found within each of the two groups of farms a high variation of production and nitrogen utilisation. Despite this, it is possible to make general statements (albeit simplifications) on the benefits of conventional and organic modes of production. Conventional farms were found to have a higher production of milk and meat per farm, which is in line with the results of a study by Ponti et al.

(2012) in Northern Europe. When comparing milk production per area, we found that identifying the area used for the calculation, i.e., dairy farm or dairy system area, is important, which is a point also highlighted by Thomassen et al. (2008) and Marton et al. (2016). On organic farms, the produce related to dairy farm area corresponded to 5,100 ± 1,200 kg milk·ha^{-1} (Table 3), which is 64 % of the amount produced on conventional farms (8,200 ± 2500 kg·ha^{-1} DF).

When the entire area of the DS used for feed production is considered, the production on organic farms corresponded to 3,000 ± 50 kg·ha^{-1} DS, or 76 % of that on conventional farms (4,100 ± 700 kg·ha^{-1} DS; Table 3). This indicates that including the area of the entire DS is important when comparing area productivity. Having said this, however, the data obtained for off-farm yields tend to be more uncertain than those obtained for dairy farm yields. In regard of embodied energy, Koesling (2017) found that grazing reduced the overall use of energy, but for nitrogen, no such connection could be found.

4.1 N-surpluses of DF

Although there is international interest in increased milk production on an area basis, such an increase is often associated with a risk of decreasing N-recovery and increasing N-losses (Stott and Gourley, 2016). It is therefore not surprising that the higher production on conventional farms in this study can be attributed to the larger amounts of purchased N, which resulted in higher N-surpluses per hectare farm area and per unit produced, than on organic farms (Table 4). Such high N-surpluses are found to represent high costs for society (Sutton et al., 2011). Feeding a high proportion of concentrates and importing most of the protein-rich ingredients have contributed to Norway's ranking among the top 10 worldwide net importers of N per capita (Oita et al., 2016, supplementary material).

In addition to the fact that high N-surpluses are responsible for the significant emissions of reactive N, the excessive use of N-fertilizers also needs to be constrained for other reasons. Producing N-fertilizers requires energy, and the purchase of N-fertilizers has a significant impact on the total energy use on conventional farms (Koesling, 2017). Nitrous oxide (N_2O) is not only emitted from fertilized fields but also from the production of N-fertilizers (Nemecek and Kägi, 2007).

On conventional farms, the input of N-fertiliser was shown to be highly positively correlated with increased N-surplus on the dairy farm scale (Table 4). Surprisingly, regression analysis showed no significant positive effect of increased use of N-fertiliser on the estimated DM yield per DF area. This finding and the high N-surplus per ha and per produced unit raises the question as to whether many conventional farmers not only use purchased N-fertilisers to increase yields, but also as an insurance to grant high yields (Sheriff, 2005; Øgaard, 2014). Different strategies to improve nitrogen utilisation are presented by Godinot et al. (2014), among which is

This is the post-peer review, pre-copyedit version of an article published in Agricultural Systems.
The final authenticated version is available online at: http://dx.doi.org/10.1016/j.agsy.2017.06.001.

the extensification strategy, which by reducing the system N-surplus is comparable to the organic farms surveyed in the present study. Owing to the high N-surplus on many conventional dairy farms, improving the utilization of N-fertiliser while increasing milk production, could be a solution to reduce the N-surplus and improving net profit on farms (Mihailescu et al., 2015). In this regard, improved utilisation of the manure produced on-farm can be an important strategy to reduce the requirement for purchased N-fertilizer.

The organic farms surveyed in the present study were shown to use purchased inputs more efficiently than the conventional farms. This is because fertilization on organic farms in mainly facilitated by biological N-fixation in grass–clover leys rather than by purchased N-fertilizer. Thus, the N-import of organic farms consists mainly of feed, which has a higher trophic level than fertilizer, and thus appears to be more efficient (Bleken et al., 2005). An increase in roughage yields through improved utilisation of the farms own manure and biologically fixed nitrogen on organic farms could decrease the needs for feed import.

