STELLINGEN

1. Bij de huidige stand van de wetenschap moet het toepassen van gedwongen koeverkeer in een ligboxenstal met een automatisch melksysteem ontraden worden.
   Dit proefschrift

2. Het beschikbaar stellen van een krachtvoerbox die alleen na het passeren van het automatisch melksysteem bereikbaar is, maakt een efficiënt gebruik van het automatisch melksysteem mogelijk.
   Dit proefschrift

3. Leveranciers van automatische melksystemen dienen er bij de berekening van de capaciteit van hun systemen rekening mee te houden dat de koeien het systeem niet gelijkmatig verspreid over de dag bezoeken.
   Dit proefschrift

4. Het achterwege laten van weidegang bij de toepassing van automatische melksystemen is overbodig.
   Dit proefschrift

5. "The most unnatural of all unnatural acts is to breed a cow capable of producing over 40 litres/day then restrict her to two milkings instead of the 5-7 feeds she would normally allow her calf."
   (John Webster, Understanding the dairy cow, 2nd. Edition, Blackwell Science, Cambridge, 1993)

6. De vooruitgang in de statistiek heeft het mogelijk gemaakt om van het eenvoudigste experiment nog een statistisch meesterwerk te maken.

7. Wetenschappers die denken de waarheid in pacht te hebben, zijn niet wetenschappelijk.

8. Het fokken van dieren met morfologische kenmerken die een normaal functioneren in de weg staan, zou verboden moeten worden.

9. Als het effect van reorganisaties net zo groot zou zijn als dat van de aankondiging ervan, zou met minder bezuinigingen volstaan kunnen worden.

10. Werkende moeders worden nogal eens als ontaard bestempeld terwijl ze zich niet anders gedragen dan werkende vaders.

11. De vooruitgang in de kloontechnologie maakt het mogelijk een wereldbevolking te creëren die uit louter vrouwen bestaat; dit biedt wellicht perspectief voor de wereldvrede.

12. Leidinggevenden zouden moeten worden verplicht een cursus Human Resource Management te volgen.

13. Handsfree telefoneren in de auto maakt zelfs van de saaiste automobilist een volmaakte mimespeler.

Stellingen behorende bij het proefschrift:
Cow behaviour and managerial aspects of fully automatic milking in loose housing systems

Carolien C. Ketelaar-de Lauwere
Wageningen, 11 juni 1999

COW BEHAVIOUR AND MANAGERIAL ASPECTS OF FULLY AUTOMATIC MILKING IN LOOSE HOUSING SYSTEMS

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COW BEHAVIOUR AND MANAGERIAL ASPECTS OF FULLY AUTOMATIC MILKING IN LOOSE HOUSING SYSTEMS

Carolien C. Ketelaar-de Lauwere

Proefschrift

ter verkrijging van de graad van doctor,
op gezag van de rector magnificus
van de Landbouwuniversiteit Wageningen,
Dr. C.M. Karssen,
in het openbaar te verdedigen
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ABSTRACT

Ketelaar-de Lauwere, C.C., 1998. Cow behaviour and managerial aspects of fully automatic milking in loose housing systems.

In this study of cow behaviour and managerial aspects of fully automatic milking, the emphasis was on implementing automatic milking systems (AMS) in cubicle houses in a way that suits cows and farmer. The starting points of the research were that the cows would visit the AMS voluntarily and that the system would be available almost continuously. The effects of the cows' social hierarchy, the cow traffic towards the AMS and the combination of grazing and fully automatic milking were studied.

The cows' social hierarchy only affected the timing of forage eating and AMS visits. Cow routing procedures that more or less forced cows to visit the AMS because that was the only way they could reach the forage appeared to be questionable with regard to the cows' adaptation to the AMS environment. In these cases of forced cow routing, eating behaviour seemed to be postponed or even thwarted and there was more idle standing. Free cow traffic, during which cows could themselves decide when to visit the AMS, did not appear to suit the farmer because the milking frequency of individual cows was not sufficiently reliable. A third type of cow traffic in which cows could move freely between the feeding and lying areas but had to pass through the AMS to reach the concentrate feeder appeared to be a good solution for both the farmer and the cows. The cows paid sufficient visits to the AMS, had shorter waiting times in front of the concentrate feeder and less aggression was seen there. Supplying new concentrate every four hours instead of every two hours increased the time spent resting in the barn.

It was found that grazing and fully automatic milking could be combined. When cows had access to a pasture they did return to the AMS by themselves several times a day, depending on the weather and the sward height. Cows spent more time indoors when the ambient temperature was high. At lower sward heights, they also spent more time indoors and at the feeding gate, paid more visits to the AMS and were milked more often. Distances of up to 350 m between the pasture and the barn did not affect the number of AMS visits.

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Voor Gerard, Jos, Robin en Remco

en mijn moeder en pleegvader

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Carolien Ketelaar

Bennekom, april 1999

CONTENTS

CHAPTER 1

GENERAL INTRODUCTION

BACKGROUND

Dairy production systems have gone through marked changes in recent decades. The main reasons for these changes are a decrease of economic margins, further intensification and increasing labour costs. Comparing surveys of farm profits for the financial years 1981/1982 and 1994/1995 shows that labour costs on Dutch dairy farms increased by ten guilders per 100 kg milk (Anonymous, 1984 and 1997). However, advances in mechanisation, automation, housing and milking facilities have allowed labour efficiency in milk production to improve (Rossing and Spahr, 1992). Loose housing was introduced and, related to that, milking parlours. These innovations offer great advantages as they reduce the capital expenditure on buildings and stalls, have good ergonomics and are adaptable for automation (Dodd and Hall, 1992). Simultaneously with the advance in technology the production potential of dairy cows increased as a result of genetic improvement. Surveys done by the Royal Dutch Cattle Syndicate show that the average milk yield per cow per lactation for Holstein Friesian cows rose from 5540 kg in 1982 to 7951 kg in 1997 (Anonymous, 1984 and 1997).

Both the technological development and the improved production potential of dairy cows increased the need for automation on dairy farms. Electronic identification developed rapidly and the invention of sensors enabled farmers to monitor the cows' milk yield, health, reproduction status and temperature on-line (Rossing and Spahr, 1992). Concentrate feeders were installed on farms enabling cows to be fed according to their individual needs with regard to milk yield, age and lactation stage. Concomitantly, management information systems became ever more sophisticated.

The last step in this progress is the development of fully automatic milking systems (AMS) in which cows are milked without human interference by a milking robot. When such a system is introduced on the dairy farm, more frequent milking becomes possible without extra labour (Sonck, 1995; Ipema, 1997). This suits the farmer very well, because both the labour efficiency of the farm and the milk production per cow will increase (Ipema and Benders, 1992). More frequent milking may be good for the cow because the high production potential of modern dairy cattle raises doubts about the advisability of the traditional twice-daily milking. Webster (1993) stated that restricting a high producing cow to two milkings daily is a major contributor to udder distension and thereby to disorders such as mastitis. Indeed indications have been found that higher milking frequencies improve udder health (Hillerton and Winter, 1992) and benefit the cows' welfare. It increased the lying times of high producing cows, presumably as a result of a lower pressure in the udder (Ipema, et al., 1988, 1991).

The introduction of automatic milking systems will provoke a complete change on dairy farms (De Boer et al., 1994). For the farmer changing to an AMS means a shift from several hours of routine labour seven days a week to more management-oriented tasks (Devir et al., 1993; Sonck, 1996). The extent of the shift depends on the way the AMS is used: if it is used solely to replace the farmer in the milking parlour, the farmer will still have to fetch the cows two or three times daily, and bring them to a waiting area in front of the AMS. This will not change his bondage to the farm. Moreover, this way of using an AMS will probably result in long waiting times for the cows because most systems in commercial use have only one or a few milking stalls in tandem. Hence the cows are milked more or less one by one (Uetake et al., 1997). In the present development of automatic milking systems the emphasis is on 'self service' milking (Ipema, 1997). For this, cows have to report to the system by themselves regularly, and the milking robot operates round the clock. When an AMS is used in this way, the reduction in labour is indeed substantially larger than when the AMS is used solely as a replacement for the farmer in the parlour (Sonck, 1995). The farmer or his deputy only has to be available for control tasks (Sonck, 1995).

For the cow, changing from two or three daily milkings at fixed times to 'self service' milking means that her environment and day is no longer distorted to fit human perceptions of what constitutes a working day and a working environment, but are instead predominantly shaped by the physiological and psychological needs of the cow herself (Webster, 1993). Whereas this may benefit her welfare, it means that cows cannot act as a co-ordinated social unit because they have to report to the system on an individual basis one after another. This can disturb social facilitation and reduce synchronised behaviour (Hurnik, 1992).

The most important condition for the success of automatic milking systems is that cows visit the system frequently enough and at regular intervals (Ketelaar-de Lauwere, 1992, Winter and Hillerton, 1995). This should be achieved in such a way that it suits both the farmer and the cow. For the farmer this means that fully automatic milking should be truly labour-saving. The attachment of the teat cups to the udder by the milking robot should be reliable, the need to fetch cows and bring them to the milking robot should be kept to a minimum, and the milking frequency attained should preferably be higher than the traditional twice daily. These aspects have been studied earlier by Devir (1995), who focussed on the dairy control and management system in the robotic milking farm, and by Sonck (1996), who studied the labour organisation on robotic milking dairy farms. In addition, much work has been dedicated to the technical functioning of automatic milking systems (Ipema, et al., 1992; Devir et al., 1996).

An automatic milking system may suit the cows, if the fully automated milking process is integrated into the cows' daily behavioural cycles of feeding and lying in a 'natural' way such that disruption of lying periods is minimal, feeding is not postponed and sufficient time is available for other maintenance behaviours (Metz and Ketelaar-de Lauwere, 1995). Therefore, the design of an automatic milking system should harmonise with the psychological and social tendencies of dairy cows (Hurnik, 1992). These aspects were studied by Winter (1993) who focussed on the modification of inherent behaviour patterns of dairy cows under frequent and automatic milking systems and by Prescott (1995) who studied the behaviour of dairy cows in relation to automatic milking, looking especially at the cows' motivation for milking and the factors affecting this.

OBJECTIVES OF THE STUDY

In the research described in this thesis the emphasis lay on the implementation of fully automatic milking systems in cubicle houses in a way that suits the cows and the farmer. The starting points of the research were that the cows would visit the AMS voluntarily and that the system would be available almost continuously.

The approach followed was intended to elucidate the consequences of fully automatic milking for the cows' social hierarchy, the cow traffic towards the AMS and the combination of fully automatic milking with grazing. The focus was on the cows; they must be able to adapt to a new AMS environment successfully. Therefore, their behaviour was studied in different AMS environments. The cows' time budgets were studied and, also the occurrence of aggression, because maintaining lying and eating times (Winter, 1993) and the exposure to aggression (Webster, 1993) are useful indicators for adaptation to a new environment. In addition, the effects of the type of the previous AMS visit on the cows' behaviour thereafter were studied because for a cow reporting to the AMS, it can be unpredictable, and therefore stressful (Wiepkema, 1988), whether she will be milked and receive concentrate there. However, new AMS environments cannot be implemented unless they are acceptable to the dairy farmer too. His interest is the timely milking of each cow under these new automated conditions. Hence, the frequency and timing of the cows' visits to the AMS were also studied.

OUTLINE OF THE THESIS

The thesis focuses on three main themes: social hierarchy, cow traffic and grazing.

Social hierarchy

The influence of social hierarchy on the cows' time budget and their visits to an AMS was studied (chapter 2) because the necessity for cows to report to the milking place individually is an important feature of automatic milking systems. This means that a competitive situation is created at the entrance of the AMS; this was expected to show similarities with the situation at automatic concentrate feeders (Winter, 1993).

Cow traffic

Cows have to visit an automatic milking system by themselves regularly. This can be achieved by either free or forced cow traffic (Ketelaar-de Lauwere, 1991, 1992). In free cow traffic, cows can decide by themselves whether to visit the AMS. In forced cow traffic, cows are more or less forced to visit the AMS because it is their only way to reach the forage. Free and forced cow traffic were compared in different experimental situations, first with a simulated AMS (chapter 3), and then in real AMS situations (chapter 4). This resulted in two other experiments in which a third type of cow traffic was studied. In these experiments concentrate was used to entice cows into the AMS (Pirkelmann, 1992; Ketelaar-de Lauwere and Benders, 1994). Cows could move freely between the feeding and the lying areas (as in free cow traffic), but had to pass through the AMS to reach the concentrate feeder. This type of cow traffic was compared with free cow traffic, in which the concentrate feeder was freely available (chapter 5).

Grazing

In the concept of automatic milking it is often assumed that grazing of cows is no longer possible because cows have to be kept near the AMS so that they will report to the system voluntarily (Prescott, 1995). But farmers, animal rights organisations, dairy industry and milk consumers all agree that grazing is an important condition for the successful introduction of fully automatic milking systems on the dairy farm (De Boer et al., 1994). Therefore, it was studied whether it would be possible to combine grazing with fully automatic milking on a voluntary basis (chapter 6). This study was set out to obtain information about the behaviour of cows under different grazing regimes, and about the external factors affecting this. The influence of the amount of grass and of the distance between the pasture and the AMS on the cows' visits to the AMS and other behaviour are examined in the last experiments described in this thesis (chapter 7).

In the general discussion (chapter 8), the main results of the experiments mentioned above are discussed in the light of the suitability of automatic milking systems for dairy farming. That chapter concludes by presenting the main conclusions of the thesis.

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CHAPTER 2

THE INFLUENCE OF SOCIAL HIERARCHY ON THE TIME BUDGET OF COWS AND THEIR VISITS TO AN AUTOMATIC MILKING SYSTEM

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ABSTRACT

The influence of social dominance on visits to an automatic milking system (AMS) was studied in 30 crossbred Holstein-Friesian dairy cows, kept in a cubicle house. The cows were fed concentrate and milked in the AMS, which consisted of two selection units (where cows were automatically identified and either sent to milking or back to herd) and one milking unit. In the first phase of the experiment (A), cows had a milking regime of 3 times per day. At first they always received 100 g of concentrate when they visited a selection unit (A1). Later, they were dispensed concentrate in the selection unit only if they still had some of their daily ration owed to them (A2). In the second experimental phase (B), 10 cows had a milking regime of 5 times a day and 19 cows of 3 times a day (one cow was culled due to severe mastitis). Concentrate was dispensed in time windows corresponding with the planned milking frequencies, and taking the individual pattern of visits to the AMS into account, in such a way that cows which visited the AMS less than they should according to their planned milking frequency were stimulated to pay more visits by being rewarded with a fixed amount of concentrate (100 g) in the selection unit even if they had already consumed their concentrate allocation for that particular feeding period. Social dominance was expressed as the dominance value of each cow, representing the relative number of cows which are subordinate to the cow concerned.

In A and B, there was a negative correlation between the cow's dominance value and her daily concentrate allotment ($r=-0.56$; $p<0.001$ and $r=-0.45$; $p<0.01$ respectively). Therefore the daily concentrate allotment was incorporated into the statistical model. Dominance value was positively related to the number of lactation days in A and B ($r=0.55$ and 0.53 respectively; $p<0.01$) and to the milking interval (as an expression of milking frequency) in B ($r=0.45$; $p<0.01$). These variables were not incorporated into the statistical model because they were also related to daily concentrate allotment. The daily number of visits to the AMS and the daily total time spent lying or feeding were not related to dominance value, but the timing of visits to the AMS and to the feeding gate were. In A2 and B, cows with higher dominance values paid more visits to the AMS between 12:00 and 18:00 h ($p<0.05$). In B, these cows paid fewer visits to the feeding gate ($p<0.05$) between 0:00 and 6:00 h. The waiting in front of the AMS was also affected by dominance value: cows with higher dominance could enter the AMS more often without waiting in A1 ($p<0.05$) and spent less time in the waiting area in B ($p<0.01$).

It is concluded that the introduction of fully automatic milking systems will trigger effects of social dominance, especially concerning the timing of visits to the AMS and the feeding gate and the waiting of low ranking cows in front of the AMS.

Keywords: automatic milking system, timing of visits, dominance value

1. INTRODUCTION

The automatic milking system (AMS) is the latest development in automation in dairying. An important feature of the present system is that the cows have to report to the milking place individually, voluntarily and at regular intervals. The traditional two or three milkings a day at fixed times is being or can be replaced by a flexible milking routine based on the round-the-clock availability of the system (Ipema et al., 1992). The AMS may consist of one or a few milking stalls in tandem, thus the cows are no longer milked in batches but more or less one by one. There are similarities with automatic concentrate feeders, in that the cows have to report there individually as well (Wierenga and Hopster, 1991; Winter, 1993). Also, cows are eager to visit the AMS because part of their daily concentrate ration is dispensed there (Devir et al., 1993). So, at present, AMS designs are based on sequential access of cows to the system over a 24-hour period, with a feed reward to attract them. Until the present research, the effects of this design on social interactions in the herd had not been studied.

Social dominance in domestic animals becomes especially important when resources such as feed and water are scarce (Syme and Syme, 1979) or are restricted in space and time. Many authors have stated that dominant animals in a cattle herd have priority whenever there is a competitive situation at the feeding site (McPhee et al., 1964; Friend and Polan, 1974; Metz et al., 1979; Morita et al., 1989; Kabuga, 1992), resting places are restricted (Wierenga and Hopster, 1990) or when feeding and/or resting places cannot be reached easily due to high social density (Metz and Mekking, 1984). According to Metz (1983), food competition may adversely affect animal welfare because of an increase in aggression and disturbances to behavioural daily rhythms and group coherence.

A competitive situation, expected to show similarities with that at the automatic concentrate feeders, is created at the entrance of an AMS as presently used. The aim of the present study was to evaluate the effects of social dominance on the cows' visits to the automatic milking system (AMS) and their daily activity pattern. It was a part of a longer experiment to examine the technical operation of the AMS (Devir et al., 1995).

2. MATERIALS AND METHODS

2.1. Materials

A group of 30 crossbred Holstein-Friesian dairy cows was used, consisting of 18 heifers and 12 2nd and 3rd parity cows. At the beginning of the experiment the number of lactation days varied between 6 and 216 for the heifers (average 154 days) and between 31 and 244 days for the 2nd and 3rd parity cows (average 113 days). The cows were kept in a cubicle house in which the feeding and lying areas were separate but connected by two open passages, so that the cows could move freely from one area to the other. There were 30 cubicles available (Figure 1). The floor consisted of concrete slats, over which a dung scraper moved once an hour. During the day, daylight was supplemented with artificial light, while at night dim light was available to allow the necessary control of the herd.

Roughage consisting of a mixture of 60 % grass silage, 20 % maize silage and 20 % corn cob silage on the basis of dry matter, was fed ad libitum to all cows at a feeding gate with 18 feeding places and two drinking places. The roughage was distributed once a day at 12:00 h and redistributed twice a day at 9:00 h and at 22:00 h.

The cows were fed concentrate and milked in an automatic milking system (AMS) consisting of two selection units and one milking unit. The entrance to the selection units was in the feeding area. The cows had to enter one of these units first to gain access to the milking unit. In the selection unit they were automatically identified, after which the computer decided whether to allow access to the milking unit. The exit from the milking unit led to the feeding area. Cows that were refused entrance to the milking unit were sent to the lying area. The part of the feeding area directly in front of the selection units was defined as the waiting area (Figure 1). The AMS was available for about 22 hours per day. The other two hours were used for cleaning and maintenance of the system between 7:00 and 8:00 h., and at 0:00 and 16:00 h for approximately 20 minutes. The major part of the concentrate was fed in the milking unit. A small amount of concentrate was provided in the selection unit to make visits there more attractive. A new concentrate dispensing cycle started every day at midnight. The milking process was monitored continuously by human observers.

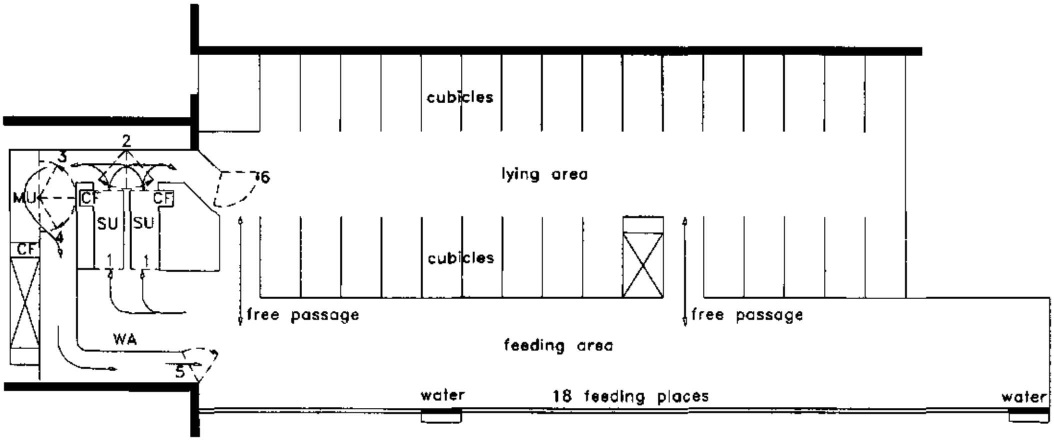

Figure 1. Plan of the cowshed with automatic milking system consisting of two selection units (SU) and one milking unit (MU); WA = waiting area; CF = concentrate feeder; 1 = SU entrance; 2 = control gate to send cows either to MU or back to herd; 3 = MU entrance; 4 = MU exit; 5 = AMS exit after SU and MU visit; 6 = AMS exit after SU visit only.

2.2. Experimental design

The experiment ran from March-May 1993 and consisted of two phases A and B, which differed in feeding and milking regime and in barn structure. (For details see Devir et al., 1995.) Table 1 gives the experimental schedule.

Table 1. The experimental schedule

phase	days[1]	data collection days		
		computer	continuous	time sampling
A1	1-17	14,15,16,17	14,15	-
A2	18-36	24,25,27,28	21,27	-
B	37-66	52,53,65,66	44,50,57[2],64[2]	52,65

[1] day 1 = 8 March 1993

[2] only 14 hours instead of 24 hours, due to technical problems

2.2.1. Phase A

In this phase, lasting 36 days, all cows had a milking regime of 3 times per 24 hours. Their total daily concentrate ration was determined according to their stage of lactation and production, based on the recommendations of the ARGOS management information system (Kroeze, 1990). They were allowed into the milking unit after a minimum interval of 6 hours from the last milking. If cows did not report to the AMS voluntarily within 10 hours, they were brought to the AMS manually.

Phase A was divided into two subphases:

A1. In this phase the amount of concentrate fed in the selection unit was unrestricted. The cows always received 100 g of concentrate each time they visited the selection unit, regardless of the balance of their daily ration and/or milking in the milking unit. The daily concentrate allotment was fed during milking in the milking unit, with a maximum of 3.5 kg per visit.

A2. In this phase the proportions of the daily concentrate ration fed in the selection unit and in the milking unit were predetermined. The cows received concentrate in the selection unit only if they still had some of their daily concentrate ration owed to them. This was determined using a system which continuously adds small amounts of concentrate to the available ration per cow throughout a 24-hour cycle. The maximum amount of concentrate fed in the milking unit was 3.5 kg per visit.

2.2.2. Phase B

In this phase the milking regime was changed to 5 milkings per day for 10 cows at the beginning of the lactation and 3 times per day for 19 cows later in the lactation. The planned milking intervals for these two groups were respectively between 6 and 9 hours and between 4 and 7 hours since the previous milking. Cows were brought to the AMS if their maximum milking interval had been exceeded. One cow was removed because of severe mastitis, leaving 29 animals.

For the feeding of concentrate the 24-hour period was divided into 8-hour periods for the cows with 3 milkings daily and into 5 periods of 4.5 hours for those with 5 milkings daily. The daily ration of concentrate was divided equally over these periods and, within these periods, between the selection unit and the milking unit. In addition, each individual cow's pattern of visits to the AMS was taken into account: cows which visited the system according to their planned milking frequency or more received concentrate in the selection unit only on milking visits and on the first non-milking visit within a feeding period. Cows which visited the system less than needed according to their planned milking frequency received concentrate in the selection unit on each visit. This portion was restricted to 100 g if the cows had already consumed their selection unit allotment of concentrate in that particular feeding period (Devir et al., 1995).

2.3. Data collection and behavioural observations

Data on the behaviour of the cows were collected in three different ways (Table 1):

1. Continuous observations: video equipment was used to monitor the passages between the lying and the feeding areas, the waiting area and the entrances and exits of the AMS. In A1 and A2, 2x24 hours of observations were carried out, in B 2x24 hours and 2x14 hours. The waiting in the waiting area was divided into: cow did not have to wait (i.e. walked straight through to the selection unit), cow had a short wait (i.e. less than 20 min), cow had a long wait (i.e. 20 min or more), cow left waiting area without a visit to AMS (i.e. gave up). In A, observations in the waiting area were also used to determine the dominance value of each cow. This was calculated as follows:

   dominance value of cow A = no. of cows subordinate to cow A/no. of known dominance relationships of cow A (Sambraus, 1975). A dominance relationship exists when, within a pair of cows, one cow defers to the other (Wierenga, 1990) and was classed as 'known' when one cow of a pair had displaced the other at least once more than vice versa. Cows with dominance value > 0.60 were classified as high ranking, cows with 0.60 > dominance value > 0.40 as middle ranking and cows with dominance value < 0.40 as low ranking. It was presumed that the ranking order remained stable throughout the experimental period, hence dominance value was not determined again in B.
2. Time-sampling observations : the behaviour and position of cows everywhere in the cowshed was recorded once every ten minutes with the help of video equipment. These observations were carried out for 2x24 hours in B only (Table 1). The recorded activities were: lying or standing in the cubicle, standing on the slatted floor in the lying or the feeding area, standing with the head through the feeding gate, standing in the waiting area, and standing in the AMS.
3. Computer data: Using on-line data acquisition, the frequency and visits to the AMS were recorded for individual cows for 4x24 hours in A1, A2 and B.

   The day was divided into 4 periods of 6 hours to evaluate the distribution of visits throughout the day: from 0:00 to 6:00 h, from 6:00 to 12:00 h, from 12:00 to 18:00 h and from 18:00 to 0:00 h.

In A and B, besides behavioural data, data also were collected on the planned daily concentrate allotment of each individual cow and her milk production. In B data were also collected for calculating the average milking interval of each cow as an expression of the differences in milking frequencies. This was done in the same periods that the behaviour was observed.

2.4. Statistical analysis

In A and B correlations were calculated between dominance value and age (in days), lactation number, lactation days, daily concentrate allotment, milking interval (in B) and milk production.

Behavioural parameters were analysed with a general linear model (GLM) with a binomial distribution and a logit link (McCullagh and Nelder, 1989).

In the model:

$\log (Ey) = \beta_0 + \beta_1 x_1 + \beta_2 x_2$,

the dominance value (x_1) and the daily concentrate allotment (x_2) were used as predictors for the different parameters (y) monitored. Correction took place for the fact that cows within one group can influence each other ('over-dispersion'; see McCullagh and Nelder, 1989, p. 198-200 or Oude Voshaar, 1994; p. 132). In that case the 'deviance ratio' can be used to determine whether a predictor has a significant effect or not. This value is by approximation F-distributed (Oude Voshaar, 1994). In the model the daily concentrate allotment was incorporated first and then the dominance value. This ensured that the effect of dominance value was estimated correctly.

Differences between A1 and A2 were analysed by means of a paired t-test (Parker, 1979). The GLMs were calculated with the Genstat 5 statistical package (Genstat 5 committee, 1993). SPSS/PC+ was used to calculate the correlations mentioned above and to perform the paired t-test (SPSS/PC+ V2.0, 1988).

3. RESULTS

3.1. Correlation between dominance value and some individual cow data

It appeared that the daily concentrate allotment was distributed unequally over the cows with different dominance values. In A the average daily concentrate allotment was 3.0 $\pm$ 3.5 kg for high ranking cows, 7.0 $\pm$ 3.4 kg for middle ranking cows and 8.7 $\pm$ 4.1 kg for low ranking cows. In B the average daily concentrate allotment was 2.5 $\pm$ 3.2 kg for high ranking cows, 5.2 $\pm$ 3.5 kg for middle ranking cows and 6.7 $\pm$ 3.9 kg for low ranking cows. In both A and B a significant negative correlation was found between dominance value and daily concentrate allotment ($r=-0.56$; $p<0.001$ and $r=-0.45$; $p<0.01$ respectively). Therefore the daily concentrate allotment of each cow was incorporated into the statistical model.

In both phases a significant positive correlation was also found between dominance value and the number of lactation days ($r=0.55$ and 0.53 respectively in A and B; $p<0.01$). This variable was nevertheless not incorporated into the statistical model, because there was a significant negative correlation between the number of lactation days and the daily concentrate allotment in A and B ($r=-0.89$ and -0.74 respectively; $p<0.001$).

In B a significant positive correlation was found between dominance value and milking interval ($r=0.45$; $p<0.01$). It was nevertheless not incorporated into the statistical model, because there was a significant negative correlation between milking interval and daily concentrate allotment ($r=-0.49$; $p<0.01$). In both experimental phases no significant correlations were found between dominance value and age, lactation number and milk production.

3.2. Visits to the AMS

The number of visits made by each cow to the AMS was not related to dominance value in A1, A2 and B. In A1 the average number of visits to the AMS was 35.6 $\pm$ 7.9 for high ranking cows, 33.0 $\pm$ 5.2 for middle ranking cows and 16.9 $\pm$ 2.2 for low ranking cows (mean $\pm$ SE). In A2 the average number of visits to the AMS was 20.8 $\pm$ 4.2 for high ranking cows, 22.8 $\pm$ 2.9 for middle ranking cows and 18.0 $\pm$ 2.3 for low ranking cows. In B the average number of visits to the AMS was 8.3 $\pm$ 1.7 for high ranking cows, 9.1 $\pm$ 1.1 for middle ranking cows and 8.2 $\pm$ 0.8 for low ranking cows. The comparison between A1 and A2 showed that both high ranking and middle ranking cows paid significantly more visits to the system in A1 than in A2 ($p=0.025$ and 0.008 respectively). There was no such difference in low ranking cows.

In A1 the distribution of visits over the day was not affected by dominance value.
Table 2 shows the distribution of visits to the AMS over an average 24-hour day based on 4x24 hours of computer registrations in A2 and B. In both phases, cows with higher dominance values paid significantly more visits to the AMS between 12:00 and 18:00 h (deviance ratio=4.60 and 5.30 respectively; $p<0.05$). In B, cows with lower dominance values seemed to pay more visits to the AMS between 0:00 and 6:00 h. This almost reached significance ($p<0.10$).

Table 2. Percentage of visits to the AMS per period per day (mean $\pm$ SE) in relation to dominance value in A2 and B.

phase	rank	period of day			
		0:00-6:00 h	6:00-12:00 h	12:00-18:00 h	18:00-0:00 h
A2	high	20.3 $\pm$ 3.7	21.5 $\pm$ 1.6	30.2 $\pm$ 2.1*	28.1 $\pm$ 3.0
	middle	20.3 $\pm$ 2.0	24.8 $\pm$ 1.9	26.0 $\pm$ 1.5*	28.9 $\pm$ 1.9
	low	23.1 $\pm$ 2.5	25.0 $\pm$ 2.9	23.3 $\pm$ 1.6*	28.6 $\pm$ 1.5
B	high	18.8 $\pm$ 3.4	30.4 $\pm$ 4.2	29.4 $\pm$ 2.6*	21.4 $\pm$ 2.0
	middle	27.8 $\pm$ 3.1	25.7 $\pm$ 1.8	25.7 $\pm$ 2.0*	20.9 $\pm$ 1.7
	low	31.6 $\pm$ 5.2	26.9 $\pm$ 3.3	17.8 $\pm$ 2.6*	23.7 $\pm$ 2.4

* significant effect of dominance value across column within an experimental phase ($p<0.05$)

3.3. The use of the waiting area

In A1 the percentage of times that the cows entered the waiting area and did not have to wait was significantly higher for cows with higher dominance values (deviance ratio=4.61; $p<0.05$). High ranking cows could enter the AMS immediately in an average of 76.8 $\pm$ 2.5 % of the cases after entering the waiting area (mean $\pm$ SE). This percentage was 71.5 $\pm$ 2.5 for middle ranking cows and 62.7 $\pm$ 5.3 for the low ranking cows. In A1 and B cows with lower dominance values seemed to leave the waiting area more often without visiting the AMS. In A1, they did this on average 13.1 $\pm$ 3.4 % of the cases that they entered the waiting area, and in B on average 14.2 $\pm$ 2.3 %. These percentages were 7.5 $\pm$ 1.3 and 9.7 $\pm$ 2.5 in A1 and B respectively for the middle ranking cows and 6.7 $\pm$ 2.0 and 7.4 $\pm$ 2.2 in A1 and B respectively for the high ranking cows. In both phases this almost reached significance ($p<0.10$). In A2 no significant effects were found of dominance value on the use of the waiting area.

3.4. Time budget of the cows

Table 3 shows the time budget of the cows in B. Cows with higher dominance values spent less time in the waiting area (deviance ratio=8.74; $p<0.01$). The total time spent lying or feeding was not affected by dominance value, neither was the distribution of lying. Cows with different dominance values showed an almost identical lying pattern. The feeding gate was visited significantly less between 0:00 and 6:00 h by cows with higher dominance values (deviance ratio=5.23; $p<0.05$) (Table 4).

Table 3. The time budget of the cows in relation to dominance value (mean percentage of time ± SE) in B.

cow behaviour	rank		
	high	middle	low
lying in cubicle	47.0 ± 2.8	47.2 ± 2.9	44.9 ± 3.8
standing in cubicle	13.7 ± 2.1	9.0 ± 2.0	8.2 ± 1.8
slatted floor lying area	6.1 ± 1.3	7.3 ± 0.9	5.4 ± 1.5
slatted floor feeding area	9.8 ± 1.3	10.9 ± 0.6	12.1 ± 0.8
feeding gate	14.2 ± 1.4	14.5 ± 1.6	14.9 ± 0.7
waiting area	1.1 ± 0.3*	1.9 ± 0.3*	2.9 ± 0.5*
AMS	8.1 ± 1.1	9.2 ± 1.1	11.5 ± 1.3

* significant effect of dominance value across row ($p<0.01$).

