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Sustainability evaluation of automatic and conventional milking systems on organic dairy farms in Denmark

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ABSTRACT

Organic dairy farmers in Denmark currently are implementing automatic milking systems (AMS) to save labour costs. As organic agriculture aims at sustainable production, the introduction of a new technology such as AMS should be evaluated regarding its economic viability, environmental impact, and social acceptability, i.e., its contribution to sustainable development. The objective of this research, therefore, was to evaluate sustainability of AMS use on organic dairy farms in Denmark, by comparing results of a set of sustainability indicators for nine farms using AMS with nine farms using conventional milking systems (CMS). Sustainability indicators were quantified for economic performance of the farm, on-farm eutrophication, on-farm biodiversity, animal welfare (including health), grazing time, milk composition and labour time. Milk yield per cow per year was higher for AMS farms (9021 kg energy corrected milk [ECM] per cow per year) than for CMS farms (7664 kg ECM), but did not result in a higher net profit or gross margin per cow for AMS farms. Nitrogen surplus per hectare of available land was higher for AMS farms (110 kg N ha^{-1}) than for CMS farms (66 kg N ha^{-1}). This difference was not due to the use of AMS but was caused by a higher export of manure by the CMS farms. The number of veterinary treatments per cow per year was unaffected by AMS use, but culling rate was higher for the AMS farms (38%) than for the CMS farms (32%). There was no difference between the AMS and CMS farms in milk composition indicators such as somatic cell count, clostridium spores, and urea. The acid degree value (ADV), measuring free fatty acids (FFA) in the milk, was higher in the milk from the AMS farms (0.78 meq l^{-1}) compared with the CMS farms (0.49 meq l^{-1}). Labour time measured in hours of work per dairy cow per day, was only half for the AMS compared with the CMS users; i.e., 2.3 min per cow per day. Grass intake by grazing as percentage of total feed intake was reduced by AMS (5.1 kg DM per cow per day for the AMS farms against 6.8 kg DM per cow per day for the CMS farms). From this quantification of selected sustainability indicators it can be concluded that organic dairy farms using AMS, in spite of the substantial decrease in grazing time, show the potential of economic and environmental sustainable development within the range of herd sizes investigated (65–157 cows per farm). Even though the lower number of grazing hours per cow per year on the AMS farms did not affect indicator scores for animal health or milk quality, this reduction in grazing hours might be a problem for consumers to accept AMS use.

1. Introduction

Parallel to conventional farmers, organic dairy farmers in Denmark expand their herd size, increase the annual milk yield per cow and the crop yield per ha, improve feed efficiency, and substitute labour by mechanization [1,2]. Introduction of new technology is part of this development. For example, to save labour costs when suitable labour is scarce, organic dairy farmers are implementing automatic milking systems (AMS), and using information and communication technology (ICT) [2].

As organic agriculture aims at sustainable production [3], introduction of a new technology such as AMS should be evaluated regarding its contribution to sustainable development. Agricultural farms are sustainable if they are economically viable, environmentally sound, and socially acceptable [3–5]. AMS implementation can have diverse consequences at farm level. The drive to invest often requires higher economic returns, possibly influencing intensity of production and influencing environmental constraints [6]. A sustainability evaluation of AMS use on organic dairy farms,

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therefore, should comprise all three domains of sustainability [7]. At this moment, no sustainability evaluation of AMS use on organic dairy farms has been performed.

Mollenhorst et al. [8] developed a framework for evaluating the contribution of innovations such as AMS to sustainability performance of a farm. This framework, based on quantification of sustainability indicators, comprises 4 steps: (1) definition of the cause of action, (2) identification and definition of relevant sustainability issues, (3) selection and quantification of sustainability indicators, (4) evaluation of the consequences for sustainable development. In previous research, we described the cause of action (step 1) and reviewed sustainability issues related to AMS use on conventional dairy farms [3]. That review was subsequently translated to organic production circumstances [3]. The translation process was supplemented by knowledge of organic stakeholders on AMS use (step 2) [2]. The aim of the present study was to select and quantify a set of sustainability indicators (SI) for a group of farms using AMS, and a group of farms using CMS (step 3), and to use these results to evaluate the contribution of AMS use to sustainable development of organic dairy farming in Denmark (step 4).

2. Materials and methods

2.1. Selection of farms

In 2005, the organic dairy authorization archive in Denmark contained 480 active organic dairy farms, of which 45 used AMS. In order to avoid an effect of breed on SI quantification, we first selected only those farms that used Holstein Frisian (HF) cows (408 out of 480 farms). Secondly, we selected 10 farms among the AMS users and 10 farms among the CMS users. As herd size was assumed to influence some of the sustainability indicators (SI), the AMS and CMS farms were preset to have a parallel herd size distribution. From each group, nine farmers responded positively to the request to share performance data and complete a questionnaire. Data required to quantify SI on the AMS and CMS farms were collected that focused on a single year (1 January to 31 December 2005) to avoid effects of fluctuations in price level and emerging technological development.

2.2. Selected sustainability issues

Sustainability issues to be addressed regarding AMS use in organic farming were identified in previous research [2,3]. Issue identification was based on a review of sustainability issues related to AMS use on conventional dairy farms [3]. That review was subsequently translated to organic production circumstances [3] and supplemented by knowledge of stakeholders on organic AMS use [2,3]. The sustainability issues we focused on were: economic performance, on-farm eutrophication and biodiversity, animal welfare including health, milk composition, and labour time.

2.3. Selection of sustainability indicators

For each issue defined, we selected (a set of) sustainability indicators(s) (SI). An indicator was defined as a quantitative parameter that measures the state of a sustainability issue [9]. The first question to be answered before selecting an indicator is: what is the purpose of using this indicator? [10]. In our case, sustainability indicators were used to evaluate economic, ecological and social consequences of the introduction of AMS on an organic dairy farm and, therefore, we defined SI at farm level. Furthermore, an indicator has to conform to general premises: it has to be relevant, simple and understandable for the user, sensitive, and reliable. In addition, it must be possible to determine a target value or a trend in space and time, and data should be accessible [11,12].

In this study, the target value for each indicator was equal to the average value of the same SI on CMS farms. In other words, CMS farms were taken as a reference, and the SI performance of AMS farms was presented relative to CMS farms. If available, the performance of farms was related also to absolute target values at national level. We present the results of the quantification of individual SI without aggregating SI results into one overall value for sustainability. In the following sections we describe the selection of SI for each sustainability issue in more detail.