Our results for the N-efficiencies (E_{DF}) of conventional (0.16 ± 0.02) and organic (0.24 ± 0.06) DFs are comparable with those reported by Cederberg and Mattsson (2000) and Dalgaard et al. (1998) in Denmark. Cederberg and Mattsson (2000) calculated an N-surplus of 198 kg $N \cdot ha^{-1}$ for conventional dairy farms and 65 kg $N \cdot ha^{-1}$ for organic dairy farms. This is a little lower

This is the post-peer review, pre-copyedit version of an article published in Agricultural Systems.
The final authenticated version is available online at: http://dx.doi.org/10.1016/j.agsy.2017.06.001.

than that found in our study (B_{DF}: 220 and 88 kg N·ha^{-1} for conventional and organic dairy farms, respectively; Table 4). In contrast, compared with the present study, Godinot et al. (2014) found that conventional mixed dairy farms in France had on average a considerably higher N-efficiency (0.36 + 0.09) based on net N inputs and outputs and lower farm (122 ± 31) and system N-surpluses per hectare (142 ± 34).

For the production on a farm, yields depend on sufficient N-inputs. Since N-surpluses are calculated as kg N-surplus per kg N-produce, low N-inputs will result in low N-intensities and might be perceived as environmentally beneficial. The same problem arises when calculating efficiencies. To overcome this problem, including the production per area (White, 2016) in addition to intensities or efficiencies is important with respect to address environmental issues.

Further, to achieve an overall reduction in N-surplus on their dairy farms, some farmers ensure a balanced fodder composition (energy and protein) to create optimal conditions for good animal health, improve the N-utilisation of their farm manure, reduce losses from field to feed, improve soil drainage, and reduce soil compaction. These are all factors that can affect N-utilisation, but because of lack of data could not be included in the statistical analyses in the present investigation. Because all farms are in the same geographical region, the variation in farm management is likely to be more important than variation in soil type and climate for the variation in estimated N-utilisation at the farm level.

As indicated by van Middelaar et al. (Van Middelaar et al., 2013), it is not only important to include both farm and off-farm levels, but also to differentiate different farm areas with different plant products and fertilisation schemes, as for example in the study by Verloop et al. (2006). In the present study (Table 5), we found that there were large differences for both N-inputs and -outputs as well as for N-surpluses between the two major types of on-farm area, with the largest differences being observed on conventional farms. Since surpluses for the entire dairy farm can underestimate the potential for N leaching for the areas with the highest N-intensity, we recommend that N-surpluses should be separately calculated for different farm areas, when there are variations in the N-intensity on different areas on a farm and the focus is on local environmental effects.

4.2 N-surplus of DS

We found that inclusion of the N-surplus derived from producing feed and heifers off-farm made little difference to our calculations of the N-surplus per produced unit and the N-efficiency (Results 3.3 and Table 4). According to the findings of Nadeau et al. (2007), a cow needs approximately 3.3 kg N from feed to produce 1 kg N in milk. Thus, N-input/N-produce ratios above and below 3.3 for the entire dairy farm represent mainly the utilisation of N in feed production on the dairy farm and utilisation of N on off-farm area.

On conventional farms, feed production with a high N-surplus (B_{DS}) and a high proportion of imported N-fertiliser results in higher N-surpluses on thea dairy farm area. In this study, for the conventional farms with high N-intensities, the import of concentrates produced with a relatively low N-surplus resulted in lower calculated N- surpluses per unit N-produce for the DS. Growing soybeans in Brazil and maize in France resulted, for example, in an N-surplus of 27 kg N·ha^{-1} and 108 kg N·ha^{-1}, respectively (Nemecek et al., 2011). These N-surpluses are low compared to the average N-surplus for total N inputs in the dairy system found for the conventional farms in the present study (Table 4). Although the N-surpluses on off-farm areas are low, the import of (ingredients for) concentrates increases the dairy farm N-surpluses on both conventional and organic farms. Nemecek et al. (2011) suggest that modelling simplifications and uncertainty need to be considered when data are used. Better data on the production of ingredients for imported feed, separately for conventional and organic production, would allow further in-depth analyses and enable the selection of feed components with lower off-farm N-surplus.

