

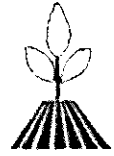


WAGENINGEN UNIVERSITY
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Proceedings
of the Dutch-Israeli Seminar on
Robotic Milking and Heat Stress

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PREFACE

A little more than a year ago, Dutch and Israeli researchers came in contact with regard to automatic milking. On the initiative of Dr Flamenbaum (Ministry of Agriculture and Rural Development, Israel) and Mr Schaap (Agricultural Counsellor, Royal Netherlands Embassy), the idea arose for a workshop on this subject. It was decided that it should be good to bring two strong research areas from Israel and the Netherlands together: Automatic milking is a subject on which there is much practical and experimental knowledge in the Netherlands. Introduction of automatic milking is of growing interest in Israel. Moreover, there is much knowledge on heat stress in Israel, while heat stress is seen more and more as problem in the Netherlands.

The objectives of the workshop are to share our knowledge, to develop a research framework for future co-operative research between Israel and the Netherlands, and to explore the possibilities for funding of this research. As a starting point, a seminar is held in which available knowledge on robotic milking and on heat stress is shared and discussed. This proceedings gives a view of the knowledge presented during this one-day seminar.

The workshop is carried out as part of the research program DIARP (Dutch Israeli Agricultural Research Program). We acknowledge the financial contributions of the participants in DIARP, the Israeli Ministry of Agriculture and Rural Development and the Dutch Ministry of Agriculture, Nature and Fisheries, that made the workshop and this seminar possible.

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COOLING DAIRY COWS UNDER HEAT-STRESS CONDITIONS

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Introduction

Heat-stress affects production and reproduction of high producing dairy cows. Conception-Rate (CR) during winter months in Israel reaches more than 50 %, while during summer it drops below 20%. Estrus behavior is less intensive in summer and combined with low fertility increases calving interval lowers production efficiency and creates undesired seasonally in milk supply to processing industry. Under summer conditions in Israel, milk protein and fat are reduced, while somatic cells count is increased, creating a significant drop in milk quality. Israeli "Herdbook" data shows that peak lactation of summer calving cows is 4-6 kg/day lower than those calving in winter. (1000 kg less for lactations starting in July compared to those starts in December).

Heat- stress relief from dairy cows includes prevention of direct and indirect solar radiation, reduction of ambient temperature inside closed houses and increase evaporation from cows' surface and respiratory tract.

A cooling system combining wetting and forced ventilation, effectively increases evaporation from cows and prevents high producing dairy cow to become hyperthermic in summer under heat-stress conditions. This cooling system makes use of low pressure sprinklers and large size droplets for wetting the cows, combined with high potential fans. Providing effective wind velocity to evaporate in short time the moisture from cow's surface. For efficient cooling, cows are "treated" in the holding area before milking and in the feeding strip, while eating.

The described cooling system enables the dissipation of heat produced by cows producing 12000 -13000 kg of milk per year.

Evaluation of a cooling system

Since 1983 some experiments were carried out to evaluate the described cooling system capability to cool high producing dairy cows in Israeli summer, when provided intensively to dry and milking cows in different stages of lactation.

The above mentioned cooling system was first developed in a study carried out in summer 1983 (1). Combining wetting time by sprinkles (30 sec.) followed by forced ventilation time (4.5 minutes) in cycles of 30-45 minute each in 2.5-3 hours interval, permitted high producing cows to be normothermic most part of the day under Israeli summer condition.

The effect of cooling dry cows on their subsequent lactation performance was studied in summer 1984 in a commercial herd located in the coastal part of Israel (2). Calves born to cooled dry cows were 2-3 kg heavier than those born to non-cooled cows. Cooling improved milk production in the first 150 days of subsequent lactation by near 3 kg/day.

During two consecutive summers in 1985-86, (3), the effects of cooling high producing cows in early lactation and body reserves at calving were tested in a factorial experiment carried out under experimental herd conditions. Higher body reserves at calving were related to higher production in non-cooled cows but not in the cooled ones. Cooling maintained cows normothermic most of daytime all over the summer, while non-cooled cows presented hyperthermia (above 39 C) at least part of the day. Milk production and milk protein content in the first 22 weeks of lactation were significantly higher in cooled compared to non-cooled cows. Conception rate to first insemination reached more than 50% in cooled cows compared to less than 20% in non-cooled ones. Pregnancy rate 150 days after calving was 75% for cooled cows compared to 35% in the non-cooled cows (4).

"Short-period" cooling (1 day before to 9 days after) of estrus-synchronized cows was tested in cows provided these cooling methods in the feeding strip. Milk production after 10 days cooling was 3 kg/day higher in cooled compared to the non-cooled ones. "Short period" cooling did not improve conception rate, suggesting that longer cooling period before and after insemination is needed to improve fertility of high producing cows in summer (5).

A large scale survey (6), carried out in three consecutive summers (1994 to 1996), in which effect of cooling the cows in the holding and the feeding areas for at least 6 times a day was evaluated in 15 high producing 3X dairy herds every year. Milk production and conception rates of cooled cows were compared to those in control herds located in the same regions and reaching the same annual production, which used only to wet the cows in the holding pen before milking. In regular summers milk production and conception rates of cooled cows were close to those obtained in the same herds in winter. This results were different from those obtained in non-cooled cows: a significant summer drop was obtained in milk production and conception rate. Under severe summer conditions a slight decrease in cows' performance was obtained in the cooled herds while a large decrease of more than 20% in average daily milk production and a conception rate to first insemination below 15%.

Recent data from summer 2000 (Published in Hebrew), compared highly intensive use of the cooling system (10 "coolings" and a total of 8 h of cooling per day) to moderately cooled cows (only before milking). Intensively cooled first calf heifers

and adult cows calving in early summer reached near 99% of early winter calving cows' potential (305 days). In the same time, moderately cooled early summer cows reached only 94% of early winter calvers.

Evaluation of an alternative cooling system

In the last 3 years an alternative cooling system, based on low and high pressure misting is intensively tested in different parts of Israel. The reason for testing these systems is the aim to reduce water use in the cooling process and in the same time reducing liquid waste production. The use of low pressure misting, by allocating misters in front of each fan in the resting area, nearly did not changed air temperature (a decrease of 1-2 centigrade compared to control barn), in the humid climate of the Israeli sea coast. Low pressure misting slightly wetted and cooled the cows lying in front of fans.

High pressure misting provided by iron misters allocated in front of fans, used in dry regions (Jordan valley), reduced air temperature by 7-8 centigrade in extremely hot days (>45 centigrade air temperature). No significant influence was obtained in milk production of cows receiving the misting treatment, compared with intensive conventional cooling system describes above but Economic Corrected Milk (ECM) was higher, suggesting higher dry matter intake.

The results obtained by our team indicate that Intensive cooling have the potential to reduce the summer decline in milk production and conception rate of high producing dairy cows under Israeli summer conditions and allow to obtain near full winter lactation potential. Large scale use of the described cooling systems in the Israeli dairy farms is expected to save millions of dollars every year to the local dairy sector.

There is a room for more research to be done in the future to improve the existing cooling methods aforementioned described and adapt them to different farm conditions, among them the robotic milking system .

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HEAT STRESS IN A MILD CLIMATE: DUTCH EXPERIENCES

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Introduction

The most comfortable environmental temperature range for dairy cows, the thermal comfort zone, is between 5°C and 25°C (Shearer and Beede, 1990a). When environmental temperature is above 25°C for an extended period, an alteration in basal metabolic rate is required in order to maintain normal body temperature. Dairy cows respond to high temperatures by seeking shade and wind, increasing water intake and respiration rate (Shearer and Beede, 1990a; Elvinger et al., 1991; Lacetera et al., 1996). The total body heat production of a cow is a combination of heat derived from normal metabolism, from the environment, and from physical and performance activities, such as milk production. Metabolic consequences of heat stress are increased heart rate (Elvinger et al., 1991), lower plasma glucose levels (Lacetera et al., 1996; Ronchi et al., 1999), changes in the levels of stress hormones (Giesecke, 1985; Collier et al., 1982; Katti et al., 1987) and an increase in rectal temperature (Johnson et al., 1989; Berman et al., 1985, Elvinger et al., 1991, Lacetera et al., 1996; Ronchi et al., 1999). In order to lower body heat production, cows experiencing heat stress will voluntarily reduce dry matter intake, which results in depressed milk production (Johnson et al., 1989; Ronchi et al., 1999; Shearer and

Beede, 1990b; Lacetera et al., 1996). Other factors that may play a role in milk yield decline, associated with heat stress, are changes in hormone levels and an increase in maintenance requirements (Bernabucci and Calamari, 1998; Collier et al., 1982). Generally, these responses decrease short-term animal performance (Shearer and Beede, 1990a).

High temperatures may also affect susceptibility to infection, either by decreasing host resistance or by increasing the exposure to pathogens. Elevated temperature and high relative humidity enhance the survival and proliferation of pathogens in the environment. Under circumstances of heat stress, cows may lie in the alleyways of free stall barns or wallow in ponds, streams and mud holes in pastures, in order to increase heat loss. This behaviour increases the risk of infection (Shearer and Bray, 1995). Increased milk SCC and a higher incidence of clinical mastitis in dairy cattle have been found in cows exposed to a hot environment (Elvinger et al., 1991; Collier et al., 1982).

Evidence for a direct effect of elevated environmental temperature on the immune system is limited (Elvinger et al., 1991; Shearer and Bray, 1995). An indirect effect on immunity may occur as a result of decreased feed intake and, consequently, insufficient uptake of essential nutrients, which are important to optimal immune function (Shearer and Beede, 1990b).

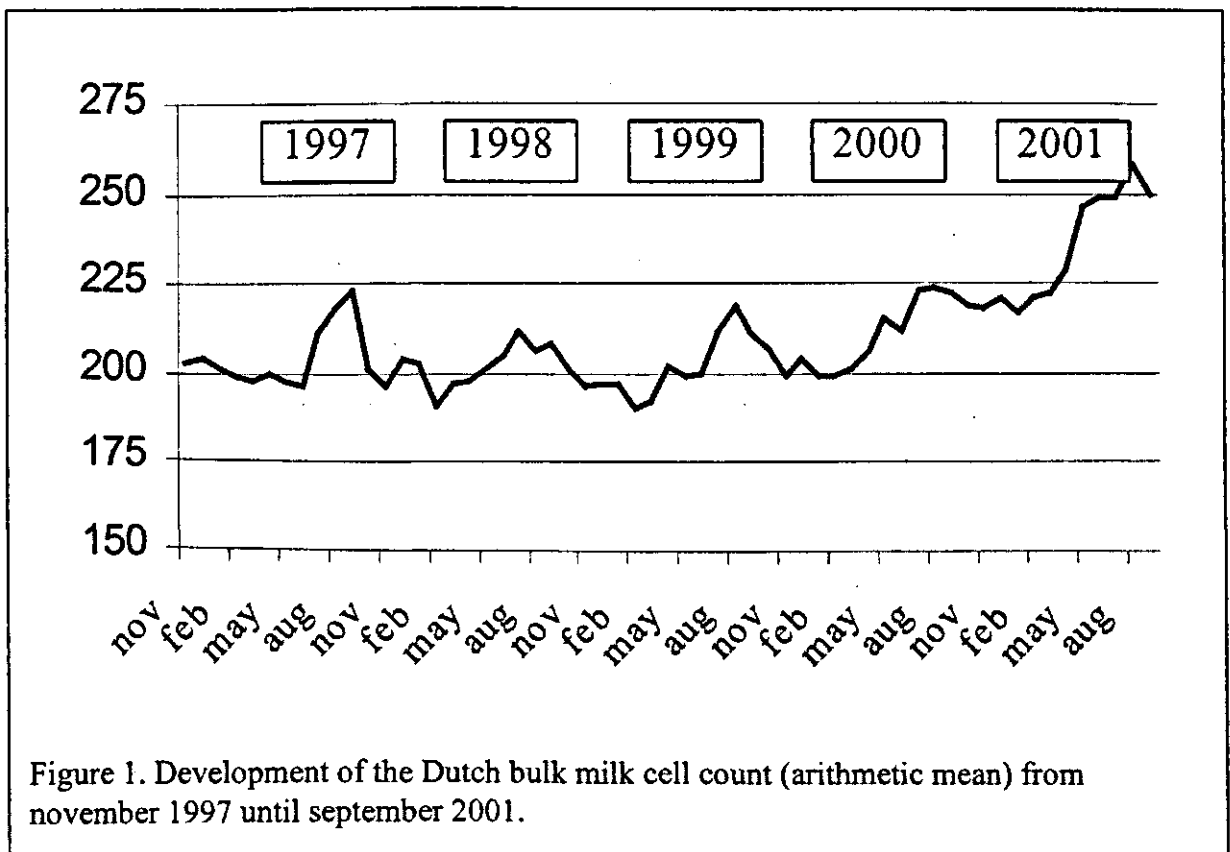


Figure 1. Development of the Dutch bulk milk cell count (arithmetical mean) from november 1997 until september 2001.

Heat or climate stress is a phenomenon commonly associated with extreme climatic circumstances such as in Israel or Arizona. However, mild stress can occur at a temperature of 25°C and a relative humidity of 50% (Armstrong, 1994). These are circumstances that do occur in mild climates such as in the Netherlands. A little more than 5 years ago, in the Netherlands the first signs of occurrence of heat stress were reported from practice. These reports were partly based on the observation that the bulk milk SCC seemed to be higher in summers, whereas the bulk milk SCC used to decrease in summers due to a decreased risk on intramammary infection since cows were grazed outside. Figure 1 illustrates these increases in bulk milk somatic cell count (Dutch arithmetic average) during summers. In summers with longer periods of high temperatures, such as 1997 and 1999, the average bulk milk SCC increased even more than in other, cooler, summers. The bulk milk SCC increased during 2000 and 2001. This is partly caused by a change in the Dutch milk quality scheme. Milk price reduction used to be applied when one bulk milk tank exceeded the limit of 400.000 cells/ml. From 2000 milk price reduction was given when the geometric mean of three monthly taken bulk milk SCC measurements exceeds the limit of 400.000 cells/ml. This means that for part of the farmers the financial motivation to be alert on a high BMSCC is partly removed. Part of the exceptional increase in 2001 might be caused by heat stress in the months July and August. Another part might be caused by the exceptional circumstances due to the foot and mouth disease outbreak.

Since the first evidence for the occurrence of heat stress in dairy cattle in the Netherlands, two scientific studies have been carried out to get more insight in the occurrence and background of heat stress in the Netherlands. This paper presents the results of both studies. The objective of the first study was to find statistical evidence for the assumed relation between hot summers and an increased BMSCC. The objective of the second follow-up study was to evaluate dairy cow characteristics that play a role in the cow's reaction to periods with increased environmental temperatures in a mild climate. Both studies have already been published by Sampimon et al. (1999) and Poelarends et al. (2000).

Material and methods

Study 1. Relation between high temperatures and heat stress under mild climatic circumstances

BMSCC and temperature data were obtained for the years 1993, 1994 and 1995. From each year nearly 300.000 BMSCC measurements from 23.325 farms (70 % of all Dutch farms) were available. These measurements came from three large dairy industries. Only days with more than 1.000 measurements were included in the study. Per day the average BMSCC was calculated and regarded as the average Dutch BMSCC at that moment. The temperature data were obtained from a weather station on research farm Aver Heino from the Research Institute for Animal Husbandry in the east of the Netherlands. To reduce the variation, the moving average from three successive days of the maximum temperature was calculated. The average maximum temperature and BMSCC were compared on each date in the

years 1993, 1994 and 1995. The years 1994 and 1995 were years with periods of a high summer temperature. The year 1993 was used as a control year.

Study 2. Dairy cow characteristics related to heat stress response

Data of 47 randomly chosen herds, with a total of 1563 dairy cows, that participated in the Dutch milk recording system and measured cow SCC at least every 4 weeks, were used. Data were available for the years 1995 and 1997 with long warm periods during the summer and for the year 1996 with a moderate summer.

The following parameters were available: cow SCC (5 categories with limits 75.000, 150.000, 250.000 and 500.000 cells/ml), milk production (6 categories with limits 15, 20, 25, 30 and 35 kg/day), parity (3 categories with parity 1, parity 2 and 3, and parity ≥ 4) and stage of lactation (6 categories with limits 75, 125, 200, 250 and 300 days in lactation).