2.4. Economic performance of the farm

To assess the economic performance of a farm, profitability is of major importance [13]. Earlier farm research on the economic perspectives of AMS use, identified net profit and gross margin per cow as indicators to quantify profitability [14,15]. Net profit was computed as the difference between revenues and fixed costs (i.e., maintenance, rent, housing, depreciation, energy), variable costs (i.e., feed, medical treatment), and financing costs (interest, rent). Gross margin was computed as the difference between revenues and variable costs only. Besides net profit and gross margin, an indicator used to assess economic performance is percentage debt. In this study these economic indicators were registered for 18 organic farms. To compare values among farms and to use the commonly used indicator in accounting systems in Denmark, indicators were expressed per dairy cow. Economic indicators were derived directly from the farmer's economic accounts, authorized by a registered public accountant.

2.5. On-farm eutrophication

On-farm eutrophication can be quantified by determining an input–output balance of nitrogen (N) and phosphorus (P) that is reported to be relevant and reliable [16]. The difference between the N–P input and N–P output of a farm or a field, referred to as the farm or field balance, determines the N–P surplus, and is assumed to be lost into the environment. In this study, we computed a farm and field balance for N and P. The N–P farm balance determines the average N and P surplus per hectare of farmed land [16,17]. In order to quantify the effect of overstocking on eutrophication of individual fields more precisely, we also computed an N balance for individual fields, i.e., pasture used for grazing or mowing. The P balance of individual fields was not determined, because the estimated P surplus at farm level appeared to be low.

The N–P input at farm level was determined by quantifying input through imported feed (i.e., roughage, concentrates, and other feeds), mineral supplements, manure, bedding material, and livestock acquisition. In addition, the N fixation of fields by pulses and grass–clover was computed using documented data [18]. We assumed an annual N fixation by a grass–clover ley of 18 kg N ha^{-1} for a clover percentage between 1% and 9%, 78 kg N ha^{-1} for a percentage between 10% and 29%, 156 kg N ha^{-1} for a percentage between 30% and 49%, and 248 kg N ha^{-1} for a percentage >49% [18]. The percentage clover was estimated visually by a trained observer. Annual N fixation for pulses was assumed to be 80 kg N ha^{-1}. An equal atmospheric N deposition of 16 kg N ha^{-1} per year was assumed for the AMS and CMS farms [19]. The N–P output was determined by quantifying the amounts of sales of milk and livestock, manure, feedstuffs, and crops. Standard N–P contents were used [20]. The N content of milk, as well as the amount of energy corrected milk (ECM), was computed using data from the milk delivery registration. A standard P content of milk was assumed. The difference between the N–P input and N–P output determined the N–P surplus per farm, and was expressed per hectare of farmed land.

The field balance was determined only for pastures that were fully used for mowing or grazing. The N surplus per hectare was computed as the difference between the N input and N output for this particular field. The N input for each hectare was estimated by computing the amount of N applied by manure, the amount of N deposited by faeces and urine during grazing, the N fixation, and N deposition. The amount of manure applied on each hectare of land was registered in the farmers' obligatory mineral account. In order to estimate the amount of N deposited by faeces and urine during grazing, information about the grazing time (hours per day and days per year) and stocking rate was acquired from the farmer. Using documented data for excretion of N per cow based on measured milk yield on a yearly basis and milk–urea content [21] and deposition related to grazing time [22], the amounts were calculated as shown in Eq. (1). N-fixation and N deposition were computed in a similar way as for the farm balance.

$$\text{days grazing} \times \frac{\text{hours (h) grazing}}{24\,\text{h}} \times \frac{\text{cow}}{\text{ha}} \times \frac{\text{excertion of kg N}}{\text{cow day}} \qquad (1)$$

The N output was computed as the N removed from the field by grass harvested by mowing or during grazing. Grass–clover yield per hectare was estimated by combining the farm advisory estimate that is used to plan manure application, with the farmer's registration of yields that is used to plan the herd's diet for summer and winter. An average crude protein content of clover–grass of 17% was assumed (% of clover between 22 and 35) [22].

2.6. On-farm biodiversity

To evaluate on-farm biodiversity, we quantified the number of plant species in selected pasture fields. During a farm visit in August, one field used for grazing and one field used for mowing were sampled on each farm. The number of plant species was counted in fixed circular areas of 0.1 m^2 at 20 random places. All grass species were counted as one species, as were white and red clover, whereas all other herbs were counted as separate species.

In addition, average field size, and the amount and area of biotopes with nature value were quantified to evaluate biodiversity. Larger fields tend to indicate landscape impoverishment, as field boundaries are often marked by trees, bushes, or remnant biotopes [23]. With increasing dimensions of machinery, field enlargement is to be expected, especially when grass–clover is grown mainly for mowing. Average field size was computed based on obligatory annual reports for requiring EU subsidy. To quantify amount and area of biotopes, the farm area map was examined and discussed with the farmer, and areas of bush and forest patches were pinpointed and estimated and the length of the hedges was measured.

2.7. Animal welfare including health

Both grazing time and fresh grass intake can affect animal welfare, including health. A decrease in grazing time can be associated with claw and leg problems, reproduction problems, summer mastitis, death of young calves, death of milking cows, and the culling of cows [24]. So the following indicators for animal welfare and health were quantified: the area available for grazing per cow, the grass intake, the grazing hours per cow per day, and the annual number of grazing days per cow. The area available for grazing was registered using the rotation and crop planning schemes that are also used for applying for EU subsidies, in combination with personal inquiry. The time (hours per day, days per year) a cow had access to pasture was obtained through a personal interview with the farmers.

Furthermore, for each farm we quantified several indicators related to cow health, i.e., the number of treatments per cow for claw problems, mastitis, and reproduction problems, as well as the total number of treatments per cow per year. Treatment indicators were computed as the number of treated cows per 100 cows.

In addition, the numbers of cows and calves that died were registered as well as the culling rate and veterinary costs. In Denmark, veterinary treatments are reported compulsory by the vet at individual cow level. Treatments registered were sorted by month, and used to compute the number of treatments per cow for the winter and summer period separately.

2.8. Milk composition

The indicators selected to evaluate milk composition were related directly to AMS technique [2], to grazing time [25,26], or quality related to consumption [27]. The free fatty acids (FFA) content of milk is assumed to be influenced by milking frequency, milk flow per milking, storage time, pumping and mixing (especially of milk that is not cooled), and diet composition [27]. Large amounts of saturated lipids in the diet can result in large fat globules in the milk, which are susceptible to lipolysis and cause the breakdown of protected fat into free fatty acids. The milk-FFA content measured in acid degree value (ADV in milliequivalents per litre [meq l^{-1}] milk) was therefore chosen as an indicator of milk quality in relation to technique. Data on milk-FFA content were collected from a milk composition survey that included all dairy farms in Denmark [27].