However, N-intensities that are too low can be detrimental. In stockless organic farms that export cereals or roughage, a negative N-balance is possible, resulting in a large risk of future decreased soil fertility, if the system persists. To our knowledge, apart from the studies of Godinot et al. (2014) and Bleken et al. (2005), there have been no studies that have discussed or evaluated N-surplus on off-farm area for imported feed.

Although the amounts of the different inputs have often been presented, their influence on the total surplus per produced unit in the dairy system has not been discussed.

Another important aspect of the DS is the effect of the entire dairy system area, including both on-farm and off-farm area, needed for milk production. The importance off including off-farm area has, for example, been underlined by Thomassen et al. (2008) and Kristensen et al. (2011). In the present study, we found that for conventional farms, the area required to produce the equivalent of 1 L of milk nearly doubles to 2.5 m^2 when dairy system area is considered rather than the dairy farm area. This value is higher than the range (1.1–2.0 m^2 per kg milk) presented in a review by Vries and de Boer (2010), for Sweden, the Netherlands, and the United Kingdom. On the organic farms surveyed in the present study, the area demand increased by 62 % to 3.4 m^2. For the Netherlands, Thomassen et al. (2008) found a considerably lower area demand, but comparable relationships between dairy farm and dairy system area and between conventional and organic production. For dairy farms in Denmark, Kristensen et al. (2011) reported a considerably lower proportion of off-farm area, particularly on organic farms.

Expanding from the dairy farm to dairy system level, to include the effect of off-farm area, depends on a comparison of the utilisation of nitrogen on the dairy farm area and the off-farm area.

4.3 Effect of milk yield on N-surplus

Increased production of milk per cow has previously been found to be positively correlated with better N-efficiency and thus lower N-surplus (Børsting et al., 2003; Kristensen et al., 2015; Nadeau et al., 2007). This effect was also shown for conventional farms (Fig. 4) in the present study. There appears to be at least two reasons for the reduced N-surplus associated with increased milk yield on conventional farms. First, the share of feed needed for a cow's metabolism per litre of milk produced decreases with increasing milk yield. Second, imported concentrates are produced with lower N-surplus than for roughage produced on the farm.
Unlike conventional farms, milk yield did not affect the N-surplus on organic farms, regardless of whether milk yield was 3.000 or 8.300 kg ECM·cow^{-1}·year^{-1}. Further investigations are needed to explore the reason for this finding.

4.4 Effect of free rangeland

We estimated that an average of 5.9 % of the entire feed demand for conventional farms and 8.1 % for organic farms is provided by free rangeland. On the organic farm with the longest annual grazing period on free rangeland, we estimated the energy uptake to be 27.0 % of the entire energy demand. Without free rangeland, more cultivated or off-farm area would have to be used to produce the same amount of milk and meat.

4.5 Representativeness

Ten of the 13 dairy farms certified for organic production in Møre og Romsdal County participated in the current study. Thus, the organic farms surveyed in this study can be considered as representative of organic dairy farming in the county. The proportion of conventional dairy farms included in the study is rather small relative to the total number of such farms in the region. However, since the farms differed in the size of agricultural area, number of dairy cows, and use of N-fertiliser per hectare, we expected them to show representative variation of that found on conventional farms in the region.