Table 4. The average percentage of time standing at the feeding gate per period per day (mean ± SE) in relation to dominance value in B.

period of day	rank		
	high	middle	low
0:00 - 6:00 h	9.5 ± 1.9*	16.9 ± 1.2*	16.5 ± 2.5*
6:00 - 12:00 h	28.7 ± 2.9	21.7 ± 2.5	20.1 ± 2.0
12:00 - 18:00 h	29.0 ± 2.9	27.6 ± 2.0	31.3 ± 1.5
18:00 - 0:00 h	32.8 ± 2.0	33.8 ± 3.4	32.2 ± 2.0

*significant effect of dominance value across row ($p<0.05$).

4. DISCUSSION

4.1. Dominance value and some individual cow data

The dominance value of the cows appeared to be correlated negatively with the daily concentrate allotment of each cow. Thus cows with lower dominance value had higher daily concentrate allotment and vice versa. Besides this, the dominance value also correlated positively with the number of lactation days and, in B, with the milking interval. These relations were nevertheless ignored because lactation days and milking interval were also correlated with the daily concentrate allotment, as a result of cows early in lactation receiving more concentrate, as in daily practice, and in B, being milked more frequently.

Dominance value did not correlate with age (in days), lactation number and milk production. The literature is contradictory about the correlation between rank and individual cow factors. Most authors have found that rank is related to age (Reinhardt, 1973; O'Connell et al., 1989), but not to milk production (Reinhardt, 1973; Friend and Polan,1974; Collis, 1976).

In the present study, the reason that dominance value did not correlate with age was probably because all the cows were from 1st, 2nd or 3rd parity. According to Beilharz and Zeeb (1982) the initial formation of a dominance relationship of any pair of animals is a result of learning, with many different factors involved, including trivial ones. In the present study one of these factors seems to have been the daily concentrate allotment.

4.2. Visits to the AMS

The effects of social dominance might be expected to appear after the introduction of an AMS, especially if all concentrate is dispensed in this system. However, the effects seem to depend on how the concentrate is allocated. In A1, in which the cows always received 100 g of concentrate when they visited the system, high and middle ranking cows paid significantly more visits to the AMS than in A2, in which the cows received 100 g of concentrate in the selection unit only when there was still some concentrate owing to them from their daily ration. This suggests that the high and middle ranking cows adapted their visiting pattern to the AMS according to the feeding system used. This difference was not found for the low ranking cows. They could probably not allow themselves this 'luxury' of adapting their visiting pattern to the feeding system used. In addition, cows with higher dominance values had a lower daily concentrate allotment. This probably made them more eager to visit the AMS, especially in A1 in which they could obtain some extra concentrate fairly easily. Wierenga and Hopster (1991) found that different feeding systems evoked a typical pattern of visits to a feeding station. According to Livshin et al. (1994) cows easily adapt to a proposed feeding regime. They concluded that this can be exploited to achieve specific goals, such as manipulating cows' voluntary visits to a feeding/milking station, which is desirable for automatic milking systems.

In both A and B the dominance value of the cows did not affect the total number of visits to the AMS, but it did affect the visiting pattern in some cases. In general, cows with higher dominance values paid more visits to the AMS during the day time, between 12:00 and 18:00 h, whereas cows with lower dominance values seemed to pay more visits in the early hours, between 0:00 and 6:00 h. Wierenga and Hopster (1991) found that over a 24-hour period in a feeding station only the pattern of intake was affected by social dominance, and the total time spent in the feeding station was not relevant. According to Collis (1980), time of day is important when visiting a feeding station. He found that a cow was more likely to spend a long period there if there was less competition.

4.3. Waiting in front of the AMS

The behaviour of the cows in the waiting area in front of the AMS showed some effects of social dominance. In general, cows with lower dominance values spent more time in the waiting area and seemed to leave it more often without visiting the AMS (thus gave up). Wierenga and Hopster (1991) indicated that in a situation in which a new feeding cycle started at 11:00 and

23:00 h, low ranking cows waited longer before they entered the feeding station during the night period. Therefore, when designing new housing with a waiting area in front of an AMS, provision should be made for the occurence of effects of social dominance.

Metz and Mekking (1984) have stated that a small idling area can lead to extra aggression and therefore impairs an animal's well-being. In their experiment, low ranking cows remained longer in the cubicles (which were connected to the idling area), presumably to avoid aggression from dominant herdmates. Potter and Broom (1987) concluded likewise after their observation that low ranking cows spent more time standing in the cubicles.

Thus, when designing new housing with a waiting area in front of an automatic milking system, it might be important to include a kind of safety zone to enable low ranking cows to withdraw from aggression or to leave the area to avoid long waiting times.

4.4. Lying and feeding pattern

Neither the lying time nor the lying pattern were affected by social dominance. This is in agreement with results obtained by Andreae and Smidt (1983) and Wierenga and Hopster (1990). The time spent at the feeding gate was not affected by social dominance either, but the pattern of visits to the feeding gate was. This showed similarities with the observed visiting pattern to the AMS. The cows with higher dominance values paid fewer visits to the feeding gate during the late night period between 0:00 and 6:00 h. So, as found with the visits to the AMS, high ranking cows seemed to pay more visits during the day and low ranking cows more during the late night.

Miller and Woodgush (1991) found that cows kept in a modern cubicle house spent 45 to 66 % of their 'active' time (i.e. being active without feeding or milking) anticipating the movements of dominant and subordinate herd members. They termed this type of alertness 'social tension'. According to Manson and Appleby (1990) the distribution of cows at a food trough is rank related: cows of similar rank feed closer together than those of dissimilar rank. Potter and Broom (1987) found that low ranking cows spent a slight but not significantly smaller proportion of time feeding in the post a.m. feed period.

4.5. Evaluation of the experiment

The setup of the experiment did not provide replications as recommended for example by Jansen, 1990). This is because of the extremely high costs associated with this 'high-tech' experiment (the AMS was still in a developmental stage, so it had to be guarded 24 hours a day). Furthermore, the results showed that, as expected, both the cows' visits to the AMS and their activity were generally affected in the same way by social factors under circumstances of fully automatic milking as found under more 'traditional' circumstances, such as feeding of concentrate at the feeding gate or in a feeding station and milking twice a day in the milking parlour (Potter and Broom, 1987; Hopster and Wierenga, 1989, Wierenga and Hopster, 1991). This confirms that the present study is a useful contribution to the justified introduction of fully automatic milking systems.

5. CONCLUSIONS

Based on the present study, it can be concluded that effects of social dominance will appear when fully automatic milking systems are introduced. These effects may not concern the daily frequency of visits, nor the total time spent lying or feeding, but may be seen in the timing of the visits to the AMS and to the feeding gate and the time spent in the waiting area in front of the AMS.

Cows with low dominance values seemed to adapt their visits to the AMS and the feeding gate to the cows with higher dominance values by visiting both parts of the cowshed more at quiet times. In the present study, cows with lower dominance values spent more time waiting in front of the automatic milking system. Therefore, the waiting area should be designed to prevent them from being subjected to severe aggression from higher ranking cows.

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CHAPTER 3

BEHAVIOUR OF DAIRY COWS UNDER FREE OR FORCED COW TRAFFIC IN A SIMULATED AUTOMATIC MILKING SYSTEM ENVIRONMENT

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ABSTRACT

The introduction of fully automatic milking systems (AMS) on dairy farms can only succeed if cows visit the system more or less voluntarily, at regular intervals. This can be arranged by either forced or free cow traffic. In the case of forced cow traffic the AMS is the only route from the lying area to the feeding area. An alternative is free cow traffic, where the cows can decide whether to visit the AMS or not. The behaviour in 3 x 20 crossbred Holstein Friesian dairy cows in three experiments (Experiment Ia, Ib and II) was studied in a cubicle house with a selection system consisting of a selection stall and a concentrate feeder, simulating an AMS. Cows could obtain 250 g of concentrate in the system once every six hours. Actual milking occurred in a conventional milking parlour twice a day. Experiment Ia consisted of (1) a reference phase with no use of the selection system, (2) free cow traffic, (3) forced cow traffic, and (4) a reference phase. Experiment Ib was a repetition of Experiment Ia. Experiment II was divided into (1) a reference phase with no use of the selection system, (2) forced cow traffic with two oneway passages between the feeding and lying areas, (3) forced cow traffic with one oneway passage, (4) free cow traffic with one free passage between the feeding and lying areas, and (5) free cow traffic with two such passages and (6) a reference phase.

The number of visits paid to the selection system by individual cows appeared to be consistent in the different phases in each experiment ($r=0.52$ in Experiment I ($p<0.05$);$r=0.68$-0.86 ($p<0.01$) in Experiment II). In Experiments Ia and Ib cows seemed to visit the selection system more often during forced cow traffic than during free cow traffic, but this was because some of the cows did not visit the system at all during free cow traffic. Therefore, the differences were not significant. In Experiment II cows paid the same number of visits to the selection system during different types of cow traffic, but when two passages were open during free cow traffic, the cows visited the system less ($p<0.01$). During forced cow traffic, cows spent more time standing on the slatted floor in the feeding area, spent less time standing at the feeding gate and made less journeys from the lying to the feeding area (significant in two of three experiments; $p<0.01$).

It was concluded that forced cow traffic may improve the frequency of visits to the AMS, but somewhat restricts the cows' behaviour, and may therefore be questionable. Free cow traffic could work if cows are previously conditioned to take the route to the AMS.

Keywords: cow behaviour, cow traffic, selection system, automatic milking system (AMS), simulation

1. INTRODUCTION

In the near future it will be possible for cows to be milked without human interference, in a fully automatic milking system (AMS) equipped with a milking robot (Devir et al., 1993a, 1996a).

The success of such a system partly depends on the cows, which have to visit the system on a voluntary basis and at regular intervals (Winter et al., 1992; Ketelaar-de Lauwere, 1992). In earlier experiments in which an AMS was simulated by milking with manpower in an automatic concentrate feeder, Ipema et al. (1988) showed that some cows visited the system too often, which affected the system's capacity negatively, while other cows visited it too little, which meant that they had to be brought to the milking place by the farmer. To prevent cows from making unwarranted visits, a selection stall, positioned in front of the milking stall with the milking robot, has been developed as a part of the AMS (Swierstra and Smits, 1989; Devir et al.,1993a, 1996a). When a cow enters the selection stall, she is automatically identified by her own individual transponder and the computer decides whether to allow her access to the milking stall or send her back to the herd.

Until now, it was often presumed that forced 'oneway' cow traffic was the only way to lead cows to an AMS (Artmann, 1992; Dück, 1992). It meant positioning the AMS in the barn in such a way that the cows were forced to pass through the AMS to go from the lying area to the feeding area or vice versa. It is, however, questionable whether the restriction of a forced cow traffic situation delays the cows' activities and negatively affects their behavioural patterns. The alternative to forced cow traffic would be free cow traffic, allowing the cow to decide where to go and whether to visit the AMS.

The present study addresses the comparison of free and forced cow traffic in a simulated AMS situation. The question is how the type of cow traffic affects the cows' visits to the AMS, and their lying and feeding times, compared with a reference phase without an AMS.

2. MATERIALS AND METHODS

2.1. Animals, housing and feeding

The research involved three experiments (Experiment Ia,Ib and II) each with a group of 20 lactating crossbred Holstein Friesian dairy cows at "De Ossekampen" experimental farm of

Wageningen Agricultural University, between December 1989 and May 1991. In Experiment Ia the group consisted of one heifer and 19 second or higher parity cows, of which 2 older cows were not yet in calf. Average post-calving stage was 171.8 days (sd 53.6) at the beginning of the experiment. In Experiment Ib the group consisted of 7 heifers and 13 second or higher parity cows, all of which were pregnant except for one older cow. Average post-calving stage was 198.8 days (sd 40.4). In Experiment II the group consisted of 2 heifers, one of which was in calf, and 18 second or higher parity cows, of which 8 were not yet in calf. Average post-calving stage was 137.9 days (sd 82.0). During this experiment two cows had to be taken out of the group because of severe lameness.

The cows were kept in one section of a cubicle house with a slatted concrete floor, a lying area with twenty cubicles and a feeding area with a feeding gate with twenty feeding places (Figure 1). The cows could go to and from the lying area and the feeding area along two passages, one adjacent to the outside wall of the cowshed and far from the selection system and the other near the selection system, respectively referred to as the passages far from and near the selection system (see section 2.2) (Figure 1). Grass silage was fed ad libitum at the feeding gate. Water was continuously available in two troughs, one in the feeding area and one in the passage adjacent to the outside wall, which was accessible from both the feeding and the lying area. The cows were milked twice daily in a milking parlour at approximately 6.00 h. and 16.00 h. They received 1 kg of concentrate at each milking. The rest of their ration was fed in a concentrate feeder, which was placed in the lying area in a row of cubicles. The cows daily received 1 kg of concentrate in this feeder in Experiment Ia, and 2 kg in Experiments Ib and II. During daytime the cowshed was illuminated by daylight and a double row of fluorescent lighting and at night by a single row of fluorescent lighting.

2.2. The selection system and milking robot simulation

A selection system was positioned adjacent to another section of the cubicle house, leaving enough space for the passage at this location (Figure 1). The system consisted of a selection stall and a special concentrate feeder which the cows could leave at the front. It had its entrance in the lying area and its exit in the feeding area. A milking robot was simulated by the special concentrate feeder, so in these experiments the cows were not actually milked in the selection system. The cows could obtain 250 g of concentrate once every six hours in the special feeder. Cows paying more visits to the selection system within these 6-hour periods were directly sent to the feeding area without passing the special feeder (Figure 1).

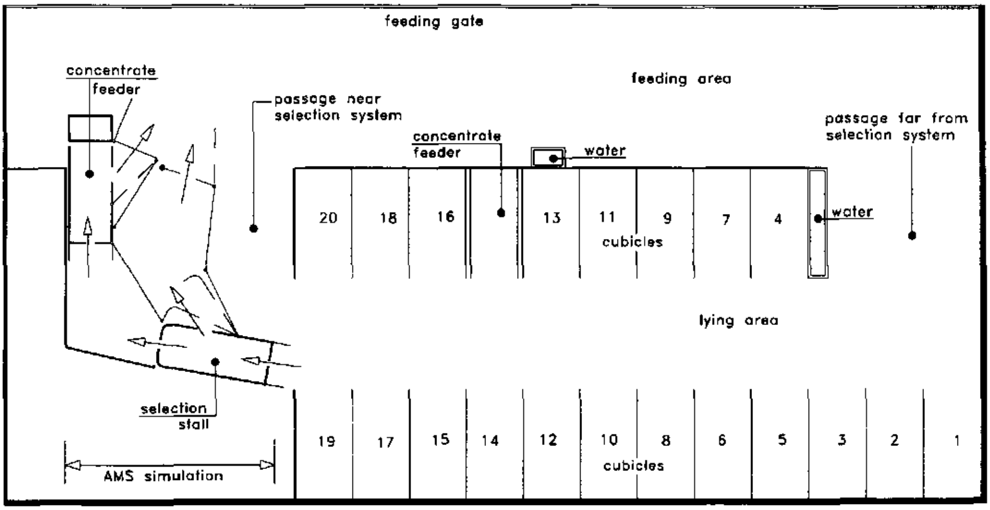

Figure 1. Plan of the cowshed; the AMS simulation is identified by the selection stall and the concentrate feeder in front of it

2.3. Experimental design

2.3.1. General

Different types of free and forced cow traffic were compared in Experiments I and II. Experiment Ib was the same as Experiment Ia. In Experiment II, there was some variation in the order in which different experimental phases were imposed upon the cows and in the number of passages available for going from the feeding to the lying area or (in case of free cow traffic) vice versa. Most of the experimental phases lasted between 11 and 22 days (at least 5 days to get cows used to a new phase and at least 6 observation days). Some variation in the number of days per experimental phase was inevitable owing to minor technical problems with the selection system or the video equipment for behavioural observations. Unavoidably, some periods were prolonged because of serious technical problems with the selection system. Table 1 gives the experimental schedule.

Table 1. The experimental schedule; variation in the number of days per experimental phase can occur owing to technical problems

Exp.	phase	kg conc. in cf/*slf**	selection system	passage near system	passage far from system	no. of days **
Ia	REFB	1/*0*	closed	open	open	37
	training a	0/*1*	open	open	open	31 ***
	training b	0/*3*	open	open	open	8
	FREE	0/*1*	open	open	open	13
	FORCED	0/*1*	open	closed	oneway @	18
	REFE	1/*0*	closed	open	open	11
Ib	REFB	2/*0*	closed	open	open	23
	training a	1/*1*	open	open	open	11 ***
	training b	0/*4*	open	open	open	12
	FREE	1/*1*	open	open	open	12
	FORCED	1/*1*	open	closed	oneway @	19
	REFE	2/*0*	closed	open	open	22
II	REFB	2/*0*	closed	open	open	21
	FORCED2	1/*1*	open	oneway @	oneway @	17 ***
	FORCED1	1/*1*	open	closed	oneway @	21
	FREE1	1/*1*	open	closed	open	12
	FREE2	1/*1*	open	open	open	15
	REFE	2/*0*	closed	open	open	11

REFB/REFE= reference situation at the beginning and end of each experimental phase

@ cows can go from feeding area to lying area only

* cf=concentrate feeder in the lying area; *slf*=concentrate feeder in selection system

** including getting used to a new phase

*** including four days of intensive training

2.3.2. Experiment I

Experiment Ia and Ib were divided into the following successive experimental phases: (1) a reference phase, in which the selection system was closed; the passages far from and near the system were both open (REFB), (2) four days of intensive training of the cows in the use of the selection system; the cows were brought to the system by the same two persons 3 times daily, (3) a training period with free cow traffic in which the cows first received 1 kg of concentrate in the selection system during a number of days and after that 3 and 4 kg in Experiment Ia and Ib respectively; during this training period there was no human interference, so cows had to visit the system by themselves (4) free cow traffic; the passages far from and near the system were both open (FREE), (5) forced cow traffic with an oneway gate in the passage far from the system to go from the feeding to the lying area; the passage near the system was closed (FORCED), (6) a reference phase as mentioned under (1) (REFE). In those phases in which the selection system was used, the cows received 1 kg of concentrate daily there. This amount was deducted from the daily amount they normally received in the concentrate feeder in the lying area, leaving 0 kg daily in this feeder in Experiment Ia (except for one cow in an early lactating stage which received 11 kg), and 1 kg daily in Experiment Ib.

2.3.3. Experiment II

Experiment II was divided into the following successive experimental phases: (1) a reference phase analogous to Experiment I (REFB), (2) four days of intensive training of the cows in the use of the selection system, analogous to Experiment I, (3) forced cow traffic with oneway gates in the passages far from and near the system to go from the feeding to the lying area (FORCED2), (4) forced cow traffic analogous to Experiment I (FORCED1), (5) free cow traffic; the passage far from the system was open and the passage near the system was closed (FREE1), (6) free cow traffic analogous to Experiment I (FREE2), (7) a reference phase analogous to Experiment I (REFE). The training period was not necessary in the third experiment because two phases of forced cow traffic followed the intensive training. The cows were fed concentrate analogous to Experiment Ib.

2.4. Behavioural observations

Behaviour was monitored by video cameras during each experiment. There were two types of video recordings. Continuous observations of the time and number of visits to the selection system and to the passages far from and near the selection system were recorded. These observations served to ascertain the cows' use of the selection system and their movement in the cowshed. Time-sampling observations of the behaviour of each cow were recorded once every 10 minutes, to get data of the cows' activities. These included lying or standing in a cubicle, standing on the slatted floor in the lying or feeding areas, and standing at the feeding gate, defined as standing with the head through the gate.

In every phase of each experiment, 3 x 24 hours of continuous observations and time-sampling observations were carried out. The cows were allowed at least five days to become accustomed to each experimental phase before the observations started. No behavioural observations were carried out during the training phase. Only feed leftovers were recorded during 3 x 24 hours for each cow.

Before the REFB phase of Experiment Ib and II the dominance value of each cow, representing the proportion of cows that were subordinate to that particular cow, was established to get an impression of the position in the rank order of each cow (Sambraus, 1975). To do this cows were deprived of forage between 22:00 h and 8:30 h for five consecutive days. When on 8:30 h a part of the feeding gate was opened giving access to 9 feeding places, the occurrence of aggressive interactions between cows was recorded continuously for 4 hours with the help of video recordings.

2.5. Statistical analysis

In the three experiments, Pearson's correlation coefficients were calculated, using the SPSS/PC+ statistical package (SPSS/PC+ V2.0, 1988), between the number of visits to the selection system and the age of the cows (in months), the number of lactation days and (in Experiment Ib and II) the dominance value (Parker, 1979).

In each experiment, the influence of type of cow traffic on the cows' use of the selection system, and their activity and movement through the cowshed, was statistically analysed for each experiment, using the Iterative Reweighed Residual Maximum Likelihood procedure (IRREML). This algorithm estimates the treatment effects and variance components in a generalized linear mixed model with both fixed and random effects (Keen, 1994). The Genstat 5 statistical package was used for the analyses (Genstat 5 Committee, 1993). The dependent variables lying and standing in the cubicle, standing on the slatted floor in the lying or the feeding area, and standing at the feeding gate were expressed as percentages of time spent by the cows in the concerned activity, and therefore analysed with a binomial distribution and a logit link function. The resulting model was:

$$\log(p/(1-p))=\beta x+uz+\varepsilon,$$

where $p=y/n$, and p is the chance that the cow shows the behaviour under consideration (y) and n is the number of cows.

The variables number of visits to the selection system, number of passages between the lying and feeding areas and number of lying and feeding periods were analysed according to a Poisson distribution, and the variables duration of lying and feeding periods were analysed according to a gamma distribution. The resulting model for the last two group of variables was:

$y=\beta x+uz+\varepsilon$.

In both models y is the behavioural variable under consideration, ß is the fixed effect of the experimental phase x, u is the random effect of cow and ε is the random error.

The Wald statistic was calculated to test for the significance of fixed effects (in this case only the experimental phase) under the null Hypothesis that there were no differences between experimental phases. This statistic has an asymptotic chi-squared distribution (Genstat 5 Committee, 1993)

3. RESULTS

3.1. The use of the selection system

3.1.1. Experiment I

The average number of visits paid to the selection system per cow per day in Experiment Ia was 5.4 ± 4.2 during free cow traffic and 7.5 ± 3.2 during forced cow traffic, and in Experiment Ib 5.6 ± 5.0 and 7.2 ± 3.1 respectively (mean ± sd). These apparent differences were caused by cows that did not visit the system during free cow traffic. In both Experiments Ia and Ib the number of cows that did not visit the selection system at all was higher during free cow traffic, whereas the number of cows that visited the system 3 times or more was higher during forced cow traffic (Figure 2). The predicted means from the IRREML analysis of number of visits paid to the system in Experiment Ia were 7.0 and 7.2 during free and forced cow traffic respectively. In Experiment Ib the figures were 7.7 and 7.3 respectively. The difference between free and forced cow traffic were not significant in both experiments (Wald Statistic=0.2, d.f.=1, p=0.654, sed=0.5275 in Experiment Ia and Wald statistic=0.38, d.f.=1, p=0.539, sed=0.5248 in Experiment Ib).

In both Experiments Ia and Ib the correlation coefficient between the number of visits paid to the selection system per cow during free and forced cow traffic was 0.52 ($p<0.05$). No significant correlations were found between the number of visits the cows paid to the selection system during different types of cow traffic and the cows' age, the number of lactation days and (in Experiment Ib) the dominance value. One exception was a negative correlation, found in Experiment Ia, between the cows' age and the number of visits they paid to the selection system during forced cow traffic (r=-0.60; p<0.01).

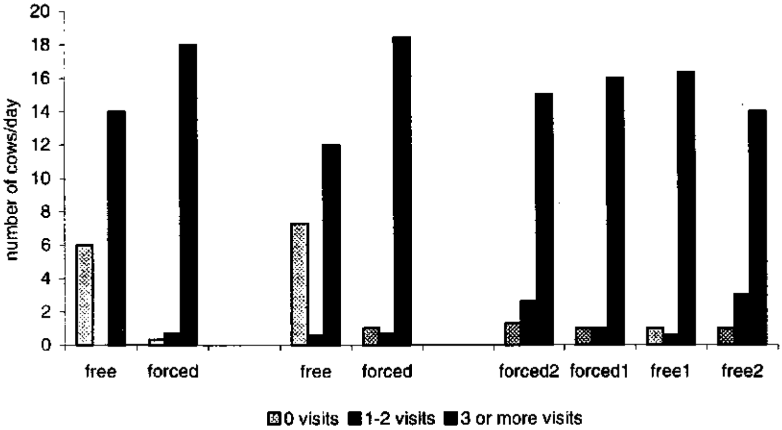

Figure 2. The average number of cows per day that visited the selection system during different types of cow traffic.

3.1.2. Experiment II

The average daily visits paid by the cows to the selection system was 7.7 ± 5.2 during FORCED2, 6.8 ± 3.6 during FORCED1, 7.4 ± 3.6 during FREE1 and 5.8 ± 3.7 during FREE2. The number of cows that visited the system 3 times or more was high in all the experimental phases. However, when a free passage was available near the selection system during FREE2, the number of cows that visited the system 3 times or more appeared to decrease (Figure 2). The predicted means from the IRREML analysis of the number of visits paid to the system were 7.3 for FORCED2, 6.8 for FORCED1, 7.4 for FREE1 and 5.6 for FREE2. FREE2 differed significantly from the other experimental phases (Wald statistic=25.11, d.f.=3, p<0.01, average sed=0.4304). Correlation coefficients between number of visits to the selection system during different types of cow traffic ranged between 0.68 and 0.86 (p<0.01). As in Experiment I, no significant correlations were found between the number of visits the cows paid to the selection system during different types of cow traffic and the cows' ages, the number of lactation days and the dominance values. Positive correlations were found between the cows' ages and the number of visits they paid to the selection system during FREE1 (r=0.52; p<0.05) and between the cows' dominance values and the number of visits they paid to the system during FREE2 (r=0.44; p<0.05).

Table 2. Time budget of cows over all experiments per experimental phase (mean ± sd).

behaviour	Reference begin	Reference end	FREE1	FREE2	FORCED1	FORCED2
lying in cubicle (% of time)	46.4 ± 10.9	47.6 ± 9.7	48.0 ± 9.9	46.4 ± 9.5	48.8 ± 11.9	51.1 ± 12.2
standing in cubicle (% of time)	11.5 ± 8.3	11.7 ± 7.8	10.2 ± 7.8	12.1 ± 7.2	10.7 ± 9.4	12.4 ± 9.7
standing on slatted floor lying area (% of time)	6.0 ± 4.9	4.7 ± 3.3	3.3 ± 3.9	4.1 ± 3.8	4.2 ± 3.7	4.8 ± 3.5
standing on slatted floor feeding area (% of time)	6.0 ± 3.7	7.1 ± 4.4	6.2 ± 4.9	7.1 ± 4.0	10.3 ± 6.7	6.8 ± 7.8
standing at the feeding gate (% of time)	21.7 ± 4.6	21.7 ± 5.0	22.7 ± 3.3	20.7 ± 4.5	17.9 ± 4.8	17.2 ± 3.6
number of lying periods	7.9 ± 2.4	7.6 ± 2.2	7.4 ± 2.2	8.0 ± 2.5	7.4 ± 2.6	7.8 ± 2.3
duration of lying periods (min)	93.1 ± 37.5	97.1 ± 30.3	106.2 ± 47.3	90.4 ± 32.2	110.5 ± 65.2	100.0 ± 27.0
number of feeding periods	10.0 ± 2.9	9.4 ± 2.6	9.8 ± 2.8	10.8 ± 2.9	9.2 ± 2.9	9.0 ± 3.4
duration of feeding periods (min)	33.1 ± 10.6	35.6 ± 12.9	36.0 ± 12.7	29.5 ± 11.1	29.9 ± 11.5	29.6 ± 9.3

3.2. Activity of cows

Table 2 shows the time budget of cows per experimental phase over all three experiments. The statistical analysis of the behavioural variables under consideration did show some significant differences between the experimental phases within experiments, but most of these were not consistent between experiments, and therefore, are not mentioned further. Interesting are those significant differences which are found in more experiments and point in the same direction. In all experiments cows spent more time standing on the slatted floor in the feeding area (significant in Experiment Ia and Ib) and less time standing at the feeding gate (significant in Experiment Ia and II) during forced cow traffic than in the other phases ($p<0.01$; Table 3).

The diurnal pattern of the cows, expressed as the percentage of cows lying per hour, did not show clear differences between the different phases within each experiment. In all phases the highest percentages of lying cows were recorded during the night, with the clearest drops around the hours that the cows were milked in the milking parlour (Figure 3).

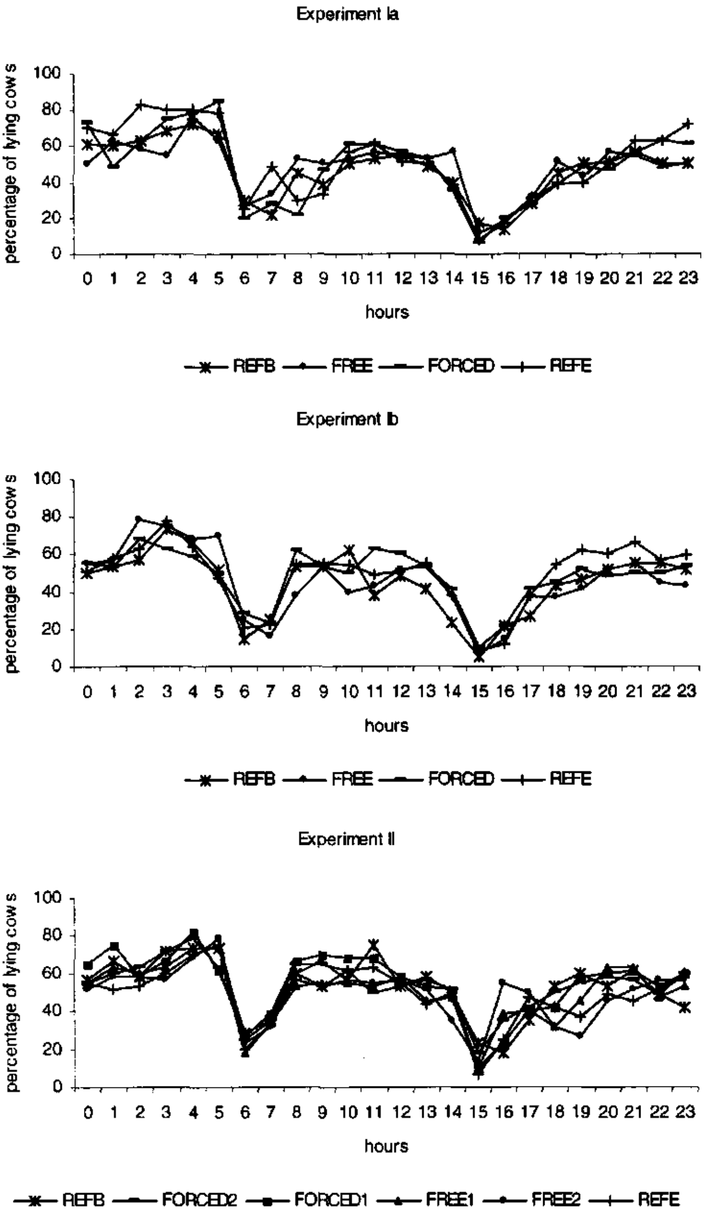

Figure 3. Diurnal pattern of the cows in Experiments Ia, Ib and II, expressed as the number of cows lying per hour; (REFB/REFE= reference situation at the beginning and end of each experimental phase)

Table 3. Effect of type of cow traffic (on logit scale) of the percentage of time spent standing on the slatted floor in the feeding area and standing at the feeding gate; effect of REFB is set to 0.0; other values are with regard to REFB.

Experiment Ia	Slatted floor feeding area		Standing at feeding gate	
REFB	0.0 a	Waldstat.= 71.6	0.0 a	Waldstat.= 70.1
FREE	+ 0.29 b	d.f.= 3	- 0.08 a	d.f.= 3
FORCED	**+ 0.84 c**	p= 0.000	**- 0.43 b**	p= 0.000
REFE	+ 0.25 b	avg. sed*= 0.11	- 0.18 c	avg. sed= 0.05
Experiment Ib				
REFB	0.0 a	Waldstat.= 65.5	0.0 a	Waldstat.= 106.5
FREE	+ 0.19 a	d.f.= 3	- 0.14 b	d.f.= 3
FORCED	**+ 0.63 b**	p = 0.000	- 0.21 b	p= 0.000
REFE	+ 0.04 a	avg. sed= 0.10	+ 0.15 c	avg. sed= 0.04
Experiment II				
REFB	0.0 a		0.0 a	
FORCED2	+ 0.29 b		**- 0.22 b**	
FORCED1	+ 0.29 b	Waldstat.= 9.5	**- 0.15 b**	Waldstat.= 61.4
FREE1	+ 0.16 ab	d.f.= 5	+ 0.10 c	d.f.= 5
FREE2	+ 0.05 ab	p= 0.092	+ 0.01 a	p= 0.000
REFE	+ 0.22 ab	avg. sed= 0.12	- 0.01 a	avg. sed= 0.05

REFB/REFE= reference situation at the beginning and end of each experimental phase;

a,b,c different characters between rows of a column within an experiment indicate a significant difference; differences found in two or more experiments are printed in **bold** characters.

* differences between experimental phases are significant when the values found > avg. sed (average standard error of differences)*2.

3.3. Movement through the cowshed

3.3.1. Experiment I

In Experiment Ia the number of journeys from the lying area to the feeding area (including the visits to the selection system) was significantly higher during free cow traffic in comparison with the other experimental phases (p<0.01; Table 4). In Experiment Ib this number was significantly lower during forced cow traffic in comparison with the other phases (p<0.01; Table 4).

To gain a better understanding of the way the cows spent their time in the feeding area, the time distribution of the cows' stays in the feeding and lying areas was calculated for each first observation day of those experimental phases in which the selection system was used. The number of stays shorter than 16 minutes in the feeding area was higher during free cow traffic and the number of stays longer than 60 minutes was higher during forced cow traffic. The same counted for the stays in the lying area.

Table 4. Predicted means of the number of journeys from the lying area to the feeding area per cow per day in every phase of each experiment.

