Innovative Technology and Sustainable Development of Organic Dairy Farming

The case of automatic milking systems in Denmark

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Thesis

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Abstract

Development of organic dairy farming in Denmark is characterized by up-scaling, increasing productivity and automation. Increasing discussion on compliance with organic principles and sustainability has been forwarded. Automatic milking systems (AMS) are part of this development and have been implemented in organic dairy production in Denmark the last 10 years. The systems' consequences on economic, ecological and societal issues were unknown.

The general objective of the PhD assignment was to assess the contribution of new technologies to the sustainable development of organic dairy farming (i.e., determine economic, ecological and societal consequences), using AMS as a case for the present technological situation.

To evaluate sustainability, a framework was used which adhered to the following consecutive steps: 'identification of sustainability issues by involving identified stakeholders', 'quantification of indicators defined for these issues and investigating them' and 'evaluation of obtained results by using them in goal-vision based scenarios, again involving relevant stakeholders'. Focus group interviews and questionnaires revealed general concerns among farmers and consultants on the grazing possibilities when using AMS, as well as milk quality aspects and economy. Quantification of indicators on sustainability, where farms using AMS were compared with non-users, showed higher milk yield, lower labour use, and differences in some management aspects like higher culling rate and also a shorter grazing time when using AMS. The shorter grazing time especially could compromise the sustainability of the system, as grazing is essential for the customers buying organic dairy products. A focussed experiment showed how cows perform and react following a reduction in grazing time, while stimulated to eat fresh grass by limiting supplementary feed in the barn. High compensation ability of the cows was seen, with increased grass uptake and limited negative consequences on milk yield. However, cows were provoked to be more active when outside and the relatively high and large amount of grass eaten in short time span could be registered in the milk quality. Finally, goals and visions of future sustainable organic dairy farming were deduced from participative sessions with stakeholders and used for scenario definition. Subsequently, three goal-vision based scenarios were parameterized by quantification of identified production parameters for a model farm of 200 ha. Economic and ecological evaluation of these scenarios revealed that investing in animal welfare comprised trade-offs regarding farm profitability and especially global environmental issues such as climate change and fossil energy use. Minimizing environmental impact by introducing self sufficiency reduced local environmental impact without an economic trade-off. Prolonging the current main stream strategy resulted in a high local environmental impact, a moderate global environmental impact and a high economic risk to changes in milk price. The scenario analysis as the final step in the sustainability assessment offers possibilities to interact and counteract in the development of future organic dairy farming using new technologies. AMS use in sustainable organic dairy farming is possible, if the grazing can be practiced satisfactorily.

Key words: Organic dairy farming, AMS, sustainability assessment, grazing, Denmark.

Preface

I owe a very special thanks to Svend Christensen, my former research leader at the department of Agricultural Engineering, who gave me the possibility and motivated me to start this PhD work on implementation of innovative technology in organic dairy production in Denmark. Eleven years of work as an advisor and five years as scientific manager of the organic research farm Rugballegaard in Horsens ignited my interest in research. However, the odds of accomplishing a promotion to Doctor of Philosophy were bad for a person whose career had so far focused on practical field work, and the time when study and education was diurnal passed long ago. I was warned many times, and it took some time to decide, but eventually it also became the motivation to accomplish the task started. The next obstacle to overcome was to find scientific supervision for a topic as unusual as multidisciplinary assessment of technology and organic dairy farming. Here the unique talents of Akke van der Zijpp in Wageningen were the next inspiration needed to start. She completely understood and accepted my primary motivation and interests, and guided the obviously much too broad spectrum of ideas, towards a focused and scientific approach of the topic. Without doubt, the special analytical and systematical talents of Imke de Boer supplemented this start, and guided the process of this research, from data analysis to scientific writing of this final result. Turbulence in the location of the research center Bygholm, and the many months of debate interfered with the continuation of the PhD work, and at times made it hard to concentrate. Especially when, for a year, I was given the responsibility to coordinate the research group “Automation and system engineering”. With patience and respect, my supervisors, colleagues and friends continued to assist and motivate me to proceed. Finally the faculty of agricultural sciences from Aarhus University agreed upon a new structure of the research center, with allocation in Foulum in the north of Jutland. Here too, the new staff supported this PhD work and made it financially possible to complete my degree. Not in the least, I wish to mention also the stimulating cooperation with Troels Kristensen from the department for Agro-ecology and Environment at Foulum, who’s quick and clear responses always supported me. In addition the practical experiments had never been accomplished without the great help of Gorm Veggerby, the daily manager of the research farm. Farmers and advisors in Denmark and The Netherlands had agreed to spend time in cooperating with answering detailed questions and to discuss farm management and economic topics. The sessions were meaningful and met with enthusiasm from their side. Finally the everlasting faith of Karin in my ability and the necessity to finish the job was unbelievably important for me.

I am convinced this thesis is interesting for many, and I hope it can contribute to further understanding and knowledge.

Frank W.Oudshoorn
Foulum, October 2009.

Contents

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Chapter 1

General Introduction

1.1 Organic dairy farming in Denmark

Organic dairy farming has been characterized as relatively easy to convert from conventional dairy, and the motor in the consistent growth of the organic sector (Mogensen, 2004). Organic milk production is robust in practice (field rotation, mineral redundancy), economically competitive, and has a positive image amongst consumers, not in the least because grazing is obligatory. This can be seen in the number of farms converted. In Denmark organic production comprises 7% of the dairy cows but only 0.8% of the pigs, In Sweden 4.3% of the dairy cows are kept organically versus 0.9% of the pigs. In the Netherlands 0.5% of the cows are kept organically and 0.05% of the pigs (Rosati and Aumaitre, 2004). The strong growth in the beginning of the 90's, was seen in several European countries, and was in Denmark followed by a period of stagnation from 2000-2004 (Oudshoorn et al., 2008). From 2000-2003 it was reported that only 31% of the organic milk produced in Denmark was sold as organic product, whereas the rest was processed in the conventional circuit (Jacobsen et al., 2005). Reasons for this stagnation could well have been concern amongst consumers about the benefits of organic dairy production for environment, human health and animal welfare. Differences in production methods between organic and conventional dairy farming were fading and not as obvious as for instance in organic horticulture where zero-pesticides are quite easy to use as a benchmark. Up-scaling and structural development towards higher mechanization and productivity seemed to dissolve differences that were obvious for consumers. In Denmark, milk yield per cow (Fig 1) has been increasing over the last 6-8 years. Questions arose such as "can the welfare of cows be guaranteed in barns of over 100 cows" or "how to combine grazing (fresh grass consumption) and a large herd size"? and "is quality of organic products better than that of conventional products ?" More systematic research was conducted for solid documentation on the impact of organic dairy production on environment, animal welfare and farm profitability. However, greenhouse gas (GHG) emissions per kg milk or nitrogen losses per ha, which were and are focus institutional parameters, are hard to understand for consumers of organic products. In addition, assessments on GHG emissions per kg of milk were not always significantly different between organic and conventional milk production (De Boer, 2003).

Animal welfare on organic farms is a hot topic and large differences in welfare scores among countries are found. In Denmark, organic herds score higher on animal welfare than conventional herds (Bennedsgaard et al., 2003). This, however, is not the case in all countries (Sundrum, 2001). Even though profitability of organic milk production in Denmark and other countries has been good, supported by premium prices, conventional dairy farmers seem not to feel comfortable enough to convert to organic practice. The future development of price, quota, and costs for organic feed and possibly tightening demands for organic standards, were mentioned in different interviews with farmers as reasons for doubt. In addition the structural development, including considerable increase of herd size (Fig 2), was giving documented problems addressing the grazing issue (Kramer, 2006). Research in product quality differences between organic and conventional dairy production has been only recently thoroughly analyzed. Differences were found and mainly caused by intake of fresh grass, which clearly is higher in organic herds (Slots et al., 2008).

After 2005, the organic dairy sector in Denmark grew again, both in absolute terms, i.e., number of organic cows (Fig 1), and in relative terms, i.e., % of total milk produced. In 2004, 7.8% of all dairy herds were organic, whereas in 2008 this was 9.6%. (FØI, 2008).

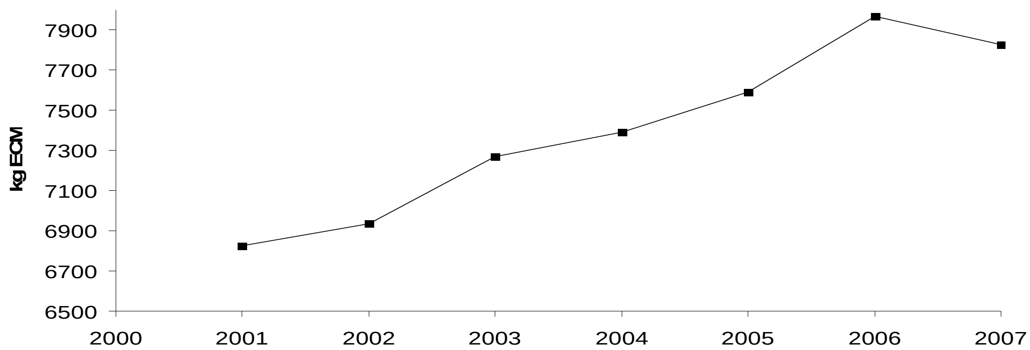

Fig 1. Development in milk yield cow^{-1} y^{-1} in energy corrected milk (ECM) on organic dairy farms in Denmark (FOI, 2008).

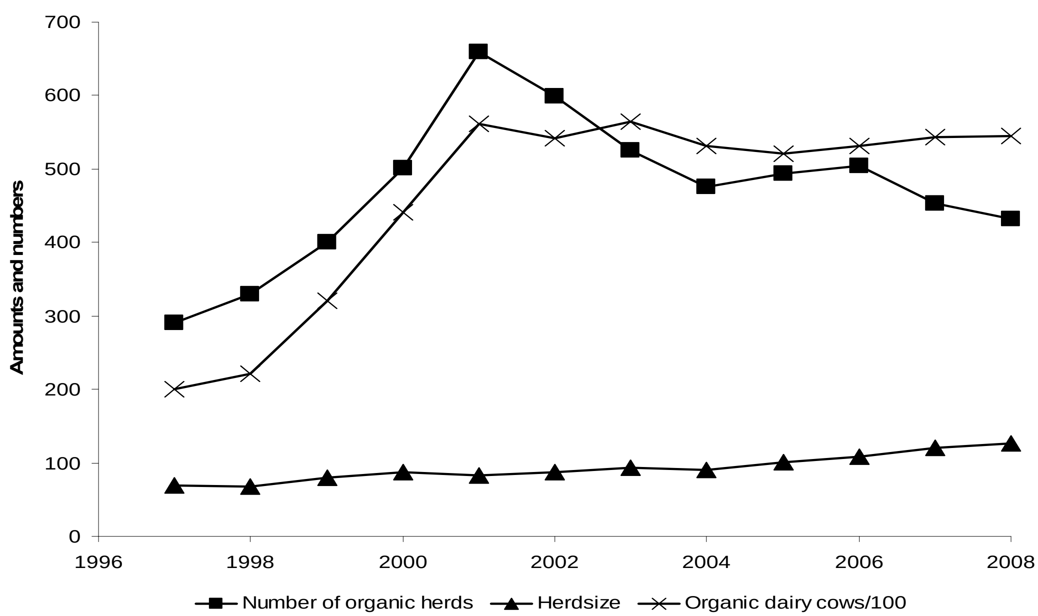

Fig 2. Development of number of organic dairy herds, the herd size and the number of organic cows in Denmark between 1996 and 2008 (FOI, 2008).

1.2 Organic agriculture, technology, and sustainable development

Organic agriculture originally started as resistance to the use of synthetic fertilizers (Steiner, 1924). Later, during the 60's, the organic agricultural movement focused on environmental protection (Anonymous, 1977). The common use of chemical pesticides and negative side effects of persistent residues in food chains started the movement also called "alternative agriculture". Eventually, during the 70's and 80's, the need to incorporate social and economic aspects into the concept of organic agriculture gained ground. In the 90's organic agriculture further matured from idealistic to pragmatic.

Nowadays, organic agriculture often claims and encourages being sustainable. Organic principles mention terms like fairness, ecology awareness in terms of closed biological cycles, and care (IFOAM, 2008). Fairness, although subjective, requires economic reserves and social stability. Care also is a social aspect and nowadays has been acknowledged as care for health and welfare of humans and animals. Most definitions of sustainability originate from the relation between humans and the resources they use. The most cited definition is the one of Brundtland (WCED, 1987) "Meet the needs of the present, without compromising the ability of future generations to meet their own needs". Clear parallels can be observed between principles for organic production, as documented by the International Federation of Organic Agricultural Movements (IFOAM) and Brundtland's definition of sustainability. Three fundamental components are mentioned in Brundtland's statement as being important for sustainable development: environmental protection, economic growth and social equity (EES), also described as Planet, Profit and People (3P's) (Elkington, 1998). Social equity has been discussed and was later translated to social acceptability including issues related to human production such as ethics on animal welfare (Appleby, 2005). This definition of sustainability has been defined as the competing-objectives view of sustainability, which constantly discusses trade-offs among economic, environmental and social aspects. This in contrast to the critical-limits view which focuses only on limited natural assets such as soil fertility, fossil fuels, and healthy wetlands, which provide services that humans need to sustain living (Jabareen, 2008).

Development of organic agriculture was and is stimulated by focusing on specific needs or problems in the sector (ICROFS, 2008). For example, how to control weed growth in arable farming or the presence of insects in cereal storages? Or how to fulfil additional labour required complying with standards for animal welfare? Often technological innovation could provide encouraging results. Technology is by some seen as the solution to many problems of the future; and characterized as technocratic, or technocentric. In the past, however, technological development was seen as a threat (Roszak, 1972) referring that all moral and ethical standards were subordinate to the technical development. At present, technology advance is more accepted, but often still only evaluated on its own premises (Markussen, 2003) using terms like economic feasibility, production requirements, labour input, and profitability. Often technology is lacking a more embedded comprehensive and system oriented sustainability concept, where both the physical technology itself and the implications of its usage are evaluated (Grigg, 1974). Economic feasibility assessments are performed because the implementation of new technologies is not always evident, even though short term economy looks sound. Reasons for high-tech solutions not being implemented can be the sophistication level, mismatched expectations between farmer and product developer, and commitment for learning caused by work stress (Eastwood et al., 2006). Demont et al. (2001), advocate for a broader assessment of innovative technologies, exemplifying this by citing a number of externalities which occurred, when technology was implemented without environmental or social feed-back. Within agriculture we can see some examples of more interdisciplinary assessments. In order to evaluate if emerging technologies were "green" a Danish project has worked with defining which parameters were desirable for validation, using an iterative process involving stakeholders (Borch, 2007). Impact assessments on known technologies, which have not been implemented, have also been performed (Sørensen et al., 2005). In a process of extrapolating test-prototypes results to agricultural systems, assessment on economic consequences (revenue, labour) was performed. Based on previous examples of detrimental impact, a perpetual evaluation of new technologies when implemented in organic practice is required, to avoid externalities on environmental or social aspects. Challenge lies in selecting and agreeing on relevant issues to assess, incorporating the holistic approach of the organic principles and making trade-offs. In addition the conclusion of foresight technology research can be quoted; 'it is necessary to define clear sustainability criteria and matching indicators. Only in this way can technological development be evaluated and prioritized' (Borch, 2007). Compliance of the sustainability criteria to organic principles is necessary in this process.

An example of an innovative technology in organic dairy production is the use of an automatic milking system (AMS). In 2007, 10% of the organic farms in Denmark used an AMS (Danish Agricultural Advisory System), whereas in the Netherlands this was around 8.7% (Smolders, 2008). Its introduction occurred relatively quickly during the last decade. The economic, environmental and social consequences of introduction of AMS technology in organic dairy farming, however, were never assessed. Integrating EES issues into technology assessments and exploring future situations, is quite a challenge. Disciplinary impact analyses are dominant, and often research prefers to investigate present situations rather than referring to the unsure foresight of the future.

In literature, a framework has been described, that could be used to evaluate the economic, environmental and social consequences of the introduction of AMS (Mollenhorst et al., 2006). Other methods have been developed to explore future development (Sonesson et al., 2005). Both methods implicate use of stakeholders, which seems necessary for technology assessment. The framework described by Mollenhorst et al. (2006) consists of the following steps:

1. Identification of stakeholders and description of the problem situation.
2. Determination of the goals of production and relevant economic, ecological and societal (EES) issues.
3. Translation of the selected issues into quantifiable indicators for sustainability.
4. Final assessment of the contribution of a technology to sustainable development based on indicator quantification in step (3)
5. Communication and dissemination of results to stakeholders, review of the process, and evaluation of results based on the original problem definition.

In conclusion, the importance of a holistic assessment of innovative technology is evident and concerning implementation on organic farming, the necessity is extra important due to specific defined goals on environmental and societal level (IFOAM, 2008).

1.3 Objectives of the research

The general objective of the PhD assignment was to assess the contribution of new technologies to the sustainable development of organic dairy farming, using AMS as a case for the present technological situation.

To accomplish this general objective, the framework as described in 1.2 was used. This resulted in the following research questions;

a. What are the economic, ecological and societal issues when introducing AMS on organic dairy farms in the Netherlands and Denmark?
b. Do economic, ecological, and social indicator scores differ between organic dairy farms using AMS and farms using a conventional milking system (CMS) in Denmark?
c. What is the effect of time-limited grazing on eutrophication, animal behaviour and milk quality?
d. What are the economic and environmental consequences of three vision-based scenarios for organic dairy farming in 2020?

1.4 Outline of the thesis

The outline of the thesis is schematically represented in Fig 3. After the general introduction, each above described research question will be explored in a different chapter.

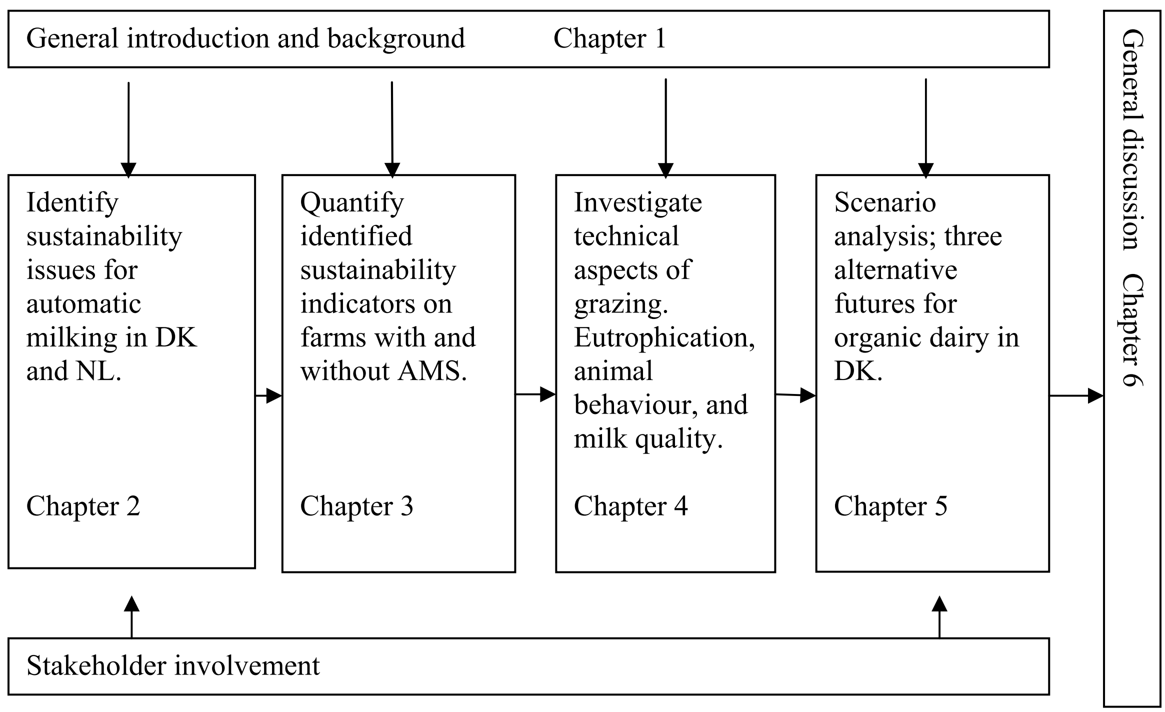

Fig 3. Schematic representation of the outline of the thesis (DK is Denmark; NL is the Netherlands, AMS is automatic milking systems).

In the next paragraphs there follows a short outline of the general goal and scope of chapter 2 to 5, which focus on research questions a to d, respectively.

Identify sustainability issues for automatic milking in Denmark and the Netherlands

In chapter two, the general problem situation of AMS use in Denmark and the Netherlands is described (step 1 of framework). Furthermore, economic, ecological and social issues related to introducing AMS on organic dairy farms in Denmark and the Netherlands were investigated (step 2). Identification of

EES issues was based on a comprehensive literature survey (Oudshoorn and de Boer, 2005) in combination with focus group interviews.

Quantify identified sustainability indicators

In chapter three, indicators which were identified and selected to measure relevant sustainability issues, were quantified. The literature survey (Oudshoorn and De Boer, 2005) and participatory research (chapter two) concerning technology implementation on organic dairy farms concentrating on AMS, highlighted several sustainability issues. There was concern regarding the economic consequences of introducing AMS and also concern regarding the grazing possibilities connected to animal welfare and milk quality. Therefore EES indicators on 9 organic dairy farms with AMS and 9 organic farms with a conventional milking system were quantified.

Investigate technical aspects of grazing; eutrophication, animal behaviour, and milk quality

In chapter four, technical aspects of eutrophication in relation to grazing time were investigated. Results of participative research (chapter two) and parallel studies on grazing practice on organic dairy farms using AMS (Kramer, 2006) revealed that many farmers had problems with satisfactory grazing.
For the organic AMS farm wanting to maintain milk yield level and comply with the standards of grazing, the question was: how much grass can a cow eat in a short time span, without compromising animal welfare or milk quality? These questions were addressed in a grazing experiment, where grazing time was varied between 4, 6.5, and 9 hours. Grass uptake was registered, together with cow behaviour, urination, and defecation frequency.

Scenario analysis; three alternative futures for organic dairy in DK

In chapter five, a scenario analysis on three alternative futures for organic dairy farming in Denmark is described. The assessment of use of innovative technologies, described in the previous chapters, comprises sustainable development, meaning not only the present status is considered but also where the future is heading for. This scenario analysis presents three alternative futures based on visions and goals derived from stakeholder opinions and expert estimates, and were determined at farm level. Extrapolated data from the quantification research (chapter three) were integrated together with historical data and expert knowledge.

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Chapter 2

Systems in Organic Dairy Production

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Abstract

The aim of this study was to explore stakeholder perceptions of the contribution of an Automatic Milking System (AMS) to sustainable development of organic dairy production in Denmark and the Netherlands. In addition, reasons for the current difference in AMS use on organic dairy farms between both countries were explored. To answer above mentioned aims, farmers and advisors in both countries were interviewed using a focus group approach. Questions of the interviews were based on a literature review on sustainability issues affected by introduction of AMS. Participants expressed no moral problems regarding AMS use. They, however, pointed out uncertainty about the economic gain, difficulties with grazing, adaptation problems to technology, and image problems towards consumers. The latter results from a reduction in grazing time affecting both animal welfare and product quality. The participants did not recognize eutrophication, as result of high stocking density on farmstead lots, as a problem caused by AMS. The milk quality problem related to AMS use, although acknowledged as crucial towards consumers, was not prioritized very highly, especially not by the farmers in both countries. All groups were, however, unanimous in their perception of how important image was as far as the consumers are concerned. The perception analysis revealed that Dutch participants were more concerned about the economic payoff of AMS use, and showed more reluctance towards enlargement than Danish ones. In addition, they acknowledged the small-scale naturalness of organic production. These differences in perception could possibly explain observed differences in AMS use in organic dairy production between Denmark and the Netherlands.

Keywords*: Automatic milking system, organic dairy farming, sustainability, perception, grazing, stakeholders.*

2.1 Introduction

Organic dairy production has spread to a considerable production area in Europe (Anonymous, 2006b). Policy-makers stimulated the growth of organic production starting mid eighties, by subsidizing conversion from conventional to organic production, and through extended research programs to provide practical knowledge (Mogensen, 2005). As a result, Denmark and the Netherlands showed continuous growth and similar development of the organic production sector. The last few years, however, the number of organic dairy farms has not further increased (Table 1). Due to increasing herd size and milk production per cow, the total amount of organic milk has almost stabilized. In addition, the percentage of organic dairy farms relative to the total amount of dairy farms is rather constant during the years. In Denmark farm size and milk yield per cow have increased more than in the Netherlands (Table 2), resulting in a decrease in the amount of organic dairy farms. This is parallel to general structural dairy development in the two countries, where in Denmark farm quota increased with 40% over the last four years and in the Netherlands only with 20% (Anonymous, 2006a).

Table 1. Total number of organic dairy farms in Denmark (DK) and the Netherlands (NL) from 1990 to 2005.

	1990	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
DK*	63	147	344	430	672	751	827	749	695	636	513	490
NL**	71	80	95	m.v.[1]	179	189	300	340	315	304	304	301

* Figures from dairy industry in Denmark (www.mejeri.dk).
** Figures from SKAL (certification body in the Netherlands), LEI (www.lei.wur.nl), and EKO monitor (www.biologica.nl).
¹ m.v.; missing value

Structural development like scaling-up often goes hand in hand with technological innovation, which is used to increase productivity or save labour. For example, the use of AMS in dairy production is increasing. The current percentage of dairy farms (organic and conventional) with an AMS is 4% in the Netherlands and 8 % in Denmark (De Koning, 2006; Rasmussen, 2006). Application of such a new technology on an organic dairy farm, however, is not self-evident, just because it functions on a conventional farm (Alrøe and Kristensen, 2004). In Denmark, more than 9% of the 490 organic dairy farmers use AMS, and this percentage is increasing (Oudshoorn and de Boer, 2005). In the Netherlands, however, AMS has been implemented only on 1.7% of the 300 organic dairy farms (SKAL[1], KOM[2]). This is a divergent development in AMS use, in spite of uniform EU organic standards for both countries (see EEC regulation nr. 2092/91). The question arises if there are different perceptions between the Netherlands and Denmark in how organic dairy production can contribute to future sustainable development of the organic dairy sector, as embedded by the international federation of organic agricultural movements. (Anonymous, 2005b).

[1] SKAL: Certification for Organic Production in the Netherlands.
[2] KOM: “Kwaliteitszorg Onderhoud Melkinstallaties,” Quality Maintenance Milking Machines in the Netherlands.

Table 2. Structural development of organic dairy farms in Denmark (DK) and the Netherlands (NL) from 2003-2005.

	DK*			NL**		
	2003	2004	2005	2003	2004	2005
Milk per farm (1000 kg)	605	725	824	325	360	400
Number of milking cows per farm	87	95	100	54	60	65
Average milk yield per cow (kg)	6954	7631	7800	6000	6300	6400

* Estimations made using statistical data from Danish Dairy (www.mejeri.dk)
** Estimations made using statistical data from SKAL (certification body in NL), LEI (Agricultural economical Institute; www.lei.wur.nl), and DLV (Dutch Agricultural consult

An assessment of the contribution of AMS to sustainable development of organic dairy production should comprise Economic, Ecological, and Societal (EES) issues, the main aspects of sustainability. To assess the EES consequences of the introduction of AMS on organic dairy farms, stakeholders' perceptions are essential (Van der Zijpp, 2001; Mollenhorst and de Boer, 2004). Stakeholders are interest groups that either influence the functioning of the production system or depend on the functioning of the production system (Johnson and Scholes, 1997). Stakeholders often judge the relevance of problems and possible solutions differently even though the hard facts (such as capacity, influence on production) generally are accepted.

The main objective of this study was to explore stakeholder's perceptions of the contribution of AMS use to sustainable development of organic dairy production in Denmark and the Netherlands. In addition, possible reasons for recent diverging development in AMS use between both countries were investigated. A literature review was used to select stakeholders and relevant EES issues for questioning, as also to evaluate the results from the interviews.

2.2 Theoretical background

Consequences of AMS use on conventional dairy farms have been investigated extensively (Meijering et al., 2004), whereas literature on AMS use on organic farms is absent. Hence, the available literature on AMS use on conventional dairy farms has been used to determine the relevant EES issues raised by the AMS use on organic farms. In addition, EES issues of AMS use on organic farms were related to internationally accepted organic principles, standards, and measures, including ethical aspects (Benbrook and Kischenmann, 1997; Alrøe and Kristensen, 2000, 2004; Biao et al., 2003; Verhoog et al., 2003; Anonymous, 2005a, c; EEC regulation nr. 2091/92).

2.2.1 Sustainability Issues Related to AMS Use in Organic Dairy Production

Economic Issues

From a review on sustainability issues influenced when introducing AMS (Oudshoorn and de Boer, 2005) on conventional dairy farms, it can be concluded that net farm income did not increase as expected. AMS use influences especially costs (increase), labour (decrease of demand), and milk yield (increase) (de Koning and Rodenburg, 2004). In organic agriculture, however, relationships between these factors differ, for example, organic concentrates are relatively more expensive and there is a premium price for organic milk. The time saving of between 27 and 70% (Rasmussen, 2000) by using AMS also is for the organic farmer hard to capitalize. Combining AMS and grazing might even result in additional work, such as having to fetch the cows, rather than them coming voluntarily (Van Dooren et al., 2003). The demand for grazing could result also in a decrease in milking frequency, affecting the expected annual milk yield increase (Ketelaar-de Lauwere et al., 2000).

The data show that organic dairy farms in general have a better financial income than their conventional colleagues (Water, 2002; Nielsen and Vestergaard, 2003; Jørgensen and Pedersen, 2004). This could decrease the risk of large expenses when investing. However, judging from the experience of conventional AMS farms and the presumed consequences for the organic herds, no large economic gain is expected for organic farms using AMS compared to non AMS organic farms.

Ecological Issues

The environmental impact of AMS use can be assessed by estimating its effect on the use of natural resources such as water and fossil energy, and its effect on eutrophication, climate change, acidification, and biodiversity (Audsley et al., 1997; de Boer, 2003). From the literature review based on conventional farms only (Oudshoorn and de Boer, 2005), it can be concluded that water and fossil energy use is higher for farms with AMS. This is not expected to be different for the organic farms.

Eutrophication especially with nitrogen, and possibly phosphorous, due to high stocking rates caused by intensive grazing of farmstead lots, could be a problem for farms with AMS compared to farms without. This is especially true for organic farms, for which grazing is obligatory.

Global warming due to emission of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) is estimated not to be affected substantially by AMS use, neither for organic nor for conventional dairy. The increase in CO_2 emission from the increase in fossil energy use is expected to be compensated by a higher milk yield per cow, which decreases methane production per unit milk (de Boer, 2003). This is not expected to differ for organic practices. The emission of N_2O, which is directly related to the amount of N applied on the field, is not expected to be different for organic farms with and without AMS. Similarly, the emission of ammonia (NH_3) causing acidification, from animal manure in stable, in storage facilities, during grazing and application of manure is not expected to change by AMS use. Biodiversity of landscape and pasture flora(Noe et al., 2005) are expected to be affected by AMS use as a result of a change in the pasturing system, i.e., less grazing and more mowing.

Societal Issues

On-farm societal issues affected by AMS use comprise animal health and welfare, milk quality, and the farmer's satisfaction, partially based on labour circumstances. The impact of AMS use on these issues is not always quantifiable and is subject to attitudes and reflections (ethical, pragmatic, impulsive). From the literature review (Oudshoorn and de Boer, 2005) it can be concluded that some health parameters and welfare of dairy cows is influenced negatively when grazing is reduced (Somers et al. 2003). Recent investigation showed that AMS use on organic dairy farms reduced grazing time (Kramer, 2006; Hoeksma, 2005), just as on conventional dairy farms (Mathijs, 2004). EU regulations enforce grazing, but do not specify exactly how much. AMS use affects milk quality directly through an increase in Free Fatty Acid (FFA) content, and indirectly (vitamins, carotene, and fatty acid profile) through a reduction of the intake of fresh grass resulting from a reduction in grazing time. Farmers generally are very satisfied with their gain of free time. Technical dependency of the farmer and negative influences on milk quality could influence the image and trust of the consumer (Meskens et al., 2001). Within the organic sector, where milk quality is believed to be one of the motives for buying (Torjusen et al. 2004), this is important also.

Conclusions

Overall, a literature review on AMS use shows that no data could be found specifically for organic dairy farms. Therefore, literature on AMS use on conventional farms was submitted to a validation of documented standards, principles, and practices in organic dairy farming and the conclusions mentioned here relate to organic farms with AMS. Concerning economy, AMS use is not expected to increase net farm income substantially, as milk yield increase might be limited by grazing and the labour savings might be hard to capitalize. Concerning ecology, AMS use will increase water and energy use per kg of milk. Eutrophication is expected to increase as a result of a high stocking density of farmstead lots. Biodiversity is expected to decrease as a result of a change in the pasturing system Acidification and greenhouse gas emissions are expected to be affected hardly by AMS use.

Concerning societal issues, AMS use is expected to influence animal welfare and health, and product quality, through a possible reduction in grazing time. Additionally, mechanical processes in the AMS influence product quality.

Considering the stakeholder perception investigation, economic issues (labour requirement and milk yield), the ecological impact of grazing (eutrophication and biodiversity), and the societal consequences of AMS (welfare and product quality and farmers satisfaction), imply a large influence of the primary sector.

2.3 Method

2.3.1 Focus Group Interviews

The aim of this research was to explore stakeholder perceptions in Denmark and the Netherlands of AMS use on organic dairy farms addressing sustainability issues in relation to organic principles and standards. The means adopted to achieve this aim was the focus group interview technique, where the topics discussed were based on the analyzed theoretical background. Such a technique combines quantitative factual research with qualitative participatory investigation (Halkier, 2002). The technique is appropriate for observing and tracing the divergence in development of AMS use in the Netherlands and Denmark and the expected ethical conflicts and attitudes for introducing AMS on organic farms. Focus group interview technique generates interaction between the participants in the group. It is an effective way to explore participants' perceptions and arguments. The participants themselves determine which topics they discuss in depth, showing where their interest lies. Focus group interviews produce data for groups, not individuals; how the group interprets or values the facts (Halkier, 2002). This, rather than a detailed knowledge of individual behavior and attitudes, can answer the main question of this research.

2.3.2 Participants

Evaluation of the literature showed that the main sustainability issues, affected by the use of AMS on organic dairy farms, addressed the primary sector. In addition, the difference in AMS use between countries could emerge from the producers themselves or from the advisory system. Two stakeholder groups, therefore, were selected: farmers and advisors. Parallel sessions were organized in both countries, leading to four focus group interviews; two with organic dairy farmers, and two with advisors working in this sector. From the experiences of other group interviews with the objective of generating debate, a minimum of four people should participate in each group (Kvale, 1994). The aim of this research was to gather the range of perceptions and values. To secure a discussion based on experience and visions, some farmers working with AMS were selected. This resulted in the following group sizes: farmers in the Netherlands – five, of which two had AMS; farmers in Denmark – six, of which three had AMS; advisors in the Netherlands – eight; advisors in Denmark – six. The advisors chosen had knowledge about production of roughages, animal nutrition, and farm economics, which is due to the holistic view inherent to organic farming. In the Netherlands, most of the practicing organic advisors participated, and, therefore only one group session was arranged. Consequently, in Denmark also one session was arranged. All participants were between 30 and 60 years old. The participants in each group were personally recruited by telephone. They knew they were going to talk about the use of AMS on organic dairy farms, although information was kept to a minimum prior to the meetings.

2.3.3 Procedure

The four group interviews were held between September 2004 and March 2005. No major events that could influence the perception of the stakeholders took place during this period. It was clearly stated at the beginning of each session that the results and conclusions of the interviews would be published ensuring anonymity of the participants. The bilingual moderator explained the aim and procedure of the meeting, after which the participants introduced themselves to each other. The participants were invited to react freely to each of the moderator's questions and to each other's answers, remarks, and opinions. They were thus left free to interact and to react to everything that occurred during the session. During the focus group interview, the moderator (who was the same for all the sessions) introduced the topics. These topics were similar for the sessions in Denmark and the Netherlands, making it possible to pinpoint possible differences in perception between countries. The sessions lasted between 90 and 120 minutes. The interviews were audio taped and notes were made by the moderator. After the interviews, all material was transcribed and then analyzed. The condensation/indexation technique was used to analyze the sessions (Halkier, 2002). This was done by coding and categorizing all transcripts. Statements and discussion topics were systemized and grouped under coded headlines or keywords, frequency of occurrence, and time period in which they were discussed. This resulted in a schematic presentation of the topics and statements discussed, and the frequency and length of the coded topics. These schemes were then used to represent the essence of the analysis, conceptualizing the results. The results are discussed, using the literature review, based on conventional dairy farms with AMS, as reference.