To investigate the changes in milk production and SCC during the summer, two four-week periods in every year were defined. Per four-week period, the weighed average SCC was calculated. For all years, the period with the highest average SCC was defined as effect period. The preceding period was defined as the control period. In the years with a warm summer, the effect periods coincide with the higher temperatures, although the defined effect period starts later than the increase in temperature.

The relative changes in cow SCC were calculated by dividing the SCC in the effect period by the SCC in the control period. The relative changes in daily milk production were calculated in a similar manner. The relative changes in SCC were log-transformed to obtain better statistical properties. The milk production index per cow was calculated as follows: milk production of the cow/mean daily milk production of the herd * 100. The milk production index was divided into 5 categories with limits 70%, 90%, 110% and 130%. Effects of parity, stage of lactation, production and year on change in milk production and SCC were estimated using models (1) and (2). The models were fitted with the REML procedure of Genstat (Genstat 5, 1994).

Results

Study 1. Relation between high temperatures and heat stress under mild climatic circumstances

In the year 1993 with no warm periods the BMSCC was stable (Figure 2). In the years with long warm periods, 1994 and 1995, the BMSCC was significantly elevated during these warm periods (Figures 3 and 4). It seemed that the periods with increased BMSCC lasted longer than the warm periods. Although not statistically checked, this could also be noticed from Figure 1.

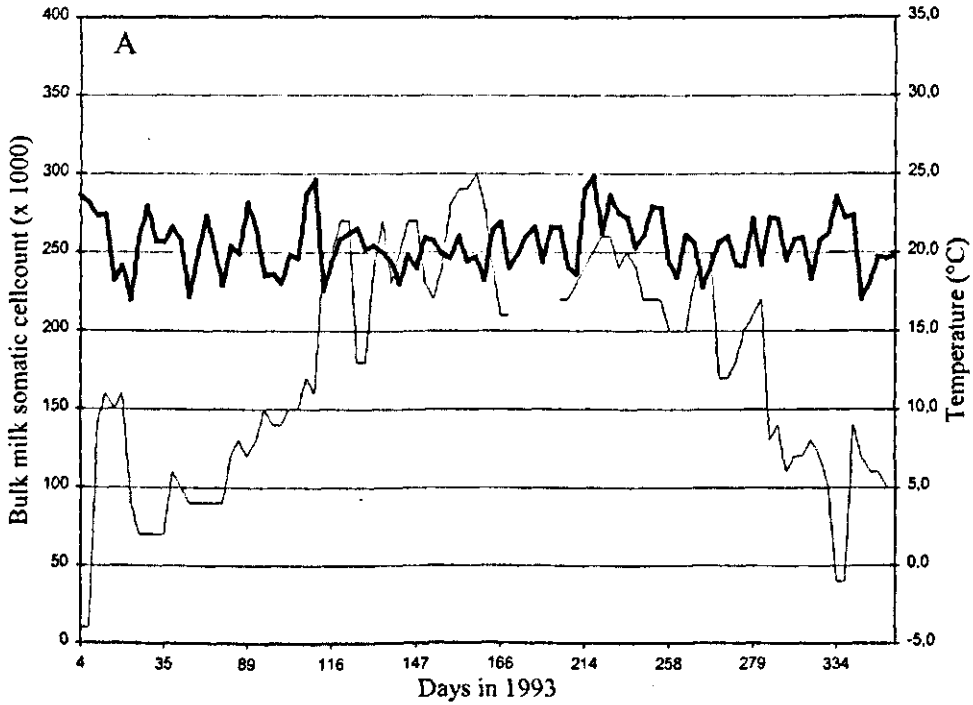


Figure 2. Temperature (— lower line) and BMSCC (— upper line) for Dutch dairy herds in the year 1993.

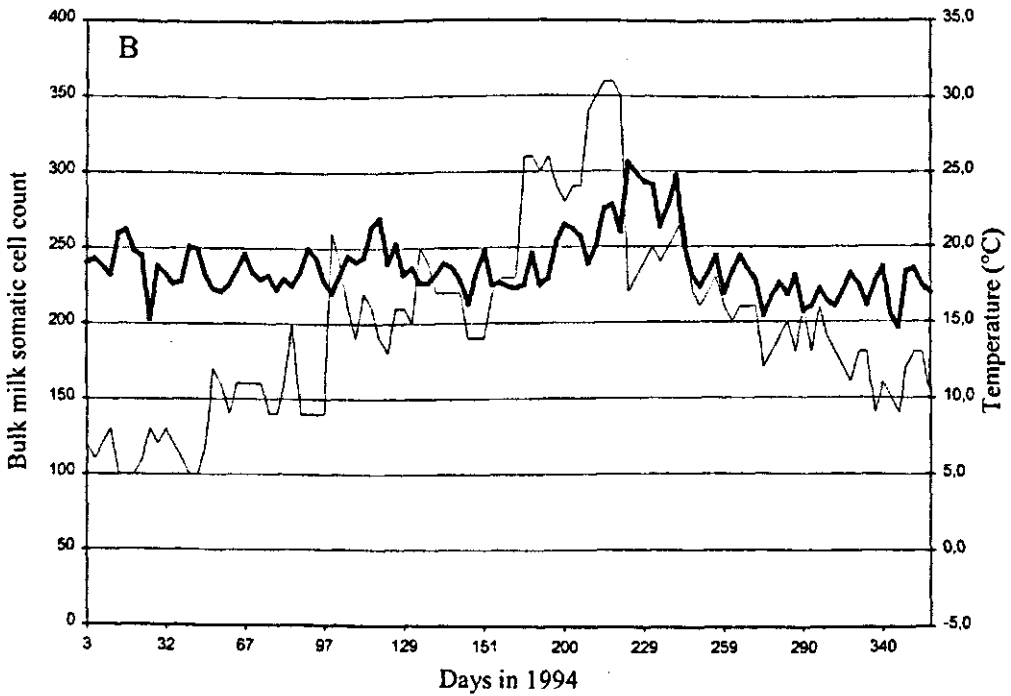


Figure 3. Temperature (— lower line) and BMSCC (— upper line) for Dutch dairy herds in the year 1994.

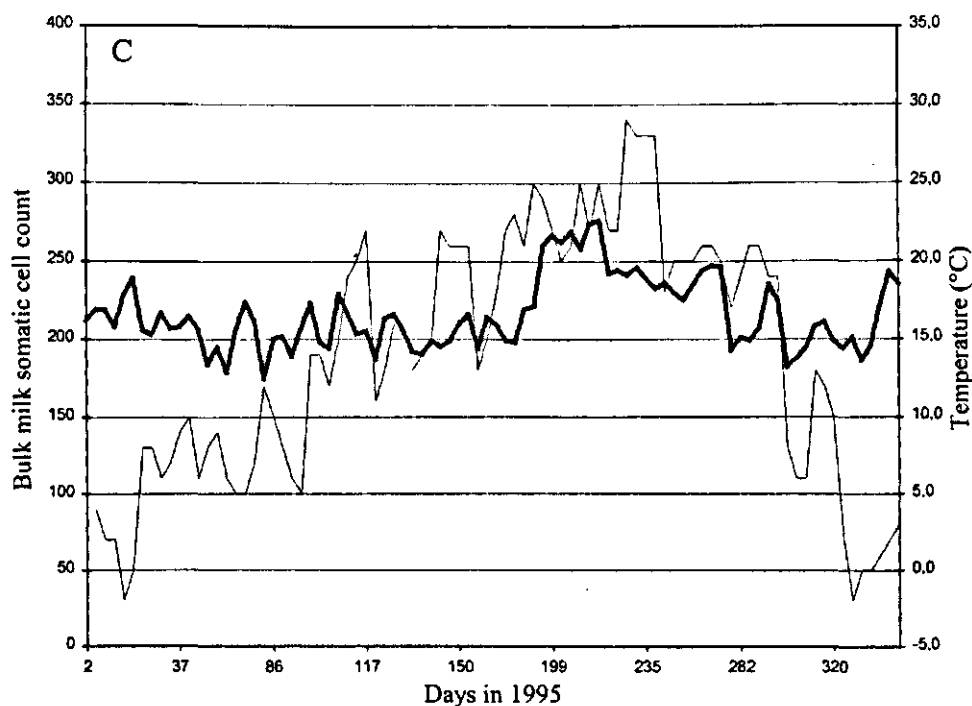


Figure 4. Temperature (— lower line) and BMSCC (— upper line) for Dutch dairy herds in the year 1995.

Study 2. Dairy cow characteristics related to heat stress response

In table 1, mean SCC in the effect and control period and changes in SCC both based on the rough data as well as on the statistical model are given per year. Results show that SCC increases in each year. In 1997 the increase in SCC is highest and tends to differ significantly from the increase in 1996, in which the increase is lowest.

Table 1. Mean cow SCC in the control and effect periods. Changes are based on original data and estimated by a statistical model.

Year	Control period (cells/ml)	effect period (cells/ml)	change	estimated change
1995	140.000	154.000	10%	8%
1996	133.000	140.000	5%	3%
1997	120.000	152.000	27%	15%

Estimated changes in SCC for the different categories of daily milk production are presented in table 2. Cows with the highest daily milk production in the control period (>35 kg/day), have the largest increase in SCC (21%).

The estimated changes in SCC for the different parity groups were -10%, 10% and 28% for the parities 1, 2-3 and parity ≥ 4 respectively. These estimations all differed significantly and show that the older cows have the greatest increase in SCC in the effect periods.

Table 2. Estimated change in SCC for the different categories of daily milk production in the control periods.

daily milk production (kg/day)	<15	15 - 20	20 - 25	25 - 30	30 - 35	>35
Estimated change in SCC	4% ^a	0% ^a	12% ^{ab}	4% ^a	13% ^{ab}	21% ^b

^{a,b} Means with different superscripts differ significantly at $P < 0.05$

Table 3 presents the mean daily milk yield in the effect and control periods and changes in daily milk yield per year. Milk production was most decreased in 1997 compared to 1995 and 1996. The difference between 1995 and 1997 is remarkable since both years had comparable warm summers. The only difference is the fact that the effect period was in 1997 one month later than in 1995 and 1996.

Table 3. Mean daily milk production in the control and effect periods. Changes are based on original data and estimated by a statistical model.

Year	control period (kg/day)	effect period (kg/day)	change	estimated change
1995	24.7	23.7	- 4.0%	- 3.3% ^a
1996	25.8	24.4	- 5.4%	- 5.6% ^a
1997	24.9	21.8	- 12.5%	- 12.2% ^b

^{a,b} Means with different superscripts differ significantly at $P < 0.05$

Estimated changes in milk production by a statistical model for varying milk production indexes are presented in table 4. Milk production decrease is greatest for the high producing cows in a herd.

Table 4. Estimated change in daily milk production for the different categories milk production indexes in the control periods.

daily milk production (kg/day)	<70	70 - 90	90 - 110	110 - 130	>130
estimated change in milk prod.	- 4.0% ^a	- 4.1% ^a	- 5.6% ^a	- 8.5% ^b	- 12.8% ^c

^{a,b,c} Means with different superscripts differ significantly at $P < 0.05$

There was no apparent trend in effect of parity on milk production decrease. Only parity 1 and 2-3 differed slightly in milk yield decline.

Discussion and conclusions

As a first step in the Dutch research into heat stress, the anecdotal evidence of the relation between high temperatures and an increased BMSCC has been verified statistically (study 1). This means that the assumption that heat stress occurs in the Netherlands during hot periods seems to be true. Unfortunately humidity, an important factor in the occurrence of heat stress, could not be taken into the research. In the Netherlands, not many farmers have taken measures against heat stress. However, measures such as keeping the cows inside during hot periods, do seem to be effective. A study was carried out in which farmers with and without an increase in BMSCC during a hot period were asked to fill in a questionnaire. The results showed that farmers without an increase in BMSCC during a hot period adjusted the grazing routine more often than farmers with an increase of BMSCC. The most effective measure was to keep the cows inside during daytime (Poelarends et al., 1999).

In a next step (study 2), heat stress was analysed at the cow level. The data in that study show that during summer, milk production declined and SCC increased. The increase in SCC seemed to be highest during warm summers ($P=0.06$). Both summers, 1995 and 1997 were warm, but milk yield decline was significantly larger in 1997 than in 1995. A possible reason for this may be the fact that in 1997 the effect period was one month later than in 1995. Pasture quality might also have had an effect on the difference in milk production. High producing cows were the most susceptible to an increase in SCC. Based upon literature, some theories can be made about the physiological background of heat stress under mild climatic circumstances (Poelarends et al., 2000).

It can be concluded that heat stress in mild climatic circumstances does occur. Moreover, the dairy cow characteristic parity and milk production are also important factors in the cow's reaction to mild heat stress. In order to gain more insight in the

occurrence, effects and prevention of heat stress in mild climatic circumstances, further research should focus on the state of infection of the cows and the relationship with changes in SCC under mild heat stress. Further research should also focus on the role of certain hormones and metabolites in the responses of dairy cows to mild heat stress. Besides on physiological parameters, further research should also be directed towards cost-efficient methods to reduce heat stress in these circumstances.

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THE HIGH-TECH BARN'S CLIMATE IS SORTED

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Introduction

In summer 1999 a climate monitoring system was installed on two of the Waiboerhoeve experimental farms: the high-tech farm and the feed and dairy farm. The roof of the high-tech farm has been insulated the sides are almost entirely open, so as to avoid heat stress in the summer. To study the effect of the better ventilation and the insulated roof, smoke tests and climate measurements were done. Comparisons of these two farms reveal that the measures are effective.



Photo 1: High-tech farm barn roof

Why climate is so important

By producing milk a cow generates heat which has to be transmitted to her surroundings, as otherwise her body temperature rises. If opportunities to lose this heat are limited, the result is heat stress: the animal eats less and produces less, in order to reduce the heat generation. High temperatures also adversely affect cows' welfare. So, in order to optimise production and improve welfare, it is important to create a barn climate that matches the animal's needs. Important factors in this are air temperature, relative humidity and air speed. As air temperature and relative humidity are closely related, they are often combined to give the THI (temperature-humidity index), which can be used as a yardstick for heat stress. But this yardstick has shortcomings: it ignores solar radiation and airflow, both of which influence thermal welfare and the prevention of heat stress. Airflow can help conduct heat

away, but may also cause a draught. A draught arises when a too high air speed (> 0.5 m/s) occurs in combination with a difference between indoor and outdoor temperature of more than 5 °C.

The differences between the two barns

The climate in the barn of the high-tech farm was compared with the climate in the barn of the feed and dairy farm. The barn design on both farms deviates from that of the traditional cubicle barn, especially with regard to the roof. The feed and dairy farm has a 'ventilating roof', which is in two parts, each with a different gradient. The first part, from the gutter upwards, is virtually an extension of the side wall and has a gradient of 60 degrees. The second part, which extends to the ridge, has a gradient of only 3 degrees. This design ensures that the ridge is low, even though the barn is wide. The sheets of corrugated iron are separated by 4 cm gaps, which allow ventilation to occur all over the roof. A gutter mounted under these openings prevents rain falling through inside. The façades are spaceboarded.

The roof of the high-tech farm is also unusual. It is sawtoothed, with the ridge lines running diagonal to the long axis, creating spacious north-facing openings in the roof that can be covered with tarpaulin. This keeps out direct radiation from the sun's rays. The roof panels are insulated sandwich panels. The side walls are largely open and are fitted with windbreak mesh.

The feed and dairy farm barn differs less from a traditional cubicle barn than the high-tech farm barn.

roof



Photo 2: Smoke tests in the high-tech barn

The measurements

The sensors for recording temperature, air humidity and air speed were hung in the barn at animal level, but just out of reach of the cows. Also installed were a sensor to

measure radiated temperature and one to measure roof temperature. In addition, a mast on which were mounted sensors for measuring the outdoor climate was attached to the outside wall of the high-tech farm, where wind direction, wind speed and solar radiation were also measured. Furthermore, seven smoke tests were conducted on the high-tech farm, to assess the ventilation.

The rest of this article begins with the results of the smoke tests and goes on to discuss the barn climate in the high-tech farm and feed and dairy farm.

Airflow on the high-tech farm

The ventilation vents in the high-tech farm barn are much bigger than is usual in Dutch cubicle barns. Three of the four side walls are almost entirely open, and the ridge vents are also considerably larger than normal. As it was not clear what the airflows in the stall were, smoke tests were done under different weather conditions, to establish the airflow pattern.

The wind direction is clearly important for the ventilation, but the barn's orientation in relation to other buildings or trees can also influence the flow pattern in the barn. Our rule of thumb for good air renewal was that smoke would clear from the barn within 3 minutes.