Experiment	phase	predicted mean	
Ia	reference begin	6.9 a	Waldstat.= 38.0
	free cow traffic	10.3 b	d.f.= 3
	forced cow traffic	7.3 ac	p=0.000
	reference end	7.9 c	avg. sed*= 0.53
Ib	reference begin	14.3 a	Waldstat.= 134.7
	free cow traffic	13.6 a	d.f.= 3
	forced cow traffic	7.8 b	p= 0.000
	reference end	11.0 c	avg. sed= 0.67
II	reference begin	12.4 a	
	FORCED2	7.7 b	
	FORCED1	7.3 b	Waldstat.= 38.7
	FREE1	9.9 c	d.f.= 5
	FREE2	10.3 ac	p= 0.000
	reference end	9.1 bc	avg. sed= 0.93

a,b,c different characters between rows within an experiment indicate a significant difference

* differences between experimental phases are significant when the values found > avg. sed (average standard error of differences)*2.

3.3.2. Experiment II

The number of journeys from the lying to the feeding area was lower during FORCED1 and FORCED2 than in the other phases. These figures differed significantly from REFB, FREE1 and FREE2 ($p<0.01$; Table 4). Like in Experiment I, the time distribution of the cows' stays in the feeding and lying areas was calculated for each first observation day of those experimental phases in which the selection system was used, with similar results.

4. DISCUSSION

4.1. The selection system as simulation of an automatic milking system

The resemblance between the selection system, as used in the experiments, and a real AMS is that it takes time and effort for the cows to enter and to pass through the systems, and that the cows are rewarded with concentrate in the systems when they deserve any. No milking was done in the simulated AMS as a robotic milking device was not available at this stage. The important question then is whether the omission of milking makes the system less attractive to the cows so that the visiting frequency is less than it would be in the real situation. On the basis of research of other authors this effect seems unlikely to exist. They found the motivation to be milked unlikely to be a sufficient stimulus to attract cows into the AMS, whereas motivation to be fed would well be (Pirkelmann, 1992; Devir et al., 1993b; Winter, 1993; Prescott et al., 1996).

This suggests that the selection system was a useful simulation of the AMS because the role of the concentrate reward was more important than the omission of the milking.

4.2. The use of the selection system during free and forced cow traffic

When free cow traffic was imposed upon the cows first and forced cow traffic afterwards, the herd visited the (simulated) automatic milking system more often during forced cow traffic (Exp. I). This was, however, caused by a number of cows that did not visit the system at all during free cow traffic. When the order of the treatments was reversed, the number of cows that visited the selection system frequently enough (i.e. three times or more) did not differ anymore between free and forced cow traffic (Exp. II). During free cow traffic the cows kept to the route that had been forced upon them previously. Some habituation or conditioning must have occurred, which is supported by a conclusion of Albright (1993) that cows are creatures of habit. The cows' pattern of movement through the cowshed had been changed significantly in the reference phase at the end of each experiment: cows went more often from the lying to the feeding area through the passage near the selection system than they did in the beginning of the experiments ($p<0.01$). This again suggests that cows easily establish habits in their way of passing the cowshed.

When an extra free passage between the feeding and the lying area was available adjacent to the selection system (Exp. II; FREE2), the number of cows that entered the selection system frequently enough (i.e. three times or more) decreased. Apparently, cows approaching the selection system choose the easy way to the feeding area (through the free passage) instead of the more complex route through the selection system, in spite of the concentrate reward. It seemed that some cows preferred to use the free passage, especially at times when the selection system was occupied or when other cows were there. The positive correlation between the dominance value and the number of visits paid to the selection system under these experimental circumstances may support this statement.

Cows were quite consistent in the number of visits they paid to the selection system during different types of cow traffic. This was most clear for those cows not visiting the system at all during the training and free cow traffic phases of Experiment Ia and Ib. Despite the training, the cows probably had not yet understood what was expected of them, and therefore did not enter the selection system voluntarily. According to Devir (1995) cows need approximately 10 days to adapt to a fully automatic milking routine and voluntary visits. The quantity of the concentrate reward in the system may also have played a role. When the amount of food was increased during the training, more cows started to visit the system regularly. Ketelaar-de Lauwere and Benders (1994) found that the number of visits to a selection system increased if a bit of concentrate is provided in the selection stall during each visit.

In the experiments at the Ossekampen, the cows entering the system did not know whether they would get access to the special concentrate feeder or be diverted back to the herd without receiving any reward. 'Warning' the cow about what is going to happen to her in the system in the form of a feed reward may help to reduce the unpredictability of the system (Winter and Hillerton, 1995) and may increase its comprehensibility and the attractiviness of visiting the system during the demanded periods of the day.

The fact that some cows had problems with the selection system while others did not is obviously a matter of individuality. Several authors have stated that the same condition may have different implications for different animals because of individual differences in coping response (Broom, 1988; Hopster and Blokhuis, 1993; van Reenen et al., 1995). It seems useful to examine how this knowledge can be applied in AMS management strategies.

4.3. Consequences for other behaviour

From the farmer's point of view it may be better to install forced cow traffic in the AMS cowshed because the required number of AMS visits per cow can be guaranteed more easily. This opinion is confirmed by Devir (1995), although he points out that even with forced cow traffic there may be cows that do not visit the AMS enough, especially when higher milking frequencies are required.

In this study we focused on effects on the time budget of the cows. The lying times and the diurnal pattern were not affected by different types of cow traffic. Some differences in the number and duration of lying and feeding periods were observed, but this was not consistent throughout the experiments. The only obvious effect was that the cows spent less time standing at the feeding gate and more time standing on the slatted floor in the feeding area during forced cow traffic situations. Winter and Hillerton (1995) also found an increased standing time in a 5-day experiment with forced cow traffic, but in their experiment the lying time decreased and the time spent at the feeding gate did not. Several authors described increased standing time in a group of cows as a possible sign of stress or discomfort (Albright, 1987; Winter and Hillerton, 1995).

During forced cow traffic there was also less movement through the cowshed. Similar results were found by Winter et al. (1992) and Metz-Stefanowska et al. (1993). Any 'extra' movement through the cowshed in free cow traffic situations can be explained by the short journeys between the feeding and lying areas. These were probably associated with visits to the concentrate feeder, placed in the lying area. Metz et al. (1991) described that 87% of the journeys to a feeding area were directly associated with a visit to a concentrate feeder positioned in this area.

Whether restriction of their movement through the cowshed has a negative effect on the cows is questionable. According to Metz-Stefanowska et al. (1993) cows tended to behave more 'efficiently' under conditions of forced cow traffic because the number of stays in the feeding area not connected with intake of concentrate, forage and water diminished. Van Putten et al. (1989) pointed out that freedom to act and easy access to important sources (such as feeding, drinking and resting places) are important items concerning animal welfare and automation. During forced cow traffic, as used in our experiment, cows were somewhat restricted in their behaviour and the feeding gate and resting places were not as easy to reach as during free cow traffic.

Visiting an AMS may involve a substantial amount of queueing and waiting time, especially when forced cow traffic is applied and/or the occupation rate of cows per milking stall is high (Metz and Ketelaar-de Lauwere, 1995; Devir et al., 1996b). Here, effects of social dominance may arise. Ketelaar-de Lauwere et al. (1996) found that cows lower in rank spent more time waiting in front of the AMS. Queueing and a longer waiting time does not have to be a problem as long as the cows can perform maintenance behaviours such as lying and feeding sufficiently and with a normal temporal distribution (Miller and Wood-Gush, 1991; Metz and Ketelaar-de Lauwere, 1995). Devir et al. (1996b) stated that extra selection stalls in front of the milking stalls could reduce waiting times. They suggested a ratio of two selection units to one milking stall. According to Winter and Hillerton (1995) more milking stalls or a holding pen allowing access to feed following recognition may reduce forced cow traffic problems. These solutions are nevertheless not 'simple' and not 'non-confusing' to the cow as stated by Hurnik (1992) as critical requirements of the AMS.

To our knowledge at present and with regard to the cows' behaviour and welfare forced cow traffic could be considered to be a questionable procedure. However, on the basis of the presented data hard conclusions cannot be drawn. Investigations into stress-like physiological responses on the slowdown and delay of behavioural cycles could help (Broom, 1988). In the first instance, it may be advisable to pay more attention to the improvement of cows' visits to an AMS in free cow traffic situations, rather than to focus on forced cow traffic situations.

5. CONCLUSIONS

Individual cows appeared to be rather consistent in their visiting frequency of the selection system during different types of cow traffic. The application of forced cow traffic in a cubicle house with a selection system, simulating an AMS, may give the best results from a technical point of view. This is because the cows' only way to get access to the feeding area is through the selection system; thus high visiting frequencies can be guaranteed more easily. However, during forced cow traffic, cows spent more time standing on the slatted floor in the feeding area, spent less time standing at the feeding gate, and there was less movement through the cowshed. From the cow's point of view free cow traffic could be the better procedure. If the cows have been previously conditioned to take the route to the AMS, visits would not be affected.

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CHAPTER 4

THE INFLUENCE OF ROUTING TREATMENTS ON COWS' VISITS TO AN AUTOMATIC MILKING SYSTEM, THEIR TIME BUDGET AND OTHER BEHAVIOUR

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ABSTRACT

Four cow routing treatments related to fully automatic milking were compared consecutively in one group of 24 Holstein Friesian cows. The objective of the experiment was to investigate how cow traffic towards the automatic milking system (AMS) should be routed and whether a pre-selection or a waiting area in front of the AMS should be used. The treatments were (1) free routing with selection of cows in the AMS (FREE), (2) free routing with a pre-selection system in front of the AMS (FREE_SS), (3) free routing with a pre-selection system and a waiting area in front of the AMS (FREE_WA), (4) one-way gates resulting in forced routing with pre-selection and a waiting area in front of the AMS (FORCED_WA). Evaluation of the treatments reveals that FREE may be questionable with regard to the cows' visiting frequency to the AMS and that the use of a waiting area in combination with free routing (FREE_WA) may slow down the passing through the AMS. FORCED_WA may be the best option in relation to the cows' use of the AMS, but this traffic system seems to postpone or even thwart the feeding. The treatment that appears to give the best results is FREE_SS.

The type of AMS visit appeared to have a marked influence on the cows' subsequent behaviour. Cows returned to the AMS sooner after non-milking visits and failed attachments ($p<0.01$). This increases the occupation rate of the AMS and may induce some extra unrest in the herd.

Keywords: cow traffic, fully automatic milking, type of AMS visit

1. INTRODUCTION

Milking without human interference in an automatic milking system (AMS) equipped with a milking robot will be common practice on dairy farms in the near future (Devir et al., 1996; Rossing et al., 1997). Management methods and tools have to be adapted if an AMS is to be installed in a loose housing dairy farm to enable daily automatic milking and feeding (Devir et al., 1993). When a farmer has decided to replace his traditional milking parlour by an AMS, he has to choose where to locate the AMS in the cowshed and how to route the cows to the AMS (Ipema, 1997). In cubicle houses in which the feeding area is separated from the lying area, the AMS can be located between these two areas. In that case two routing strategies are possible: free and forced. In free routing, cows can decide whether and when to visit the AMS. In forced routing, they must pass through the system to access the feeding area (or lying area) because there are one-way gates in the passages (Ketelaar-de Lauwere, 1991). In free routing, each cow can develop her own individual visiting pattern (Ketelaar-de Lauwere et al., 1998), but some cows may not enter the AMS sufficiently often and will have to be fetched by the farmer (Ipema et al., 1988). Forced routing may be the best solution for the farmer because it most easily ensures that cows will visit the system often enough (Devir, 1995). On the other hand, forced routing requires extra behavioural efforts of the cows and may be questionable with regard to the cow's welfare (Ketelaar-de Lauwere et al., 1998; Prescott et al., 1996a; Winter and Hillerton, 1995).

Other decisions the farmer must make are whether to use a pre-selection system, and whether to combine this with a waiting area. A pre-selection system is positioned in front of the AMS, and cows have to enter it before they can reach the AMS. If they do not have to be milked, they are selected on the basis of individual electronic identification and diverted from the AMS (Swierstra and Smits, 1989). When the AMS is occupied, cows who want to visit it have to wait their turn in front of it. This can cause them to withdraw from the system and perform some other activity first (eg. feeding or lying) thus postponing their AMS visit. A waiting area between the pre-selection system and the entrance of the AMS may prevent cows from postponing their milking visit, when the AMS is occupied (Uetake et al., 1997).

Experiments are needed to clarify the pros and cons of the different designs and layouts, to help the farmer choose appropriately. Therefore, four different cow routing treatments were compared. Free routing without a pre-selection system, free routing with a pre-selection system, free routing with a pre-selection system and a waiting area, and forced routing with a pre-selection system and a waiting area were studied consecutively. The aim of the study was to evaluate these AMS environments with respect to the cows' visiting frequency to the AMS and their time budgets. In addition, the influence of the type of AMS visits on the cows' behaviour between consecutive AMS visits was used to identify an optimal design.

2. MATERIAL AND METHODS

2.1. Animals, housing and feeding

A group of 24 Holstein Friesian dairy cows was used, consisting of 9 heifers and 15 second or higher parity cows. At the beginning of the experiment, the heifers were between 96 and

164 days in lactation, and the second or higher parity cows between 28 and 131 days. Five heifers and seven second or higher parity cows were pregnant at the beginning of the experiment. One 4th. parity cow had to be culled after two of the four treatments due to severe mastitis.

The cows were kept in a section of a cubicle house with the feeding area separated from the lying area but connected by a passage and an AMS (with its entrance in the lying area and its exit in the feeding area: Figure 1). The floor consisted of concrete slats. There were 24 cubicles available in the lying area. In the feeding area, there was a feeding gate with an automatic forage feeding system with cow identification equipment and 12 feeding troughs and 2 water troughs. A total mixed ration of 48 % grass silage, 22 % maize silage, 9 % sugar beet pulp and 21 % concentrate on dry matter base was fed ad libitum. Water was continuously available at the two troughs in the feeding area and in a special stall with a cow identification unit in the lying area (Figure 1). The cows could be milked throughout the 24-hour period in one of the two milking stalls of the AMS, except between 8:00 and 8:30 a.m. and p.m. when the AMS was cleaned and between 0:00 and 0:15 a.m. when the data of the previous day were backed up. Concentrate was dispensed in the AMS during milking visits: second or higher parity cows received 1.5 kg and heifers 1 kg of concentrate. The minimum milking interval was 6 h, thus cows visiting the AMS within these 6 hours, were sent back to the herd without milking and without a concentrate reward. Cows with a milking interval of 7 hours or longer were fetched.

The cubicle house was illuminated by daylight and by a double row of fluorescent light between 6:00 a.m. and midnight. During the rest of the 24-hour period a single row of fluorescent light was on. The AMS was illuminated permanently.

2.2. *Experimental design*

The four cow routing treatments of increasing complexity studied consecutively were:

1. Free routing without a pre-selection system or waiting area (FREE). During this treatment the cows could move freely between the lying area and the feeding area of the cowshed. They could enter the AMS, whether or not they were entitled to milking. When both AMS milking stalls were occupied, they could wait in front of the entrance of the AMS, or they could postpone their milking visit and perform some other activity first. When the cows were milked, the cluster was attached by the milking robot and concentrate was supplied

automatically. When the cows were not entitled to milking, they did not receive any concentrate and were sent out of the milking stall (Figure 1a).

2. Free routing with a pre-selection system, but no waiting area (FREE-SS). This was the same as the first treatment, with the exception that a pre-selection system was positioned in front of the entrance of the AMS. A cow had to enter this system first to seek access to the AMS. After electronic identification, the cow was sent back to the herd, if her milking interval was less than 6 hours, or was allowed access to the AMS to be milked. In contrast with earlier experiments (Devir et al., 1996), the cows were not locked in the pre-selection system after identification, so they could withdraw from it (Figure 1b).

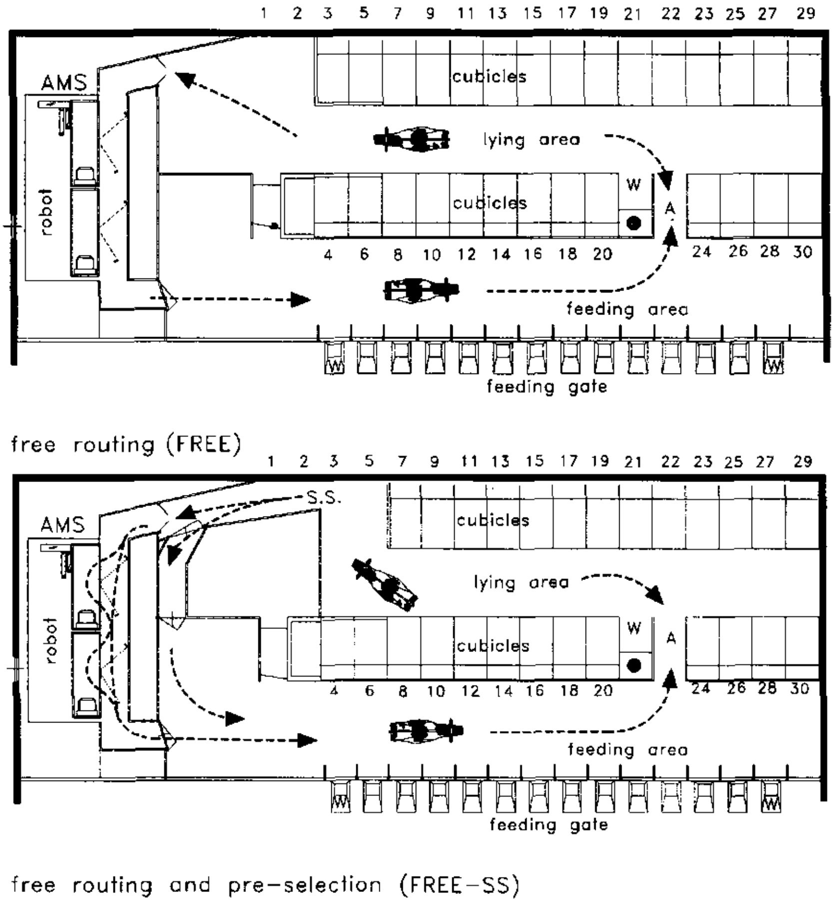


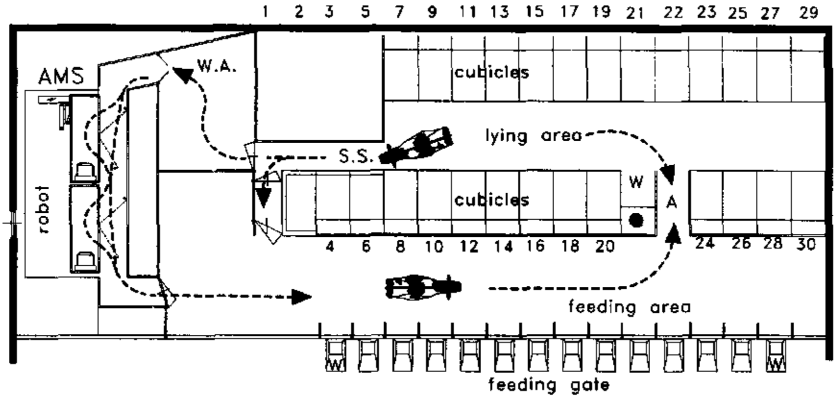
Figure 1a and 1b. Plan of the cowshed during free cow traffic and during free cow traffic with pre-selection; AMS = automatic milking system; S.S. = pre-selection system; W = water trough; A = passage between feeding and lying areas.

3. Free routing with a pre-selection system and a waiting area (FREE-WA). As in the first two treatments, the cows could move freely between the lying and feeding areas of the cowshed. This time a waiting area was created between the pre-selection system and the entrance of the AMS. When cows who had to be milked came to the selection system, they could be "herded" in the waiting area, and thus not postpone their milking visit if both milking stalls of the AMS were occupied (Figure1c).
4. Forced routing with a pre-selection system and a waiting area (FORCED-WA). During this treatment a one-way gate was positioned in the passage between the lying and feeding areas, so that cows could only go from the feeding area to the lying area. To return to the feeding area, they had to go via the AMS. If they did not have to be milked, they were routed through the pre-selection system; if they were due to be milked, they were routed via the waiting area and the AMS (Figure 1d).

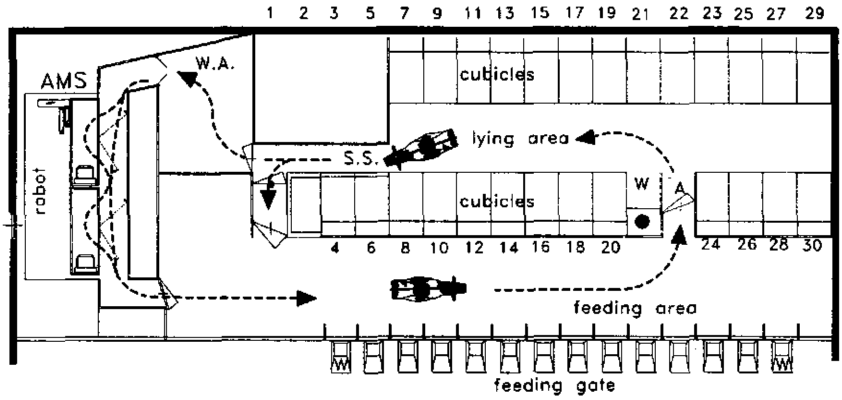
Each treatment lasted four consecutive weeks: the first week for adaptation to a new treatment, two weeks for behavioural observations; and the last week for converting the section of the cubicle house in which the cows were housed for the new treatment.

In this paper "AMS area" refers to the area from the entrance of the pre-selection system to the exit of the AMS itself, and "AMS" refers to the area between the entrance and exit of the AMS (so, in FREE the AMS area and the AMS are identical, whereas in the other treatments the AMS area includes the equipment in front of the AMS which is used to select or 'herd' cows (Figure 1).

Three types of AMS visits can be distinguished: (1) milking visits for cows which were milked by the robot when they entered the system; the cluster was attached automatically in most cases or manually in a few cases; the cows received concentrate during milking; (2) non-milking visits for cows which reported to the AMS before the minimum interval of 6 hours had passed and therefore were refused milking; the cows did not receive any concentrate; (3) failed attachments for cows which came to the system and should have been milked by the robot but were not because of technical failure; they did receive some concentrate. The type of AMS visit appeared to affect the cows' behaviour. Therefore, the period between consecutive AMS visits was defined as a "complete" or a "incomplete" behavioural cycle. During "complete" behavioural cycles, cows ate forage and lay down between consecutive AMS visits; during "incomplete" behavioural cycles, they only ate forage, only lay down or performed neither of these behaviours between consecutive AMS visits.



free routing, pre-selection and waiting area (FREE-WA)



forced routing, pre-selection and waiting area (FORCED-WA)

Figure 1c and 1d. Plan of the cowshed during free cow traffic with pre-selection and waiting area and during forced cow traffic with pre-selection and waiting area; AMS = automatic milking system; S.S. = pre-selection system; W.A. = waiting area; W = water trough; A = passage between feeding and lying areas.

2.3. Observations

The behaviour of the cows was monitored by video recording and by computer registration. For each treatment, 4 x 24 hours of video recordings were analysed. It was recorded whether individual cows were lying or standing in the cubicles every 9 minutes. Each cow was also electronically identified on-line at several places in the cowshed. This enabled the number and duration of stays in the feeding, lying and AMS areas, at the feeding gate and in the drinking stall to be calculated. The forage intake, water intake, amount of concentrate in the AMS and milk production were also registered on-line. In each treatment, 6 complete 24 hours of computer registrations were analysed.

2.4. Statistical analyses

Differences between treatments were estimated according to the Iterative Reweighted Residual Maximum Likelihood treatment (IRREML) (Engel and Keen, 1994). This algorithm estimates treatment effects and variance components in a Generalised Linear Mixed Model (GLMM) with both fixed and random effects. Fixed effects were treatment, lactation number, type of AMS visit when the behaviour between consecutive AMS visits was under consideration, and the interaction between these factors. Cows were incorporated into the model as random effect, because observations on the same cow were not independent. Model selection took place by backwards elimination. The Wald statistic (VWS) was calculated to test on a 99% probability for the significance of fixed effects under the null hypothesis that there were no differences between treatments and/or types of AMS visits. This statistic has an asymptotic chi-squared distribution (Genstat 5 Committee, 1993).

Response variables concerning a time duration or a count were analysed according to the model:

$$y = \beta x + uz + \varepsilon,$$

in which y was the response variable (i.e. the behaviour under consideration), β are the fixed effects of treatment, lactation number, type of AMS or either interaction between those factors (x), u is the random effect of cow z and ε is the residual error term. It was reasonable to assume that the variance of response variables concerning a duration increased proportionally with the square of the response value of that duration and the variance of response variables concerning counts increased proportionally with the response value of these counts. This was confirmed by the residual plots of the analyses. The response variables "lying and standing in the cubicle" and those concerning the behaviour between consecutive AMS visits were expressed as percentages and, therefore, analysed with a GLMM, assuming a binomial distribution and a logistic link function (Oude Voshaar, 1994). The resulting model was:

$$\log(p/(1-p) = \beta x + uz + \varepsilon,$$

where p is the probability that the cows are seen performing the behaviour under study. In general, no effect of treatment and lactation number was found on the behaviour between consecutive AMS visits when the free routing treatments were analysed together. When FORCED_WA was incorporated into the analysis, an interaction between treatment and type of AMS visit was sometimes found. Therefore, this statistical analysis was combined for free routing and executed separately for FORCED_WA.

The Genstat 5 statistical package was used for the analyses (Genstat 5 Committee, 1993).

3. RESULTS

3.1. The cows' visits to the AMS and AMS Area

Table 1 gives an overview of the cows' use of the AMS during the different treatments. Only the most notable results are described below.

The number of visits to the AMS area increased during the experiment. All treatments differed significantly from each other. No overall effect of treatment could be estimated for the number of milking visits, due to an interaction between treatment and lactation number (Table 1). The number of non-milking visits was highest during FORCED_WA and lowest during FREE. Both treatments differed significantly from each other and from the other two treatments. Irrespective of the treatment, heifers paid significantly more non-milking visits to the AMS than second or higher parity cows (predicted means are 4.8 and 3.2 respectively; avg. sed = 0.6; $VWS_{df=1} = 7.5$; p=0.006). No overall effect of treatment on the total time spent in the AMS could be estimated due to a significant interaction between treatment and lactation number (Table 1). The time spent in the AMS area was longer in FREE_WA than in the other 3 treatments.

3.2. The cows' time budget with respect to the lying and feeding area

Table 2 gives a complete overview of the cows' use of the lying and feeding areas in the four treatments. In FREE, the cows had more stays in the lying area with lying of the shortest average duration than in the other treatments. In FORCED_WA, cows spent more time in the lying area and more time standing in the cubicles than in the other treatments. No overall effect of treatment could be estimated for lying in the cubicle, due to an interaction between treatment and lactation number (Table 2). Cows spent least time in the feeding area in FORCED_WA and most time in FREE_SS. Both differed from the other treatments. In FORCED_WA, there were fewer stays at the feeding gate, the cows spent the least time eating forage and had higher forage eating rates than in the other treatments. No effect of treatment was found for the forage intake. Irrespective of the treatment, second or higher parity cows ate more forage than heifers (predicted mean = 30.1 kg for heifers and 33.5 kg for second or higher parity cows; sed = 1.1; $VWS_{df=1}$ = 10.6; p=0.001).

Table 1. Predicted means of the cows' daily visits to the AMS, based on 6 complete 24 hours of computer registrations per treatment.

treatment:	FREE	FREE_SS	FREE_WA	FORCED_WA	*sed*	$VWS_{df=3}$; p
no. of visits to AMS area	5.8^{a}	6.6^{b}	7.2^{c}	9.9^{d}	0.3	182.2;p=0.000
milking visits[1]					0.1	27.6; p=0.000
heifers	2.5^{*a}	3.1^{b}	2.9^{c}	3.0^{bc}		
2nd. or higher parity cows	2.9^{*a}	2.8^{a}	2.8^{a}	3.0^{a}		
non-milking visits	2.6^{a}	3.3^{b}	3.3^{b}	5.6^{c}	0.3	117.8;p=0.000
failed attachments	1.8^{a}	1.7^{a}	2.8^{b}	2.4^{ab}	0.5	7.4; p=0.06
total time spent in AMS (min)[1]					4.5	19.0; p=0.000
heifers	69.2^{*a}	39.9^{b}	46.6^{b}	38.9^{b}		
2nd. or higher parity cows	44.0^{*a}	41.6^{ab}	42.3^{ab}	36.9^{b}		
total time spent in AMS area (min)	48.1^{a}	49.0^{a}	61.9^{b}	51.1^{a}	2.8	24.8; p=0.000

a,b,c,d in a row indicate a significant difference between treatments.

* indicate a significant difference between heifers and second or higher parity cows in a certain treatment.

[1] predicted means are given separately for heifers and second or higher parity cows when a significant interaction was found between treatment and lactation number.

Table 2. Predicted means of the cows' use of the lying and feeding areas based on 6 complete 24 hours of computer registrations, unless stated otherwise.

treatment:	FREE	FREE_SS	FREE_WA	FORCED_WA	sed	$VWS_{df=3}$; p
total time spent in lying area (min)	922.8^{a}	887.3^{b}	907.3^{ab}	965.3^{c}	12.5	40.9; p=0.000
no. of stays in lying area	10.1^{ac}	10.4^{ab}	10.8^{b}	9.6^{c}	0.3	17.7; p=0.000
no. of stays in lying area with lying[2]	6.4^{a}	5.6^{b}	5.7^{b}	5.3^{b}	0.2	38.0; p=0.000
av. duration of lying periods (min)[2]	116.8^{a}	135.0^{bc}	127.5^{b}	141.0^{c}	5.2	26.0; p=0.000
total time spent lying in cubicle(min)[2]						17.7; p=0.001
heifers[1]	725.5^{ac}	675.9^{abc}	630.4^{b}	687.6^{c}	*47.8**	
2nd. or higher parity cows[1]	700.4^{a}	736.1^{ab}	745.9^{b}	740.2^{ab}	*38.5**	
total time spent standing in cubicle (min)[2]	121.7^{a}	118.5^{a}	126.3^{a}	156.6^{b}	*26.6**	
total time spent in feeding area (min)	468.0^{a}	494.7^{b}	459.0^{a}	426.0^{c}	0.7	34.6; p=0.000
no. of stays in feeding area	10.1^{a}	10.5^{ab}	11.0^{b}	9.9^{a}	0.3	16.5; p=0.001
no. of stays at feeding gate	8.5^{a}	8.2^{a}	8.5^{a}	7.8^{b}	0.2	16.9; p=0.001
av. duration of stays at feeding gate (min)	28.6^{ab}	29.2^{a}	27.4^{bc}	27.1^{c}	0.7	11.0; p=0.012
total time spent eating forage (min)	226.8^{a}	223.2^{ab}	215.5^{b}	195.8^{c}	2.5	74.6; p=0.000
forage intake (kg)	33.0^{a}	31.6^{a}	32.2^{a}	31.6^{a}	0.7	5.4; p=0.146
eating rate (g/min)	149.7^{ab}	145.8^{a}	152.1^{b}	168.6^{c}	2.9	70.4; p=0.000

^{a,b,c} in a row indicate a significant difference between treatments.

* no reliable estimation of sed can be made when using logistic models; therefore, *SE* has been given in italics as degree of deviation

[1] predicted means are given separately for heifers and second or higher parity cows when a significant interaction was found between treatment and lactation number.

[2] based on 4 complete 24 hours of video observations.

3.3. The role of the type of AMS visit

A significant interaction was found between treatment, type of AMS visit and lactation number for the time interval between consecutive AMS visits (Table 3; avg. sed = 20.1 min; $VWS_{df=6} = 17.0$; p = 0.009). Irrespective of the treatment and the lactation number, the time until a next AMS visit was longer after a milking visit than after a non-milking visit or a failed attachment. After a milking visit, the time until the next AMS visit was shorter in FORCED_WA than in the other treatments both for heifers and second or higher parity cows. Differences between treatments after non-milking visits and failed attachments were less consistent (Table 3). When differences between heifers and second or higher parity cows were found, the time until the next AMS visit was shorter for heifers than for second or higher parity cows.

Table 4 shows the behaviour of the cows between consecutive AMS visits, in relation to the type of the previous AMS visit. The most obvious results were that in the free routing treatments, there were more complete behavioural cycles and fewer incomplete behavioural cycles after milking visits than after the other two types of AMS visits. During forced routing, the same was found for the complete behavioural cycles and for the incomplete behavioural cycles with eating only, or for those without eating and without lying. However, the behavioural cycles with lying only were seen more often after milking visits and failed attachments than after non-milking visits.

Table 3. Predicted means of the time between AMS visits in the four treatments in relation to the type of AMS visit and the lactation number.

	treatment			
	FREE	FREE_SS	FREE_WA	FORCED_WA
heifers				
milking visits	$333.0^{x\,a}$	$289.1^{x\,a}$ *	$300.8^{x\,a}$	$178.1^{x\,b}$
non-milking visits	$171.5^{y\,a}$	$103.9^{y\,b}$	$70.2^{y\,c}$	$69.3^{y\,c}$
failed attachments	$97.5^{z\,a}$	$58.4^{z\,b}$	$76.9^{y\,ac}$	$67.9^{y\,bc}$ *
second or higher parity cows				
milking visits	$396.5^{x\,a}$	$395.7^{x\,a}$ *	$362.2^{x\,a}$	$220.9^{x\,b}$
non-milking visits	$143.4^{y\,a}$	$96.2^{y\,b}$	$78.9^{y\,c}$	$88.7^{y\,bc}$
failed attachments	$100.8^{z\,a}$	$81.5^{y\,ab}$	$69.7^{y\,b}$	$100.0^{y\,a}$ *

^{x,y,z} in a column indicate a significant difference between different types of AMS visits for a certain treatment and a certain lactation number.

^{a,b,c} in a row indicate a significant difference between treatments for a certain type of AMS visit and a certain lactation number.

* indicate a significant difference between heifers and second or higher parity cows for a certain treatment and a certain type of AMS visit.