5 Conclusions

Despite a high variation within each of the two groups of farms and also some overlapping in the range of variables generally considered important for a high production level, as the milk yield per cattle and the use of concentrate feed, there was a clear indication that the conventional mode of production generally provided substantially higher milk and meat yield (+ 61 %) per ha of dairy farm area than the organic mode of production. This advantage of the conventional mode of farming was less, though still conspicuous when also the land area off-farm used for the production of

This is the post-peer review, pre-copyedit version of an article published in Agricultural Systems.
The final authenticated version is available online at: http://dx.doi.org/10.1016/j.agsy.2017.06.001.

purchased feed and live animals was included (+ 35 % yield/total DS area, compared to organic management).

On the other hand, the organic management mode was more efficient in term of nitrogen utilisation, and thus environmentally had a lower risk of nitrogen pollution, whichever indicator was used to measure it. Measured relative to the land area of the whole system, the average surplus in the conventional mode of management was double that of the organic systems. However, the real disadvantage of the conventional systems in terms of risk for leaching and GHG emissions is found on the fully cultivated area of the dairy farms, where the average surplus was about 250 kg N/ha for conventional farms and just less than 100 kg N/ha on the organic farms. For N surplus per unit of N-produce (N in milk and meat), the conventional mode of production was still generally less N efficient than the organic ones, with a 50 % larger nitrogen surplus at the whole system level, where also the production of bought feed was included.

The relative differences between the two mode of production were large, and thus robust indicators of the main tendencies, in spite of uncertainties connected to the estimates of both biological nitrogen fixation and of N surplus related to feed (and some live animals) produced off-farm.

Both conventional and organic farms used a high share of imported feed, though the variation was large in both groups. Also the milk yield per cow was high, but with large variations, in both systems. Ultimately the input of

N-fertilizer appeared to be the major cause of the main differences in productivity level and N-efficiency between the mode of management, while other management choices and local resources has certainly plaid an important role in the variation within both groups of farms.

Although both the dairy farm and the off-farm area are components of the dairy system, the present study has revealed that there are substantial differences within the different areas of this system. For the off-farm area, it is important to be aware that feed is delivered without any re-allocation of manure from the dairy farm. For the farm area, the fully-cultivated area has higher N-intensity and N-surplus than native grassland.

When the area on a farm is diverse with regards to yields and N-surpluses, we recommend that separate N-balances are calculated for fields of comparable intensity; otherwise, a high N-surplus and the potential for losses on fields with high N-intensity can be underestimated by calculating average data for the entire farm.

Acknowledgements

Funding from the Research Council of Norway (grant number, 199487/E40) and 'Møre og Romsdal' County Council, Division for Agriculture and Food, is gratefully acknowledged. We would like to thank the participating farmers for their interest and willingness to provide data and for sharing the requisite information, and other project partners for discussing the planning and execution of the study, and advising on evaluation of the results. The staff of Bioforsk Organic Food and Farming Division made valuable contributions to the data collection, and Bo Willem Woelfert assisted with calculations, layout, and figures. Gustav Fystro contributed to the design and execution of the study, together with Maximilian Schüler who discussed the results and advised on the calculation of indicators.

References

Andrew, S.M., Waldo, D.R., Erdman, R.A., 1994. Direct Analysis of Body Composition of Dairy Cows at Three Physiological Stages. J. Dairy Sci. 77, 3022–3033. doi:10.3168/jds.S0022-0302(94)77244-1

Bleken, M.A., Bakken, L.R., 1997. The Nitrogen Cost of Food Production: Norwegian Society. Ambio 26, 134–142.

Bleken, M.A., Steinshamn, H., Hansen, S., 2005. High nitrogen costs of dairy production in Europe: Worsened by intensification. Ambio 34, 598–606. doi:10.1579/0044-7447-34.8.598

Børsting, C.F., Kristensen, T., Misciattelli, L., Hvelplund, T., Weisbjerg, M.R., 2003. Reducing nitrogen surplus from dairy farms. Effects of feeding and management. Livest. Prod. Sci. 83, 165–178. doi:10.1016/S0301-6226(03)00099-X

Cederberg, C., Flysjö, A., 2004. Life Cycle Inventory of 23 Dairy Farms in South-West Sweden, SIK-rapport. The Swedish Institute for Food and Biotechnology. Swedish Dairy Association. Food 21.