2.3.4 Questions

Questions were designed to investigate whether the sustainability issues identified by literature as being influenced by AMS use on organic dairy farms, matched the stakeholders' perceptions. This resulted in a list of questions, which were preceded by so-called positioning questions (Halkier, 2002) giving information on the participants' backgrounds and practice and putting the group members at ease. The questions were mostly open, so as to let the participants take initiatives in relation to addressing topics. Later in the sessions, information from the theoretical review was brought up by the moderator for comment. In focus group interviews, general attitudes are discussed and not individual performances. Specific issues, which were identified in the theoretical background, as milk yield, direct energy consumption, therefore, were not brought forward. Sustainability issues that were not expected to be influenced substantially by AMS use on organic farms, such as acidification and global warming were not introduced by the moderator. Biodiversity was not brought up in the groups as changes in landscape or flora, between farms with AMS and without, have not been documented.

Table 3. Questions used in the focus groups.

1.	The participants were asked to say who they are, how much experience they have with organic farming and with AMS, and also the farmers are asked to describe their family and other social activities
2.	The participants were asked to react to the statement that the situation and development of organic dairy farming doesn't look good:, a decline in amount of organic milk delivered, some organic farmers converting back, worsening economic results and flagging demands
3.	The participants were asked to estimate the future percentage of organic milk that will be sold in 10 years time
4.	The participants were asked to reflect on the AMS as part of organic dairy farming
5.	The participants were asked what they think of grazing, as part of the organic standards
6.	The organic farmers were asked what their reasons were for farming organically
7.	The organic farmers were asked what they think motivates consumers to buy organic produce
8.	The organic advisors were asked what reasons they think the farmers will give for farming organically
9.	The participants were confronted with nine sustainability issues selected from the literature survey and asked to prioritize them according to their perception of relevance and their factual knowledge
10.	All participants were individually asked to comment on the possibility of a new rule involving pasturing on organic dairy farms making it compulsory to have the cows out for at least six hours in the 150 days of the grazing season and have at least 0.2 ha per cow of grassland accessible (not available all the time)
11.	The participants were confronted with a statement that there is hardly any difference between organic dairy and conventional farming

The 11 questions (Table 3), focused on three areas, each with their own agenda. The first area (questions 2, 3, 6, and 8) focused on the participants' perception of the stagnation in growth of the sector, and how they looked at the future in relation to their personal involvement with organic production. These personal motives were considered important in our study because AMS use can possibly contribute to overcoming the observed stagnation of the sector. Introduction of innovative technology could well be connected to perceptions regarding the future. Personal motives were expected to generate ethical discussions that could be projected onto using AMS. The second area (questions 4, 5, 9 partial, and 10) focused on the participants' opinions of the relationship of AMS to organic standards and principles and grazing issues. The literature review showed that grazing was a major issue concerning AMS use on organic dairy farms, as it was connected to the farm's economy, ecological factors such as eutrophication, and societal issues like animal welfare, product quality, and image. The third area (questions 4, 7, 9 partial, and 11) focused on the participants' perceptions on other sustainability aspects of concern found in the literature, such as animal health, natural resources, technical dependency, farmers satisfaction, and consumer behaviour.

A confrontation with identified relevant sustainability issues (question 9) was presented rather late in the session to avoid influencing the group, and was introduced once they had discussed the possible use of AMS on organic farms in the earlier questions.

Incidentally, the participants themselves focused on other aspects than those originally planned by the moderator. On these occasions, the statements and opinions were indexed to the relevant aspects.

2.4 RESULTS

2.4.1 Participants Viewpoints on Organic Farming

When confronted with the statistics showing the decrease in growth of organic milk production and the decline in the number of organic dairy farms in Denmark in the period 2000–2004, nobody perceived the current stagnation as a real threat or a negative signal. Some even seemed surprised by these numbers. In general, all four groups perceived a period of stabilization and consolidation important after a period of fast growth in the 1990s. They agreed that increased concentrate prices, the accomplishment of 100% organic feeding, and lower organic premiums and subsidies are reducing the financial incentive to convert from conventional to organic dairy production. This reduced conversion together with the structural development resulting in fewer farms with increased production, results in a plateau in the number of organic farms. A better marketing effort could, according to the participants, have led to higher sales and consequently a higher percentage of organic farms.

Dutch participants generally were more optimistic about future development than Danish ones. They identified some positive ongoing developments, such as nature management, as possibilities for generating extra income and stimulating positive future expectations among the producers. They also mentioned that continuous growth of the sector should not be the only objective.

When discussing the future market share of organic dairy production in each country, no participants predicted a serious decline in organic dairy production. Dutch farmers expected a future market share of organic dairy production of on average 10% (range 5%–22%), whereas Danish farmers expected a future share of on average 12% (range 7%–22 %). The current market share of organic dairy production is around 2.5% in the Netherlands and 10% in Denmark. Hence, Dutch farmers expected a larger growth than Danish farmers did. Advisors, however, did not want to predict exact percentages. Danish advisors stated a status quo or small growth in the market share, whereas almost all Dutch advisors expected an intermediate growth in the market share of organic dairy production.

When farmers were asked why they were farming organically, Dutch and Danish farmers mentioned the following: absence of chemicals, economic prosperity, satisfied and happy with the work of farming, responsibility for maintaining a natural environment, animal welfare, worth living in for the next generation, and professional challenge. They also mentioned the skills to manage weeds without chemicals and animal health problems without prophylactic treatments. All farmers interviewed were satisfied with current practices, and had a positive attitude towards the future. Advisors in both countries had the same perception and stated that even where economic prosperity had been the main motive for some farmers to convert from conventional to organic production, some years of practice often showed that other motives became more important, like the joy of farming.

According to the advisors, reasons to stop producing organically were not related to organic farming. Farmers (conventional as well as organic) stopped because the owners were ageing and had no successors, or because of structural developments (i.e., their farms were becoming too small).

2.4.2 Participants Viewpoints on AMS use and Grazing

The stakeholders, when asked to react freely on the use of AMS on organic dairy farms, came up with a massive response and discussion, not only about AMS as new acceptable technology or its impact on animal health, but also overwhelmingly about the grazing issue. All four groups were unanimous in not having any moral problem with this new technology. Participants also agreed that the desire to uphold organic principles and standards was no reason to reject AMS. The groups concluded that AMS use on organic farms probably will not improve the financial situation, whereas it will cause some problems with respect to the grazing that need to be solved.

In the Netherlands, advisors and farmers stated that AMS was feasible for bigger farms only, whilst Danish advisors were of the opinion that AMS was not of interest for farms of over 250 milking cows, referring to organic standards that demand grazing. Grazing problems and economic reasons were mentioned as disadvantage for the use of AMS in very big herds. Large carousel milking stalls with a capacity of 250 cows an hour were mentioned as more profitable in big herds than AMS, with capacities of 60–70 cows a day. In addition, the allocation of fields and maintenance of access roads, including labour time spent driving the cattle, were mentioned as disadvantages.

In the course of the interview, the moderator specifically asked the participants in all groups about their perception of grazing. All groups responded that grazing is closely connected to the image of organic dairy farming, expressed very succinctly by the following remarks: "it is the face of organic dairy," "no discussion possible," "definitely crucial," and "essential." Both Dutch and Danish farmers put forward additional arguments for why grazing was important to them, such as image and naturalness, but there were also differences of opinion regarding animal welfare, health, and product quality, when grazing was considered.

Danish farmers stated that grazing was sometimes labour intensive, difficult to manage correctly, and was not always animal-friendly. However, they were in no doubt that it was worthwhile, and they even encouraged the certification bodies to "tighten" their control on pasturing management. In contrast to this, Danish advisors, who also mentioned some of these difficulties, argued for the idea of substituting grazing by time spent outdoors or indoor cubicles well covered with straw. Only the Danish participants specifically mentioned the positive effects of grazing on milk quality such as CLA (Conjugated Linoleic Acid) content, vitamin E concentration, and the presence of antioxidants.

When the participants were asked to prioritize among nine sustainability issues selected from the literature review, grazing was ranked as second most important, except by the Danish advisors (Table 4). This group felt that the pasturing problem had already been discussed intensively before the advent of AMS in organic dairy farming. In their opinion, solutions could and should be found, and this would help the organic dairy farms with and without AMS. Looking at the other issues, it is interesting to see that advisors ranked milk quality slightly higher than farmers do, both in Denmark and in the Netherlands. Milk quality was connected partly to the functioning of the AMS and partly to the pasturing on clover/grass mixtures. The issue of eutrophication was ranked completely differently by the groups. Eutrophication in connection to grazing had to be explained by the moderator and was not seen as a threat by the advisors, but it was by the Danish farmers; not so much as environmental threat but as an administrative one because of mineral bookkeeping obligatory measures in the Netherlands and in Denmark. Animal welfare and health were thought unlikely by the farmers to cause problems with AMS use, but these problems were rated higher by the advisors in both countries. Farmers connected the health and welfare aspects more directly to the robotic character of AMS, stating there was absolutely no negative influence of the machines. The advisors clearly saw the lack of grazing as an indirect consequence of AMS. This would eventually cause problems with health and welfare, according to the Dutch advisors. The discussions arising whilst prioritizing the issues showed that the stakeholders recognized that many issues were connected to grazing, as seen in the literature.

Table 4. Focus group participants priority of nine selected sustainability issues' importance when implementing AMS, scored (sc.) in consensus within the groups, by two different stakeholders, farmers and advisors in two countries, Denmark (DK) and the Netherlands (NL).

sc.	NL farmers	sc.	DK farmers	sc.	NL advisors	sc.	DK advisors
1	economy	1	economy	1	economy	1	economy
2	grazing	2*	grazing	2	grazing	2	concentrates
3	technical dependency	2	eutrophication	3	animal welfare	2	milk quality
4	sales	4	technical dependency	4	milk quality	4	technical dependency
5	milk quality	5	sales	7	technical dependency	5	grazing
6	eutrophication	6	milk quality	7	animal health	6	animal heath
7	concentrates	7	animal health	7	eutrophication	7	animal welfare
8	animal welfare	8	animal welfare	7	concentrates	8	sales
9	animal health	9	concentrates	7	sales	9	eutrophication

* Where the score shows the same number, this means that no priority was given within these issues

To relate the discussion on grazing to the direct practice, the moderator asked for the farmers' and advisors' perceptions on a possible new rule, prescribing grazing. The current EU standards state that in general cows should graze when possible. The Dutch authorities interpret this as a minimum of 120 days and the Danish as a minimum of 150 days. The EU standards imply no grazing hours per day and no strict control. A new rule could be that dairy cows should pasture for at least 6 hours a day on 150 days per year and have access to an area of 0.2 ha per cow (in the grazing season). These time and area definitions have been suggested as sustainable measures by Danish authorities, addressing both the issue of eutrophication and the cows' welfare.

All groups mentioned and concluded that there are potential problems controlling such a rule (Table 5). All groups also acknowledged that if such a rule were enforced, some organic farmers would have to stop production. All other reactions on a possible new rule revealed different perceptions, resulting in a large variation within and among groups. Consequently, no general conclusions could be drawn. It is, however, worth mentioning that Danish advisors were mostly against extra restrictions. The Danish farmers concluded differently from their advisors, declaring that farms that could not live up to these rules should be excluded from delivering organic products.

Table 5. Dutch (NL) and Danish (DK) farmers' and advisors' categorized statements mentioned by at least one member of the group, on a possible new rule suggesting a minimum 0.2 ha grazing area and 6 hours of grazing per cow per day on 150 days per year.

Statements	NL **Farmers**	DK **Farmers**	NL **Advisors**	DK **Advisors**
0.2 ha is too much	•		•	•
Should be for all countries	•		•	
Hard to regulate, control	•	•	•	•
6 hours is not enough			•	
6 hours is OK, 0.2 ha is too much		•	•	•
0.2 ha is necessary		•	•	
Too radical: not what the farmer accepted when they converted			•	
People deciding this don't know anything about practical farming		•	•	•
Fine	•	•	•	•
Would destroy the rotation			•	•
Would be hard on the economy	•			•
Make welfare score: grazing gives points, can be substituted by other measures		•		•
Not possible for all organic dairy farmers	•	•	•	•
You have to be clear addressing the consumers	•	•		
Makes it difficult to grow larger	•	•		
Necessary for milk quality, price		•		

2.4.3 Affect of AMS on Sustainability Issues

When the participants were asked to react freely on AMS use on organic dairy farms, they mentioned other issues than grazing. The use of new technology was described with the following statements; "we should not be nostalgic," "no principal problems," "let new technology help us," and "new technology cannot be stopped." Referring to some critical opinions stating that automatic milking would remove animals from the farmers' caretaking, some participants mentioned that AMS could directly improve the animals' welfare by having a stable and calm herd. All participants knew that AMS could have a negative influence on milk quality, regarding both fatty acid content and hygienic standards; however, they did not see this as an insuperable obstacle. Some Dutch advisors mentioned negative factors including: cows cannot be managed from behind computers; not all farmers can handle information technology; AMS is just another technique in the efficiency race to make agricultural products cheaper, it will not help the sector; the introduction of AMS on organic farms reduces the differences between organic and conventional production. Dutch advisors and farmers focused more on the economic feasibility of AMS.

At a later stage in the interview, the stakeholders discussed and prioritized the expected effect of AMS on sustainability issues and derived aspects, selected from the literature review. All groups rated failing economic return as the primary threat to sustainability (Table IV), and the Danish advisors also linked concentrates and milk quality to economy. In general, farmers ranked sales much higher than advisors did, indicating the threat of not being able to sell the product. Furthermore, farmers expressed concern for their premiums and contracts to the dairy industry. They argued that bad quality and image would decrease the sales of the product. None of the participants regarded the use of AMS to be a threat for animal health and some Dutch farmers criticized the moderator for even mentioning the aspect in this assignment, as it was postulated as gossip, brought into the discussion by anti-technology activists.

Throughout the interviews, the participants mentioned the consumers as an important unknown factor influencing the sustainability of organic dairy production with or without AMS. All participants agreed that consumers' own personal health, no use of chemicals, more natural methods, and animal health and welfare were the most important motives for buying organic products (see Table 6). For example the statement, "The consumer wants to see the cow outside," was expressed in all groups. Some participants claimed that consumers would not know the difference between a dry cow and a lactating cow, and the cows in the field a couple of hours a day would be enough to satisfy the consumers' desires. When more specifically asked about how the farmers and advisors thought about the lack of difference between conventional dairy farming and the present organic practice, the Dutch farmers in particular reacted by saying that there was a difference, referring to the consumers' desire for small scale, non technological farming. The Danish advisors and farmers mentioned the AMS as an example. According to them, not many consumers know what robotic milking is and how it affects the organic practice, nor the fact that many organic dairy farmers are using it. This gives the consumers the idea that there is no big difference.

Table 6. What farmers (NL and DK) think (quotes) consumers want when they buy organically produced food. Categorized and indexed but not rated (not in priority order).

Category	**Key issues for the consumers**
Personal health	no chemicals better quality healthier egocentric buying behaviour
Environment	no artificial fertilizer respect for nature natural
Animal welfare	grazing better animal welfare cow outside
Other reasons	relatively cheap compared to what conventional food should cost without subsidies. it gives a good image clear difference from conventional methods because of scandals in conventional agriculture

2.5 Discussion

2.5.1 Perceptions: Dutch and Danish

On average, a Dutch organic farm is smaller than a Danish farm. Dutch farmers and advisors mentioned that structural development towards bigger farms was difficult in the Netherlands. Dutch stakeholders assumed that farms with around 50–60 cows could not afford an AMS. This perception is in contradiction to economic model calculations done in France and in the USA, where farms with herds of 60 cows were regarded as ideal for the introduction of AMS (Veysset et al., 2001; Rotz et al., 2003). In Denmark, the discussion on the optimal size for farms using AMS also involved factors such as difficulties with grazing and technical dependency. Technical dependency can be a major pitfall when introducing innovative technology, as the overwhelming amount of computer data can sometimes be counterproductive (Eastwood et al., 2005). In Denmark almost 10% of AMS users have converted back to bulk milking (Rasmussen, 2006), but the exact reasons have not yet been investigated. In the Netherlands, AMS was used only by six out of approximately 300 organic farms in 2005, and in Denmark by 46 out of 500 organic farms. It is reasonable to assume that the size, and recent enhanced structural development towards bigger farms in Denmark, is partly causing this. Often farmers introduce AMS when they built new housing facilities or enlarge their milk production. However, the percentage of organic farms in the Netherlands with AMS is also lower than the percentage of conventional farms with AMS in the Netherlands; 1.7% and 4%, respectively. The percentage in Denmark is on the contrary higher; 9% and 8%, respectively (de Koning, 2006; Rasmussen, 2006).

Reactions of Dutch advisors and farmers showed that other factors might be involved. The Dutch farmers explicitly mentioned that expanding their farm unit was not their main goal with organic farming, and in the course of the interviews a more sceptical opinion on the use of AMS was observed, both economic and strategic. Growth expectations of the sector were discussed. Dutch participants responded more optimistically than the Danish participants did. This could be a result of the present relatively low percentage of organic sales in the Netherlands (van Ruiterbeek, 2005), and the Dutch aspiration to come up to levels of trade achieved in Denmark or other countries in the EU. Both countries, however, expressed some optimistic future view, which will be necessary if an enterprise makes large investments such as AMS. Accepting the difficulties associated with expanding in size, Dutch farmers expressed views on finding alternative enterprises for the future, like starting on-farm cheese and yoghurt dairies, or other financial possibilities such as bed-and breakfast, farm campgrounds, and residence for socially deranged people offering therapy or just relaxation. Danish farmers and advisors expressed views more along the lines of economizing, labour saving, and having a good life.

All groups prioritized the failing economic performance of the farm as the main threat to sustainability when introducing AMS. This corresponds to the results found in the literature (Nielsen and Vestergaard, 2003). In the focus group sessions, where possibilities of AMS use within the organic system were discussed, the Dutch farmers and advisors emphasized the economic performance more often than the Danish participants. Even though economic performance was mentioned as crucial, this was relativized. Social factors, such as the need for family free time or flexibility, in the end determine what the enterprise decides. Here the organic farmers do not respond differently from their conventional colleagues (Meskens and Mathijs, 2002). In addition, Mathijs (2004) presents a clear difference in motivation to invest in AMS between Denmark and the Netherlands; in general the

Dutch want to *save* time (economic incentive), while the Danish want more *flexible* time (well-being incentive). The number of farms using AMS is increasing (Nielsen and Vestergaard, 2003; Meijering et al., 2004), confirming that even though the net income is not improving, AMS investment is continuing. The critical view on economic gains from using AMS, in addition to the perception that units of 60–70 dairy cows are not profitable for AMS that was registered in both the Dutch advisor and farmer group, could be part of the explanation why not many organic dairy farms in the Netherlands have converted to AMS.

There seems to be no difference in primary incentives for farmers to start organic production in Denmark and the Netherlands. Their expressed ethics concerning animal welfare or use of chemicals are not in conflict with the introduction of AMS and the above-mentioned professional challenge. Furthermore, the positive reaction to the use of modern technology is in line with technological development. In addition, the acknowledgement of small-scale naturalness, representing less mechanized agriculture perhaps, is motivating the Dutch farmers not to start harvesting their milk by robot.

2.5.2 Grazing, Milk Quality, and Image

Grazing was in the literature review (Oudshoorn and de Boer, 2005) not defined as a sustainability issue, but is associated with many issues, and as such grazing is an important aspect, as clearly mentioned in the literature (Ketelaar-de Lauwere et al., 2000; Mathijs, 2004; Raun and Rasmussen, 2001; Van Dooren et al., 2003). Recent studies confirmed that organic farmers with AMS in Denmark and the Netherlands have decreased the amount of grazing (Kramer, 2006; Hoeksma, 2005), just as their conventional colleagues have done (Van Dooren et al., 2003). The focus group interviews showed that grazing problems were complex. Because the economic incentives for grazing were not always obvious, the organic sector has discussed other moral or marketing-oriented arguments to motivate the farmers to maintain a high level of grazing. However, when discussing a tightening of the organic rules, specifying how long and what area the animals should be able to access, all groups, but especially the advisors, are relatively pragmatic. They understand very well that a number of farms will not be able to live up to these standards, and will have to stop their organic practice.

In all group discussions, the practical implementation of grazing rules divided the participants into two groups; one side arguing that more grazing is better for welfare and product quality; the other side suggesting that just showing that the animals are kept outside would be enough to satisfy the customers and arguing animal health and welfare not always improved by grazing the animals. Literature on this subject is not unanimous although most references state that grazing improves welfare and health (Munksgaard and Søndergaard, 2006, Somers et al., 2003). Welfare issues like more motion, better lying conditions, less aggressiveness, and better reproduction are mentioned as well as health issues like fewer claw disorder and lameness. The Danish farmers, in particular, were clear in their opinion that organic dairy farmers without facilities for sufficient grazing should stop. In the end, this would help the sector improve its image. The production of organic milk in Denmark and the Netherlands is higher than the consumption and can absorb easily those few farms stopping deliveries. On the other hand, the Danish advisors in their group argued to slack the rules, giving the possibility to compensate for fewer grazing hours by providing extra straw areas.

Danish farmers and advisors stated that the sector's image could be improved by focusing more on the product quality. Here the direct positive influence of grazing on vitamin E, fatty acids as CLA, and antioxidants was mentioned. This positive influence has been mentioned also in the literature (Collomb et al., 2002; Elgersma et al., 2004; Nielsen, 2005). Danish participants discussed these topics because of a recently published article in a popular agricultural magazine in Denmark. All groups expected a solution for the negative influence of AMS on the FFA concentration of the milk. Farmers perceived milk quality aspects less important than the advisors, when rating them among the nine threats of AMS to sustainability. This could be due to less knowledge among the farmers on this subject.

Although connecting many sustainability issues to the grazing aspect, stakeholders did not prioritize eutrophication. Eutrophication, however, can be a problem (Søegaard et al., 2001; Kristensen et al., 2005b) and the organic dairy sector will be confronted with this (Kristensen et al., 2005). It is not always clear to farmers and advisors that grazing management can result in excessive stocking rates, which provokes eutrophication. Eutrophication causes high nitrate levels in ground and surface water and might affect, therefore, the image of public indirectly.

All participants agreed that AMS had no direct negative influence on animal welfare and health aspects, only indirectly, by reducing grazing time. This corresponds to the conclusions found in literature (Oudshoorn and de Boer, 2005).

2.5.3 The future

Both the literature review and the analysis of stakeholders' perceptions reveal that AMS use on organic dairy farms is not without problems. There should be no doubts about the milk quality, grazing should be possible, and the cost price and yearly maintenance should not be too high compared to the economic gains. Variation in economic results between best and worst for all AMS dairy farms has proven to be large (Nielsen and Vestergaard, 2003). The economic challenge for organic dairy farming could well be even bigger, as it needs more labour for maintaining grazing and the costs for concentrates use are higher (Ketelaar-de Lauwere et al. 2000; Kristensen et al., 2005; Kristensen et al. 2005b).

A lack of sufficient farmstead lots can easily cause overstocking and will demand strict management. The problem of achieving a high level of grazing when using AMS is acknowledged by the primary stakeholders of organic production. Organic farmers and advisors require research on the use of AMS and grazing, which might result in technical or operational solutions. The organic advisory system in Denmark has financed projects aiming at increasing grazing together with AMS. The challenge for the future, therefore, will be to decide how much grazing is necessary to satisfy, on the one hand, the animals' welfare, the milk quality, stocking rate, and the wishes of the consumer and, on the other hand, economic feasibility. Animal welfare organizations are demanding obligatory pasturing of ruminants, organic and conventional (Anonymous, 2006c). One year after the focus groups discussed the tightening of the grazing rules, the Danish certification body (Danish Plant Directorate) for organic agriculture brought in a new minimum for grazing (0.2 ha and six hours). As the participants mentioned during the interviews, the consumer demands and their view of the image of organic dairy farming is important, but was not investigated in this paper.

2.6 Conclusions

Farmers and advisors in Denmark and the Netherlands, representing relevant stakeholders of the organic dairy sector, expressed AMS use as a good development, giving the farmers more free time and possibilities to manage their farms effectively. In addition, they expressed no moral problems regarding AMS use. They, however, pointed out the uncertainty of economic gain, difficulties with grazing, adaptation problems towards new technology, and possible image problems towards consumers. Consumers' image was considered to be affected negatively by a reduction in grazing time, affecting both milk quality and animal welfare. The Dutch as well as the Danish farmers were more radical than their advisors in their suggestions for solving the grazing problem, stating that if colleagues could not live up to the grazing standard, they should stop. Within all groups, there were different perceptions on the effect of grazing on welfare, health, product quality, and economy. In particular, the Danish advisors disagreed that grazing automatically enhances animal welfare.

The participants did not recognize eutrophication, as result of grazing a large number of cows on a relatively small area, as a problem caused by AMS. The milk quality problem related to AMS use, although acknowledged as crucial towards consumers, was not prioritized very highly, especially not by farmers in both countries. All groups were, however, unanimous in their perception of how important image was as far as the consumers are concerned. The perception analysis revealed that Dutch participants were concerned more about the economic payoff of AMS, and showed more reluctance towards enlargement. In addition, they acknowledged the small-scale naturalness of organic production, and as their primary goal they did not express growth or increasing productivity. These differences in perception could possibly explain observed differences in AMS use in organic dairy production between Denmark and the Netherlands, where the Danish, parallel to their conventional colleagues, expand the size and try to replace manual labour by machines, whereas the Dutch seek other ways to support their income.

The stakeholders' perceptions were in many ways parallel to literature review based on AMS use on conventional farms. The focus group interview technique showed its ability to identify perceptions of stakeholders regarding sustainability issues of AMS use on organic dairy farms as also problems and mitigation options for implementation. In addition, the focus group interview technique identified differences in perception between the Dutch and Danish participants for the future of organic farming and future developments addressing AMS.

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Chapter 3

Quantification of Sustainability Indicators on Organic Dairy Farms in Denmark using Automatic or Conventional Milking Systems

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Abstract

The objective of this research was to make a sustainability assessment of organic dairy farms using automatic milking systems (AMS), and to compare them with a group of organic dairy farms using conventional milking systems (CMS). The selection of farms and indicators are presented and methods of quantification are described.

Milk yield per cow was higher for AMS farms (8,539 kg energy corrected milk [ECM] per cow per year compared with 7,302 kg ECM) but did not result in higher net profit to management. Nitrogen surplus per hectare of available land was higher for AMS farms than for CMS farms (110 kg N/ha compared with 66 kg N/ha). Animal health was unaffected by AMS use, as were most milk quality aspects such as somatic cell count, clostridium spores, and urea. Acid degree value (ADV), measured as free fatty acids (FFA) in the milk, was higher in milk from AMS users (0.78 mEq/l compared with 0.49 mEq/l). Labour time measured in hours of work per dairy cow per year, was decreased by almost 50% for AMS users, to 2.3 min/cow per day.

It can be concluded from quantification of selected indicators on economy, environment, cow health, milk quality, and labour time, that the organic dairy farms using AMS, in spite of the substantial decrease in grazing time, show the potential for sustainable development within the range of herd sizes investigated (65–157 cows per farm).

Key Words*: organic dairy farming, automatic milking systems, sustainability indicator, milk quality*

3.1. Introduction

Organic dairy farms in Denmark expand in herd size, annual milk yield per cow increases and farmers are improving efficiency (Kristensen et al., 2005). Introduction of new technology is part of this development. To save labour costs when suitable labour is scarce, expensive automatic milking systems (AMS) are being implemented, and information and communication technology (ICT) is used. AMS use on conventional dairy farms has been subject to evaluation, but first after the year 2000 it was no longer obstructed by technological inadequacies (Meijering et al., 2004). New technologies are often contentious and tend to provoke skepticism and need general comprehension before public acceptance (Meskens and Mathijs, 2002). This can be expected especially for the use of AMS technology on organic farms, where other principles on areas such as animal health and welfare, feeding, and marketing have to be addressed, than on conventional farms (Oudshoorn et al., 2008). Assessment of the AMS use on organic dairy farms was found necessary.

As organic agriculture claims to be a sustainable alternative (Oudshoorn and De Boer, 2005), a sustainability assessment using a 4-step methodology as defined and applied by Mollenhorst and de Boer (2004) was used. The 4 steps comprise: (1) definition of the cause of action, (2) identification and definition of relevant sustainability issues, (3) selection and quantification of sustainability indicators, (4) assessment of the consequences for sustainable development. Sustainable development has over the years been accepted as a development that meets the needs of current generations without compromising future generations. To ensure needs of today and needs and aspirations of future generations, economic, ecological, and societal issues (EES) should be considered simultaneously (De Boer and Cornelissen, 2002). For step 1 and 2 of the methodology, a literature survey on sustainability for conventional farming using AMS, was carried out and scrutinized for organic implementation (Oudshoorn and De Boer, 2005). Selected organic stakeholders gave their opinion on perceptions of the use of AMS which supplemented the theoretical selection of EES issues, relevant to assess the sustainability of organic farms using AMS (Oudshoorn et al., 2008). In order to complete the sustainability assessment according to the 4-step methodology, sustainability indicators (SI) were selected for the identified issues. AMS implementation has interdependent consequences at farm level. The drive to invest often requires higher economic returns, possibly influencing intensity of production and influencing environmental constraints (Haas et al., 2007). Quantification was performed on farm basis, so consequences of AMS for a sustainable development, comprising all EES issues, could be determined. On farm quantification of selected indicators gives the possibility for interdisciplinary assessment of sustainability (Mollenhorst and De Boer, 2004). The objective of this research, therefore, was to assess the EES consequences of use of AMS on organic dairy farms, by comparing selected EES indicators of organic dairy farms using AMS with organic dairy farms using a conventional milking system (CMS).

3.2 Materials and Methods

3.2.1 Selection of Farms

In 2005, there were 480 active organic dairy farms in Denmark, of which 45 had AMS. Twenty farms were randomly picked from the organic dairy authorization archive of which 10 used AMS and 10 used CMS. From each group, 9 farmers responded positively to the request to share performance data and complete a questionnaire. Beforehand the archive had been filtered, allowing only the Holstein Frisian (HF) breed (85% of all organic herds in 2005) to be included, in order to avoid breed differences in the data set. As the size of the herd was assumed to influence some of the sustainability indicators (SI), the AMS and CMS group were preset to have parallel herd size distribution. As a result, the average herd size of selected AMS farmers was 114 dairy cows, whereas the average herd size of selected CMS farms was 118 cows. The registration of data focused on a single year (2005; Jan. 1 to Dec. 31) to avoid annual climate influences, price level influences, and influences caused by technological development.

3.2.2 Selected EES Issues

Sustainability issues were defined, based on a literature survey on sustainability of conventional farms using AMS, scrutinized for organic implementation and supplemented with participative research exploring perceptions of the use of AMS by selected organic stakeholders (Oudshoorn et al., 2008; Oudshoorn and De Boer, 2005). Sustainability issues defined were: economic performance of the farm, on-farm eutrophication and biodiversity, labour circumstances, animal welfare including health, and milk composition and quality aspects.

3.2.3 Selection of Sustainability Indicators

For each issue defined, we selected a set of sustainability indicators (SI). We followed the definition of (Bell and Morse, 1999), who stated that an indicator should be an operational representation of a property, quality, or characteristic of a system. In this study we chose only to use quantitative indicators, omitting information on farmers' satisfaction or motivation. The first question one has to answer before selecting an indicator is what the purpose is (Mitchell, 1996). In our case the aim was to determine the EES consequences of the introduction of AMS on an organic dairy farm and, therefore, SI were defined 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 (Mitchell et al., 1995).

In this study, the target value for each SI was set 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 also related to absolute target values on national basis. The aim of this research was to quantify the situation for 1 year, as growing seasons or particular situations between years are often not comparable. We present the outcome of the quantification of SI without making trade-offs and without aggregating data. We selected transparent and tangible indicators that people can readily understand and visualize, and can relate to their own situation (Mitchell, 1996; Bell and Morse, 2003) . In the following paragraphs we describe the selection of SI for the selected issues in more detail.

3.2.4 Economic Performance of the Farm

To assess the economic performance of a farm, profitability is of major importance (Van Calker et al., 2005). Earlier farm research on the economic perspectives of AMS use, identified the following indicators to quantify profitability: net profit (i.e., agricultural revenues minus fixed and variable costs), gross margin, annual milk yield, variable costs with specification of contractor and veterinary costs, fixed costs, financing costs, and percentage debt (De Koning and Rodenburg, 2004; Mollenhorst et al., 2006). These economic indicators were registered for the 18 organic farms in this research.

Indicators were expressed per dairy cow, to be able to compare values among farms. Economic data were derived directly from the farmer's economic accounts, authorized by a registered public accountant.

3.2.5 Eutrophication

On-farm eutrophication can be quantified by input–output accounting of nitrogen (N) and phosphorus (P), which is reported to be relevant and reliable (Mollenhorst et al., 2006). By input–output accounting of nutrients, one can determine the nutrient surplus, which is assumed to be lost to the environment. In this research, we computed both a farm and field nutrient balance. The farm balance determines the average N and P surplus per hectare of farmed land (Thomassen and De Boer, 2005; Halberg et al., 2005). In order to quantify the effect of overstocking on eutrophication of individual fields, we also computed a nitrogen balance for specific individual fields, representing grazing pasture and pasture for mowing, determining the N surplus in kg per hectare of field per year. The P balance of individual fields was not determined, because the estimated P surplus at farm level appeared to be low, which corresponds to other registrations in Denmark (Hvid et al., 2004).

The NP input at farm level was determined by quantifying input through imported feed (i.e., roughage, concentrates, and other feeds), mineral supplements, manure, and livestock. In addition, the N fixation of fields through pulses and grass–clover was computed using empirical data from. We assumed N fixation in grass–clover ley of 18 kg/ha per year for a clover percentage between 1% and 9%, of 78 kg/ha per year for a percentage between 10% and 29%, of 156 kg/ha per year for a percentage between 30% and 49%, and of 248 kg/ha per year for a percentage >49% (Kristensen and Kristensen, 1992). The percentage of clover was estimated visually by one observer. N fixation for pulses was assumed to be 80 kg N/ha per year. Atmospheric N deposition was assumed to be the same for AMS and CMS farms, 16 kg N/ha per year (Ellermann et al., 2005). The NP output was determined by quantifying the amounts of sales of milk and livestock, manure, feedstuffs, and crops. Standard concentrations of N and P were used (Poulsen et al., 2001). The N content of milk, as well as the amount of milk, was taken from the milk delivery registration. A standard P content of milk was assumed. The difference between the NP input and NP output determined the NP surplus, and was expressed per hectare of farmed land.

The field balance was determined only for fields that were fully used for mowing or grazing. The N surplus per hectare of field balance was computed as the difference between the N input and N output. The N input for each hectare was estimated by computing the amount of N applied by manure, the amount of N deposited via feces and urine during grazing, and the N fixation and deposition. The amount of manure applied was registered in the farmers' obligatory mineral account for each hectare of land. In order to estimate the amount of N deposited via feces 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 empirical data for excretion of N per cow based on measured milk yield on yearly basis and milk urea content (Jonker et al., 1998) and deposition related to grazing time (Oudshoorn et al., 2008), the amounts were calculated as shown in Equation 1.

$$\frac{\text{Used time outside (h/day)}}{24\,\text{h}} \times \text{Total excretion in kg N/cow day} \times \text{stocking rate} \times \text{days grazing} \quad [1]$$

N-fixation and N deposition were computed in a similar way as for the farm gate balance.

The N output was computed as the N removed from the field by grass harvested or during grazing. Grass–clover yield per hectare was estimated by combining the farm advisory estimate, which is used to plan manure application, with each farmer's registration of yields, which is used to plan the herd's diet for summer and winter. For crude protein concentration of the grass, an annual average value of 17% was used. Phosphorus was not analyzed in this way, because the low P surplus on organic farms.

3.2.6 Biodiversity

To quantify biodiversity, we used the number of herbal species in selected pasture. On all farms, one field used for grazing and one field used for mowing were sampled. During a visit in August, the number of herbal species in a circular fixed area of 0.1 m^2 was counted at 20 random places covering the whole field. All grass species were counted as one species, and white and red clover were also counted as one species, whereas all other herbs were counted separately.

In addition, average field size and number and area of remnant biotopes with nature value were used to assess biodiversity. Larger fields tend to indicate landscape impoverishment, as field boundaries are often marked by trees, bushes, or other remnant biotopes (Noe et al., 2005). With increasing dimensions of machinery, field enlargement is to be expected, especially when grass–clover is grown mainly for mowing. Average field size for all crops was estimated and used as an indicator. To count nature biotopes, the farm area map was examined and discussed with the farmer, and areas of bush and forest patches were pinpointed and estimated, and length of windbreak was measured.

3.2.7 Labour Circumstances

Many studies on the societal consequences of AMS have assessed labour time, physical hardiness, and flexibility, on the farm (Hogeveen et al., 2004; Jensen, 2004; Oudshoorn et al., 2008). Labour data were acquired by asking the farm manager how much time was used for selected tasks, in relation to dairy cows only, grouped as: milking, fetching and registration; treatment and surveillance; feeding; providing bedding straw in the cubicles; cleaning; and miscellaneous.