We found that the ridge vents of the sawtooth roof function as air inlets as well as air outlets. However, these vents did not result in cold air sinking into the barn, even when there was a strong northerly wind. The smoke always escaped within a minute via the sawtooth roof or side wall. The ventilation pattern at each sawtooth was virtually identical. Air replenishment was sufficient, even in windless conditions. At higher wind speeds, the cross-ventilation became increasingly important. Yet the smoke tests showed much less airflow in the lying area than in the feeding passage and feed preparation area. This shows that the 1.25 m high partitions and the windbreak mesh reduce the wind speed sufficiently.

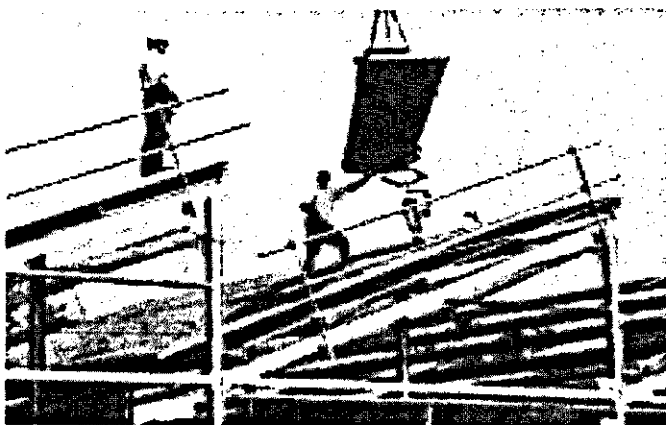


Photo 3: The roof of the high-tech barn is sawtoothed, with insulated panels

Differences between the barn climates of the high-tech farm and the feed and dairy farm.

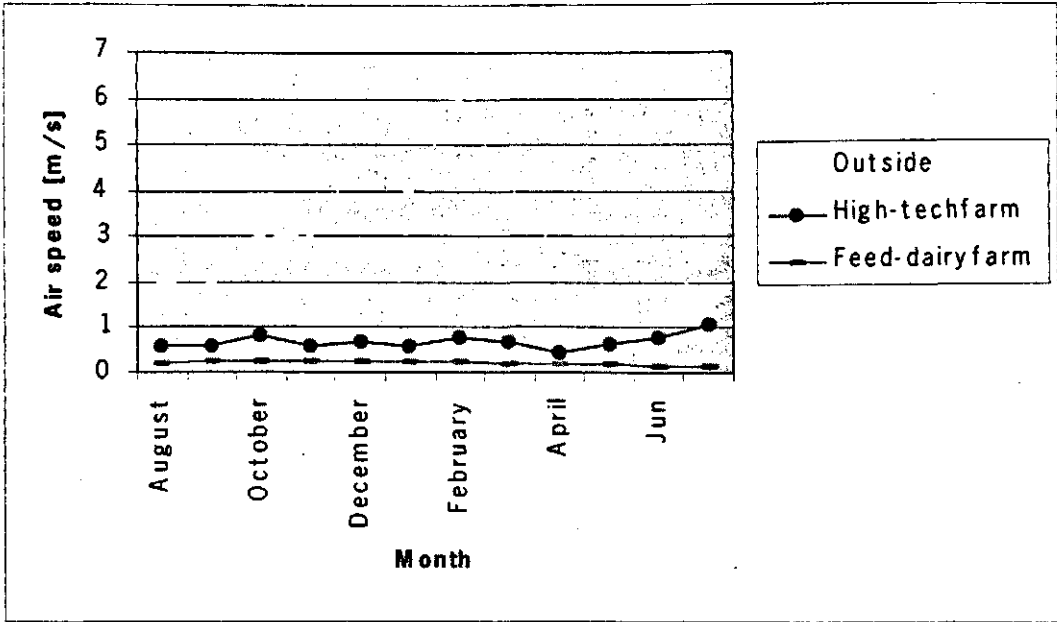


Figure 1a. Air speed during the year

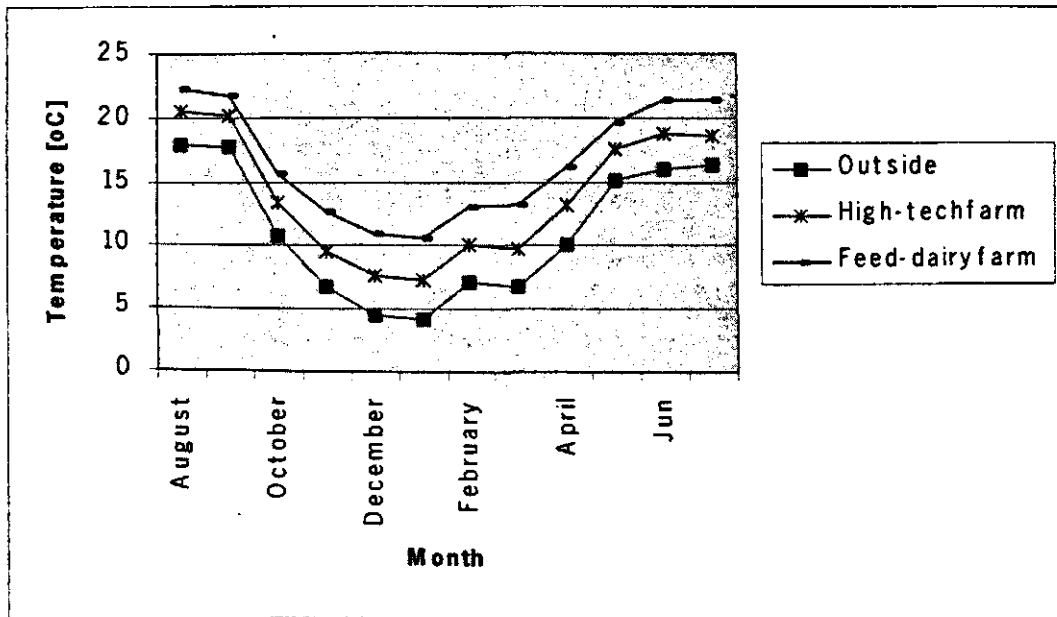


Figure 1b Air temperature during the year.

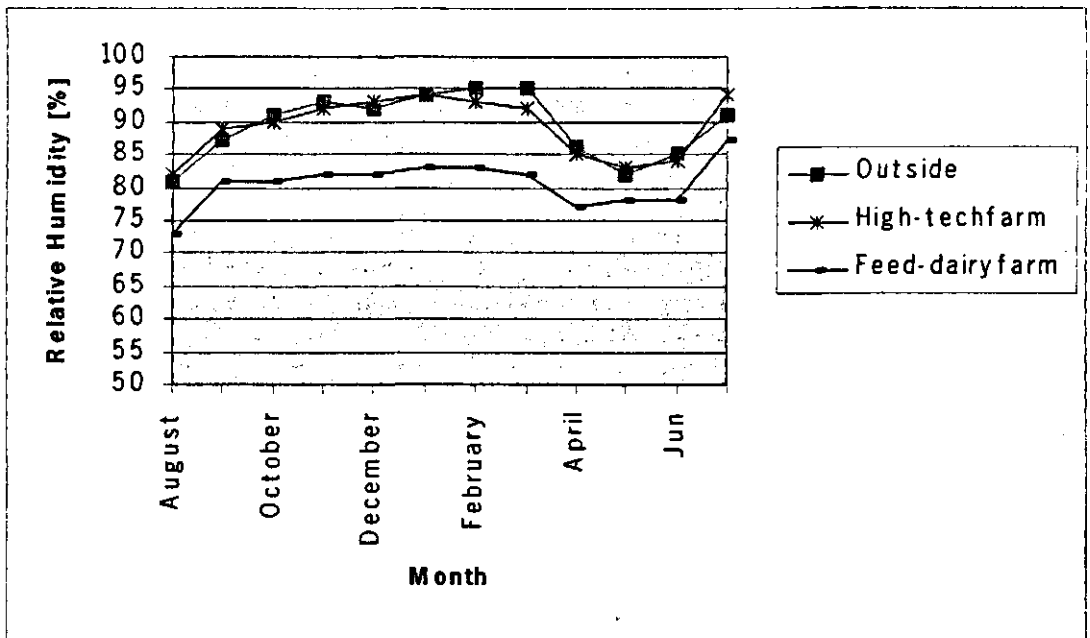


Figure 1c Relative humidity during the year

Figures 1a-1c show the mean monthly air temperature, air humidity and air speed inside the two barns and outdoors throughout the year. The mean monthly temperature was consistently higher in the feed and dairy farm. It was about 5 °C higher than the outdoor temperature. In the high-tech barn the air temperature was about 2 °C higher than the outdoor temperature.

Inside the feed and dairy farm barn, however, the relative humidity was always about 10% lower than outdoors. The relative humidity in the high-tech barn was the same as the outdoor relative humidity.

Inside the high-tech barn the air speed was 15% to 30% of the air speed outdoors, whereas in the feed and dairy farm barn it was only 5 – 10% of the outdoor air speed. The mean air speed in the high-tech barn is on the high side, but because the difference between the indoor and outdoor temperature was so small, it was not draughty in the sense of our definition. In the feed and dairy farm barn the temperature difference was greater but the air speed was considerably lower, and as a result it was not draughty either.

As well as comparing monthly or daily means it is interesting to look at the situation during hot days. The hottest part of the day (between noon and 14.00 h) is particularly important. The date selected was 31 July 1999, a day on which the outdoor temperature soared to almost 35 °C. Figure 2 is a graph of the outdoor and barn temperatures that day. It is striking that at the hottest time of the time the air temperature inside the high-tech barn remains below the outdoor temperature and, in contrast, at night the barn temperature exceeds the outdoor temperature. The temperature pattern on other hot days was similar.

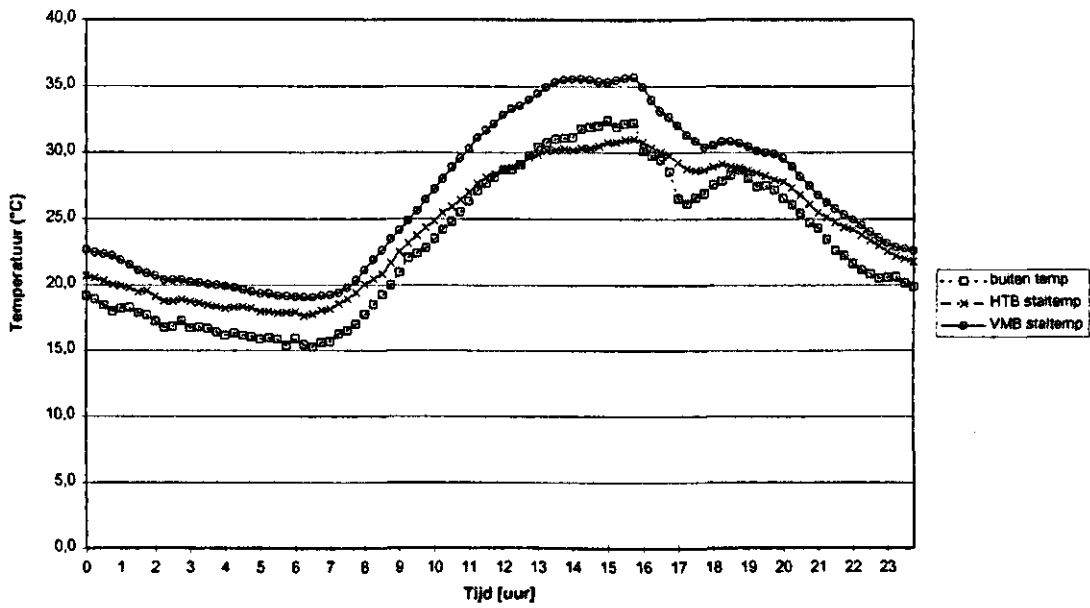


Figure 2 Example of a very warm day: 31 July 1999

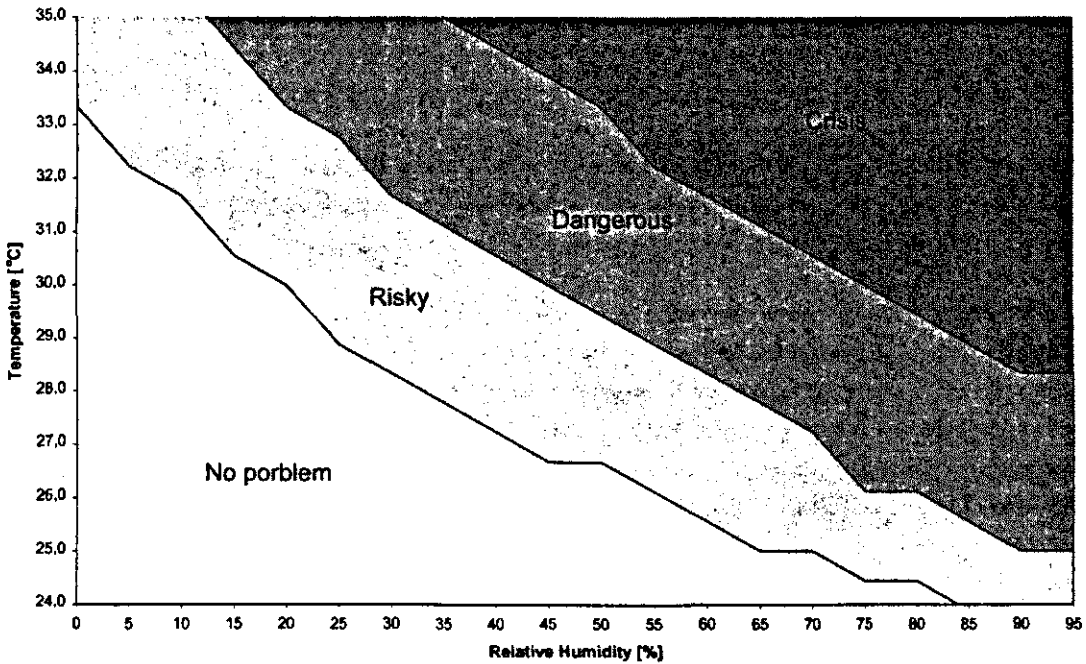


Figure 3 Temperature/humidity index

The likelihood of heat stress

The THI is calculated from the air temperature and the relative humidity. It is an indicator of the heat stress. Figure 3 shows the THI index for cattle at different temperatures and relative humidities. The four categories distinguished in the figure are:

- Risky (75-78) means that precautionary measures should be taken to lower the THI and thus avert production losses
- Danger (79-83) means that measures must be taken to avert production losses
- Crisis (>84) means that a hazardous situation has arisen. All activities that may cause stress must be minimised. Sufficient air must flow past the animals, there must be shade, and drinking water must be plentiful.
- At THI values of > 100 there is a high probability that the cows will die.

These indications hold primarily for animals having prolonged exposure to these values.

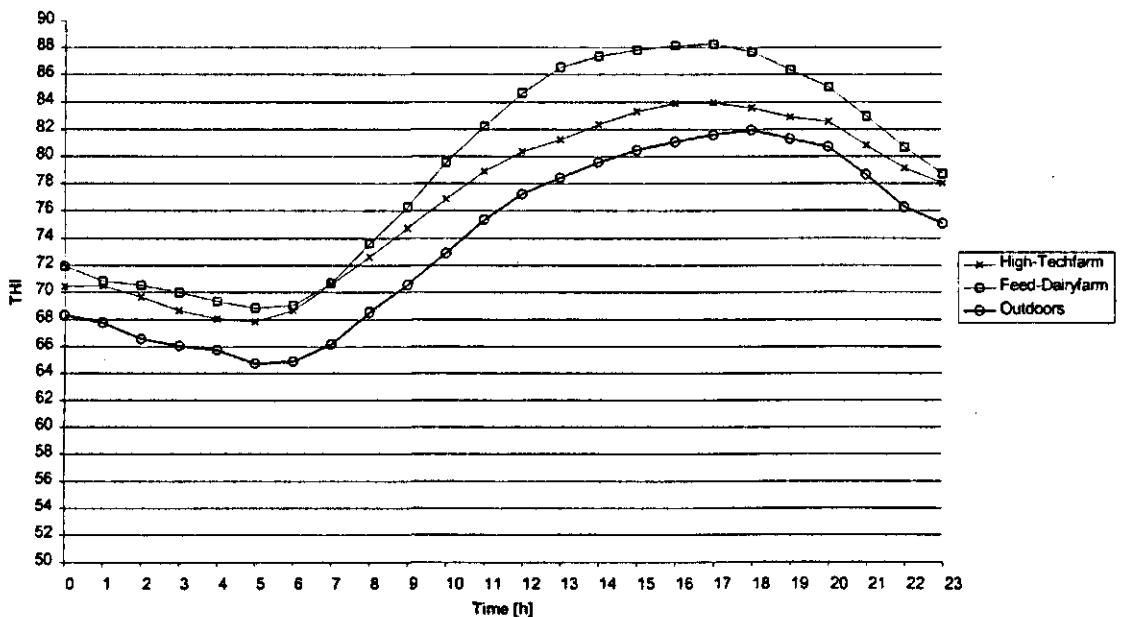


Figure 4 The THI on 19 June 2001.