Furthermore, insufficient hygiene when using AMS might result in contamination by spores of *Clostridium tyrobutyricum*. This bacterium can cause cheese to explode because of a fermentation process producing hydrogen and carbon dioxide. Spores are resistant to pasteurization and contaminate milk through contaminated silage, leading to spores in the manure that in addition can infect teats. If washing the udder before milking is neglected, this can cause high spore contents in the milk. The number of spores per litre of milk, was therefore taken as an indicator of milk quality.

A high somatic cell count (SCC) indicates mastitis problems, hygienic problems, as well as possible stress and was therefore used in this study to identify differences between AMS and CMS. Mastitis can be enhanced by stress or neglected surveillance, which have both been suggested as possible problems with AMS use [2]. SCC counts include leucocytes and cows' own udder cells, which emulsify with the milk. The amount is correlated with infection (clinical and sub-clinical) of the udder, which is usually mastitis. Both milk delivered and milk directly sampled from the cows were analysed.

2.9. Labour time

To evaluate the consequences of AMS use regarding labour circumstances, we quantified labour time per day for selected tasks, in relation to dairy cows only. These tasks were as follows: milking, fetching and registration; treatment and surveillance; feeding; providing bedding straw in the cubicles; cleaning; and miscellaneous. Such a detailed time table provides insight into the main aspects related to labour, i.e., total amount of time used per cow per day, and the relative importance of tasks differing in physical impact and labour flexibility [2,24,25].

2.10. Statistical analysis

For each farm group quantified SI were tested for normality using the Anderson-Darling test, which is suitable for small samples ($n \leq 25$) [28]. For each SI, mean and standard deviation were computed for the AMS and CMS farms. Subsequently, the SI values were analysed by one way ANOVA, with milking system as a

Table 1
General characteristics of individual organic dairy farms with a conventional milking system (CMS) and organic dairy farms with an automatic milking system (AMS) in 2005 (SD in parentheses).

Parameter	Unit	Farms with a conventional milking system											
		1	2	3	4	5	6	7	8	9	*M*		*p*-value[f]
Dairy cows	#	47	92	90	151	105	131	151	146	160	119	(38)	0.79
Area	ha	53	63	182	163	80	120	86	86	215	116	(57)	0.27
Heifers (0 = not included in average)	#	0	61	90	116	54	105	178	0	160	109	(47)	0.63
Stocking rate	LU [a] ha^{-1}	1.07	1.76	0.77	1.37	1.82	1.49	2.85	2.53	1.16	1.65	(0.68)	0.16
Milk yield (gross)	ECM [b] per cow per year	6327	8673	8161	7732	7787	6284	8750	7246	8018	7664	(880)	0.003
Area available for grazing cows	ha cow^{-1}	0.32	0.24	0.29	0.31	0.13	0.14	0.15	0.17	0.46	0.25	(0.11)	0.47
Grazed grass in summer diet	% of total diet [d]	62	51	38	36	39	40	17	mv[c]	mv	41	(14)	0.05
Concentrates in diet	% of total diet	27	43	23	32	25	24	26	37	36	30	(7)	0.20
Financial result per farm[e]	×€1000	12.4	85.7	151.3	90.7	52.1	134.5	194.4	159.8	225.6	123.0	(68.5)	0.21
Milking frequency (summer)	Milkings day^{-1}	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	(0)	<0.001
Milking frequency (winter)	Milkings day^{-1}	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	(0)	<0.001
		Farms with an automatic milking system											
Start AMS		September 1999	November 2000	December 1998	February 2003	March 2003	April 2003	April 2003	October 2003	October 2002	*M*		*p*-value[f]
Dairy cows	#	65	69	80	127	121	145	132	157	134	114	(34)	
Area	ha	77	108	134	135	109	299	154	164	157	149	(63)	
Heifers	#	77	75	64	130	128	165	132	157	149	120	(38)	
Stocking rate	LU ha^{-1}	1.37	1.02	0.89	1.48	1.75	0.78	1.34	1.49	1.37	1.28	(0.32)	
Milk yield (gross)	ECM per cow per year	10434	8989	9504	8903	9670	8400	8545	8835	7910	9021	(540)	
Area available for grazing cows	ha cow^{-1}	0.32	0.29	0.48	0.13	0.48	0.22	0.27	0.37	0.08	0.29	(0.14)	
Grazed grass in summer diet	% of total diet	35	mv	34	19	24	25	40	23	mv	29	(8)	
Concentrates in diet	% of total diet	37	28	33	30	34	35	22	30	39	32	(5)	
Financial result per farm	×€1000	119.6	157.8	145.1	142.7	114.3	294.2	187.9	133.2	157.3	161.4	(54.4)	
Milking frequency (summer)	Milkings day^{-1}	2.5	2.3	3.0	2.0	2.4	2.5	2.1	2.6	2.1	2.4	(0.1)	
Milking frequency (winter)	Milkings day^{-1}	2.8	2.5	3.2	2.5	2.8	2.8	2.4	3.0	2.6	2.7	(0.3)	0.02[g]

[a] LU: livestock unit, corresponds to an excretion of 100 kg N per year for one dairy cow producing 8000 kg ECM per year is rated as 1.18 LU. One heifer (6–28 months) is rated as 0.38 LU (Danish Enactment 814, 13-07-2006).
[b] ECM: energy corrected milk, milk yield standardized for fat and protein content [29].
[c] mv: missing value.
[d] Percentage of the total diet: calculated as kg DM.
[e] Financial result: is the gross income (from milk, animals, meat and other products) minus the fixed costs (maintenance, wages, energy) and unit costs (feed, fertilizer, contract work).
[f] *p*-value between AMS and CMS values.
[g] *p*-value for difference between summer and winter milking frequency.

factor. A *p*-value of 0.05 was used to establish statistically significant differences.

3. Results and discussion

3.1. General farm characteristics

The number of dairy cows per farm did not differ statistically between the AMS and CMS farms ($p = 0.76$, Table 1). All AMS farms raised their own heifers, whereas two CMS farms outsourced rearing of young stock in 'heifer hotels', and one CMS farm kept heifers during the barn period only. Annual milk yield per cow was higher for the AMS than for the CMS farms ($p = 0.003$). The percentage of concentrates in the diet was not higher for the AMS than for the CMS farms ($p = 0.20$). The AMS farms, however, did have a lower percentage of grazed grass in the diet than the CMS farms ($p = 0.05$). The intake of necessary supplementary silage (maize, grass, and whole grain silage), which formed the remaining part of the diet, was therefore higher for the AMS than for the CMS farms.