3.2.8 Animal Welfare Including Health

Both grazing time and fresh grass intake can affect animal welfare, including health, positively. A decrease in grazing time can be associated with claw and leg problems, reproduction problems, summer mastitis, death of young calves, and the culling of cows Somers et al., 2003). As an indicator for animal welfare and health, therefore, the area available for grazing per cow, the grazing time per day, and the number of grazing days per year a cow spent outside were registered. The area available for grazing was registered using the rotation and crop planning schemes which are also used for applying for EU subsidies, in combination with personal inquiry. The time (hours per day, days per year) a cow was allowed at pasture was obtained by means of an interview.

The indicators connected to health aspects associated with grazing were quantified on all farms, i.e., treatment index for claw problems, mastitis, and reproduction, as well as the total amount of treatments (treatments per cow per year). In addition, the numbers of cows and calves that died per year were registered as well as the culling rate. Veterinary treatment is reported by the vet at individual cow level, and was made available for research purposes. The registrations were sorted for the month of treatment, and calculated for winter and summer periods separately.

3.2.9 Milk Quality Aspects

Indicators selected to assess milk quality aspects related directly to the AMS technique (Meijering et al., 2004) or to grazing (Elgersma et al., 2004; Ellis et al., 2006). The concentration of free fatty acids (FFA) in 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 (Rasmussen et al., 2006). 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 to free fatty acids. The FFA concentration in milk, measured in acid degree value (ADV in milli equivalents per litre [meq/l] of milk), was therefore chosen as an indicator for milk quality. Data on FFA concentration in milk was acquired from a milk composition survey financed by the Danish Dairy Board (Rasmussen et al., 2006).

Furthermore, insufficient hygiene 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 roughage silage causing spores in manure, which in addition can infect teats. When washing of the udder is neglected before the milking process, this can cause high spore concentrations in the milk. The number of spores per litre of milk, therefore, was taken as an indicator of milk quality.

Somatic cell count (SCC) indicates mastitis problems, as well as possible stress and is therefore used as an indicator in this study. Mastitis can be provoked by stress or neglected surveillance, which have both been suggested as possible problems with AMS use (Meijering et al., 2004). SCC counts leucocytes and cows' own udder cells, which are in emulsion 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 was analyzed.

3.2.10 Statistical Analysis

Quantified SI of both farm groups were tested for normality, using the Anderson-Darling test, which is suitable for small sample sizes ($n \leq 25$) (Anderson and Darling, 1952). Subsequently, SI were analyzed by single-factor ANOVA testing the variance and probability for significant differences. Standard deviations were computed for each set of data registered for each SI. Only differences with a P value of <0.05 were considered significant. Correlation between indicators was tested using Spearman's rank correlation and indicated by R^2 value.

3.3 Results and Discussion

3.3.1 General Farm Characteristics

The number of dairy cows per farm did not differ between AMS and CMS farms ($P = 0.76$, see Table 1). All AMS farms raised their own heifers, whereas 2 CMS farms outsourced rearing of young stock in "heifer hotels," and one CMS farm kept heifers during the barn period only. Total milk yield for AMS farms was higher than for CMS farms ($P = 0.003$) measuring 4.5 kg ECM d^{-1}. The percentage of concentrates in the diet was not higher for AMS than for CMS farms ($P = 0.54$). AMS farms, however, did have a lower percentage of fresh grass in the diet compared with 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 on AMS than on CMS farms.

Table1. General characteristics of individual farms with a conventional milking system (CMS) and an automatic milking system (AMS) in 2005 (SD in parentheses)

Parameter	Dimension	Farms with a concentional milking system										
		1	2	3	4	5	6	7	8	9	μ	[5] *P* -value
Dairy Cows	*number*	47	92	90	151	105	131	151	146	160	119 (38)	0.8
Area	*ha*	53	63	182	163	80	120	86	86	215	116 (57)	0.27
Heifers (* not included in average)	*number*	0	61	90	116	54	105	178	0	160	109 (47)	0.6
Stocking rate	*LU* [0] *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* [1] *cow* $^{-1}$ *year* $^{-1}$	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
Fresh grass in summer diet	*% of total diet* [4]	62	51	38	36	39	40	17	mv[3]	mv	40 (14)	0.09
Concentrates in diet	*% of total diet*	27	43	23	32	25	24	26	37	36	30 (7)	0.20
Financiel result [2]	*€ farm* $^{-1}$	12420	85725	151335	90720	52110	134460	194400	159840	225585	122955 (68555)	0.21
Milking Frequency summer	*milkings d* $^{-1}$	2	2	2	2	2	2	2	2	2	2 (0)	<0.001
Milking Frequency winter	*milkings d* $^{-1}$	2	2	2	2	2	2	2	2	2	2 (0)	<0.001
		Farms with an automatic milking system										
Start AMS		sep-99	nov-00	dec-98	feb-03	mar-03	apr-03	apr-03	okt-03	okt-02		
Dairy Cows	*number*	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	*number*	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 cow* $^{-1}$ *year* $^{-1}$	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)	
Fresh grass in diet	*% of total diet*	35	mv[iii]	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)	
Financiel result	*€ farm* $^{-1}$	119610	157815	145125	142695	114345	294165	187920	133245	157275	161355 (54461)	
Milking Frequency summer	*milkings d* $^{-1}$	2.5	2.3	3	2	2.4	2.5	2.1	2.6	2.1	2.4 (0.1)	
Milking Frequency winter	*milkings d* $^{-1}$	2.8	2.5	3.2	2.5	2.8	2.8	2.4	3	2.6	2.7 (0.3)	[6]0.02

[0]LU: livestock unit, corresponds to an excretion of 100 kg N/year. One dairy cow (HF) producing 8,000 kg ECM year is rated as 1.18 LU. One heifer (6–28 months) is rated as 0.38 LU (Danish Enactment 814, 13-07-2006).
[1]ECM: energy corrected milk, milk yield standardized for fat and protein content (see Sjaunja et al., 1990).
[2]Financial result: the gross income (from milk, animals, meat, and other production) minus fixed costs (maintenance, wages, energy) plus unit costs (feed, fertilizer, contract work).
[3]mv: missing value.
[4]Percentage of the total diet: calculated as kilograms of DM.
[5]*P* value between AMS and CMS values.
[6]*P* value for difference between summer and winter milking frequency.

The feed efficiency, computed as total dry matter (DM) offered, divided by DM required in accordance with standard feed requirements for production (Strudsholm et al., 2003), did not differ between AMS and 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 notoriously higher for the AMS farms ($P < 0.001$), but for AMS farms also higher in winter time compared to summer ($P = 0.02$), confirming pasturing induces lower milking frequency (Ketelaar-De Lauwere et al., 2000). It is generally observed that daily milk yield increases by around 3.5 kg/day when shifting from 2 to 3 milkings (Erdmann and Varner, 1995). In this study, milking frequency all year round varied between 2.4 and 2.7 milkings for AMS farms, which can account for a difference in milk yield of 1.9 kg ECM d^{-1} (Erdman and Varner, 1995), indicating the higher milk yield level for AMS compared to CMS farms had other reasons. The milking frequency is 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 (Ketelaar-De Lauwere et al., 2000).

3.3.2 Economic Performance

Annual milk yield delivered to the dairy per cow was higher for AMS than for CMS farms (P = 0.003, see Table 2). However, economic indicators did not differ between AMS and CMS farms. In addition, all costs were calculated per kilogram of milk produced and delivered, but no differences were found between AMS and CMS farms, reflecting the large variation between farms.

Table 2. Mean results of economic indicators for dairy farms with an automatic milking system (AMS) and a conventional milking system (CMS) in 2005 (SD in parentheses)

Indicator	**Dimension**	**AMS**		**CMS**		***P* value**
Milk yield, delivered	[1)]ECM per cow	8,539	(557)	7,302	(880)	0.003*
[2)] Financial result	€ × 1,000	161	(54)	123	(69)	0.21
[3)] Gross margin	€ per cow	2,719	(385)	2,258	(532)	0.27
Unit (variable)costs	€ per cow	1,253	(428)	1,023	(428)	0.24
Fixed costs	€ per cow	1,221	(367)	1,275	(278)	0.73
[4)]Financing costs	€ per cow	620	(259)	723	(329)	0.47
Debts	% of net worth	46	(18)	56	(13)	0.26

[1)] ECM: energy corrected milk, milk yield standardized for fat and protein content (see Sjaunja et al., 1990).
[2)] Financial result is the gross income (from milk, animals, meat, and other production) minus fixed costs (maintenance, wages, energy) plus unit costs (feed, fertilizer, contract work).
[3)] Gross margin is total income per cow minus the unit costs per cow and unit costs for the young stock necessary to maintain the herd.
[4)] Financing costs are interest costs on loans and investments and depreciation.

Fixed costs did not differ between AMS and CMS farms, neither per cow (P = 0.73), nor per hectare (P = 0.48), nor per kilogram of milk produced (P = 0.46). This was rather surprising, as AMS is generally assumed to be costly compared with CMS. Maintenance and service costs can be higher because of technical and novelty problems, and updates. In addition, feeding costs have been reported to be higher per cow on AMS farms (Wegge et al., 2007), but the unit costs per cow measured in this study, which were the same for CMS and AMS farms, do not indicate this. Financial result and gross margin per cow did not differ between AMS and CMS farms. In many other studies not concerned with organic dairy, the AMS farms' economic results were inferior to the CMS farms' results (Rotz et al., 2003; Meijering et al., 2004), although they are mainly based on model studies. Table 1 shows that stocking rate of AMS farms had a tendency to be lower than CMS farms (P = 0.16). Nicholas et al. (2004) found that a low stocking rate was associated with better economic performance. In this study, however, a correlation between financial result and stocking rate was not found (R^2 = 0.01); possibly it was compensated by the above-mentioned negative economic impact of AMS. However, this cannot be concluded from our data.

Model calculations (Veysset et al., 2001; Rotz et al., 2003) found that a moderate herd size (45–120 cows) was associated with better economic performance. Our results (Fig. 1), on the contrary, showed a slight increase in financial result with increasing herd size (R^2 = 0.28), but no difference between AMS farms and CMS farms.

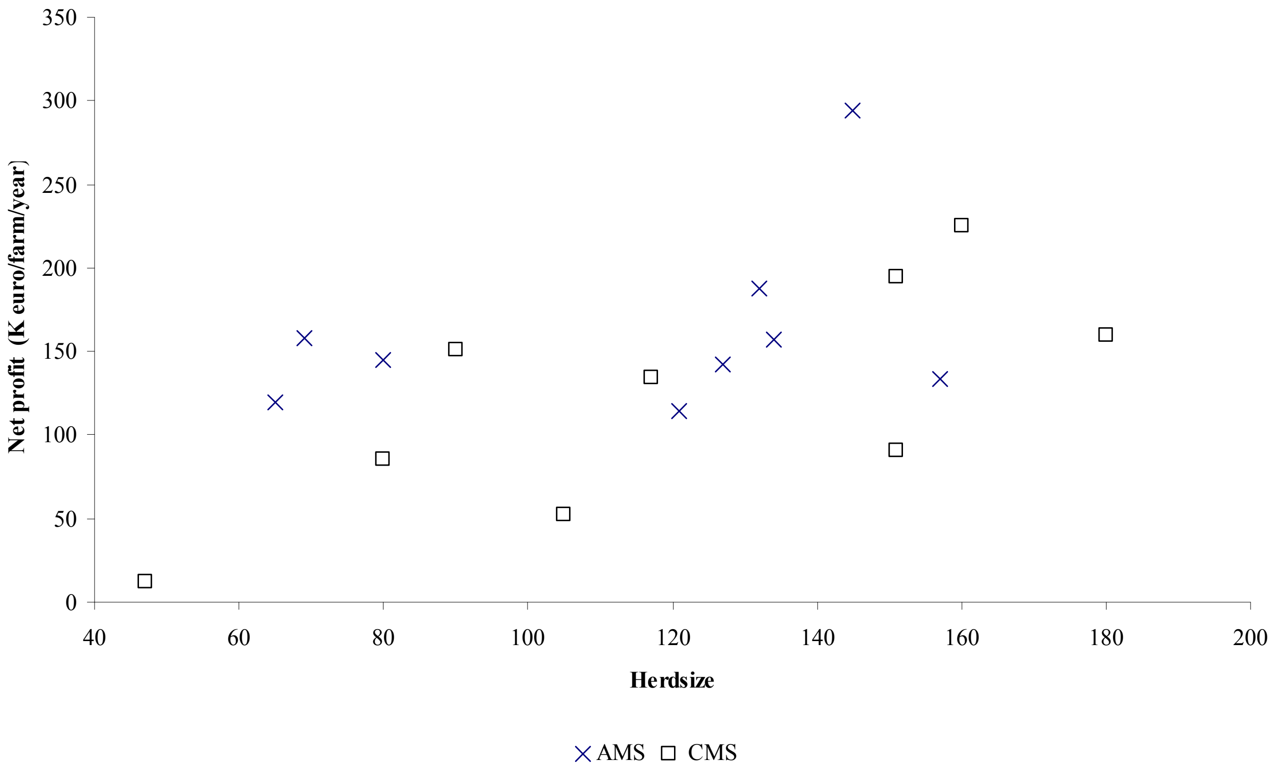

Fig. 1. Financial result in k€ in relation to the number of cows in 9 herds with an automatic milking system (AMS) and 9 herds with a conventional milking system (CMS).

3.3.3 Environment

Eutrophication

The N surplus of 110 kg N/ha for AMS farms was higher than that of 66 kg N/ha at CMS farms (P = 0.02, see Table 3). In addition, the N surplus for grazing fields was lower for AMS than for CMS users (P = 0.05), whereas the N surplus for mowing fields was higher for AMS than for CMS users (P = 0.03).

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

Indicator	**Dimension**	**AMS**		**CMS**		***P* value**
Surplus N at farm level	kg N/ha	110	(29)	66	(40)	0.02
Surplus P at farm level	kg P/ha	8.8	(6.6)	3.4	(8.7)	0.16
Surplus N on grazing fields	kg N/ha	92	(82)	166	(60)	0.05
Surplus N on mowing fields	kg N/ha	148	(79)	53	(80)	0.03
Average field size	ha	5	(1.1)	5.3	(3.8)	0.84
Plant species grazing fields	No/ha	5.4	(1.3)	5.6	(2.1)	0.83
Plant species mowing fields	No/ha	3.4	(2)	2.4	(1.1)	0.20

To explain our obtained results we used general characteristics of sampled farms as presented in Table 1 and parameters registered to capture grazing behaviour at AMS and CMS farms, which are presented in Table 4. It was expected that AMS farms would have a higher N surplus on their grazing fields, because of relatively few pastures around the barn suitable for grazing. However, the area of grassland available for grazing per dairy cow did not differ between AMS and CMS farms (Table 1). The amount of dry matter uptake from grazing, however, between AMS and CMS farms showed a tendency to be different (P = 0.09, Table 1). This was supported by registration of the amount of time cows spent grazing outside, which was higher for CMS than for AMS farms ($P < 0.001$). The fact that cows on CMS farms spent more time grazing outside causes extra N excretion on grazing fields, which explains the higher N surplus on fields used 100% for grazing. Consequently, on CMS farms, less excrement is deposited in the barn, and therefore less manure is applied on mowing fields, explaining the lower N surplus.

Table 4. Parameters registered to capture grazing behaviour.

Dimension	**Parameter**	**AMS**		**CMS**		***P* value**
kg DM/LU	Concentrates fed per LU[1)]	7.3	(1.6)	6.3	(1.7)	0.2
kg dm/day	Grass uptake from pasture[2)]	5.1	(1.6)	6.9	(2.2)	0.09
h/year	Grazing time	968	(198)	2,083	(788)	<0.001

[1)] 1 livestock unit (LU) is in Denmark defined as an excretion of 100 kg N/year; a dairy cow is rated as 1.18 LU. A heifer
(6–28 months) is rated as 0.38 LU (Danish Enactment 814, 13-07-2006).
[2)] Average for the period when the cows are grazing.

The N surplus (Farm based) of 110 kg/ha for AMS farms and 66 kg/ha for CMS farms is low compared with the average N surplus of 108 and 124 kg/ha for 1.1 and 1.3 livestock units (LU, representing N output of 100 kg /ha) per hectare, respectively for organic dairy farms (Knudsen et al., 2006). The stocking rate was on average 1.28 LU for the 9 AMS farms and 1.65 LU for the 9 CMS farms, and no correlation was found between stocking rate per farm and surplus N and surplus P at farm or field level. The most important reason for the relatively small N surplus on CMS farms in this case study was the large amount of manure exported to organic vegetable and crop growers. Due to maximum limits for use of manure originating from non-organic husbandry, these farmers are anxious to collect organic manure. The difference in net export of N via manure between CMS and AMS farms was 40 kg N/ha ($P = 0.03$), which is almost identical to the difference in N surplus between farm types. No explanation can be found for the difference in manure export between AMS and CMS farms.

Biodiversity

The average field size did not differ between 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 AMS and CMS farms. Even though AMS farms have a similar grazing area per cow as CMS farms, fresh grass contributed less to their total diet. The fact that cows spent less time grazing on AMS farms, however, did not affect the biodiversity of flora in these fields (Table 3), probably because only 100% grazed fields were sampled, which means other fields available for grazing has 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 a biodiversity indicator. 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 many nature biotopes along canals or creeks or as rough land. In addition, the presence of wind-breaking hedges is dependent on the geographic situation. To quantify indicators on biodiversity of landscape, a pair wise selection focusing on soil and landscape is necessary, and therefore the present results are not informative.

3.3.4 Society

Milk Quality

Acid degree value (ADV) of milk was higher on AMS than on CMS farms (Table 5). Milk flows lower than 10 kg per milking have been reported to have increasing effects on ADV (Rasmussen et al., 2006). Although this was lower for the AMS farms than for the CMS farms, the level is not considered to be the cause. The higher FFA level of AMS farms has been reported also for conventional milk production (Rasmussen et al., 2006). The average ADV of the 9 organic AMS farms of 0.78 mEq/l milk is considerably lower than the average of 0.88 mEq/l milk for all AMS farms ($P < 0.001$) (organic and conventional) analyzed in 2005 (Rasmussen et al., 2006).

Table 5. Mean milk quality indicators for dairy farms with an automatic milking system (AMS) and with a conventional milking system (CMS) in 2005 (SD in parentheses)

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

[1)] SCC: Somatic cell count.

Urea content in milk did not differ between 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 uptake in summer and autumn was higher at CMS than at AMS farms (Table 4), and especially because autumn grass usually contains more protein than grass silage.

Somatic cell count (SCC) did not differ between AMS and CMS farms for milk recording in the barn ($P = 0.33$) and milk delivered at the dairy ($P = 0.83$). A slightly higher SCC at AMS farms has been reported (Meijering et al., 2004) but, as in our results, the level is not critical, addressing standards for Danish dairy where a SCC value between 300 and 400×10^3 per ml is price-neutral and assumed to be safe for human consumption.

Fat and protein percentage in milk were equal at 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 (1995) state in their survey that going from 2 to 3 milkings a day reduces the fat percentage by a value of 0.14 and the protein percentage by a value of 0.06. In winter, AMS farms' milking frequency is on average 0.7 higher ($P < 0.001$) than CMS farms but fat percentage is not lower for AMS farms than for CMS farms (Table 5). On AMS farms, fat percentage increases from 3.8% in summer to 4.1% in winter ($P = 0.06$), even though the milking frequency increases from 2.4 to 2.7 milkings per day. This shows that, besides milking frequency, other factors, such as diet, influence fat percentage.

Danish dairy industry reduces the milk price when *Clostridium* spores exceed 400×10^3 per litre of milk. The high value for AMS farms in the summer was caused by 2 farms with severe spore problems.

Animal Health

Culling rate was found to be 19% higher at AMS farms than at CMS farms. No other health effects were registered as a result of AMS use compared with CMS use (see Table 6). In general, this is also concluded in the extensive global survey presented at a symposium on worldwide AMS use (Meijering et al., 2004).

Table 6. Mean results of health indicators for dairy farms with an automatic milking system (AMS) and with a conventional milking system (CMS) in 2005 (SD in parentheses)

Indicator (per dairy cow)	**AMS**		**CMS**		***P* value**
Claw treatments (summer)[1)]	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)	0.23	(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[2)] 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)	0.66	(0.43)	0.21
Dead cows per year (%)	3.9	(1.74)	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	(3.25)	5.7	(2.5)	0.22
Culling rate (%)	38	(6)	32	(5)	0.05
Vet costs (€ per cow per year)	86	(44)	60	(31)	0.17

[1)] Summer was May–October.
[2)] Sum comprises more than the 3 treatment groups mentioned in this table.

A higher culling rate at AMS farms might be due to the fact that these farmers do not accept cows that have 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 robot or peculiar teat positions and udder shape (Østergaard et al., 2002) 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. The average culling rate for all organic farms (AMS + CMS) was 34% in 2005 (Danish Cow Federation statistics, DCF, 2005).

The total of 0.88 treatments per cow per year for AMS farms seems higher than 0.65 for the CMS farms (Table 6), but the large standard deviation, again reflecting the variation between farm management systems, shows no statistical difference ($P = 0.21$). The value of 0.88 treatments per cow per year at AMS farms was close to the average value of 0.84 for all registered conventional dairy farms ($n = 4{,}512$) in 2005 (DCF, 2005), whereas the average of all registered organic dairy farms ($n =$

535) in 2005 was 0.64 (DCF, 2005). High milk yield accompanied by stress is often mentioned as a reason for increasing health problems. At CMS farms, milk yield explained 45% of the treatment index, but no correlations between specific health indicators (such as mastitis) and milk yield were found. Among AMS users, no correlation between milk yield and treatment index was found ($R^2 < 0.01$). The treatment of mastitis explicitly comprises the major part of all veterinary treatments for AMS and CMS farms. The sum of treatments primarily influenced by grazing was 0.70 per cow per year for AMS farms and 0.63 for CMS farms. One would expect that the extra time spent outside by CMS herds (2,083 h versus 968 h per year) would show positive health effects (Somers et al., 2003; Munksgaard and Søndergaard, 2006), but this was not the case.

At AMS farms 3.9% of the cows died per year. The average for all organic herds in 2005 was 4.1%. Among the 9 CMS farms, 2.7% of the cows died in 2005. Thomsen et al. (2006) found a positive relation between "loser cows" and zero grazing, and a higher death rate among "loser cows". Much longer grazing time (Table 4) among CMS users, did not influence the death rate consistently ($P = 0.16$).

Labour

In this study, AMS farms used on average 3 min per cow per day, whereas 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. Extension services in Denmark registered that 15 months after introduction of an AMS, farm management had adjusted totally to the new situation. In addition, most AMS farms have increased their herd size at the same time as they invested in AMS, and previous labour time registrations have found that larger farms saved relatively more time when using AMS. This could not be supported by our results (Fig. 2).

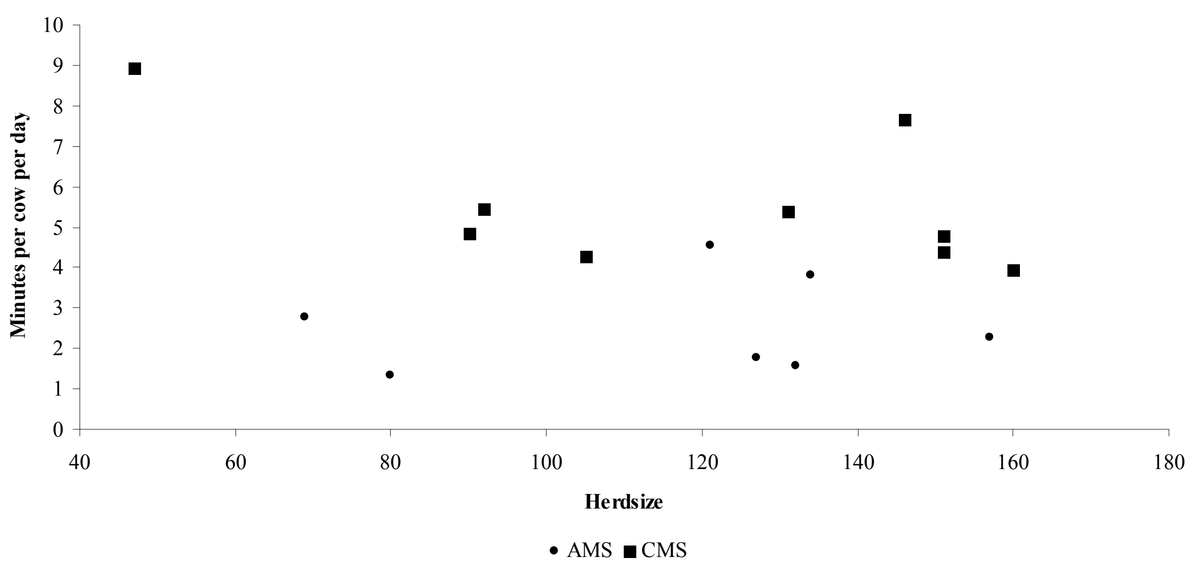

Fig. 2. Labour time related to herd size for organic dairy farms using automatic milking systems (AMS) and conventional milking systems (CMS).

An inquiry made on motivations to invest in new technologies on dairy farms concluded that saving labour time and relief of physical hardship were the most important, even more important than economic profit (Jensen, 2004). Results of this investigation clearly show this objective is fulfilled, 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, simply because it would have been impossible to find suitable labour. Labour time related to herd size showed slightly different correlations between labour time used per cow and herd size at AMS and CMS farms.

General

One of the problems with analyzing on-farm indicators is the variation between individual farms, which can be very large and are often larger than between the 2 defined systems, illustrated in this paper by hardly any significant differences being found between the 2 groups. This problem occurred even though we had tried to minimize some of the known causes of variation by selecting only one breed and choosing farms which did not differ much in herd size. Other factors such as management, educational background, or nature advantages might also be involved. By relating the AMS indicator values to general target values available on eutrophication, and some health and some milk quality indicators, it might be possible to draw conclusions about general EES issues of sustainability. A larger sample size would have made the relative validation to CMS users better; but large individual variations can always be found in on-farm research and make it difficult to generalize the results.

3.4 Conclusions

On basis of previous studies it was expected to find differences in sustainability aspects concerning economic performance, eutrophication and parameters expressing or presenting grazing behaviour between organic dairy farms using AMS contra CMS. This was addressed by quantifying selected indicators. N surplus per hectare and grazing time were significantly different. N surplus per hectare at farm level was independent of stocking rate and milking system, but related to the amount of manure imported to or exported from the farm. Large variations within the groups of AMS and CMS farms meant that only the greatest differences between the groups resulted in statistical significance. On farms using conventional milking systems, the cows were outside for longer periods, resulting in a slightly larger intake of fresh grass (7 kg DM/day compared with 5 kg DM/day; $P = 0.05$). There were, however, no direct health indicators or milk quality indicators affected by the extra grazing time of fresh herbage intake.

Additional differences were found between the farms using AMS and CMS. AMS farms saved almost 50% labour time per cow, compared to CMS farms, the milk yield per cow was higher (8,539 kg ECM per cow per year compared with 7,302 kg ECM) and the culling rate was higher (38% compared with 32% for CMS farms).

FFA was higher in milk from AMS farms, although lower than in milk from conventional farms milking with AMS. High FFA might give lower milk price in the nearby future and thus influence economic performance negatively.

Taking in account that the selected indicators were the result of participative research in possible threats when using AMS on organic farms, it can be concluded from our results of quantification that the organic dairy farms using AMS, in spite of the substantial decrease in grazing time, show the potential for sustainable development, in line with the organic farms using CMS. Even though the shorter grazing time did not result in measurable differences for the indicators concerned, the shorter grazing period itself, might be a societal problem for consumers to accept AMS. Higher milk yields, shorter labour time and higher culling rates for AMS users, indicate different management focus which could be classified as intensification.

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Chapter 4

Dairy Cow Defecation and Urination Frequency and Spatial Distribution in Relation to Time-limited Grazing

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Abstract

The objective of this paper was to investigate the effect of limited grazing time on urination and defecation frequency, spatial distribution of excrement in the paddock, and the resulting nitrogen balance at animal and field level. During a 6-week period in early summer, 60 Holstein Frisian dairy cows (31.0 ± 5.4 kg ECM) were randomly allocated to three different treatments, with grazing at clover-grass pasture during daytime for 4, 6.5 or 9 hours daily. Indoor feeding, with a mixture of roughage and concentrates (13% crude protein), was restricted for treatment 4 and 6.5 h to the amount the 9 h treatment could eat. Cows allowed grazing at pasture for 4 h moved more rapidly during pasture, moved longer distance per active hour and used a higher proportion of the time eating, both at pasture and indoor, than the cows allowed longer time at pasture. Limiting the grazing time had no influence on the urination (mean=0.26) and defecation (mean=0.37) frequency per cow per hour during pasture. Even though the proportion of time active (eating, drinking, standing or walking), and the actual time active during pasture was different for the treatments, the frequency of urination and defecation per active hour was also unaffected by the treatments. Urine and faeces were distributed in the pasture, without specific hotspots. The estimated daily N balance at animal level showed increased N excretion with time at pasture. Assuming that excretion follows the active periods during the day and 7000 kg DM foliage is available on yearly basis, this would result in total excretion at field level of 58, 86 and 108 kg N per ha respectively for treatment 4, 6.5 and 9 h. The results of this experiment show that it is possible to reduce the nitrogen excretion in a grazing system by restricting the grazing time of dairy cows together with restricted indoor feeding while maintaining high foliage intake.

Key words: *Time-limited grazing; Nitrogen excretion; Urination frequency; Defecation frequency; Spatial distribution; Time budget*

4.1 Introduction

Pasturing high-yielding dairy cows increases the potential risk of nitrate leaching, in comparison with zero grazing and barn feeding of roughage (Eriksen et al., 2004). Surplus nitrogen can be high because of high stocking rates, excessive fertilization without taking animal manure deposition in account, or the presence of 'hot-spots' (non-uniform excretion), where animals gather and tend to urinate or defecate more than average (Eriksen and Kristensen, 2001; White et al., 2001; McGechan and Topp, 2004). High stocking rates could arise due to shortage of land around the barn. The demand for documentation of mineral budgets, the extra labour necessary to pasture the cows, and also the lack of an economic incentive, are often given as the reasons for dairy farmers to decrease grazing or abandon it altogether (Pol-Van Dasselaar et al., 2002). This is increasingly causing the dairy farmers to have an image problem, as many consumers connect dairy cows with grazing. In addition, a direct correlation has been found between cow health and outdoor movement of the cows (Somers et al., 2003). Institutional activity gives us reason to believe that obligatory pasturing at summer time might be a future requirement in Denmark (Anonymous, 2006), as it already is in Sweden. A challenge for the future is to design grazing systems that accommodate the varied demands of animals, farmers, consumers and the environment. It has been suggested that time-limited grazing could be a way to reduce nutrient surpluses (Van Duinkerken et al., 2000). Earlier experiments indicate that roughage uptake per hour of grazing time can be increased by limiting the grazing time to a restricted period, thereby still providing the animals with satisfactory amounts of fresh grass (de Visser and Valk, 2004). Research on continuous day and night grazing (24 h) gives some information on the relationship between the time that highly productive dairy cows are grazing, and urination and defecation deposition (White et al., 2001). Only a few investigations have been made on the spatial distribution of urine and faeces in a grazing environment (Franzluebbers et al., 2000; Eriksen and Kristensen, 2001; White et al., 2001). In order to study spatial distribution and frequency of urine and faecal manure with varying grazing times, a grazing experiment was conducted.

The main objective of this experiment was to investigate the effect of limited grazing time on the frequency and distribution of urination and defecation in relation to the nitrogen balance at animal (cow) and field level. The research aimed to generate management solutions for how and when to graze, in order to decrease the risk of leaching of nitrogen (N) from the grazed areas.

4.2 Materials and methods

4.2.1 Design

The experimental treatments were imposed for 6 weeks in the period from 9 May until 19 June 2005. Sixty Holstein Frisian cows, averaging 31.0 ± 5.4 kg energy-corrected milk (ECM) and live weights of 592 ± 62 kg (mean ± SD) were randomly allocated to three treatments, P4, P6.5 or P9, representing 4, 6.5 or 9 h at pasture, with grazing starting at 06:30 hours for all treatments. Energy corrected milk (ECM) was calculated according to Sjaunja et al. (1990). Each group of cows was grazed in separate paddocks and housed separately in a cubicle system with slatted floors during the remaining part of the day. The same amount of supplement was fed on a daily basis in each treatment. The actual amount was adjusted according to the *ad libitum* intake in treatment P9 the previous day Production results of this experiment are presented by Kristensen et al. (2007).

4.2.2 Sward and herd management

Three fields were divided into three paddocks of 1.5 ha each, of which 0.5 ha was used as a buffer area. Each field was located in a different direction from the barn, with average distances of 300, 1000 and 1100 m to the entrance of the three paddocks in each field. There was no visual contact between the three groups of cows either during grazing or from the races between the barn and each paddock. Each paddock was only grazed every third day and always by the same group of cows. This design was chosen in order to obtain replications at field level without introducing bias between treatments and fields. The area of each paddock was adjusted to keep a sward height of 8 cm in the grazed part of the paddock. The pastures consisted of mixed grass swards dominated by perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.). The average proportion of white clover was 24%, 31% and 22% in treatments P4, P6.5 and P9, respectively. One of the fields was fertilized with 35 t slurry ha^{-1} (135 kg total N) at the beginning of April, while no fertilizer was given to the other fields. Following a predetermined route, herbage samples were collected in each paddock, three times during the experiment, by hand-plucking the herbage at the height at which cows were observed to graze. The herd was milked at 04:30 and 15:30 hours, with the cows in treatment P9 being milked last at the evening milking. After the morning milking, the cows were automatically separated when passing through the weighing box (by a forced gate system) into three groups (treatments P4, P6.5 and P9) and moved to their own field at approximately 06:30 hours. They returned to the barn at approximately 10:30, 13:00 and 15:30 hours in each of the treatments, respectively.

The cows had access to supplementary feed mixture immediately after coming into the barn, although for treatment P9 this was after evening milking, as this group was milked directly after they were taken in. The mixture consisted of (on a dry matter (DM) basis) rolled oats (42%), clover–grass silage (25%), maize silage (22%), rolled lupine (10%) and a mineral mix (1%). The mean DM content was 45% and energy concentration was 6.7 MJ net energy of lactation (NEL) per kg DM, with a nutrient concentration in DM of 13% crude protein (CP), and 34% neutral detergent fibre (NDF). Intake of supplement mix was measured at group level each day, by determining the difference between kg of leftovers and kg of the mix offered. Herbage intake was estimated from animal performance data at group level, as the intake of the indoor feed was registered at group level. The energy requirements were estimated for maintenance, including grazing activity, lactation and live weight change in MJ per day as described by Macoon et al. (2003).

4.2.3 Behaviour

Behaviour outdoors was observed by scan sampling and recording the activity of each cow every 10 min, for 3 days of pasturing periods spread over the 6 weeks of the experiment. All treatments were observed the same day. Behaviour was classified as lying down, grazing, walking, standing or drinking. The observations were used to calculate the percentage of time spent on each activity. In the barn the activity of the cows was recorded with a camera, which took pictures every 10 min. The observations were classified as lying down, eating, standing/walking or drinking. In conjunction with the paddock observations, the behaviour observations were used to calculate the percentage of time spent on each activity.

4.2.4 GPS logging of defecation and urination

A hand-held GPS navigator (Garmin®, eTrex Venture) with an estimated accuracy of 5 m was used on two separate days for all three treatments, to register all urinations and all defecations. This was done by observation during the whole of the grazing periods of 4, 6.5 and 9 h for each treatment for 2 days. All loggings were shown in real time and were classified as being urine or manure. Additionally, on three separate days for each treatment, every 10 min for a period of 5 min, the number of defecations and urinations were registered. Each paddock was virtually divided into 10 equal areas, numbered from 1 to 10, to register the spatial distribution. The quadrate containing the drinking trough and entrance was numbered as 1. The spatial distribution of manure and urine was scored in relation to the quadrates.

4.2.5 GPS logging of cow traffic and calculations

During the trial, three different cows were equipped with a neck collar, TU400 GPS Tracker (Blue Sky, Telemetry®), from which the data were downloaded and used to generate and calculate the cows' route, distance walked and velocity. To test whether the movement behaviour was different between the grazing treatments P4, P6.5 and P9, the frequency at which the cow exceeded the velocities 0.5 m s^{-1} and 1.0 m s^{-1} was estimated and compared for the three treatments. The cows wearing the collar were carefully chosen as being average in milk yield and observed behaviour. The accuracy was documented within 5 m for each logging point. The tracker was programmed to log every minute and to give a position when sufficient satellites (at least five) could be contacted. If this could not be established, the observation was recorded as 'no position'. On days when more than 10 consecutive minutes had 'no position', the data were discarded. The registering days for defecation and urination (registered with GPS Garmin®), were scheduled to coincide with the collar registrations in the same field. As the weather is known to influence cows' grazing behaviour and urination/defecation frequency, climate data (precipitation, minimum temperature, maximum temperature and average temperature) were registered and implemented. The calculations of average velocity and frequency of walking velocity exceeding 0.5 and 1.0 m s^{-1} were made on the basis of 4 days of registration.