To assess the situation in the high-tech and feed and dairy farm barns, another hot day was chosen: 19 June 2000 (Figure 4). The figure shows that the THI in the feed and dairy farm entered the crisis zone, albeit for a short period. Although such situations occur for only a short time in the day, a drop in milk production can be expected if the heat wave lasts several days. One of the ultimate aims of this research is to ascertain the effect of these hot spells on milk production.

Conclusions and lessons to be learnt

The ventilation in the barn of the high-tech dairy farm is good, even in windless conditions. At high wind speeds the cross-ventilation predominates. There is no draught. The insulated roof is beneficial for the air temperature in the barn. On hot days, the temperature inside the high-tech barn is lower than the outdoor temperature. On average, the temperature inside the high-tech barn is 3 °C lower than the temperature inside the feed and dairy farm barn. The THI is also lower than on the feed and dairy farm. We therefore expect the effects of heat stress to be reduced. The high THI on the feed and dairy farm makes production falls likely.

Though the Netherlands is not known for its hot weather, heat stress can occur during summer heat waves. Air temperature and relative humidity will certainly soar if the barn ventilation is inadequate. So if your barn is often stuffy and smells strongly of ammonia, it's likely that the ventilation is poor. Smoke tests will reveal the airflows. A high temperature in combination with a high relative humidity can lead to a fall in production, and prolonged heat stress can adversely affect reproduction too.

On hot days, make sure the cows have plenty of water. It must be clean, fresh and unlimited. Drinking water must also be available in the pasture.

If you're planning to build a barn, you should pay attention to the indoor climate. It's worth considering large ventilation vents and an insulated roof, particularly if you plan to keep your cows indoors all year. An insulated roof ensures that the air temperature in the barn is lower. Large ventilation vents will ensure the heat and humidity can escape easily. Remember that farmers feel the cold more than cows.

DESIGNING ROBOTIC MILKING FARMS FOR WARM CLIMATIC CONDITIONS; CASE STUDY OF TWO FARMS

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Abstract

The application of simulation to robotic-milking barn design methodology is addressed with reference to the layout design of two real-life farms in southeast Israel, a semi-desert area. Naturally, each farm has unique local conditions, and each farmer has his own aspirations and consequently unique design criteria that determine his optimal solution. In the first farm we addressed questions such as: (1) location and type of cow cooling system to provide a given cooling performance; (2) minimizing the building costs, e.g., by maintaining existing facilities wherever possible; (3) cow queue length in terms of number of cows waiting for available facilities; (4) dependence of robot utilization on the number of animals and on management practices; (5) where would the system bottleneck occur if a larger milk quota was awarded, allowing for the holding of more cows? In the second farm we had to draw up plans for a new farm, with the farmer's major concern being (6) whether to achieve a greater milk quota of 400,000 kg milk per year by preparing space for a few more cows, or by changing the feeding regime. In the first farm, on the basis of the numerical results, we located the cooling systems at the robot exit near the self-feeder yard, along the forage lane; it was divided into sections operated automatically only when a cow is presented and in the robot entrance but activated only when empty in order to attract the cows to the robot but not blocking the system doorway. In the second farm, the solution involved 120 cows in each cowshed, an amount of concentrate supply appropriate for producing 12,000 kg milk, 86% robot utilization, and a queue of up to eight cows, lasting 15 minutes. Besides the numerical results, a valuable benefit from the simulation runs was that the farmer was assured before the barn was active that his future barn will work properly and meet his specific demands for management practices and design criteria. Both farms are now being built.

Background

Robotic milking is a recent development that affects factors that need to be taken into account when designing barn layout (Metz and Stefanowska 2000; Ketelaar-de-Lauwere 1999; Hogeveen *et al.*, 1998; Ipema, 1998; Uetake 1997); they include cow behavior, farm routine, feeding procedures and management practices. Whereas in a conventional barn the milker brings the cows to a waiting area from where they have to enter the milking parlor, in a robotic milking barn (RMB) a cow is expected to visit a milking stall voluntarily several times per day in response to its biological clock. As the barn layout strongly influences the cows' arrivals at the milking robot, it must be carefully planned. In order to design an optimal layout, in spite of the dynamic complexity of the system and the farmer's lack of experience with robotic milking, by means of a universally applicable technique suitable for any farmer or site, a new integrated approach to planning was proposed in a previous study (Halachmi *et al.*, 1998; Halachmi 1999). The new approach can be summarized as an integration of a mathematical model (Halachmi *et al.*, 2000c), scale drawings and a computer simulation that provides the integrated design tool required for this dynamic RMB system. Simulation experiments enable equipment, management practices and physical layout to be evaluated simultaneously and potential design options to be highlighted before the barn is activated; initial design can be "fine-tuned" to produce a balanced system – a so-called optimal layout. Simulation models not only require less simplifying assumptions than scale drawings, but also improve communication between barn operators and designers.

The simulation tool was developed in a previous study (Halachmi *et al.*, 2000a-c; Halachmi *et al.*, 2001a-c). This current study applies the new simulation tool to the problem of design of the cow cooling system in the RMB. Cooling cows, either naturally or by mechanical means (ventilation, sprinklers, etc.), is common in warm climates in Israel and elsewhere. However, in a conventional farm a cow is cooled in the milking-parlor waiting yard or immediately after milking, in the feeding lane, to which all the cows rush after the milking, to consume forage feed. In a robotic milking oriented design this option cannot be strictly applied – only a few cows are waiting at the robot entrance and they move toward the forage lane one-by-one 24 hours a day, around the clock, according to their biological needs and the timing of the human milker. Neither the designers, the farmers nor the authors could find scientifically reported experience with an RMB operating under similar hot climate conditions, therefore, the barn designers and operators invited simulation experts to participate in the design of the new RMB and its integrated cow cooling system.

Materials and Methods

The local conditions of farm one were:

Four robots in phase A, possibly to be followed a few years later by 2-3 additional robots (phase B). The average milk yield is 10,500 kg per cow (29 kg per cow per

day) during the 1st lactation year and 11,500 kg per cow during the 2nd lactation year. Existing facilities are presented in fFig. 1. Because of a limited budget, the designers were asked to retain the existing facilities and to minimize additional construction costs. For example, by using the old cowshed (Fig.1) the old milk container and office building.

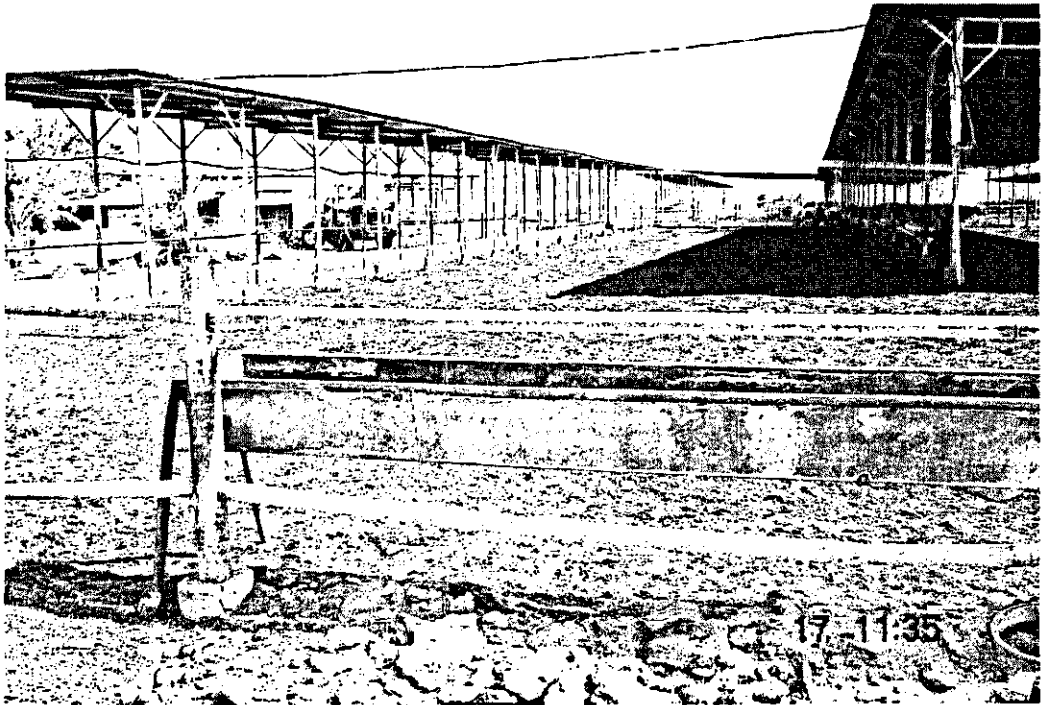


Figure 1. Existing facilities, farm 1

The design criteria were: up to 5 milkings per day; free traffic routine; no cubicle housing; more than 20 m² floor space per cow; desired robot utilization of 85% including 5% refusals; up to 4 cows waiting in front of the robot. Two feeding options were TMR feeding, and concentrate self-feeder with 3-6 kg per cow per day, which the cows receive only after being milked in the robot; the concentrate feeding time windows is set accordingly.

The design process: four conceptual alternatives were simulated. (1) Layout A with two robots in a line at the side of the cowshed; (2) two robots side by side and close to one another at the side of the cowshed; (3) two robots at the center; (4) two robots at the center, oriented at 90° to alternative 3. The simulation runs were performed in the presence of the farm manager, his veterinarian and his nutritionist (meeting 1). Then, after choosing the conceptual layout, we optimized the facility allocation by fine-tuning the chosen layout until we reached the so-called optimal layout for local conditions.

The last design phase involved integrating the cooling system, which was[?] evaluated in conjunction with the management practices, cow behavior and the proposed physical layout of the barn.

The specific conditions of the second farm were:

I is a new farm a few kilometers from the farmers' village, in the middle of a wide dry valley with strong winds in specific directions, expectation of 2.5 million liters of milk per year and an option for an additional 400,000 l in the near future. Today, with the milking parlor, the average annual milk yield is 10,500 kg/cow.

Results and discussion

The iterative design process provided many numerical results, drawings and simulation responses to many "what-if" questions raised by the farm operators during the design process. For example, the simulation software addressed questions such as: the numbers of robots needed currently and in the future; the amount of floor space needed in each barn section; the number of feeders – which depends on feed allocation now and in the future; robot locations that allow for future expansion; location of bottlenecks that would prevent the introduction of additional cows into the same facility if the milking were 15% faster; recommendations for cow traffic routine which depends on varying management practices, feeding routine and feed allocation. Therefore I have chosen only two tables for presentation: Table 1 presents the data used to determine the design of the cooling system in farm one; Table 2 presents the situation in which the manager of farm 2 is to produce an additional 400,000 l per year.

As can be seen in Table 1, locating a cooling system at the robot entrance (as in a milking parlor farm) is not efficient because it provide only 17.3 minutes of cooling. Location at the forage lane is somewhat more efficient (244.6 minutes of cooling) but because of the long length of the forage lane, we have divided it into sections, each automatically activated by a photocell. An additional option that was simulated but is not presented in the Table involved varying the area at the robot exit and a one-way gate after the self-feeder, thus providing a control tool that delayed specific cows to be kept longer in that cooling area. Eventually this area was chosen for cooling.

For the second farm, Table 2 presents two competing design concepts which were considered via simulation runs. Both aim to produce an additional 400,000 l/year. Concept 1 involves enlarging the herd by 40 cows, 20 in each cowshed, whereas concept 2 involves maintaining the same number of cows but raising their milk yield by means of superior nutrition. It can be seen that enlarging the yard to accommodate 20 additional cows raised the robot utilization from 78% to 89%, and increased the cow queuing time from 8 minutes to 21 minutes and the number of cows in the queue

from 5 to 13. When only the milk yield per cow is raised (concept 2) the robot milking time is longer and, therefore, the robot utilization is also higher (86%) and the queue length rises from 5 to 8 cows. Since the farmer's initial design criteria included robot utilization of 87% and cow queue length up to 8 cows, concept 2 was preferred and the entire layout was designed accordingly.

Table 1. Results: time spent at each barn facility (in minutes)

Facility	Time window	Mean visit duration (minutes)	Max visit duration (minutes)	Number of visits for the period of time windows	Total time at facility per time windows
Forage lane	00:00-02:00	17	62	0.73	12.4
	02:00- 08:00	17	62	1.77	30
	08:00- 10:00	33	118	0.55	18
	10:00- 12:00	34	210	0.89	30
	12:00-14:00	26	250	0.90	23.4
	14:00-16:00	25	94	0.94	23.5
	16:00-18:00	35	112	0.86	32.9
	18:00- 20:00	29	188	1.05	30.5
	20:00- 22:00	23	185	1.12	25.8
	22:00- 24:00	17	94	1.07	18.1
Total				9.88	244.6
Laying	00:00-02:00	68	215	0.77	52.4
	02:00- 08:00	98	527	2.33	228.4
	08:00- 10:00	104	538	0.71	73.8
	10:00- 12:00	70	538	0.95	66.5
	12:00-14:00	61	538	1.09	66.5
	14:00-16:00	57	537	1.14	65
	16:00-18:00	55	269	1.06	58.3
	18:00- 20:00	48	269	1.26	60.3
	20:00- 22:00	44	269	1.29	56.8
	22:00- 24:00	49	215	1.16	56.8
Total				11.76	784.8
Water trough after the robots	00:00-02:00	3.1	17	0.29	0.9
	02:00- 08:00	3.2	16	0.65	2.08
	08:00- 10:00	3.2	13	0.23	0.73
	10:00- 12:00	3.1	15	0.48	1.5
	12:00-14:00	3.1	18	0.41	1.27
	14:00-16:00	3.2	16	0.40	1.28
	:	:	:	:	:
	22:00- 24:00	3.2	14	0.46	1.47
Total				4.2	13.3
Other water troughs	00:00-02:00	3.2	15	0.48	1.53
	02:00- 08:00	3.1	17	1.33	4.12
	08:00- 10:00	3.1	17	0.42	1.3
	10:00- 12:00	3.1	19	0.61	1.9
	:	:	:	:	:
	22:00- 24:00	3.2	16	0.77	2.46
Total				7.2	22.5
Waiting yard before the robot	00:00-02:00	0.5	14	0.47	0.2
	02:00- 08:00	0.6	28	1.29	0.77
	08:00- 10:00	0.45	10	0.41	0.2
	10:00- 12:00	1.8	17	0.54	0.97
	12:00-14:00	3.8	25	0.66	2.5
	14:00-16:00	2.3	20	0.67	1.5
	:	:	:	:	:
Total				6.4	17.3

A few other figures, noticed during the simulation runs for the first farm, include: given that 5% of the herd (per day) is directed by the robot (veterinary or insemination treatment) from 02:00 to 08:00, then, the separation area should allow room for 7 cows. From 04:00 to 08:00 only 4 cows might arrive. The layout was designed accordingly.

Table 2. Results (cont.): adding 400,000 l per year

Scenario	Robot utilization	Cow queue length – mean waiting time and number of cows waiting at the robot
120 cows, milk yield 10,500 litter	78%	8 min., 5 cows
140 cows, milk yield 10,500 litter	89%	21 min., 13 cows
120 cows, milk yield 12,000 litter	86%	15 min., 8 cows

Concluding remarks

This short paper presents two farms that have ordered designs by simulation software. By means of simulation runs we considered the animal behavior, management practices and the physical layout of each specific farm and evaluated them in combination. By fine-tuning a proposed design in consultation with the farm operators and designers, we reached a simulated so-called optimal layout appropriate to local conditions. The methodology applies to RMB design in general; however, layout, herd size, equipment, climate, breeding, management philosophy, etc. all influence the cows' behavior. Therefore, the optimum solution represented by this model result presented in this paper can be considered as an optimal only for the particular barn for which it was obtained. The present paper makes no claim to present a “global optimum”, which might fit elsewhere. Consequently, if someone applies this solution without parameter adjusting and without running the model again, he does so on his own responsibility and will have no claims against us.