Feed efficiency was defined as total dry matter (DM) offered to the herd, divided by DM required in accordance with standard energy requirements for production [30]. Feed efficiency did not differ between the AMS and the CMS farms ($p = 0.65$), and was on average 83%. The grazing area available per dairy cow did not differ between milking systems ($p = 0.47$) and was on average higher than the present legal minimum for organic dairy farming in Denmark of 0.2 ha per dairy cow. Milking frequency was markedly higher for the AMS than for the CMS farms ($p < 0.001$). Furthermore, on the AMS farms, milking frequency was higher in winter than in summer ($p = 0.02$), confirming that pasturing induced lower milking frequency [31]. Literature shows that daily milk yield increases by around 3.5 kg per cow per day when increasing milking frequency from 2 to 3 [32]. In our study, milking frequency of the AMS farms varied between 2.4 and 2.7 all year round, implying an increase in milk yield of about 1.9 kg per cow per day [32] compared with the CMS farms. Given a 305-day lactation period, however, daily milk yield on the AMS farms was about 4.0 kg ECM higher compared with the CMS farms (Table 2). This indicates that a higher milk yield level for the AMS than for the CMS farms could not be explained by the measured parameters, and were therefore ascribed to differences in management.

The milking frequency on the AMS farms was lower than the milking frequency found in a study for conventional herds with AMS done in 2006, which showed an average of 2.8 (±0.3). The reason for the somewhat lower milking frequency among organic farms with AMS could be the grazing. Milking frequency on the AMS farms was 2.7 in winter and 2.4 in summer. This difference in milking frequency is probably due to the long distance from grazing field to barn in combination with synchronized cow behaviour, which has shown to decrease the visiting frequency of AMS [31].

Table 2
Means and standard deviations (in parentheses) of economic indicators for organic dairy farms with an automatic milking system (AMS) and organic dairy farms with a conventional milking system (CMS) in 2005.

Indicator	Unit	AMS		CMS		*p*-value
Revenues milk sales	€ cow^{-1}	2910	(261)	2312	(325)	<0.001
Revenues rest	€ cow^{-1}	434	(142)	612	(411)	0.24
Variable costs	€ cow^{-1}	1253	(428)	1023	(428)	0.24
Fixed costs	€ cow^{-1}	1221	(367)	1275	(278)	0.73
Financing costs[a]	€ cow^{-1}	620	(259)	723	(329)	0.47
Debts	% of net worth	46	(18)	56	(13)	0.26
Net profit[b]	×€1000	161	(54)	123	(69)	0.21
Gross margin[c]	€ cow^{-1}	2719	(385)	2258	(532)	0.27

[a] Financing costs are interest costs on mortgage, loans, and investments together with rent paid for land use.
[b] Net profit is the gross income (from milk, animals, meat, and other products) minus fixed costs (maintenance, wages, energy, contract work), variable costs (feed, fertilizer) and financing costs (interest, rent).
[c] Gross margin is total income per cow minus the variable costs per cow and variable costs for the young stock necessary to maintain the herd.

3.2. Economic performance of the farm

Annual milk yield and revenues from milk sales per cow were higher for the AMS than for the CMS farms (Tables 1 and 2). Other economic indicators did not differ between the AMS and CMS farms. When we expressed the economic indicators per kilogram milk delivered, these indicators still did not differ between the AMS and CMS farms, due to the large variation between farms in each group.

Revenues from milk sales corresponded directly to the gross milk yield and were higher for the AMS farms; revenues from meat sales, animal sales and other income did not differ between the AMS and CMS farms. There was a large variation in other revenues within the groups. Variable costs per cow quantified in this study, which for a large part consisted of concentrate feeding, were the same for the CMS and AMS farms. Other studies indicated higher feeding cost per cow for AMS users [33]. In addition, fixed costs did not differ between the AMS and CMS farms, neither per cow ($p = 0.73$), nor per hectare ($p = 0.48$), or per kilogram of milk produced ($p = 0.46$). This was rather surprising as AMS in other studies showed to be more costly than CMS [34].

Maintenance and service costs can be higher because of technical problems, and updates. Financing costs expressing size of loan and mortgage, as well as amount of land rented did not differ between the AMS and CMS farms.

Net profit and gross margin per cow did not differ between the AMS and CMS farms. In studies comparing AMS and CMS use on conventional farms, the economic results of AMS farms were inferior to the results of CMS farms [2,34,35]. Table 1 shows that the stocking rate of the AMS farms had a tendency to be lower than the stocking rate of the CMS farms ($p = 0.16$). Nicholas et al. [36] found that a low stocking rate on organic farms was associated with better economic performance. In our study, however, such a correlation between net profit and stocking rate was not found ($r^2 = 0.01$); possibly because the lower stocking rate was compensated by the above-mentioned negative economic impact of AMS. However, such a counter effect between stocking rate and higher expenses for AMS could not be concluded from our data.

Model calculations [35,37] indicated that a moderate herd size for AMS farms (45–120 cows) was associated with better economic performance. Our results (Fig. 1) did not show this correlation, and no difference was found between the AMS farms and CMS farms.

3.3. On-farm eutrophication

The average N surplus on the AMS farms was 110 kg ha^{-1}, which is higher than the surplus of 66 kg ha^{-1} for the CMS farms ($p = 0.02$, Table 3). In addition, the N surplus for grazing fields was lower for the AMS than for the CMS farms ($p = 0.05$), whereas the N surplus for mowing fields was higher for the AMS farms ($p = 0.03$).

To explain these results we used general characteristics of sampled farms (Table 1) and indicators quantified to evaluate grazing behaviour at the AMS and CMS farms (Table 4). It was expected that the AMS farms would have a higher N surplus on their grazing fields, because of relatively few pastures around the barn utilized for grazing. However, the area of grassland available for grazing per dairy cow did not differ between the AMS and CMS farms (Table 1). On the other hand, the percentage of grazed grass in the diet was higher at the CMS than at the AMS farms ($p = 0.05$, Table 1). This was supported by registration of the amount of time the cows spent grazing outside, which was higher for the CMS than for the AMS farms ($p < 0.001$, Table 4). The fact that the cows on the CMS farms spent more time grazing outside causes extra N excretion on the grazing fields, which explains the higher N surplus on fields used 100% for grazing. Consequently, on the CMS farms, less excrement is deposited in the barn, and therefore less manure is applied on mowing fields, explaining the lower N surplus.