4.2.6 N balance and slurry production

The nitrogen (N) balance was calculated per cow per day, and was based on the assumption that:

$N_{excreted} = N_{feed} - (N_{milk} + N_{weight\ gain})$

where

$N_{excreted} = N_{urine} + N_{manure}$

$N_{feed} = N_{herbage} + N_{supplement}$

N_{milk} = milk crude protein produced in g day^{-1}/6.36

$N_{weight\ gain}$ = weight gain in g $day^{-1} \times 26/1000$

$N_{herbage}$ and $N_{supplement}$ = crude protein intake in g day^{-1}/6.25

All formulas and calculation factors are from Poulsen and Kristensen (1998).

Protein intake and output were calculated on the basis of the analysis results of herbage, barn supplementary feed, and milk, combined with estimated herbage intake by grazing, and measured supplement intake in the barn, milk production and daily weight gain, which are presented in

Kristensen et al. (2007). Indoor excretion of urine and faeces during the trial was collected in a slurry tank. The production was estimated by gain in the tank over 6 weeks. The slurry collected originated from all cows in all the grazing treatments, being indoors at various time intervals. The slurry was analysed for nitrogen, and the total amount of nitrogen excreted per day per cow indoors was calculated from total N collected divided by average daily number of cows.

4.2.7 Statistical analysis

The defecation and urination frequencies were tested by analysis of variance (ANOVA). The behavioural classifications in the field and barn were analysed with treatments as experimental factors (ANOVA). The spatial distribution of urine and manure was tested statistically using the chi-squared goodness-of-fit test (Snedecor and Cochran, 1989) comparing the observed data with the hypothesis of a uniform or similar distribution in the 10 segments. Analysis results giving P values less than 0.05 were regarded as significant. LSD values were calculated to show possible bilateral correlations. As statistical analysis of the estimate for N surplus is not possible, an evaluation of possible effect of errors in the calculation and consequences for the results are discussed.

4.3 Results

4.3.1 Swards

Mean sward height, herbage allowance and sward quality showed no differences between treatments in any of the parameters, except for the proportion of rejected area, which decreased with period at pasture allowed. The paddocks in treatment P4 had a larger area containing rejected grass (14%) than the other two treatments (8% and 7%). The paddocks were adjusted in size to guarantee grass length, and by the end of the experiment the adjusted area for the three paddocks in each treatment was 3.0, 3.8 and 4.1 ha for treatments P4, P6.5 and P9, respectively. During the whole period, the average grass length of the grazed area stayed well above 8 cm.

4.3.2 Urination and defecation frequency

The dairy cows urinated and defecated on average for all treatments 0.26 and 0.37 times per hour in the field, respectively (Table 1). The cows were not affected by the different grazing times in their frequency of urination or defecation per hour ($P > 0.126$), whether in the field or for hours active in the field. Both in relation to total time and active grazing time, the results showed that the frequency of defecation (average for all treatments 0.37) was higher than the frequency of urination (average for all treatments 0.26; $P = 0.009$). Only defecation was observed when the cows were walking in the races. Defecation per hour per cow in the races was generally higher and varied more than during grazing (Table 1).

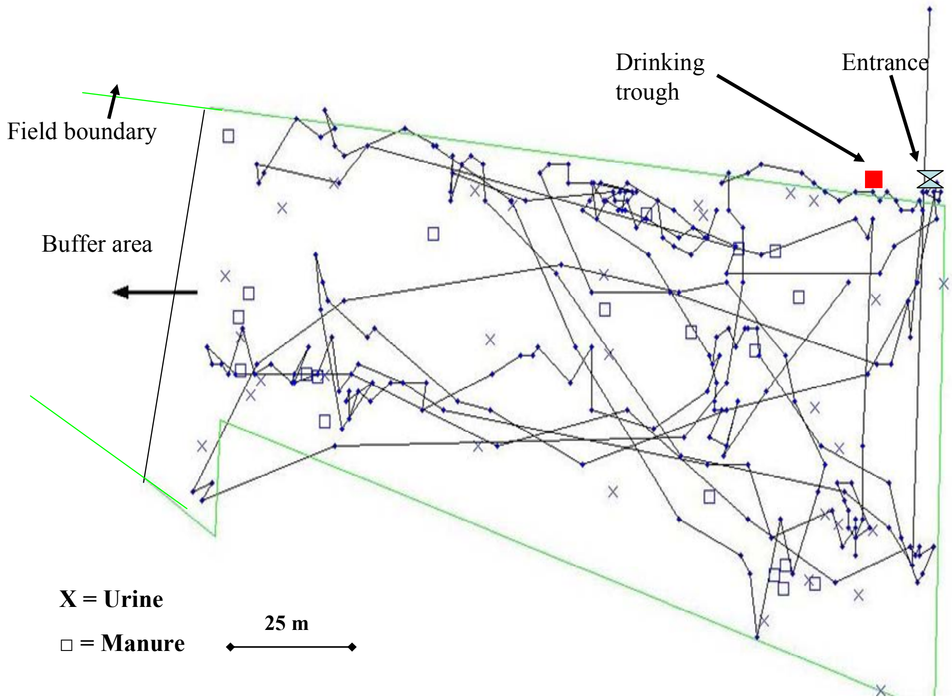
Table 1. Frequency of urination and defecation as a result of three different grazing times.

Treatment	P4	P6.5	P9	*P* value
Hours at pasture	4	6.5	9	
Active hours at pasture	3.7	5.8	7.1	
Results from GPS				
Manure patches per hour per cow	0.28	0.21	0.33	0.126
Urine patches per hour per cow	0.30	0.19	0.26	0.713
Results from visual observations				
Manure patches per hour per cow	0.41	0.48	0.42	0.735
Urine patches per hour per cow	0.30	0.28	0.24	0.773
Average GPS and visual				
Manure patches per hour per cow	0.36	0.37	0.38	0.947
Urine patches per hour per cow	0.29	0.25	0.25	0.720
Average per active hour				
Manure patches per hour per cow	0.38	0.42	0.48	0.571
Urine patches per hour per cow	0.31	0.27	0.31	0.807
In the races				
Manure patches per hour per cow	1.30	0.69	0.59	0.257

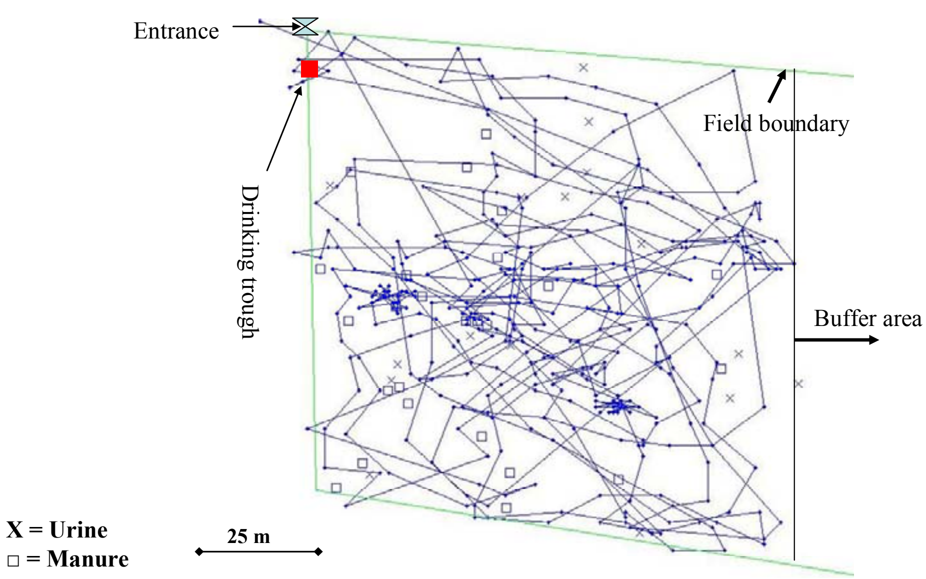
4.3.3 Spatial distribution of excrement

GPS-logged positions of urinations and defecations (Figure 1) showed the spatial distribution. Defecations in treatment P9 and urinations in treatment P6.5 were distributed uniformly between all quadrates. In the other treatments the urinations and defecations were not distributed uniformly ($P< 0.05$) but the results show they were spread among all quadrates without specific hot spots (Table 2). Distribution of urinations and defecations were tested for similarity in the three grazing treatments P4, P6.5 and P9 and no correlation between the spatial distribution of urine and faeces in the paddocks ($P < 0.002$) was found. In the 9-h grazing treatment (P9) the faeces and urine distribution were tested for similarity in distribution with the lying down areas (Table 3). This was not found.

Treatment P4, 4 hours of grazing,
from 6.30 -10.30.



Treatment P6.5, 6.5 hours of grazing
from 6.30 – 13.00.



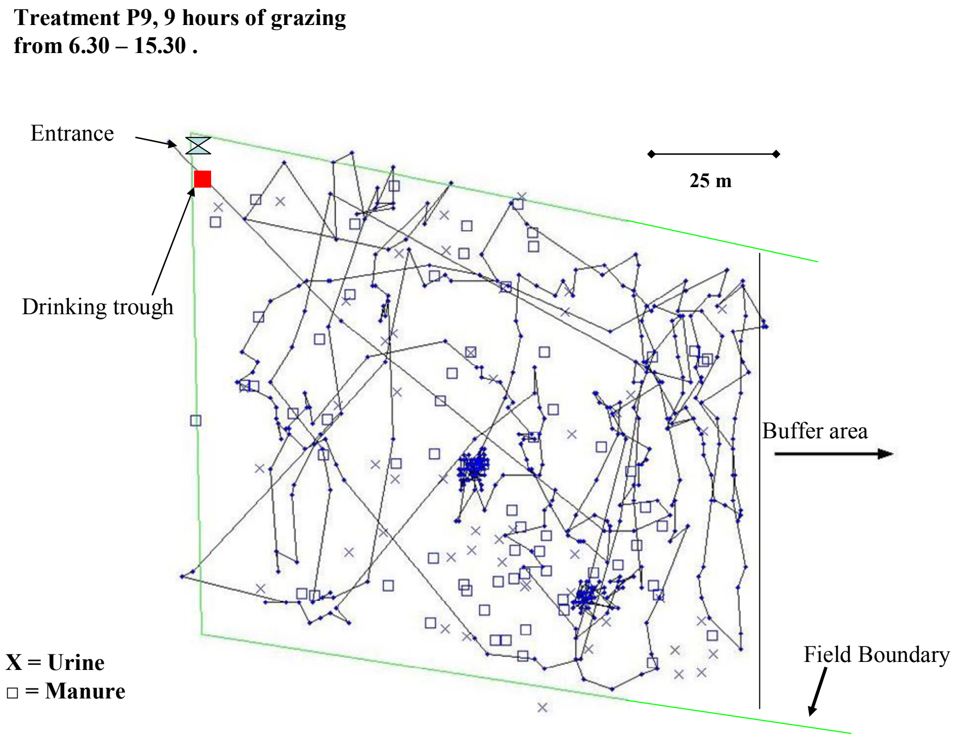


Fig 1. Route of one cow together with excrement (urine and faeces) patches from 20 cows during the same period on the same day.

Table 2. The faeces and urine depositions per day, for 20 cows in 10 quadrates of 0.1 ha, for three grazing treatments, P4 (4 h), P6.5 (6.5 h) and P9 (9 h), as mean of 5 days

	Faeces			Urine		
Treatments	**4h**	**6.5h**	**9h**	**4h**	**6.5h**	**9h**
Quadrate**1	3.8	2.8	8.4	3.6	2.8	4.4
2	2	7.8	6.6	2.2	4	7.6
3	0.6	4.4	7.6	2	3.4	5.6
4	2	3.8	4.6	0.6	2.6	3
5	2.8	5.6	8.2	1.6	2.8	3.2
6	3.2	4.6	6.4	4.2	3.8	2.6
7	2.6	2.8	6	2.6	3.6	4.4
8	3.2	3.4	9	1.8	2.2	6.6
9	3.6	7.8	7	2.4	2.8	3
10	4.6	5.6	5	2.2	4	4
P value*	0.02	<0.05	0.13	0.02	0.76	0.05

* *P* value for uniform distribution between the quadrates. < 0.05 means no uniform distribution.
**Quadrates 1 and 10 close to drinking trough, 5 and 6 furthest away.

Table 3. Total number of defecations and urinations, and lying down frequency summarized (amount of cows lying down every 10 minutes) on 2 separate days for 20 cows in 10 quadrates of 0.1 ha in pasture for 9 h.

	Lie down		**Faeces**		**Urine**		**Faeces + urine**	
Date (June)	**2nd**	**16th**	**2nd**	**16th**	**2nd**	**16th**	**2nd**	**16th**
Quadrate** 1	3	0	3	1	3	0	6	1
2	0	16	4	4	6	1	10	5
3	0	8	6	5	3	6	9	11
4	0	6	1	6	0	2	1	8
5	0	75	2	16	0	5	2	21
6	0	90	2	8	2	1	4	9
7	8	15	1	5	2	3	3	8
8	11	0	3	3	2	1	5	4
9	15	0	3	0	0	0	3	0
10	0	0	0	0	1	0	1	0
P value*			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

* *P* value for similar distribution between the quadrates for faeces + urine frequency and laying down registrations on the same day.

**Quadrates 1 and 10 close to drinking trough, 5 and 6 furthest away.

4.3.4 Walking pattern and velocity of dairy cows

The movement patterns showed that when cows entered a field, they first walked to the far end, before more slowly, during grazing, going back. The results showed that the total distance walked by the observed cows was not different for the three treatments ($P = 0.09$; Table 4). The differences in average velocity clearly showed the increasing activity for the grazing treatments (P4 > P6.5 > P9). When correcting for the active hours instead of the total amount of hours in the field, the distance per hour the cows walked in the different treatments was significantly different ($P < 0.003$; Table 4). The range in velocity was calculated to investigate whether the movement patterns for the observed cows were different for the grazing treatments (Table 4). The frequency with which the treatments exceeded 0.5 and 1.0 m s^{-1} was calculated per hour. The biggest differences were registered between the P4 (4 h) and P9 (9 h) treatments.

Table 4. Velocity and distance walked daily per dairy cow for three pasturing treatments (P4, 4 h; P6.5, 6.5 h; P9, 9 h), all starting at 06:30 hours.

Treatments	**P4**	**SE***	**P6.5**	**SE**	**P9**	**SE**	***P*******
Active hours at pasture	3.7		5.8		7.1		<0.05
Average velocity (m s^{-1})	0.30[a]	0.01	0.25[b]	0.03	0.16[c]	0.02	<0.001
Average distance (m)	4362	193	5746	616	5670	357	0.09
Average distance per active hour (m)	1179[a]		991[ab]		799[b]		0.003
Frequency per hour exceeding 0.5 m s^{-1}	10.1[a]	0.6	6.7[b]	1.3	4.0[b]	0.5	0.003
Frequency per hour exceeding 1.0 m s^{-1}	5.0[a]	0.5	1.9[b]	0.5	1.8[b]	0.3	<0.001

* Standard error.
** *P* value for the difference between treatments.
[abc] Means within a row and category bearing different superscript letters differ ($P < 0.05$) calculated as LSD between each treatment.

4.3.5 Time budget

The 24-h time budget, where barn observations were combined with the in-field registrations, shows how long the cows were active, as a percentage of their total time (Table 5). The difference in active time in the paddock (92%, 89% and 80%, respectively, for treatments P4, P6.5 and P9) was almost compensated for by their time disposal in the barn (Table 5) and resulted in a total lying time of 10, 9.8 and 10.6 h, respectively, for the grazing treatments P4, P6.5 and P9. The total eating time per day, summing up the eating time in the field and in the barn, was 6.7, 7.3 and 7.9 h for treatments P4, P6.5 and P9, respectively.

4.3.6 N-balance

From the production results of this experiment given by Kristensen et al. (2006), the nitrogen balance at herd level was calculated for each treatment. The inputs (Table 6) were derived from supplementary feed in the barn and the estimated herbage dry matter intake (DMI) in the field, and the outputs from the milk yield and live weight gain. The amount of supplement eaten throughout the experiment was, 8.8 kg DM cow^{-1} day^{-1} for treatment P9 and 9.3 kg DM cow^{-1} day^{-1} for treatments P6.5 and P4 (SE = 0.16). The average milk crude protein yields were 970, 1022 and 1067 g cow^{-1} day^{-1} (SE = 23) for treatments P4, P6.5 and P9, respectively. The live weight changes were 32, 233 and 382 g cow^{-1} day^{-1} (SE = 144) for P4, P6.5 and P9, respectively. Digestible organic matter of the herbage was 752 g kg^{-1} dry matter (DM); CP for herbage samples was 179 g kg^{-1} DM^{-1}, without any significant differences between the treatments. The estimated DMI of grazed herbage cow^{-1} day^{-1} was 10.3 kg, 11.5 kg and 12.7 kg for the treatments P4, P6.5 and P9, respectively.

Table 5. Time budget for dairy cows as a proportion of 24 h for three treatments (P4, 4 h; P6.5, 6.5 h; P9, 9 h) within paddock, races, barn and milking process.

Treatment		**P4**		**P6.5**		**P9**		
		%	**%**	**%**	**%**	**%**	**%**	***P***
Paddock		17		27		38		
a	Lie down		8^{a}		11^{b}		20^{c}	P<0.001
b	Eat/drink		84^{a}		77^{b}		65^{c}	P<0.001
c	Walk/stand		8^{a}		12^{b}		14^{c}	P<0.001
b + c	Active		92^{a}		89^{b}		80^{c}	P<0.05
Races		2		2		2		
	Walk		100		100		100	
	Active		100		100		100	
Barn		73		63		52		
a	Lie down		56^{a}		60^{a}		69^{b}	P<0.05
b	Eat/drink		18^{a}		14^{b}		15^{b}	P<0.05
c	Walk/stand		26^{a}		26^{a}		16^{b}	P<0.001
b + c	Active		44^{a}		40^{a}		31^{b}	P<0.001
Milking process		8		8		8		
	Walk/stand		100		100		100	
	Active		100		100		100	
Total		100		100		100		
a	Lie down		42		41		44	*
b	Eat/drink		28		30		33	*
c	Walk/stand		30		29		23	*
b + c	Active		58		59		56	*

[abc] Means within a row and category bearing different superscript letters differ ($P < 0.05$) calculated as LSD between each treatment.

* *P* value was not calculated as the observation methods in paddock and barn were different and correlated.

The estimated nitrogen intake was highest for treatment P9, followed by P6.5 and P4. Nitrogen intake resulting from supplementary feeding in the barn was almost the same for all treatments, while N intake from herbage was different. This resulted in an estimated surplus of 317, 351 and 367 g N cow^{-1} day^{-1} (Table 6) for treatments P4, P6.5 and P9, respectively. Based on the registration of indoor deposition, the daily nitrogen excreted in the barn during the trial was estimated to be 163 g N cow^{-1} day^{-1}.

Table 6. Nitrogen (N) balance at cow level estimated for three pasturing treatments (P4, 4 h; P6.5, 6.5 h; P9, 9 h) in g N cow^{-1} day^{-1}

Treatment	**P4**		**P6.5**		**P9**	
	Input	Output	Input	Output	Input	Output
Supplements	186		186		176	
Herbage	285		331		369	
Milk		153		160		168
Bodyweight		1		6		10
Sum	471	154	517	166	545	178
Surplus		**317**		**351**		**367**

4.4 Discussion

4.4.1 Urination and defecation frequency

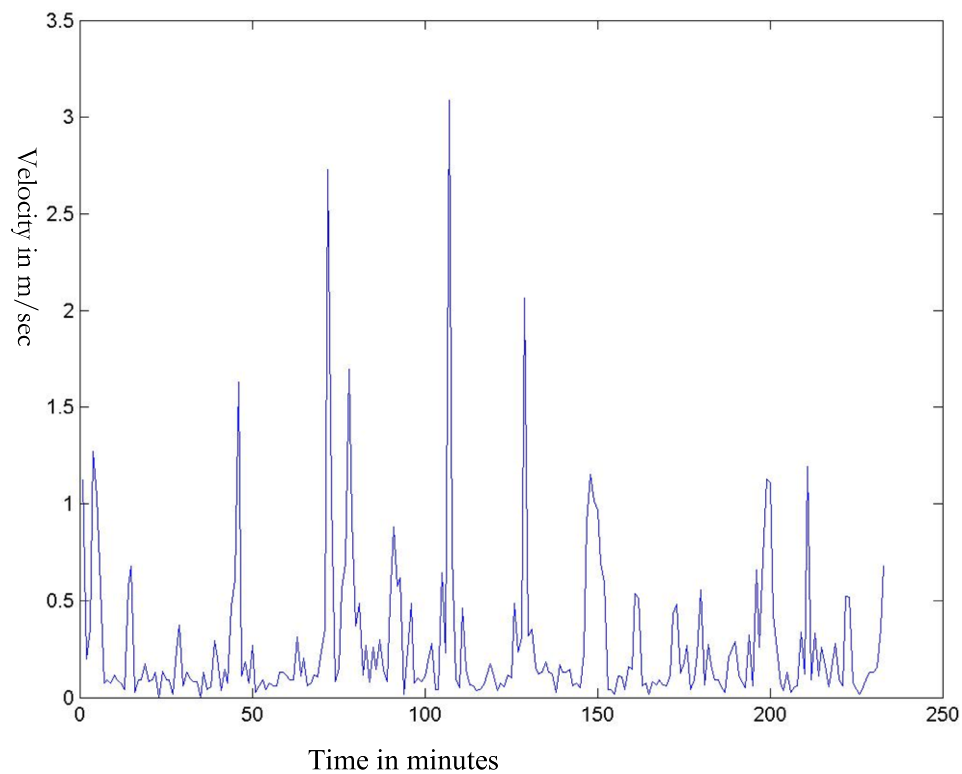
Dairy cows are stated to urinate and defecate 12 times per day (Lantinga et al., 1987), while other research registrations note between 6 and 10 times per day (Van Duinkerken et al., 2000). Stress is said to have some influence on the frequency, indicating that when imposing constraint, the frequency increases (Friend, 1991). The frequency of urination and defecation was in this experiment measured by two totally different methods. The first method was based on continuous observation of the group of 20 animals in the field. The second method was alternating every 5 minutes between behaviour registration and counting defecation and urination. The two sets of data confirm each other (Table 1), with an average frequency per day (urination: 6.5; defecation: 10.5) within the cited frequencies reported in the literature (Betteridge et al., 1986). The results show there is no difference in urination and defecation frequency per active hour compared with the total hours at pasture, even though the percentage of active time decreased with time spent outdoors.

4.4.2 Spatial distribution of excrement

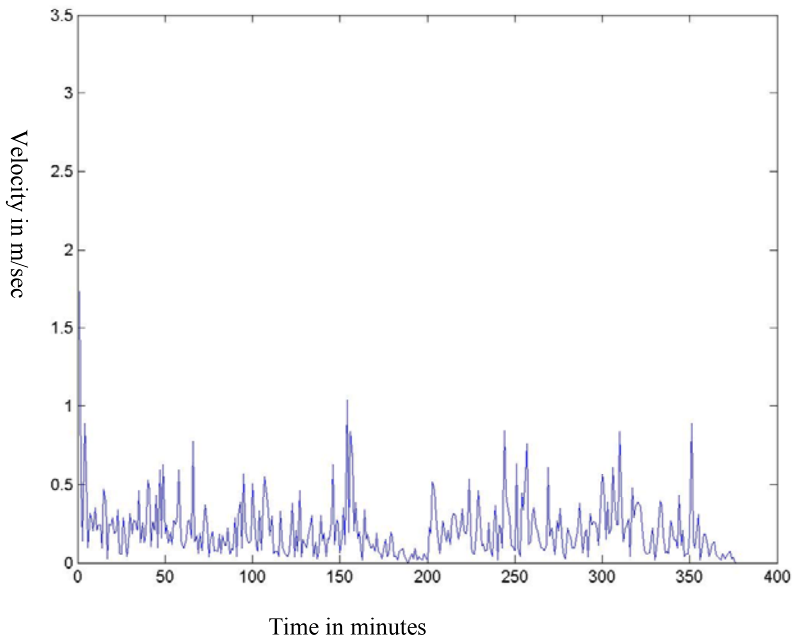
In the period when this experiment was undertaken there were measured minimum temperatures between 5 and 12°C and maximum temperatures between 13 and 28°C. The research done by White et al. (2001) suggests that, especially during warm periods, the distribution tends to be close to the water trough, due to frequent drinking. In our experiment no correlations were found between excrement pattern and dry weather, but the grazing time was limited to a maximum of 9 h, meaning that the cows could always drink in the barn. Only very few drinking observations were registered in the field (44 out of 5942 observations). This could explain why the allocation of excrement was not specifically higher in the quadrate where water was supplied. Research done with other grazing animals (pigs and beef cattle) shows higher concentrations of minerals originating from excrement around drinking or fodder troughs (Franzluebbers et al., 2000; Eriksen and Kristensen, 2001). The random spread of urinations and defecations in our experiment, for all three treatments, can be considered as positive in order to prevent excessive leaching from local hot-spots. The fact that the cows in all treatments were relatively busy grazing and moving around could have influenced this distribution in the field. Even though the cows in treatment P9, grazing for 9 h, had relatively more 'free' time, they did not use the time for drinking more. Other behavioural research has documented that cows' second preference is for lying down, after the need to eat (Munksgaard et al., 2005).

No significant correlation was found between lying down and excrement deposition, but there were high defecation numbers in some places contiguous to the quadrates where cows rested, on 16 June, which was dry, whereas 2 June was rainy. This could also explain why many more cows were lying down on 16 June. There were too few days of observation to make statements on the correlation between lying down and manure or urine allocation, from these results.

Velocity in m/sec in the 4 hour group of one cow in a herd of 20.



Velocity in m/sec in the 6.5 hour group of one cow in a herd of 20.



Velocity in m/sec in the 9 hour group of one cow in a herd of 20.

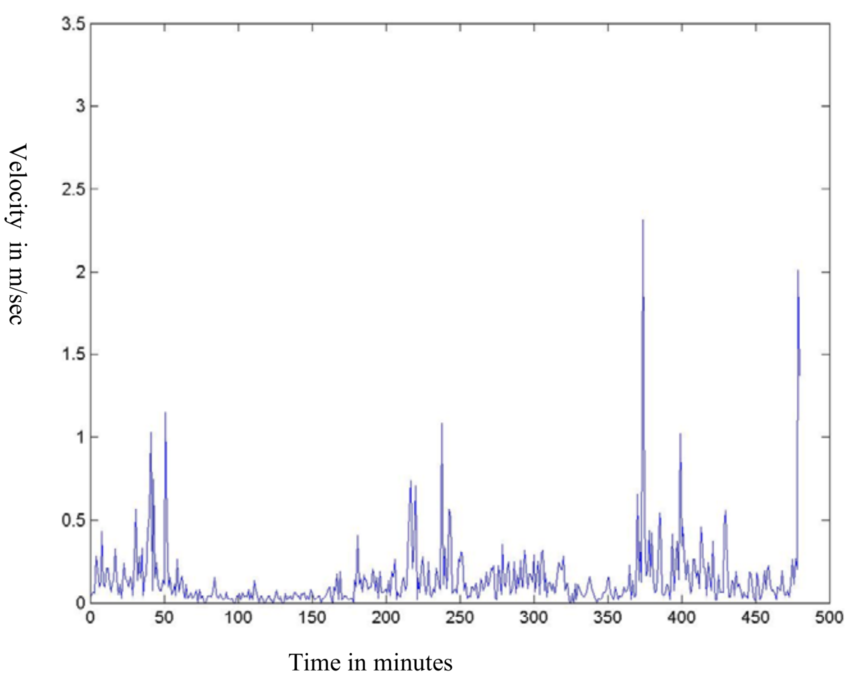


Fig 2. Velocity per cow, measured in three different grazing treatments P4 (4 h), P6.5 (6.5 h) and P9 (9 h) based on measuring positions every minute.

4.4.3 Walking pattern and velocity

The walking patterns for the individual cows were very different for the grazing treatments P4, P6.5 and P9. During the whole experiment the cows behaved very much as gregarious animals, justifying the use of registering only one cow and using those results in describing the group's movement patterns. Turner et al. (2000) investigated the percentage of error when registering one out of five cows when predicting their location in the field. An error of almost 40% was found, which confirms that cows individually chose their grazing location. However, when we registered manually the movements and the grazing time of the animals, we observed the gregarious effect. Cows walk, graze and rest within the same time bouts, justifying the use observations of only few cows. In addition, visual observations gave the impression that cows out for 4 h were very busy, almost stressed; whilst cows out for 9 h were much more relaxed. When analysing the walking patterns of the monitored cow in treatment P9, it showed that there were two (on some days three) resting bouts. The first occurred around 08:00 hours (1.5 h after having access to pasture) and lasted around 2 h. Although the movement pattern was very different for the three treatments, it affected neither the excrement allocation nor the frequency of excretion per cow per hour. The differences in average velocity found for the three treatments were probably the result of the motivation to try to eat as much grass as possible in a short time. When a period of relative starvation precedes grazing, cows' DMI h^{-1} increases, as grazing bout length also does (Greenwood and Demment, 1988). Cows tend to adapt quickly to environmental changes, such as shorter grazing time or grass length (Gibb et al., 1997; Barrett et al., 2001).

4.4.4 Time budget

Even though cows in treatment P4 were much more active, total time used on activities (eating/drinking/walking) compared with lying down, for field and barn period together, were very similar for all treatments measured over the full 24-h day. It has been discussed how long a dairy cow needs to lie down, in order to prevent becoming stressed. Munksgaard et al. (2006) mention 10 h, which was fulfilled by all treatments. It is very interesting to see how the cows quickly adapted to the different grazing treatments, using their relatively short time for eating in treatment P4 very effectively.

4.4.5 N-balance

The estimated surplus of nitrogen, for treatments P4, P6.5 and P9, of 317, 351 and 367 g cow^{-1} day^{-1} results from a different input of nitrogen as herbage DM and a slightly different output, especially as milk protein. The live weight changes in g cow^{-1} day^{-1} contribute only very little to the N-balance estimation. Herbage DM intake in kg DM cow^{-1} day^{-1} is estimated by calculating energy requirements, which relate to maintenance including grazing and walking activity, milk yield and live weight change (Macoon et al. 2003). A change of 0.5 kg ECM cow^{-1} day^{-1}, which was the calculated SE for the milk yield, results in estimated DMI changes of 0.2 kg cow^{-1} day^{-1}, which in the N-balance calculations leads to a change of 5.7 g N cow^{-1} day^{-1}. A change in milk protein of 23 g N cow^{-1} day^{-1}, which was the SE for the milk protein output, leads to a change of 3.6 g N cow^{-1} day^{-1} in the N-balance calculations. These together would result in a total error margin of 9.3 g N cow^{-1} day^{-1}. Although this is not a real SE estimate, as kg DMI and kg ECM are correlated variables where the correlation includes many other variable factors, these estimates confirm that cows eating more fresh herbage (with relatively high CP) outdoors also have a larger excretion of nitrogen (Table 6), meaning that treatment P9 had the biggest surplus of N cow^{-1} day^{-1}, followed by treatments P6.5 and P4.

The estimated surplus of N between 317–367 g N cow^{-1} day^{-1} was rather low compared with other balance results obtained with substantial grazing. Danish calculations predict N excretion per cow of up to 400 g day^{-1} when up to 10 kg DM intake is from fresh grass (Poulsen and Kristensen, 1998). Older Dutch literature states that, in urine alone, N excretion per cow can be up to 400 g day^{-1} with up to 16 kg DM grass uptake per day (Lantinga et al., 1987). An evaluation of many different N-balance research studies done for dairy cows suggests rates for manure between 83 and 285 (mean 152) g N cow^{-1} day^{-1}, and for urine between 49 and 297 (mean 155) g N cow^{-1} day^{-1} (Spanghero and Kowalski, 1997). The fresh grass consumed in our experiment gave rather low protein levels when measured (17.9% of DM), although still higher than in the supplement feed given in the barn (13%). This could explain why N-surplus, as estimated in this experiment, is on the low side compared with other balance results.

Table 7. Nitrogen deposition in grazing area on cow level and on field level for three treatments P4, 4 h; P6.5, 6.5 h; and P9, 9 h, estimated according to distribution between indoors and outdoors on a daily basis.

Treatment	**P4**	**P6.5**	**P9**
Cow level: Total in excrements (g N cow^{-1} day^{-1})	317	351	367
Deposition fraction in grazing area estimated			
a as % of cow DM intake [1)]	165	197	220
b as % of field time to total time [2)]	53	95	136
c as % of active field time to total active time [3)]	84	142	194
Field level: (kg N ha^{-1}) [4)]			
a as % of cow DM intake	115	119	122
b as % of field time to total time	36	58	76
c as % of active field time to total active time	58	86	108

1) The average amount of DM eaten per cow per day in the barn was measured for each treatment. (9.3, 9.3 and 8.8 kg for P4, P6.5 and P9, respectively). The DM intake in the field per cow per day was estimated to be 10.3, 11.5 and 12.7 kg, respectively, for treatments P4, P6.5 and P9).
2) Total time is 24 h, treatments P4, P6.5 and P9 are 4 h, 6.5 h and 9 h, respectively.
3) (Minutes active in the field / minutes active in total) multiplied by total surplus in excrements for each treatment.
4) Assuming a net herbage production of 7000 kg DM ha^{-1} $year^{-1}$.

Time budgets showing the active time indoors and outdoors can be used to explain the allocation of surplus nitrogen. From the balance results and field observations of excrement frequency and allocation, it cannot be determined which fraction of the faeces or urine is spread in the field. When comparing the measured amount of nitrogen deposited in the barn with the total estimated deposition for all treatments, the collected nitrogen in the barn was 46% of the total surplus calculated. On average for all treatments, 71% of the total time was spent in the barn, 27% in the field and races; whereas for the active time, on average 56% was spent in the barn and 41% in the field and races. Even though these figures are all weakened with errors, this suggests that allocation of excrements and urine are correlated with the cows' active time.

When using either total time or active time, estimating distribution of surplus nitrogen for the three treatments between pasture and indoor, this results in quit different estimates of excretion in the field for all treatments, as illustrated in Table 7. Based on the results of this restricted grazing time experiment using the active hours as basis for place of deposition is most plausible. Based on active time budget, excretion on a yearly basis on clover–grass pastures producing 7000 kg DM per year would be 58, 86 and 108 kg N ha^{-1} for grazing treatments P4, P6.5 and P9, respectively. If assumed that excretion of nitrogen would follow the DM intake indoors and outdoors, different results than the ones argued for here, would be the estimate (Table 7).

Not taking in account the other nitrogen inputs or outputs that can be expected at field level, these estimated depositions of nitrogen in the field are much less than the roughly calculated 200 kg N that would be removed from the field by DMI of 7000 kg per year (7000 $\times$176 [average CP content of herbage in g kg^{-1} DM^{-1}]/6.28 [ratio between CP and nitrogen]$\times$ 1000).

4.5 Conclusions

Limiting the daytime grazing time to 4 hours and 6.5 hours compared with 9 hours, while restricting the DMI indoors to the amount the cows grazing 9 hours could eat, had no influence on the urination and defecation frequency per hour in the field. Estimation of N surplus per cow per day showed a higher surplus N for the cows that were outdoors for longer. The main factor influencing this higher surplus was the higher estimated herbage DMI, which had a higher CP content than the supplementary feed. Consequently, the unchanged frequency per hour per cow of urination and defecation, together with the higher N surplus resulted in higher excretion when cows are outdoors longer and can be estimated to 58, 86 and 108 kg N ha^{-1} for the cows out for 4 h, 6.5 h and 9 h, respectively, on a yearly basis, based on a DM production of 7000 kg of herbage per ha. Regardless of grazing time, no specific hot-spot allocation of urine and manure was found and observations suggested that the high activity level for large herbage intake was a reason. The results of this experiment show that there is a possibility to reduce nitrogen excretion in a grazing system by restricting grazing time of dairy cows together with restricted indoor feeding, without compromising productivity and without compromising the fresh herbage utilization. However, it is important to design a grazing pattern without stressing the cows too much, as the shorter time in the field deprives the animals from lying down in the field.

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Chapter 5

Economic and Environmental Evaluation of Three Vision-based Scenarios for Organic Dairy Farming in Denmark

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(To be submitted)

Abstract

The objective of this study was to explore sustainability of scenarios for organic dairy farming based on visions and goals for the future, and to evaluate the economic and environmental impacts of these scenarios at farm level. Scenarios were in agreement with the scope of principles for organic farming; health, ecology, fairness and care.

Goals and visions of future sustainable, organic dairy farming, used for scenario definition, were deduced from participative sessions with stakeholders. Subsequently, goal-vision based scenarios were parameterized by quantification of identified production parameters. Finally, three scenarios were defined for a model farm of 200 ha. The business as usual (BAU) scenario is driven by economic incentives and implements new technologies and measures to enhance productivity and efficiency. This scenario is expected to be the mainstream strategy of future organic dairy production in Denmark. In the animal welfare scenario (ANW) economic efficiency is subordinate to animal welfare, and measures to improve animal welfare, such as lower milk yield, extra grazing area and a deep litter barn, are incorporated. The environmental scenario (ENV) is designed to minimize environmental burden, and, therefore is based on self-sufficiency regarding nutrients and feed. The economic evaluation of scenarios was based on quantification of farm profitability (i.e. net profit), whereas the environmental evaluation was based on quantification of the N surplus per ha, emission of green house gases and use of fossil energy per kg energy corrected milk (ECM).