Designing a good robotic milking barn is a multidisciplinary task, which requires sophisticated tools to evaluate animal behavior, farm management and the proposed building – all in combination. We have the scientific tool to solve the problem – simulation modelling – and we have used it for the design of these two farms. Layout problems such as cooling the cows, traffic routines, future expansion, feed management, and more, can be efficiently tackled by using simulation.

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AUTOMATIC MILKING – CHANCES AND CHALLENGES

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Summary

In automatic milking systems (AM-systems) cows are milked by a robotic milking system without direct human supervision. The number of farms with an AM-system is growing, especially in those countries where the costs of labour are relatively high, such as in many West European countries. Many technical problems especially concerning attachment of teat cups have meanwhile been solved, but new problems arose with the spreading adoption of AM-systems by commercial farmers. Since cows visit the AM-system more or less voluntarily, a large variation in milking intervals can be observed between cows. Special attention should be paid to the design of the barn and should be based on the principle eating – lying – milking. When the first prototypes of AM-system were introduced on farms, milk quality deteriorated compared to conventional milking systems. Special emphasis should be given to free fatty acids and bacterial counts. Automatic milking systems require a higher investment than conventional milking systems. However increased milk yields and reduced labour requirements may lead to a decrease in the fixed costs per kg milk. The introduction of automatic milking has a large impact on the farm, the management and the social life of the farmer. A successful use of automatic milking depends largely on the management skills of the farmer and the barn layout and farming conditions.

Introduction

The first ideas about fully automating the milking process were generated in the mid seventies. The growing costs of labour in several countries were the main reason to start the development of automatic milking. The final step in the automation of the milking process seemed to be the development of automatic cluster attachment systems. However it took almost a decade to convert the techniques for locating teats and attaching teat cups to fully integrated and reliable automatic milking systems. The first milking robots were installed on commercial dairy farms in the Netherlands in 1992. The breakthrough of automatic milking came at the end of the nineties and at the end of 2000, over 750 farms world-wide milked their cows automatically.

Automatic milking systems

AM-systems can be divided into single stall systems and multi-stall systems. Single stall systems have an integrated robotic and milking system, while multi-stall systems have a transportable robot device. Each stall has its own milking devices, like in a milking parlour. A single stall AM-system is able to milk 55-60 cows up to three times per day on average. Multi stall systems have 2 to 4 stalls and are able to milk a herd of 80 to 150 cows three times per day. Automatic milking relies on the cow's motivation to visit the AM-system more or less voluntarily. The main motive for a cow to visit the AM-system is the supply of concentrates, therefore all AM-systems are equipped with concentrate dispensers. An automatic milking system has to take over the 'eyes and hands' of the milker and therefore these systems should have electronic cow identification, cleaning and milking devices and computer controlled sensors to detect abnormalities in order to meet (inter)national legislation and hygiene rules from the dairy industry.

The current teat cleaning systems can be divided into three main types; cleaning with brushes or rollers, cleaning inside the teat-cup and cleaning with a separate 'teat cup like' device. Present AM-systems do not have sensors to detect the amount of dirt on the teats. Little information is available about the efficacy of teat cleaning devices. Several trials showed that cleaning with a cleaning device is better than no cleaning, but not as good as manual cleaning by the herdsman (Schuiling et al, 1992). AM-systems are equipped with a variety of sensors to observe and to control the milking process. Data are automatically stored in a database and the farmer has a management program to control the settings and conditions for cows to be milked. Attention lists and reports are presented to the farmer by screen or printer messages. However, the AM-system only notifies, the farmer has to take action.

Management and labour

One of the main benefits of automatic milking is an increase in milk yield from more frequent milking. Recent figures from the Dutch herd improvement organisation NRS showed an increase in lactation yield of 11.4 % one year after the introduction of the AM-system (unpublished). Changing over from a milking parlour to automatic milking will lead to big changes for both herdsman and cow. In the transition from conventional to automatic milking, cows have to learn to visit the AM-system at other times than before. This needs special attention and in the first weeks human assistance will be necessary. Another important aspect is the barn layout and design. Using the cows motivation for eating, the milking system should be situated in the route towards the feeding area. To minimise problems with udder health, it is generally recommended that cows stand for some time after the milking to allow the teat sphincter to close. So after visiting the milking system, the cow should have free access to the feeding area. Using this milking-feeding-lying principle, the cows are motivated to use the AM-system.

Since cows visit the AM-system more or less voluntarily, a large variation in milking intervals can be observed from cow to cow. In practice the average number of

milking per day varies from 2.5 to 3.0 and more, but rather big differences in individual milking intervals are reported. There does not seem to be a big difference in average milking frequency between the one way and the free cow traffic systems in practice (Ipema, van't Land). De Koning found that almost 10% of the cows realised a milking frequency of 2 or lower over a two year period milking with an single stall AM-system. This occurred even though cows with a too long interval were fetched three times per day. These cows will not show any increase in yield or may even show a decrease.

The effect of automatic milking on labour requirement is not very clear and depends largely on the management approach, barn layout and herd characteristics. Ipema et al (1998) and Van't Land reported labour demands for AM-systems from 32 minutes up to 3 hours per day. On average a 10% reduction in labour required is reported. Moreover the character of the labour left will change from manual work to managerial activities and observations of the cows and their behaviour. Management is the key-factor in a successful application of automatic milking.

Capacity

The capacity of an automatic milking system is often expressed as the number of milkings per day. The number of milkings per day will depend on the configuration of the AM-system, like number of stalls and the use of selection gates, herd size, barn layout and the characteristics of the herd, like milk yield and flow rate.

Increasing the number of milkings per cow per day, does not necessarily contribute to a higher capacity in terms of kg milk per day. This is due to the more or less fixed handling time of the automatic milking system per milking and the decreasing amount of milk per milking with smaller milking intervals.

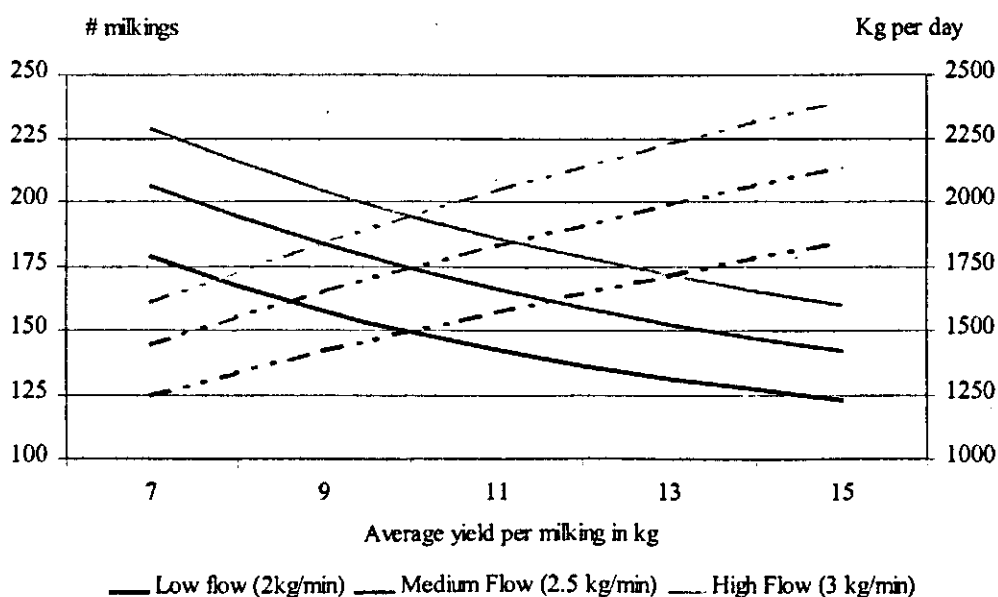


Figure 1. The calculated number of milkings per day and production per day at different yield and flow rates.

A milking visit to the AM-system consists of several activities. The cow walks to the AM-system, will be identified and if the cow is allowed to be milked, the AM-system will start the udder preparation and teat cleaning. The teats are localised and the four teat cups will be attached. The milking process will start and after teat cup take off, the teats are disinfected and the cow is allowed to leave the milking station. Each milking visit has in fact two main parts: the handling time of the AM-system and the machine on time. Handling times between 2 to 4 minutes are reported in various studies. The machine on time depends largely on the yield and flow rate of the individual cow. Between herds and between cows, the average flow rates will differ due to genetic differences. Various figures are reported from research with AM-systems. De Koning & Ouweltjes found an overall average flow rate, which could be modelled by $2.51 \text{ kg/min} + 0.051 * (\text{Yield} - 11.8)$. Other data showed average flow rates between 1.4 and 1.9 kg/min in various experiments with AM-systems (Devir, Sonck).

Daily capacity

The maximum number of milkings per day and the capacity in kg per day can be calculated for one stall AM-systems by using the handling time per milking visit, the machine on time per visit and the occupation rate of the automatic milking system. For example an occupation rate of 80% means that the automatic milking system operates for 19.2 hours per day and the remaining 4.8 hours are used for rinsing and cleaning of the milking machine, refused milking visits and so on. In figure 1 results are presented for different yields per milking and flow rates. Increasing the average yield per milking will result in less milkings, but in an increased capacity in kg per day. Milk flow rate and yield have a large impact on capacity in kg per day. By changing the milk criteria settings in the AM-system for individual cows, the AM-system can be optimised to realise a maximal capacity in kg per day.

Milk quality and cooling

Milk quality is without doubt one of the most important aspects of milk production on modern dairy farms. Milk payment systems are based on milk quality and consumers aspect a high quality level of the milk products they buy. Although automatic milking uses more or less the same milking principles as conventional milking, there are some big differences. The 24 hour continuous operation of the AM-system requires special cleaning procedures. Visual control during the milking process is not possible. Also teat cleaning cannot be adjusted to the degree of dirtiness. Furthermore the milking intervals will differ from cow to cow. All these aspects may influence the quality of the milk.

Table 1. Milk quality results for farms before and after introduction of AM-system (Van der Vorst et al, 2000)

	Dairy farmers		First generation		Second generation	
	2 times milking	3 times milking	Before	After	Before	After
Number of farms	60	45	39	39	62	62
Bacterial count (*1000/ml)	8	8	8	17	8	12
Cell count (* 1000/ml)	181	175	202	203	175	190
Freezing point (°C)	-0,520	-0,521	-0,520	-0,517	-0,521	-0,516
Free fatty acids (meq/100 gr fat)	0,44	0,54	0,49	0,63	0,41	0,59

Bacterial counts and freezing point

At the start of automatic milking on commercial dairy farms, it was a general assumption that milk quality would be equal or even be improved after the change to automatic milking. However, results from commercial farms indicate that in many cases milk quality is negatively effected (Klungel et al, Van der Vorst). Results are presented in table 1 and show a doubling of the bacterial counts, although the levels are still relatively low and far within the penalty levels. The cleaning of the milking equipment and the cooling of the milk seem to be the most important factors regarding the increase in bacterial counts. Attention should be paid to the hygienic design of the milking machine in the AM-system, but research also showed that complete cleaning and disinfection should be carried out at least three times per day. Cleaning is also necessary after milking treated, diseased or fresh calved cows, to prevent contamination of milk. Most AM-systems also use a short rinsing between two consecutive milkings, to reduce the risk of transfer of pathogens from cow to cow. However the many cleaning and rinsing cycles in AM-systems will increase the risk of an increased freezing point. Special attention should be given to the draining of the system after cleaning, the slope of pipe lines and the use of draining valves.

Cell counts, butyric acid spores

Also for cell counts a decrease was expected due to more frequent milking. Although little information is available, it seems that cell counts are not reduced in the first 12 months after the change to automatic milking. It is not clear if these changes are related to the AM-system or to the changes in management. Special attention should be given to the housing conditions of the cows, especially to the hygiene of the bedding in the cubicles and the hygiene of the slatted floors in order to keep the cows clean. Automatic manure scrapers on the slatted floors are used to keep the walking areas clean. Hygienic conditions and clean udders are also important to prevent an increase in butyric acid spores.

Free fatty acids

It is generally known that the content of free fatty acids (FFA) in milk will increase with shorter milking intervals (Ipema & Schuiling), the more so if the yield per milking is rather low. All studies with AM-systems show a significant increase in

FFA levels. This increase cannot be explained solely by the shorter intervals, because the increase of FFA with AM-systems is even bigger than with conventional milking parlours milking three times per day. Another explanation may be the increased air inlet by attachment of teat cups, during milking and at take off. Also the cooling system may play a role.

Cooling of milk

It is generally recommended that the milk should be cooled within 3 hours to, and stored at, a temperature below 4 °C. In conventional milking, cows are milked twice a day and therefore also twice a day a big volume of milk has to be cooled. In automatic milking, however, the system operates 24 hours and a relatively small amount of milk is flowing more or less continuously to the bulk tank. The average flow rate will range between 50 and 250 kg per hour from 1 to 4 milking stalls. Furthermore there may be some periods without any milk flow because of a low activity of the cows, for example in the night.

Milk can be cooled either directly or indirectly. With direct cooling of milk, the cooling process is not allowed to be started before approximately 10% of the tank capacity is filled with milk. This to prevent the risk of freezing and deterioration of milk quality. In conventional milking this 10% filling will take 1-2 hours. In automatic milking this period may increase up to 10 hours. Such a delay of cooling will increase the risk of bacterial growth, and is not allowed.

Different systems for milk storage and cooling can be applied with automatic milking systems (Wolters et al). The basic requirement is that the system can handle the specific conditions of automatic milking. It may also be useful to have a cooling system which is able to store the milk when the bulk tank is emptied and cleaned. This enables the AM-system to continue milking, thus increasing the capacity of the system. In general there are four principles to adjust the cooling system to automatic milking; 1) indirect cooling with an ice-bank tank, 2) combination of bulk and buffer tank, 3) storage tank with fractional cooling and 4) instant cooling.

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ROBOTIC MILKING: A REPORT OF A FIELD TRIAL IN ISRAEL

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Introduction

Many researches had been conducted during the last 20 years on application of automatic milkings by robots. Milk yield increased as a consequence to increasing of milking frequency (1,2,3,4,7,11,12). It was also shown in a field trial conducted in Israel comparing x3 to x4 milking a day: milk increased by 10% (11). However, age and stage of lactation were significant effects that should be considered. There are also contradicting results about increase of SCC due to higher milking frequency.

The reaction of teat end tissues to longer accumulated milking time due to higher milking frequency was found to be negative in one report from Netherlands (6) and was also approved in a study comparing x3 to x4 milking a day in Israel (12).

The popularity of automatic milking robot is increased tremendously; By the end of 2001 1000 robots were sold, mainly in western countries. (8). Today the interest to use it in Israel is increasing gradually. Two years ago it was a new technology that under Israel regulations must be tested before giving the permission for distribution. Therefore, a field trial was conducted in a commercial farm of 300 cows in Israel by August 1999 in which Two robot units (Lely Ind., Netherlands) were installed. The goals of the field trial were to examine the effect of robot on physiological aspects such as: adoption of the cows to the new milking technology, milk yield and it's composition, milk quality, teat end condition, udder health, and on robot functions.

Materials and Methods

Twenty-five pairs of Israeli-Holstein cows in Kibbutz Beit-Alfa were assigned to one of two groups according to milk yield, day in milk (DIM) and age. The trial lasted for six months after few weeks of adaptation. Cows milked by robots (CR) were housed in a free-stall barn and milked between two to four milkings a day (in average 2.8) while control cows were housed in a corral (bedding area – 14 m² per cow) and milked three times daily. The control group was fed TMR *ad libitum* only

while CR group was fed a basic mixed ration in the trough in addition to concentrates in robots and in self-dispensers.

Aseptic milk samples were collected for bacteriological diagnosis at the beginning and at the end of the trial from every quarter followed by collection of other milk samples for SCC determination.

Teat end scores were determined at the beginning and at the end of the trial. Five parameters were included: teat length, teat width, teat end score, teat end lesion, and size of teat apex orifice. Each of these parameters was categorized by one to four degrees: 1 - good condition, 4- worst condition. Composite milk samples were monthly collected for milk composition and SCC, under the recording regulations for breeding of Israel Cattle Breeders' Association. Bacteria count and BTSCC were determined frequently by the dairy.