The N surplus (farm based) of 110 kg ha^{-1} for the AMS farms and of 66 kg ha^{-1} for the CMS farms is low compared with the average N surplus of 108 and 124 kg ha^{-1} for organic dairy farms in Denmark with stocking rates of 1.1 and 1.3 livestock units per hectare (LU, representing an N output of 100 kg ha^{-1}), respectively [38]. In our study, the stocking rate was on average 1.28 LU on the AMS farms and 1.65 LU on the CMS farms. No correlation was found between stocking rate per farm and surplus N at farm or field level. The most important reason for the relatively small N surplus on the CMS farms in this study was the large amount of manure exported to organic crop growers. Due to maximum limits for use of manure originating from non-organic husbandry, organic crop growers are anxious to collect organic manure. The difference

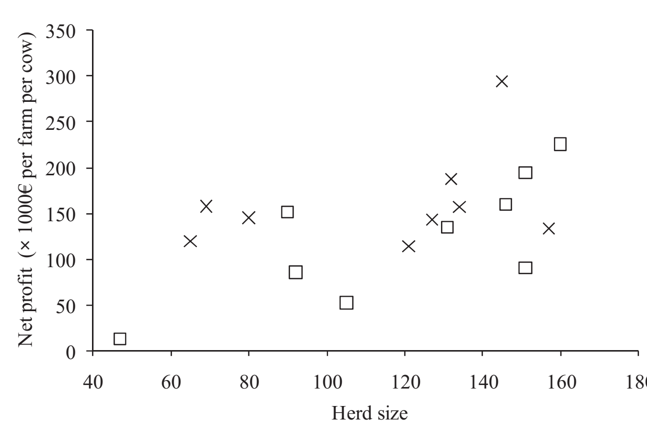

Fig. 1. Average net profit (×€1000) per organic dairy farm in relation to the number of cows in nine herds with an automatic milking system (AMS = ×) and nine herds with a conventional milking system (CMS = □).

Table 3
Means and standard deviations (in parentheses) of results of environmental indicators for organic dairy farms with an automatic milking system (AMS) and organic dairy farms with a conventional milking system (CMS) in 2005.

Indicator	Unit	AMS		CMS		*p*-value
N surplus at farm level	kg N per ha	110	(29)	66	(40)	0.02
P surplus at farm level	kg P per ha	8.8	(6.6)	3.4	(8.7)	0.16
N surplus on grazing pasture	kg N per ha	92	(82)	166	(60)	0.05
N surplus on mowing pasture	kg N per ha	148	(79)	53	(80)	0.03
Average field size	ha	5.0	(1.1)	5.3	(3.8)	0.84
Plant species grazing fields	$\#ha^{-1}$	5.4	(1.3)	5.6	(2.1)	0.83
Plant species mowing fields	$\# ha^{-1}$	3.4	(2)	2.4	(1.1)	0.20

in net export of N via manure between the CMS and AMS farms was 40 kg ha^{-1} ($p = 0.03$), which is almost identical to the difference in N surplus between farm types. No explanation could be found for the difference in manure export between the AMS and CMS farms.

3.4. On-farm biodiversity

The average field size did not differ between the AMS and CMS farms (Table 3). Similarly, no differences were found in the number of species observed in grassland used for grazing or mowing. The number of plant species on grazing land was higher than on mowing land ($p < 0.01$) for both the AMS and the CMS farms. Even though the grazing area per cow was similar for the AMS and CMS farms, grazed grass contributed less to the total diet. The fact that cows on the AMS farms spent less time on grazing, however, did not affect the number of plant species in these fields (Table 3), probably because only 100% grazed fields were sampled, which means other fields available for grazing had been cut several times as well.

It was our intention to use the number of biotopes with special nature value and the area they occupied as biodiversity indicators. When visiting farms, however, it appeared that soil type and local situation of the farm were crucial for nature establishment. Farms situated close to sea marsh land or heather did not have many bush or forest patches, but had many nature biotopes along canals or creeks or as rough land. In addition, the presence of wind-breaking hedges depends on the geographic situation. To quantify indicators on biodiversity of landscape, a pair-wise selection focusing on soil, landscape and location would be necessary. This was not possible as there were only 45 organic dairy farms with AMS in Denmark.

3.5. Animal welfare including health

The culling rate was 19% higher at the AMS farms than at the CMS farms. No other differences in health indicators were registered as a result of AMS use compared with CMS use (see Table 6). The fact that cow health was not affected by AMS use corresponds with the general conclusions from an extensive global survey presented at a symposium on worldwide AMS use [15].

The higher culling rate at the AMS farms might be due to the fact that these farmers culled cows that had difficulties with the robotic system, such as milking slowly, refusing to enter voluntarily, or peculiar teat placement and udder shape. It has been reported (for conventional AMS users) that between 40% and 70% of the reasons mentioned for culling were difficulties entering the milking robot or peculiar teat positions and udder shape [39] but they were seldom the sole reason for culling. In addition, the research reported that it takes up to 2 years to reach a new balance between reproduction and culling. Culling rate increases of up to 20% have been reported after introducing AMS. In 2005, the average culling rate for all organic farms (AMS + CMS) in Denmark was 34% [40].

The total of 0.88 treatments per cow for the AMS farms seems higher than the 0.65 for the CMS farms (Table 6), but the large standard deviation, again reflecting the variation between farm management systems, causes no statistical differences in the analysis ($p = 0.21$). The value of 0.88 treatments per cow on the AMS farms was close to the average value of 0.84 for all registered conventional dairy farms ($n = 4512$) in 2005 [40], whereas the average of all registered organic dairy farms ($n = 535$) in 2005 was 0.64 [40]. High milk yield accompanied by stress is often mentioned as a reason for increasing health problems. At the CMS farms, variation in milk yield accounted for 45% of the variation in treatment index, but no correlations between specific health indicators (such as mastitis) and milk yield were found. Among the AMS users, no correlation between milk yield and treatment was found ($r^2 < 0.01$). The treatment of mastitis explicitly comprises the major part of all veterinary treatments on the AMS and CMS farms. The sum of treatments primarily influenced by grazing was 0.70 per cow per year for the AMS farms and 0.63 for the CMS farms. One would expect that the extra time spent outside by CMS herds (2083 h versus 968 h per year) would show positive health effects [24,41], but this was not the case.

On average, 3.9% of the cows on the AMS farms died, against 2.7% on the CMS farms. The average for all herds in 2005 was 4.1% [40]. Thomsen et al. [42] found a positive relation between the percentage of cows that functioned suboptimal in a herd and absence of grazing. The death rate among cows functioning suboptimal was higher [42]. The longer grazing time (Table 4) on the CMS compared with the AMS farms did not influence death rate significantly ($p = 0.17$).

3.6. Milk composition

The acid degree value (ADV) of milk was higher on the AMS farms (0.78 meq l^{-1}) than on the CMS farms (0.49 meq l^{-1}, Table 5). A higher ADV level on AMS farms has also been reported for conven-

Table 4
Means and standard deviations (in parentheses) of grazing indicators for organic dairy farms with an automatic milking system (AMS) and organic dairy farms with a conventional milking system (CMS) in 2005.