Evaluation of scenarios revealed that compared to prolonging the current main stream strategy (BAU), investing in animal welfare comprised trade-offs regarding farm profitability and especially global environmental issues such as climate change and fossil energy use. In ANW, net profit per farm was almost 39 k€ lower than in BAU, whereas emission of greenhouse gases and energy use per kg ECM was respectively 7% and 9% higher. Minimizing environmental impact in ENV reduced local environmental impact, without an economic trade-off. The N-surplus of ENV was only 80 kg ha^{-1}, whereas this was around 116 in both BAU and ANW. Prolonging the current main stream strategy (BAU) resulted in a high local environmental impact, a moderate global environmental impact and a high economic risk to changes in milk price.

Keywords: *Organic dairy farming, scenario analysis, sustainability, technology*

5. 1 Introduction

In 2006, organic dairy farming accounted for 37% of the organic market turnover (365 mil €) in Denmark. Its development has been decisive for the organic farming structure (Mogensen, 2004). The current market share for organic products in Denmark is close to 5% and is increasing again (Lund-Jensen, 2007). Organic agriculture is known as the four no's: no to synthetic fertilizer, no to chemical pesticides, no to synthetic food additives and recently also no to GMO.

In the early period of organic farming the focus was on environment, invoking subsidies to initiate conversion and other enterprise stimulation. The last seven years of organic dairy farming development in Denmark has been demand led, and can be characterized by a "mainstream strategy" (Alrøe and Noe, 2006). This mainstream strategy is characterized by introduction of new technologies, scaling-up, specialization, and increasing productivity (Anonymous, 2008). The concept of organic agriculture arose as alternative to conventional agriculture in the 60's, but exists nowadays on the same premises.

Modernization, institutionalization, globalization, industrialization, intensification and specialization are developments found in both conventional and organic dairy farming (Fig 1).

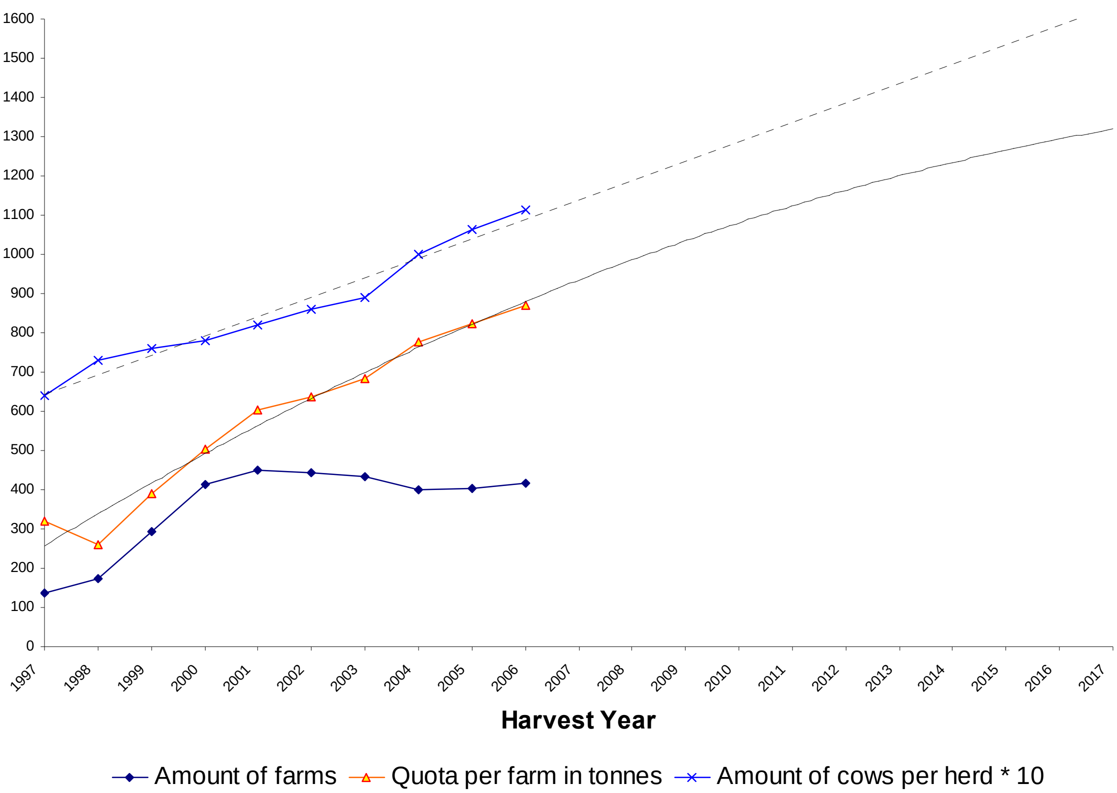

Fig 1. Development of dairy sector in Denmark (IFRE, 2008) and its projection to 2017.

One problem with the mainstream strategy is that consumers and society sometimes have difficulty identifying differences between conventional and organic production (Oudshoorn et al., 2008). This is especially the case for organic dairy farming, as fertilizers and pesticides are not used as intensively in conventional dairy farming as in conventional horticulture or arable farming. Animal welfare organizations, consumers and research are questioning conditions in organic farming management practices in Denmark. Objections brought forward are: lack of grazing (Kramer, 2006), weaning of calves after two days (Wagenaar and Langhout, 2006), lack of free space in barns (stress), disappointing taste of products (Claudi-Magnussen, 2001), and energy requirement for mechanical weed control (Dalgaard et al., 2002).

Another problem with mainstream organic dairy in Denmark is inherent to the speed of technology development and confrontation with moral and ethical acceptability (Markussen, 2003). Implementation of new technologies and measures for scaling-up can have a large impact on many aspects of the system at the same time. For example, production efficiency (yld ha^{-1}), and intensity (yield animal $unit^{-1}$), self-sufficiency of feed production, animal welfare, and societal issues like modified landscape or altered product quality (Haas et al., 2006; Mogensen et al., 2007; Bos et al., 2007).

Automatic milking systems (AMS) exemplify mainstream development in organic farming by introducing a new technology, which is facilitating labour saving, higher milk yields, and high tech farm management (Mejering et al, 2004). One can consider the implementation of AMS on organic dairy farms as a "bottom-up" development as it was introduced without predicting the consequences for organic farming conditions.

Organic agriculture builds upon the concept of sustainability, where social, economic and environmental principles are optimized jointly. These principles are periodically updated and presented worldwide (IFOAM, 2008). Therefore, a sustainability analysis was carried out for the present use of AMS in organic dairy systems (Oudshoorn et al., 2005; 2008; 2009). However, the sustainability concept is sensitive to changes over time and in location as societal values evolve (Boogaard et al., 2008). Today, we might tend to emphasize minimized GHG emission or nature impact as the focus of sustainability, yet in 10 years' time optimized animal welfare might be highlighted. Economic viability will always be necessary for a sector to be sustainable, and strongly depends on the price the future consumer is willing to pay for organic products. This future price, however, is uncertain and depends on global economic developments and external drivers like a focus on animal welfare, which cannot be foreseen. These future visions are not included in present state evaluations. In addition, within different countries, consumers and producers of organic products can influence national or local adjustments to organic standards and, through sales co-operations they can market special concepts. If specific goals or visions arise within such a network of producers and consumers, the mainstream strategy could evolve to a more specific vision-based development (Alrøe and Noe, 2006), satisfying the local objections to a previously unacceptable practice.

Both agricultural practice and institutional decision makers who care for environment and social consequences are asking for scenarios which can show alternative futures, to the continuous main stream development. This could be used for channelling funding and political strategies on research towards a continuing growth of the organic sector (Anonymous, 2008). Scenario studies can identify contingencies, uncertainties, trends and opportunities (Miller and Waller, 2003) and provide a qualitative method for comparisons. Evaluation by impact assessment can be used strategically for follow-up assessment of a changed practice.

This "top-down" development strategy has been used in many years, especially in companies (Schnaars, 1987). Contrary to modelling or extrapolation methods to predict the future, this method is based on an intuitive, narrative description of alternative futures (Börjeson et al., 2006; Meyer, 2007). Visionary future factors that do not compromise the feasibility might be added, but should not compromise reason and credibility (Van der Schilden, 2003). At the outset it is necessary to describe the goals of the scenario design and to restrict the number of alternatives, in order to focus on the desired information. Designing and defining scenarios provides scope to subject them to scientific evaluation of consequences. This introduces multi-disciplinarity, and can inform both the primary sector as well as the political decision makers. Using known mechanisms of development, and focusing on selected system parameters can further explain influential drivers and constraints that might be used to manipulate outcomes.

Different methods have been used to develop scenarios for organic production, motivated by different objectives in terms of production, or focused on technology adoption (Zanoli et al., 2000; Sonesson et al., 2003; Sonesson et al., 2005; Sørensen et al., 2004). The approach of Sonesson et al., (2003) was designed to include sustainable development at farm scale and was used in this study. System analysis methods can then be used to evaluate the scenarios as they have also been used for environmental and animal welfare assessments of farming systems and animal housing (Halberg 2008; Thomassen et al., 2008; Bos et al., 2007; Olesen et al., 2006; Weiske et al., 2006; Küstermann et al., 2008; Munksgaard and Søndergaard, 2007; Rosati and Aumaitre, 2004; Borrell and Sørensen, 2004; Oudshoorn et al., 2008; Sørensen et al., 2004).

The objective of this study, therefore, was to explore scenarios for organic dairy farming based on different visions and goals for a sustainable future, and to evaluate the economic and environmental impacts of scenarios defined. The scenarios should be in agreement with the scope of principles for organic farming; health, ecology, fairness and care (Anonymous, 2007) and standards in Denmark (Anonymous, 2007[b]).

5.2 Method

At the Royal Academy of Sciences in Sweden, a group of scientists (Sonesson at al., 2003) developed a framework to build scenarios for sustainable agricultural production. This framework defines and builds goal-vision based scenarios at farm level focusing on all sustainability aspects; i.e., economic, environmental and societal aspects. Each goal-vision scenario is a plausible future outcome of organic dairy production that is optimized for one or a few aspect(s) of sustainability. This approach is used in the present project because trade-offs among sustainability goal-visions might have existed. Possible goals and visions of future sustainable development of organic dairy production were deduced from participative sessions with relevant stakeholders. Scenarios created were evaluated for their economic and environmental performance. By comparing various scenarios and evaluating their economic and ecological impacts, insight is gained into sustainability of future organic dairy production.

In our study the framework consisted of the following steps:

1. The production system was defined taking into account regulations for organic dairy production in Denmark.
2. Goal-vision based scenarios were defined, focusing on sustainability issues presently valued as 'high', which included economic viability, environmental impact and animal welfare (Oudshoorn et al., 2009). The process was participatory, using stakeholder discussions on the subject.
3. Production parameters, essential for achieving goals and visions, were identified.
4. For each scenario, the specific farm design was quantified by specifying actual values for different production parameters involved. This parameterization was based on extrapolation of historical data and expert knowledge.
5. For each scenario, the environmental consequences were evaluated at farm level using the validated FarmGHG model (Olesen et al., 2004), whereas the economic consequences were

evaluated based on a costs-benefit analysis based on key figures from organic farming (Oudshoorn et al., 2009; Mejnertsen et al., 2008).

Below, each step is described in more detail.

5.2.1 Definition of organic dairy production system

On an organic dairy farm in Denmark two main processes take place, i.e., plant growth and animal production. Plant production mainly implies production of roughage crops like grass, maize, and whole crop silage. Dependant on the proportion of land and herd size, cereals for use in concentrates are grown. Animal production includes production of milk, meat and replacement stock. Milk production is the main activity, whereas meat production is considered a by-product. Milk is produced by Holstein Friesians as this is the most commonly used breed in Denmark. Organic dairy production should comply with organic EU council regulations (EF, 2007), and Danish national standards (Announcement, 2008). The national standards describe grazing practice with a minimum of six grazing hours during daytime between 15 April and 1 November. It is prohibited to tether animals, and young stock should be housed with cows and have access to pasture after three months of age. The organic dairy association (including the conventional dairy industry) in Denmark agreed on a maximum application rate of 140 kg N from animal manure ha^{-1}, even though EU regulations allow 170 kg N ha^{-1}. The N load in manure is calculated as the sum of N excreted by the herd, as we assumed no import or export of manure in all scenarios. In addition, all roughage is home-grown, as transport of large amounts of silage over large distance is not realistic in the Danish situation.

5.2.2 Choice and design of scenarios

Three scenarios were defined in this study and their choice and design were based on 1) a workshop with stakeholders; 2) active participation of the first author in construction of a report on future development of organic farming in Denmark; and 3) expert knowledge.

Goals and visions of organic dairy farming were discussed in a workshop with a panel of stakeholders from the sector, i.e. farmers, advisors, researchers, consumers, dairy industry, and retailers. Conflict areas discussed were automation ↔ animal welfare (including health), economy ↔ animal welfare, high stocking density ↔ eutrophication, high milk yield ↔ grazing, herd size ↔ grazing, productive crop rotation ↔ environment and slurry ↔ environment, technology ↔ product quality.

Scenarios defined in the report on future development of organic dairy farming were based on an extensive national survey (Anonymous, 2008). In this survey, representatives from the primary livestock industries, retail, institutional bodies and research were involved. Specifically, we discussed which values were expected to dominate the consumers' preferences in the next five to ten years. In an iterative process with expert panels, possible developments for the sector were discussed. The mainstream strategy, as well as animal welfare and environment strategies, was discussed.

Discussions from the stakeholder workshop strategies and comments from the national survey were used to develop scenarios. Subsequently, the actual definition of the three vision-based scenarios was based on iterative discussions of possible scenarios with experts and incorporation of relevant literature (Oudshoorn et al., 2008; Ruis and Pinxterhuis, 2007; Munksgaard and Søndergaard, 2006; Somers et al., 2003; Hovi et al., 2003 Thomassen et al., 2008; Haas et al., 2006, Mogensen et al., 2007). Below, each scenario is described in more detail.

1. The first scenario implies continuation of the present market-driven development, where economic efficiency and production intensity are the main drivers, and is referred to as business as usual (BAU). The BAU scenario was used as the baseline reference as it is supposed to be the most likely future development. We further assumed that labour costs keep on increasing and automation development continues.
2. In the animal welfare scenario (ANW), economic efficiency is subordinate to animal welfare, including animal health aspects like freedom of choice to lay down or move outside.
3. The environmental scenario (ENV) focuses on mitigation of greenhouse gas (GHG) emission, saving of fossil resources, decreasing emission of N and improving the natural environment like biodiversity and a varied landscape.

Business as usual (BAU) is defined as the scenario that will develop if market values, animal ethics and wealth remain as at present. This scenario is driven by economic incentives, both from farmers and retailers. In order to maximize milk yield from the available area, all heifers are sold to an organic heifer hotel after three months of feeding with fresh milk (i.e. legal minimum for feeding with fresh milk). A heifer hotel is a farm that specializes in raising and nursing young stock. Heifers necessary to replace culled milking cows, are repurchased some weeks before calving. All bull calves are sold straight after birth for non-organic fattening production. New technologies like AMS, management soft-ware programs and online sensors are assumed to be implemented. The free-range slatted floor system in partly open barns is expected to proceed as preferred barn types. Minimum standards on grazing are respected.

In the Animal welfare (ANW) scenario, welfare is defined by fulfilment of the five 'freedoms' as proposed by the Farm Animal Welfare Council in 1979. These freedoms imply the animal is 1) free from hunger and thirst; 2) free from discomfort; 3) free from pain, injury and disease; 4) free from fear and distress, and 5) free to express normal behaviour. In accordance with these five freedoms, animal health is an integral part of animal welfare. In the ANW scenario, economic efficiency is subordinate to animal welfare, and measurements to improve animal welfare or its public awareness are incorporated. Hence, annual milk yield per cow is lower than in BAU. A lower milk yield per cow has been advocated to be less stressing for cows and to increase cow health, and, as a result, the average longevity of the herd (Ruis and Pinxterhuis, 2007; Hamilton et al., 2002). It is expected that future consumers of organic dairy products will demand extended weaning periods. Both heifer and bull calves, therefore, are allowed to suckle for three months (Wagenaar and Langhout, 2006). Hereafter, only necessary heifer calves are kept for replacement of the herd and all other calves are sold. The type of animal housing and the number of grazing hours influence animal welfare (Ruis and Pinxterhuis, 2007). In this scenario, cows are housed in free-range stalls with an extended floor area, deep litter contrary solid concrete floors, a high roof and, therefore, natural ventilation. This choice affects costs of building and acquisition of straw material. In addition, an adequate grazing area adjacent to the barn is assumed with free excess in the summer period from 15 April to 1 November.

The environmental scenario (ENV) is defined as a scenario that will anticipate the increasing demand for environmental consideration. It focuses on mitigation of climate change, saving of fossil energy use (Bos et al., 2007) and decreasing of N losses to air, water and soil (Erichsen et al., 2008). The scenario is modelled to be self-sufficient regarding nutrients and fodder, i.e. all roughages and concentrates are home grown. This choice is made because a high self-sufficiency is found to be associated with a low nutrient surplus, and therefore, a low potential for leaching of nutrients. Furthermore, a high N surplus is found to be associated with reduced biodiversity (Haas et al., 2006). Even so, relatively high milk yields are obtainable (Mogensen, 2004). A balanced rotation alternating clover-grass with cereals and whole crop silage makes this possible. However, without purchased concentrates, fewer dairy cows can be fed from the total area of farm land available. The future housing of the animals is assumed to become more focused on mitigation of volatilization of methane, nitrous oxide and ammonia, requiring regular scraping of floors and use of straw as bedding material to reduce ammonia emissions (Gilhespy et al., 2008). In this scenario, therefore, additional straw has to be purchased.

5.2.3 Identifying production parameters

Key production parameters are those parameters that define the organic dairy system and create the scenarios. Conflicting areas between the goals and visions of the three scenarios were described and discussed among stakeholders, in order to clarify choices that had to be made as part of the production design at farm level.

Key production parameters deduced from this process were: farm size and crop rotation (ha grassland/crop land), annual milk yield per cow (kg/yr), number of milking cows, number of heifers bull calves reared, crop yields (dry matter (DM)/ha), diet (% roughage, DM intakecow^{-1}), grazing practice (hours day^{-1}), cow average lifetime (CAL), labour requirement (hours cow^{-1} day^{-1}), type of bedding and housing (slurry/manure/straw). Many parameters are strongly interrelated, therefore general principle differences between the scenarios are described in table 1.

Table 1. Schematic overview of production parameter principles for three scenarios for organic dairy farming in Denmark.

Production Parameters	I – Mainstream	II – Animal Welfare	III – Environmental Care
Diet	50-60% roughage (minimum required by law), >7 kg concentrate/cow grass silage/maize	>70% roughage. ≈ 5 kg concentrate/cow grass silage/ hay/ WCS	>75% roughage < 5 kg concentrate/cow Grass silage/ WCS /
Grazing area	0.15 ha/cow	>0.35 ha/cow Day and night grazing	0.3 ha /cow Time limited grazing
Labor	Minimized	No limit, no minimum	No limit, no minimum
Herd technology	Automatic milking/ fully integrated ICT 2.5 milking per day	Conventional milking	Conventional milking
Housing of the animals	Permanent, slurry based	Deep pit stall	Special low-emission barn
Storage of manure	Slurry tank	Manure heap	Slurry tank
Herd management/ calving strategy	Focused on high yield Culling rate 40% Weaning after suckling 3 days Bull calves sold for slaughter after birth Heifer hotel	Focused on animal welfare Culling rate 25% Weaning after 3 months (♀+♂) Bull calves sold when 3 months Surplus heifers sold 2nd year	Subordinate Culling rate 30% Weaning after 3 days Bull calves sold for slaughter Surplus heifers sold 2nd year
Field rotation	Close by and distant rotation, maximum 2 years of ley	Grazing has high priority	Production of concentrates
Field technology	Mainstream, all work done by contractors, high level of technology	Mainstream, all work done by contractors	Energy saving, soil preservation
Intensity	High input	Moderate	Low input

5.2.4 Parameterization of production parameters

Parameterization of key parameters was based on extrapolation of historical data and iterative discussions with experts.

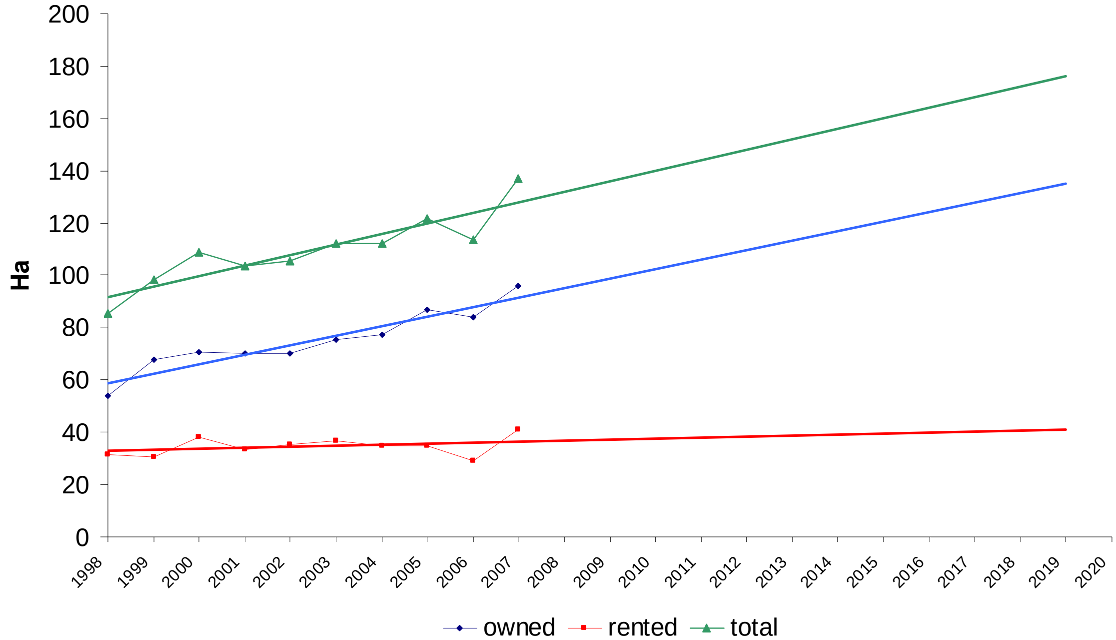

Fig 2. Development of acreage used by full time organic dairy farms in Denmark from 1998 to 2007 and the projection to 2019 (data from IFRI, 2008)

A plausible farm size for 2020 was set at 200 ha, taking into account the expectation of enhanced growth (see Fig 2). Given this farm size, the following procedure was followed to estimate other key parameters.

Given a N availability in the system, for each crop a possible yield was determined based on actual data of yields related to N application rates and their expected future development. In combination with knowledge on robust rotations and necessary feeding entities for milk production (Mogensen, 2004), this resulted in a preliminary quantification of the area required (ha) for each crop in each scenario. Subsequently, crop yield and crop area were used to calculate the amount of feed available for the herd. Furthermore, given the annual milk yield per cow and the assumed culling rate in each scenario, herd size could be calculated within the boundaries of grazing requirements. Herd size and annual milk yield per cow were then used to calculate exact feed requirements and, correspondingly, crop rotation was adjusted and concentrate requirement was estimated. This was done to check that the dairy cows' diet consisted of satisfactory amounts of energy, protein, starch and fibre. In an iterative process the N balance for the fields and fertilizer effects were used to adjust the crop yields, and thereafter determining total feed supply.

Crop yield

Average yields for wheat and barley have slightly decreased during the last decade (Fig 3). It seems there is a need for extra effort to improve crop yield and stability in organic cereal production.

However, we assumed a minor increase in crop yield in all scenarios as there currently is transition from low yielding grains to high yielding cereals like triticale and oats.

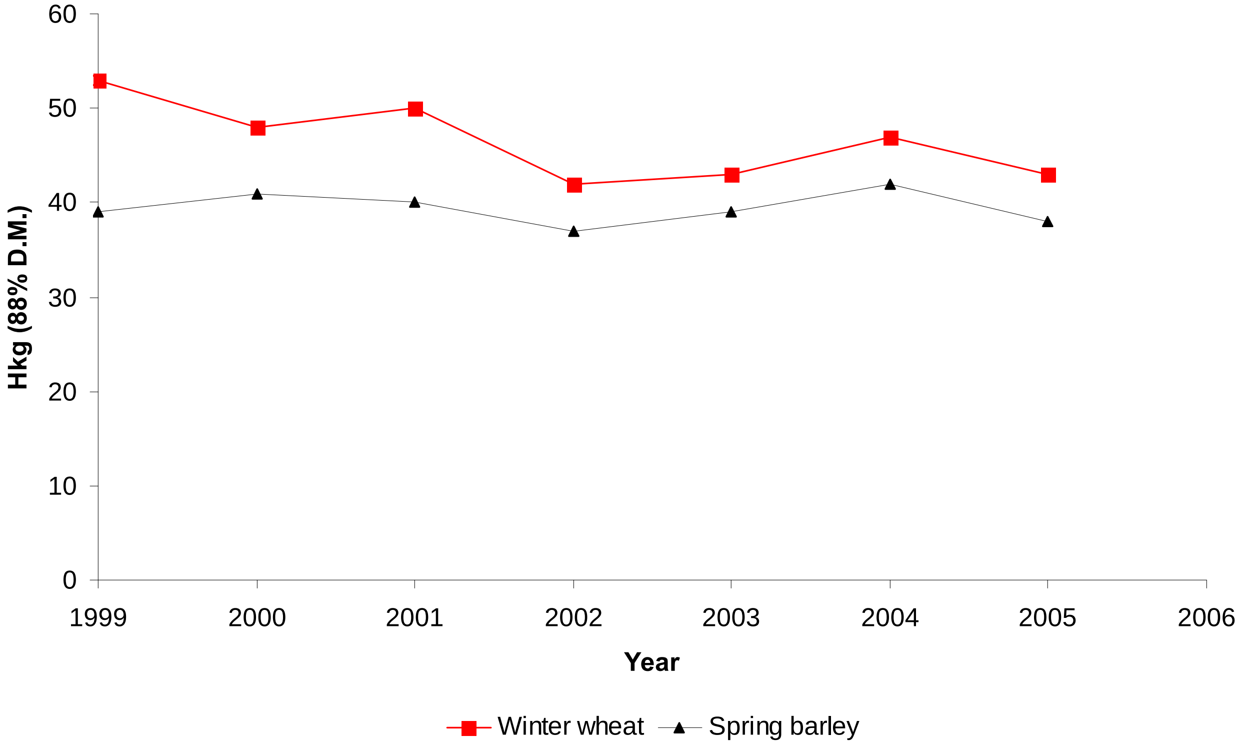

Fig 3. Average yields in HKg ha^{-1} for organic dairy farms from 1998-2005 (IFRI, 2005).

Yield potentials for roughage crops, grass, maize, and whole crop silage as well as the cereals used for concentrate, are derived from long term organic rotation research, as presented in Mogensen et al., (2007). The yield potentials for the future were estimated according to expected technological innovations and N availability within the system. The yield levels are estimated by using the last five years of actually registered yields on organic dairy farms in Denmark (Mogensen et al., 2007; Kristensen, 2008).

To compute the dry matter (DM) yield of a crop for a given amount of N application, the following marginal N effects were used. Adding one kg of N fertilizer results in an additional DM yield of 7 kg for grass-clover, of 11 kg for cereals and of 15 kg for whole crop silage. No reference study on marginal effects of N fertilizer application on organic maize was found. However, maize yields tend to drop when not fertilized at a high level, due to slow spring growth in cold soils. To guarantee sufficient concentrates in the ENV scenario, all animal manure was used to fertilize cereals and maize.

Herd size and milk yield

In order to calculate the number of milk producing units (MPU) in each scenario, N excretion is related to the diet and the milk yield of a cow. The following formula was used to compute the N-excretion per milk producing unit (MPU) (Poulsen et al., 2001).

N excretion per MPU = (SFU per MPU × g crude protein per SFU / 6250)- (kg milk per MPU × % protein in milk / 638) - 1.7
where Scandinavian feed unit (SFU) is a standard feed unit that corresponds to the energy of one kg barley which equals 7850 kJ.

The maximum N application as animal manure is 140 kg per ha and this was the limiting factor for BAU. For an annual milk yield of 9500 kg ECM (extrapolated to 2020, from the yield average increase of the last 10 years for organic dairy, see Fig 4.), this indicates a maximum of 1 milking cow per ha, excluding young stock.

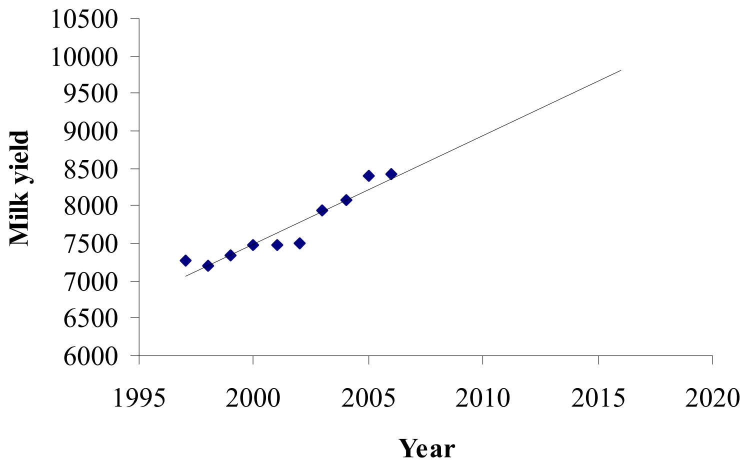

Fig 4. Actual and predicted milk yield in kg energy-corrected milk (ECM) per cow per year of the Danish Organic Dairy sector as an average of all breeds (DCA., 2008).

Energy-corrected milk (ECM) was calculated as defined by Sjaunja et al., (1990) as:
ECM = Milk yield in kg × (383 × fat% + 242×protein% + 780.8) / 3140

The herd size of the ENV scenario was dependant on the amount of feed the 200 ha could provide together with herd management factors (Table 1). The herd size of the ANW scenario was calculated considering a lower milk yield, together with herd management factors. For all scenarios the following procedure was followed. For organic dairy in Denmark, the average feed conversion rate for a production of 8000 $ECMyear^{-1}$ was 0.77 SFU kg ECM^{-1} in Danish Holstein Frisian (Kristensen and Kjærgaard, 2004). To cover maintenance, weight gain and foster growth the cow needs 1090 SFU per year, independent of the milk yield. The feed supply needs for the scenarios were estimated relative to this standard level (Olesen et al., 2005). For all scenarios, best practice for silage quality has been used. After having estimated a feed ration with best practice for quality, a more sophisticated calculation of kg ECM, using exact digestion rates for the different feedstuffs and consequences for fat, protein, energy, rumen fill and rumination time was computed (Strudsholm et al., 1999). In an iterative process, the cow's diet was adjusted to fit the needs at the given level of production. In all organic dairy cow diets, a minimum of 60% of the ration has to be roughage (EU-standard) except during the first three lactation months when the minimum is 50%. A minimum of 0.15 ha grazing area should be available per MPU (Danish guidelines) in the summer months.

The number of heifer calves on the farm is the result of the period the newborn calves are kept, the death rate, and the culling percentage.

In all scenarios, 50% of the cows give birth to heifer calves. In the BAU scenario the heifer calves are on the farm 3 months so the number of heifer calves is computed as $200 \times 0.5 \times 12/3$. All 1st lactation heifers are bought, so only death rate and culling rate influence the number of bought animals. Death rate on BAU is assumed to 4% per year which corresponds to highly productive herds (Oudshoorn et al., 2009). Bull calves are sold at birth for meat. Culling rate for the BAU scenario was assumed 40% which is normal practice for organic dairy farms at present in Denmark (Oudshoorn et al., 2009).

For the ANW scenario, the number of heifers on the farm depends on the culling rate and death rate. The assumed culling rate is 25% and the death rate 2.7% which corresponds to herds using conventional milking systems with a moderate production level (Oudshoorn et al., 2009). The number of heifer calves is therefore computed as $(185 \times 0.5) + (185 \times 0.25) + (185 \times 0.027)$. Bull calves are kept 3 months. The number of bull calves on the farm is therefore $200 \times 0.5 \times 12/3$.

For the ENV scenario the number of heifers on the farm depends also on culling rate and death rate. The assumed culling rate is 30% and the death rate 3% (higher than ANW as focus lies on environment). The number of heifer calves is therefore computed as $(125 \times 0.5) + (125 \times 0.3) + (125 \times 0.03)$. Bull calves are sold at birth for meat.

Using ECM production per MPU and the number of young stock on the farm, LSU ha^{-1} could be estimated.

Labour time

It was assumed that all field work on the farm was contract work. To calculate labour requirements for other farm activities, actual farm records (Oudshoorn et al., 2009) were used. For high-tech dairy farms with an AMS, the average labour time per milking cow appears almost independent of herd size and is estimated at 3 min d^{-1} (Fig 5). For farms with a conventional milking system, the average labour time per milking cows does depend on herd size and is estimated at 4.5 min d^{-1} for the ANW scenario (185 MPU) and at 6 min d^{-1} for the ENV scenario (125 MPU).

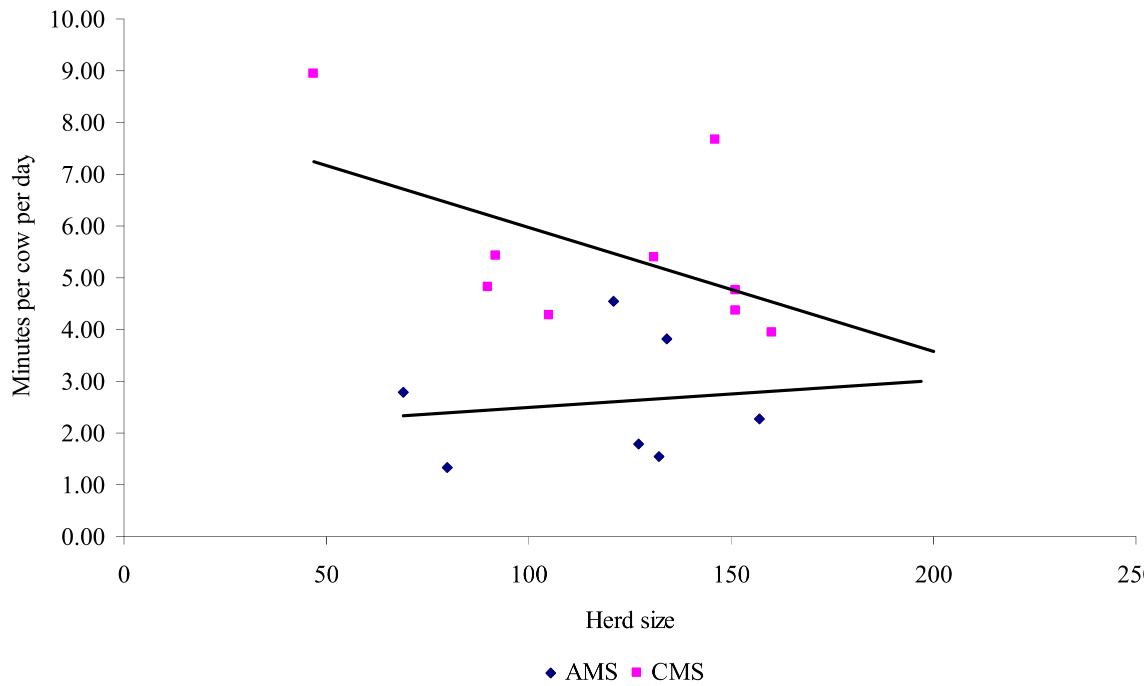

Fig 5. Labour time for milking on farms with an automatic milking system (AMS) and a conventional milking system (CMS) related to herd size as recorded in 2005 (Oudshoorn et al., 2009).

5.2.5 Evaluation of scenarios addressing sustainability

Sustainable development comprises economic, environmental and social issues. The social issues, concerning aspects like fairness, acceptability of the external impacts for the public, and integrity of production were integrated in shaping the vision-based scenarios. Scenarios were defined with the very purpose of presenting alternatives in the case of changing social moral values. The economic evaluation of each scenario was based on calculation of farm profitability (Van Calker et al., 2005). The environmental evaluation was based on calculation of the emission of greenhouse gases, eutrophying nutrients and the use of fossil energy sources such as fuel and electricity (see table 2)

Table 2. Schematic overview of issues and parameters used for evaluation.