Statistical analysis

The data of control group was collected from "afimilk" program (Zacham Afikim, Afikim, Israel) and that of robot group from Lely Astronaut system. The statistical analysis was performed by GLM procedure of SAS in linear and exponential models. The dependent variables were milk yield, Economic Corrected Milk (ECM), and SCC (log transferred). The independent variables were treatment (control vs. robot), cows within treatment, and days in milk (DIM). Milk yield at the beginning of the trial was used as a co-variance. Multi-factorial test was done wherever necessary. The Chi-square procedure was used to assess the teat end scores.

Results and Discussion

Physiological aspects

A. Milk yield, ECM - The milk yield of the cows, milked by the robot was 3.4 liter higher per day of lactation relative to control cows (42.6 vs. 39.2, $P < 0.001$). These results are with agreements with other works; Campos et al. (1994) found increase of milk yield of 15% when cows were assigned to robotic milking from 2 milkings a day in Holstein-Friesian cows but only 6-7% in Jersey cows. Other trials examined 4 milkings relative to 3 milkings a day found increase of 8-12% in milk yield (1,2,3,11,12). However, the average milkings per day by the robot was 2.8. Therefore increase of milk yield by the robot might be explained by the distribution of different milkings during lactation (see more details in chapter of robot functions).

The ECM (giving priority for payment to protein on fat in ratio 3 to 1) of CR was 3.84 kg more than the control group ($P < 0.01$). Fat content was lower in CR relative to control group during the trial (3.04 vs. 3.25%, $P < 0.01$) as was found by others (6,7). Less content of fat is probably attributed to higher milking frequency but also to the feeding regimen. No significant difference was found in protein content.

B. Somatic cell count - The SCC of composite milk (transformed to log) as monthly determined by milk recording laboratory of Israel Cattle Breeders Association of CR

was significantly lowered through the trial. No significant difference observed at the beginning of the trial (control -11.67 vs. 11.37, $P>0.05$). Later, during the last two months of the trial the difference between the two groups increased in favor of CR. The changes in SCC is contradicted: one work showed decrease of SCC due to robotic milking (9) but others did not (7,11,12). However, results from our study probably stem from the evident of better udder health, as described below.

C. Udder Health- the new infection rate of quarters (which reflects both the sub-clinical and clinical cases) was determined following diagnosis of one or more of the following bacteria: *Escherichia coli*, *Streptococcus disgalactia*, *staphylococcus aureus*, *Bacillus*, *streptococcus uberis* and *fungus*. It was almost double in the control group relative to robotic group (25% vs. 13%, respectively, table 1).

Table 1. The bacterial status of quarters expressed as percentages at the end of the trial relative to beginning (Chi square = 0.1).

	Quarters remained "clean" (%)	Quarters with new infection (%)	Quarters remained infected (%)	Quarters with spontaneous recovery (%)
Control	55	25	16	4
robot	61	13	23	3

Teat end condition was measured by three parameters:

1. Teat end score- in both groups most of the teats (95%) were categorized as "1" at the beginning of the trial and at the end. No statistical difference was observed between two groups within and between the two periods.
2. Teat end lesions- Most of teats were scored as "1" or "2" in two groups and in the two periods. No significant difference was observed between the two groups within and between the two periods; a moderate improvement was even observed in cows milked by the robot towards the end of the trial (figure 1).
3. Teat apex orifice – More quarters (10%) were scored "1" in the control group at the beginning of the trial. But this difference was abolished at the end of the trial (figure 2). Nevertheless no statistical difference was observed between two groups within and between two periods.

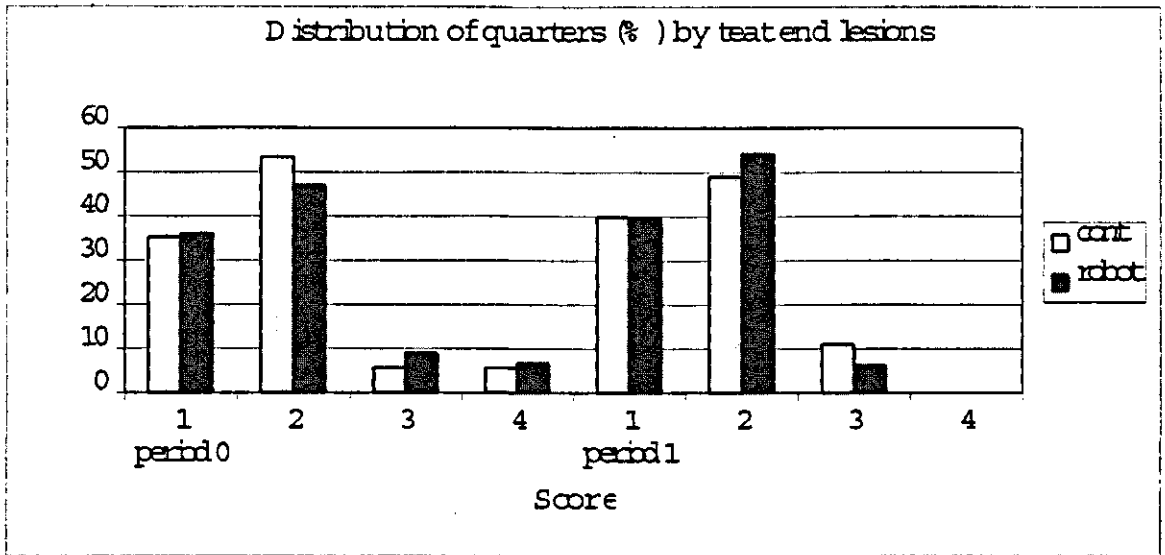


Figure 1. The distribution of quarters (%) by teat end lesions at the beginning to the trial (period = 0) and at the end (period = 1).

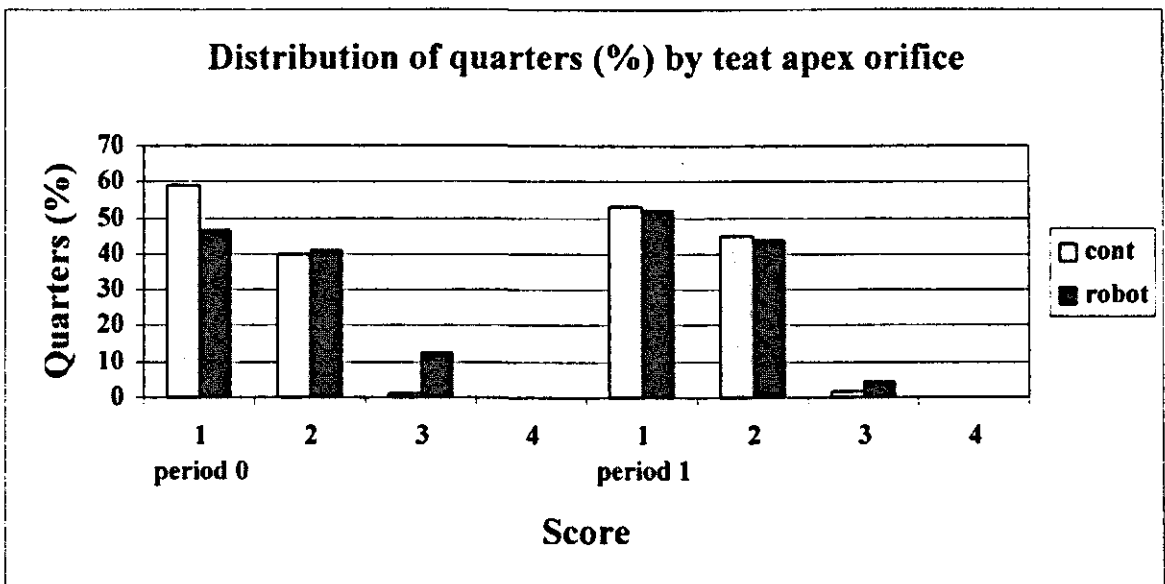


Figure 2. The distribution of quarters (%) by teat end lesions at the beginning to the trial (period = 0) and at the end (period = 1).

These results might collectively be concluded that the robotic milking did not negatively affect the teat end conditions. It is contradicted to the results of Ipema et al. (6) and Shoshani et al. (12) but in agreement with others (10). Whether it is because of a short time of a trial or due to elimination of overmilking should be explored.

Clinical rate - Clinical mastitis was defined as an infection that observed in the exceptional report (deviation in milk yield and/or electrical conductivity) and/or by visible signs in the udder (swelling, redness, sensitivity, fever) or abnormal milk (flakes and clots). One case in robotic milking comparing to eight in control group was recorded per a month.

D. Milk quality - The farmer rewards or imposes a penalty on two parameters that might interfere to milk by-products process: SCC and Total Bacteria Count (TBC).

Milk samples were taken periodically from bulk tanks of the two groups. Therefore, it represents either all cows milked by the robot (120 cows) and all cows milked in the conventional milking parlor.

The SCC of milk from robotic milking system was significantly lower during trial period relative to SCC of milk from conventional system ($223,000 \pm 15,600$ cells/ml vs. $443,000 \pm 29,000$ respectively, $P < 0.05$).

The TBC of milk from robotic milking system was also significantly lower during trial period relative to TBC of milk from conventional system ($9,160 \pm 750$ count/ml vs. $16,660 \pm 2850$ respectively, $P < 0.05$). One case of high TBC was observed during the trial period in the robotic milking due to malfunction in heating body of boiler water intended to washing system.

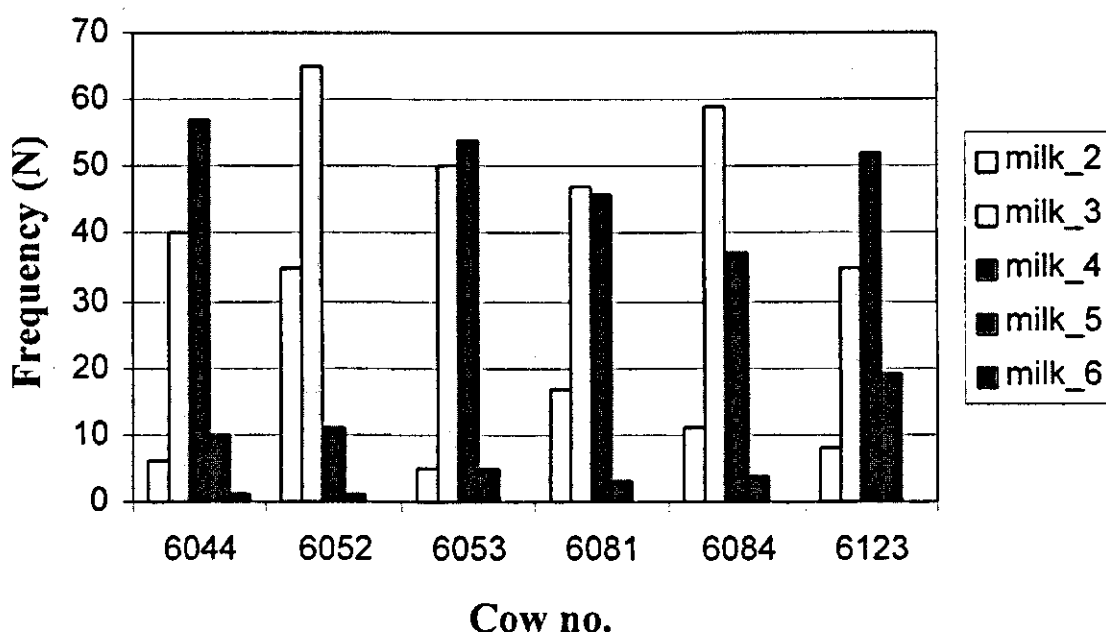


Figure 3. The distribution of days with different milking frequency of six cows, selected randomly, during trial.

Robot Functions

a. Average milkings - The average milkings/day per cow for the two robots were 2.8 ± 0.8 and 2.8 ± 0.78 , respectively. However, these figures cannot explain the increase in milk yield of cows milked by the robotic system relative to control group, milked 3 times a day. Alternatively, high milking frequency per cow for a short time at the beginning of lactation was reported to have a carry-over effect on all lactation (2, 5, 11). Therefore, it might be more important to analyze the distribution of milking frequency during the trial of individual cows rather than looking on average milkings per se (figure 3). The most frequency was 3 to 4 milkings.

b. Refusals by the robot - A follow-up of this parameter might show if a cow can respond to it if she enters the robot not in time interval the farmer wants. If a cow has the capability to respond to it someone might expect to a gradual decrease in number of refusals as long as time is in progress when all cows are at the same stage of lactation. It is shown (figure 4) that no. of refusals did not reduced during time and it might indicate that cows have difficulty to adjust to an arbitrarily routine driven by the farmer

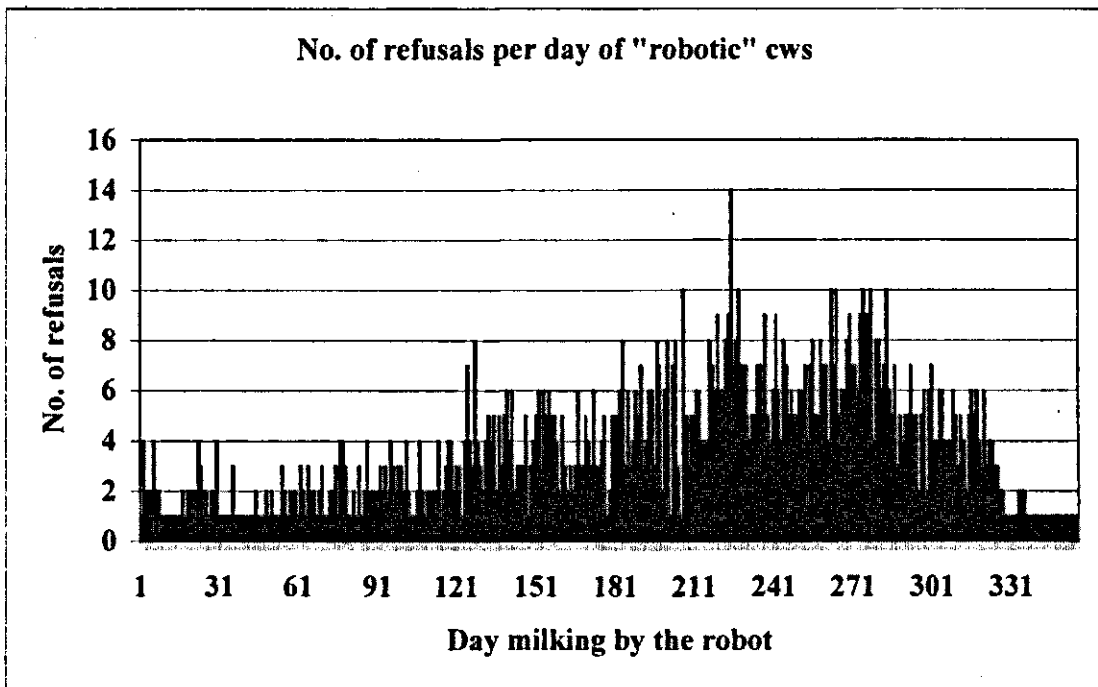


Figure 4. Number of refusals during lactation of CR

c. Number of failures during milking - A follow up on the ratio between number of failures and total number of attachment every day (figure 5) might indicate problems of maintenance or alternatively a proportion of cows that might have difficulties to be milked by the robot. The average failures ratio in case of Beit-Alfa is 5% in one robot and a slightly higher in the other. Is it high or not? It is necessary to compare

this figure with other farms. However, it is clearly shown that an unpredictable increase is probably due to mechanical malfunctions.