Cederberg, C., Mattsson, B., 2000. Life cycle assessment of milk production - a comparison of conventional and organic farming. J. Clean. Prod. 8, 49–60. doi:10.1016/S0959-6526(99)00311-X

Cederberg, C., Stadig, M., 2003. System Expansion and Allocation in Life Cycle Assessment of Milk and Beef Production. Life Cycle Assess. 8, 350–356. doi:10.1065/lca2003.07.126

Dalgaard, T., Halberg, N., Kristensen, I.S., 1998. Can Organic Farming Help to Reduce N-Losses? Experiences From Denmark. Nutr. Cycl. Agroecosystems 52, 277–287. doi:10.1023/A:1009790722044

Dannevig, P., 2009. Møre og Romsdal - klima (In Norwegian) [WWW Document]. Internet. URL http://snl.no/Møre_og_Romsdal/klima (accessed 8.9.16).

FAO, 1986. Manuals of food quality and control. 7. Food analyis: general techniques, additives, contaminants, and consumption, FAO Food and Nutrition paper. Food and Agriculture Organization of the United Nations, Rome.

Gerber, P.J., Steinfeld, H., Henderson, B., Mottet, A., Opio, C., Dijkman, J., Falcucci, A., Tempio, G., 2013. Tackling climate change through livestock - A global assessment of emissions and mitigation opportunities. Food and Agriculture Organization of the United Nations (FAO), Rome.

Godinot, O., Carof, M., Vert,s, F., Leterme, P., 2014. SyNE: An improved indicator to assess nitrogen efficiency of farming systems. Agric. Syst. 127, 41–52. doi:10.1016/j.agsy.2014.01.003

Halberg, N., Werf, H.M.G. van der, Basset-Mens, C., Dalgaard, R., Boer, I.J.M. de, 2005. Environmental assessment tools for the evaluation and improvement of European livestock production systems. Livest. Prod. Sci. 96, 35–50.

Hansen, S., Bernard, M.-E., Rochette, P., Whalen, J.K., Dörsch, P., 2014. Nitrous oxide emissions from a fertile grassland in Western Norway following the application of inorganic and organic fertilizers. Nutr. Cycl. Agroecosystems 98, 71–85. doi:10.1007/s10705-014-9597-x

Huysveld, S., Van linden, V., De Meester, S., Peiren, N., Muylle, H., Lauwers, L., Dewulf, J., 2015. Resource use assessment of an agricultural system from a life cycle perspective - a dairy farm as case study. Agric. Syst. 135, 77–89. doi:10.1016/j.agsy.2014.12.008

Høgh-Jensen, H., Loges, R., Jørgensen, F. V, Vinther, F.P., Jensen, E.S., 2004. An empirical model for quantification of symbiotic nitrogen fixation in grass-clover mixtures. Agric. Syst. 82, 181–194. doi:10.1016/j.agsy.2003.12.003

Haas, G., Wetterich, F., Geier, U., 2000. Life cycle assessment framework in agriculture on the farm level. Int. J. Life Cycle Assess. 5, 345–348.

Haas, G., Wetterich, F., Köpke, U., 2001. Comparing intensive, extensified and organic grassland farming in southern Germany by process life cycle assessment. Agric. Ecosyst. Environ. 83, 43–53. doi:10.1016/S0167-8809(00)00160-2

Koesling, M., 2017. Nitrogen and Energy Utilization on Conventional and Organic Dairy Farms in Norway. University of Kassel. doi:urn:nbn:de:hebis:34-2017041052342

Kristensen, T., Jensen, C., Østergaard, S., Weisbjerg, M.R., Aaes, O., Nielsen, N.I., 2015. Feeding, production, and efficiency of Holstein-Friesian, Jersey, and mixed-breed lactating dairy cows in commercial Danish herds. J. Dairy Sci. 98, 263–74. doi:10.3168/jds.2014-8532