Issues		***Parameter***	***Method***	***Unit***
Economic	Profitability	Net profit	Empiric	€/farm
Environmental	Eutrophication	N balance	Model	N ha^{-1},
	Climate change	GHG-emissions	Model	Eq.CO_2 kg^{-1} MPU^{-1}
	Energy use	Fuel	Model/empiric	MJ kg^{-1} ha^{-1} MPU^{-1}
		Electricity	Model/empiric	MJ kg^{-1} ha^{-1} MPU^{-1}

Economic evaluation

For each scenario, the economic evaluation was based on estimation of farm profitability. Farm profitability was measured by the difference between farm revenues and costs, i.e. net profit of the farm. As the scenarios give an outline of future possibilities, absolute costs of machinery and products sold could not be predicted. Therefore, the economic evaluation was based on current price levels (Table 3). The scenarios ANW and ENV presume public interest in the value of animal welfare and the environment, which could lead to premiums paid for the products matching these standards. This is incorporated in the economic evaluation, using 2008 prices as defaults.

Table 3. Prices for products, production factors and services used in economic evaluations

	Euro	Dimension	Reference
Milk	0.4491	kg^{-1}	(Mejnertsen et al., 2008)
*Decrease milk price for BAU	0.02	kg^{-1}	(Dairy industry & expert knowledge)
*Premium for ANW	0.03	kg^{-1}	(Dairy industry & expert knowledge)
*Premium for ENV	0.01	kg^{-1}	(Dairy industry & expert knowledge)
Straw	0.07	kg^{-1}	(Mejnertsen et al., 2008; Tvedegaard, 2007)
Veterinary (BAU/ANW/ENV)	97/67/85	cow^{-1} $year^{-1}$	(Oudshoorn et al., 2009)
Fixed costs	1200	cow^{-1} $year^{-1}$	(Pedersen, 2005; Oudshoorn et al., 2009)
Fixed costs	98	$heifer^{-1} year^{-1}$	(Holm, 2008)
Financing costs	613	$cow^{-1} year^{-1}$	(Pedersen, 2005; Oudshoorn et al., 2009)
Slaughter cow	751	$cow^{-1} year^{-1}$	(Mogensen et al., 2007)
Slaughter heifer	730	$heifer^{-1}$	(Mogensen et al., 2007)
Heifer hotel price	1.62	$heifer^{-1} day^{-1}$	(Holm, 2008)
Meat price	3.22	kg^{-1}	(Mejnertsen et al., 2008)
Seed and field work (except manure)			
Grass-clover for grazing (1 cut)	290	ha^{-1}	(Mejnertsen et al., 2008)
Permanent grazing	74	ha^{-1}	(Mejnertsen et al., 2008)
Grass-clover for silage	582	ha^{-1}	(Mejnertsen et al., 2008)
Maize	789	ha^{-1}	(Mejnertsen et al., 2008)
Barley/Oats/Triticale	467	ha^{-1}	(Mejnertsen et al., 2008)
Whole Crop Silage (WCS)	481	ha^{-1}	(Mejnertsen et al., 2008)
Labor costs	26.81	h^{-1}	Danish level for job of medium education
Concentrate	0.32	kg^{-1}	(Mejnertsen et al., 2008)
Rape seed cake	0.54	kg^{-1}	(Mejnertsen et al., 2008)
Manure spreading	3.35	ton^{-1}	(Mejnertsen et al., 2008)
Energy costs in husbandry	34.85	$cow^{-1} year^{-1}$	(Olesen et al., 2005)
Extra energy costs for AMS	8.71	$cow^{-1} year^{-1}$	(Rasmussen & Pedersen, 2004)
Extra costs for slatted floor scraper	3.49	$cow^{-1} year^{-1}$	(Dalgaard et al., 2002)

**Milk price differentiation*

The difference in milk price among scenarios is based on current price differentiation systems in Denmark and the Netherlands. In these countries, differences in milk price are considered to be an incentive for producers to deliver high milk quality. In Denmark, for example, a difference in milk price is based on somatic cell count (SCC), a measure for inflammatory infection in the udder (minus 4% in case of >400.000 per ml of milk (DM, 2008). In the Netherlands, milk price differences are additionally based on the amount of free fatty acids (FFA), a measure for careful handling of the milk (de Koning, 2008).

Veterinary costs expressed per cow are higher for herds with AMS than for herds without AMS (Oudshoorn et al., 2009). Fixed costs include the fixed costs for barn machinery, building maintenance, insurance, taxes, and animals. It does not include direct costs for field machinery, labour, energy, feed, and financing costs such as depreciation. For an AMS herd, capacity costs were on average 50 Euro per cow lower than for CMS herds. Costs were estimated by using account figures of all organic dairy farms in 2005, calculated separately for AMS farms and CMS farms (DAAS, 2005).

Costs per cow (capacity and financing) are assumed the same for the different herd sizes in the three scenarios. A body meat percentage of 48 was used to calculate the price for selling an animal, regardless of age or gender (Mogensen et al., 2007). Financing costs comprise interest on mortgage, interest on land, cost for leasing, and other debts. Costs for labour was 27 € h^{-1}, irrespective of the workers' functional level in the enterprise. In 2008, the average potential wage on an organic dairy farm was 16 € h^{-1} (Holm, 2008), but since then, an increase in wages has been observed. Costs for energy used during field work were included in costs for field work (seed and field work). Energy used on-farm for herd management and heating was estimated on the basis of 2008 energy prices and energy consumption. Energy use for transporting straw was incorporated in the straw acquisition price.
Economic impact of new technology using AMS and presumed ICT implementation is based on empiric data of case study farms (DCA, 2008, Oudshoorn et al., 2009).

Environmental evaluation

For each scenario, the environmental evaluation was based on calculation of the impact on greenhouse gas emissions, the use of fossil fuels and eutrophying compounds (via N-surplus). The emission of GHGs, the use of fossil energy and the N-surplus, were calculated with the FarmGHG model from Olesen et al., (2005). This model calculates the nutrient (i.e., carbon (C) and nitrogen (N)) and energy flows as well as GHG emissions from external inputs and transport to the farm until the product leaves the farm (see fig. 6). The model was designed and built in the MIDAIR project (EU 5th Framework program) to evaluate mitigation options for GHG emission. In this study we used the model to evaluate and compare the environmental impact of the three vision-based scenarios.

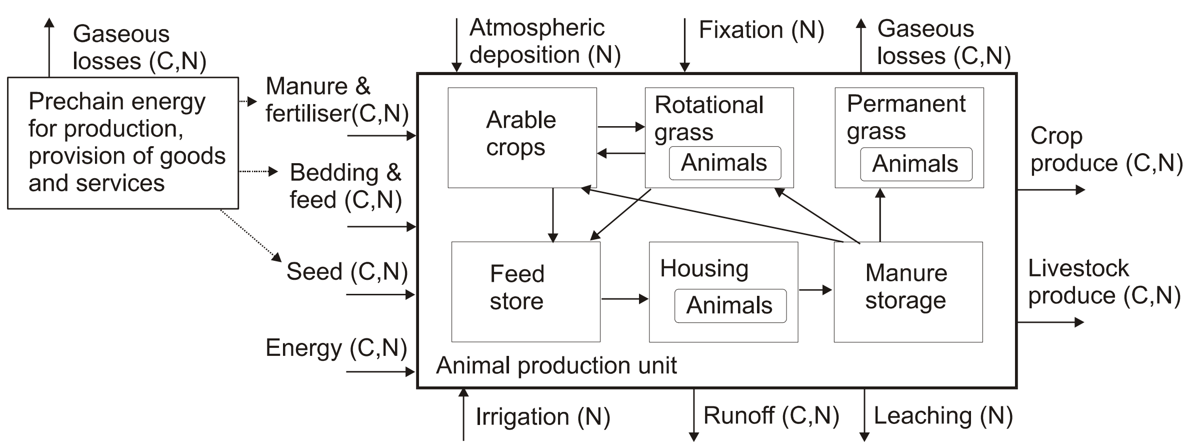

Fig. 6. Flows of carbon (C) and nitrogen (N) in and out of the total model farm system and between compartments within the system represented in the FarmGHG Model (Olesen et al., 2004).

Emission of GHGs in the model includes emission of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) and is expressed in kg CO_2 equivalents per year (i.e., 1 for CO_2, 21 for CH_4 and

310 for N_2O). GHG emissions are computed for production of purchased inputs (see fig 6), and production of milk on the dairy farm. Emission of CO_2 mainly results from combustion of energy sources. Sequestration of carbon in the soil is not included.

Methane emission originates from enteric fermentation and from manure in the house and manure storage facilities. Calculation of methane emissions are from enteric fermentation in the model is based on Kirchgessner's et al. (1995).

$$Methane\left(g\,day^{-1}cow^{-1}\right) = a + 79CF + 26CP - 212Fat$$

Where, a is 63 g CH_4 day^{-1} for cows and 16 g CH_4 day^{-1} for heifers, CF is intake of crude fibre (kg day^{-1}), NFE is intake of N free extracts (kg day^{-1}), CP is intake of crude protein (kg day^{-1}), and Fat is intake of crude fat (kg day^{-1}).

Emission of N_2O is computed with internationally accepted emission factors of the N inputs to the field, including fertilizer, crop residues and N fixation (IPCC, 1996, 2006) Acidification impact is not evaluated in this study. Acidification from dairy farms is for 81% caused by volatilization of ammonia (Thomassen et al., 2008). Volatilization of ammonia is quantified in the model to calculate emissions of nitrous oxide. Accounted sources in the GHG model are from housing of animals (differentiated between floor type, cleaning frequency, stall type, and slurry collection), storage of manure and slurry, application of manure or slurry in the field, and grazing.

Energy use was calculated by using most recent updates on energy use for production and transport of feed-stuffs imported, water consumption, housing, milking and field operations (Olesen, et al., 2004). The energy use on the farm is the sum of the diesel use for cultivation of on-farm feed and the electricity use for heating the barn, the feeding and milking processes. The diesel use for crop cultivation is computed using average diesel use for each treatment in the field (Olesen et al., 2004). Energy use for processing pre-chain goods, storing and transport, are not included in the model of Olesen (2005) but added separately. For transport an average length of 200 km was used (Cederberg and Flysjø, 2004), and only unprocessed barley and rape seed cake were imported. The emissions associated with the production, transport and use of these two energy sources are shown in Table 4. These data were taken as values being representative for Central Europe (Olesen et al., 2004).

Table 4.Greenhouse gas emissions associated with production, transport and use of diesel and electricity.

Energy source	**Emissions**			
	CO_2	CH_4	N_2O	NH_3
Diesel (g kg^{-1} diesel)	3668	4.565	0.346	0.0204
Electricity (mg MJ^{-1} electricity)	200600	400	7.5	0.042

The farm N surplus was calculated as the difference between imported and exported N. The imported N included imported feed, seeds, N deposition and biological N fixation, and the exported N included N in meat, milk (Olesen et al., 2004).

5.3 Results

5.3.1 Farm characterization of scenarios

The amount of N from animal manure applied per ha of land is approximately the same for BAU and ANW, i.e. 140 kg/ha and 130 kg/ha respectively, whereas in ENV this was only 86 kg N per ha. Estimated crop yields reflect these differences in available N in the different scenarios. In Denmark, whole crop silage on organic dairy farms usually consist of a large percentage of fodder peas, which due to N fixation can compensate for the lower N input (Table 5). Grass-clover yields differ, especially because spring growth is accelerated due to applied manure.

Table 5. Estimated gross yields in kg dry matter per ha for three scenarios, i.e. BAU: Business As Usual, ANW: ANimal Welfare; and ENV: ENVironmental.

Crops	**BAU**	**ANW**	**ENV**
Grass-clover, silage	6325	6325	5750
Grass-clover grazing	6600	6600	6000
Maize-silage	9200	9200	8050
Whole Crop silage	5750	5750	5750
Cereals (barley, oats, wheat)	4400	4400	4400

To calculate the amount of available fodder after harvesting of grass, maize and whole crop silage, we assumed that 15% of the gross DM yield is lost during the silage process, whereas 20% is lost during grazing (Olesen, 2005).

A diet of fresh grass-clover, grass-clover silage, whole crop silage, maize silage and barley (rolled or ground) was not sufficient to provide a balanced diet in the BAU scenario. Additional fatty, protein-rich feed ingredients were necessary to fulfil animal requirements and, therefore, rape seed cake was introduced. The non-restrictive import of feed ingredients in the BAU scenario and the relatively small land occupation for grazing, gave the opportunity to grow relatively more maize. This effect is strengthened by the out-sourcing of young stock (heifer hotels).

The crop rotations expressed in Table 6 show a significantly higher area in grass-clover in the ANW than in the BAU and ENV scenarios. This is due to the high requirements for grazing in the ANW scenario compared to the BAU and ENV scenario. In the ENV scenario a large area is needed for production of cereals to produce feed grains, because no concentrates were imported. Alternating cereals (oats, barley, summer triticale) and maize will be sufficient to maintain the grass-clover pastures at least three years.

Table 6. Production parameters estimated for the three scenarios, i.e. business as usual (BAU), animal welfare (ANW) and environmental scenario (ENV).

Farm Characteristics	Dimension	BAU	ANW	ENV
Area in grass-clover	ha	118	130	115
Area for grazing	ha	32	70	40
Area for silo maize	ha	25	10	10
Area whole crop silage	ha	40	30	25
Area for cereals	ha	17	30	50
Dairy cows	Nr/farm	200	185	120
Heifer calves	Nr/farm	25	148	96
Bull calves	Nr/farm	0	23	0
Animal density	LSU[1] ha^{-1}	1.41	1.38	0.88
Milk yield per milking cow	kg ECM[2]	9500	7800	8300
Milk yield per ha	kg ECM ha^{-1}	9500	7215	5188
Total milk production	Ton ECM	1900	1443	996
Cow DM intake (summer and winter)	SFU cow^{-1} day^{-1}	19.8	16.8	17.6
Dietary roughage (summer and winter)	% roughage	63	69	76
Dietary (concentrate)	SFU cow^{-1} day^{-1}	7	5	5
Pasture intake (summer)	% of diet	22	49	37
Amount of slurry/manure to spread	Ton $year^{-1}$	3062	2724	2546

[1]LSU = Livestock unit is a standardized animal that excretes 100 kg N per year;
[2]ECM = energy-corrected milk.

Calculation of LSU per ha is based on the CAL, management strategy for young stock and feed supply.

3.2 Economic evaluation of scenarios

Results of the economic evaluation of scenarios are presented in table 7. Milk revenues are related directly to total amount of milk produced, which was highest in BAU and lowest in ENV (Table 6). Quality regulations for milk result from premiums for high values of Conjugated Linoleic Acid (CLA) and vitamin E as well as a high cow longevity in ANW. In ENV, a premium presumed to be granted for a low N surplus per ha, as well a low feed mileage due to absence of import of feed-stuffs. Premiums assumed for CLA, longevity, a low N application rate, low feed mileage or animal welfare are not paid at present, but are presumed feasible in 2020. The negative milk premium in BAU resulted from high SCC and FFA values in milk. The reduced price was based on current penalties or fees used for SCC as explained in the Methods section 2.

As a result of high milk premium and high revenues from meat, total revenues in ANW were only slightly smaller than in BAU. The higher meat revenues in ANW resulted from the fact that in ANW bull calves were fattened on farm until thee months of age and the fact that heifers were not reared in the BAU scenario. Total revenue in ENV was significantly lower due to lower total milk production of the farm.

Table 7. Cost-benefit analysis of three scenarios of organic dairy production in Denmark (in Euro per year), including estimation of relative impact of milk price and capacity cost decrease i.e. business as usual (BAU), animal welfare (ANW) and environmental scenario (ENV).

	BAU	ANW	ENV
Revenue, € year^{-1}			
Milk	853,217	647,996	465,901
Product quality regulation	-30,614	38,686	11,126
Meat	64,772	93,569	65,831
Sum	887,375	780,252	542,859
Costs, € year^{-1}			
Contract work	106,253	76,117	90,782
Handling of manure	10,261	11,310	8,532
Concentrates	181,166	115,266	0
Labour, livestock	101,933	162,847	139,281
Straw	3,377	45,222	6,427
Veterinary	43,619	34,718	25,771
Energy	8,713	6,448	4,792
Capacity costs	309,015	246,716	166,153
Financing costs	139,410	136,394	88,807
Sum	903,747	835,038	530,544
Net profit, € per year	-16,371	-54,786	12,315
Milk price reduction 10%	-41,840	-74,129	-1,593
Capacity costs decrease 10%/cow	7,757	-31,227	28,233

In each scenario, costs for contract work were calculated by adding the costs for field work for the different areas of crop production (Table 6). Costs to produce grass-clover silage are almost twice as high as costs related to grazing of grass-clover pasture. This is the reason why costs for contract work were higher in BAU than in ANW and ENV (Table 7).

Costs related to spreading of manure were slightly lower in ENV compared to BAU and ANW. This is due to the relatively small herd in ENV (Table 6). Even though the total amount of manure produced was larger in BAU than in ANW, costs for handling manure were higher in ANW than in BAU. This was because in ANW relatively more solid manure was produced and the cost for handling solid manure was higher than for slurry. Costs for purchased concentrates are directly related to the amount purchased, which was highest in BAU (Table 5). Costs for labour and livestock were lowest in BAU because of the high level of automation and the out-sourcing of young stock. Costs for purchased straw were especially high in ANW as a result of use of a deep-litter barn.

Veterinary costs were highest in BAU which was not only caused by the larger herd but also by the slightly higher number of treatments per cow for farms with AMS versus farms without AMS farms, i.e. 0.8 versus 0.7 treatments per cow per year respectively (Oudshoorn et al., 2009). Capacity costs include the purchase of heifers as compensation for the culled and deceased cows. This was expensive for the BAU scenario, but in ENV and ANW scenario costs for rearing young stock, i.e. feed, labour and capacity costs, were included (table 6). Financing costs were lowest in ENV because the herd was smaller.

The estimation of net profit was lowest in ANW scenario, followed by BAU and ENV. Net profit includes all labour expenses, resulting in a negative figure for BAU and ANW. In practice this implies that the payment per hour of work for the farmer will be lower than the one assumed in table 5.

5.3.2 Environmental evaluation of scenarios

Results of the environmental evaluation of scenarios are presented in table 8. The environmental evaluation of scenarios quantified N-surplus, GHG emissions and energy consumption. The N-surplus was lowest in ENV, which resulted from the low N-input. This low N-input was due to the fact that ENV is self-sufficient with respect to feed. In all scenarios we assumed no import or export of manure. In BAU, however, manure import would have been impossible, as the limit of 140 kg of N ha^{-1} from manure from the home herd input was reached (Danish standard).

Table 8. Greenhouse Gas emission, nitrogen (N) surplus and fossil energy use per year for three scenarios of organic dairy production in Denmark, i.e., business as usual (BAU), animal welfare (ANW) and environmental scenario (ENV).

	BAU	**ANW**	**ENV**
Farm N-balance			
N-surplus (kg N ha^{-1})	**117**	**116**	**80**
N-input[1)] (kg N ha^{-1})	169	160	109
N-output[2)] (kg N ha^{-1})	51	44	30
N-output / cow year (kg N cow^{-1})	141	127	132
Greenhouse gas emissions			
Total (kg CO_2-eq)	**1,741,563**	**1,409,821**	**910,523**
Relative percentage (%)	100	81	52
Expressed per kg ECM[3)] (%)	100	107	96
Expressed per MPU[4)] (%)	100	88	87
Relative percentage from Enteric Fermentation per MPU (%)	100	92	106
From external source (%)	42	26	9
From energy use (%)	5	6	8
Fossil energy consumption			
Total (MJ)	**1,753,080**	**1,453,243**	**1,009,779**
Relative percentage (%)	100	83	69
Expressed per kg ECM (%)	100	109	105

[1)]N import comprises nitrogen in seed, N- fixation, concentrates and precipitation
[2)]N export comprises nitrogen in milk and meat
[3)]ECM = energy-corrected milk
[4)]MPU = milk producing unit

Total emission of GHG was highest in BAU and lowest in ENV. Expressed per kg of ECM, however, GHG emission was highest in ANW and lowest in ENV. GHG emissions from external sources (fig 6) show the influence of the large import of concentrates, highest for BAU and moderate for ANW. For BAU, this percentage of 42 also included GHG emissions during rearing of out-sourced young stock. For ENV, GHG emission during production and transport of external sources originated from the use of diesel, electricity and seeding material.

GHG emission from enteric fermentation expressed per MPU was lowest for the ANW farm because the total amount of feed fed per MPU was lowest in ANW. The difference in GHG emission from enteric fermentation per MPU between the BAU and ENV farm (even though the feeding level is similar) is caused by a different feeding regime. In ENV, the diet consisted of relatively more crude fibre and less fat compared to BAU. Crude fibre increases methane production in the rumen, fat decreases the methane production (see formula I, section 2.5). In total, however, GHG emission per kg of ECM was lowest in ENV due to lowest emissions of N_2O.

The fossil energy consumption is highest for BAU, but expressed per kg ECM, lowest. The deliberately low milk yield in ANW and the relative high energy costs per cow account for this difference.

5.4 Discussion

5.4.1 Definition of scenarios

The plausibility and feasibility of the scenarios is a principle part of the definition of scenarios (Berentsen et al., 1996; Van der Schilden, 2003; Meyer, 2007). The current situation in Denmark is based predominantly on the BAU scenario, where average herd size for organic dairy farms has passed 100 milking cows, annual milk yield per cow is increasing rapidly and LSU per ha is close to 1.4 (DCA, 2008). Also, implementation of high technology solutions for milking, herd management software, and data registration are in the process of being implemented. Animal welfare is certainly a hot topic, but are consumers willing to pay extra? Targeted surveys confirm willingness to pay a premium for better quality, which is not fully represented in actual buying behaviour (Lassen, 2008). The conclusion from discussions on whether or not lower milk yield, more time spent outside grazing, and deep-pit straw housing enhances animal welfare is still pending among experts, but is generally accepted by practitioners. Environmentally friendly design of the farm unit is built on research studies showing a direct relationship between LSU ha^{-1} (Kristensen et al., 2003) and potential leaching from farm N surplus. In addition, biodiversity in species decreases with increasing N-surplus per ha (Haas et al., 2006). Numerous minor improvements for environmental care could be introduced, like planting more hedges or small biotopes, shallow and no tillage, but these would be difficult to evaluate, as few empirical data are available (Hansen et al., 2001). Both animal welfare and the positive impact of organic farming on the improved environment have been driving forces for consumers to prefer products from organic farming (Hansen et al., 2001) and for farmers to use these farming methods (Oudshoorn et al., 2008).

Holistic evaluation of impact assessment can be difficult, especially in trade-off situations between totally different entities (Duinker and Greig, 2007). Sustainability is such a holistic concept, comprising environmental, economic and social aspects. A scenario analysis offers the possibility to integrate a broad selection of sustainability issues, including economy and social aspects. Contrary to most other scenario analysis, the method used to design alternative futures in this research was normative, using visions (Börjeson et al., 2006; Meyer, 2007). This procedure was chosen to secure the social dimension in the analysis. In addition, the path to get to the described alternative futures for ENV and ANW was not specified. The end-situation was designed and evaluated. The results can be used in decision processes with environmental, social or other objectives.

5.4.2 Economic assessment

The question arises if practising organic farming following the BAU scenario, with high investment levels and specialization (no heifers), new technologies, large imports of concentrates, and a management that focuses on maximizing the genetic merit of the cow, is rational. In economic terms, results of BAU were lower than for the scenario that focussed on environment, where the practice was not to press the cows to the ultimate level, and to minimize the impact on the environment. In addition, the economic risk, was higher for BAU than for ENV, i.e., when milk price drops 10%, net farm income in BAU decreased relatively more than in ENV or ANW (Table 7). From an economic perspective, therefore, ENV performs better than BAU. It, however, should be taken into account that estimation of costs was based on fixed values averaged over 255 farms with an average herd size of 110 cows. Usually fixed costs per cow decrease when herd size increases, and this could relatively improve net farm profit more for BAU than for ENV or ANW. In addition large herds offer the possibility to hire cheap labour, which is not included in our calculations.

The economic evaluation of scenarios also showed that net profit was lowest for ANW, due to high costs per kg of milk sold and the lower production of milk per MPU. In addition the extra revenue from meat for keeping the heifer and bull calves on the farm longer, do not compensate for the extra work. The price of having many cows with low milk yields receiving large amounts of concentrates, is high (116 k€ y^{-1}, on a whole farm basis).

The choice of a farmer to focus on animal welfare, therefore, would need an idealistic motivation, accepting a lower financial benefit. Using AMS and new technologies could possibly save labour time in the ANW scenario and decrease the difference between BAU and ANW (60 k€ y^{-1} on a whole farm basis, see table 7). This, however, would require additional investments to facilitate grazing, as the ANW scenario specifically focuses on this aspect, and large time spent grazing together with AMS, is difficult (Meijering et al., 2004).

Income is considered a pivotal parameter for farm managers, and therefore important to consider when assessing sustainability of a system. Introducing specific economical instruments like subsidies or premiums for environmental or animal welfare initiatives, or better price differentiation milk quality, does not compensate ANW enough to be competitive to BAU. If premiums for environment remain few, it is likely that the BAU scenario will still be the dominating future organic production form. Tendencies in this direction have been identified in Germany (Haas et al., 2007).

5.4.3 Environmental assessment

In this study GHG emissions were expressed per kg ECM milk produced or MPU and not per ha of agricultural land. Emission of GHG results in climate change which is a global problem, and therefore, global warming potential should be expressed per kg of product produced (Halberg et al., 2005). European countries have committed to comply with national reductions agreed in the European climate convention at Poznan in 2008 (Europe as a whole committed itself to a reduction of GHG emissions of 20% by 2020, Denmark 30%). To calculate and document this reduction, countries should produce the same amount of product with less emission of GHG.

Eutrophication, however, implies direct leaching of e.g. nitrate to the subsoil and water reserves, or run-off of phosphate to surface water, and, therefore, is a local problem. For environmental problems with a local aspect, environmental impact should be quantified per kg of product and per ha (Halberg et al., 2005). In our case we concentrated on N, as in organic production the phosphorous balance generally is close to zero (Hvid, 2008). The N-surplus per ha was 117 kg ha^{-1} in BAU, 116 kg ha^{-1} in ANW and 80 kg ha^{-1} in ENV. The difference in N-surplus could be explained by differences in stocking density among scenarios (see table 6, LSU per ha), as no manure was imported to or exported from the farm. In addition, Olesen et al. (2006) showed that a high N-surplus per ha was associated with a high GHG emissions per ha. In our study, we expressed emission of GHG emission per kg of ECM, and we found no correlation between N-surplus per ha and emission of GHG per kg ECM

In this scenario analysis we assumed no import or export of manure. In Denmark, the maximum N application from animal manure is 140 kg N per ha. Berntsen et al. (2004) showed that organic dairy farms in Denmark, on average, import 24 kg N ha^{-1} and export 14 kg N ha^{-1} in the form of animal manure. It will always be a possibility for intensive organic dairy farms to further intensify their enterprise by extending herd size and exporting manure from the farm, in order to produce more milk. However, they have to comply to the standards of grazing. To facilitate grazing, a Danish farm needs at least 0.2 ha of pasture per MPU. The different levels of excreted N per MPU, as result of varying production, complicate the estimation of allowable stocking density and calculations of obligatory manure export.

Optimizing longevity of dairy cows can reduce GHG emissions per kg milk produced by 13% compared to an average culling rates of 35% (Weiske et al., 2006). Culling rate assumed in ANW and ENV was lower than in the BAU scenario. The expected positive effect of an extended longevity on GHG emission per kg ECM in ANW was not achieved due to the lower annual milk production per cow, and the fact that bull calves are kept on the farm for three months and storage of manure in a deep pit.

A fixed feed conversion rate was used to estimate feed requirements for a certain milk yield per cow. Feed conversion, however, depends on the level of feed intake. For each additional1000 SFU a cow eats per lactation, the feed conversion efficiency drops by 6.5% (Kristensen and Kjærgaard, 2004). This effect was not included in our computations, consequently production efficiency in BAU and ANW were overestimated in by 6% and 2%, respectively.

The total amount of fossil energy used was clearly highest in BAU where energy use is expressed per kg ECM, it was lowest in BAU and highest in ANW. Unlike high energy requirements for AMS use in BAU (Rasmussen and Pedersen, 2004), energy use per kg ECM was low because feed production on farm is low, whereas import of concentrates was high (BAU: 421 ton y^{-1}, ANW: 213.5 ton y^{-1}). Energy use for storage, drying and processing of purchased feed was not included in the analysis, resulting in an underestimation of energy use in ANW and especially in BAU. Energy use per kg ECM in ANW was high due to the low annual milk yield per cow. The relatively high use of fossil energy in ENV resulted mainly from the relatively high use of on-farm diesel to cultivate arable crops, and to cut and carry grass, instead of grazing (BAU; 1492 MJ ha^{-1}, ANW; 1195 MJ ha^{-1} , and ENV; 1485 MJ ha^{-1}).

Compared to other estimations of energy use per kg ECM (Cederberg and Flysjö, 2004; Thomassen et al., 2008) the values calculated in this study were low. One explanation is that direct and indirect energy used to process feed ingredients were not included in our analysis. Another reason could be that in practice only very few farms use “raw” components as concentrates, whereas most buy standard mixtures containing components such as soy beans and palm oil which have to be transported from far away.

Often "kg milk" (fat corrected or energy corrected) is used as the functional unit for estimating environmental impacts (de Boer, 2003; Thomassen et al., 2008). However, produced milk is not the same as delivered milk. On average only 96.5 % of the milk produced requires further processing (range 2,5-5%), depending on antibiotic treatments, number of calves on the farm, type of milking system and lactation length (Oudshoorn et al., 2009). Therefore, GHG emission estimation differences between 2,5 and 5% are within the probable influence of management, which makes the differences found for the three scenarios, small.

The European strategy for mitigation of greenhouse gas emissions and usage of fossil energy, is to decrease GHG emissions by 20% before 2020. Dependent on the outcome of the upcoming climate conference in Copenhagen, Denmark might even aim for a 30% emission reduction. One of the focus areas is energy usage, so energy saving technologies or substitution by renewable energy resources can be obtained by progressive government policy. Countries agree on administration and budgeting for usage and, for agriculture, this can be done per kg milk produced, per cow, or per ha land. This scenario study showed that the environmental scenario resulted in slightly lower emission of GHG per kg of ECM compared to the business as usual scenario. Given the same amount of land, the total amount of milk produced in ENV, however, was 48% lower than in BAU. Production of the same amount of milk in ENV as in BAU, therefore, would reduce emission of GHG's but increase land requirements. Land suited to cultivation is scarce and therefore expensive, which makes conversion to environmental-friendly organic dairy farming difficult.

5.5 Conclusions

The objective of this study was to explore scenarios for organic dairy farming based on visions and goals of a sustainable future, and to evaluate the economic and environmental impacts of the three scenarios defined. The goal of thoroughly documented scenarios at the whole farm scale is to influence the present production environment or development. Simultaneously, the outcomes of the negative impacts of present developments towards unwanted future impacts must be avoided.

Net profit per farm for ANW was almost 39 k€ lower than net profit of BAU and 66 k€ lower than the profit of ENV. The N surplus per ha was 116 kg for ANW, 117 kg N for BAU, but only 80 kg of N per ha for ENV. Per kg of energy corrected milk, emission of greenhouse gasses was highest for ANW, and lowest for ENV. The difference between ENV and BAU, however, was small. Per kg of energy corrected milk, energy use was also estimated highest for ANW: 9% higher than BAU and 11% higher than ENV.

Evaluation of scenarios revealed that compared to prolonging the current main stream strategy (BAU) investing in animal welfare (ANW) comprised trade-offs regarding farm profitability and especially global environmental issues such as climate change and fossil energy use. In ANW, net profit per farm was almost 39 k€ lower than in BAU, whereas emission of greenhouse gases and energy use per kg ECM was respectively 7% and 9% higher. The economic and environmental trade-offs for increased animal welfare resulted from additional labour and energy use for breeding and rearing young stock, a lower annual milk yield per cow, use of additional straw, large grazing area and, therefore, less area for on-farm feed production. Additional costs were not compensated by the assumed premium obtainable because of consumer sympathy.

Minimizing environmental impact in ENV, especially reduced local environmental impact, without an economic trade-off. The N-surplus of ENV was only 80 kg per ha, whereas this was around 116 in both BAU and ANW. Prolonging current main stream strategy (BAU) using AMS resulted in a high local environmental impact and a moderate global environmental impact. The high production of milk in BAU also contains a risk, as small changes in interest rate or prices of concentrates have a relatively large affect on net profit.

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Chapter 6

General Discussion

6.1 Introduction

In this chapter the method used and the results obtained from the separate projects which shape this thesis are discussed coherently. The main objective, which leads to the focused research as mentioned in the introduction, was to find out if use of an automatic milking system (AMS) is contributing to sustainable development of organic dairy farming. An AMS was used as a case to exemplify the use of innovative technology, which currently is influencing organic dairy farming. The contribution of an AMS to sustainable development was analyzed by answering the following research questions:

a What are the economic, ecological and societal issues at focus when introducing AMS on organic dairy farms in the Netherlands and Denmark ?
b Do economic, ecological and social indicator scores differ between organic dairy farms using AMS and farms using a conventional milking system (CMS)in Denmark?
c What is the effect of time-limited grazing on eutrophication, animal behaviour and milk quality?
d What are the economic and environmental consequences of three vision-based scenarios for organic dairy farming in 2020?

These research questions are closely related to the methodology used during the research. Firstly, therefore, the logical design of the research questions and the connection between results found and the following steps are discussed. Already in the first part of the work it became clear that grazing was a crucial aspect when analyzing and specifying sustainability aspects of the use of an AMS. Grazing encompasses aspects concerning economic, ecological and social issues. Secondly, therefore, grazing is discussed in an integrated way, which implies showing necessary trade-offs among different sustainability aspects.

6.2 Framework to assess sustainability of an innovative technology

An AMS in dairy production was quite a revolutionary technology when introduced, not only because centuries of traditions for manual work are substituted by machines, but also because the concept of milking all cows in a short time-span is replaced by voluntary individual milking during 24-hours a day. AMS, or other robotic systems, are assumed to take over most of the traditional conventional milking systems (CMS). At present, 80% of all new houses for dairy cattle are equipped with AMS in Denmark (Press, 2008).

Dairy farmers, especially in Western Europe, are asking for an automation of labour consuming and monotonous work loads, like the milking process. Industries working on these innovative technologies have been analyzing the market for their product, as development of the whole concept is expensive. Such a market analysis, however, generally was performed within industries' research and technological development (RTD) departments. Some applicative governmental research institutes have been involved in partial problem solving studies, such as a study about the willingness of a cow to enter a milking unit voluntarily (Ketelaar-de Lauwere et al., 1998). Furthermore, several international conferences were arranged on the use of AMS since 1992. In 1992 the first human aspects appeared in the list of topics addressed, but these were mainly related to the safety when working with robotics (Lundqvist, 1992). Harsh et al. (1992) predicted that farms would become larger if AMS was implemented. Kuipers and Scheppingen (1992) mentioned the problem of zero-grazing, as they announced that AMS use requires cows at close distance, preferably in the barn. Perceptions of farmers and public acceptance were investigated, but only by very few researchers (Hogeveen and Meijering, 2000; Meijering et al., 2004; Jansen, 2004).

Organic dairy farming was never specifically mentioned in any of these conferences or international journals. However, this did not hamper organic dairy farmers from investing in AMS, even though the perception of organic farmers on AMS use and the compliance of its use with organic principles on sustainability had not been addressed or critically evaluated.

The question arises how to evaluate a topic comprising so many issues and being strongly connected to societal and personal ethics and values. Mollenhorst et al. (2006) used a methodology to assess the contribution of egg production systems to sustainable development, which appears useful for a holistic evaluation of the use of an innovative technology such as AMS. In this thesis, the methodology as presented by Mollenhorst et al. (2006) was used to evaluate the contribution of AMS to sustainable development of organic farming. The methodology consisted of the following steps:

1. Identification of stakeholders and description of the problem situation.
2. Determination of the goals of production and relevant economic, ecological and societal (EES) issues.
3. Translation of the selected issues into quantifiable indicators for sustainability.
4. Final assessment of the contribution of a technology to sustainable development based on indicator quantification in step 3.
5. Communication and dissemination of results to stakeholders, review of the process and evaluation of results on basis of the original problem definition.

The process to identify relevant stakeholders and consulting them to identify sustainability issues of concern and define goals was used to analyze the first research question. Translation of selected issues to quantifiable indicators for sustainability and analysis of these results was analyzed by comparing two groups of organic dairy farmers, one group with automatic milking systems and one group with conventional milking systems, as described in research question three and four. The communication and dissemination, as described as final step of the methodology, was conceptualized by designing three scenarios, based on results of the sustainability assessment supplemented by the results of the in-depth analysis of impact of limited grazing strategies.

The initial survey on sustainability issues when introducing AMS on organic dairy farms, resulted in focus on problematic issues like farm profitability, combining grazing and AMS use, adaptation of farm management to new technology, and the image problem towards the consumer caused by reduction of grazing time affecting milk quality and animal welfare (Oudshoorn and De Boer, 2005; Oudshoorn et al., 2008[a]). Dissemination of these problems at local conferences, farmer's meetings and extension services, brought the topic of grazing in relation to AMS to priority research within the Danish Dairy Association as well as the Danish Advisory Service, and stimulated innovative research on technologies to improve the AMS together with grazing.