Table 4. Predicted means of the cows' behaviour between consecutive AMS visits in relation to the type of the previous AMS visit (in %); SE in brackets.

	milking visit	non-milking visit	failed attachment	$VWS_{df=2}$; p
free cow traffic situations				
eating and lying	89.5 (3.7)^{a}	39.4 (4.4)^{b}	29.8 (6.6)^{b}	186.9; p=0.000
only eating	5.3 (2.7)^{a}	43.6 (3.1)^{b}	36.9 (4.8)^{b}	159.6; p=0.000
only lying	2.8 (2.5)^{a}	7.3 (3.1)^{b}	7.3 (4.4)^{b}	17.9; p=0.000
no eating; no lying	2.4 (3.0)^{a}	7.7 (3.7)^{b}	18.8 (5.8)^{c}	47.7; p=0.000
forced cow traffic				
eating and lying	61.9 (4.4)^{a}	44.4 (3.6)^{b}	18.2 (6.7)^{c}	36.3; p=0.000
only eating	10.1 (3.9)^{a}	40.5 (3.3)^{b}	44.0 (6.1)^{b}	61.2; p=0.000
only lying	22.8 (3.4)^{a}	6.6 (2.7)^{b}	14.8 (5.6)^{a}	36.9; p=0.000
no eating; no lying	3.3 (3.8)^{a}	6.4 (3.4)^{b}	16.7 (6.3)^{c}	22.4; p=0.000

^{a,b,c} in a row indicate a significant difference between different types of AMS visits.

4. DISCUSSION

4.1. The cows' visits to the AMS

For the successful introduction of fully automatic milking systems, cows have to report voluntarily at regular intervals (Ipema, 1997; Ketelaar-de Lauwere, 1992; Winter et al., 1992). In the present experiment, cows paid most visits to the AMS during FORCED_WA, which is similar to earlier results obtained by Ketelaar-de Lauwere et al. (1998). This implies that when the milking frequency is the only criterion under consideration, FORCED_WA is better than the other routing treatments. The higher number of AMS visits during FORCED_WA was, nevertheless, associated with more non-milking visits.

Visiting an AMS may involve a substantial amount of queuing and waiting time, especially if the milking frequency per cow and the occupation rate of the milking stall is high (Metz and Ketelaar-de Lauwere, 1995). In the present experiment, the time spent in the AMS area was highest with free routing in combination with a waiting area. Thus, under these circumstances, a waiting area retards the passing through the AMS. Passing through the AMS was not slowed down when a waiting area was combined with forced routing. In this case, cows were forced to enter the AMS area to reach the forage. Therefore, the cows were probably more motivated to pass through the system quickly under this treatment than under the other treatments. According to Prescott et al. (1996b) food is more likely to be a sufficient stimulus to attract cows into the AMS than milking itself.

4.2. The time budget of the cows

Resting and eating are both basically important in animal self-maintenance (Fraser, 1983). Therefore, an AMS should be positioned in the barn in such a way, that milking is integrated into the cows' daily feeding and resting patterns in a "natural" way, so that there is minimal disruption to lying periods, feeding is not postponed and sufficient time is available for other maintenance behaviours (Metz and Ketelaar-de Lauwere, 1995). In the present experiment, the treatment in which the total time spent in the lying area and standing in the cubicle was highest, and the total time spent in the feeding area and eating forage was lowest, was FORCED_WA. An increase in "idle" standing and a decrease in lying and eating time had been reported earlier (Ketelaar-de Lauwere et al., 1998; Prescott et al., 1997; Winter and Hillerton, 1995). Increased standing of cattle is often taken as a sign of discomfort or discontent (Albright, 1987). Decreased eating may indicate that the cows were in some way restricted in this behaviour (Ketelaar-de Lauwere et al., 1998). In the present experiment, the forage intake did not differ between the treatments, but the cows ate faster during FORCED _WA. Higher eating rates of dairy cows have been found when the number of feeding places or the amount of food was restricted (Gerstlauer, 1979; Olofsson and Wiktorsson, 1994). Therefore our finding again may indicate that the cows' feeding behaviour was restricted in some way under forced routing. It seems likely that the cows were reluctant to enter the AMS and thus postponed eating and, thereby, limited their eating time. The "extra" idle standing supports this explanation.

4.3. The role of the type of AMS visit on the behaviour between consecutive AMS visits

The results of the present study show that the type of AMS visit had a clear influence on the cows' behaviour after that visit. Irrespective of the cow routing treatment, cows returned sooner to the AMS after non-milking visits or failed attachments than after milking visits. This has been reported earlier (Devir, 1995; Ketelaar-de Lauwere and Benders, 1994; Ketelaar-de Lauwere and Ipema, 1996). Cows also had more complete behavioural cycles (with eating and lying between consecutive AMS visits), after milking visits than after non-milking visits or failed attachments. This effect was seen in all treatments, although the total number of these cycles per day was lower during forced routing than in other routing treatments. Conversely, the number of incomplete behavioural cycles with only lying after milking visits was highest during forced routing.

Incomplete behavioural cycles are disadvantageous for the AMS capacity (Morita et al., 1996). They cause cows to move through the barn more often, which may lead to increased unrest and more social interactions in the herd (Wierenga and Hopster, 1991). In the present study, incomplete behavioural cycles were more a feature of forced routing, and also of the type of AMS visit, being especially common after a non-milking visits or a failed attachment. Cows tended to return to the AMS without taking the opportunity to eat and rest. Morita et al. (1996) has reported that after AMS visits without concentrate (such as non-milking visits) cows either made a new attempt to obtain concentrate or satisfied their demand for concentrate by eating roughage. It is unlikely that non-milking visits can be prevented in future AMS; it is, however, expected that the incidence of failed attachments can be reduced or almost eliminated in the further technical refinement of AMS. This will avoid unnecessary movement of cows through the barn.

4.4. Evaluation of the experiment

Comparison of different cow routing treatments, studied consecutively in one group of cows and without replications, gives only tentative results (Jansen, 1990). Unfortunately, research on dairy cows which are milked in an AMS is prohibitively expensive for experimental replications. Nevertheless, the present study provides much information about the implementation of AMS in dairy husbandry, as on-farm experiments can be a useful tool in systemic research (Sørensen, and Hindhede, 1997). This is supported by the fact that the differences between treatments found in the present study reinforce the findings of previous studies (Ketelaar-de Lauwere et al., 1998; Prescott et al., 1996a, Winter and Hillerton, 1995). When an effect of lactation number was found, this was mostly in the way that heifers were more active than older cows. Others have found analogous results regarding age effects in relation to general activity (Baehr, 1984, Kempkens and Boxberger, 1987), visits to an automatic feed dispenser (Collis, 1980) and visits to an AMS (Devir, 1995, Prescott, 1995).

The statistical analysis did not allow us to distinguish between the effect of treatment and the effect of lactation stage. It is, however, unlikely that the described effects of treatment were actually an effect of the stage of lactation. The number of AMS visits increased during the experiment, but if lactation stage would have had a substantial impact, it is more likely that an inverse relationship between number of AMS visits and lactation stage would have been found. Similarly, Little and Harrison (1984) reported an inverse relationship between lactation stage and the number of visits paid to concentrate dispensers and Ipema et al. (1988) reported such a relationship for cows near drying-off visiting a combined milking and feeding stall. The fact that the cows spent less time eating forage at the end of the experiment (during FORCED_WA) is also unlikely to be an effect of stage of lactation as other authors have not found an effect of the stage of lactation on feeding or lying times (Baehr, 1984; Dechamps et al., 1989).

5. CONCLUSIONS

From the results presented above, it is not immediately obvious which cow routing treatment is preferable. Free routing with selection of cows in the AMS seems the most questionable in relation to the cows' visits to the AMS, as some cows visited too infrequently. A waiting area in combination with free routing slowed down the passing through the AMS, which is unfavourable in terms of AMS capacity. Forced routing may be the best option in relation to cows' use of the AMS, because the cows passed through the system quickly and the number of visits was highest, but this traffic system seems to postpone or even thwart feeding. From this we conclude that free routing in combination with a pre-selection system may be the best compromise between technical and behavioural issues, given that the other treatments all appeared to have their own specific "problems". It should be taken into account that this study involved 24 cows only. With larger herds, it is likely that the typical problems of the non-preferred routing systems will be more pronounced and have a more negative impact on the cows' visits to an AMS and their time budget.

The study demonstrated that the type of AMS visit has a marked influence on the cows' subsequent behaviour. Complete behavioural cycles with eating and lying between two consecutive AMS visits were seen more often after milking visits than after non-milking visits and failed attachments. Non-milking visits and failed attachments were followed more often by incomplete behavioural cycles comprising only eating, only lying or neither between AMS visits. Cows returned to the AMS sooner in that case. This increases the occupation rate of the AMS and may induce some extra unrest and social interaction in the herd. Non-milking visits cannot be prevented in future AMS design, but failed attachments can, by further technical improvements.

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CHAPTER 5

THE INFLUENCE OF THE ACCESSIBILITY OF CONCENTRATE ON THE BEHAVIOUR OF COWS MILKED IN AN AUTOMATIC MILKING SYSTEM

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ABSTRACT

Forcing cows to visit the automatic milking system (AMS) regularly because it is their only way to roughage, might be questionable with regard to the cows' welfare, but leaving them free to choose whether to visit the AMS also seems to be questionable because some will pay insufficient visits to the AMS. Therefore, an alternative routing method was studied, in which the cows could move freely between the feeding and lying areas, but were stimulated to visit the AMS as only way of accessing the concentrate feeder. Two experiments were conducted, each with two treatments and 20 Holstein Friesian dairy cows. In the first treatment of experiment I, the concentrate feeder was accessible only via the AMS, and in the second treatment, it was freely accessible. In both cases a new portion of concentrate became available once every two hours. In experiment II, the concentrate feeder was available only via the AMS. A new portion of concentrate became available every two hours during the first treatment of this experiment and every four hours during the second treatment.

The results showed that allocation of concentrate in a feeder which can only be reached via the AMS is a good stimulus to attract cows to the AMS regularly, because the milking frequency increased in this situation, and the waiting time in front of the concentrate feeder and the number of aggressive interactions in this area decreased. It is better to make concentrate available once every four hours than once every two hours, because this increases concentrate intake and rest in the barn.

Key words: automatic milking system, concentrate feeding, behaviour

1. INTRODUCTION

Automatic milking systems (AMS), which enable cows to be milked without human interference, are coming into commercial use (Devir et al., 1996, Rossing et al., 1997). In the present stage of development the emphasis is on "self service" milking of cows. In this approach, cows are expected to visit the milking stall of the AMS voluntarily and regularly (Ipema, 1997). By creating a forced routing (also referred to as one-way routing), in which cows have to pass through the AMS to get access to the feeding area, visits can be obtained regularly (e.g. Dück, 1992; Rossing et al., 1997, Hogeveen et al., 1998). This may be supported by allocating concentrate in the AMS (Devir et al., 1997). However, forced routing is associated with decreased movement of cows through the barn (Winter et al., 1992; Metz-Stefanowska et al., 1993, Ketelaar-de Lauwere et al., 1998) as well as less lying in the cubicles (Winter and Hillerton, 1995), less eating forage or both (Prescott et al., 1997) and increased idle standing (Winter and Hillerton, 1995; Ketelaar-de Lauwere et al., 1998), which may be a sign of stress or discomfort (Albright, 1987). Therefore, forced routing seems questionable from the welfare point of view.

An alternative to forced cow routing is free routing in which cows can choose to visit the AMS whenever they want. However, the drawback of this method is that some cows will visit the AMS insufficiently (Ketelaar-de Lauwere et al., 1998). Concentrate allocation is a good stimulus to attract cows to the AMS, as motivation to be fed is more likely to be a sufficient stimulus than motivation to be milked (Prescott et al., 1996). If all concentrate is supplied in the AMS, cows with a large daily ration may not have sufficient time to consume it during milking; on the other hand, using the AMS for feeding without milking would reduce the capacity of the AMS (Devir et al., 1997; Ipema, 1997). Moreover, with consumption of high amounts of concentrate at one time, the probability of rumen acidosis increases (Kaufmann, 1972; Webster, 1993).

An alternative to the above methods is to locate a concentrate feeder at the exit of the AMS in such a way that it only can be reached by passing through the AMS (Prescott, 1995; Ipema, 1997). In such a situation, the forage area remains freely accessible from the lying area, and the cows' motivation for concentrate will be used to attract them to the AMS. This alternative type of cow traffic was studied in the experiments reported in this paper. In the first experiment the effect of the accessibility of the concentrate feeder was studied by comparing a treatment in which the concentrate feeder was accessible only through the AMS with one in which the concentrate feeder was freely accessible. In the second experiment the concentrate feeding regime was studied because this can affect the behaviour of the cows as well (Wierenga and Hopster, 1991).

The aim of the study was to evaluate this type of routing in terms of the cows' visits to the AMS and the concentrate feeder, their concentrate intake, their time budget and other behaviour.

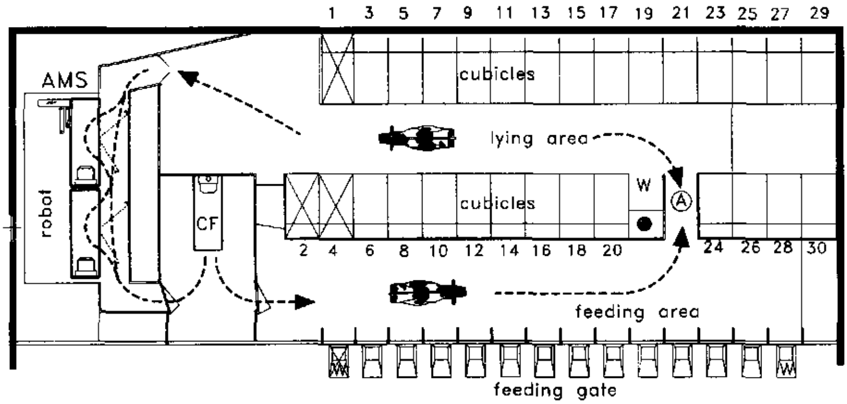
2. MATERIAL AND METHODS

2.1. Animals, housing and feeding

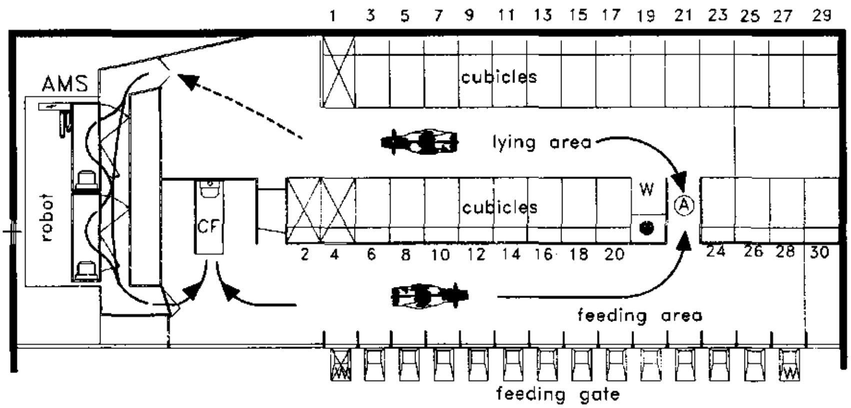
Two experiments (Experiments I and II) were carried out, each with a group of 20 lactating Holstein Friesian dairy cows. None of the cows in experiment I were used again in experiment II. Both experiments started with a group of 9 heifers and 11 second or higher parity cows. Days in lactation ranged from 33 to 61 for the heifers and from 34 to 150 days the second or higher parity cows in experiment I, and from 24 to 122 days for the heifers and from 8 to 113 days for the second or higher parity cows in experiment II.

The cows were kept in a section of a cubicle house with separate feeding and lying areas and a concrete slatted floor, from which manure was removed once every hour with a scraper. There were 21 cubicles available in the lying area as well as a drinking stall equipped with cow identification. In the feeding area was one drinking place and an automatic forage feeding system with 12 feeding places, each with an own feeding trough with weighing scale. The drinking place and all feeding places were equipped with cow identification. The cows could move freely between the lying area and the feeding area using a passage in the middle of the barn. They could also pass from the lying to the feeding area through an automatic milking system (AMS) (Figure 1). Forage was fed ad libitum. In experiment I, it consisted of a mixture of 60 % grass silage and 40 % maize silage on a dry matter basis, and in experiment II of a mixture of 50 % grass silage and 50 % maize silage on a dry matter basis. Fresh forage was provided automatically for each feeding trough separately when it was empty. Water was continuously available. In both experiments, heifers received 9 kg of concentrate daily and second or higher parity cows 12 kg. Part of this ration (6 kg for heifers and 8 kg for second or higher parity cows) was dispensed in the automatic concentrate feeder sited in the feeding area near the exit of the AMS (Figure 1). The remaining part was fed during milking in the AMS. Heifers received 1 kg of concentrate per milking visit and second or higher parity cows 1.3 kg.

The AMS was always available except during cleaning between 7:30 and 8:15 a.m. and between 7:30 and 8:15 p.m.. The AMS consisted of two milking stalls and a robot arm equipped with sensors for teat location. It was manufactured by Prolion in Vijfhuizen, the Netherlands. When a cow entered the AMS, the computer decided whether she should be milked. If the decision was positive, the cow received concentrate firstly, and then the cluster was attached automatically (milking visit). The minimum milking interval was 6 h, thus cows visiting the AMS within these 6 hours were sent out of the milking stall without a concentrate reward (non-milking visit). Twice a day, before the AMS was cleaned, cows with a milking interval of 18 hours or longer were fetched. During daytime the cowshed was illuminated by daylight and a double row of fluorescent lighting and at night by a single row of fluorescent lighting. The AMS was illuminated permanently.



concentrate feeder accessible through AMS (CF_AMS)



concentrate feeder freely accessible (CF_FREE)

Figure 1. Plan of the cowshed during CF_AMS of experiment I and CF_AMS2 and CF_AMS4 of experiment II (above) and during CF_FREE of experiment I (below) (AMS = automatic milking system; CF = concentrate feeder; W = water; A = free passage between feeding and lying areas)

2.2. *Experimental design*

2.2.1. *General*

Two experiments were carried out. In each experiment, two treatments, differing in the way concentrate was available in the concentrate feeder, were compared. Each treatment was applied during 3 weeks. The first week was reserved for habituation of the cows. Data were collected in the subsequent two weeks. Depending on the treatment, the daily concentrate ration of each cow was divided over 12 periods at two-hour intervals or 6 periods at four-hour intervals.

Any concentrate remaining at the end of a period was added to the next period. Concentrate left at the end of the day, was not added to the ration of the next day.

2.2.2. *Experiment I*

In experiment I, the daily concentrate ration of each cow was divided over 12 periods of 2 hours. The portions dispensed at the two-hour intervals were 0.5 kg of concentrate for heifers and 0.7 kg for second or higher parity cows. During the first treatment of experiment I, the cows could access the concentrate feeder via the AMS (CF_AMS). This was achieved installing a one-way gate that divided the feeding area into a forage feeding area and an area with the concentrate feeder (Figure 1). The cows could move freely from the lying area to the forage area and vice versa, but they could only reach the concentrate feeder via the AMS. They could leave the concentrate area through the one-way gate to the forage area. During the second treatment of experiment I, the one-way gate was removed and the same concentrate feeder was freely accessible from all areas of the cowshed (CF_FREE; Figure 1).

2.2.3. *Experiment II*

In experiment II, the concentrate feeder was accessible only via the AMS, as during the first treatment of experiment I. The first treatment of experiment II was the same as the first treatment in experiment I (CF_AMS2). During the second treatment, the daily concentrate ration of each cow was divided over 6 periods of 4 hours (CF_AMS4). The portions dispensed at the four-hour intervals were 1.0 kg of concentrate for heifers and 1.3 kg for second or higher parity cows.

2.3. Behavioural observations

During the treatments of both experiments behaviour was monitored by video and by computer registrations for three complete 24 hour periods. Lying and standing in the cubicle and waiting in front of the concentrate feeder were recorded once every ten minutes by video. The camera for these recordings could move along a rail in the ridge of the barn. The occurrence of aggression in front of the concentrate feeder was monitored continuously by video. In addition, aggression directed towards cows in the concentrate feeder and directed towards other cows waiting in front of the concentrate feeder was distinguished. The camera for these recordings was attached to a fixed point above the area with the concentrate feeder. On-line electronic identification of each cow at several places in the barn enabled the number and duration of stays in the lying area, the forage and the concentrate area (or the entire feeding area during CF_FREE) and the AMS area to be calculated. Furthermore, the time spent at the feeding gate and the drinking trough, and the number of visits to the AMS and concentrate feeder were calculated, as well as the concentrate intake and the feed left per cow per day in the AMS and in the concentrate feeder.

The types of visit to the AMS and the concentrate feeder were also monitored. AMS visits were divided into milking visits, non-milking visits and failed attachments. During milking visits, cows were milked and received concentrate in the AMS. During non-milking visits, cows were not milked and did not receive any concentrate in the AMS as their minimum milking interval of 6 hours had not yet been exceeded. During failed attachments, cows should have been milked but were not because the milking robot failed to attach the milking cluster. In that case they received some concentrate in the AMS until it was obvious that the attachment process had failed. Visits to the concentrate feeder were divided into rewarded visits, during which the cows received concentrate, and unrewarded visits, during which they did not. AMS visits and visits to the concentrate feeder were independent of each other, i.e. an unrewarded visit to the concentrate feeder could follow a milking visit, or a non-milking visit could be followed by a rewarded visit to the concentrate feeder.

2.4. Statistical analysis

Experiments I and II were analysed separately. The Iterative Reweighted Residual Maximum Likelihood procedure (IRREML) from the Genstat 5 statistical package was used to estimate differences between treatments in both experiments (Anonymous, 1993). This algorithm estimates treatment effects and variance components in a generalised linear mixed model with both fixed and random effects (Engel and Keen, 1994). The fixed effects were the experimental situation, the lactation number and the interaction between these two factors. Because observations on the same cows were not independent, cows were incorporated into the model as random effects. Model selection was carried out by backward elimination. The Wald statistic (VWS) was calculated to test on a 99 % probability level for the significance of fixed effects under the null hypothesis that there were no differences between treatments and/or the lactation number. This statistic has an asymptotic chi-squared distribution (Anonymous, 1993).

The behavioural variables under consideration expressed in numbers or in durations were analysed according to the generalised linear mixed model:

$y = \beta x + uz + \varepsilon$,

in which the response variable y was the behaviour under consideration, β are the fixed effects x mentioned above, u is the random effect of cow z and ε is the residual error term. The variance of variables expressed in numbers was assumed to increase proportionally with y and the variance of variables expressed in durations was assumed to increase proportionally with y^2.

The behavioural variables lying and standing in the cubicles and the occurrence of events in front of the concentrate feeder were expressed as percentages and therefore analysed with a generalised linear mixed model assuming a binomial distribution and a logistic link function (Mc Cullagh and Nelder, 1989). The resulting model was:

$\log(p/(1-p)) = \beta x + uz + \varepsilon$,

in which p is the probability that the cows are seen performing the behaviour under study or the probability that a certain event in front of the concentrate feeder occurs; β are the fixed effects x, u is the random effect of cow z and ε is the residual error term.

3. RESULTS

3.1. The cows' visits to the AMS

Table 1 gives an overview of the cows' visits to the AMS in both experiments. In experiment I, cows paid more milking and slightly more non-milking visits to the AMS during CF_AMS than during CF_FREE. In experiment II, the cows' visits to the AMS did not differ between treatments. In both experiments, all cows visited the AMS at least twice daily on average.

Table 1. Predicted means for the cows' visits to the AMS per day in experiments I and II.

Experiment I	CF_AMS	CF_FREE	sed	Wald Statistic $_{df=1}$; P^1
No. of AMS visits	7.5	6.5	0.4	7.4; $P = 0.007$
milking visits	3.0	2.6	0.1	9.1; $P = 0.003$
non-milking visits	4.2	3.3	0.4	5.9; $P = 0.015$
failed attachments	1.6	2.3	0.5	1.9; $P = 0.165$
Total time in AMS (min)	38.1	33.7	3.6	1.6; $P = 0.213$
Avg. time in AMS (min)	5.9	6.2	0.6	0.2; $P = 0.626$
Experiment II	**CF_AMS2**	**CF_AMS4**	**sed**	**Wald Statistic $_{df=1}$; P^1**
No. of AMS visits	7.3	7.0	0.4	0.4; $P = 0.529$
milking visits	2.7	2.8	0.1	1.3; $P = 0.253$
non-milking visits	4.2	4.0	0.3	0.4; $P = 0.525$
failed attachments	1.5	1.8	0.5	0.4; $P = 0.532$
Total time in AMS (min)	39.7	41.6	3.4	0.3; $P = 0.578$
Avg. time in AMS (min)	6.3	6.6	0.6	0.4; $P = 0.508$

[1]differences between treatments are considered to be significant when $P < 0.01$.

3.2. The cows' visits to the concentrate feeder

Table 2 gives an overview of the cows' visits to the concentrate feeder. In experiment I, cows paid more rewarded and unrewarded visits to the concentrate feeder during CF_FREE than during CF_AMS. The concentrate intake did not differ between the treatments. However, more feed left-overs were registered in CF_AMS. In experiment II, the number of visits to the concentrate feeder did not differ between the treatments, but the concentrate intake was higher and the amount of feed left-overs lower in CF_AMS4 than in CF_AMS2 . The visits to the concentrate feeder were divided equally over the 24-hour period in both treatments of the experiments.

3.3. The cows' time budget

The cows' time budget is summarised in Table 3. In experiment I, more time was spent in the forage area during CF_FREE than during CF_AMS (but the time in the forage area included the time in the concentrate area during CF_FREE). When the time in the forage area and the concentrate area were combined for CF_AMS, no difference in the time spent in the feeding area was found between the treatments of experiment I (Table 3). In addition, an interaction was found between treatment and lactation number for the time spent at the feeding gate. Second or higher parity cows spent more time at the feeding gate during CF_AMS than during CF_FREE. No difference between treatments was found for heifers.

In experiment II, the cows spent more time lying in the cubicles in CF_AMS4 than in CF_AMS2. Besides this, the average duration of feeding periods was longer and the total time spent in the concentrate area was lower during CF_AMS4 than during CF_AMS2.

Table 2. Predicted means for the cows' visits to the concentrate feeder per day in experiments I and II.

Experiment I	CF_AMS	CF_FREE	sed	Wald Statistic $_{df=1}$; P^1
Visits to concentrate feeder	7.7	11.9	0.4	122.4; $P = 0.000$
rewarded visits	5.8	7.8	0.3	52.5; $P = 0.000$
unrewarded visits	2.3	4.0	0.3	32.1; $P = 0.000$
Concentrate intake (kg)	6.3	6.6	0.2	2.6; $P = 0.104$
Feed left-overs (%)	12.8 (3.3)	6.9 (3.2)	*	7.8; $P = 0.005$
Experiment II	**CF_AMS2**	**CF_AMS4**	**sed**	**Wald Statistic; P^1**
Visits to concentrate feeder	7.3	6.9	0.4	0.9; $P = 0.345$
rewarded visits	5.2	4.7	0.2	5.0; $P = 0.025$
unrewarded visits	2.4	2.7	0.3	1.2; $P = 0.284$
Concentrate intake (kg)	5.6	6.4	0.2	13.7; $P = 0.000$
Feed left-overs (%)	16.5 (4.9)	8.9 (4.5)	*	8.9; $P = 0.003$

[1]differences between treatments are considered to be significant when $P < 0.01$;

*no reliable estimation of sed can be made when using logistic models; therefore, SE has been given in brackets, as indication of deviation.

Table 3. Time budget of cows (per day) in experiments I and II (predicted means).

Experiment I	CF_AMS	CF_FREE	sed	Wald Statistic $_{df=1}$; P[1]
Time in lying area (min)	983.5	967.5	18.9	0.7; $P = 0.394$
No. of stays in lying area	12.9	12.3	0.4	2.9; $P = 0.090$
Lying in cubicle (min)	612.9 (31.6)	628.9 (31.7)	*	0.9; $P = 0.356$
no. of lying periods	6.7	6.9	0.3	0.5; $P = 0.465$
av. duration of lying periods (min)	97.5	96.1	4.9	0.1; $P = 0.779$
Standing in cubicle (min)	200.9 (32.3)	210.4 (32.7)	*	0.6; $P = 0.455$
Time in forage area (min)[2]	347.2	430.7	15.7	28.5; $P = 0.000$
No. of stays in forage area	12.3	11.9	0.4	1.4; $P = 0.236$
Time at feeding gate (min)[3]				11.7; $P = 0.001$
heifers	163.5	180.8	10.1	not significant
2nd. or higher parity cows	206.8	175.2	10.2	significant
no. of feeding periods	9.9	9.8	0.3	0.1; $P = 0.784$
av. duration of feeding periods (min)	19.8	19.3	1.1	0.2; $P = 0.691$
Time in AMS (min)	38.1	33.7	3.6	1.6; $P = 0.213$
Time in concentrate area (min)[4]	59.8	---	---	---
Time in feeding area (min)	410.3	429.7	15.7	1.5; $P = 0.214$
Experiment II	**CF_AMS2**	**CF_AMS4**	**sed**	**Wald Statistic $_{df=1}$; P[1]**
Time in lying area (min)	969.5	993.2	19.8	1.4; $P = 0.231$
No. of stays in lying area	11.9	11.2	0.4	2.8; $P = 0.096$
Lying in cubicle (min)	601.8 (37.4)	661.5 (37.6)	*	7.6; $P = 0.006$
no. of lying periods	6.2	6.8	0.3	5.2; $P = 0.023$
av. duration of lying periods (min)	99.6	100.0	5.0	0.01; $P = 0.923$
Standing in cubicle (min)	195.1 (38.2)	176.8 (37.2)	*	2.3; $P = 0.129$
Time in forage area (min)	333.0	337.0	13.9	0.1; $P = 0.772$
No. of stays in forage area	11.6	10.8	0.4	3.2; $P = 0.072$
Time at feeding gate (min)	181.8	189.2	5.1	2.1; $P = 0.151$
no. of feeding periods	9.3	8.6	0.3	4.6; $P = 0.032$
av. duration of feeding periods (min)	20.3	22.5	0.7	10.0; $P = 0.002$
Time in AMS (min)	39.7	41.6	3.4	0.3; $P = 0.578$
Time in concentrate area (min)	74.4	62.9	3.9	8.7; $P = 0.003$

[1] differences between treatments are considered to be significant when $P < 0.01$;

[2] includes the concentrate area in CF_FREE;

[3] predicted means are mentioned separately for heifers and second or higher parity cows when a significant interaction was found between treatment and lactation number;

[4] no separate concentrate area in CF_FREE;

*no reliable estimation of sed can be made when using logistic models; therefore, SE has been given in brackets as indication of deviation.

3.4. Events in front of the concentrate feeder

Table 4 summarises events in front of the concentrate feeder. During CF_FREE (experiment I), cows waited longer and more aggressive interactions were seen in front of the concentrate feeder than during CF_AMS. Besides this, during CF_FREE, cows more often left the AMS without visiting the concentrate feeder and the concentrate feeder was more often occupied when they wanted to visit it. In experiment II, cows waited in front of the concentrate feeder longer and the concentrate feeder was more often occupied when cows wanted to visit it during CF_AMS2 than during CF_AMS4. Aggression directed towards the cow in the concentrate feeder was seen more frequently during CF_AMS4.

Table 4. Daily events in front of the concentrate feeder (CF) in experiments I and II (predicted means; SE in brackets).

Experiment I	CF_AMS	CF-FREE	Wald Statistic $_{df=1}$; P^1
Waiting in front of CF (min)	24.8 (14.5)	53.1 (17.6)	46.0; $P = 0.000$
No. of aggressive interactions in front of CF	2.1 (0.3)	4.2 (0.3)	23.5; $P = 0.000$ sed = 0.4
% leaving AMS without CF visit	3.5 (2.8)	7.1 (2.2)	7.6; $P = 0.006$
% CF occupied related to no. of CF visits	53.5 (2.3)	65.3 (1.7)	18.3; $P = 0.000$
Occurrence of aggression (in %) directed towards cow in CF related to no. of times that CF was occupied	91.8 (4.4)	91.0 (3.5)	0.2; $P = 0.690$
Experiment II	**CF_AMS2**	**CF-AMS4**	**Wald Statistic; P^1**
Waiting in front of CF (min)	34.4 (14.8)	22.3 (13.5)	11.7; $P = 0.001$
No. of aggressive interactions in front of CF	1.8 (0.2)	1.5 (0.3)	0.9; $P = 0.349$ sed = 0.3
% leaving AMS without CF visit	4.5 (2.9)	3.8 (3.2)	0.3; $P = 0.603$
% CF occupied related to no. of CF visits	59.3 (2.2)	43.5 (2.4)	25.9; $P = 0.000$
Occurrence of aggression (in %) directed towards cow in CF related to no. of times that CF was occupied	39.0 (6.5)	57.7 (6.9)	15.1; $P = 0.000$

[1]differences between treatments are considered to be significant when $P < 0.01$.

Table 5. Differences between heifers and 2nd. or higher parity cows in experiments I and II (predicted means).

Experiment I	Heifers	2nd. or higher parity cows	sed	Wald Statistic$_{df=1}$; P[1]
No. of AMS visits	9.0	4.9	1.0	16.3; $P = 0.000$
Non-milking visits	5.0	2.5	0.7	13.7; $P = 0.000$
Avg. time in AMS (min)	4.7	7.4	1.0	7.4; $P = 0.007$
Visits to concentrate feeder	11.3	8.0	1.0	11.4; $P = 0.001$
Unrewarded visits to CF[2]	4.1	2.2	0.5	16.3; $P = 0.000$
No. of stays in lying area	14.3	10.9	1.0	11.4; $P = 0.001$
No. of stays in forage area	13.7	10.5	1.0	10.4; $P = 0.001$
No. of feeding periods	10.8	8.8	0.8	7.6; $P = 0.006$
Avg. duration of feeding periods (min)	16.3	22.8	1.8	12.8; $P = 0.000$
Time at feeding gate (min)[3]				11.7; $P = 0.001$
CF_AMS	163.5	206.8	11.5	significant
CF_FREE	180.8	175.2	11.2	not significant
% leaving without CF visit related to no. of CF approaches[2]	8.1 (2.8)	3.1 (2.5)	*	13.4; $P = 0.000$
Concentrate intake in CF (kg)	5.7	7.2	0.2	46.2; $P = 0.000$
Experiment II				
Avg. time in AMS (min)	7.5	5.5	0.7	7.9; $P = 0.005$
Concentrate intake in CF (kg)	5.0	7.1	0.4	30.2; $P = 0.000$

[1]differences between treatments are considered to be significant when $P < 0.01$;

[2] CF = concentrate feeder;

[3]predicted means are mentioned separately for different treatments when a significant interaction was found between treatment and lactation number;

*no reliable estimation of sed can be made when using logistic models; therefore, SE in brackets as indication of deviation.