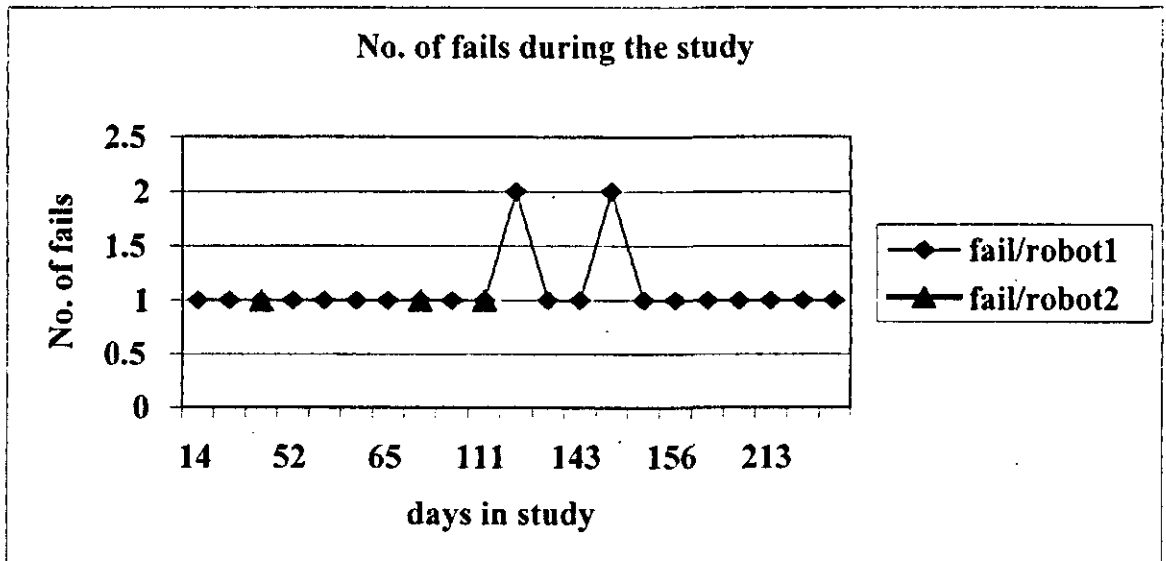


Figure 5. Number of failures (for each robot)

d. Average cows milked by a robot, number of milkings and milk quantity -

These three parameters might define the effectiveness of the robot. However, the average cows milked by a robot will not indicate its effectiveness due to a variation between cows in the frequency of milkings per day. Total number of milkings per se will not indicate the effectiveness also because it does not inform about the available number of cows and the frequency distribution between them. On the other hand, the daily milk yield produced by the robot will be a better indicator because it is a consequence of successful management imposed by the farmer which includes number of cows, optimum strategy to determine the milking frequency per day, number of failures and number of refusals.

Daily milk yield, plotted against trial days, showed that until 90 days after beginning of the trial the milk yield ranged between 1800 to 2000 litres (figure 6). Milk yield gradually reduced subsequently although the number of cows did not change; it is the result of grouping cows with similar DIM. Cows were at their peak of lactation at the beginning of the trial (35 liters/day) and later they entered to a decline phase of lactation (29 liters/day). Creating a heterogeneous group of cows of different stages in lactation might keep the milk quantity achieved by the robot steady.

e. "Dead time"- "Dead time" is defined as the time passing between teatcup attachment to the beginning of milk flow. If this time is too long it will sign on improper stimulation for let down milk ejection. The average dead time was 26 s but the dead time of rear quarters was longer than that of front quarters (28.2 s vs. 23.17, $P < 0.05$). Milking time of rear quarters was also longer (by 10%). The longer milking time of rear quarters is a consequence of higher milk yield but longer dead time

might stem from the fact that teatcups are initially attached on rear quarters, which are less stimulated relative to front quarters.

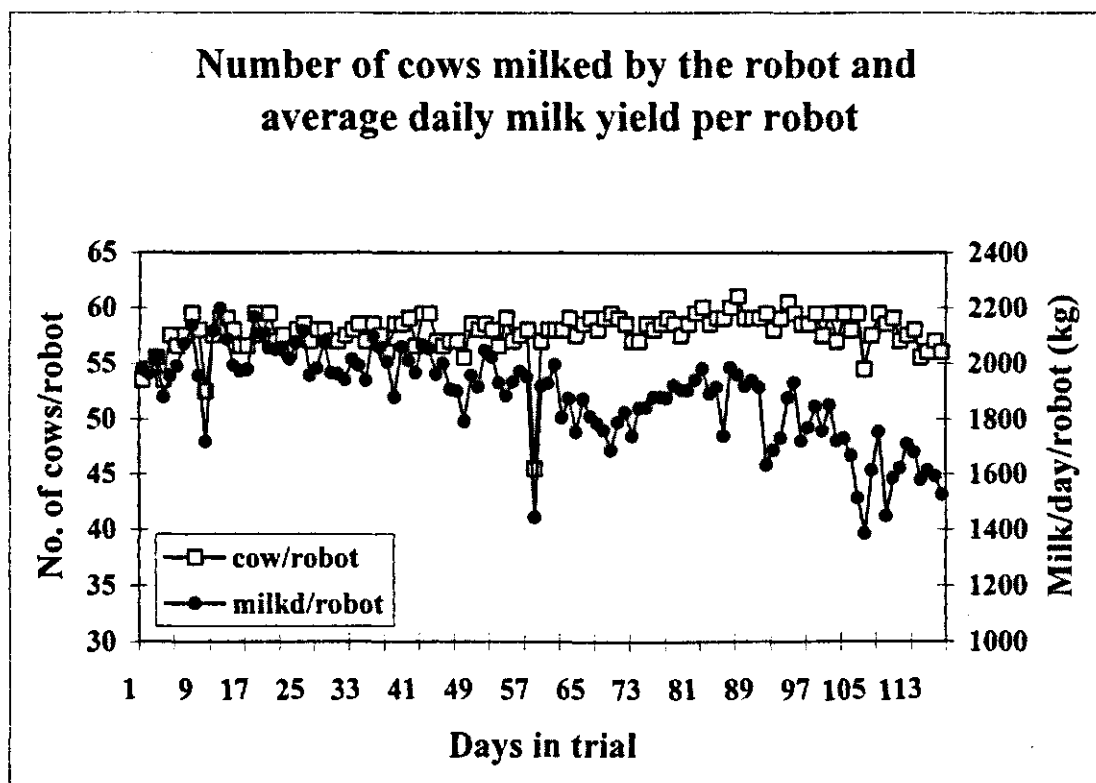


Figure 6. Effectiveness of the robot represented by daily milk yield and number of cows milked by the robot.

f. Selection rate - Of all cows transferred to the robot housing 14% were returned back to the conventional milking parlor. This rate is relatively high to the rates which are common in Netherlands. The reasons for it were mostly because of teats' angle and partly- udder structure. The presence of other alternative (conventional milking parlor) might contribute to it. However, the high rate might be expected at the initial phase of transferring an herd to robotic milking.

g. Water usage - The average water quantity per cow per day in the robotic milking is 8-10 liters relative to 70 liters in family farms and to 150-240 liters in cooperative farms. This fact has a lot importance from environment quality aspects and water reservoir as well.

h. Teat cleaning - Teats, cleaned by the two cylinders, were visually observed; all teats were satisfactory cleaned. By-product effect of cleaning is the stimulation for let down ejection; in most cows teats were "swollen" due to milk accumulation in teats' cisterns. Another by-product is disinfecting the teats by the solution that disinfects the rollers between cows; the low incidence of new infection in the robotic system might partially be explained as a consequence to it.

i. Teat disinfection - Visual observation lead to the conclusion that the effectiveness of the sprayer is far from satisfying; the area covered by the iodine solution is randomly rather than precisely on teats.

j. Robot preference by cows - It is well known that cows prefer to enter in a particular side in a milking parlor. Is it the same in the robot?

The two robots were positioned in parallel to each other (“a mirror image”) which leads the cows to choose one of the robots. If cows develop dependence in one of the robots, a temporary cessation of one robot, resulting of malfunction or for routine maintenance, might interfere the routine milking of the cows. To examine it the number of visits of a cow was calculated for each of the robots. A ratio between number of visits of a cow in a particular robot was calculated from all visits in two robots. If the ratio was 70% and higher cow was identified to prefer a particular robot.

Forty-nine cows out of 119 cows (41%) occupied a particular robot 70% of all visits and higher. Additional 24 cows (20%) milked by a specific robot only. In total, 61% of the cows tended to be milked by a particular robot. It is questionable if other robots positioning (such as one after the other) changes this tendency and what impact it might have on the behavior of the cows.

k. Health report- Health report is based on exceptions in quarter milk conductivity measurements and composite milk yield. An attempt to assess the reliability of this report milk samples for bacteriological diagnosis and SCC should be taken frequently for the determination of false positive and false negative. It was difficult to make such a trial in this farm due to technical and cost limitations. It is recommended to make such a study elsewhere. However, there were few cases in which particular quarters appeared as excepted few times. None of those cases developed to clinical mastitis.

Conclusions

Milking by the robot increased the milk yield. Fat content was lowered. Udder health tended to be improved relative to conventional milking as reflected by the new infection rate and the clinical incidence. Teat end condition was not negatively affected by robotic milking. Milk quality, as assessed by SCC and bacteria count, was superior to conventional milking. Selection rate was pretty high relative to other reports. Breeding for udder and teats will lower it for the long run. Robotic milking dramatically reduces the water usage and consumption of detergents; ecological aspects are therefore improved.

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ON-LINE DATA FOR INDIVIDUAL MILKING FREQUENCY AND CONCENTRATES SUPPLEMENTATION IN THE ROBOT MILKING DAIRY

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ABSTRACT

Automatic milking systems (AMS) have the potential to apply individual management (IM) in the dairy, by assigning a specific milking frequency (MF) and individual concentrates supplementation (ICS) according to the cows' production potential (PrP) as reflected by the performance along lactation. The absence of an automatic decision-making and control system prevents the application of IM, hence restricting the ability of the AMS to increase production efficiency. The two basic components required for cows' PrP evaluation and physiological response to management changes are milk meters and a scale for on line body weight (BW) scale. These two along with routine milk composition measurements provide the parameters to estimate dry mater intake (DMI) and body condition (BC). These, combined with physiological interpretations of the performance variables enable to assign MF and ICS accustomed to each cow which can vary throughout the dynamic process of lactation.

Performance variables of primiparous and multiparous dairy cows including: milk yield (MY), BW, DMI, and BC, were analyzed along lactation. In the cases that MF and/or ICS decisions were taken the response could be quantified. In other cases their response to varying MF and ICS was assessed at the various stages along lactation. Conclusions regarding response of individual cows, in relation to the stage of lactation, were withdrawn.

A set of rules for varying MF and ICS allocation was formulated, based on physiological interpretation of the measured and calculated performance variables. This set of rules can be tuned to suit the economical strategic goals of the AMS dairy. These rules can be programmed into an IM expert system, which utilizes real-time accurate performance data, for assigning MF and ICS to each individual cow. These decisions can than be executed automatically by the computer controlled milking robot and concentrates self-feeders.

INTRODUCTION

Precision agriculture aims to manage the basic production unite. In the dairy herd this is the individual cow. The first and utmost justification for IM is the big variety in cows' response to a certain milking and feeding strategy. This calls for management strategies and routines that take into consideration these individual differences in performance and physiological capacity. Yet, group and whole herd management is the accepted approach because in the conventional dairy, operational limitations prevent efficient application of MI. The AMS lifted up most of the restrictions imposed by the conventional milking parlor and in addition, provided two components that are essential to manage every cow individually:

1. The ability to affect production through MF manipulation and the ability to back it up by ICS.
2. Hardware and software infrastructure to execute its task of milking and concentrates feeding.

Currently, the decision-making routine regarding MF and ICS is predefined and rigid with no flexibility of on-line real-time changes corresponding with actual performance of each cow that uses the AMS.

After setting up the strategic goals of the dairy that are dictated by the economical environment in which it operates (Maltz 2000), the herdsman is interested to execute a management routine that will encourage all cows to perform in that preferable direction. Under conventional dairy conditions the producer will select a management strategy that will affect favorably the majority of the cows giving up in advance any attempt to address the margins because of objective limitations. This doesn't mean that he wouldn't like to attend to them and economize on the ration of cows that do not respond favorably. It would save their food and reducing their effect on the global herd production (especially significant under quota conditions, and a demands for milk of specific composition), or encourage production of cows responding favorably. The AMS gives us, like never before, an access to attempt and address every cow in the herd according to her capacity to produce in accordance with an economical goal set to the herd.

However, this can be done only after we interpreted the continuously recorded and calculated performance data, decide about the PrP, and characterized the response to a certain management routine of MF and CF. In other words, build physiological models.

This requires research in which performance data of individual cows are analyzed in response to MF and ICS manipulation. Another way is to predict physiological responses to MF and ICS manipulation by using state of the art physiological knowledge.

The two basic components that required for cows' PrP evaluation and physiological response to management changes are milk meters and a scale for on line body weight

(BW) measurements. These two along with routine milk composition measurements provide the parameters to estimate dry mater intake (DMI) (Halachmi et al. 1997) and body condition (BC) (Maltz et al. 2001). These, combined with physiological interpretations of the performance variables enable to assign MF and ICS accustomed to each cow which may vary along the dynamic process of lactation.

However, in order to translate the physiological knowledge by the possibilities offered by the AMS into an efficient management tool we still need to develop decision making capabilities that are based on the physiological models and are executed automatically. The AMS and other existing technologies are justifying the attempt to apply individual management.

METHODS

Measured performance (MY and BW) and calculated (DMI and BC) data of individual cows from a variety of trials the author was involved in were analyzed. Trials where:

- Both MF and IICS were manipulated (Devir 1995, Maltz et al. 1997(a,b).
- Only MF (Bar Peled et al. 1995).
- Only IICS (Maltz et al. 1991, 1992, Maltz et al 1997, Tavory et al. 1998, Morag et al., 2001) was manipulated.
- Cows were transferred between feeding groups (Maltz et al. 1992, Spahr et al. 1993, Grinspan et al.1994).
- Flat rate TMR feeding (Maltz et al. 1997).

Where manipulations took place, the response to changes of individual cows was carefully studied in relation to performance, PrP, lactation number and stage of lactation.

The PrP was defined as MY as percent of BW. Lactation and BW curves were analyzed for dynamic responses, such as rate of increase and decline as well as stability periods. Out of MY and BW the DMI (Halachmi et al. 1997) and BC (Maltz et al. 2001) were calculated.

In periods along lactation where there were no MF and ICS manipulations, the response of the cow was estimated in view that increased MF increases MY and vice versa (Hillerton, et al. 1990, Shoshani et al. 1999, Shoshani et al., 2000). Also response to decrease in IICS corresponded to a decline in MY and an increase in milk fat percentage (Maltz et al. 1991, 1992) Tavory et al. 1998).

RESULTS AND DISCUSSION

Production potential

Production potential (PrP) was indicated as a significant variable that can be used for decision making in different nutritional strategies (Maltz et al. 1991, 1992, Spahr et al. 1993, Grinspan et al. 1994, Morag et al 2001). However, the range of this value varies from herd to herd and certainly varies along lactation and among lactations

(Maltz et al 1997, Maltz 1997). Since we need this value as soon as possible after calving to decide about ration density (Spahr et al. 1993, Maltz et al 1997, Morag et al. 2001), we cannot wait until peak production to get a “standard” value (Spahr et al. 1993). Therefore, PrP is evaluated for every week after calving as a relative value. This has to be done for each dairy. Until the data are accumulated in a particular dairy, reference values can be used with caution. The cows’ PrP is ranked for every week after calving. The cows’ PrP were divided into thirds. The upper PrP third were high potential (HP), the middle third were medium potential (MP), and the lowest third were low potential (LP).

Basic conditions

In this paper it is taken for granted that cows start lactation in a satisfactory BC. It is suggested that the daily ration of concentrates should be divided into 6 diurnal feeding windows (FW) of equal amounts in equal 4 h durations (Livshin et al. 1955, Devir 1995). This way the cows can be attracted to the milking stall in interval suiting any MF from 2 to 6. Since the cows’ main motivation to visit the milking stall is concentrates, and all the cows have to receive some amount regardless their production level, it is suggested that the mixture distributed in the common trough will contain only forages or a mixture with a small amount of concentrates. This low energy density of the mixture will permit a wide range of ICS to satisfy the needs of the heavily supplemented cows corresponding with their MF on one hand, and of the low producing cows by limiting them in an amount that will not frustrate the cow that visits the milking stall on the other hand. The ration energy density (NEL) has to be defined in accordance to the available feedstuffs as well as the economical strategic goal of the dairy.

Transition time

This is the most sensitive period in lactation. Decision taken during this period can influence the whole lactation. The analysis of the data sets showed that the main problem is the contrast between high milk-production driving-force and limited ability to increase food consumption and mobilize energy reserves to balance the increasing energy drain via milk, which is reflected in lactation curve collapse. The approach of a lactation curve collapse can be foreseen by a big MY increasing rate on one hand and big rate of decline in BW on the other: In other words, big slopes of MY and BW curves that at this stage are almost linear. This situation, if unattended, brings to a sharp drop in MY and loss of production that usually stops the decline of BW. After a period that can last up to two weeks, MY increase is resumed after a recovery of BW indicating, in most cases, the increase of gastrointestinal tract made possible by reducing energy drain via milk (Maltz and Metz 1994, Maltz et al. 1997).