Parallel to this process a quantification of indicators which measured identified issues of concern, was performed. This quantification was based on interviews and registered data of nine organic dairy farms with AMS and nine farms with conventional milking systems (CMS). Results of this quantification (chapter 3) revealed lower nitrogen surplus at field level which is a local environmental advantage. Milk yield per cow was lower and labour time longer for CMS farms. The cows on CMS farms were out grazing longer, which is considered as animal friendly. Content of free fatty acids (FFA) in the milk was higher for AMS farms which is a negative milk quality aspect. Some of the differences were identified as sustainability indicators, such as N balance and grazing time. Labour quantity, besides from being an important parameter influencing net farm income, can be classified as a social indicator for sustainability. The focus group interview results conclude that possibility for free-time and flexible time is important in the discussion on AMS. The additional questions in the quantification research (Table 1) confirm this. In addition the quantification of sustainability indicators revealed higher culling rate for AMS users compared to CMS users. This is increasingly becoming a topic of concern as described by animal welfare research (Sundrum 2001, Hovi et al., 2003, Haas and Babst, 2004). A higher culling rate could therefore be unsustainable, if consumers consider this animal welfare aspect important. This is indeed so as presented by consumer incentive investigations (Torjusen et al., 2004; Christensen et al., 2006) Although there was a clear difference in milk yield level between AMS and CMS farms the net farm income was not higher for AMS compared to the CMS farms. However, the integral evaluation of multidisciplinary quantification gave insight in the farms technology implementation and uncovered aspects which should be given attention. One could classify the quantification results as different management vision characterized by high milk yield, low labour time per cow, and early culling. The perceptual part of the evaluation emphasizes desire for more flexible labour time and less importance of grazing (Table 1).

Table 1. Score of farmers on importance of listed values when investing in an automatic milking system (AMS) or a conventional milking system (CMS).

	AMS[a]	CMS[a]	*P-value*
(score 1- 7: not important- very important)			
Save labour time	4.9	5.3	0.67
Decrease physical labour	6.1	6.3	0.42
Make labour burden more flexible	6.3	4.3	**0.05**
Social life	6	6	1.00
Udder health	4.9	6.2	**0.02**
Animal welfare	5.1	6.2	0.20
Milk yield	5	4.3	0.23
Save time keeping eye on the animals	5	5	1.00
Possibilities for automatic steering	5.3	4.5	0.46
Have a steady milk yield	4.6	5	0.87
Fits the herd	4.5	4.7	0.81
Acquisition of software	3.6	3.3	0.83
Variable costs per kg milk	4.5	5.3	0.15
Grazing possibilities	4.8	6.2	**0.05**
Possibilities for growing	4	4.7	0.33
Joy of working	5.4	6.2	0.33
Mental labour environment	4.7	5.7	0.13
Reliability	4.3	5.2	0.13

[a)] average score of 9 farms

The results show tendencies amongst CMS farmers towards more concern on reliability of the technique used and mental stress, where in particular the “round the clock” chance of possible alarms was mentioned. Both AMS and CMS users seem to have a positive opinion on use of new technology

(Table 2.) This was confirmed by another investigation where dairy farmers in Denmark, including organic dairy farmers, declared not to reject innovative technology and primarily seek for labour relief (Andersen et al., 2006).

Table 2. Score of farmers on agreement to statements on farms with an Automatic milking system (AMS) or a conventional milking system (CMS).

(score 1- 7; agree- disagree)	AMS[a]	CMS[a]	*P-value*
High-tech is needed to develop organic agriculture	2.4	2.8	0.89
Structural Development of the sector is threat to organic principles	4.2	3.8	0.50
There should be a maximum size for organic dairy herds	5.2	4.2	0.27
Electronic surveillance for organic control is fine	4	4.5	0.68

a) average score of 9 farms

As described in the previous paragraph, results of the indicator quantification also uncovered unsustainable aspects that deserve attention. One central theme that needed detailed elaboration was grazing. This aspect will be discussed thoroughly in the next section of this general discussion.

Once detailed knowledge about the economic, ecological and social consequences of introduction of AMS was gained, this knowledge was used to develop scenarios which focused on identified themes within sustainable agriculture. Sustainability should always be seen as a development (WCED, 1987), to ensure future generations the same possibilities and by creating scenarios, which represent possible future alternatives, the consequence of development in the described ways can be evaluated. Three scenarios were designed and defined:

1 The first scenario implies continuation of the present market-driven development, where economic efficiency and yield level are the main drivers, and is referred to as business as usual (BAU). The BAU scenario was used as baseline reference as it is supposed to be the most likely. Labour costs keep on increasing and automation development continues. It was defined that this scenario only uses AMS and a high level of information technology.
2 In the animal welfare scenario (ANW), economic efficiency is subordinate to animal welfare, including animal health, behaviour and freedom of choice. The scenario implies extra investments for welfare reasons for example in housing, straw for bedding and farm land for grazing. In addition a lower milk yield is defined per dairy cow.
3 The environmental scenario (ENV) focuses on mitigation of greenhouse gas (GHG) emission, saving of fossil resources, decreasing emission of N and nature aspects like biodiversity and a varied landscape. This can be obtained by a system of self –sufficiency.

The scenario analysis is a tangible conceptualization of goals and visions for the future. During the process of designing and defining the scenarios with stakeholders, many interesting aspects for strategic development came forward. One of the main conclusions was that intensification and rationalization by automation does not negatively affect emission of greenhouse gasses per kg of milk produced, whereas the local impact due to leaching of nitrogen increases. The economic performance, measured as farm profitability, was best for ENV. Profitability in BAU scenario was moderate and more vulnerable to economic changes in milk price or cost price of production factors. If the concern about animal welfare becomes more important in society, consumers have to be willing to pay additional money, and research should focus on reduction of greenhouse gas emission, while preserving animal welfare.

The framework used to assess sustainability of introduction of AMS on organic dairy farms appeared suitable to identify relevant economic, environmental and social consequences of AMS use. In general, introduction of innovative technology is not assessed in such a holistic way (Demont et al., 2001, see also introduction, chapter I). Identification of relevant economic, environmental and social consequences, however, is of importance before introduction of an innovative technology, as it avoids mismatch between user and technology (Eastwood et al., 2006). In addition, it could maybe have avoided social disturbances in developing countries when introducing high yielding varieties (Anonymous, 2002) or possibly have avoided environmental havoc (Carson, 1962).

Furthermore, by exploring various scenarios, insight is obtained in possible trade-offs between different aspects of sustainability, such as between animal welfare and environmental performance. Trade-offs, which are not always possible to quantify as economy and social equity or animal ethics are entities with different dimensions. Efforts to model different dimensions with a mutual scale have been made, for example on sustainability of Dutch dairy farming (Van Calker, 2005) and on trying to prioritize importance of world wide problems (CCC, 2008). The process is arbitrary as value of importance cannot always be expressed in money. Result of the difficulty of trade-offs can be a choice for different systems simultaneously, like we can see in most countries where organic agriculture exists parallel to conventional agriculture and factory farming parallel to free range. Even within the organic sector there still might be a group which does not want to implement AMS, specifically because of certain principles, such as negative effect on milk quality by disruption of fat globules causing higher free fatty acid concentrations (FFA).

The final step of the framework used to evaluate AMS use will be the presentation of the results in popular sector magazines and presentations at congresses and meetings for further dissemination. Here the feed-back from users and constructors can supplement the final evaluation.

6.3 Grazing in relation to sustainability when using AMS

6.3.1 Perceptions on grazing

The participative analysis of sustainability issues using focus groups composed of farmers and advisors indicated that grazing was a central theme, which was affirmed when quantifying indicators to measure sustainability effects.

When the participants of the focus groups (Oudshoorn et al., 2008[a]) were asked to prioritize nine sustainability issues selected from a literature review, grazing was ranked as second most important, just after farm profitability. All groups responded that grazing is closely connected to the image of organic dairy farming, expressed very succinctly by the following remarks: ‘it is the face of organic dairy,’ ‘no discussion possible,’ ‘definitely crucial,’ and ‘essential.’ There were also differences of opinion regarding the relation between grazing and animal health and welfare and product quality. Danish farmers stated that combining AMS use and grazing was sometimes labour intensive, difficult to manage correctly, and was not always animal-friendly. Recurrently doubts concerning economy of grazing were mentioned. However, no participants were in doubt that grazing was necessary for organic dairy farming to survive. Some participants specifically mentioned the positive effects on milk quality.

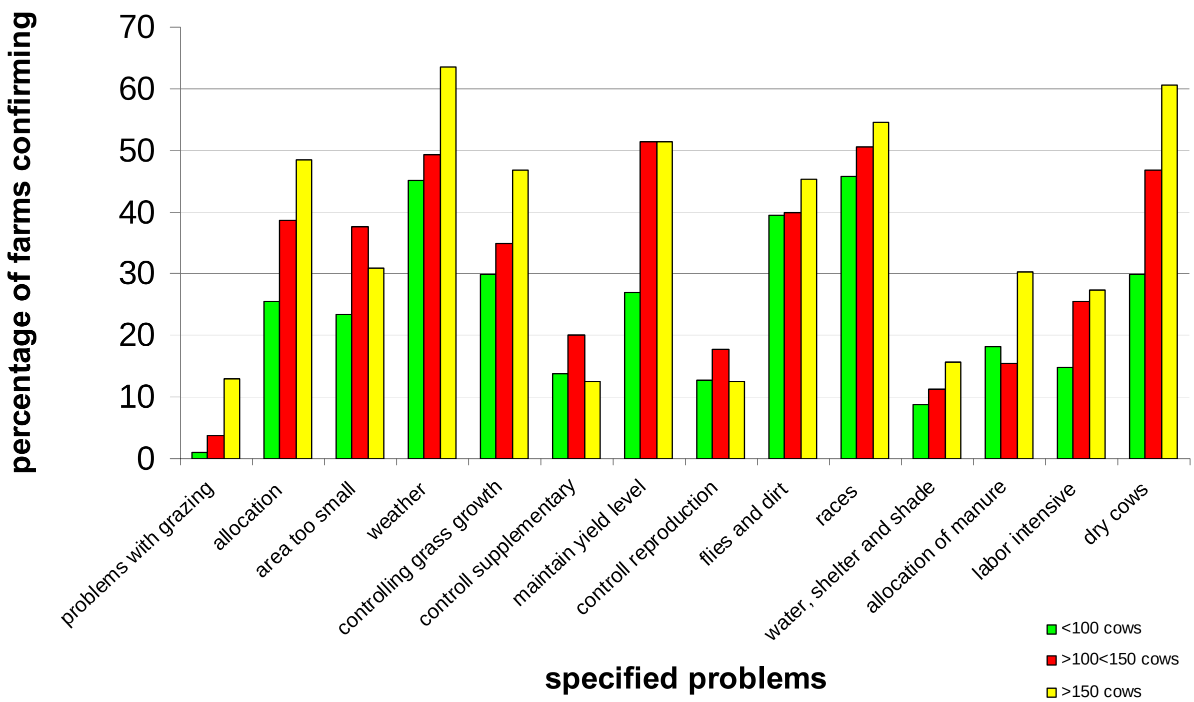

Fig 1. Percentage of farmer that perceive specified problems with grazing of 198 herds (88 farms < 100 cows; 79 farms with 100< cows< 150, and 31 farms >150 cows)

Maintaining a high milk yield and a low labour requirement, however, is expected to be negatively correlated with grazing time (Ketelaar-de Lauwere et al., 1998; Van Dooren et al., 2004). A questionnaire addressing grazing was distributed among all organic dairy farms in Denmark (500) in 2005, funded by the Danish Cattle Association, a farmers union. The questionnaire was anonymous and voluntarily and had a response of 42 %. The response rate should be seen in relation to massive focus on grazing problems of organic farms in the press. Hesitation among farmers to answer, as additional focus could be harmful for the sector, might be an explanation for the relatively low response. Results were only presented as general conclusions (Enemark, 2005) but by using herd size and use of AMS as determination factor, it showed that some of the perceived problems were correlated to either herd size (Fig 1) or use of AMS (Fig 2).

Differentiated for herd size gave an indication of where problems arise when farms grow in size. Allocation of the fields and area for grazing as a whole, controlling grass growth, maintaining yield level (grass and milk), and allocation of manure were clearly seen to increase with herd size. The fact that weather and dry cows also seem to be increasing problems with larger herds could be seen as a general stress on labour when combining grazing and large herds. More than 10 % of the organic dairy farms with herds larger than 150 cows experienced problems with the grazing practice. This farm size could easily become standard for most dairy farms in Denmark (Anonymous, 2008).

When differentiated for use of AMS (Fig 2) the concerns about labour use and the ability to maintain high yield levels for farms using AMS were registered. In addition the response gave a picture on perception of some generic problems parallel to large scale farms like allocation of fields and too little area, weather, control of grass growth, allocation of manure and control of dry cows. Quantification of sustainability indicators (chapter III) revealed a significant higher annual milk yield, less grazing time, and lower labour use on AMS than on CMS farms. So the perception of problems is confirmed by the facts.

Generally farmers that use an AMS perceive considerably more problems with grazing than farmers with CMS (Fig 2). These problems also related to some of their business targets, like maintaining high annual milk yield, controlling supplementary feed and saving labour, which were found by quantifying sustainability indicators (chapter III). Business targets found for AMS users were higher milk yield and low labour use per cow even if this meant less grazing. A hypothesis could be that AMS and professional ambition to intensify farm practice and maximize milk yield go together and lead to less grazing practice.

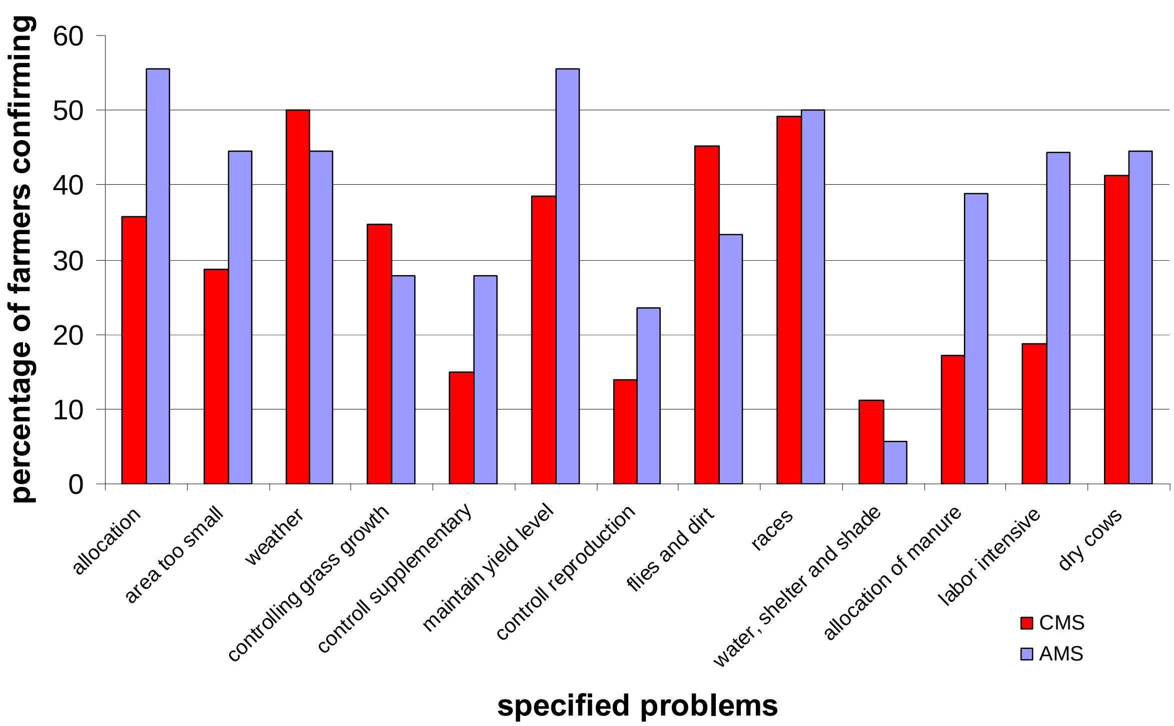

Fig 2. Specified grazing problems determined for 197 herds of which 19 had an automatic milking system and 179 had a conventional milking system.

Analysis of herd size on AMS and CMS farms showed that a large percentage of the AMS farms have a herd between 100 and 150 cows, whereas only a few AMS farms had herds exceeding 150 cows (Table 3). Parallels could be found in studies on conventional dairy herds, less grazing when implementing AMS and not especially large herds using AMS (Meijering et al., 2004). Recent investigation however, on the factual differences between AMS and CMS farms showed AMS farms' herd size exceeded the CMS by 20% (Kramer, 2009).

Table 3. Distribution of herd size among milking systems (Enemark, 2005).

	AMS	CMS	All
<100	33%	47%	46%
100-150	56%	37%	39%
<150	11%	16%	16%
total	18	188	206

AMS, automatic milking systems
CMS, conventional milking systems

6.3.2 Perceptions on grazing technique

Analysis of time limited grazing (Oudshoorn et al., 2008[b]) revealed an influence of grazing time on deposition of faeces and urine, with potential leaching as consequence. It showed, however, disposition correlated to active time rather than total time outside. This finding could be utilized by careful planning of feed intake in the barn, giving cows time outside to relax and rest, alternating with necessary grass uptake. The questionnaire results show farmers are aware of the potential eutrophication problems (Fig 1. allocation of manure), this in contradiction to the answers in the focus group analysis (Oudshoorn et al., 2008[a]) where eutrophication was not acknowledged as a problem.

6.3.3 Milk quality aspects of grazing

One of the motivations for organic farmers as well as consumers to prefer dairy cows to graze and thus to ensure a significant fraction of the cows diet to be fresh, is the quality of the product. Different scientific investigations have confirmed an interaction between fresh grass consumption and milk composition. Slots et al. (2008) concluded that an increased fraction of fresh grass in the diet increased the concentration of favourable fatty acids (e.g. conjugated linoleic acid (CLA)), but also increased the amount of vitamin E (α-tocopherol) in milk. Elgersma et al. (2004) concluded that consumption of silage did not show these favourable effects of fresh herbage (grass / clover) consumption. In addition, fresh herbage consumption was found to influence differences in CLA content (Adriaansen-Tennekes et al., 2005). Reduced grazing practice in organic dairy farms using AMS (Kramer, 2006) will therefore have influence on milk quality. As part of the grazing experiment of this research (chapter IV), milk from the two most extreme experimental settings, i.e. four hours of grazing per day and nine hours per day, were analyzed for quality aspects. Milk from morning and evening milkings were analyzed. Results showed that milk quality aspects differed not between the milk from cows grazing different time lengths, but between milk from morning milking and evening milkings in the case of 4 hours grazing (Jayashree et al., 2008). The cows had an enormous compensation ability to eat more in a shorter time; the 4 h cows ate 10.3 kg DM, the 9 h cows ate 12.7 kg DM. This compensation rate probably caused the differences found between morning and evening milk for the 4 h cows. The compensation rate could be obtained by feeding the cows the same ration of supplementary feedstuff in the barn. The 4 h cows quickly learned that they had to eat fast in order not to be hungry. Conclusions of this research were that large intake of fresh herbage in a short time (>10 kg dry matter in 4 hours) can change the fatty acid profile including CLA content, β Hydroxy Butyrate, α-tocopherol, β-carotene and milk uric acid concentration. This difference in milk quality could be obtained within the period from grazing between 7 and 11 a.m to 5 p.m when the cows were milked. The results confirm what dairy industry, retail and consumers claim; time on grass has influence on milk quality and harmonious diets have to be obtained every day, not as average over a period of weeks or months.

6.3.4 Social aspects of grazing

Organic dairy farming is submitted to organic standards. These standards in principle are established by the European Council, but can be adjusted on a national level resulting in country specific rules, accepted by the legislation authorities and again by the EU, to prevent these adjustments being used in competition between countries. Even at a national level the grazing practice is subject to conflicting interest and concerns of different stakeholders. Farmers for example, seek for increased flexibility and easy administration of their obligatory log-book, whereas authorities aim for optimal control. Consumers wish transparency of practice and reliability of control.

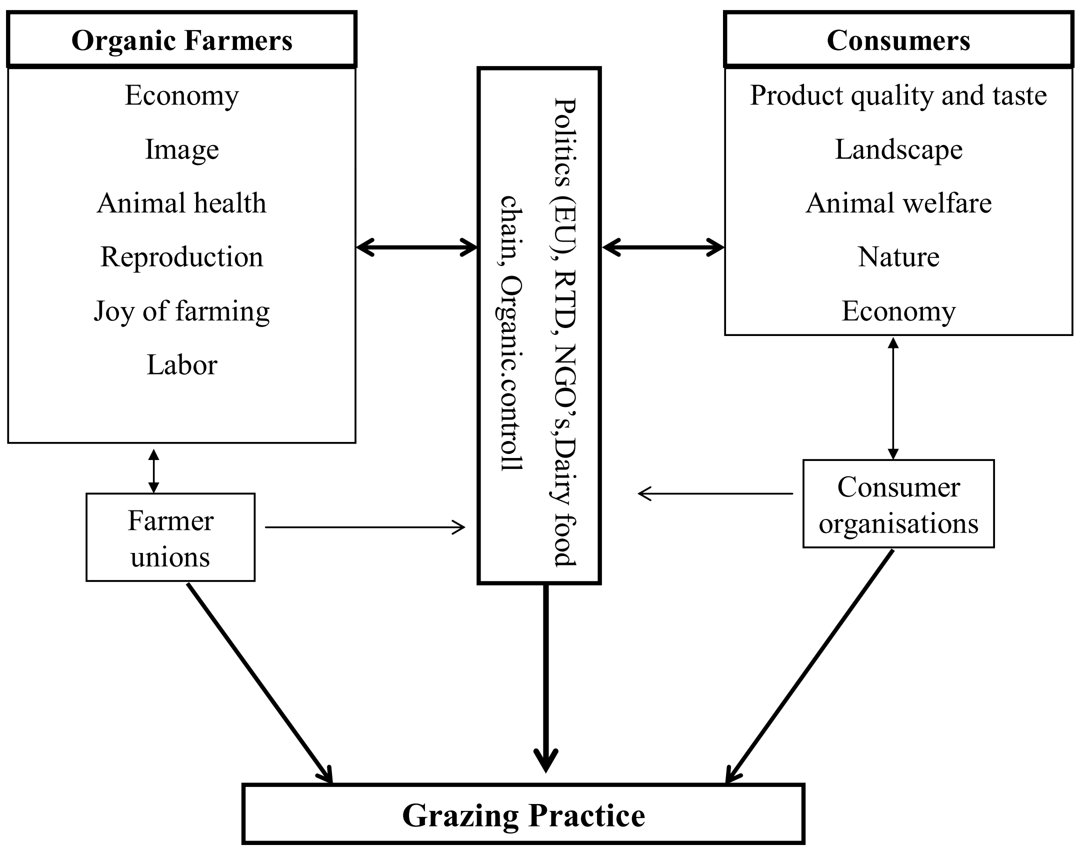

Fig 3. Entity relation diagram showing societal aspects influencing grazing practice

EU; European union, RTD; Research and technology development, NGO, Non governmental organization.

The grazing practice is a result of ethical considerations and factual knowledge, in a balance between producers and consumers. Both farmers and consumers can have their consideration on what is right or wrong, as well as they can reflect on factual knowledge on health aspects or environmental effects. Their influence on each other and the authorities will in the end result is some kind of consensus (Fig 3). Economic motives will be an important factor in this balance, the scenario analysis clearly shows the differences when goals and visions determine the practice (chapter V, Oudshoorn et al., 2009[b]). The animal welfare scenario scores badly on economic performance. This is not only caused by difference of grazing: model calculations have shown grazing can contribute positively to economy (Raun and Rasmussen, 2001). Consumers, however, are not willing to pay large premiums to compensate negative net farm income effects of increased animal welfare measures. Investigations of consumer motivations show many are willing to pay a premium of 20% and when asked why, 78 % mention animal welfare, 74% mention environment, 67% mention their own health and 61% a general sense of sustainability. (Wier and Calverley, 1999; Alrøe and Halberg, 2008). Implementation of AMS on organic dairy farms complicates the process of trade-offs between economy and animal welfare. AMS farmers would rather see the organic standards more flexible and perhaps allow cows' night time registered as grazing time also. In addition, sufficient grazing also could be achieved by a shorter grazing time than 6 hours at daytime, as the outside time at night could be accounted for to comply with the rules, as this also gives cows exercise (EF, 2007). This study reveals in chapter II that identified stakeholders mention ethical aspects in favour of grazing. 'Better for the cow, more natural, and consumer desire' are mentioned. Questionnaire results show farmers perceive problems with grazing (Fig 1,2) and quantification show the volume of grazing is reduced (chapter III). Grazing seems to fit badly with AMS farmers' aspirations to yield and profit (Oudshoorn et al., 2009[a]). Farmers consider consumers opinions, i.e. when the farmers mention the sectors' image towards the consumer as an important incentive (Oudshoorn et al., 2008[a]). This shows how high they value the fulfilment of demands of the people buying their products. In this complex process official governmental standards in Denmark to a more precise minimum grazing area per dairy cow for organic dairy farming was decided in 2007 (PD, 2008). Organic dairy farms are obliged to offer their animals 0.1 ha grazing land per livestock unit in spring, expanding to 0.2 ha grazing land in autumn. Two years before a questionnaire among all organic farmers (Fig 1 and 2; Enemark, 2005) asked the participants if they could comply with this minimum (Table 4), which at that moment was not decided.

Table 4. Percentage of farms able to comply with different grazing areas and uptake of dry matter (DM) cow^{-1} day^{-1}.

Herd size	0.2 ha cow^{-1}	0.25 ha cow^{-1}	6 kg DM d^{-1}
<100	98	94	94
100 - 150	93	86	81
>150	87	60	69
Automatic milking system	94	71	65
Conventional milking system	94	87	87

If 0.25 ha per cow is required for large herds (>150 cows), close to 40% of the larger farms will have difficulty in complying with the demands. Of the AMS herds this number is close to 30%. Seen in this perspective, the grazing issue is still highly problematic for organic dairy in Denmark and a threat to its sustainability. The continuous up-scaling and the introduction of AMS contribute to the problem, and needs further elaboration and development to find appropriate ways of implementation.

6.3.5 Mobile automatic milking

Scenario analysis in general often describes consequences of known technologies projected on future designs. Emerging technologies however are usually not included to avoid "educated guesswork". However, to be able to give a future vision, one has to think innovatively. Usually the first reaction to innovative technology is rejection, followed by scepticism, where only technology enthusiasts and visionaries adopt the idea. After crossing the chasm (Moore, 1991) pragmatics can start using the technology, if it has proven to be adoptable, reliable and feasible. The road to success is visualized in Fig 4.

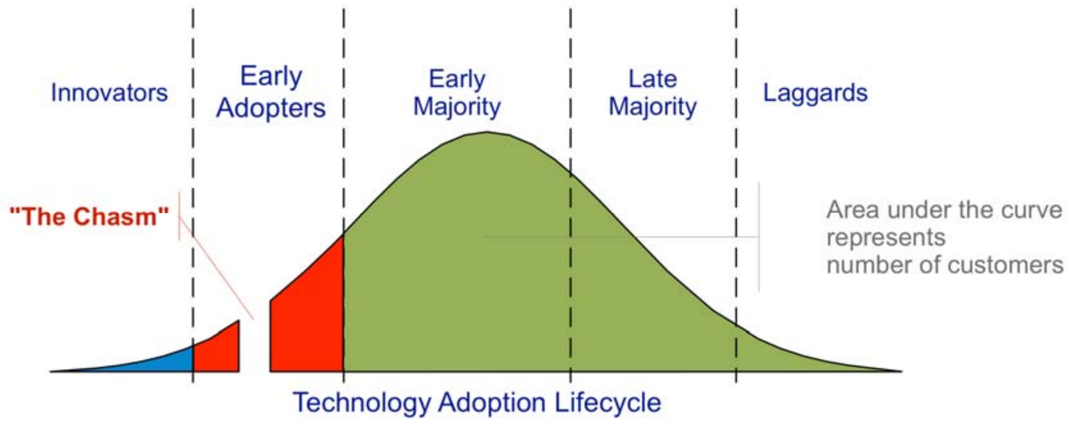

Fig 4. Technology adoption lifeline showing transition from one group of users to another (Moore, 1991).

Innovative technology is often developed in RTD-programs or when patents need proof of concept. In order to gather more substantial data on emerging technologies, prototypes are used. Prototypes can be tested to avoid unacceptable performance. This can be done for new technologies, but also for whole systems (Vereijken, 1997). Prototyping is usually preceded by brainstorm sessions based on initial identified needs. This was executed in several meetings with farmers as early as 2003. The first exploratory design of a prototype was published as a student project (Kromdijk, 2003). Evaluation of sustainability aspects of AMS resulted in more detailed knowledge about the problems with grazing, and the need for innovative ideas to combine the wishes for labour reduction and efficiency together with rational and optimal use of pasture for grazing, animal care and consumer desire. The principle idea of this adapted AMS technology was to prevent fetching of cows from the field to be milked in the barn by transporting the milking device into the field, in order to maintain the cow's grazing situation. In this way the problem of allocation of fields too far away from the barn could be addressed.

The process of actually building an experimental prototype took a further 4 years and in 2007 the world's first mobile automatic milking prototype was presented (Oudshoorn, 2007). When testing the prototype, it showed that even though the automatic milking unit was situated in the field, which maximized grazing (one of the identified sustainability issues which was threatened by the AMS in the barn); there were numerous other practical problems to be solved. The first years have been used to document the results and optimize construction and management in an iterative way to progressively refine the system. The mobile automatic milking unit is still in the innovation phase of the technology adoption lifecycle (Fig 4), and in 2009 only three mobile automatic milking systems of this design (Oudshoorn, 2007) are in practice. Parallel to the development in Denmark, another idea was launched in the Netherlands. Mobile automatic milking could also be used to facilitate profitable grazing of remnant nature areas. Also here a prototype was constructed and tested (Van Houwelingen et al., 2009).

The sustainability analysis of automatic milking systems on organic dairy farms as performed in this PhD study gives a well documented path for evaluating the mobile AMS, before coming in the early majority phase.

6.4 General Conclusions

The conclusions are based on the work presented in this thesis including the general discussion of the project;

- Consequences of implementation of AMS go far beyond simple economic performance. Farm management aspects like grazing, labour requirements, animal welfare, milk quality and environmental aspects like eutrophication and greenhouse gas emissions are at stake.
- Systematic quantification of sustainability indicators on nine organic farms with automatic milking systems (AMS) and nine with conventional milking systems (CMS), identified a 40% lower N surplus per ha on CMS compared to AMS farms. Direct labour time per milking cow per year was 50% lower on AMS compared to CMS farms. Culling rate was 6% higher and grazing time was halved on AMS compared to CMS farms.
- The level of free fatty acid (FFA) was higher in milk from organic AMS farms (0.78 mEq/l) compared to organic CMS farms (0.49 mEq/l); For both AMS and CMS farms, however, this FFA content still is lower than the FFA of milk from conventional farms with AMS.
- The effect of limiting grazing time from nine to four hours on milk yield was small, while feeding the same supplementary feed in the barn. Cows compensated their reduced grazing time by using all their time outside for grazing, instead of lying down or ruminating, causing increased activity outside among the animals.
- Limiting grazing time in combination with targeted feeding management could reduce N surplus problems arising in pasture, without compromising grass uptake.
- Evaluation of scenarios revealed that a high yielding organic dairy farm with major import of concentrates and outsourcing of field work and young stock (BAU), had a high local environmental impact per ha, a moderate GHG emission and energy use per kg produced milk, and a high economic risk to changes in milk price.
- Evaluation of scenarios revealed that introducing self sufficiency (ENV) especially reduced local environmental impact per ha, without an economic trade-off. The N-surplus was only 80 kg per ha, whereas this was around 116 in both the scenario prolonging current mean stream strategy (BAU) and the scenario investing in animal welfare (ANW).
- Evaluation of scenarios revealed that compared to BAU, investing in animal welfare (ANW) comprised trade-offs regarding farm profitability and especially global environmental issues such as climate change and fossil energy use.
- Considering that current strategic and technological development influences possible future threats on sustainability, scenario analysis in cooperation with stakeholders, using on-farm data, can be an option for policy making.
- Automatic milking can be characterized as innovative technology, which has been adopted by organic dairy farmers without thorough evaluation of the consequences.
- A stakeholder based, holistic sustainability assessment, as described in this study, was found suitable for analysis and evaluation of introduction of an automatic milking system on organic dairy farms.

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Summary

Organic agriculture provides products to a growing market segment in Denmark existing of consumers asking for healthy and high quality food products, an environmental friendly way of production and respect for animal welfare. Organic agriculture often claims and encourages being sustainable. Organic principles mention terms like fairness, ecological awareness in terms of closed biological cycles, and care. Fairness, although subjective, requires economic reserves and social stability. Care also is a social aspect and nowadays has been acknowledged as care for health and welfare of humans and animals. Three fundamental components can be mentioned as being important for sustainability: economic growth, environmental protection, and social acceptability (EES). Social acceptability includes issues related to human production such as ethics on animal welfare.

Development of organic agriculture was and is stimulated by focusing on specific needs or problems in the sector. Concerning primary production, technological innovation has shown encouraging results, such as mechanical weed control, and precision slurry injection techniques. Novel technology however, is often evaluated only on its own using premises like profitability, production requirements, and labour input. Often a holistic evaluation is lacking where both the physical technology itself, and the economic, ecological and societal implications of its usage, are evaluated. An example of an innovative technology in organic dairy production is the use of an automatic milking system (AMS). The economic, environmental and social consequences of introduction of AMS technology in organic dairy farming, however, have never been assessed.

The general objective of this PhD assignment, therefore, was to assess the contribution of new technologies to the sustainable development of organic dairy farming, using AMS as a case for the present technological situation. To accomplish this general objective, a framework for sustainability assessment, integrating qualitative and quantitative research, was used. This framework consists of the following steps:

1. Identification of stakeholders and description of the problem situation.
2. Determination of the goals of production and relevant economic, ecological and societal (EES) issues.
3. Translation of the selected issues into quantifiable indicators for sustainability as determined in step 2.
4. Final assessment of the contribution of a technology to sustainable development based on the indicator quantification in step (3)
5. Communication and dissemination of results to stakeholders, review of the process, and evaluation of results on basis of the original problem definition.

Use of this framework for a sustainability assessment of AMS use on organic dairy farms resulted in the following research questions:

a. What are the economic, ecological and societal issues at focus when introducing AMS on organic dairy farms in the Netherlands and Denmark?
b. Do economic, ecological, and societal indicator scores differ between organic dairy farms using AMS and farms using a conventional milking system (CMS) in Denmark?
c. What is the effect of time-limited grazing on eutrophication, animal behaviour and milk quality?
d. What are the economic and environmental consequences of three vision-based scenarios for organic dairy farming in 2020?

To answer what economic, ecological and societal issues are at focus when introducing AMS on organic dairy farms, the general problems using AMS in Denmark and The Netherlands was described. Identification of EES issues was based on a comprehensive literature survey followed by focus group interviews. Evaluation of the literature showed that the main sustainability issues, affected by the use of AMS, addressed the dairy farm. In addition, the amount of AMS farms in Denmark was bigger than in The Netherlands, absolute and relative. The difference in AMS use between countries could emerge from the producers themselves or from the advisory system. Two stakeholder groups, therefore, were selected: farmers and advisors. Parallel sessions using focus group technique, were organized in both Denmark and The Netherlands.

Identified EES issues were: farm profitability, eutrophication, acidification, climate change, biodiversity, animal welfare, and milk quality. Many issues were connected to grazing, which was mentioned by stakeholders and literature as a crucial aspect for sustainability of organic dairy farming. Conclusions of the research pointed out uncertainty about the economic gain, difficulties with grazing, adaptation problems to technology, and image problems towards consumers. The latter results from a reduction in grazing time affecting both animal welfare and product quality.

For each EES at focus, we identified a sustainability indicator, i.e., a parameter to measure the state of that issue. Subsequently, to find out if economic, ecological, and social indicator scores in Denmark differ between organic dairy farms using AMS and farms using a conventional milking system (CMS), EES indicators were quantified on nine organic dairy farms with AMS and nine organic farms with CMS in Denmark. Milk yield per cow was higher for AMS farms (8,539 kg energy corrected milk (ECM) per cow annual compared to 7,302 kg ECM on CMS farms) but did not result in higher net profit to management. Nitrogen (N) surplus per hectare of available land was higher for AMS farms than for CMS farms (110 kg N/ha compared with 66 kg N/ha). Animal health was unaffected by AMS use, although culling rate was 6% higher (38%). Most milk quality aspects such as somatic cell count, clostridium spores, and urea were the same for AMS and CMS users. Acid degree value (ADV), measured as free fatty acids (FFA) in the milk, was higher in milk from AMS users (0.78 mEq/l) compared CMS users (0.49 mEq/l). Labour time measured in hours of work per dairy cow per year, was decreased by almost 50% for AMS users, to 14 h/cow/year. Grazing time for the cows on CMS farms was more than twice the time as for AMS farms (2083 hours and 968 hours respectively for a growing season). It was concluded from quantification of selected indicators, that the organic dairy farms using AMS, in spite of the substantial decrease in grazing time, show the potential for sustainable development.