3.5. Differences between heifers and second or higher parity cows

In both experiments, differences between heifers and second or higher parity cows were found for several aspects of the cows' behaviour described above. These differences are summarised in Table 5. In experiment I, the total number of AMS visits, the number of non-milking visits, the total number of visits to the concentrate feeder, the number of unrewarded visits to the concentrate feeder, the number of stays in the lying and forage area, the number of feeding periods and the percentage of times that the cows did not visit the concentrate feeder when leaving the AMS was higher for heifers than for second or higher parity cows. Besides this, in experiment I, the average time spent in the AMS per visit, the average duration of feeding periods and the time spent at the feeding gate during CF_AMS was lower for heifers than for second or higher parity cows. In experiment II, heifers spent more time on average in the AMS per visit than second or higher parity cows. In both experiments heifers ate less concentrate in the concentrate feeder than second or higher parity cows.

4. DISCUSSION

4.1. The cows' visits to the AMS and the concentrate feeder

Allocating concentrate in a concentrate feeder that can be reached only via the AMS, appeared to be a good stimulus to attract cows to the AMS in this study. The total number of visits to the AMS was sufficient, with an estimated average daily milking frequency of almost 3 (including failed attachments). This is comparable with other findings in free and forced routing situations (Devir, 1995). A daily milking frequency of 3 seems to be optimal, as Ipema and Benders (1992) have found that raising the daily milking frequency from 2 to 3 can boost milk production by 14 %, and raising it from 2 to 4 boost it by 15 % but causes more erosion and eruption of the teat ends. Rossing et al. (1985) and Rabold (1986) report a daily milking frequency of 4 when cows are milked in a concentrate feeder, but in both cases the criterion for milking was a minimum interval of 3 hours (additionally, in the experiment of Rossing et al., the expected milk yield had to be higher than 3.5 kg).

When the concentrate feeder was freely accessible from all areas of the cowshed, the number of AMS visits decreased. Similar results are reported by Ketelaar-de Lauwere et al. (1993) for visits to a simulated AMS. It is striking that the number of visits to the concentrate feeder during CF_FREE is similar to the findings of other authors (Andreae and Smidt, 1983; Wierenga and Hopster, 1991), but that visits during CF_AMS were lower. Grimm et al. (1980) report that the number of visits to a concentrate feeder fell from 15.3 to 5.4 when cows were also milked in it. Rossing et al. (1985) and Rabold (1986) report average visiting frequencies of 5.4 and 5.9 respectively when cows could also be milked in a concentrate feeder. It seems likely that, milking in a concentrate feeder or in front of it, deters cows from visiting the feeder. A possible explanation for this might be the cows' reluctance to 'isolate' themselves from the herd (Hurnik, 1994), their dislike of the milking procedure (Royle et al., 1992), or of the uncertainty (Wiepkema and Koolhaas, 1993) of being milked or their dislike of the milking device itself

(Hurnik, 1994). The 'extra' visits to the concentrate feeder when it was freely accessible, increased waiting times and aggressive interactions in front of it. More cow traffic in the cubicle house is indeed likely to result in more social confrontations (Wierenga and Hopster, 1991).

When the concentrate feeder was accessible only via the AMS and concentrate became available every four hours instead of every two hours, the number of rewarded visits to the concentrate feeder decreased slightly, but the concentrate intake was higher and less feed was left. In that case, the cows also had shorter waiting times in front of the concentrate feeder and it was less often occupied when they approached it. Aggression directed towards the cow in the concentrate feeder has been reported to be 60 % and 67 % (Metz-Stefanowska and Spahr (1989) and Hettinga and Van Der Burg (1989) respectively). These levels varied from 39 % to 92 % in the present experiments. It is not clear why the level of aggression directed to other cows in the feeder was higher in experiment I than in experiment II. This might be an observer's effect. In experiment II, though it was striking that aggression directed towards cows in the feeder was seen more frequently when concentrate became available every four hours. Probably, cows were more eager to visit the concentrate feeder and therefore more aggressive in this case. Metz (1983) and Olofsson (1994) report more aggression when food is restricted in either time or space. In the present study, there was less opportunity to obtain concentrate when this became available every four hours. This may have resulted in the 'increased level of competition'.

4.2. The cows' time budget

Cows should have enough time to rest and eat because these behavioural activities are important for maintenance of homeostasis (Webster, 1993) and successful adaptation to the environment (Wierenga, 1991). Metz (1985) described lying as an important behaviour for which cows demonstrate a strong motivation. In experiment I, no important differences were found in the cows' time budget. In experiment II, lying times were longer and the time spent in the concentrate area was shorter when concentrate became available every four hours instead of every two hours. This promoted rest in the barn. Furthermore, when concentrate became available every two hours, the average duration of feeding periods was shorter and there were slightly more feeding periods, indicating that cows probably interrupted their activities more often in this case. Therefore, allocating concentrate every four hours instead of every two hours may be preferable. Research has shown that cows easily adapt to different concentrate feeding routines (Wierenga and Hopster, 1991; Livshin et al., 1994) and that this might affect the timing and duration of general activities such as lying and eating forage (Wierenga and Hopster, 1991, Morita et al., 1996).

4.3. Heifers and second or higher parity cows

All the statistically significant differences found between heifers and second or higher parity cows in this study show that heifers were more active (or restless) than second or higher parity cows. This has been reported earlier for behaviour in general (Baehr, 1984; Kempkens and Boxberger, 1987), for visits to an AMS (Devir et al., 1995; Prescott, 1995, Hogeveen et al., 1998), and for visits to a concentrate feeder (Collis, 1980).

4.4. Evaluation of the experiment

The cows' visits to the AMS and the concentrate feeder and their time budget were quite similar during similar treatments (CF_AMS of experiment I and CF_AMS2 of experiment II). Therefore, CF_AMS and CF_AMS2 seem to be a reliable basis for studying the effects of the accessibility of the concentrate feeder (experiment I) and the feeding regime (experiment II). It would, nevertheless, have been better if more replications of all treatments could have been studied (Mead, 1988). Unfortunately, the cost of experiments with fully automatically milked cows precludes this. Despite these restrictions, the results presented, provide information that might be useful for installing fully automatic milking systems on commercial farms so that cows benefit by not being forced to follow a certain route, and the farmer benefits because cows use the AMS adequately. However, it should be taken into account that the cows of the presented experiment were all in the first part of their lactation, and, therefore, received a high daily ration of concentrate.

Further research to study the effect of the level of concentrate on the cows' visits to the AMS and their behaviour if the concentrate feeder is accessible only through the AMS could be useful. In such an experiment, the level of concentrate could be varied per group, but also per cow, as both versions may have different consequences for the cows' visits to the AMS and their behaviour. In addition, it should be taken into account that the experiments were carried out with 20 cows only. This means that the capacity of the AMS was not fully utilised. Therefore, it could be useful to study the presented type of cow routing with more cows in future research as well.

5. CONCLUSIONS

Allocation of concentrate in a concentrate feeder which can only be reached by passing through the AMS appeared to be a good stimulus to attract cows to the AMS at regular intervals as the cows were milked sufficiently often. It appeared to be more favourable to make concentrate available every four hours rather than every two hours, because there was more rest in the barn, the concentrate intake was higher and less feed was left over in that case. A critical observation should, however, be added: the cows that had to pass through the AMS instead of having free access to the concentrate feeder, paid fewer visits to this feeder, and more feed was left. Using this way of concentrate allocation to attract cows to the AMS, therefore, might be a good tool, but remains a compromise in terms of cows' voluntary feed intake.

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CHAPTER 6

VOLUNTARY AUTOMATIC MILKING IN COMBINATION WITH GRAZING OF DAIRY COWS; MILKING FREQUENCY AND EFFECTS ON BEHAVIOUR

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ABSTRACT

Automatic milking systems (AMS) enable cows to be milked without human interference. Such systems are more acceptable to consumers and from the animal welfare point of view if they can be combined with grazing in the summer season. In this study, grazing was combined with fully automatic milking for a group of 24 crossbred Holstein Friesian cows. It was assumed that the cows would visit the AMS voluntarily. Zero grazing (G0) was compared with restricted grazing (cows could spend up to 12 hours outdoors daily; G12) and unrestricted grazing (cows could spend up to 24 hours daily at pasture; G24). The AMS was continuously available in the cowshed adjacent to the pasture of 1.5 ha. Water was available in the barn, but not at pasture. The average daily milking frequency was 2.3 in G24 compared with 2.5-2.8 in the other treatments ($p<0.01$). The reason was that the cows spread their visits to the AMS less evenly over the day in G24 (more visits in the afternoon and less visits at night; $p<0.01$). In the grazing treatments, the cows spent more time eating forage ($p<0.01$). The lying times did not differ between the treatments, but the cows lay between 80 and 99.6 % of their total lying time at pasture, when they had the opportunity to be outdoors. In the grazing treatments, cows entered or left the barn in the company of at least one other cow in 76.6 to 90.7 % of the cases. The cows' arrival times at the barn or pasture were not randomly distributed ($p<0.01$). In G24, cows spent less time in the pasture between 10:00 and 17:00 h when the Black Globe Humidity Index was high ($p<0.01$), and, related to that, a likeliness for conditions of heat stress.

It was concluded that automatic milking on a voluntary basis can indeed be combined with grazing. Grazing seems to be advantageous for the welfare of the cows, as they clearly preferred to lie in the pasture rather than in the cubicles. For the farmer, restricted grazing is more reliable than unrestricted grazing, as milking frequency will be higher on average. Farmers wishing to apply automatic milking with grazing should manage this flexibly, in accordance with ambient conditions, as the weather affects cow behaviour.

Keywords: dairy cows, grazing, fully automatic milking, milking frequency, behaviour, weather

1. INTRODUCTION

When an automatic milking system (AMS) in which cows can be milked throughout the day without human interference is introduced on the dairy farm, it is often assumed that cows have to be zero-grazed during the summer or milked at fixed times during the day after being collected from the pasture by the farmer (Prescott, 1995). Denial of grazing seems to be a potential threat to the welfare and health of dairy cows because the grazing period is generally a period of recovery (Hopster, 1996). The reported effects of grazing are less severe hoof disorders and recovery from such disorders (Frankena et al., 1991), a decrease of stereotypies (Redbo, 1990), and a decrease of aggression in the herd (O'Connell et al.; 1989, Miller and Wood-Gush, 1991). Swedish animal welfare legislation even stipulates that cattle kept for milk production that are more than six months old must be pastured in the summer for several hours daily (Gustafsson and Magnusson, 1994). Dutch farmers, animal protection organisations, consumers and dairy industry agree that the opportunity for grazing is an important condition for the successful introduction of AMS on the dairy farm, both from the viewpoint of the cows' health and welfare, and the maintenance of the 'green' public image of milk (De Boer et al., 1994).

This paper describes research in which fully automatic milking on a voluntary basis was combined with grazing. The starting points of the research were that the AMS was available for the cows throughout the 24-hour period and that they had to report to the system voluntarily on an individual basis. The objectives of the study were to determine: (1) whether it is possible to obtain a sufficient daily milking frequency when fully automatic milking is combined with grazing ; (2) the consequences of different grazing routines for the behaviour of the cows; and (3) the factors that may affect the cows' milking frequency and their behaviour when grazing is available.

2. MATERIAL AND METHODS

2.1. Animals, housing and feeding

The experiment was carried out with a group of 24 lactating Holstein Friesian cows consisting of 11 first lactation cows and 13 older cows. At the beginning of the experiment, the lactation stage of first lactation cows ranged from 162 to 272 days and that of the older cows from 90 to 271 days. The experimental facilities consisted of a sectional cubicle house with concrete walls of about one metre high and a suspended P.V.C.-coated membrane roof. The opening between the top of the concrete walls and the roof was approximately 1.2 metres and was fitted with mesh to reduce the effect of wind. The cubicle house had a lying area with 30 cubicles and a separate feeding area with 12 feeding places. The lying and feeding areas were connected by a passage (Figure 1). The floor consisted of concrete slabs. Dung was removed by an automatic scraper every hour. The cubicle house was adjacent to a pasture of 1.5 ha. A comparable reserve pasture was available in case the grass amount would become insufficient for the cows. Both pastures and the cubicle house were connected by a collecting area of approximately 48 m^2. Cows at pasture had to pass through a one-way gate to reach this collecting area. From this area, they could enter the barn to be milked in the AMS (which had its entrance in the lying area and its exit in the feeding area) to eat silage in the feeding area or to lie down in the lying area. Cows wishing to leave the barn, had to pass through a selection gate with its entrance in the feeding area. When a cow arrived at this selection gate, she was identified by computer. If she had been milked more than 6 hours previously, she was sent to the lying area. If she had been milked more recently, she was allowed access to the pasture via a passage approximately 35 metres long and one metre wide. Water troughs were located in the feeding area, the lying area and the collecting area, but not in the pasture (Figure 1).

The cows received forage ad libitum consisting of a mixture of 60 % grass silage, 30 % maize silage and 10 % ground maize ear silage with husks, on a dry matter basis. It was supplied at 8:30 and 17:30 h and raked up at 13:00 and 20:30 h. Concentrate was fed during milking in the AMS. First lactation cows received 1 kg of concentrate, and older cows 1.5 kg per milking. The system consisted of two milking stalls and a robot arm equipped with sensors for teat location. When a cow entered the AMS, the computer decided whether she should be milked. If the decision was positive, the cow received concentrate and the cluster was attached automatically. These visits are referred to as 'milkings'. If the decision was negative, the cows were sent out of the milking stall without milking and a concentrate reward. These visits are referred to as 'non-milking visits'. In addition, it sometimes occurred that the milking robot failed to attach the milking cluster. In that case cows received some concentrate in the AMS until it was clear that the attachment had failed. These visits are referred to as 'failed attachments'.

Before the AMS was cleaned, between 7:30 and 8:15 h, between 13:00 and 13:45 h and between 19:30 and 20:15 h, cows with a milking interval of 18 hours or longer were brought to the AMS to be milked by the milking robot.

The barn and in the collecting area outside the barn were lit between 20:00 and 6:00 h.

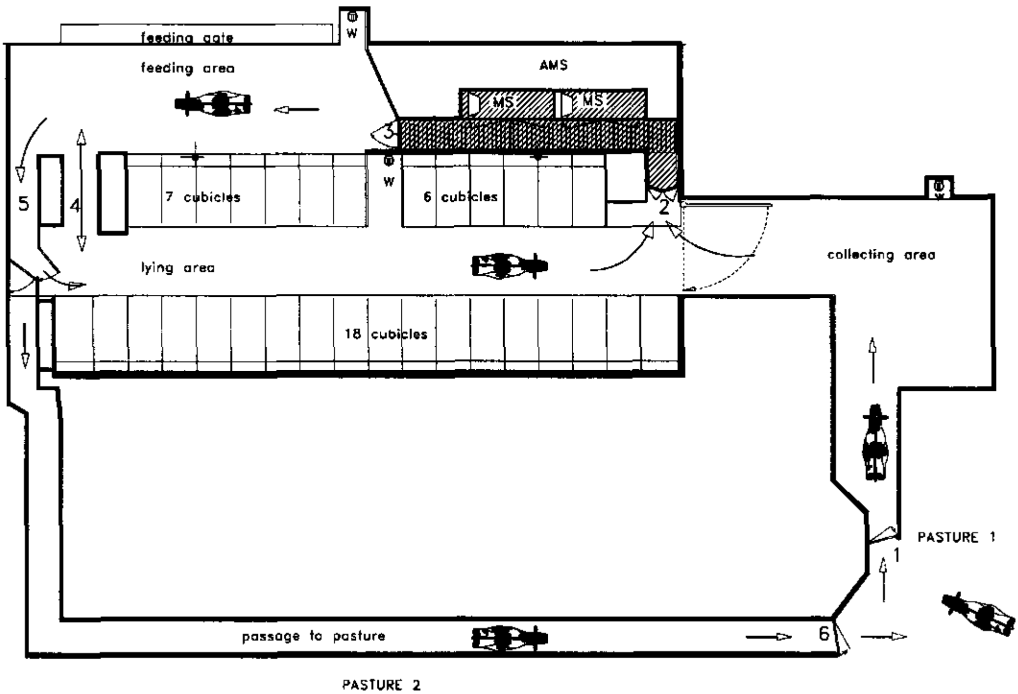

Figure 1. Plan of the cowshed; AMS = automatic milking system; MS = milking stall; W = water; electronic identification at: 1 = one-way passage from pasture to collecting area; 2 = entrance AMS; 3 = exit AMS; 4 = passage between feeding and lying area; 5 = selection gate; 6 = exit to pasture

2.2. Experimental design

Five consecutive treatments differing mainly in the availability of the pasture, were compared in the experiment. Each treatment was applied for 14 to 24 days. The first days were reserved for habituation of the cows; data were collected in the subsequent period. The treatments were:

1. *Zero grazing I* (G0-1) (habituation period: 12 days; observational period: 8 days): In this treatment cows were kept inside the barn throughout the 24-hour period. They had no access to the pasture nor to the collecting area outside the barn. They could move freely

between the lying and the feeding areas and could access the AMS via a waiting area of approximately 7.5 m^2 in front of it. This waiting area was intended to ensure that in the treatments with grazing the cows would enter the AMS first before they could enter the barn. However, it appeared to interfere with the cows' visits to the AMS and therefore was discarded in the following treatments.

2. *Restricted grazing 1* (G12-1) (habituation period: 13 days; observational period: 11 days): In this treatment cows were allowed access to the pasture during 12 hours between 5:30 and 17:30 h. At 17:30 h, they were fetched and kept inside the barn until 5:30 h the next day. When the cows had access to the pasture, the passage between the lying area and the feeding area was closed and the cows could only go from the lying to the feeding areas via the AMS or from the feeding to the lying areas via the selection gate. This barn routing was chosen to help the cows find their way to the pasture (in the habituation period they appeared to have difficulties finding this). During the night, the passage between the feeding and lying areas was open and the cows could move freely between those two areas. They could enter the AMS directly from the lying area.
3. *Zero grazing 2* (G0-2) (habituation period: 10 days; observational period: 8 days): same as G0-1, but the cows could enter the AMS directly from the lying area.
4. *Unrestricted grazing* (G24) (habituation period: 8 days; observational period: 12 days): In this treatment cows were allowed access to the pasture throughout the 24-hour period. To prevent cows from staying outside longer than 24 hours (and thus not visiting the AMS), they were fetched once per day at 17:30 h. After fetching, cows with a milking interval shorter than 6 hours could return to the pasture immediately via the selection gate. Cows with a milking interval longer than this had to pass through the AMS first before they could go to the pasture. The cows could move freely between the feeding and the lying areas and enter the AMS directly from the lying area throughout the 24-hour period.
5. *Restricted grazing 2* (G12-2) (habituation period: 7 days; observational period: 7 days): same as G12-1, but this time the cows could move freely between the feeding and the lying areas throughout the 24-hour period. The cows had access to the reserve pasture because the first pasture had been overgrazed.

2.3. Data collection

2.3.1.Behaviour

In each treatment, behaviour was monitored by video or direct observations for 4 scattered diurnal periods of 24 hours, and by computer registrations for 8 scattered diurnal periods of 24 hours. Behaviour was monitored by video round the clock in G0-1 and G0-2, between 17:30 and 5:30 h in G12-1, and between 23:30 and 5:30 h in G12-2. The rest of the time on observation days, an observer monitored behaviour directly. During indirect and direct behavioural observations the following activities were recorded for each cow once every ten minutes: lying in the cubicles or at pasture, eating forage at the feeding gate or at pasture, drinking, and standing in the lying area, the collecting area, the AMS area, the feeding area or at pasture. Lying was divided into lying with the head raised and lying with the head in a resting position. When a cow was lying with her head in resting position she lay flat on her side or on her chest with her head back on the shoulder or on the ground. Activities other than lying, eating forage or AMS visits were summarised as "other activities" in further analyses.

The number and duration of stays of cows in the lying and feeding areas, the AMS area and the pasture could be calculated by installing on-line electronic identification of each cow at the one-way passage between the pasture and the collecting area, the entrance and exit of the AMS, the passage between the feeding and the lying area, the selection gate and the entrance of the pasture (Figure 1). The computer could not distinguish between the lying and the collecting areas, thus when only electronic data were analysed, the collecting area was seen as an extension of the lying area.

The 24-hour period was sometimes divided into 4 periods of 6 hours. In those cases, 'morning' refers to the period between 5:30 and 11:30 h, 'afternoon' to that between 11:30 and 17:30 h, 'evening' to that between 17:30 and 23:30 h and 'night' to that between 23:30 and 5:30 h. When the 24-hour period was divided into 2 periods of 12 hours, 'day' refers to the period between 5:30 and 17:30 h, and 'evening and night' to that between 17:30 and 5:30 h.

2.3.2. Weather

In all treatments weather conditions were recorded automatically. The dry bulb temperature, the humidity and the black-globe temperature were recorded in the barn and outside once every 10 minutes. This enabled the Black Globe Humidity Index (BGHI) to be calculated, which is a comfort index for dairy cows based on the combined effects of dry bulb temperature, humidity, net radiation and air movement (Buffington et al., 1981). The likeliness for conditions of heat stress increases with increasing BGHI. Information about rainfall was gathered every 10 minutes during the behavioural observations of the grazing treatments (Table 1).

Table 1. Weather conditions (averages per observation period) and height of grass (mean ± SD) if cows had the opportunity to be outdoors

treatment	obs. day	exp. day	temperature (°C)	humidity (%)	BGHI[1]	% of 10-min observations with rain	height (cm) of grass[2]
restricted grazing 1	1	34	19.4	90.5	72.4	9.7	9.3 ± 3.9
	2	35	19.3	81.7	74.2	0	
	3	41	19.6	87.1	70.3	36.1	
	4	44	18.9	87.1	70.8	13.9	
unrestricted grazing; 5:30 -17:30 h	1	71	22.8	74.2	77.7	0	8.6 ± 2.1
	2	75	26.0	76.4	81.9	1.4	
	3	78	17.7	98.1	66.6	58.3	8.4 ± 1.7
	4	82	20.9	79.9	72.2	0	
unrestricted grazing; 17:30-5:30 h	1	71	22.3	75.5	69.6	0	8.6 ± 2.1
	2	75	20.9	94.1	68.4	15.3	
	3	78	16.2	89.2	62.5	0	8.4 ± 1.7
	4	82	17.9	86.9	52.8	54.2	
restricted grazing 2	1	90	16.9	80.0	57.3	0	7.9 ± 1.7
	2	91	14.8	86.4	54.2	0	
	3	92	14.9	85.2	60.0	0	
	4	96	12.5	81.4	55.5	0	6.5 ± 1.8

[1] BHGH = Black Globe Humidity Index; likeliness for conditions of heat stress increases with increasing BGHI.

[2] Height of grass was not measured on observation days, but has been shown in the table for the observation day nearest to the day of measuring.

2.3.3. *Amount of grass*

Throughout the experiment, the amount of grass was assessed once a week with a rising-plate meter. This meter consists of a shaft and a disc. To take a measurement, the shaft is positioned vertically so that its tip rests on the soil surface but the disc settles on the grass. The distance between the disc and the soil surface is a measure of the height of the grass crop (Gabriëls and van den Berg, 1993). The measurements were carried out between observation days (Table 1).

2.4. Statistical analyses

In general, differences in behaviour were assessed assuming that a generalised linear mixed model (GLMM) can be used to describe the relation between differences in treatments and behavioural response variables. Cows were incorporated into the model as a random effect, because the effect of a specific cow can be seen as a random deviation of the population mean and observations on the same cow are dependent. Overdispersion which results from the dependence between cows is taken into account in the model estimation. The Iterative Reweighted Residual Maximum Likelihood algorithm (IRREML) (Engel and Keen, 1994) was used to estimate fixed (treatment) effects and random effects in a GLMM. Covariables, such as lactation number or period of the day were also incorporated into the model as fixed effects, if relevant. The Wald statistic (VWS) was calculated to test for a 99% probability for the significance of fixed effects under the null hypothesis that there were no differences between treatments. This statistic has an asymptotic Chi-squared distribution (Genstat 5 Committee, 1993). Model selection took place by backward elimination. The following GLMMs were analysed:

AMS visits: Response variables concerning AMS visits were analysed according to the model:

$y = \beta x + uz + \varepsilon,$

in which y was the response variable (i.e. the type of AMS visit under consideration), β are the fixed effects of treatment, lactation number or either interaction between those factors (x), u is the random effect of cow z and ε is the residual error term. It was assumed that the variance of each response variable increased proportionally with the expected response value. This was confirmed by analysis of the residual variance structures.

Time budget: Response variables concerning the cows' time budget were analysed assuming that the distribution of response variables resembles a binomial distribution and a logistic link function (McCullagh and Nelder, 1989). The resulting model was:

$\log p/(1-p) = \beta x + uz + \varepsilon,$

in which p is the probability that the cows are seen performing the behaviour under study, and the other terms are similar to those mentioned above.

Distribution of the cows' behaviour: For the analysis of the distribution of AMS visits, and the activities 'eating forage' and 'lying' over the 24-hour period, a log-linear model with random effects was used. It is assumed that the time y that an activity was performed in a certain period is proportional to the total time Y_{tot} that that activity was performed in the 24-hour period ($y = c * Y_{tot}$). The proportionality coefficient c depends on period, treatment and cow. After a logarithmic transformation this results in the model:

$\log(y) = \log(Y_{tot}) + \beta x + uz$,

where βx represents the interaction between period and treatment (McCullagh and Nelder, 1989), and other terms are similar to those mentioned above. Furthermore, it was assumed that the variance of the time y that an activity was performed is proportional to the expected value of y. A log-linear model was also used to analyse the distribution of the cows' activities over the cowshed and the pasture. In that model, the total time an activity was performed outdoors (y) was assumed to be proportional to the total time the activity was performed. The treatment was used as an explanatory variable.

Weather: During part of the unrestricted grazing treatment the weather was extremely hot. Therefore, for all 12 days that the treatment was applied, we attempted to calculate a relationship between the Black Globe Humidity Index (BGHI) and the time that the cows spent in the pasture between 10:00 and 17:00 h. The resulting model was:

$y = \beta x + uz + \varepsilon$,

in which the BGHI and the lactation number were incorporated in the model as fixed effects (βx). The other terms were similar to those mentioned above. It was assumed that the variance of the response variable was constant.

The Kolmogorov-Smirnov two sample test was used to test whether the time intervals between AMS visits in different treatments were distributed equally (Conover, 1971). Furthermore, these time intervals were divided into 5 categories (less than 1 hour, between 1 and 6 hours, between 6 and 12 hours, between 12 and 18 hours and 18 hours or more). It was assumed that the number of milking intervals per category (y) for each cow per treatment was proportional to the total number of milking intervals for each cow in each treatment. A log-linear model was assumed with the interaction between treatment and category as explanatory variables (in this case a Generalised Linear Model (GLM) was fitted instead of a GLMM because differences between treatments were tested per cow over all days, as there were too few intervals per category to be able to test per cow per day) (McCullagh and Nelder, 1989).

It was checked whether time intervals between cows arriving at the pasture or at the barn were distributed negatively exponentially (Parzen, 1962), because this would mean that the arrival times of cows at the pasture or at the barn were distributed randomly.

The Genstat 5 statistical package was used for all analyses (Genstat 5 Committee, 1993).

3. RESULTS

In G0-1, the behavioural observations of one complete 24-hour period failed, due to technical problems with the video equipment, leaving 3 complete 24-hour periods for this treatment.

In G24, data from the last observation day were discarded because the behaviour of the cows was aberrant in this period due to bad weather from 23:30 h until the next morning, so there were also three complete 24-hour periods for this treatment.

Table 2. Predicted means of the cows' visits to the AMS

	zero grazing 1	restricted 1	zero grazing 2	unrestricted	restricted 2	SED	$VWS_{df=4}$
no. of AMS visits	4.9^{a}	6.9^{b}	6.0^{c}	6.6^{b}	6.7^{b}	0.2	99.8
no. of AMS visits (excluding failed attachments)[1,2]							
1st. lactation cows	4.3^{a}	6.1^{b}	4.8^{ac}	4.7^{ac}	5.0^{c}	0.6	14.6
older cows	4.9^{a}	6.0^{b}	6.0^{b}	6.1^{b}	5.9^{b}	0.6	14.6
milking visits	2.5^{a}	2.8^{b}	2.7^{bd}	2.3^{c}	2.6^{d}	0.1	66.2
non-milking visits[1]							
1st. lactation cows	2.5^{a}	3.7^{bd}	2.8^{a}	3.0^{ac}	3.4^{cd}	0.5	15.9
older cows	3.2^{a}	3.6^{ab}	3.5^{ab}	4.0^{b}	3.2^{a}	0.5	15.9
failed attachments[1]							
1st. lactation cows	1.4^{a}	1.8^{ac}	1.7^{a}	4.4^{b*}	2.6^{c}	0.4	32.9
older cows	1.1^{a}	1.4^{a}	1.3^{a}	1.3^{a*}	1.6^{a}	0.4	32.9

[abcd] within a row indicate a significant difference between treatments ($p<0.01$).

[1] failed attachments are excluded because these describe behaviour of the AMS rather than of the cows.

[2] a statistically significant interaction was found between treatment and lactation number; therefore predicted means are mentioned separately for 1st. lactation cows and older cows.

[*] indicates a significant difference between 1st. lactation cows and older cows for a certain treatment and parameter.

3.1. Cows' visits to the AMS

Table 2 gives an overview of the cows' visits to the AMS in each treatment. The cows paid more visits to the AMS in the grazing treatments than in the zero-grazing treatments. If, however, failed attachments were excluded, an interaction was found between treatment and lactation number and there were no more clear differences between grazing treatments on one hand and zero-grazing treatments on the other hand (Table 2). The milking frequency was lower in G24 than in the other treatments. An interaction between treatment and lactation number was found for the non-milking visits and the failed attachments. First lactation cows had more non-milking visits in G12-1 and G12-2 than in the zero-grazing treatments. No clear differences were found for older cows. The number of failed attachments was higher in G24 for first lactation cows.

Table 3 shows how the time intervals between AMS visits are distributed, when failed attachments are excluded. The most striking results were that in G24 there were more time intervals between AMS visits that lasted less than 1 hour and between 12 and 18 hours ($p < 0.01$). The Kolmogorov-Smirnov two-sample tests revealed that there were significant differences among the treatments in the distributions of the time intervals between AMS visits ($p < 0.01$).

Table 3. Distribution of the time intervals between AMS visits per treatment (excluding failed attachments); predicted means (in %) and SE in brackets

	zero grazing 1	restricted grazing 1	zero grazing 2	unrestricted grazing	restricted grazing 2
< 1 hour	10.4 (1.8)^{a}	11.7 (1.6)^{a}	11.0 (1.7)^{a}	29.2 (2.7)^{b}	17.8 (2.1)^{a}
1-6 hours	57.7 (4.3)^{ab}	72.9 (4.1)^{a}	68.0 (4.2)^{a}	47.1 (3.4)^{b}	61.3 (3.9)^{a}
6-12 hours	26.1 (2.9)^{a}	14.7 (1.8)^{b}	18.8 (2.2)^{ab}	13.8 (1.9)^{b}	19.5 (2.2)^{ab}
12-18 hours	3.6 (1.1)^{a}	0.5 (0.4)^{b}	1.7 (0.7)^{ab}	9.1 (1.5)^{c}	1.4 (0.6)^{ab}
>= 18 hours	2.2 (0.9)^{a}	0.3 (0.2)^{a}	0.6 (0.4)^{a}	0.7 (0.4)^{a}	0.0 (0.0)^{a}

^{abc}within a row indicate a significant difference between treatments ($p < 0.01$).

3.2. Time budget

Table 4 gives an overview of the cows' time budget. The total lying times did not differ between treatments, but cows spent more time lying with the head resting on the ground or on the shoulder in G12-1 and G24. Eating forage, either at the feeding gate or in the pasture, was seen more frequently in the grazing treatments than in the zero-grazing treatments in both first lactation cows and older cows. During the zero-grazing first lactation cows spent more time at the feeding gate than older cows. In G24 the cows spent less time in the AMS than in the other treatments. In the grazing treatments, the cows spent less time at the drinking troughs than in the zero-grazing treatments. Activities other than those mentioned above were seen less in G24 than in the two zero-grazing treatments and G12-2.

Table 4. Predicted means of the cows' time budget (min)

behaviour	zero grazing 1	restricted grazing 1	zero grazing 2	unrestricted grazing	restricted grazing 2	SE (range)	$VWS_{df=4}$
total lying	678.7[a]	663.7[a]	683.4[a]	706.2[a]	658.8[a]	19.5-20.6	10.6
lying in rest	33.6[a]	76.5[b]	51.2[c]	72.2[b]	48.3[c]	11.1-12.9	136.7
foraging at feeding gate or at pasture[1]							
1st. lactation cows	297.7[a*]	366.9[b]	331.3[c*]	375.8[b]	380.3[b]	19.3-20.7	17.3
older cows	227.7[a*]	355.4[b]	266.4[c*]	341.4[b]	336.2[b]	17.4-19.0	17.3
time in AMS	47.4[a]	41.5[ac]	46.0[a]	30.8[b]	38.5[c]	9.7-11.1	30.2
drinking time	27.5[a]	20.3[b]	26.3[a]	21.6[b]	19.6[b]	7.9-9.3	22.4
other activities	420.2[a]	346.9[bd]	381.3[c]	317.7[b]	359.9[cd]	10.6-11.8	97.9

[abcd] within a row indicate a significant difference between treatments ($p < 0.01$);

[1] a statistically significant interaction was found between treatment and lactation number; therefore predicted means are mentioned separately for 1st. lactation cows and older cows.

[*] indicates a significant difference between 1st. lactation cows and older cows for a certain treatment and behavioural parameter.

3.3. Distribution of activities over the 24-hour period

Table 5 gives an overview of the distribution of the AMS visits, the lying and the foraging over the 24-hour period. In all treatments, except G12-2, cows paid least visits to the AMS in the night. The most striking difference found between treatments was that cows paid more visits to the AMS in the afternoon and less visits in the night in G24 than in the other treatments.

In all treatments, the cows spent most time lying and least time eating forage in the night. As well, compared with the other treatments, in G24 they spent less time lying in the morning and in G12-1 and G12-2 they spent more time eating forage in the afternoon and less time eating forage in the evening.