Parameter	Unit	AMS		CMS		*p*-value
Grazing time[a]	h $year^{-1}$	968	(198)	2083	(788)	<0.001
Grass intake from pasture	kg DM[b] per day	5.4	(1.6)	6.9	2.2)	0.09
Grass intake from pasture	% of total diet	40	(14)	29	(8)	0.05

[a] Grazing time is computed from registered number of hours grazing per day (24 h) specified for spring, summer and autumn, and which months.
[b] DM: dry matter.

Table 5
Means and standard deviation (in parentheses) of milk composition indicators for organic dairy farms with an automatic milking system (AMS) and organic dairy farms with a conventional milking system (CMS) in 2005.

Indicator	Unit	AMS		CMS		*p*-value
SCC[a] dairy delivery	10^3 ml^{-1}	219	(67)	226	(65)	0.83
SCC barn control	10^3 ml^{-1}	300	(104)	257	(61)	0.33
Clostridium (winter)	10^3 spores l^{-1}	297	(246)	313	(342)	0.91
Clostridium (summer)	10^3 spores l^{-1}	411	(661)	244	(108)	0.49
Acid degree value	meq l^{-1}	0.78	(0.16)	0.49	(0.11)	<0.001
Milk-fat	% of milk	3.94	(0.20)	4.05	(0.16)	0.23
Milk-protein	% of milk	3.41	(0.10)	3.32	(0.12)	0.11
Milk-urea (summer)	mmol l^{-1}	3.64	(0.50)	3.43	(0.58)	0.42
Milk-urea (winter)	mmol l^{-1}	3.69	(0.48)	3.47	(0.46)	0.37
Milking frequency (field)	milkings day^{-1}	2.4	(0.11)	2	(0)	0.002
Milking frequency (barn)	milkings day^{-1}	2.7	(0.31)	2	(0)	<0.001
Flow per milking (barn)	kg	10.3	(0.82)	12	(1.44)	0.008

[a] SCC: somatic cell count.

tional milk production [27]. A milk production that is lower than 10 kg per milking has been reported to have increased milk ADV [27].

The average ADV of the AMS farms of 0.78 meq l^{-1} was lower than the average of 0.88 meq l^{-1} for all AMS farms in Denmark ($p < 0.001$) (organic and conventional) analysed in 2005 [27]. Reasons for the lower ADV value for organic milk is unknown and further research on the actual cause of this quality improvement is being conducted.

The milk–urea content did not differ between the AMS and CMS farms, neither in summer nor in winter (Table 5), indicating no demonstrable differences in protein feeding. This could have been expected because grass intake in summer and autumn was higher at the CMS than at the AMS farms (Table 4), and especially because autumn grass usually contains more protein than grass silage.

The somatic cell count (SCC) did not differ between the AMS and CMS farms for milk recorded in the barn [gross] ($p = 0.33$) and milk delivered at the dairy [net] ($p = 0.83$). A slightly higher SCC for AMS farms has been reported [15] but, as in our results, the level was not critical, using standards for Danish dairy where an SCC value between 300 and 400 × 10^3 per ml is price-neutral and assumed to be safe for human consumption.

Milk fat and milk protein percentages were equal at the AMS and CMS farms (Table 5), even though it is known that a higher milking frequency 'dilutes' the milk, causing lower fat and protein percentages. Erdman and Varner [32] state in their survey that going from a milking frequency of 2 to 3 a day will reduce the fat percentage by a value of 0.14 and the protein percentage by a value of 0.06. In winter, milking frequency on the AMS farms was on average 0.7 higher ($p < 0.001$) than on the CMS farms, whereas fat percentage was about the same on both farm types (Table 5). On the AMS farms, fat percentage increased from 3.8% in summer to 4.1% in winter ($p = 0.06$), even though the milking frequency increased from 2.4 to 2.7 per day. This shows that, besides milking frequency, other factors such as diet, influence fat percentage.

The Danish dairy industry reduces the milk price when *Clostridium* spores exceed 400 × 10^3 per litre milk. The high value for spores on the AMS farms in summer was caused by two farms with severe spore problems.

3.7. Labour time

In this study the AMS farms used on average 3.0 min per cow per day, whereas the CMS farms used on average 5.3 min per cow per day ($p < 0.001$); a saving of 2.3 min per cow per day. The extension services in Denmark registered that farm management in general adjusts to the new situation 15 months after purchase of an AMS, which all farms investigated had (Table 1). In addition, most AMS farms had increased their herd size at the same time as they invested in AMS, and previous labour time registrations had found that larger farms saved relatively more time when using AMS. This could not be confirmed by our results (Fig. 2).

The inquiry made on motivations to invest in new technologies on dairy farms concluded that saving labour time and relief of physical effort were the most important, even more important than economic profit [43,44]. The results of our study clearly showed achievement of this objective, which can explain the continuous growth in the number of organic dairy farms using AMS. Several farmers using AMS reported that if there had not been the alternative of automatic milking, they would have ceased dairy farming,

Table 6
Means and standard deviation (in parentheses) of health indicators for nine organic dairy farms with an automatic milking system (AMS) and for nine organic dairy farms with a conventional milking system (CMS). Treatment indicators are computed as the number of treatments per cow (i.e., 0.04 means 4 out of 100 cows were treated).

Indicator	AMS		CMS		*p*-value
Claw treatments (summer)[a]	0.04	(0.03)	0.02	(0.02)	0.30
Claw treatments (winter)	0.03	(0.01)	0.02	(0.02)	0.34
Mastitis treatments (summer)	0.25	(0.20)	0.18	(0.15)	0.44
Mastitis treatments (winter)	0.19	(0.09)	0.20	(0.14)	0.82
Reproduction treatments (summer)	0.10	(0.05)	0.09	(0.06)	0.89
Reproduction treatments (winter)	0.09	(0.08)	0.09	(0.06)	0.89
Sum[b] all treatments (summer)	0.48	(0.24)	0.33	(0.23)	0.20
Sum all treatments (winter)	0.40	(0.09)	0.32	(0.21)	0.31
Sum all treatments	0.88	(0.29)	0.65	(0.43)	0.21
Dead cows per year (%)	3.9	(1.7)	2.7	(1.6)	0.17
Dead calves after 180 days (%)	3.4	(2.6)	6.0	(5.6)	0.23
Born dead calves per year (%)	7.5	(3.3)	5.7	(2.5)	0.22
Culling rate (%)	38	(6)	32	(5)	0.05
Vet costs (€ per cow per year)	86	(43)	60	(31)	0.17

[a] Summer: May–October; winter: January–April.
[b] Sum comprises more than the 3 treatment groups mentioned in this table.