Results of participative research and results from the quantification of sustainability indicators revealed that many farmers had problems with satisfactory grazing. For the organic AMS farm wanting to maintain milk yield level and comply with the organic standards of grazing, the question was how much grass a cow can eat in a short time span, and how this affects manure deposition in the field. To investigate if time limitation of grazing, whilst feeding the same amount of supplementary feed in the barn, could affect eutrophication, urination and defecation behaviour were quantified. These questions were addressed in a grazing experiment, where three different grazing times, i.e. four, six and a half, and nine hours a day, were compared while providing the animals with the same amount of supplementary feed inside. Milk yield and grass uptake were estimated (Kristensen et al., 2007), together with walking distance, urination and defecation frequency and location. Using the same experimental setup, milk quality aspects (i.e., fatty acid concentration) were investigated by comparing milk from four hours grazing with milk from nine hours grazing, pooling the milk samples from morning and evening milking. (Jayashree et al., 2008).

Cows allowed grazing at pasture for four hours moved more rapidly during pasture, moved longer distance per active hour and used a higher proportion of the time eating, both at pasture and indoor, than the cows allowed longer time at pasture. Limiting the grazing time had no influence on the urination (mean=0.26) and defecation (mean=0.37) frequency per cow per hour during pasture. Urine and faeces were distributed in the pasture, without specific hot-spots. The estimated daily N-balance at animal level showed increased N excretion with time at pasture. The conclusion of this research was that it is possible to reduce the nitrogen excretion in a grazing system by restricting the grazing time of dairy cows together with restricted indoor feeding while maintaining high foliage intake.

To investigate what could be the economic and environmental consequence of organic dairy farming in the future in Denmark, three goal vision scenarios were defined for 2020 and evaluated. Goals and visions for future organic dairy farming were investigated and defined in a participatory process involving stakeholders. The business as usual scenario (BAU), was driven by economic incentives, and implemented new technologies and measures to enhance productivity and efficiency. This scenario was expected to be the mainstream strategy of future organic dairy production in Denmark. The animal welfare scenario (ANW), where economic efficiency was subordinate to animal welfare, aimed to improve animal welfare by incorporating a lower milk yield, extra grazing area and a deep litter barn. The environmental scenario (ENV), was designed to minimize environmental burden, and, therefore was based on self-sufficiency regarding nutrients and feed. Scenarios were defined based on extrapolated data from the quantification research integrated with historical data, on-farm registration from national data managing systems, and expert knowledge, and evaluated on their economic and ecological performance. Evaluation of scenarios revealed, that compared to prolonging the current main stream strategy (BAU), investing in animal welfare comprised trade-offs regarding farm profitability and especially global environmental issues such as climate change and fossil energy use. In ANW, net profit per farm was almost 39 k€ lower than in BAU, whereas emission of greenhouse gases and energy use per kg ECM was respectively 7% and 9% higher. Minimizing environmental impact in ENV reduced local environmental impact with 31% compared to BAU and ANW, without an economic trade-off.. Prolonging the current main stream strategy (BAU) resulted in a high local environmental impact, a moderate global environmental impact and a high economic risk to decrease of milk price.

The final conclusions of the research presented in this thesis are:

- Consequences of implementation of AMS go far beyond simple economic performance. Farm management aspects like grazing, labour requirements, animal welfare, milk quality and environmental aspects like eutrophication, acidification, biodiversity and greenhouse gas emissions are at stake.
- Systematic quantification of sustainability indicators on nine organic farms with automatic milking systems (AMS) and nine with conventional milking systems (CMS), identified a 40% lower N surplus per ha on CMS compared to AMS farms. Direct labour time per milking cow per year was 50% lower on AMS compared to CMS farms. Culling rate was 6% higher and grazing time was halved on AMS compared to CMS farms.
- The level of free fatty acid (FFA) was higher in milk from organic AMS farms (0.78 mEq/l) compared to organic CMS farms (0.49 mEq/l); For both AMS and CMS farms, however, this FFA content still is lower than the FFA of milk from conventional farms with AMS.
- The effect of limiting grazing time from nine to four hours on milk yield was small, while feeding the same supplementary feed in the barn. Cows compensated their reduced grazing time

by almost using all their time outside for grazing, instead of lying down or ruminating, causing increased activity outside among the animals.

- Limiting grazing time in combination with targeted feeding management could reduce N surplus problems arising in pasture, without compromising grass uptake.
- Evaluation of scenarios revealed that a high yielding organic dairy farm with major import of concentrates and outsourcing of field work and young stock (BAU), had a high local environmental impact per ha, a moderate GHG emission and energy use per kg produced milk, and a high economic risk to changes in milk price.
- Evaluation of scenarios revealed that introducing self sufficiency (ENV) especially reduced local environmental impact per ha, without an economic trade-off. The N-surplus was only 80 kg per ha, whereas this was around 116 in both the scenario prolonging current mean stream strategy (BAU) and the scenario investing in animal welfare (ANW).
- Evaluation of scenarios revealed that compared to BAU, investing in animal welfare (ANW) comprised trade-offs regarding farm profitability and especially global environmental issues such as climate change and fossil energy use.
- Considering that current strategic and technological development influences possible future threats on sustainability, scenario analysis in cooperation with stakeholders, using on-farm data, can be an option for policy making.
- An automatic milking system can be characterized as innovative technology, which has been adopted by some organic dairy farmers without thorough evaluation of all sustainability consequences.
- A stakeholder based, holistic sustainability assessment, as described in this study, was found suitable for analysis and evaluation of introduction of an automatic milking system on organic dairy farms.

Samenvatting

De biologische landbouw in Denemarken voorziet in de groeiende vraag van consumenten naar gezonde kwaliteitsproducten die op een milieuvriendelijke manier met respect voor dierwelzijn zijn geproduceerd. Biologische landbouw streeft naar en werkt aan duurzaamheid. De uitgangspunten van de biologische landbouw zijn: sociaal-maatschappelijke rechtvaardigheid, milieubewustzijn en zorg voor de gezondheid en het welzijn van mens en dier. Deze uitgangspunten komen ook terug in de drie domeinen van duurzaamheid. Een agrarisch bedrijf is duurzaam indien deze economische rendabel, ecologisch verantwoord en sociaal-maatschappelijke acceptabel is. Sociaal-maatschappelijke acceptatie van een productiemethode omvat onder andere de ethiek van dierwelzijn.

De ontwikkeling van de biologische landbouw werd en wordt gedreven door het zoeken naar oplossingen voor problemen in de sector. Technische innovaties, zoals mechanische onkruidbestrijding of precisie-injectie van drijfmest, hebben bemoedigende resultaten voor de primaire sector opgeleverd. Innovatieve technologieën worden, voor introductie, veelal enkel beoordeeld op hun directe gebruiksaspecten, zoals winstgevendheid, grondstofgebruik, hanteerbaarheid of arbeidsbehoefte. Een holistische beoordeling waarbij naast deze directe gebruiksaspecten ook aandacht is voor andere economische, ecologische en sociaal-maatschappelijke gevolgen ontbreekt.

Een voorbeeld van een innovatieve technologie die is ingevoerd in de biologische landbouw is het gebruik van een automatisch melksysteem (AMS). De economische, ecologische en sociaal-maatschappelijke gevolgen van het gebruik van AMS in de biologische melkveehouderij zijn niet eerder geëvalueerd.

De doelstelling van het onderzoek, zoals beschreven in dit proefschrift, was het vaststellen van de bijdrage van innovatieve technologieën aan de duurzame ontwikkeling van de biologische melkveehouderij. De introductie van een AMS is in dit onderzoek als een casus uitgewerkt.

Om inzicht te krijgen in de bijdrage van de introductie van een AMS aan de duurzame ontwikkeling van de biologische melkveehouderij is gebruikt gemaakt van een bestaand raamwerk voor de evaluatie van duurzaamheid. In dit raamwerk worden de volgende stappen onderscheiden:

1. Vaststellen van relevante belanghebbenden en een nauwkeurige beschrijving van het probleem.
2. Analyseren van het doel van het systeem en definiëren van de relevante economische, ecologische en sociaal-maatschappelijke thema's.
3. Definiëren van een meetbare duurzaamheidindicator voor ieder thema zoals vastgesteld in stap 2.
4. Kwantificeren van duurzaamheidindicatoren voor bedrijven met en zonder AMS en analyseren van bijbehorende scores aangaande duurzaamheid.
5. Communiceren en verspreiden van de resultaten aan belanghebbenden, en evalueren van het proces op basis van de originele probleemstelling.

De toepassing van dit raamwerk voor het evalueren van de bijdrage van AMS aan een duurzame ontwikkeling van de biologische melkveehouderij resulteerde in de onderstaande vier vraagstellingen.

a. Welke economische, ecologische en sociaal-maatschappelijke thema's zijn van belang bij de introductie van een AMS in de biologische melkveehouderij in Nederland en Denemarken?
b. Zijn er verschillen in de scores van duurzaamheidindicatoren tussen biologische melkveebedrijven met een AMS en een conventioneel melksysteem (CMS) in Denemarken?
c. Wat is het effect van beweidingduur op de thema's eutrofiëring, diergedrag en melkkwaliteit?

d. Wat zijn de economische en ecologische gevolgen van drie scenario's in 2020, gebaseerd op verschillende toekomstvisies op de biologische melkveehouderij.

Om de vraag te beantwoorden welke economische, ecologische en sociaal-maatschappelijke thema's van belang zijn bij introductie van een AMS op biologische melkveebedrijven is eerst de algemene problematiek rondom AMS gebruik in Denemarken en Nederland beschreven. Vervolgens zijn op basis van een literatuuronderzoek en focusgroep interviews de relevante thema's geïdentificeerd. Uit het literatuuronderzoek bleek dat de belangrijkste thema's die beïnvloed werden door het gebruik van AMS betrekking hadden op het melkveebedrijf. Ook bleek het aantal melkveebedrijven met AMS groter in Denemarken dan in Nederland, zowel absoluut als relatief. Dit is mogelijk een gevolg van de houding van boeren of van de voorlichting. Er zijn daarom boeren en voorlichters in zowel Denemarken als Nederland geïnterviewd (focusgroep methode) om inzicht te krijgen in de relevante duurzaamheidthema's.

De geïdentificeerde thema's waren: winstgevendheid, arbeidsbehoefte, eutrofiëring, verzuring, klimaatverandering, biodiversiteit, dierwelzijn, en melkkwaliteit. Een groot aantal van deze thema's was gerelateerd aan beweiding. Zowel het literatuuronderzoek als de interviewresultaten lieten zien dat beweiding een essentieel onderdeel is van een duurzame biologische melkveehouderij. Ook werd duidelijk dat boeren en voorlichters onzeker waren over de het feit of AMS wel economisch rendabel was, problemen verwachtten rondom de combinatie AMS en beweiding en de techniek, en een mogelijke negatief effect verwachtten van AMS gebruik op het imago van consument over biologische melk. Dit laatste aspect zou het gevolg kunnen zijn van een verminderde beweiding, hetgeen effect kan hebben op dierwelzijn en melkkwaliteit.

Voor ieder relevant thema is vervolgens een duurzaamheidindicator geïdentificeerd. Dit is een parameter die de status van dat thema meet. Om inzicht te krijgen in de scores van duurzaamheidindicatoren tussen bedrijven met AMS en CMS zijn deze indicatoren gekwantificeerd op negen bedrijven met AMS en negen bedrijven met CMS. De jaarlijkse melkgift per koe bleek hoger op bedrijven met AMS (8539 kg meetmelk/koe/jaar) dan op bedrijven met CMS (7302 kg meetmelk/koe/jaar), maar het ondernemersinkomen verschilde niet tussen bedrijven met AMS en bedrijven met CMS. Het stikstof (N) overschot per hectare was hoger op bedrijven met AMS (110 kg N/ha) dan op bedrijven met CMS (66 kg N/ha). Dierwelzijn werd niet aantoonbaar beïnvloed door het gebruik van een AMS, alhoewel het percentage afgevoerde dieren 6% hoger was op bedrijven met AMS dan op bedrijven met CMS (nl. 38%). De meeste aspecten van de melksamenstelling, zoals het celgetal, het coligetal, het kiemgetal en het ureumgehalte waren gelijk voor bedrijven met AMS en met CMS. De concentratie aan vrije vetzuren in de melk (Free Fatty Acids) was hoger voor bedrijven met AMS (0,78 mEq/l) dan voor bedrijven met CMS (0,49 mEq/l). De benodigde arbeidstijd per koe was bijna 50% lager op bedrijven met AMS (14 u/koe/jaar) dan op bedrijven met CMS. De beweidingduur op CMS bedrijven (2083 uur per koe per jaar) was meer dan het dubbele van die op AMS bedrijven (968 uur per koe per jaar). Op basis van scores van deze duurzaamheidindicatoren is geconcludeerd dat bedrijven met AMS, ondanks de vermindering in beweidingduur, potentieel hebben voor duurzame ontwikkeling.

De resultaten van zowel de focusgroep interviews als de kwantificatie van duurzaamheidindicatoren op bedrijven lieten zien dat bedrijven met AMS moeite hadden met voldoende beweiding. Voor bedrijven met AMS die een hoge melkopbrengst willen halen is het van belang inzicht te krijgen in de vraag hoeveel gras een koe in een bepaalde tijd kan opnemen en wat het effect is van een bepaalde beweidingduur op dierwelzijn, eutrofiëring en melkkwaliteit. In dit promotieonderzoek is onderzocht wat het effect is van beweidingduur op de voeropname en de verdeling van mest en urine in het veld.

Dit is onderzocht in een beweidingproef, waarin drie beweidingtijden zijn vergeleken (vier, zes-en-een-half en negen uur) terwijl de dieren dezelfde hoeveelheid aanvullend voer kregen toegediend in de stal. In deze proef zijn de volgende parameters gekwantificeerd: de melkgift per koe, de grasopname per koe (Kristensen et al., 2007), de loopafstand in het veld, en de plek en de frequentie van mesten en urineren. In dit experiment is, voor een beweidingduur van vier en negen uur, eveneens de melksamenstelling gemeten (bijv. de vetzuursamenstelling van de melk). De melksamenstelling is apart geanalyseerd voor de ochtend- en avondmelk (Jayashree et al., 2008).

Koeien die vier uur graasden bewogen meer en sneller, liepen langere afstanden per uur en gebruikten een groter deel van hun tijd om te eten, zowel in de wei als in de stal, dan koeien die negen uur graasden. De beweidingduur had geen invloed op de frequentie van urineren (gemiddeld 0,26/koe/uur) en mesten (gemiddeld 0,37/koe/uur). Ook bleek de urine en mest gelijkmatig verdeeld over de wei. De N-uitscheiding per koe in de wei nam toe met de beweidingduur. De conclusie van dit onderzoek was dat het mogelijk is een hoge grasopname te combineren met een verminderde N-uitscheiding in de wei door de beweidingtijd te verminderen in combinatie met beperkte voerverstrekking in de stal.

De economische en ecologische gevolgen van de toekomstige biologische melkveehouderij in Denemarken zijn onderzocht met behulp van een scenariostudie. In deze studie zijn in een participatief proces met belanghebbenden, drie scenario’s voor de biologische melkveehouderij in 2020 gedefinieerd, op basis van doelen en visies voor de toekomstige melkveehouderij. Het “business as usual” scenario (BAU) had als hoofddoel winst maken en combineerde een efficiënte en productieve bedrijfsvoering met het gebruik van nieuwe technologie, waaronder een AMS. Dit scenario wordt beschouwd als het meest waarschijnlijk voor de toekomstige biologische melkveehouderij in Denemarken. In het “dierwelzijn” scenario (Animal welfare scenario oftewel ANW) was winst maken ondergeschikt aan dierwelzijn. Dit scenario streefde naar een verbeterd dierwelzijn door een lagere melkproductie per koe te combineren met meer land voor beweiding en een potstal in plaats van een ligboxenstal. Het ecologische scenario (Environmental scenario oftewel ENV) streefde naar het minimaliseren van de milieubelasting en is gebaseerd op zelfvoorziening met betrekking tot nutriënten en voer. De parameters in ieder scenario zijn gekwantificeerd op basis van extrapolatie van data afkomstig uit zowel dit onderzoek als historische databestanden in combinatie met kennis van experts. Ieder scenario is vervolgens bedrijfseconomisch en ecologisch geëvalueerd. Deze evaluatie liet zien dat investeren in dierwelzijn in vergelijking tot “Business as usual” resulteert in een 39 k€ lager bedrijfsresultaat, een toename van 7% in het gebruik van fossiele energie en 9% in de emissie van broeikasgassen per kg meetmelk. Het minimaliseren van de milieubelasting in ENV resulteerde in een vermindering van de lokale milieubelasting, door een 31% lager N-overschot ten opzichte van het “Business as usual” en “Dierwelzijn”, zonder afwenteling ten aanzien van het bedrijfsresultaat. Het “Business as usual” scenario daarentegen resulteerde in een hoog N-overschot per ha (lokale milieubelasting), een laag gebruik van fossiele energie en een lage emissie van broeikasgassen (globale milieubelasting) en bleek sterk afhankelijk van een goede melkprijs.

De volgende conclusies kunnen worden getrokken op basis van het onderzoek zoals gepresenteerd in dit proefschrift:

- De gevolgen van het invoeren van een AMS op bedrijven zijn veel breder dan enkel bedrijfseconomisch. Inzicht is van belang in de gevolgen van het gebruik van een AMS voor bedrijfsvoering zoals beweiding, arbeidsbehoefte, dierwelzijn en melkkwaliteit, en milieu effecten zoals eutrofiëring, verzuring, de emissie van broeikasgassen en biodiversiteit.

- Een systematische kwantificering van duurzaamheidindicatoren op negen biologische melkveebedrijven met AMS en negen met CMS liet zien dat het N-overschot 40% lager was op CMS dan op AMS bedrijven, de directe arbeidstijd per koe 50% lager was op AMS dan op CMS bedrijven, het afvoerpercentage 6% hoger was op AMS dan op CMS bedrijven en de beweidingduur 50% lager was op AMS dan op CMS bedrijven.
- Het gehalte aan vrije vetzuren in de melk was hoger op biologische bedrijven met een AMS (0,78 mEq/l) dan op biologische bedrijven met een CMS (0,49 mEq/l). Voor beide type biologische bedrijven was het gehalte aan vrije vetzuren in de melk echter lager dan die in de melk van gangbare bedrijven met een AMS.
- Bij een gelijkblijvende voervoorziening in de stal bleek het effect van een vermindering van de beweidingduur van negen uur naar vier uur per dag nauwelijks van invloed op de melkgift per koe. De koeien compenseerden de verminderde beweidingduur door bijna al hun tijd buiten te grazen, in plaats van te liggen of te herkauwen, met als gevolg een hoger activiteitsniveau in de wei.
- Een vermindering van de beweidingduur van negen naar vier uur in combinatie met doelgericht voermanagement kan het N-overschot per ha in de wei verminderen zonder effect te hebben op de dagelijkse grasopname per koe.
- Evaluatie van scenario's duidde erop dat hoog productieve biologische melkveebedrijven met grote import van krachtvoer en uitbesteding van werk en jongvee (BAU), een grote regionale milieu belasting vormen per ha, een beperkte broeikasgasemissie en energie verbruik per kg geproduceerde melk, en een groter risico bij prijsdaling van de melk hebben.
- Een scenario-analyse liet zien dat zelfvoorziening ten aanzien van nutriënten en voer (ENV scenario) op een biologisch melkveebedrijf het N-overschot per ha vermindert zonder afwenteling ten aanzien van de winstgevendheid van het bedrijf. Het N-overschot per ha in ENV was 80 kg, terwil het N-overschot in het "Business as usual" en "Dierwelzijn"scenario 117 en 116 kg was.
- Een scenario-analyse liet zien dat investeren in dierwelzijn (ANW scenario) in vergelijking tot "Business as usual" resulteert in een vermindering van de winstgevendheid van het bedrijf en een toename van het gebruik van fossiele energie en de emissie van broeikasgassen (globale milieubelasting).
- Gegeven dat de huidige strategische en technologische ontwikkelingen een negatief effect kunnen hebben op duurzaamheid, kan een evaluatie van scenario's ontwikkeld in samenwerking met belanghebbenden een mogelijkheid bieden voor beleidsbepaling.
- Een automatisch melksysteem blijkt een innovatieve technologie, die reeds door een aantal biologische melkveehouders in gebruik is genomen zonder een zorgvuldige analyse van de consequenties.
- Een holistische evaluatie van een technologie in samenspraak met belanghebbenden, zoals beschreven in het onderzoek in dit proefschrift, is geschikt voor de evaluatie van de introductie van een AMS op biologisch melkveebedrijven.

Resumé

Økologisk landbrug leverer produkter til et voksende dansk marked, som består af forbrugere, der efterspørger sunde kvalitetsprodukter, produceret på en miljøvenlig måde og med respekt for dyrevelfærd. Økologisk landbrug dels hævder og dels arbejder for at være bæredygtig, dvs. landbrug drevet efter de økologiske principper, som er social retfærdighed, miljøhensyn og omsorg. Omsorg omfatter sundhed og velfærd for både mennesker og dyr. Disse principper stemmer overens med de basisbegreber, som danner rammen for bæredygtighed, nemlig at produktionsmetoden er: a) økonomisk rentabel, b) miljøbeskyttende og c) social acceptabel (inkl. etik og dyrevelfærd).

Udvikling af økologisk landbrug fremmes ved at fokusere på både behov og problemer i sektoren. Hvad den primære produktion angår, har den teknologiske udvikling vist opmuntrende resultater, f.eks. mekanisk ukrudtsbekæmpelse og præcisionsinjektion af gylle.

Ny teknologi bliver desværre ofte kun evalueret efter dets egne præmisser i form af rentabilitet, produktions- og arbejdsbehov. Ofte mangler en holistisk evaluering, hvor ikke kun brugsværdi og økonomi tages i betragtning, men også økologiske og sociale følger af ibrugtagning indgår i vurderingen. Et eksempel på en innovativ teknologi er brugen af automatiske malkesystemer (AMS) i økologiske malkekvægsbesætninger. De økonomiske, miljømæssige og sociale konsekvenser ved introduktion af AMS på økologiske kvægbrug har aldrig været undersøgt.

Formålet med denne PhD afhandling har derfor været at analysere de nye teknologiers bidrag til bæredygtig udvikling af økologisk malkekvægsproduktion. Introduktionen af AMS bruges i dette studie som et eksempel på ibrugtagning af nutidens teknologi.

For at analysere, hvordan AMS kan bidrage til bæredygtighed i økologiske malkekvægsbedrifter blev en anerkendt systematisk bæredygtighedsanalyse anvendt, hvor både kvalitativ og kvantitativ forskning indgår. Analysen omfatter følgende trin:

1. At identificere interessenter og i fællesskab med dem identificere, præcisere og beskrive problematikker.
2. At fastsætte mål for produktionen, og fastlægge relevante økonomiske, økologiske og sociale temaer.
3. At definere kvantificerbare indikatorer for hvert af de identificerede bæredygtighedstemaer.
4. At analysere teknologiens bidrag til en bæredygtig udvikling, baseret på kvantificeringen foretaget i trin 3.
5. At kommunikere og formidle resultaterne til interessenter, gennemgå analyseprocessen, og derefter evaluere resultaterne på baggrund af den oprindelige problemformulering.

Bæredygtighedsanalysen af brugen af AMS på økologiske malkekvægbrug førte til følgende forskningsspørgsmål:

a. Hvilke økonomiske, økologiske og sociale temaer fremkommer, når AMS introduceres på økologiske malkekvægbrug i Danmark og Nederland?
b. Scorer økologiske kvægbrug, der bruger AMS og økologiske kvægbrug, der bruger konventionelt malkeudstyr (CMS) forskelligt, når økonomiske, økologiske og sociale indikatorer kvantificeres?
c. Hvilken effekt har tidsbegrænset afgræsning på eutrofiering, dyreadfærd og mælkekvalitet?
d. Hvad er de økonomiske og miljømæssige konsekvenser af scenarier år 2020, som er baseret på tre forskellige fremtidsvisioner for økologiske malkekvægbrug?

For at kunne besvare hvilke økonomiske, økologiske og sociale temaer, der skal fokuseres på når AMS introduceres på økologiske malkekvægbedrifter, blev den generelle problematik ved AMS-brug i Danmark og Nederland beskrevet. Identifikationen af økonomiske, økologiske og sociale temaer var baseret på en udførlig litteraturgennemgang, efterfulgt af en fokusgruppeundersøgelse.
Evalueringen af litteraturen viste, at de identificerede bæredygtigheds temaer i forbindelse med brug af AMS på økologiske bedrifter, knyttede sig til bedriftens produktion. Yderligere viste det sig, at forskellene mellem antallet af økologiske AMS brug i Danmark og Nederland kan være en følge af holdningen blandt driftsledere og rådgivere. Derfor blev der valgt to grupper af interessenter: landmænd og rådgivere. Fokusgruppemetoden blev anvendt, og parallelmøder blev arrangeret i Danmark og Nederland.

Identificerede temaer var: bedriftsøkonomiske resultater, arbejdsbehov, eutrofiering, forsuring, klimaændring, biodiversitet, dyrevelfærd og mælkekvalitet. Mange af disse temaer havde forbindelse med afgræsning, hvilket af både interessenter og litteraturen blev nævnt som afgørende for bæredygtigheden af økologisk malkekvægsbrug. Konklusionerne af denne undersøgelse pegede på usikkerheden blandt interessenter med hensyn til økonomisk gevinst, problemer med afgræsning, problemer med tilvænning til ny teknik og imageproblemer overfor forbrugerne. Det sidste blev nævnt i forbindelse med formindsket afgræsning, hvilket påvirker både dyrevelfærd og produktkvalitet.

For hvert relevant tema, blev bæredygtighedsindikatorer kvantificeret, det vil sige parametre, der kunne gøre temaet målbart og sammenligneligt. Derefter, for at analysere om økonomiske, økologiske eller sociale indikatorer scorer forskelligt mellem økologiske malkekvægbedrifter, der bruger AMS eller CMS, blev økonomiske, økologiske og sociale indikatorer kvantificeret på ni økologiske kvægbedrifter med AMS og ni med CMS i Danmark. Mælkeydelsen var højere for AMS bedrifter (8539 kg energi korrigeret mælk [EKM] per år sammenlignet med 8302 kg EKM på ECM bedrifter), men resulterede ikke i bedre økonomiske driftsresultater.
Kvælstof (N) overskud per hektar jord var højere for AMS bedrifter end for CMS bedrifter (110 kg/ha sammenlignet med 66 kg/ha). Dyrenes sundhed var ikke påviselig anderledes ved brug af AMS , selvom udskiftningsprocenten var 6% højere (38%). De fleste mælkekvalitetsaspekter som celletal, sporetal, kimtal eller Ureum indhold var ens for AMS brug og CMS brug. Surhedsgraden, målt som frit fedtsyreindhold i mælken, var højere i mælk fra AMS brugere (0,78 mEq/l) end for mælk fra CMS brugere (0.49 mEq/l). Arbejdstidsforbrug blev reduceret med 50% for AMS brugere (14 timer/ko/år). Afgræsningstiden var næsten dobbelt så lang for CMS bedrifter som for AMS bedrifter (2083 timer og 968 timer respektive for en afgræsningssæson). På basis af disse bæredygtighedsindikatorer kunne konkluderes, at økologiske malkekvægbedrifter, som bruger AMS, har en potentiale for bæredygtighed, selvom de afgræsser betydeligt mindre.

Resultaterne af fokusgruppeundersøgelser og kvantificeringen af bæredygtighedsindikatorer på økologiske malkekvægbedrifter med AMS afslørede, at mange driftsledere havde problemer med tilstrækkelig afgræsning. For den økologiske AMS bedrift, der vil sikre mælkeydelsen og leve op til de økologiske standarder angående afgræsning, er spørgsmålet: hvor meget græs kan en ko æde i kort tid, og hvordan påvirker det koens gødningsmængder og adfærd i marken. For at undersøge hvordan tidsbegrænset afgræsning påvirker eutrofieringen, blev urin- og gødningsadfærd undersøgt. Et afgræsningseksperiment udført, hvor tre afgræsningsperioder indgik: fire, seks-og-en-halv og ni timer per dag, mens dyrene fik den samme mængde suppleringsfoder i stalden. Mælkeudbytte og græsoptag blev kvantificeret (Kristensen et al., 2007), ligesom dyrenes bevægelsesmønster incl. hastighed, urin- og gødningsfrekvens, samt placering. I samme eksperiment blev mælkekvalitetsaspekter (fedtsyrekoncentration og sammensætning) undersøgt ved at sammenligne mælk fra fire timers afgræsning med mælk fra ni timers afgræsning, hvor morgen- og aftenmælk blev holdt adskilt (Jayashree et al., 2008).

Køerne, som kun var ude i 4 timer, bevægede sig hurtigere mens de græssede, gik længere afstande per time, de var mere aktive og brugte en længere procentdel af deres tid med at æde, både i græsmarken og i stalden. Begrænsning af afgræsningstiden havde ingen effekt på urin- (gennemsnit = 0,26) og gødnings- (gennemsnit = 0,37) frekvensen per ko per time udenfor. Urin og gødning blev ligeligt fordelt i marken. Den estimerede mængde N-overskud på ko-niveau viste en stigning ved længere tid i marken. Konklusionen af denne undersøgelse var, at det er muligt at begrænse N-udledning i et afgræsningssystem ved at begrænse afgræsningstid fra ni til fire timer ved samme mængder suppleringsfoder i stalden, og dermed fastholde et højt optag af græs i marken.

For at undersøge de økonomiske og økologiske konsekvenser for et fremtidigt malkekvægbrug blev tre scenarier defineret på bedriftsniveau, baseret på forskellige visioner og mål. Målene og visionerne for en fremtidig økologisk malkekvægsbrug i 2020 blev undersøgt og defineret i en interaktiv proces, hvor interessenter var involveret. ”Business as usual” scenariet (BAU) havde økonomi som hovedmål, og nye teknologier indføres for at producere effektiv og produktiv. Dette scenario forventes at være mest sandsynligt for fremtidens økologiske mælkeproduktion i Danmark. I ”dyrevelfærd” scenariet (animal welfare og derfor ANW) betragtes økonomi underordnet dyrevelfærd, og dette efterstræbes ved at satse på lave mælkeudbytter per ko, større afgræsningsareal og mere afgræsningstid, kombineret med dybstrøelsesstald. Miljøscenariet (environmental og derfor ENV) blev udformet til at minimere miljømæssig belastning, hvilket efterstræbes ved selvforsyning for foder og næringsstoffer. De tre scenarier blev udarbejdet ved at sammensætte ekstrapoleret data fra kvantificeringsundersøgelsen på gårdniveau med kvægdatabasens oplysninger og ekspertviden på dette område. Derefter blev scenarierne evalueret på deres økonomiske og miljømæssige præstation. Evaluering af disse scenarier viste, i sammenligning med ”Business as usual” (BAU), ville investeringer i dyrevelfærd (ANW) give lavere økonomiske driftsresultater og betydelige globale miljøbelastninger i form af drivhusgas og energiforbrug. I ANW scenariet var bedriftsresultatet næsten 39.000 Euro lavere end i BAU scenariet, og samtidig var drivhusgasbelastningen og energiforbruget 7% og 9% højere per kg EKM. Begrænsning af miljøbelastning (ENV) reducerede de lokale miljøpåvirkninger per ha, uden økonomisk tab. N-overskuddet for ENV var kun 80 kg/ha, hvor det var 117 kg/ha for BAU og 116 kg/ha for ANW. Fortsættelse af den nuværende strategi (BAU) resulterede i høje lokale miljøbelastninger og begrænset global belastning, men en høj økonomisk risiko ved faldende mælkepriser.

De samlede konklusioner af tesens forskning er:

- Konsekvenserne af implementering af AMS er langt bredere end økonomisk præstation. Managementaspekter som afgræsning, arbejdsbehov, dyrevelfærd, og mælkekvalitet samt miljøpåvirkninger som eutrofiering, forsuring, biodiversitet og drivhusgas emissioner bliver berørt.
- Systematisk kvantificering af bæredygtighedsindikatorer fra ni økologiske bedrifter med AMS og ni med CMS, viste 40% lavere N overskud per ha på CMS sammenlignet med AMS. Det direkte arbejdsbehov per malkeko om året var 50% lavere for AMS bedrifter sammenlignet med CMS bedrifter. Udskiftningsprocenten var 6% højere og afgræsningstiden blev halveret for AMS bedrifter sammenlignet med CMS bedrifter.
- Niveauet af frie fedtsyre var højere i mælken fra økologiske AMS bedrifter (0,78 mEq/l) sammenlignet med økologiske CMS bedrifter (0,49 mEq/l); for både AMS og CMS

bedriftens mælk var det frie fedtsyreindhold dog lavere end i mælk fra konventionelle bedrifter med AMS.

- Indflydelsen af begrænsning af afgræsningstid fra ni timer til fire timer på mælkeydelsen, mens niveauet af suppleringsfoder i stalden blev holdt konstant, var lille. Køerne kompenserede for begrænsningen ved at bruge al deres tid ude med afgræsning, i stedet for at ligge ned eller drøvtygge, hvilket gav et forhøjet aktivitetsniveau udenfor.
- Begrænset afgræsningstid i kombination med målbevidst fodring indenfor kunne reducere de N-overskudsproblemer, der opstår i græsmarken, uden at det går ud over græsoptagelsen.
- Evalueringen af scenarierne påviste, at en højtydende økologisk malkekvægsbedrift med stor import af kraftfoder og udlicitering af markarbejde og kvier (BAU) havde en høj lokal miljøbelastning per ha, en begrænset drivhusgasemission per kg EKM og var følsom for faldende mælkepriser.
- Evalueringen af scenarierne påviste, at introduktion af selvforsyning (ENV) specielt reducerede lokal miljøbelastning per ha, uden negativ økonomisk følge. N-overskuddet var kun 80 kg/ha, sammenlignet med ca. 116 i både scenariet, der viser den nuværende udvikling (BAU), og scenariet der satser på dyrevelfærd (ANW).
- Evalueringen af scenarierne påviste, at sammenlignet med BAU, investeringer i dyrevelfærd (ANW) giver negative økonomiske konsekvenser og større global miljøbelastning med hensyn til drivhusgas og energiforbrug per kg EKM.
- I betragtning af, at nuværende strategisk og teknologisk udvikling har indflydelse på mulige fremtidige belastninger af bæredygtighed, kunne en scenario analyse, hvor interessenter involveres, være en mulighed for strategisk politik.
- Automatiske malkningssystemer er en innovativ teknologi, som blev indført af nogle økologiske kvægbrugere uden grundig evaluering af alle bæredygtigheds-konsekvenserne.
- En interessent baseret, holistisk bæredygtigheds analyse, som beskrevet i denne tese, er fundet brugbar til analyse og evaluering af introduktion af automatiske malkesystemer på økologiske malkekvægsbedrifter.

Future Perspectives

Based on the research presented in this thesis it would be interesting to follow the introduction of novel technologies to organic farming and possibly introduce a form for holistic sustainability assessment before implementing them. Novel technologies which are being introduced and discussed at this moment are use of autonomous robots in horticulture and livestock farming, sexing of sperm to secure female stock in dairy herds, and the use of GMO (Genetically Modified Organisms) in arable cropping. The sustainability analysis used in this PhD research would be suitable, as also the scenario analysis which was used for final integration of the results of the first steps comprising definition of the goals, analysis of sustainability issues, and definition and quantification of relevant indicators.

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Curriculum vitae

Frank Willem Oudshoorn was born in 1957 in Geleen, in the south of The Netherlands. After completing secondary education he started his study of plant sciences at Wageningen University in 1976 (formerly Agricultural University in Wageningen) with special emphasis on crop production, organic agriculture, soil fertility and philosophy. After graduation in 1984, he worked as an academic employee for the department of alternative agriculture where he evaluated the perceptions of other departments on this relatively new research area. In 1985, he immigrated to Denmark, the country where he fulfilled an internship of three months during his studies. After some different jobs as farm and gardening employee, and freelance journalist for the Danish agricultural press he started a job as an agricultural consultant in Jutland. This job started with advising conventional crop producers and slowly changed to advising organic farmers, which became his expertise area. During the boost in growth of organic farming in Denmark, over 100 organic farms had an advisory contract with him. In 1999 he became scientific manager of the first Danish organic research farm, comprising arable production, pig and dairy cattle farming. As scientific manager he was employed by the Danish applied research center for agricultural science and worked for the department of agricultural engineering. During this period, he was inspired to continue working in research. In 2004 a stipendium was found for a PhD. At that time organic dairy farmers in Denmark were investing in automatic milking systems and experienced problems with implementing this new technology. The topic for his PhD study was born. He thoroughly discussed this idea with the head of his department and found a promoter at the animal production systems group of Wageningen University. In 2004 he officially started his PhD work which resulted in this thesis. During his PhD period he also continued his work at the department of agricultural engineering and helped to develop the first mobile milking robot, milking in the field at summertime. After promotion he will work as researcher within the group of automation and system engineering, within the department of agricultural engineering, Aarhus University.