If the cows had access to the pasture, they were outdoors most of the time and spent most of their lying and foraging time there (Table 6). In G24, the cows spent more time at pasture during the evening and night than during the day. The same was true of the time spent lying at pasture and grazing. In addition, in G24 the cows spent less time outdoors and less time grazing during the day than in G12-1 and G12-2. Figure 2 shows that the distribution of the time spent outdoors in G12-1 and G12-2 differed compared with G24.

Table 5. Distribution of AMS visits, lying and forage eating over the 24-hour period (predicted means in %); morning = 5:30 – 11:20 h; afternoon = 11:30 – 17:20 h; evening = 17:30 – 23:20 h; night = 23:30 – 5:20 h.

	zero grazing 1	restricted grazing 1	zero grazing 2	unrestricted grazing	restricted grazing 2	avg. SED	$VWS_{df=12}$
AMS visits						1.1	211.1
morning	$27.0^{w\,ab}$	$27.8^{w\,ab}$	$28.6^{w\,a}$	$28.8^{w\,a}$	$24.8^{w\,b}$		
afternoon	$25.9^{w\,a}$	$32.1^{x\,b}$	$25.9^{w\,a}$	$36.5^{x\,c}$	$24.8^{w\,a}$		
evening	$29.2^{w\,a}$	$23.3^{y\,b}$	$26.6^{w\,ac}$	$23.7^{y\,bc}$	$25.4^{w\,bc}$		
night	$17.9^{x\,a}$	$16.8^{z\,a}$	$18.9^{x\,a}$	$11.0^{z\,b}$	$24.9^{w\,c}$		
lying						1.1	223.9
morning	$24.7^{w\,a}$	$25.0^{w\,a}$	$25.6^{w\,a}$	$19.8^{w\,b}$	$26.9^{w\,a}$		
afternoon	$25.6^{w\,a}$	$14.9^{x\,b}$	$20.7^{x\,c}$	$17.3^{x\,d}$	$19.7^{x\,c}$		
evening	$15.9^{x\,a}$	$18.0^{y\,bc}$	$17.5^{y\,ac}$	$19.6^{w\,b}$	$16.7^{y\,ac}$		
night	$33.8^{y\,a}$	$41.8^{z\,b}$	$36.2^{z\,ac}$	$43.2^{y\,b}$	$36.7^{z\,c}$		
forage eating						1.1	637.1
morning	$29.0^{w\,abd}$	$33.2^{w\,c}$	$30.4^{w\,cd}$	$29.4^{w\,d}$	$30.0^{w\,d}$		
afternoon	$24.6^{x\,a}$	$43.9^{x\,b}$	$25.9^{x\,a}$	$24.3^{x\,a}$	$42.6^{x\,b}$		
evening	$37.1^{y\,a}$	$22.1^{y\,b}$	$35.0^{y\,a}$	$37.8^{y\,a}$	$23.3^{y\,b}$		
night	$9.3^{z\,a}$	$1.5^{z\,b}$	$8.7^{z\,a}$	$8.4^{z\,a}$	$4.1^{z\,c}$		

^{wxyz} in a column of an activity indicates a significant difference between the periods of a treatment ($p<0.01$).

^{abcd} in a row indicate a significant difference between treatments ($p<0.01$)

Table 6. Predicted means (in %) of the time that the cows were at pasture, were lying in the pasture or were grazing, related to the total time that the cows could be at pasture, were lying or were foraging; day = 5:30 –17:20 h; evening and night = 17:30 – 5:20 h.

treatment	part of 24hours	being at pasture	lying in pasture	grazing
restricted grazing 1	daytime	72.3^{w}	84.4^{w}	75.8^{w}
unrestricted grazing	daytime	61.8^{x}	82.6^{wy}	54.2^{x}
	evening and night	90.0^{y}	99.6^{x}	74.1^{w}
restricted grazing 2	daytime	76.3^{z}	80.0^{y}	81.8^{y}
avg. SED		1.0	1.0	1.0
$VWS_{df=3}$		284.6	152.0	169.9

^{wxyz} different character in a column indicate a significant difference ($p<0.01$).

3.4. Synchronisation of behaviour

Figure 2 shows that the cows were at pasture in a rather synchronised way in the three grazing treatments. In G12-1, G12-2 and G24, more than 75 % of the cows were at pasture in respectively 49.3 %, 48.7 % and 34.2 % of the 10-min observations of the day (n=72). In G24, more than 75 % of the cows were at pasture in 87.7 % of the 10-min observations of the evening and night (n=72), and were lying in the pasture in 55.8 % of these 10-min observations. In the grazing treatments it was rare that only one cow was in the pasture or in the barn (Table 7). If cows left the pasture to go to the barn without being fetched or when they left the barn to go to the pasture, they mostly did this in the company of at least one other cow (Table 7). The statistical analyses confirmed that the moments of arriving at the pasture or at the barn were not randomly distributed ($p < 0.01$).

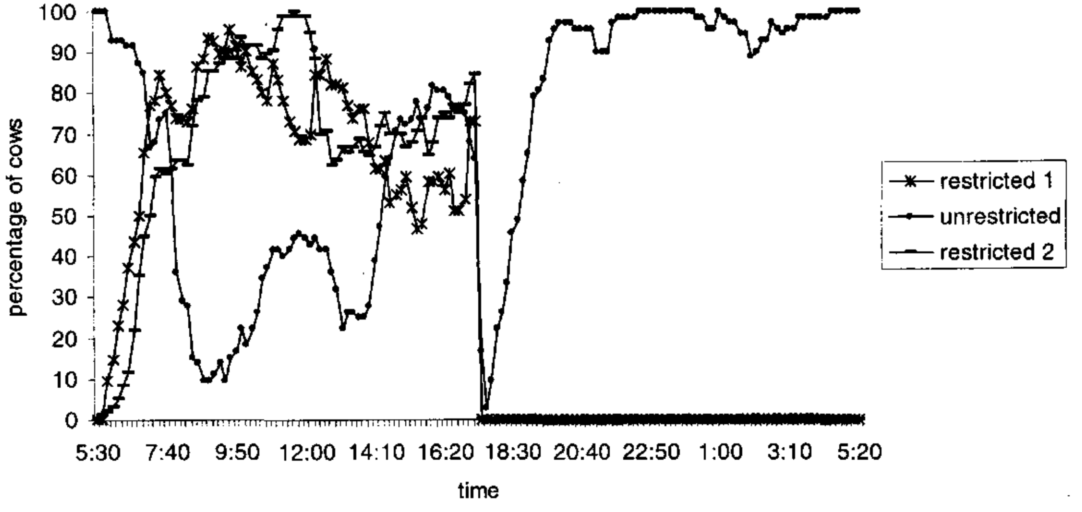

Figure 2. Percentage of cows outside per 10-min observation in the grazing treatments.

Table 7. Number of observations in which only one cow was at pasture or in the barn, as percentage of the total number of observations that cows had the opportunity to be at pasture; number of times that cows went to the barn or to the pasture accompanied by at least one other cow as percentage of the total number of times that cows went to the pasture or to the barn (excluding going to the barn when fetched at 17:30 h).

	one cow at pasture		one cow in barn		go to pasture 'together'		go to barn 'together'	
	n	%	n	%	n	%	n	%
restricted grazing 1	288	0.4	288	10.8	590	90.7	384	76.6
unrestricted grazing	432	3.7	432	12.7	672	88.7	625	78.2
restricted grazing 2	288	2.8	288	9.7	437	80.3	279	82.4

3.5. Weather

In G24, a significant inverse relationship was found between the BGHI and the time that the cows spent in the pasture between 10:00 and 17:00 h (effect for BGHI = -0.18; sed = 0.05; $VWS_{df=1} = 14.4$; $p < 0.01$).

3.6. Water

In the grazing treatments, cows had to go to the barn for water. In G12-1, in 48.0 % of cases (n=585) the cows were recorded at one of the drinking troughs within 10 minutes after entering the collecting area. In another 20.7 % of cases, they were recorded at the drinking trough between 10 minutes and one hour after entering the collecting area, and in 13.5 % more than an hour later. In 17.8 % of cases, they left the barn again without being recorded at one of the drinking troughs. In G24, the cows were recorded at one of the drinking troughs within 10 minutes after entering the collecting area in 35.0 % of (765) cases. In 19.5 % of cases, they were recorded at one of the drinking troughs between 10 minutes and one hour after entering the collecting area, and in 11.0 % of cases more than an hour later. In 34.5 % of cases, they left the barn again without being recorded at one of the drinking troughs. In G12-2, these figures could not be calculated due to technical failures at one of the drinking troughs.

4. DISCUSSION

4.1. Fully automatic milking in combination with grazing

The results demonstrate that fully automatic milking in an AMS which is almost continuously available throughout the day can be combined with grazing. The cows paid sufficient visits to the AMS on a voluntary basis, which resulted in a higher daily milking frequency than the traditional two in all treatments. Thereby, failed attachments had to be excluded because these describe behaviour of the AMS rather than that of the cows. Moreover, these failed attachments appeared to increase in the course of the experiment, especially for first lactation cows. This would have affected the results in favour of the grazing treatments and would have lead to inaccurate conclusions.

It is an important result that grazing can be combined with fully automatic milking, because grazing during summer is advantageous for both health and welfare of dairy cows (Metz et al., 1986). The welfare benefit is supported by the findings of this study, that when the cows had the choice between indoors and outdoors, they spent most of their lying time at pasture. Krohn et al. (1992) also found that cows prefer to lie in the pasture rather than in cubicles. In addition, and similar to the results reported by Krohn and Munksgaard (1993), the cows more often lay on their side or with their head back on the shoulder or on the ground when at pasture. These lying postures are important for comfortable sleep (Merrick and Scharp, 1971; De Wilt, 1985).

During grazing treatments, cows spent more time eating forage. This is not surprising, because grazing takes more time than eating forage indoors as the latter can be obtained and ingested with relative ease and is usually presented in an easily manageable form (Miller and Woodgush, 1991; Phillips, 1993).

Another finding reported about grazing is that the behaviour of cows is more synchronised at pasture than indoors (Miller and Wood-Gush, 1991; Krohn et al., 1992). The cows in our study indeed tend to be outdoors in a rather synchronised way. Furthermore, in most cases they went indoors or outdoors in the company of at least one other cow, which agrees with Hurnik's (1994) contention that cows act as a co-ordinated social unit. The corollary was that cows were rarely alone at pasture or in the cowshed. This might have been a result of 'social facilitation', which means that a cow is stimulated to perform a certain behaviour, because other cows perform this behaviour (Metz and Mekking, 1978). Several times we observed that one cow had to remain in the barn because of a failed attachment by the milking robot.

Isolating a cow from her herd can bring the animal under stress (Hopster, 1998). It is therefore important to prevent failed attachments that leave a cow alone in the barn.

4.2. Factors affecting the cows' behaviour at the pasture

Although the total number of visits to the AMS was similar in the three grazing treatments, the milking frequency was lower in unrestricted grazing than in the other treatments. The weather may have affected this. In unrestricted grazing, the ambient temperatures were quite high during the day, which caused the cows to stay indoors in the shade (and near the AMS), but they stayed outdoors (and far from the AMS) during the night. Therefore, in this period they visited the AMS less evenly over the 24-hour period. It is well known that dairy cows are sensitive to heat stress, and that this is a significant limiting factor to maximum milk production from high-yielding dairy cows (Buffington et al., 1981; Fuquay et al., 1993; Muller et al., 1994; Hall et al., 1997). Heat stress is caused by any combination of environmental conditions that will cause the effective temperature of the environment to be higher than the temperature range of the animal's thermoneutral zone (Buffington et al., 1981). Cows will seek shade when the ambient temperature is high (Phillips, 1993; Goodwin et al., 1997; Albright and Arave, 1997), or stay indoors more (Krötzl and Hauser; 1997). In our underlying experiment a significant relationship was indeed found between the time spent at pasture and the Black Globe Humidity Index.

Heavy rainfall can affect the behaviour of cows at pasture (Phillips; 1993). This was also observed in the present study. Heavy rainfall occurred on four of the observation days of the treatments with grazing. On three of these occasions, it was observed that the cows went indoors, and in one occasion that they stopped their activities in the pasture. In addition, it was observed that the cows' behaviour was not markedly influenced by light rain or showers.

Another factor that may have affected the results is the quality of the pasture (Ruckebusch and Bueno, 1978). At the beginning of the restricted grazing treatments, cows were on a 'fresh' pasture, but this was not the case in unrestricted grazing. In 'grazed' pastures there are always areas of less tasty and less nutritious herbage close to faecal deposits that are avoided (Phillips, 1993). In unrestricted grazing, cows started to leave the pasture and walk to the cowshed at 7:30 h to wait for the forage in the feeding area which was fed at 8:30 h. It is unlikely that the reason that they came inside around this time was because the ambient temperature was already too high (see above). Phillips and Hecheimi (1989) found that cows spent more time eating silage at low herbage heights.

It is likely that the cows would have stayed outdoors more in unrestricted grazing if the weather had been more moderate and the quality of the pasture had been better (as in the restricted grazing treatments). This would probably have reduced the number of visits to the AMS.

4.3. Water

In the grazing treatments, water was used to entice cows from pasture into the cowshed. This might be a critical factor in the research, especially given that cows spent less time at the drinking troughs during grazing treatments than during zero-grazing treatments. On the other hand, in most cases cows did not drink immediately after entering the collecting area, and shorter drinking periods do not mean that the cows were drinking too little, because voluntary water intake implies quite a large 'luxury' uptake (Phillips, 1993). Phillips (1993) reports that if they have to walk more than 250 m to water, cows will reduce their luxury uptake of water, but not the intake they require for physiological purposes. This needs attention though, especially when ambient temperature is high, as adequate availability of water is important under conditions of heat stress (Mader et al., 1997), and cattle only will be able to tolerate typical summer conditions if water is freely available (Blackshaw and Blackshaw, 1994). In our experiment, extreme high ambient temperatures only occurred in the unrestricted grazing treatment, which is probably why the cows stayed in the barn (and near the drinking troughs) more at the middle of the day. In the Netherlands, extremely high ambient temperatures are not very common. Therefore, water might be a mean to entice cows into the cowshed in countries with moderate climates, though probably not in countries with more extreme climates.

4.4. Evaluation of the experimental set-up

The results obtained represent the first detailed observations on the behaviour of cows in a situation during which fully automatic milking on a voluntary basis was combined with grazing. Practical considerations precluded extra repetitions and the use of more than one group of cows. Despite these restrictions, the research provides information about the possibility of combining grazing and fully automatic milking, about the factors affecting this and about the advantages of grazing for the welfare of dairy cows. The repetitions of the non-grazing treatments and the restricted grazing treatments were intended to explain time-dependent fluctuations in the data. Slight changes in the barn layout between these treatments might have had some effect. The waiting area in front of the AMS may have interfered with the cows' visits to the system in the first zero-grazing treatment. The 'extra' time spent on 'other activities' and the fact that the cows spent less time standing at the feeding gate in the first zero-grazing treatment than in the second zero-grazing treatment may also be a result of this. More idle standing and thwarting of feeding was also found by Ketelaar-de Lauwere et al. (in preparation) in an AMS environment with a waiting area, but only when the cows were subjected to forced cow traffic. The probable explanation for the cows paying more milking visits to the AMS in the first restricted grazing treatment than in second restricted grazing treatment is the difference in barn layout in these treatments during the day. In the first restricted grazing treatment, cows had to pass through the AMS to reach the feeding gate, but in the second restricted grazing treatment the feeding gate was freely accessible. Ketelaar-de Lauwere et al. (1998) found that cows paid less visits to a simulated AMS in a free cow traffic situation. Other differences observed between the restricted grazing treatments cannot be explained by the difference in barn layout during the day. The aberrant finding in the second restricted grazing treatment, that the cows spread the AMS visits almost evenly over the day might reflect seasonal variation or changes in lactation stage. Ambient conditions were indeed most moderate during this restricted grazing treatment. Earlier, Perera et al. (1986) had also reported a differential response of cows in different stages of lactation to changes in ambient conditions.

5. CONCLUSIONS

Automatic milking on a voluntary basis in an automatic milking system which is available almost throughout the 24-hour period can be combined with grazing. This is important because grazing seems to be advantageous for the welfare of the cows; one of the reasons being that they clearly prefer to lie in the pasture rather than in the cubicles. From the farmer's point of view, restricted grazing may be preferable to unrestricted grazing, because the milking frequencies will be higher. The weather and the quality of the pasture may affect the results. High ambient temperatures and a 'grazed' pasture may cause the cows to stay indoors during the day and to stay at pasture during the night. Heavy rainfall may also cause cows to go indoors. This means that a farmer wishing to combine fully automatic milking with grazing has to manage this dynamically, taking ambient conditions into account as well.

It should be taken into account that this study involved 24 cows only and that the grazing area used was relatively small (1.5 ha). This may have affected the results. More research is needed in larger herds and at longer distances between the pasture and the barn. In addition, it should be taken into account that there were no lame cows in the experimental herd. Such animals probably would have had serious problems to attend to the AMS in the grazing treatments.

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CHAPTER 7

EFFECT OF SWARD HEIGHT AND DISTANCE BETWEEN PASTURE AND BARN ON COWS' VISITS TO AN AUTOMATIC MILKING SYSTEM AND OTHER BEHAVIOUR

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ABSTRACT

Two experiments were conducted: to study the effects of sward height (experiment I) and the distance between barn and pasture plot (experiment II) on cows' visits to an automatic milking system (AMS) and other behaviour. The study was carried out in a situation in which grazing was combined with fully automatic milking on a voluntary basis. The AMS was continuously available in the barn adjacent to the pasture of approximately 10 ha. This pasture was divided into 10 plots of 1 ha for the two experiments and the preceding habituation. The same group of 24 Holstein Friesian cows was used in both experiments. The cows were allowed to spend up to 15 hours at pasture daily.

The results of experiment I (rotational grazing) show that at lower sward heights ($p < 0.01$) cows paid more visits to the AMS, were milked more often and spent more time indoors. The results of experiment II (strip grazing) show that a distance of 360 m between pasture and barn did not affect the cows' visits to the AMS. Indications were found that cows needed some extra time to become accustomed to the 'far' pastures. In both experiments, cows preferred to lie in the pasture, when available, rather than in the cubicles, and tended to visit the barn group-wise and to enter the AMS in close succession. As a consequence, in the period that the cows had access to the pasture there were peaks in AMS visits, and the AMS was unvisited for several hours.

Key words: voluntary automatic milking, grazing, sward height, walking distance

1. INTRODUCTION

The number of dairy farms where cows are milked without human interference in an automatic milking system (AMS) with a milking robot is rising steadily (Rossing, et al., 1997). Many farmers considering changing from milking in a milking parlour to fully automatic milking want to be able to allow the cows to graze during the summer (De Boer et al., 1994), as this reduces feeding costs and labour and is often seen as a period of recovery for the cows (Hopster, 1996). It is known that the behaviour of cows at pasture is affected by many factors, such as seasonal variation (Krohn et al., 1992; Rook and Huckle, 1996), either very warm (Muller et al., 1994; Mader et al., 1997) or very cold weather (Dunn et al., 1988; Prescott et al., 1994), sward height (Phillips and Hecheimi, 1989; Rook et al., 1994), concentrate supplementation (Rook et al., 1994) and forage supplementation (Phillips and Leaver, 1986; Phillips and Hecheimi, 1989). However, little is known about factors affecting the behaviour of dairy cows in a situation in which grazing is combined with fully automatic milking. The novel element in such a situation is that cows at pasture have to return to the barn by themselves several times per day, to be milked in the AMS. It seems likely that the amount of grass in the pasture and the distance between the barn (with the AMS) and the pasture may play a role in a situation in which grazing and fully automatic milking on a voluntary basis are combined. It can be expected that cows will return to the barn more often if the sward is short, and extra forage is supplemented in the barn. Conversely, if there is plenty of grass in the pasture, cows may be reluctant to return to the barn, so there will be fewer visits to the AMS. Distance between the barn and the pasture may also influence frequency of AMS visits. This is a point of concern in practice because on many farms the barn and the pasture are not adjacent.

In the experiments described in this paper, the effects of the sward height and the distance between the barn and the pasture on the cows' visits to the AMS and associated behaviours were tested, in order to determine the feasibility of combining AMS with grazing.

2. MATERIAL AND METHODS

2.1. Animals, housing and feeding

Two consecutive experiments were carried out with a group of 24 Holstein Friesian dairy cows. At the beginning of the first experiment, the group consisted of 12 first lactation cows with a lactation stage ranging from 92 to 274 days and 12 older cows with a lactation stage ranging from 39 to 206 days at the beginning of the lactation. The second experiment started one month after the first. At the beginning of this experiment one third lactation cow had to be culled for reasons of udder health.

The experimental facilities consisted of an open barn with a lying area with 30 cubicles and a separate feeding area with 12 feeding places (Figure 1; for more details, see Ketelaar-de Lauwere et al., 1999). The barn was adjacent to a pasture of approximately 10 ha, which was divided into 10 plots of one ha. All plots were connected to a 4 m wide central alley, leading to the barn. The plots differed in distance to the barn, which was measured from the centre of the plot to the entrance of the barn (Figure 2).

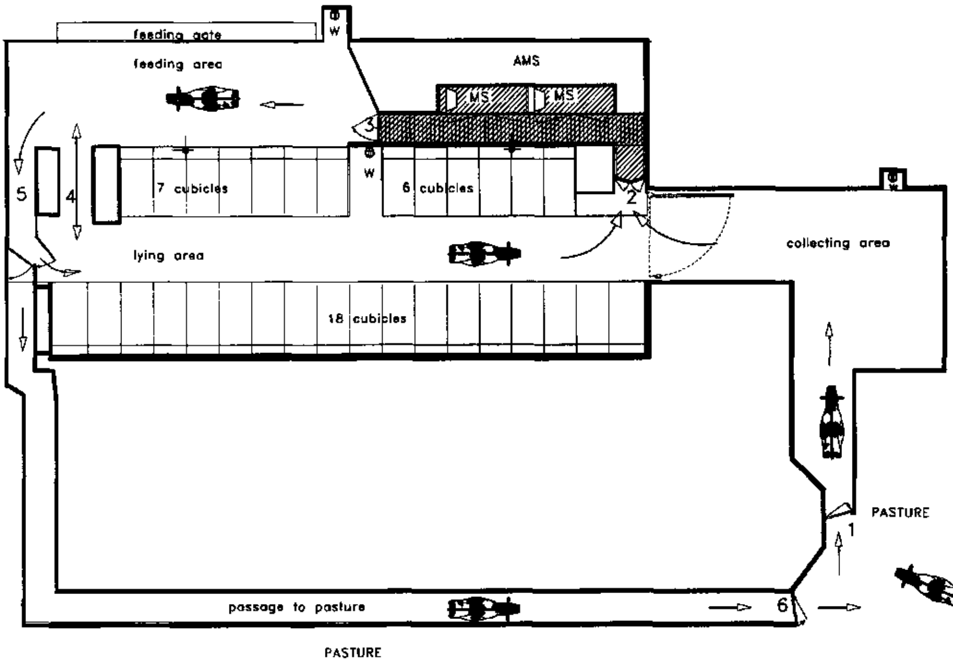

Figure 1. Plan of the cowshed; AMS = automatic milking system; MS = milking stall; W = water; 1 = one-way passage from pasture to collecting area; 2 = entrance AMS; 3 = exit AMS; 4 = passage between feeding and lying area; 5 = selection gate; 6 = exit to pasture

The central alley of the plots led to a collecting area of approximately 48 m^2 in front of the barn. To reach this collecting area, cows had to pass through a one-way gate. From this area, they could enter the barn. Cows wishing to leave the barn had to pass through a selection gate with its entrance in the feeding area. When a cow arrived at this selection gate, she was identified by computer. If she had been milked more than 6 hours ago, she was sent back to the lying area, giving the cow a new chance to visit the AMS. If she had been milked more recently, she could leave the barn via a passage along the barn to the central alley of the plots. Water troughs were located in the barn, but not in the plots (Figure 1).

The cows daily received 440 kg maize silage on a dry matter basis in the barn. The forage was supplied at 8:30 and 20:15 h and raked up at 13:00 h. Concentrate was dispensed during milking in the automatic milking system (AMS). First lactation cows received 1 kg of concentrate, and older cows 1.5 kg per milking. The system consisted of two milking stalls and a robot arm equipped with sensors for teat location. When a cow entered the AMS, the computer decided on the basis of the time that had elapsed since the previous milking whether she should be milked. If the decision was positive, the cow received concentrate and the milking cluster was attached automatically. These visits are referred to as 'milkings'. If the decision was negative, the cows were sent out of the milking stall without milking or a concentrate reward. These visits are referred to as 'non-milking visits'. Sometimes, cows that should have been milked were not, because the milking robot failed to attach the milking cluster; in that case cows received some concentrate in the AMS until it was clear that the attachment had failed. These visits are referred to as 'failed attachments'.

The AMS was cleaned twice a day, between 7:30 and 8:15 h and between 17:15 and 18:00 h. Cows with a milking interval of 12 hours or longer, and cows that were not milked due to technical failure of the milking robot were fetched and milked before the morning cleaning and around 20:30 h.

The barn was lit between 20:00 and 6:00 h.

2.2. *Experimental design*

In both experiments the cows had access to one of the plots between 5:30 and 20:30 h. In this period they could choose between being indoors and outdoors. They were kept indoors between 20:30 and 5:30 h. Each time a cow was milked in the AMS her milk yield was measured with a milk meter. In the first experiment, the average daily milk yield per cow ranged from 20.0 kg to 31.8 kg, and in the second experiment, it ranged from 23.1 kg to 28.6 kg. The amount of grass was assessed with a rising-plate meter (Gabriëls and van den Berg, 1993) on the day previous to the first day of an experimental period and on the day following the last day of an experimental period. (For more details about the rising-plate meter, see Ketelaar-de Lauwere et al., 1999). Weather conditions were recorded on-line. The dry bulb temperature, the humidity and the black-globe temperature were registered in the barn and outdoors. In addition, data about rainfall or sunshine were gathered during behavioural observations at pasture.

2.2.1. *Experiment I: Rotational grazing*

The effect of the sward height on the cows' visits to the AMS and other behaviour was studied in this experiment, which was divided into 4 periods of 4 days. At the beginning of each period, cows were given a fresh pasture. Grazing reduced the sward height, so after 4 days, cows were moved to another fresh pasture. The four pastures used in this experiment differed as little as possible in distance to the barn. In the first period, the distance to the barn was 218 m, in the second period 288 m, in the third period 232 m and in the fourth period 296 m (plots S1, S2, S3, S4; Figure 2). The sward height decreased from 11.0 cm to 7.8 cm in the first period, from 10.8 to 7.2 cm in the second period, from 12.3 cm to 7.3 cm in the third period, and was 14.5 cm at the beginning of the fourth period (the decrease in that period was not measured because of problems with electronic storage of data from the rising-plate meter). The dry matter of the sward decreased from 1334.7 to 809.0 kg/ha in the first period, from 1300.9 to 703.0 kg/ha in the second period, from 1554.3 to 717.5 kg/ha in the third period and was 1909.1 kg/ha at the beginning of the fourth period. Before the experiment started, the cows had access to the central alley during 2 days and consecutively to two 'habituation pastures' adjacent to the barn (plots H1, H2; in Figure 2) for 2 x 5 days to accustom them to the combination of grazing and AMS visits. The average black globe temperature between 10:00 and 17:00 h ranged from 15.2 to 32.1 ^{0}C over all periods.

2.2.2. *Experiment II: Strip grazing*

In this experiment, which was divided into 4 periods of 5 days, the effect of the distance between the pasture and the barn on the cows' visits to the AMS and other behaviour was studied. Cows were given a fresh pasture at the beginning of each period, but the amount of fresh grass available was more or less the same on each day, because every day an electrified wire was moved, giving the cows access to a fresh strip of grass. The four pastures used in this experiment differed in the distance to the barn. In the first period this distance was 146 m, in the second period 360 m, in the third period 355 m and in the fourth period 168 m (plots D1, D2, D3, D4; Figure 2). The cows were strip grazed during 6 days in the 'habituation pastures' adjacent to the barn before the experiment started (plots H1 and H2; Figure 2). The average black globe temperature between 10:00 and 17:00 h ranged from 17.1 to 31.8 ^{0}C over all periods.

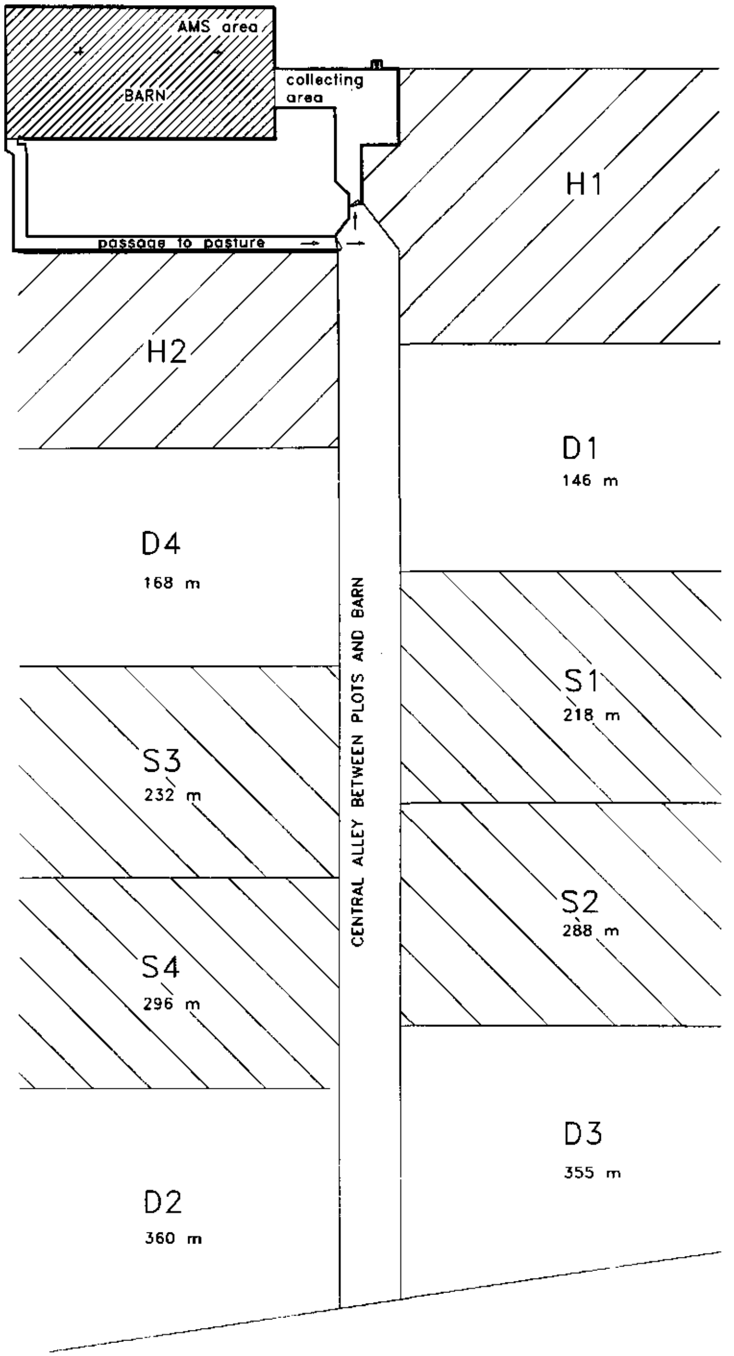

Figure 2. Plan of the plots used in the rotational grazing experiment and the strip grazing experiment; H1, H2: plots for habituation; S1, S2, S3, S4: plots for rotational grazing experiments; D1, D2, D3, D4: plots for strip grazing experiment; distances in meters from the centre of the plot to the collecting area.

2.3. Data collection and parameter choice

2.3.1. Indirect behavioural observations

In both experiments, behaviour was monitored daily by computer registrations. There were six points at which cows were electronically identified on-line: in the one-way passage between the central alley of the pastures and the collecting area, at the entrance and exit of the AMS, in the passage between the feeding and the lying area, at the selection gate and at the entrance of the central alley of the pasture (Figure 1). Every day the number and duration of stays of cows in the lying and feeding areas, the AMS area and the pasture were calculated, using the data collected at these registration points.

2.3.2. Direct behavioural observations

Behaviour was recorded in more detail by video or by direct observations on the first and the fourth days of the second and the fourth experimental periods in the rotational grazing experiment and on the second day of each experimental period in the strip grazing experiment. Direct behavioural observations started at 5:30 h. and lasted 24 hours. An observer monitored the behaviour of the cows outdoors and indoors between 5:30 and 20:30 h, when the cows had access to the pasture. The behaviour was recorded by video between 20:30 and 5:30 h, when the cows had to stay indoors. During the behavioural observations the following activities were recorded for each cow once every ten minutes: lying in the cubicles or at pasture, eating forage at the feeding gate or grazing, drinking, standing or walking in the lying, the collecting, the AMS or the feeding areas, and standing or walking in the central alley between the plots and the barn and at pasture. On both observation days at the 'far' plots in the strip grazing experiment, a cow was in heat. Data on these cows from the days in question were discarded.

2.4. Statistical analyses

In general, differences in behaviour were assessed assuming that a generalised linear mixed model (GLMM) can be used to describe the relation between differences in sward height (rotational grazing) or distance (strip grazing) and behavioural response variables. The Iterative Reweighted Residual Maximum Likelihood algorithm (IRREML) (Engel and Keen, 1994) was used to estimate fixed effects and random effects in a GLMM. Observations on the same cow are dependent and the effect of a specific cow is treated as a random deviation from the population mean. Therefore, cows were incorporated into the model as a random effect.

Overdispersion resulting from the dependence between cows was also taken into account in the model estimation. The sward height was incorporated into the model as a fixed effect for the analysis of the indirect behavioural data of the rotational grazing experiment, and distance was incorporated into the model when analysing the indirect behavioural data of the strip grazing experiment. In the rotational grazing experiment, the covariables lactation number and experimental period were also incorporated into the model as fixed effect if relevant, and in the strip grazing experiment the covariables lactation number and observation day. For the analysis of the direct behavioural data, the sward height (rotational grazing experiment) or the distance between the pasture and the barn (strip grazing experiment) were incorporated into the model as fixed effect as well as the covariable lactation number, if relevant. The Wald statistic (VWS) was calculated to test for a 99% probability level whether fixed effects were significant under the null hypothesis that there was no effect. This statistic has an asymptotic chi-squared distribution (Genstat 5 Committee, 1993). Model selection took place by backward elimination.