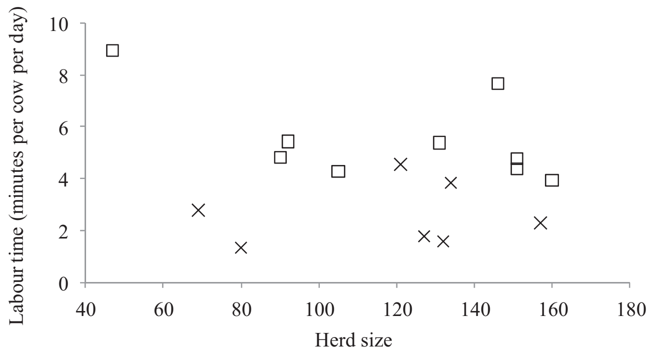

Fig. 2. Labour time in relation to herd size for seven organic dairy farms using automatic milking systems (AMS = ×) and nine using conventional milking systems (CMS = □).

simply because it would have been impossible to find suitable labour.

3.8. *General discussion*

One of the problems with comparing indicator scores between farming systems (such as AMS and CMS farms) is the large variation in scores among individual farms within each farming system. A large variation in indicator scores among individual farms can hamper detection of statistically significant differences between farming systems. This problem also occurred in our study, even though we tried to minimize some of the known causes of variation by selecting only one breed and choosing farms with similar herd size. Other factors such as management, educational background, or soil characteristics might have increased variation in indicator scores among individual farms. However, other recent research on economic indicators for AMS and CMS users using a larger sample size, confirms our results.

4. Conclusions

On the basis of previous research, we expected to find differences in the sustainability indicators economic performance of the farm, on-farm eutrophication, grazing behaviour, labour time, animal welfare and health, and milk composition between organic dairy farms using AMS and CMS. Although annual milk yield per cow was higher for the AMS than for the CMS farms, economic indicators did not differ between the two farm types. The N surplus per hectare and grazing time per cow differed between the AMS and CMS farms. The N surplus per hectare at farm level, however, appeared independent of stocking rate and milking system, but was due to a difference in amount of manure imported to or exported from the farm. Longer grazing time and different management of manure resulted in a higher N surplus for grazing fields on the CMS farms and a higher N surplus for mowing fields on the AMS farms. In addition, the higher number of grazing hours per cow per year on the CMS compared with the AMS farms, resulted in a higher percentage of fresh grass in the total diet on the CMS compared with the AMS farms. This higher percentage of fresh grass in the diet on the CMS farms, however, did not significantly affect health or milk quality indicators.

The AMS farms saved almost 50% labour time per cow per day, compared with the CMS farms. Furthermore, culling rate was higher on the AMS (38%) than on the CMS farms (32%). Milk-FFA was higher on the AMS than on the CMS farms. A high milk-FFA is expected to influence economic performance negatively due to reduction in payments. Taking into account that the selected indicators that were quantified are the result of participative research in possible threats when using AMS on organic farms, it can be concluded that the organic dairy farms using AMS, in spite of the substantial decrease in grazing time, show the potential of economic and environmentally sustainable development in line with the organic farms using CMS. Even though the lower grazing hours per cow per year on the AMS farms did not affect indicator scores related to animal health or milk composition, this reduction in grazing hours might be a problem for consumers to accept AMS use. The annual higher milk yield per cow, the lower labour time per cow and the higher culling rate at the AMS farms indicate a different management focus, which could be classified as intensification.

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References

[1] T. Kristensen, K. Søegaard, I.S. Kristensen, Management of grasslands in intensive dairy livestock farming, Livest. Prod. Sci. 96 (2005) 61–73.
[2] F.W. Oudshoorn, R.J. Renes, I.J.M. de Boer, Systems in organic dairy production, J. Agric. Environ. Ethics 21 (2008) 205–228.
[3] F.W. Oudshoorn, I.J.M. de Boer, Survey of the sustainability aspects of automatic milking systems (AMS) in organic dairy production, in: S. Cox (Ed.), Precision Livestock Farming '05, Wageningen Academic Publishers, Wageningen, The Netherlands, 2005, pp. 193–199.
[4] R.K. Turner, Sustainable Environmental Economics and Management. Principles and Practice, Belhaven Press, London and New York, 1993.
[5] L. Meskens, E. Mathijs, Socio-economical aspects of automatic milking, Deliverable D2 EU Report QLK5-2000-31006, 2002, http://www.automaticmilking.nl/, Verified Sept. 2010.
[6] G. Haas, C. Deittert, U. Köpke, Impact of feeding pattern and feed purchase on area- and cow-related dairy performance of organic farms, Livest. Sci. 106 (2007) 132–144.
[7] I.J.M. de Boer, A.M.G. Cornelissen, A method using sustainability indicators to compare conventional and animal friendly egg production systems, Poult. Sci. 81 (2002) 173–181.
[8] H. Mollenhorst, P.B.M. Berentsen, I.J.M. de Boer, On-farm quantification of sustainability indicators: an application to egg production systems, Br. Poult. Sci. 47 (2006) 405–417.
[9] S. Bell, S. Morse, Sustainability Indicators: Measuring the Immeasurable? Earthscan Publications, London, 1999.
[10] G. Mitchell, Problems and fundamentals of sustainable development indicators Sustain. Dev. 4 (1996) 1–11.
[11] G. Mitchell, A. May, A. McDonald, PICABUE: a methodological framework for the development of indicators of sustainable development, Int. J. Sustain. Dev. World Ecol. 2 (1995) 104–123.
[12] S. Bell, S. Morse, Measuring Sustainability: Learning from Doing, Earthscan Publications, London, 2003.
[13] K.J. van Calker, P.B.M. Berentsen, G.W.J. Giesen, R.B.M. Huirne, Identifying and ranking attributes that determine sustainability in Dutch dairy farming, Agric. Human Values 22 (2005) 53–63.
[14] C.J.A.M. de Koning, J. Rodenburg, Automatic milking: state of the art in Europe and North America, in: A. Meijering, H. Hogeveen, C.J.A.M. de Koning (Eds.), Automatic Milking: A Better Understanding, Wageningen Academic Publishers, Wageningen, The Netherlands, 2004, pp. 27–37.
[15] A. Meijering, H. Hogeveen, C.J.A.M. de Koning, Automatic Milking: A Better Understanding, Wageningen Academic Publishers, Wageningen, The Netherlands, 2004.
[16] M.A. Thomassen, I.J.M. de Boer, Evaluations of indicators to assess the environmental impact of dairy production systems, Agric. Ecosyst. Environ. 111 (2005) 185–199.
[17] N. Halberg, G. Verschuur, G. Goodlass, Farm level environmental indicators; are they useful? An overview of green accounting systems for European farms, Agric. Ecosyst. Environ. 105 (2005) 195–212.
[18] E.S. Kristensen, I.S. Kristensen, Analysis of Nitrogen Surplus and Efficiency on Organic and Conventional Dairy Farms (in Danish), Report Nr. 710, Danish Institute of Animal Science, 1992.
[19] T. Ellermann, H.V. Andersen, C. Monies, K. Kemp, R. Bossi, B.B. Mogensen, P. Løfstrøm, J. Christensen, L.M. Frohn, Atmosfærisk deposition, NOVANA.555, pp. 1–76.
[20] (a) Danmarks Miljøundersøgelse, Faglig rapport fra DMU, 2005 (in Danish); (b) H.D. Poulsen, C.F. Børsting, H.B. Rom, S.G. Sommer, Nitrogen, Phosphorus and Potassium in Animal Excretion (in Danish), DIAS Report Nr. 36, Livestock Production, 2001.