Kristensen, T., Mogensen, L., Knudsen, M.T., Hermansen, J.E., 2011. Effect of production system and farming strategy on greenhouse gas emissions from commercial dairy farms in a life cycle approach. Livest. Sci. 140, 136–148. doi:10.1016/j.livsci.2011.03.002

Kraatz, S., 2009. Ermittlung der Energieeffizienz in der Tierhaltung am Beispiel der Milchviehhaltung (In German). Landwirtschaftlich-Gärtnerischen Fakultät der Humboldt-Universität zu Berlin.

Marton, S.M.R.R., Zimmermann, A., Kreuzer, M., Erard Gaillard, G., 2016. Comparing the environmental performance of mixed and specialised dairy farms: the role of the system level analysed. J. Clean. Prod. 124, 73–83. doi:10.1016/j.jclepro.2016.02.074

Mihailescu, E., Ryan, W., Murphy, P.N.C., Casey, I.A., Humphreys, J., 2015. Economic impacts of nitrogen and phosphorus use efficiency on nineteen intensive grass-based dairy farms in the South of Ireland. Agric. Syst. 132, 121–132. doi:10.1016/j.agsy.2014.09.008

Nadeau, E., Englund, J.-E., Gustafsson, A.H., 2007. Nitrogen efficiency of dairy cows as affected by diet and milk yield. Livest. Sci. 111, 45–56. doi:10.1016/j.livsci.2006.11.016

Nemecek, T., Kägi, T., 2007. Life Cycle Inventories of Agricultural Production Systems, Ecoinvent report. Agroscope Reckenholz-Tänikon Research Station ART, Zürich and Dübendorf.

Nemecek, T., Weiler, K., Plassmann, K., Schnetzer, J., 2011. Geographical extrapolation of environmental impact of crops by the MEXALCA method. Agroscope Reckenholz-Tänikon Research Station ART, Zürich.

Nielsen, A.H., Kristensen, I.S., 2005. Nitrogen and phosphorus surpluses on Danish dairy and pig farms in relation to farm characteristics. Livest. Prod. Sci. 96, 97–107. doi:10.1016/j.livprodsci.2005.05.012

NORSØK, 2001. Handbok økologisk landbruk. Del 1 Planteproduksjon (In Norwegian). NORSØK, Tingvoll.

Norwegian Food Safety Authority, 2015. Matvaretabellen - The food composition table 2015 [WWW Document]. URL http://www.matvaretabellen.no/milk-and-milk-products-g1/milk-whole-milk-39-fat-01.235 (accessed 9.1.16).

Norwegian Agricultural Authority, 2011. Veiledningshefte søknad om produksjonstilskudd i jordbruket og tilskudd til avløsning ved ferie og fritid (In Norwegian).

Oita, A., Malik, A., Kanemoto, K., Geschke, A., Nishijima, S., Lenzen, M., 2016. Substantial nitrogen pollution embedded in international trade. Nat. Geosci. 9, 111–115. doi:10.1038/ngeo2635

Olesen, I., Strøm, T., Lund, V., 1999. Økologisk husdyrhald (In Norwegian). Landbruksforlaget, Oslo.

Oudshoorn, F.W., Sørensen, C.A., de Boer, I.J.M., 2011. Economic and environmental evaluation of three goal-vision based scenarios for organic dairy farming in Denmark. Agric. Syst. 104, 315–325. doi:10.1016/j.agsy.2010.12.003

Paustian, K., Ravindranath, N.H., van Amstel, A., 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 4. Agiculture, Forestry and Other Land Use. Hayama.

Ponti, T. de, Rijk, B., Ittersum, M.K. van, 2012. The crop yield gap between organic and conventional agriculture. Agric. Syst. 1–9. doi:10.1016/j.agsy.2011.12.004

Rekdal, Y., 2008. Utmarksbeite - kvalitet og kapasitet (In Norwegian). Skog og landskap, Ås.