The following GLMMs were analysed:

AMS visits: Response variables concerning AMS visits were analysed according to the model:

$$y = \beta x + uz + \varepsilon \qquad (1)$$

In this model, y is the response variable (i.e. the number of the type of AMS visit in question); β are the fixed effects of sward height, experimental period and lactation number in the rotational grazing experiment or either interaction between those factors (x) and the fixed effects of distance, observation day and lactation number in the strip grazing experiment or either interaction between those factors (x); u was the random effect of cow z and ε was the residual error term. It was assumed that the variance of each response variable increased proportionally to the expected response value. This was confirmed by residual plots.

Time budget: Response variables concerning the duration of the cows' sojourns in the pasture, and in the lying, feeding and AMS areas as monitored by on-line registrations were analysed according to model (1), but it was assumed that the standard error of the response variables increased proportionally to expected response values.

Monitoring the cows' time budget during direct behavioural observations resulted in binary response variables. These were analysed assuming that the distribution of response variables resembles a binomial distribution and a logistic link function (McCullagh and Nelder, 1989), which resulted in the model:

$$\log p/(1-p) = \beta x + uz + \varepsilon \quad (2)$$

In this model, p is the probability that the cows are seen performing the activity under study, and the other terms are similar to those mentioned under model (1).

Distribution of the cows' activities over the pasture and the barn: A log-linear model with random effects was used for the analysis of the distribution of the cows' activities over the barn and the pasture. In that model, the total time an activity was performed outdoors (y) was assumed to be proportional to the total time the activity was performed (Y_{tot}). In the rotational grazing experiment, the sward height was used as an explanatory variable. In the strip grazing experiment, the distance between the pasture and the barn was used as an explanatory variable. In both experiments, the lactation number was used as a covariable. After a logarithmic transformation of the response variable y, the resulting model was:

$$\log (y) = \log (Y_{tot}) + \beta x + uz \quad (3)$$

In this model, βx represents the effect of sward height or distance (and lactation number if relevant) (McCullagh and Nelder, 1989), and other terms are similar to those mentioned under model (1).

Weather: A relationship was calculated between the black globe temperature outdoors and the time the cows spent indoors between 10:00 and 17:00 h per experimental day over all experimental periods in the rotational grazing experiment because the sward height decreased from the first to the fourth experimental day of an experimental period. In the strip grazing experiment this relationship was calculated per experimental period because the distance between the pasture and the barn differed in each experimental period. The resulting model was comparable to model (1). In the model, the black globe temperature and the lactation number were incorporated as fixed effects (βx) and the other terms were similar to those mentioned under model (1). It was assumed that the Standard Error of the response increased proportionally to the expected response values.

In both experiments, the Kolmogorov Smirnov two-sample test (KS2 test) was used to test whether there was a difference in the distribution of time intervals between AMS visits for different sward heights and distances (Conover, 1971). In addition, the distribution of AMS visits over the 24-hour period was analysed, assuming that the number of AMS visits (y) in a certain period is proportional to the total number of AMS visits (Y_{tot}). After a logarithmic transformation this results in the model:

$$\log (y) = \log(Y_{tot}) + \beta x \quad (4)$$

In this model, βx is the interaction between sward height and time period in the rotational grazing experiment and the interaction between distance and time period in the strip grazing experiment. The 24-hour period was divided into eight periods of three hours (5:30 – 8:30 h, 8:30 – 11. 30 h etc.). A Generalised Linear Model (GLM) was fitted instead of a GLMM because differences between sward heights were tested per cow over all experimental periods in the rotational grazing experiment and differences between distances were tested per cow over all observation days in the strip grazing experiment (McCullagh and Nelder, 1989).

It was checked whether time intervals between cows arriving at the AMS followed a negative exponential distribution, because this would mean that the arrival times were randomly distributed (Parzen, 1962).

The Genstat 5 statistical package was used for all analyses (Genstat 5 Committee, 1993).

3. RESULTS

3.1. Sward height

3.1.1. AMS visits

Over the course of each experimental period the number of milkings, the number of non-milking visits and the total number of AMS visits increased as sward height decreased (Table 1). An interaction was found between experimental period and sward heights for the non-milking visits and the total number of AMS visits, because the effect of sward height was not equally strong in all periods. The number of failed attachments was not affected by sward height. The negative cumulative frequency distribution of time intervals between consecutive AMS visits, measured between 5:30 and 20:30 h differed between sward heights. KS2 tests showed that the time intervals between consecutive AMS visits at sward heights of the first day and second day were distributed differently from those of the third and fourth days ($p < 0.01$) (Figure 3). Cows reported at the AMS in closer succession at the sward heights of the third and fourth days than at those of first and second days, indicating that they spread their AMS visits more evenly over the day on first and second days. The statistical analyses confirmed that the time intervals between consecutive AMS visits were not randomly distributed ($p < 0.01$).

Table 1. Predicted means of the number of AMS visits in rotational grazing; sward height decreased from day 1 to day 4.

	day 1	day 2	day 3	day 4	SED	$VWS_{df=3}$
milkings	2.6^a	2.7^a	2.9^b	3.0^b	0.1	24.1
non-milking visits	2.0^a	2.5^a	3.4^b	4.6^c	0.3	73.0
failed attachments	1.4^a	1.5^a	1.5^a	1.2^a	0.3	2.4
AMS visits[1]	4.4^a	4.6^a	5.9^b	7.3^c	0.3	115.3

[abc] different characters in a row indicate a significant difference between days ($p < 0.01$);

[1] excluding failed attachments because these reflect the 'behaviour' of the milking robot instead of that of the cows.

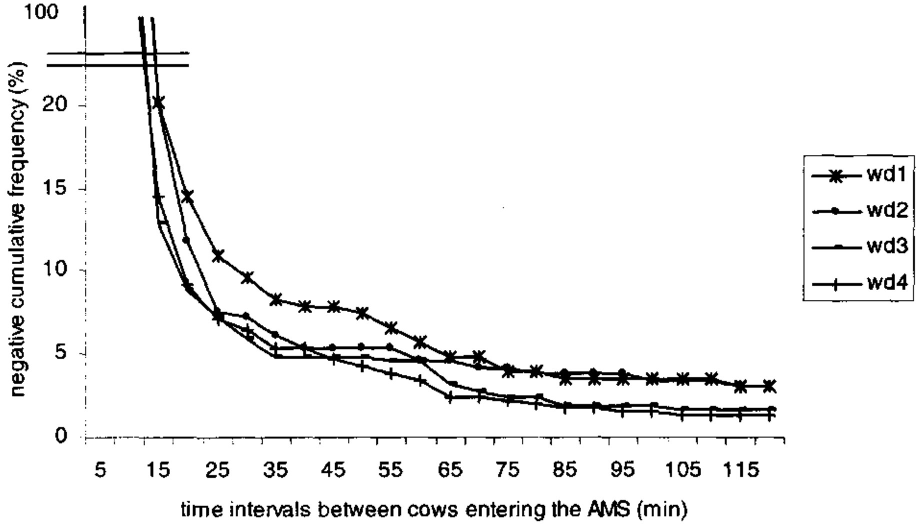

Figure 3. Negative cumulative frequency of the time intervals between consecutive AMS visits during the grazing period (between 5:30 and 20:30 h) in the rotational grazing experiment (intervals after failed attachments are excluded).

3.1.2. The cows' time budget

Table 2 gives an overview of the cows' time budget. In the rotational grazing experiment, the time in the AMS area and indoors increased as sward height decreased and the time in the pasture decreased. A significant interaction was found between experimental period and sward height for the time spent in the lying and AMS areas and for the time spent outdoors and at pasture. This interaction is attributable to differences in the strength of the effects of sward heights in different periods. Some differences between observation days were found for the percentage of time spent lying and the percentages of time spent lying in the pasture and grazing, but these could not be related to an effect of sward height. There was a tendency for cows to be seen more often at the feeding gate at the sward heights of the fourth days of the experimental periods than at the sward heights of the first days ($p < 0.05$). The percentage of time spent standing or walking at the pasture was lower on fourth days than on the first days, and the percentage of time spent standing or walking on the central alley and in the barn was higher ($p < 0.01$).

3.2. Distance between barn and pasture

3.2.1. AMS visits

Although some significant differences were found in the number of milkings, failed attachments and total number of AMS visits between experimental periods, none of these differences could be related to the distance between the pasture and the barn (Table 3). Significant interactions between distances to the barn and observation days for the milking visits and the total number of AMS visits did not change this. The cumulative frequency distribution of time intervals between consecutive AMS visits between 5:30 and 20:30 h did not seem to be affected by the distance between the pasture and the barn. However, after reducing the groups to two by pooling the two experimental periods with 'far' pastures and the two experimental periods with 'near' pastures, the KS2 test showed a significant different distribution ($p < 0.01$) (Figure 4). On one hand, cows at the 'far' pastures reported to the AMS in closer succession, but on the other hand there was more time between 'clusters' of AMS visits. It was confirmed by the statistical analyses that the time intervals between consecutive AMS visits were not randomly distributed ($p < 0.01$).

Table 2. Predicted means of the cows' time budget in the rotational grazing experiment based on on-line computer registrations (A) and on direct behavioural observations (B) on the first and fourth days of the second and fourth experimental periods; sward height decreased from day 1 to day 4.

(A) time spent (min):	day 1	day 2	day 3	day 4	SED	$VWS_{df=3}$
in lying area	500.7^{a}	512.5^{a}	563.5^{b}	553.3^{b}	14.7	26.0
in feeding area	152.1^{a}	147.6^{a}	167.9^{a}	164.6^{a}	11.3	4.5
in AMS area	34.0^{a}	33.1^{a}	38.6^{b}	39.1^{b}	1.7	20.3
indoors	684.0^{a}	719.8^{b}	796.0^{c}	784.2^{c}	10.1	170.9
outdoors	755.2^{c}	719.8^{b}	643.7^{a}	653.8^{a}	10.7	147.2
(B) behaviour (in %):	period 2; day 1	period 2; day 4	period 4; day 1	period 4; day 4	SE[2]	$VWS_{df=3}$
total lying	40.6^{b}	38.1^{b}	34.1^{a}	43.1^{b}	1.2	53.0
lying at pasture[1]	27.1^{c}	20.6^{b}	13.4^{a}	24.9^{c}	1.3	136.6
grazing[1]	40.8^{a}	38.3^{a}	50.7^{b}	39.0^{a}	1.3	72.5
feeding gate	5.4^{AB}	6.3^{B}	5.1^{A}	6.3^{B}	1.0	10.6
standing at pasture[1]	8.8^{c}	0.3^{a}	10.8^{c}	1.2^{b}	1.3	203.1
central alley[1]	3.2^{a}	5.8^{b}	2.6^{a}	5.0^{b}	1.5	26.8
standing in barn	13.0^{a}	21.3^{c}	12.6^{a}	16.0^{b}	1.9	58.6

^{abc} different characters in a row indicate a significant difference between days ($p < 0.01$);

^{AB} different characters between a row indicate a difference between days ($p < 0.05$);

[1] based on the period of 15 hours that the cows had access to the pasture;

[2] no reliable estimation of SED can be made when using logistic models; therefore, SE has been given as indication of deviation.

Table 3. Predicted means of the number of AMS visits in strip grazing; the distance between the pasture and the barn was different in different experimental periods.

	period 1 (near)	period 2 (far)	period 3 (far)	period 4 (near)	SED	$VWS_{df=3}$
milking visits	2.8^{a}	2.8^{a}	2.8^{a}	2.8^{a}	0.1	0.2
non-milking visits	2.6^{a}	2.6^{a}	2.7^{a}	2.8^{a}	0.2	1.7
failed attachments	1.5^{AB}	1.2^{A}	1.4^{AB}	1.7^{B}	0.2	10.0
tot. no. of AMS visits[1]	5.0^{a}	5.0^{a}	5.1^{a}	5.2^{a}	0.2	1.8

^{abc} different characters between rows indicate a significant difference between experimental periods ($p < 0.01$);

^{AB} different characters between rows indicate a difference between experimental periods ($p < 0.05$);

[1] excluding failed attachments because these reflect the 'behaviour' of the milking robot instead of that of the cows.

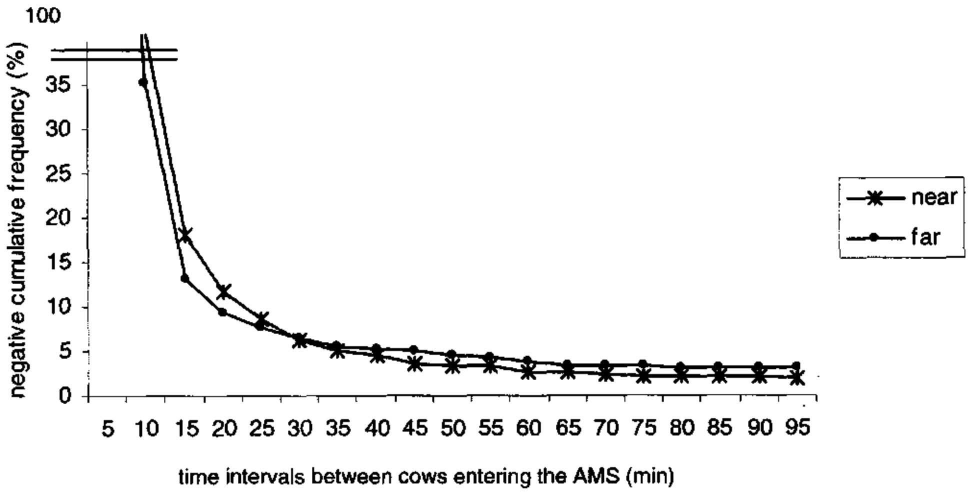

Figure 4. Negative cumulative frequency of the time intervals between consecutive AMS visits during the grazing period (between 5:30 and 20:30 h) in the strip grazing experiment (intervals after failed attachments are excluded).

3.2.2. The cows' time budget

Significant interactions were found between the distances and experimental days for the time in the lying and the feeding areas and for the time spent indoors and at pasture. None of these could be related to the distance between the pasture and the barn. Table 4 gives only the main effects. When the pasture was far from the barn, the percentage of time spent lying and that of lying in the pasture was lower and the percentage of time spent standing or walking on the central alley was higher. Differences found between experimental periods for the percentages of time spent grazing, standing at the feeding gate, standing at the pasture and standing in the barn, could not be related to the distance between the pasture and the barn. In the third experimental period, i.e. their second time on a 'far' pasture, the cows spent more time in the feeding area, indoors and at the feeding gate and less time outdoors and grazing than in the second experimental period (Table 4).

Table 4. Predicted means of the cows' time budget in the strip grazing experiment based on on-line computer registrations (A) and on direct behavioural observations (B) on the second days of each experimental period; the distance between the pasture and the barn was different in different experimental periods.

(A) time spent (min):	period 1 (near)	period 2 (far)	period 3 (far)	period 4 (near)	SED	$VWS_{df=3}$
in lying area	519.2^{a}	532.7^{a}	559.7^{a}	541.5^{a}	14.3	8.3
in feeding area	154.5^{b}	126.7^{a}	140.7^{b}	150.7^{b}	7.0	21.0
in AMS area	37.4^{a}	38.0^{a}	40.8^{a}	47.9^{b}	2.4	20.7
indoors	729.2^{b}	700.5^{a}	738.5^{b}	738.0^{b}	11.3	15.6
outdoors	709.2^{a}	741.3^{b}	699.5^{a}	700.7^{a}	11.4	16.8
(B) behaviour (in %):	**period 1 (near)**	**period 2 (far)**	**period 3 (far)**	**period 4 (near)**	**SE[2]**	**$VWS_{df=3}$**
total lying	47.5^{c}	41.1^{a}	39.7^{a}	44.3^{b}	1.2	56.5
lying at pasture[1]	32.6^{b}	25.9^{a}	26.5^{a}	31.1^{b}	1.6	27.0
grazing[1]	41.8^{b}	45.5^{c}	38.8^{a}	45.9^{c}	1.1	41.0
feeding gate	6.1^{b}	5.1^{a}	6.2^{b}	5.9^{b}	1.0	11.9
standing at pasture[1]	3.2^{cd}	1.9^{ab}	3.3^{c}	2.4^{bd}	1.6	13.3
central alley[1]	1.6^{a}	7.3^{b}	5.5^{c}	2.5^{d}	1.2	125.1
standing in barn						13.4
first lactation cows	11.0^{a}	11.2^{a}	18.3^{c}	13.3^{b}	2.1	
older cows	11.7^{a}	13.0^{ab}	14.4^{b}	11.5^{a}	2.2	

[abcd] different characters in a row indicate a significant difference between experimental periods ($p < 0.01$);

[1] based on the period of 15 hours that the cows had access to the pasture;

[2] no reliable estimation of SED can be made when using logistic models; therefore, SE has been given as indication of deviation.

3.3. Other results

3.3.1. Distribution of activities over the barn and the pasture

When given a choice between being indoors or outdoors, cows spent most of their time outdoors. If they could choose between lying indoors or outdoors, they mostly lay in the pasture. If they had the opportunity to eat forage indoors or outdoors, they spent most of the time grazing. This was found in both experiments (Table 5). In addition, in the rotational grazing experiment the cows spent a bigger part of the time that they could be outdoors at pasture, and a bigger part of the time that they could eat forage at pasture at higher sward heights. The same was found in the strip grazing experiment when the second experimental period (cows in a 'far' pasture for the first time) was compared with the third (cows in a 'far' pasture for the second time) (Table 5).

Table 5. Predicted means (in %) of the time spent at pasture, the time spent lying at pasture and the time spent grazing related to the total time that cows could be at pasture, or were lying or eating forage between 5:30 and 20:30 h. Results are given for rotational grazing and strip grazing respectively. In rotational grazing, the observations on day 1 and 4 were done in the 2nd. and 4th. experimental periods.

	rotational grazing					
	period 2		period 4			
	day 1	day 4	day 1	day 4	SED	$VWS_{df=3}$
being at pasture	86.3^b	68.2^a	84.7^b	73.4^a	1.0	122.5
lying at pasture	90.8^b	90.0^b	71.3^a	84.8^b	1.0	38.0
grazing	93.5^b	87.7^a	95.5^b	86.7^a	1.0	70.5
	strip grazing					
	period 1 (near)	period 2 (far)	period 3 (far)	period 4 (near)		
being at pasture	82.4^b	86.0^c	79.5^a	85.1^c	1.0	29.5
lying at pasture	91.1^a	96.3^b	94.8^b	94.5^b	1.0	11.5
grazing	88.4^b	91.2^c	85.9^a	90.8^c	1.0	29.0

^{abc} different characters in a row indicate a significant difference ($p < 0.01$)

(near), (far) refer to distance between pasture and barn.

3.3.2. Time intervals between cows entering the barn

In both experiments cows tended to enter the barn in close succession. In the rotational grazing experiment, 83.3 % (2.7) of the time intervals between cows entering the barn were shorter than six minutes, and 6.7 % (0.8) of these time intervals ranged from six to sixteen minutes (predicted means with SE in brackets). No differences between experimental days were found that could be related to an effect of sward height. In the strip grazing experiment, 78.4 % (2.4) of the time intervals between cows entering the barn were shorter than six minutes, and 8.2 % (0.8) of these time intervals ranged from six to sixteen minutes (predicted means and SE in brackets). No differences between experimental periods were found which could be related to the distance between the pastures and the AMS.

3.3.3. Distribution of AMS visits over the 24-hour period

In the rotational grazing experiment, cows distributed their AMS visits differently over the 24-hour period at different sward heights. The cows had a low percentage of AMS visits between 8:30 and 11:30 h and between 14:30 and 17:30 h, especially on the first days of the experimental periods, when they had been given a fresh pasture. In the strip grazing experiment, the distance between the pasture and the barn had no effect on the distribution of AMS visits over the 24-hour period.

3.3.4. Weather

On the third days of the rotational grazing experiment, a positive relationship was found between the black globe temperature outdoors and the time spent indoors by the cows between 10:00 and 17:00 h (temperature effect = 0.4247; SE = 0.1; $p < 0.01$). The average black globe temperature between 10:00 and 17:00 h on these days ranged from 18.9 to 32.1 ^{0}C. No such effects were found on the other days of the rotational grazing experiment and in the strip grazing experiment.

On one of the observation days of the rotational grazing experiment lying time was much shorter than on all other observation days (including those of the strip grazing experiment). This day was the rainiest of all observation days: it rained for 61.1 % of the time that the cows could be outdoors.

4. DISCUSSION

4.1. Sward height

The rotational grazing experiment showed that the sward height affects the cows' visits to an AMS if fully automatic milking on a voluntary basis is combined with grazing. At lower sward heights, cows paid more visits to the AMS, and were milked (slightly but significantly) more often. This means that a farmer will have to pay more attention to the daily milking frequency of his cows when he has offered them a fresh pasture, because in such a situation they probably will be more reluctant to return to the barn. According to Phillips (1993), there is an increase in grazing intensity when a fresh pasture is offered to cattle. This would also account for the low percentage of AMS visits between 8:30 and 11:30 h found on the first days of experimental periods in our experiment, and the fact that cows spent more of their time eating forage at pasture on the first days of experimental periods than on fourth days. However, total time spent grazing did not differ between different sward heights, which is in agreement with findings of Phillips and Hecheimi (1989). Those authors nevertheless did find higher biting rates at lower herbage heights, which is reported also by Phillips and Leaver (1986) and Rook et al. (1994). Unfortunately, we did not measure bite size in our experiment, but we did find an indication that cows spent more time at the feeding gate at low herbage heights; this, too, agrees with the results of Phillips and Hecheimi (1989), who found that cows spent more time eating silage at low herbage heights.

Lying times were not affected by sward heights, but if cows had access to the pasture they clearly preferred lying in the pasture rather than in the cubicles. This confirmed earlier findings (Ketelaar-de Lauwere et al., 1998).

The decreasing sward height was probably not the only factor causing the extra time spent indoors (and probably related to this the extra AMS visits) on third days of the rotational grazing experiment. High temperatures on these days may also have been influential. Similar results were found by Krötzl and Hauser (1997) and Ketelaar-de Lauwere et al. (1998). On fourth days of the rotational grazing experiment, the temperature did not contribute to the extra time spent indoors (and probably to the extra AMS visits).

Another factor which may affect the cows' behaviour at pasture is rain. The shortest lying time was found on the rainiest day of both experiments. Phillips (1993) has stated that cattle are reluctant to lie on wet grass.

4.2. Distance

The cows' visits to the AMS in this study were not affected by the distance between the pastures and the barn. However, some indirect effects of the distance were found. Cows on 'far' pastures spent less time lying on the pasture and more time standing or walking in the central alley between the pastures and the barn. In addition, it appeared that if they had access to the pasture cows preferred lying in the pasture rather than in cubicles, irrespective of the distance to the barn; this is similar to the findings of the experiment about sward height. On both days of direct behavioural observations on the 'far' pastures a cow was in heat. Even though the data on these cows for the days in question were discarded, these oestral cows may have affected the lying times of the other cows in the groups. It is questionable whether the shorter lying times and longer standing or walking time at the central alley affected the cows.

The time lactating dairy cows spend lying depends on many factors (Albright and Arave, 1997). The lying times found in our experiment were in the range of those reported by others (Krohn and Munksgaard, 1993; Singh et al., 1993). It should also be noted that daily exercise is known to be beneficial for cows improving reproduction performance and increasing milk protein percentages (Lamb et al., 1981), and improving physical fitness (Blake et al., 1982). Cows that exercise daily lie down more easily in comparison with cows kept tethered (Gustafson and Lund-Magnussen, 1996).

In our experiment it was striking that the cows seemed to habituate to the 'far' pastures; this can be inferred from the behavioural differences found between the first and second times that the cows were on a 'far' pasture. In general, when the cows had access to a 'far' pasture for the second time the data on the behavioural parameters were more comparable to those recorded on the 'near' pastures. This suggests that the cows were better adapted to the 'far' pasture the second time around, which implies that cows may need some extra time to become accustomed to a 'far' pasture.

4.3. Time intervals between cows entering the barn

In both experiments, cows returned to the barn several times in the period that they had access to the pasture. They always did this more quickly after one another than could be expected on the basis of an exponential factor alone. This phenomenon has been described previously in comparable situations (Ketelaar-de Lauwere et al., 1999). Connected with the group-wise entering of the barn, the cows also reported to the AMS quickly after one another. For a farmer who combines grazing with fully automatic milking in an AMS, this means that in the period that cows have access to the pasture there will be peaks in AMS visits and the AMS will be unvisited for several hours. Thus 'group arrival' of cows from pasture will negatively affect the throughflow of the AMS. This group behaviour is a result of the natural habit of cows to act as a co-ordinated social unit (Hurnik, 1994). Farmers should be aware of this phenomenon when deciding about what capacity AMS to install.

5. CONCLUSIONS

Under circumstances comparable to those in our experiment, cows will pay more visits to an AMS and spend more time indoors at lower sward heights. Farmers who combine grazing with fully automatic milking on a,voluntary basis have to take this into account with regard to the daily milking frequency. More cows will probably have to be brought to the AMS if they are in a fresh pasture.

Distances between barn and pasture up to a maximum of 360 m do not affect the number of AMS visits. It is not known what would happen at longer distances. There are indications that cows need some extra time to become accustomed to 'far' pastures.

Irrespective of the sward height and the distance between the barn and the pasture, the cows preferred lying in the pasture rather than in the cubicles, and tended to enter the barn group-wise and, as a consequence, to visit the AMS in close succession. The latter means that in the periods that cows have access to the pasture there will be peaks in AMS visits, and also periods when the AMS will be unused for several hours. This means that the AMS's capacity will not be used optimally; this should be taken into account when calculating what capacity of the AMS is required.

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CHAPTER 8

GENERAL DISCUSSION

INTRODUCTION

Cows have to adapt to a completely new milking routine if an automatic milking system (AMS), in which cows are milked without human interference, is introduced on the dairy farm (chapter 1). The research in this thesis shows that cows manage to do so. The cows did visit the AMS by themselves at regular intervals in all experiments after a certain period of training and habituation. Nevertheless there were individual differences between cows (chapter 2). The extent of the cows' adaptation varied in different AMS environments, which has implications for cow welfare. This topic will be discussed in the first part of this chapter.

Though this thesis focuses on the cows, an AMS environment that is ideal for cows will still not be applied in practice if it is not suitable for the farmer. Therefore, the implications of different AMS environments will also be discussed below, with emphasis on the milking frequency, the AMS capacity and the AMS design. Finally, the prospects for fully automatic milking will be discussed from the viewpoint of the farmer, the cow and public perception, and recommendations for further research will be given.

ADAPTATION OF COWS TO THE AMS ENVIRONMENT

Useful indicators for the adaptation of cows to a new environment are the maintenance of feed intake and feeding and lying times and the temporal distribution of these behaviours (Winter, 1993), and the extent to which an environment offers social security to an animal (Webster, 1993). From that viewpoint, the effects of social dominance that appear under conditions of fully automatic milking (chapter 2) do not seem to be very dramatic. It is true that the timing of eating and AMS visit were affected by social rank, but the lying pattern and the total lying and eating time were not (silage was continuously available). In fact, it is natural for cows in a herd to establish a more or less stable social hierarchy (Phillips, 1993; Webster, 1993) and have rules of precedence at resources. Social rank is even advantageous, because it enables cows to predict the outcome of agonistic interactions in which they are involved (Wierenga, 1990), which limits the need for physical aggressive encounters, once the hierarchy has stabilised (Kondo and Hurnik, 1990).

The type of cow traffic applied appeared to have more impact than social rank on the cows' adaptation to the AMS environment. Forced cow traffic, during which cows are more or less forced to visit the AMS because it is the only way they can reach the forage, seemed to be especially questionable with regard to the cows' adaptation to the AMS environment (chapters 3 and 4). Other authors had also found this (Winter et al., 1992; Winter and Hillerton, 1995; Prescott et al., 1998). Metz and Ketelaar-de Lauwere (1995) stated that an AMS should be positioned in the barn in such a way that milking is integrated in the cows' daily behavioural cycles of feeding and resting in a 'natural' way. This means that disrupting of lying periods is minimal, feeding is not postponed and sufficient time is available for other maintenance behaviours. During forced cow traffic, the eating behaviour seems to be postponed or even thwarted. The cows somehow seemed to be confused by this type of cow traffic, somewhat analogously to the state of 'social tension' Miller and Woodgush (1991) described. Larkin and McFarland (1978) found in a study with Barbary doves that the costs of changing from one activity to another affects the temporal organisation of the behaviour. Analogously to this, the costs of changing from the feeding area to the lying area or vice versa may be higher for cows during forced traffic than during free traffic. It is not clear why cows disliked the forced routing. They probably did not like having to pass through the one-way gates. It is also possible that they 'knew' that it would be 'complicated' to return to the feeding gate or cubicle after leaving these facilities; Baily et al. (1989) report that cattle have a 'spatial memory'.

Free cow traffic is the opposite of forced cow traffic. This type of cow traffic may suit the cows better but the farmer has less certainty of achieving the required milking frequency of individual cows, which should preferably be higher than the traditional twice daily (chapters 3 and 4). Hence, this gives rise to a conflict of interests between the cows' comfort and the farmer's aims. This can be solved by the application of a third type of cow traffic in which free and forced cow traffic are combined: cows can move freely between the feeding area and the lying area, but must pass through the AMS to reach the concentrate feeder (chapter 5). Independently, this type of cow traffic was recommended but not studied by Prescott et al. (1998). As reported in this thesis (chapter 5), the cows adapted well to this new environment and were milked more often than the traditional twice daily. Therefore, this type of cow traffic is recommended as an optimal AMS environment inside the barn, with the caveat that the precise design of the 'concentrate area' behind the AMS needs further attention.

Grazing is another important factor when fully automatic milking is applied. When AMS first came into practice it was assumed that cows should be zero-grazed during summer or otherwise be milked group-wise at fixed times during the day after being collected from the pasture by the farmer (Prescott, 1995). Our research showed that this does not have to be the case. Cows adapted well to the AMS environment when grazing was applied (chapters 6 and

7). They returned to the barn with the AMS voluntarily several times per day. What is unique to the combination of grazing and fully automatic milking on a voluntary basis is that the cows can choose between being indoors or outdoors and therefore anticipate their environment very well: the cows stayed indoors more and spent more time at the feeding gate if the amount of grass at pasture was smaller, they preferred to stay indoors when the ambient temperatures were high or the weather was very bad, they clearly preferred to be outdoors when ambient conditions were moderate and the amount of grass was sufficient, and they preferred to lie in the pasture rather than in the cubicles. Indications were also found that they could lie more comfortably at pasture (chapter 6). It is therefore concluded that the option of grazing in the summer is obviously advantageous for the welfare of the cows as contended earlier by Metz et al. (1986), and cow welfare may even be further improved when grazing is combined with fully automatic milking. Therefore, the availability of grazing is an important condition for the introduction of AMS on the dairy farm.

IMPLICATIONS OF THE AMS ON COW WELFARE

The introduction of AMS on the dairy farm will be acceptable only if the welfare of the cows is not compromised. In this context, it is important that forced cow traffic is avoided and grazing is applied in the summer season. However, other aspects should be considered as well.

The requirement that cows have to report to the AMS individually may be a problem as cows usually act in groups (Hurnik, 1992). They nevertheless seem to have adapted to the individual entrance of the AMS because they all managed to report to the AMS several times a day, analogously to visiting concentrate feeders on an individual basis. In addition, cows at pasture seemed to have adapted to the individual attendance by entering and leaving the barn group-wise (chapters 6 and 7). Cow behaviour is known to be more synchronised at pasture than in the barn (O'Connell, et al., 1989; Miller and Woodgush, 1991; Krohn et al., 1992). Hence, a decrease in synchronised behaviour does not seem to be related to cows in AMS environments in particular but more generally to cows that are confined. Little research has been done to elucidate the rationale or mechanisms of this phenomenon.

More frequent milking is one way fully automatic milking benefits cow welfare. This seems to be most important for high yielding cows because it reduces pressure in the udder (Ipema et al., 1988).

Improved health monitoring can be another advantage of automatic milking systems with regard to the cows' welfare. The application of automatic milking and feeding systems provides an unique opportunity to monitor the health of the cow each time she visits such facilities (Metz et al., 1998). This is becoming increasingly important, because the metabolic load on high-yielding dairy cows in early lactation may become a welfare issue due to health problems (Webster, 1993). High production levels can be associated with decreased reproductive performance and a higher prevalence of production diseases (Nielsen, 1998). This increased risk of disease in combination with lack of human inspection in automatic milking systems may be a factor limiting the implementation of fully automatic milking in practice, unless the AMS is provided with adequate sensing systems to detect diseases and oestrus (Mottram, 1997).

The lack of human/animal contact in AMS may not be solved by replacing the milker with sensing systems. According to Seabrook (1984), positive interaction between a farmer and his animals can have a positive effect on animal performance. In positively handled heifers Coleman et al. (1998) found lower cortisol levels and less behaviour related to fear of humans (such as shorter latency to interact and more interactions with experimenter, smaller flight distance) than in negatively handled heifers. This is clear evidence that human contact is an important determinant of fear for humans and acute and chronic stress in heifers. A well-functioning AMS will probably handle the animals neutrally. It is not clear how this affects the cows. The results presented in chapter 5 showed that the cows paid fewer visits to the concentrate feeder if it could be reached only through the AMS. This is similar to findings of Grimm et al. (1980) that cows paid fewer visits to a concentrate feeder when they were also milked in it, and it may indicate that cows are less attracted to the AMS than to a normal concentrate feeder. On the other hand it is unlikely that the AMS was really frightening to the cows (as 'unfriendly' or 'neutral' human beings probably are), because in that case the cows would have refused to go near it. It is clear that more research is needed in this field.

The functioning of the AMS is another point of concern in terms of the cows' welfare. Cows returned to the AMS sooner after failed attachments and non-milking visits, and had more incomplete AMS cycles (i.e. only eating, only lying or neither of these behaviours between consecutive AMS visits) than after milking visits (chapter 4). This has negative consequences for the cows in more respects. They have to re-enter the AMS, which can cause more waiting in front of the AMS than necessary. Moreover, extra movement through the barn caused by cows wanting to re-enter the AMS after a failed attachment or non-milking visit can increase unrest and aggression in the barn. An extra disadvantage of failed attachments becomes clear when grazing is applied: cows may be forced to stay indoors after failed attachments, while the rest of the herd is able to go out to pasture (chapter 6). This can cause social isolation of one cow, which can be very stressful (Hopster, 1998). It will probably be impossible to avoid non-milking visits if an AMS is introduced on the dairy farm. Nevertheless, failed attachments should be minimised.