[21] J.S. Jonker, R.A. Kohn, R.A. Erdman, Using milk urea nitrogen to predict excretion and utilization efficiency in lactating dairy cows, J. Dairy Sci. 81 (1998) 2681–2692.
[22] F.W. Oudshoorn, T. Kristensen, E.S. Nadimi, Dairy cow defecation and urination frequency and spatial distribution in relation to time-limited grazing, Livest. Sci. 113 (2008) 62–73.
[23] E. Noe, N. Halberg, J. Reddersen, Indicators of biodiversity and conservational wildlife quality on Danish organic farms for use in farm management: a multidisciplinary approach to indicator development and testing, J. Agric. Environ. Ethics 18 (2005) 383–414.
[24] J.G.C.J. Somers, K. Frankena, E.N. Noordhuizen-Stassen, J.H.M. Metz, Prevalence of claw disorders in Dutch dairy cows exposed to several floor systems, J. Dairy Sci. 86 (2003) 2082–2093.
[25] A. Elgersma, G. Ellen, H. van der Horst, H. Boer, P.R. Dekker, S. Tamminga, Quick changes in milk fat composition from cows after transition from fresh grass to a silage diet, Anim. Feed Sci. Technol. 117 (2004) 13–27.
[26] K.A. Ellis, G. Innocent, D. Grove-White, P. Cripps, W.G. McClean, C.V. Howard, M. Mihm, Comparing the fatty acids composition of organic and conventional milk, J. Dairy Sci. 89 (2006) 1938–1950.
[27] M.D. Rasmussen, L. Viking, M. Bjerring, H.C. Larsen, Influence of air intake on the concentration of free fatty acids and vacuum fluctuations during automatic milking, J. Dairy Sci. 89 (2006) 4596–4605.
[28] T.W. Anderson, D.A. Darling, Asymptotic theory of certain "goodness-of-fit" criteria based on stochastic processes, Ann. Math. Stat. 23 (1952) 193–212.
[29] L.O. Sjaunja, L. Baevre, L. Junkkainen, J. Pedersen, J. la Seta, A Nordic proposal for an energy corrected milk (ECM) formula, in: van Arendonk, J.A.M. (Ed.), EAAP publication no. 50: performance recording of animals: state of the art, Proceedings of the 27th biennial session of the International Committee for Animal Recording (ICAR), Paris, 2–6 July 1990, Wageningen Academic, The Netherlands.
[30] F. Strudsholm, K. Sejersen, Kvægets Ernæring og Fysiologi, DIAS report nr. 54, volume 2, Fodring og produktion, 2003, Available on www.agrsci.dk (in Danish).
[31] C.C. Ketelaar-de Lauwere, A.H. Ipema, C. Lokhorst, J.H.M. Metz, J.P.T.M. Noordhuizen, W.G.P. Schouten, A.C. Smits, Effect of sward height and distance between pasture and barn on cows' visits to an automatic milking system and other behaviour, Livest. Prod. Sci. 65 (2000) 131–142.
[32] R.A. Erdman, M. Varner, Fixed yield responses to increased milking frequency, J. Dairy Sci. 78 (1995) 1199–1203.
[33] M. Wegge, J.B. Rasmussen, H.F. Pedersen, AMS does best in middle-sized herds, Info Nr. 1415, Building and Technique, 2005, www.landscentret.dk/ landbrugsinfo (in Danish).
[34] R. Bijl, S.R. Kooistra, H. Hogeveen, The profitability of automatic milking on Dutch dairy farms, J. Dairy Sci. 90 (2007) 239–248.
[35] C.A. Rotz, C.U. Coiner, K.J. Soder, Automatic milking systems, farm size, and milk production, J. Dairy Sci. 86 (2003) 4167–4177.
[36] P. Nicholas, S. Padel, N. Lampkin, S. Fowler, K. Topp, R. Weller, Modeling organic dairy production systems, in: A. Hopkins (Ed.), Organic Farming: Science and Practice for Profitable Livestock and Cropping, vol. 37, Occasional Symposium of the British Grassland Society, 2004, pp. 145–148.
[37] P. Veysset, P. Wallet, E. Prugnard, Automatic milking systems: characterizing the farms equipped with AMS, impact and economic simulations, in: A. Rosati, S. Mittina, C.S. Mo (Eds.), International Committee for Animal Recording (ICAR) TS 7, 2001, pp. 141–150.
[38] M.T. Knudsen, I.S. Kristensen, J. Berntsen, B. Molt Petersen, E.S. Kristensen, Estimated N leaching losses for organic and conventional farming in Denmark, J. Agric. Sci. 144 (2006) 135–149.
[39] S. Østergaard, J.T. Sørensen, J. Hindhede, Culling strategies in herds with automatic milking systems analyzed by stochastic models, in: Proceedings of the First North American Conference on Robotic Milking, Ontario, Canada, 2002, pp. 12–23.
[40] Danish Cow Federation statistics, DCF, 2005, Available on www.vfl.dk.
[41] L. Munksgaard, E. Søndergaard, Welfare for dairy cows and young stock, DIAS Livestock Production Report Nr. 74, 2006 (in Danish).
[42] P.T. Thomsen, A.M. Kjeldsen, J.T. Sørensen, H. Houe, A.K. Ersbøll, Herd level risk factors for cow mortality in Danish dairy cattle herds, Vet. Rec. 158 (2006) 622–626.
[43] H. Hogeveen, K. Heemskerk, E. Matijs, Motivations of Dutch farmers to invest in an automatic milking system or a conventional milking parlour, in: A. Meijering, H. Hogeveen, C.J.A.M. de Koning (Eds.), Automatic Milking: A Better Understanding, Wageningen Academic Publishers, Wageningen, The Netherlands, 2004, pp. 56–61.
[44] Jensen, Expectations of automatic milking and the realized socio-economic effects, in: A. Meijering, H. Hogeveen, C.J.A.M. de Koning (Eds.), Automatic Milking: A Better Understanding. Wageningen Academic Publishers, Wageningen, The Netherlands, 2004, pp. 78–79.