Samuelsen, R.T., 2004. Hvordan beiter dyrene? - og hvilke planter foretrekkes? (In Norwegian). Norden 2004, 8–10.

Schader, C., Muller, A., Scialabba, N.E.-H., Hecht, J., Isensee, A., Erb, K.H., Smith, P., Makkar, H.P.S., Klocke, P., Leiber, F., 2015. Impacts of feeding less food-competing feedstuffs to livestock on global food system sustainability. J. R. Soc. Interface 12, 1–12. doi:10.1098/rsif.2015.0891

Sheriff, G., 2005. Efficient waste? Why farmers over-apply nutrients and the implications for policy design. Rev. Agric. Econ. 27, 542–557. doi:10.1111/j.1467-9353.2005.00263.x

Sjaunja, L.O., Bævre, L., Junkkarinen, L., Pedersen, J., Setälä, J., 1991. A nordic proposal for an energy corrected milk (ECM) formula, in: Gaillon, P., Chabert, Y. (Eds.), Performance Recording of Animals: State of the Art, 1990. European Association for Animal Production (EAAP), Paris, pp. 156–157.

Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M., de Haan, C., 2006. Livestock's long shadow: environmental issues and options. Food and Agriculture Organization of the United Nations, Rome.

Stott, K.J., Gourley, C.J.P., 2016. Intensification, nitrogen use and recovery in grazing-based dairy systems. Agric. Syst. 144, 101–112. doi:10.1016/j.agsy.2016.01.003

Sutton, M.A., Oenema, O., Erisman, J.W., Leip, A., van Grinsven, H., Winiwarter, W., 2011. Too much of a good thing. Nature 159–161. doi:10.1038/472159a

Thomassen, M.A., Calker, K.J. van, Smits, M.C.J., Iepema, G.L., Boer, I.J.M. de, 2008. Life cycle assessment of conventional and organic milk production in the Netherlands. Agric. Syst. 96, 95–107. doi:10.1016/j.agsy.2007.06.001

Van Middelaar, C.E., Berentsen, P.B.M., Dijkstra, J., De Boer, I.J.M., 2013. Evaluation of a feeding strategy to reduce greenhouse gas emissions from dairy farming: The level of analysis matters. Agric. Syst. 121, 9–22. doi:10.1016/j.agsy.2013.05.009

Verloop, J., Boumans, L.J.M., Van Keulen, H., Oenema, J., Hilhorst, G.J., Aarts, H.F.M., Sebek, L.B.J., 2006. Reducing nitrate leaching to groundwater in an intensive dairy farming system. Nutr. Cycl. Agroecosystems 74, 59–74. doi:10.1007/s10705-005-6241-9

Vries, M. de, de Boer, I.J.M., 2010. Comparing environmental impacts for livestock products: A review of life cycle assessments. Livest. Sci. 1–11. doi:10.1016/j.livsci.2009.11.007

Werf, H.M.G. van der, Kanyarushoki, C., Corson, M.S., 2009. An operational method for the evaluation of resource use and environmental impacts of dairy farms by life cycle assessment. J. Environ. Manage. 90, 3643–3652. doi:10.1016/j.jenvman.2009.07.003

White, R.R., 2016. Increasing energy and protein use efficiency improves opportunities to decrease land use, water use, and greenhouse gas emissions from dairy production. Agric. Syst. 146, 20–29. doi:10.1016/j.agsy.2016.03.013

Øgaard, A.F., 2014. Nitrogen balance and nitrogen use efficiency in cereal production in Norway. Acta Agric. Scand. Sect. B - Soil Plant Sci. 63, 146–155. doi:10.1080/09064710.2013.843718

Aas, W., Solberg, S., Manø, S., Yttri, K.E., 2011. Monitoring of long-range transported air pollutants. Annual report for 2010. Norwegian Institute for Air Research.