During the first week after calving, it is suggested that the same MF and ICS routines will be applied to all cows, but ready to be changed if exceptional performance that indicate difficulties in balancing the MY energy output is recorded. This is mainly related to big BW decline slope. The danger is magnified if MY increase slope is also large. MF after calving is suggested to be as high as the visiting behavior of the cow to the milking stall permits, but not more than 6 times a day. This is to induce the

carry over effect reported by Bar-Peled et al. (1995). During this period the ICS has to be at least 6 kg/d with left over turns only from one feeding window (FW). This amount will provide 1 kg of concentrates per visit suspended during 4 minute (a suspension rate of 250 g/min). The time concentrates will be fed to the cow will coincide with the milking time if the cow misses one FW (which is expected to happen in the first days after calving), and the amount not consumed in that FW, it is divided between the next 5 FW. ICS should be increased gradually, in parallel to the calculated increase in DMI, by 1 kg/d every two days until reaching 8 kg/d on day 6 after calving. On day 7 the PrP for the 1st week is assessed, and ration density is adjusted according to a predefined classification for the different PrP levels. At this stage, ICS policy should be in the direction of encouraging forage consumption, which means to provide ICS below the predefined level at first and top up to the predefined level only when alarming signs occur (see below). This policy is also aimed to prevent production of high amounts of low fat milk that is in contrast to most of the economical goals. Usually, during the first days, or even weeks, after calving we don't have a clue as for the milk composition and how is the MF and ICS routine affecting it. Therefore, at this stage we have to use an estimated milk composition versus time after calving curve, based on herd information, and assume that the milk composition until first milk test is the value located on that curve at any given time after calving until the first milk test. After the first milk test, the milk composition is evaluated by applying the milk composition curve coefficients to the values of the last milk test until the next milk test. This way the PrP can be evaluated as FCM production as percent of BW.

The high MF should be maintained until degree of the MY curve is changing from linear to polynomial when approaching peak production regardless the situation of BW curve. One possibility to assess this time was described by Maltz (1997). BW and MY curves are closely examined. When alarming signs occur such as a sharp decline in BW and if ICS is still below the upper limit, ICS is increased. If the situation does not improve or the cow fails to consume the full amount of ICS, then MF is reduced regardless the situation of the lactation curve. If ICS is already in the upper limit then MF is reduced immediately.

After transition time

The MF should be reduced to 3 times a day as soon as possible. The reduction rate should be weekly. Milking 3 times a day can be maintained for the rest of lactation unless: a) the milk composition of this cow is not fulfilling the economical goal, and reduction of ICS didn't improve it, and b) the cow fails to regain initial weight when approaching dry out. MF has then to be reduced to twice daily with a reduction in ICS that will lead to an increase in BC score on the account of milk production. ICS is adjusted after transition time to the PrP and is reduced in parallel with DMI. It is suggested that the amount of ICS fed to the cow at the stage when MF was reduced for the first time, be the maximal value even if the PrP ranking indicates otherwise, and the ICS thereafter should be reduced in from the maximal level. This routine can be carried out for cows that their performance variables indicate an efficient production.

Table 1. Performance variables measured and calculated that are used to design rules for milking frequency and concentrates supplementation to be applied to each individual cow

BW curve type
1. With trough
2. Straight
3. Increasing
Expressing cows ability to increase DMI at transition time
BW curve slope
1. Large, 1%/d or more,
2. Medium, 0.5-1%/d
3. Small less than 0.5%/d
Significant at transition time. Strongly effected by parity.
MY curve slope
1. Large
2. Normal
Significant at transition time. The range strongly effected by lactation number and nutrition.
Peak MY
Absolute value
Weekly average
Peak MY
Week after calving
BW trough
% of post calving weight
Weekly average
BW trough
Week after calving
Time related to peak MY
Time related to BW trough
Before or after
Before or after
Milk composition
Separate attitude to fat and protein
Time after calving
Week
MY curve slope
Positive, zero, negative
After trough
BW curve slope
Positive, zero, negative
After trough

After milk test ICS has to be adjusted in accordance with milk composition and the economical goals of the dairy. For example: if the goal is to produce high fat milk than for cows with low fat ICS will be reduced and MF as well if need be. On the other hand increasing ICS will encourage a cow with favorable composition. MF will be increased after reduction only if there is an unplanned demand for milk. At this case, it will be increased only for pregnant cows that their BW is increasing and above 95% of post calving weight in the second half of lactation. Performance of these cows should change within one week after the change of routine. If it does not, MF will be reduced. An increase in ICS will be provided only for the cows that the

increase in MF stopped the increase in BW. If the ICS increase will not resume BW gain, than the policy for this cow will be reevaluated in view of the need to regain BW until drying of and the economical goal. In any case MF can be reduced accordingly at the proper time to allow that.

The variables that have to be considered for the MF and ICS decision rules are summarized in Table 1. This are modified from Maltz et al. (1992) and Grinspan et al. (1994).

In order to incorporate these variables into rules of the kind described above, ranges, margins, and limits have to be applied. This requires a substantial amount of research. However, even if we'll have all the rules tested and working, we still need a decision making process that will analyze the data and execute the decision. For this we need an expert system in which the performance data will be analyzed according to the physiological models structured after testing and executing the MF and ICS decisions according to the predefined economical goal.

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AUTOMATIC MILKING: FARM ECONOMIC ASPECTS

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Introduction

From the 1970's research of automation on dairy farms started with the development of reliable cow identification systems. The first applications were automatic concentrate feeders. With the introduction of milk yield recording equipment, automation started also in the milking parlour. At the same time, developments of milking technology reduced labour input during milking. In a well-equipped milking parlour, the tasks of the milker are limited to attachment of the teat cups and control of the milk and the cow. To study the last step in total automation of the milking process, in the mid 1980's a concentrate feeder was used to build a 1 cow milking parlour. Cows could enter the concentrate feeder 24 hours a day. When cows entered, the milking cluster was attached manually. This first experiment showed that, in principle, it would be possible to automatically milk a cow in a concentrate feeder (Rossing et al., 1985). The last and most challenging step in the complete automation of milking was the development of automated cluster attachment. In the beginning of the 1990's, a series of cluster attachment principles were in development. Finally, in 1992 the first automatic milking systems were installed at commercial dairy farms in the Netherlands. Since that time, developments have gone fast. In Europe, almost all dairy equipment companies have an AM-system in their range of products and AM has become a fact instead of fiction. In the first years, the number of farms with an AM-system did not increase very rapidly. From 1998, in the Netherlands AM became an accepted technology by a large part of the dairy sector and also other countries adopted AM-systems. In January 2001, world-wide more than 700 commercial farms used one or more AM-systems to milk their cows (Hogeveen et al., 2001). Many farms have, because of the number of cows to be milked, more than one milking stall on their farm. Therefore, the number of sold AM-systems is much higher than 700. Most dairy farms with an AM-system can be found in the Netherlands. And more than 90 % of all dairy farms with an AM-system are located in north-western Europe (Hogeveen et al., 2001).

Since dairy farms are economic enterprises and the investments in an AMS are

higher than in a traditional milking parlour, economics will play a role. This paper gives a broad overview of the published studies on the economic aspects of automatic milking.

Economic studies

Five studies were found on economic aspects of automatic milking: Arendzen and van Scheppingen (2000), Armstrong and Daugherty (1997), Cooper and Parsons (1999), Dijkhuizen et al., (1997) and Pellerin et al. (2001).

In the study of Arendzen and van Scheppingen (2000), the cost-effectiveness of an AMS compared to a traditional milking parlour is calculated using the room for investment (RFI) methodology. The RFI is the total amount of money which may be invested in an AMS on the farm so that the yearly income will remain the same as with an traditional milking parlour. The calculations are based on the farm simulation model BBPR of the Research Institute for Animal Husbandry in the Netherlands (Mandersloot et al., 1999). The following factors are used in the calculations to compare an AMS with a milking parlour: returns from an increase in milk yield, savings in labour costs, annual costs (price of the milking parlour, annual costs for maintenance and depreciation of the AMS based on price and maintenance). The basis farm consisted of 133 cows with 1.000.000 kgs of milk quatum. Basic calculations assumed a decrease in labour costs with 10%, an increase in milk production per cow of 10 % and the annual costs of the AMS were assumed to be 25 % of the replacement value of the AMS.

The study of Armstrong et al. (1992) and Armstrong and Daugherty (1997) was directed at large farms in the US situation. Since at the time of the study, no prices of AMS were available, the study is based upon cash outflows (capital investment, capital replacement and pertinent costs) of 4 types of milking parlours for a 15 year planning period for a 500 cow and a 1500 cow herd. It was calculated that the labour costs did not change much when changing from 2 to 3 times per day milking. Therefore, no milk production increase was expected and labour savings should pay the additional costs for an AMS. This latter assumption is rather strange in the eyes of the authors.

Cooper and Parsons (1999) carried out a cost-benefit analysis in which they calculated the extra profit of an AMS compared to a milking parlour with a high level of automation. The yearly profit minus the annual costs for the milking equipment was calculated for a farm with an AMS and a farm with a milking parlour. The differences were compared. Profits were defined as milk sales minus labour costs, feeding costs and other costs. The latter is assumed to be equal for both type of farms. Calculations were made for a farm of 125 cows. An increase of milk production of 10-15 % was assumed and a decrease in labour was estimated at 18%. This is under the assumption that a conventional farm is grazing the cows and the AMS has a zero-grazing system.

Dijkhuizen et al. (1997) used capital budgetting procedures to calculate the room for investment. By cumulating the yearly net return (after tax), the remaining value of the system and the investment costs, the net present value of a system (either AMS or a milking parlour) is calculated. Because of differences in the depreciation time of an AMS and a milking parlour, yearly net return was standardised. In this study a decrease of labour for milking of almost 70 % and an increase of milk production of 10 to 15 % were assumed. The increase in milk production was combined with a decrease in fat and protein content of 0.15 %.

Pellerin et al. (2001) have calculated the cost-effectiveness of an AMS using partial budgetting for a farm of 50, 100 and 200 cows. With partial budgetting only the additional costs and benefits of a system are compared and calculated. Basic assumptions were a decrease of labour of 50 % for milking, an increase of milk production of 5 %, an increase of energy consumption of 50 %, an increase of feeding costs of 0,25 \$Ca per hectoliter milk, an increase in calving interval of 10 days and an increase in penalties for milk quality of 8 %.

Results and discussion

The room for investment, as calculated in the various studies with the input described above, is presented in Table 1. It can be seen that the RFI differs between the studies. The study that has been carried out for large dairies under US circumstances came with a very low RFI. The outcome of both Dutch studies are rather well comparable. The UK study gave the highest room for investment. However, in this study a rather large change in management was assumed, changing from grazing to a zero-grazing system. Keeping in mind the investment for a one-box system (for approximate 60 cows) of Euro 135,000,-. It seems that the additional returns do not offset the additional costs. The study for Québec did not give a room for investment calculation (Pellerin et al., 2001). In this study, the net farm income (including labour) was calculated. The net farm income was calculated to be lower for a farm with an AMS than for a farm without an AMS. The difference varied from \$Ca 5,500,- for a 50 cow herd to \$Ca 43,500 for a 200 cow herd.

Table 1. The room for investment (* 1,000 Euro) as calculated by A: Arendzen and van Scheppingen (2000), B: Armstrong and Daugherty (1997), C: Cooper and Parsons (1999), D: Dijkhuizen et al. (1997) and E: Pellerin et al (2001).

	A	B		C	D	E		
country	NL	USA		UK	NL	Canada (Québec)		
# cows	133	500	1500	86	125	50	100	200
RFI	125	233 ¹	189 ¹	175	141	? ²	? ²	? ²
RFI/60 cows	56	27	7	122	67			

¹Assuming an investment life of 10 years

²Not known

Preliminary calculations for the mid west region in the US showed a positive effect of automatic milking on the cost price of milk (Reinemann and Jackson Smith, 2000). Based on these calculations, Rodenburg and Kelton gave also a positive evaluation the introduction of automatic milking in Ontario (Canada). However, these calculations are difficult to verify.

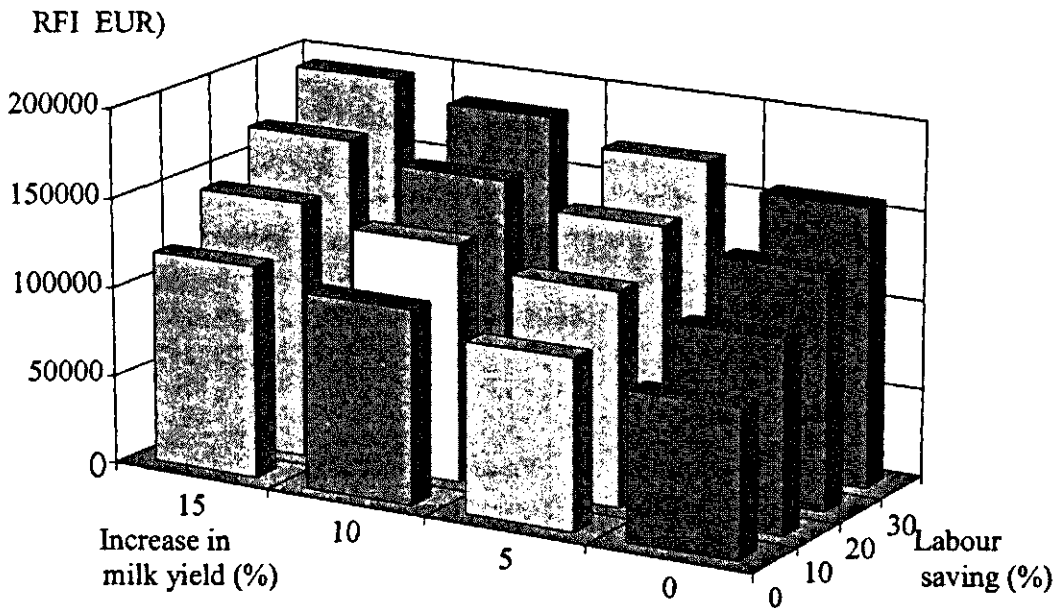


Figure 1. Room for investment with increase of milk yield varying from 0 to 15 % and labour savings varying from 0 to 30 %, given an annual cost of an AMS of 25 % of the replacement value.

The cost-effectiveness of AMS is very dependent on technical results. Figure 1 gives results of a sensitivity analysis of Arendzen and van Scheppingen (2000). Both labour savings and increase in milk production have been varied. The difference between the maximum and minimum RFI is more than Euro 110,000,-. This shows that technical results obtained with automatic milking are a very important factor in the cost-effectiveness of the AMS. This subject needs attention in the future. Moreover, the technical farm results of farms with an AMS are not precisely known and those are important to be able to calculate the cost-effectiveness of the investment. At the Farm Management Group of Wageningen University, in cooperation with the Research Institute of Animal Husbandry, a study is carried out to calculate the cost-effectiveness of automatic milking using technical results from the Dutch practise. These calculations will be carried out using a linear programming (LP) model of a dairy farm designed by Berentsen and Giesen (1995). Using this LP model, labour income is maximised.

The difference in labour savings between 0 % and 30 % saving of labour is Euro 74,000 (Figure 1). However, from a farm-economic point of view labour savings only add to the net farm income, when there is an alternative usage for the labour or when less labour has to be hired. This adds to the fact that even with labour savings

taken into account the investment in an AMS is not cost-effective. However, many farmers have invested in an AMS. There must be other reasons to do so. Important reasons might be the change of labour load. Milking has to be carried out twice a day, 7 days a week at unsocial hours. Replacing this labour might be worth much money. Moreover, in some countries it becomes more and more difficult to hire skilled labour force and an AMS might help with that. On family farms, the difficulties to hire labour (administrative tasks, social security premiums, the risk of illness etc.) might be an incentive to invest in an AMS. Finally image might play a part, especially in the first farms investing in an AMS (Meskens et al., 2001).

In general, one of the key factors influencing the adoption process is the perceived economic gains that producers will reap from technology. This stresses the importance of cost-effectiveness, especially now that the early adopters have already invested in an AMS. Moreover, it is expected that in EU countries the milk price will drop in the near future, which will make the dairy farmer more conscious of the cost price of milk.

Conclusions

From several desk studies, all based upon assumptions, it is clear that from a pure farm-economical point of view investment in an AMS is not cost-effective. However, many dairy farmers have invested in automatic milking indicating that there are other reasons besides pure farm-economical reasons to invest in an AMS.

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