CONSEQUENCES OF THE AMS IN TERMS OF MILKING FREQUENCY, AMS CAPACITY AND AMS DESIGN

The success of an AMS largely depends on the cows that have to visit the system at regular intervals (Ketelaar-de Lauwere, 1992). The findings reported in this thesis shows that the cows' daily milking frequency will be more reliable under forced cow traffic than under free cow traffic (chapters 3 and 4). However, forced cow traffic appeared not to be suitable for the cows. The third type of cow traffic, in which cows could move freely between the feeding and the lying areas, but had to pass through the AMS to reach the concentrate feeder, appeared to be suitable to both the farmer and the cow. The same positive conclusion can be drawn for the combination of fully automatic milking on a voluntary basis with grazing. Cows at pasture did return to the barn several times a day and were milked. However, farmers who want to combine grazing with fully automatic milking have to manage this flexibly and according to ambient conditions. Cows may be reluctant to enter the barn if ambient temperatures are moderate (chapter 6) and the cows are in a fresh pasture (chapter 7). Restricted grazing (12 to 15 hours per day) may give more reliable results with regard to the milking frequency (chapter 6). Distances between the barn and the pasture up to a maximum of approximately 350 m did not affect the cows' milking frequency (chapter 7).

The AMS capacity is a point of concern for the farmer. Calculations of AMS capacity are often based on the assumption that the AMS is almost continuously or evenly attended by the cows throughout the 24-hour period (Devir et al., 1995; Devir et al., 1999). Indeed Devir et al. (1995) found that cows spread their AMS visits almost evenly over the day, but this was in a forced cow traffic situation. De-synchronisation of feeding and lying patterns in a forced cow traffic situation have been described by Winter et al. (1992) and Winter and Hillerton (1995). However, if cows visit the AMS voluntarily it is likely that the milking stall will be occupied for less time than the time available, because the cows' normal visiting pattern and cows loitering at or obstructing the entrance or exit of the AMS will cause extra idle time (Ipema, 1997; Rossing et al., 1997). In the experiment described in chapter 6 of this thesis cows paid fewer visits to the AMS between midnight and 6:00 a.m.. This indicates that it is not realistic to calculate the AMS capacity on the basis of the continuous reporting of cows to the AMS throughout the 24-hour period. However, it is not only the fact that cows will pay less visits to the AMS between midnight and 6:00 a.m. that has to be taken into account when calculating the AMS capacity; the phenomenon observed in all experimental situations with pasturing that the cows tended to enter or to leave the pasture or the barn group-wise (chapters 6 and 7) is also important. The consequence of the group-wise behaviour was that the cows also entered the AMS in close succession, causing peaks in AMS visits in the period that the pasture was available to the cows, but also causing the AMS to be unvisited for several hours in this period. It is obvious that this will reduce the AMS capacity. Therefore, if grazing is applied it may be necessary to have more AMS capacity.

The AMS design is also an important factor. In our research, only one type of AMS was used. This existed of two milking stalls and a milking robot equipped with sensors for teat location. The robot arm was used for both milking stalls (For more details, see Devir et al., 1996a). Cows entering the AMS had to pass through an entrance gate which led them to one of the milking stalls. After a visit to the milking stall, the exit gate opened and the cows could leave the AMS. So, part of the time that the cows spent in the AMS area was needed for moving through the AMS. When a selection stall and/or a waiting area was used in front of the AMS this time increased (chapter 4, Devir et al., 1996b; Stefanowska et al., 1997). It is likely that technical solutions can reduce the time needed for moving through the AMS. First of all, the AMS must be designed to be simple and non-confusing to the cows (Hurnik, 1992). This implies that equipment in front of the AMS and separate milking stalls in the AMS should be avoided. The latter is possible only when each milking stall has its own entrance and exit. One advantage of this design may be that effects of social hierarchy will decrease, because cows do not have to use the same entrance to reach the milking stall. However, in such a design the farmer needs one milking robot per milking stall. This is an extra investment, but it does increase the capacity of the AMS. In addition, the farmer who needs more than one milking stall will be able to manage his cows more flexibly because he can locate the milking stalls as separate units in different places in the barn.

The improvement of the technical functioning of the AMS will also reduce the time needed to move through the AMS (Devir et al., 1995). The speed of the teat cup attachment process must improve and failed attachments of the milking robot should be minimised, especially because these technical failures induce extra AMS visits (chapter 4) and thus affect the system capacity negatively (Morita et al., 1996).

PROSPECTS FOR FULLY AUTOMATIC MILKING, FOR COW AND FARMER

Under optimal conditions of cow traffic and technical functioning of the AMS the quality of life of both the cow and the farmer will improve. For the farmer and his relatives, the physical and mental load will be lower (Sonck, 1996). The farmer will be able to take care of his cows optimally, because on-line data of individual cows, such as body weight, electrical conductivity of milk and activity, can be used to get more insight into the physiological state of each cow (Devir et al., 1996), and thus for daily adjustment of the individual feeding and milking regime (Maltz and Metz, 1994). For cows, 'self-service' milking means that milking is no longer dictated by labour and social demands of humans, but predominantly by the physiological and psychological demands and desires of the cow herself (Winter and Hillerton, 1995). When grazing is applied in the summer, cows are able to choose between indoors and outdoors. This is advantageous for their welfare because they can choose between lying in the cubicle or at pasture and seek shade when ambient temperature is high or shelter during heavy rainfall. When the amount of grass at pasture decreases, they can enter the barn and compensate for the shortage of grass by the intake of forage there.

Some farmers will not be able to cope with AMS conditions. Though some will experience the shift to more management-directed tasks as an enrichment, others may suffer from stress (Sonck, 1996). Seabrook (1992) found that livestock-orientated stockpersons appeared to be more demeaned by the prospects of automatic milking than machinery-orientated stockpersons, and that progressive farmers saw greater opportunities in fully automatic milking than the more traditional ones. He stated that projection of automatic milking in terms of "enabling better stockmanship and care for cows " might create less dissonance for those whose self-esteem would otherwise be compromised. Those farmers who worry about losing contact with the cows may find comfort in the knowledge that it is reasonable to assume that an average AMS farmer will visit his herd at least 3 to 5 times daily (Devir et al., 1999).

Another aspect of the lack of human/animal contact may be a long term one. Automation in dairying will not be restricted to fully automatic milking. Rearing conditions of calves will also be increasingly automated. Le Neindre et al. (1996) found that extensively reared cattle are more difficult to handle and more fearful than intensively reared cattle and sometimes even aggressive towards caretakers, due to the lack of contact between humans and animals. A high level of automation in feeding and milking on the dairy farm during rearing and adulthood may have the same consequences because in such a situation close contact with caretakers will be easily limited to situations that involve some kind of unpleasant treatment (Hopster, 1998). This needs more research attention, because fear adversely affects cow welfare (Webster, 1993), and also because fearful animals may endanger the caretakers.

When an AMS is introduced on the dairy farm ethical considerations need to be addressed. A common criticism of modern intensive livestock farming is that animals are considered only as machines or units of resource within an enterprise whose sole objective is to make a profit (Webster, 1993). This criticism may increase when an AMS is introduced on the dairy farm, as consumers may not like the 'machinery-orientated' character of fully automatic milking. The perceived public concern about cows having to stay indoors all year round if fully automatic milking is applied is a clear example. The research presented in this thesis shows that this concern appears to be unfounded (chapters 6 and 7). This may help to improve public opinion about fully automatic milking but will not be able to take away consumer concerns completely. Therefore, the final acceptance of fully automatic milking systems on the dairy farm under optimal conditions of cow traffic and technical functioning of the system may be more an ethical matter than an ethological one.

FURTHER RESEARCH

Relatively small groups of cows (20 to 30) were used in this research, which meant that the AMS capacity was always sufficient. It is possible, however, that in larger herds the effects of social hierarchy and forced cow traffic described in this thesis may be more pronounced and have more negative impact on the cows' behaviour. A study by Hogeveen et al. (1998) in a 53-cow dairy herd confirms this, especially with regard to the waiting in front of the AMS. The AMS environment in which cows can move freely between the feeding and the lying areas but have to pass through the AMS to reach the concentrate feeder, may also be less optimal in larger herds. Hence, the design of the optimal 'concentrate area' in such an environment also needs more attention in larger herds.

Studies in large groups of cows are complicated, especially in combination with fully automatic milking in an AMS. Simulation techniques may be a useful tool to support the discussion about the optimal design of the robotic farm, but will not be able to replace 'the real world' completely. Field experiments and observations will therefore still be necessary.

Behavioural studies of the cows in different AMS environments should be combined with measurement of stress-related physiological parameters because the evaluation of welfare in different housing systems requires a wide range of measurements, and long-term studies (Broom et al., 1995).

The lack of contact between the farmer and his cows is another aspect that should receive more attention in AMS studies (see also the previous sections). Waiblinger and Menke (1998) found that the approach and, more particularly, the avoidance reactions of cows on dairy farms reflect the quality of human versus animal relationships and can be used as a basis for on-farm assessment of this aspect.

Grazing also needs more research. Although our research showed that grazing can be combined with fully automatic milking (chapters 6 and 7), it relied on water to entice cows at pasture back to the barn, because no water was available in the pastures. This may not be a problem under normal Dutch conditions with moderate ambient temperatures: in 17.8 to 34.5 % of the cases that they had entered the barn the cows left without drinking (chapter 6). But it will not always be possible to restrict water at pasture, for example in The Netherlands, where pastures are often surrounded by ditches. Furthermore, under more extreme ambient conditions in other countries, restrictions in the availability of water may adversely affect the cows' health. Little et al. (1980) found that restricted availability of water had marked effects such as lower milk yield, changes in blood composition and more aggression around water troughs. Thus, more research is needed to find methods to attract cows at pasture back to the barn (and the AMS) without water restriction. In addition, methods have to be developed to deal with the cows' habit of entering and leaving the barn group-wise, which results in the AMS being unused for several hours a day in the period that grazing is possible. As group action is a natural habit of cows, some caution is needed when 'solving' this 'problem'. At this point the importance of research on group size returns: in a larger herd the cows might have had problems with the restricted availability of water. Furthermore, in a larger herd it is questionable whether they would have behaved as one unit when returning to the pasture or the barn. Subgroups would probably have arisen, visiting the AMS at different moments of the day. Finally, research should also be done to ascertain the minimum time needed for grazing and the consequences of 'group entering' for individual cows.

MAIN CONCLUSIONS

1. Cows are able to adapt to milking on a voluntary basis in an automatic milking system which is almost continuously available.
2. Effects of social hierarchy may arise if an AMS is introduced on the dairy farm. These have less to do with the number of visits to the AMS or the total time spent lying or eating, but do concern the timing of these behaviours, as low ranking cows paid a larger part of their visits to the AMS and the feeding gate during the evening and night than high ranking cows.
3. Free cow traffic should be avoided from the farmer's point of view because the cows' daily milking frequency will be less reliable than under other types of cow traffic. Forced cow traffic should be avoided because it seems to restrict the cows in their behaviour; this is indicated by less movement trough the barn, more idle standing, less time at the feeding gate and higher eating rates. Cow traffic under which cows can move freely between the feeding and the lying areas but have to pass through the AMS to reach a concentrate feeder appeared to be a good method to attract cows into the AMS regularly without negative consequences for their behaviour. In addition, it appeared to be better to supply new concentrate every four hours than every two hours, because this increases rest in the cowshed and decreases waiting in front of the concentrate feeder.
4. Grazing can be combined with fully automatic milking. Cows at pasture do report to the AMS by themselves several times a day. Restricted grazing, during which cows were given access to the pasture for 12 or 15 hours gave more reliable results with regard to the cows' daily milking frequency than unrestricted grazing, during which cows had access to the pasture throughout the 24-hour period. The distribution of the cows' behaviour over the pasture and the barn is affected by external factors such as the weather and the sward height. If ambient temperatures were high the cows tended to stay indoors. At lower sward heights, they spent more time indoors and paid more visits to the AMS. This indicates that a farmer who wants to combine grazing with fully automatic milking has to manage this flexibly, taking account of ambient conditions. Cows may be reluctant to return to the barn and the AMS if they have just been turned out on a fresh pasture and the ambient temperature is pleasant. If grazing and fully automatic milking are combined, the extent to which cows return to the barn and the number of visits they pay to the AMS are not affected by distances of up to 350 m between the pasture and the barn.
5. Cows prefer to lie in the pasture rather than in the cubicles.

6. Cows at pasture tend to return to the barn group-wise. This causes peaks in AMS visits in the period that the pasture is available to the cows, and means that the AMS is idle during several hours in this period. This reduces AMS capacity. In addition, cows tend to pay fewer visits to the AMS in the middle of the night (between 0:00 and 6:00 h). Therefore, calculations of AMS capacity should not be based on the assumption that cows will report to the system continuously throughout the 24-hour period.
7. More research on fully automatic milking is needed to elucidate the effects of group size, the lack of contact between humans and animals, and grazing.

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COW BEHAVIOUR AND MANAGERIAL ASPECTS OF FULLY AUTOMATIC MILKING IN LOOSE HOUSING SYSTEMS

SUMMARY

INTRODUCTION

When an automatic milking system (AMS) in which cows can be milked without human interference is installed on a dairy farm, much will change for both the dairy farmer and the cow. The two or three daily milkings at fixed times will be replaced by milking in an AMS which is available to the cows almost continuously. The cows have to visit the system voluntarily at regular intervals. The farmer has to abandon much routine labour in favour of more management-oriented tasks. This thesis describes research on some of the consequences of introducing fully automatic milking on a dairy farm in terms of the social hierarchy of cows, the cow traffic towards the AMS and the combination of fully automatic milking on a voluntary basis with grazing. In this research emphasis was on the cow. It is assumed that she must be able to adapt successfully to her new environment. However, an AMS environment will not be applied in practice unless it has been accepted by the dairy farmer. Therefore, the final goal of the research was to indicate how fully automatic milking systems could be implemented in loose housing systems to benefit both the cow and the farmer.

SOCIAL HIERARCHY

The research described in this thesis showed that cows are able to adapt to an AMS environment in which milking at fixed times is replaced by milking in an AMS available almost continuously. In the experiments, all cows were milked by the milking robot. Low ranking cows avoided cows of higher rank by visiting the AMS more often during the evening and night. Neither the total time spent lying and eating nor the lying pattern were affected by social hierarchy. As these are useful indicators of the extent to which cows have adapted to a new environment it could be concluded that the effects of social hierarchy did not exceed the animals' normal adaptation. This conclusion is reinforced by the fact that all groups of cows have a social hierarchy and therefore some effects of this hierarchy seem to be inevitable if cows are kept in groups.

COW TRAFFIC

Free cow traffic means that the cows themselves can decide whether to visit the AMS. During forced cow traffic, they are more or less forced to do so because they can only reach the forage through the AMS. The cows seemed to find it difficult to adapt to the AMS environment under forced cow traffic, but under free cow traffic the daily milking frequency of individual cows was not sufficiently reliable. Under forced cow traffic a number of behavioural changes were seen that indicated that the cows were somehow confused by the compulsory routing. Compared with under free cow traffic, cows under forced cow traffic spent less time at the feeding gate, more time idle standing (which may be a sign of stress or 'discomfort') moved less through the barn and ate faster. A third type of cow traffic in which the cows could move freely between the cubicles and the forage but had to pass through the AMS to reach the concentrate feeder, appeared to be a good solution. This type of cow traffic was compared with free cow traffic with a concentrate feeder which was freely available. If the concentrate feeder was available only through the AMS the cows visited the AMS more often and the concentrate feeder less often, left less feed, had shorter waiting times in front of the concentrate feeder and displayed less aggression there. Under this type of cow traffic it appeared to be preferable to supply new concentrate every four hours instead of every two hours. In both cases the number of visits to the AMS and the concentrate feeder was comparable, but if new concentrate was supplied every four hours the cows ate more concentrate, left less feed, had shorter waiting times in front of the concentrate feeder and lay longer. It was striking that under the latter treatment the cows were more aggressive towards cows in the concentrate feeder. This suggests that cows were more eager to visit the concentrate feeder if concentrate was supplied every four hours.

GRAZING

Dutch farmers, dairy industry, animal protection organisations and consumers all agree that providing an opportunity to graze is an important condition for the successful application of AMS on the dairy farm. From the research described in this thesis it appeared that if grazing was available the cows also visited the AMS several times per day on a voluntary basis. Compared with unrestricted grazing, in which cows were able to spend up to 24 hours daily at pasture, restricted grazing in which cows were able to spend up to 12 to 15 hours daily at pasture gave more reliable results for the farmer in terms of the milking frequency of individual cows. Distances of up to 350 m between the barn and the pasture did not affect the extent to which cows returned to the barn. The cows clearly preferred to lie in the pasture rather than in the cubicles. External factors such as the weather and the amount of grass in the pasture appeared to have a significant effect. Cows spent more time indoors during the day (between 10:00 and 17:00 h) when ambient temperatures were extremely high. At lower sward heights they also spent more time indoors and at the feeding gate (where forage was supplied), paid more visits to the AMS and were milked more often. Dairy farmers should take these findings into account if they wish to combine grazing with fully automatic milking. If the ambient temperature is pleasant and the cows are in fresh pasture, they may be reluctant to return to the barn with the AMS.

The social behaviour of the cows also plays a role if grazing and fully automatic milking are combined. When returning from pasture, the cows tended to enter the barn group-wise and to visit the AMS in close succession. This is natural behaviour for cows, but it has consequences: in the period that cows had access to the pasture, there were peaks in AMS visits, and the AMS was unvisited for several hours. This has to be taken into account when calculating the capacity of an AMS.

DISCUSSION

Cows can be milked in an AMS several times daily without the need for extra labour from the farmer. This is especially advantageous for high yielding cows because it is often assumed that more frequent milking reduces pressure in the udder and, therefore, may reduce discomfort. In addition, the AMS offers an unique opportunity to monitor a cow's health each time she visits the system. This is becoming increasingly important because at the beginning of the lactation much is demanded physiologically of especially high yielding cows.

One point of concern is the lack of human/animal contact in AMS. Positive human/animal contact can increase the animal's productivity and reduce its stress response. An AMS will probably handle the cows neutrally.

Another point of concern is the technical functioning of the AMS. A milking robot sometimes fails to milk a cow that should have been milked at that moment. This can have negative consequences for the cows. During the research a cow sometimes had to stay behind in the barn because the milking robot failed to milk her, but her herd mates could go out to the pasture. Another consequence of a failed attachment can be that a cow tries to re-enter the AMS several times. This may put unnecessary pressure on the AMS and, therefore, reduce the AMS capacity.

The AMS capacity also needs attention because calculations are often based on the assumption that the cows visit the system evenly over the 24-hour period. However, the cows pay fewer visits to the AMS in the night (between 0:00 and 6:00 h), and if grazing is available, when they return from the pasture, they tend to enter the barn group-wise and to visit the AMS in close succession.

The research presented in this thesis was always carried out with relatively small herds (20 to 30 cows). It is unclear what would happen in larger herds. It is possible that in larger herds the effects of social hierarchy and forced cow traffic might be intensified and have more negative impact on the cows' behaviour. Furthermore, the group-wise entering of the barn if grazing is available might also lead to extra 'queuing' in front of the AMS. These aspects should be researched, probably also with the aid of simulation techniques.

The consequences of the lack of human/animal contact in the AMS also need to be examined. Cows that spend more time during their rearing and their productive life in automated environments might become more difficult to handle and more fearful. This would have negative consequences for the cows, because they might experience even the most simple treatments as stressful, and also for their handlers, because fearful animals might even harm them.

When grazing and fully automatic milking are combined, the question remains of how it can be guaranteed that cows will return to the barn and the AMS under all circumstances. In the presented research water was used to entice cows at pasture back to the barn. However, it would be better to develop other methods to attract cows at pasture back to the barn (and the AMS), not only because it is not possible to restrict water under all circumstances (e.g. in warm climates) but also because the tendency of cows to enter the barn group-wise may result in some individuals having to endure long waiting times in front of the AMS.

SAMENVATTING

KOEGEDRAG EN MANAGEMENTASPECTEN VAN VOLLEDIG AUTOMATISCH MELKEN IN LOOPSTALLEN

INLEIDING

In een automatisch melksysteem (AMS) kunnen koeien worden gemolken zonder menselijk ingrijpen. Als een AMS op het melkveebedrijf wordt geïntroduceerd, zal er veel veranderen voor zowel de melkveehouder als de koe. Het twee- of hooguit driemaal daags melken op vaste tijdstippen zal vervangen worden door het melken in een AMS dat vrijwel continu beschikbaar is voor de koeien. De koeien moeten het systeem vrijwillig en met regelmatige intervallen bezoeken. De melkveehouder zal moeten omschakelen van veel routinematige arbeid naar meer managementgerichte taken.

Dit proefschrift beschrijft onderzoek naar een aantal consequenties van de introductie van volledig automatisch melken op het melkveebedrijf met betrekking tot de sociale rangorde van koeien, het koeverkeer naar het AMS en de mogelijkheid om een AMS met weidegang te combineren. Het onderzoek beperkt zich tot de koe. Zij moet in staat zijn zich succesvol aan te passen aan haar nieuwe omgeving. Een AMS omgeving kan echter niet toegepast worden in de praktijk zonder acceptatie van de veehouder. Het uiteindelijke doel van het onderzoek is dan ook te komen tot de implementatie van automatische melksystemen in ligboxenstallen op een manier die zowel de koe als de melkveehouder past.

SOCIALE RANGORDE

Het in dit proefschrift beschreven onderzoek heeft aangetoond dat koeien zich kunnen aanpassen aan een AMS omgeving waarin melken op vaste tijdstippen is vervangen door melken in een AMS dat vrijwel continu beschikbaar is. Alle koeien lieten zich door de melkrobot melken. Ranglage koeien vermeden ranghoge koeien door het AMS 's avonds en 's nachts vaker te bezoeken. De totale tijd die de dieren aan eten en liggen besteedden en het ligpatroon werden niet beïnvloed door de sociale rangorde. Dit zijn belangrijke maatstaven voor de mate waarin een koe zich aan haar omgeving aanpast. De gevolgen van de sociale rangorde leken het normale aanpassingsvermogen van de dieren dan ook niet te overschrijden. Dit wordt nog duidelijker als men in ogenschouw neemt dat in alle groepen koeien een sociale rangorde voorkomt en dat enige effecten van sociale rangorde dus onvermijdelijk zijn als koeien in een groep gehouden worden.

KOEVERKEER

Bij vrij koeverkeer kunnen de koeien zelf bepalen of en wanneer ze het AMS willen bezoeken. Bij gedwongen koeverkeer worden ze hiertoe min of meer gedwongen omdat ze alleen via het AMS bij het ruwvoer kunnen komen. De koeien leken het moeilijk te vinden zich bij gedwongen koeverkeer aan de AMS-omgeving aan te passen. Als vrij koeverkeer werd toegepast kon echter onvoldoende gegarandeerd worden dat de gewenste melkfrequentie voor iedere koe gehaald werd. Bij gedwongen koeverkeer trad een aantal veranderingen in het gedrag van de koeien op, dat een bepaalde staat van 'verwarring' leek uit te drukken. Voorbeelden zijn: minder tijd doorgebracht aan het voerhek, meer doelloos staan (wat wel gezien wordt als teken van 'discomfort' of stress), minder beweging door de stal en sneller eten in vergelijking met vrij koeverkeer. Een derde vorm van koeverkeer, waarin de koeien vrij tussen de ligboxen en het ruwvoer heen en weer kunnen lopen maar het AMS moeten betreden om bij de krachtvoerbox te komen, bood een goede oplossing. Deze vorm van koeverkeer werd vergeleken met vrij koeverkeer met een vrij toegankelijke krachtvoerbox. Als de krachtvoerbox alleen toegankelijk was via het AMS, hoefden de koeien minder lang te wachten voordat ze de krachtvoerbox konden betreden en werd er rond de krachtvoerbox minder agressie waargenomen. Verder brachten de koeien in deze situatie meer bezoeken aan het AMS en minder bezoeken aan de krachtvoerbox. Het bleek bij deze vorm van koeverkeer beter te zijn om eenmaal per vier uur krachtvoer beschikbaar te stellen dan eenmaal per twee uur. In beide gevallen was het aantal bezoeken aan het AMS en de krachtvoerbox vergelijkbaar, maar als eenmaal per vier uur nieuw krachtvoer beschikbaar kwam, namen de koeien meer krachtvoer op, hadden minder krachtvoerresten, besteedden minder tijd aan wachten voor de krachtvoerbox en lagen langer. Opvallend was dat de koeien tijdens deze behandeling wel agressiever waren tegen andere koeien in de krachtvoerbox. Blijkbaar waren ze meer op het krachtvoer gebrand als het eenmaal per vier uur beschikbaar kwam.

WEIDEGANG

De mogelijkheid voor weidegang wordt door veel melkveehouders, maar ook door de zuivelindustrie en consumenten- en dierenbeschermingsorganisaties, als randvoorwaarde gezien voor een succesvolle toepassing van een AMS op het melkveebedrijf. Uit het in dit proefschrift gepresenteerde onderzoek is gebleken dat de koeien het AMS, ook als weidegang wordt toegepast, een aantal malen per dag vrijwillig bezoeken. Beperkt weiden waarbij de koeien 12 tot 15 uur per dag in de weide konden als ze dat wilden, gaf voor de melkveehouder betrouwbaarder resultaten ten aanzien van de gewenste melkfrequentie dan onbeperkt weiden waarbij de koeien 24 uur per dag naar de weide konden. Afstanden tussen de stal en de weide tot 350 m beïnvloedden de mate waarin de koeien terugkeerden naar de stal niet. De koeien prefereerden de weide duidelijk boven de ligboxen om te liggen. Externe factoren zoals het weer en het grasaanbod bleken een rol van betekenis te spelen. Bij extreem hoge temperaturen bleven de koeien meer binnen op het heetst van de dag (tussen 10:00 en 17:00 uur). Als er minder gras was in de wei, bleven ze ook meer binnen, brachten meer tijd door aan het voerhek (waar ruwvoer werd bijgevoerd), brachten meer bezoeken aan het AMS en werden vaker gemolken. Een melkveehouder die weidegang met volledig automatisch melken wil combineren dient hiermee rekening te houden. Als de temperatuur aangenaam is en de koeien hebben de beschikking over een verse weide, zullen ze waarschijnlijk minder makkelijk terugkeren naar de stal met het AMS.

Het sociale gedrag van de koeien speelt ook een rol als weidegang wordt gecombineerd met volledig automatisch melken. De dieren zijn geneigd om vanuit de weide gezamenlijk terug te keren naar de stal, en daarna het AMS snel achter elkaar te bezoeken. Dit is voor de koeien heel natuurlijk gedrag, maar kan leiden tot piekbelasting van het AMS in de periode dat de koeien de beschikking hebben over de weide, terwijl het AMS op andere momenten in deze periode langere tijd stil ligt. Hiermee dient rekening gehouden te worden bij het berekenen van de capaciteit van automatische melksystemen.

DISCUSSIE

Koeien kunnen in een AMS meerdere malen per dag gemolken worden zonder extra arbeid voor de veehouder. Vaker melken is een voordeel voor met name hoogproductieve koeien omdat vaak wordt aangenomen dat het de druk in het uier vermindert, en derhalve de belasting van een hoge productie op het dier vermindert. Daarnaast biedt het AMS een unieke mogelijkheid om elke koe meerdere malen per dag op haar gezondheidstoestand te 'monitoren'. Dit wordt steeds belangrijker omdat aan het begin van de lactatie fysiologisch veel gevraagd wordt van met name hoogproductieve koeien.

Een punt van zorg is het ontbreken van mens/dier contact bij robotmelken. Een positief mens/dier contact kan de productiviteit van de dieren vergroten en hun stress respons verminderen. Een AMS zal waarschijnlijk neutraal met de dieren omgaan.

Een ander punt van zorg is het technisch functioneren van het AMS. De melkrobot slaagt er soms niet in om koeien te melken die op dat moment wel gemolken zouden moeten worden. Dit kan negatieve gevolgen hebben voor de koeien. Tijdens het onderzoek moest een koe soms alleen achterblijven in de stal omdat de melkrobot er niet in slaagde haar te melken, terwijl haar kuddegenoten naar de wei konden. Een ander gevolg van mislukt aansluiten kan zijn dat koeien steeds weer opnieuw terugkomen naar het AMS. Dit leidt tot onnodige druk op het AMS, en vermindert derhalve de AMS-capaciteit.

De AMS-capaciteit vraagt ook aandacht omdat berekeningen hiervan vaak gebaseerd zijn op de aanname dat de koeien het systeem gelijkmatig verspreid over het etmaal bezoeken. De koeien bezoeken het systeem 's nachts echter minder vaak (tussen 0:00 en 6:00 uur), en als weidegang wordt toegepast treden pieken in AMS-bezoeken op omdat de koeien sterk geneigd zijn om gezamenlijk vanuit de wei terug te keren naar de stal en dan het AMS snel na elkaar te bezoeken.

Het in dit proefschrift beschreven onderzoek werd steeds uitgevoerd met relatief kleine kuddes (20 tot 30 koeien). Het is de vraag wat er zal gebeuren met grotere groepen. In grotere kuddes zullen ranglage koeien wellicht meer problemen krijgen om in het AMS te komen. Problemen die bij de toepassing van gedwongen koeverkeer kunnen optreden, zullen groter worden (wachttijden voor het AMS). Het gezamenlijk binnenkomen van koeien als weidegang wordt toegepast, zal mogelijk ook leiden tot 'files' voor het AMS. Er is dus meer onderzoek nodig, mogelijk ook in de vorm van simulatiemodellen.

De gevolgen van het ontbreken van mens/dier contact in het AMS dienen ook onderzocht te worden. Als koeien zowel in de opfokperiode als in het productieve leven steeds meer in 'geautomatiseerde' omgevingen leven, zullen ze mogelijk moeilijker te hanteren zijn en banger worden. Dit heeft negatieve gevolgen voor de koeien omdat ze zelfs de meest eenvoudige behandelingen mogelijk als stressvol zullen ervaren, maar ook voor degenen die de koeien moeten behandelen omdat bange dieren gevaarlijk kunnen zijn.

Bij de combinatie weidegang en volledig automatisch melken blijft de vraag open hoe het gegarandeerd kan worden dat koeien onder alle omstandigheden naar het AMS komen. In het gepresenteerde onderzoek werd water als lokmiddel gebruikt om de koeien vanuit de weide terug te laten keren naar de stal. Het zou echter beter zijn om andere methodes te ontwikkelen om koeien uit de weide terug te lokken naar de stal (en het AMS), omdat het niet onder alle omstandigheden mogelijk is water te beperken (bijv. in warme klimaten), en omdat de neiging van koeien om gezamenlijk binnen te komen voor sommige koeien zou kunnen betekenen dat ze met lange wachttijden voor het AMS geconfronteerd zullen worden.

BELANGRIJKSTE CONCLUSIES

1. Koeien kunnen zich aanpassen aan melken op een vrijwillige basis in een automatisch melksysteem dat vrijwel continu beschikbaar is.
2. Het is mogelijk dat effecten van sociale rangorde zullen optreden als een AMS wordt geïntroduceerd op het melkveebedrijf.
3. Vrij koeverkeer zou vermeden moeten worden omdat de dagelijkse melkfrequentie per koe minder betrouwbaar is dan bij andere vormen van koeverkeer. Gedwongen koeverkeer zou vermeden moeten worden omdat het de koeien lijkt te beperken in hun gedrag. De toepassing van een vorm van koeverkeer, waarin de koeien vrij tussen de ligboxen en het ruwvoer heen en weer kunnen lopen, maar alleen via het AMS de krachtvoerbox kunnen bereiken, blijkt een goede methode te zijn om koeien regelmatig in het AMS te krijgen zonder dat dit negatieve consequenties heeft voor het gedrag
4. Weidegang kan gecombineerd worden met volledig automatisch melken. Koeien in de weide zullen een aantal keren per dag uit zichzelf naar de stal met het AMS teruggaan. De AMS bezoeken en de mate waarin de koeien terugkeerden naar de stal werden beïnvloed door externe factoren zoals het weer en het grasaanbod. Als de koeien bij een aangename buitentemperatuur in een verse weide lopen, zullen ze minder makkelijk terugkeren naar de stal. Het terugkeren van de koeien naar de stal en het aantal bezoeken dat ze aan het AMS brengen, worden niet beïnvloed door afstanden tussen de stal en de weide tot een maximum van 350 meter.
5. Koeien liggen liever in de weide dan in de ligboxen.
6. Koeien in de weide zijn sterk geneigd gezamenlijk terug te keren naar de stal (met het AMS). Dit geeft een piekbelasting van het AMS in de periode dat de koeien de beschikking hebben over de weide terwijl het AMS op andere momenten in deze periode stil ligt.
7. Meer onderzoek is gewenst op het gebied van volledig automatisch melken met betrekking tot de gewenste groepsgrootte, het gebrek aan mens/dier contact en weidegang.

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CURRICULUM VITAE

Caroline Charlotte de Lauwere werd op 1 september 1962 geboren te Den Haag. In 1980 behaalde ze het Gymnasium ß diploma aan het Coornhert Gymnasium te Gouda. In september van datzelfde jaar begon ze aan de studie Zoötechniek aan de toenmalige Landbouw Hogeschool in Wageningen. In november 1986 rondde ze haar studie af met Ethologie en Gezondheids- en Ziekteleer der Landbouwhuisdieren als hoofdvakken en Bedrijfseconomie als bijvak. Vanaf 1 november 1986 is zij aangesteld als wetenschappelijk onderzoeker bij het DLO-instituut voor Milieu- en Agritechniek (IMAG-DLO). Hier hield ze zich de eerste jaren bezig met onderzoek naar de huisvesting van vleeskalveren. Hierna werd de overstap gemaakt naar gedragsonderzoek bij melkkoeien in relatie tot de implementatie van automatische melksystemen in ligboxenstallen. Dit onderzoek heeft uiteindelijk geleid tot de totstandkoming van dit proefschrift. Hiervoor werd in september 1996 een begeleidingscommissie samengesteld.

Vanaf 1 januari 1999 is ze bij het IMAG-DLO aangesteld als wetenschappelijk onderzoeker systeeminnovatie.