Milk Quality on Farms with an Automatic Milking System

Effects of Automatic Milking on the Quality of Produced Milk

February 2002

Information

This report is produced within the EU project *Implications of the introduction of automatic milking on dairy farms* (QLK5 -2000-31006) as part of the EU-program 'Quality of Life and Management of Living resources'.

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February 2002
Deliverable D8

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Abstract

As part of work package 4 within the European project 'Implications of the Introduction of Automatic Milking on Dairy Farms' recent milk quality data from farms with an automatic milking system (AM-system) were analysed for four consecutive groups (based on date of installation) and compared to data from conventional farms.

Data of 99 Danish farms, 33 German and 262 Dutch farms were included and analysed for possible relations and courses in the milk quality from January 1997 until January 2001. Data of Dutch farms that milked twice (n=295) or three times a day (n=40) in conventional milking parlours during the same period, were used as controls.

Milk quality was slightly lower when milking with an automatic milking system, in all three countries. The poorest levels of all measured parameters were found in the first six months after introduction of the AM-system. After this period the milk quality improved slightly and all farms then produced to a stable level (with exception of free fatty acids (FFA)). However, other than bulk milk somatic cell count (BMSCC), the quality from farms with an AM-system remained slightly lower than from conventional farms. Differences between farms were seen both in averages and in variance. This, together with the knowledge that the milk quality improves about 6 months after introduction indicates that improvements are possible.

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Introduction

Automatic milking (AM) in Europe has evolved rapidly after the introduction on the first commercial Dutch dairy farms in 1992. AM is widely accepted and works satisfactory, however, it requires significant changes to the farm management.
An AM-system is in use for 24 hours per day, it needs different machine cleaning and milk cooling procedures, complicates visual inspection of milk and udders and the milking frequency varies from cow to cow and from day to day.
One of the aspects affected by AM is milk quality. Milk payment systems and consumer acceptance are, to a great extent, based on milk quality. Automatic milking is a fully automated process. In addition, visual inspection of the milk is not possible as with conventional milking. Therefore, the milk quality needs to be managed in a different manner. Several devices are integrated in different AM-systems in order to provide information on the (udder) health status and yield. These may include sensors for conductivity, colour and temperature of the milk, indicators for yield and data on the milking machine performance. These devices mainly serve for prevention of high BMSCC. Methods to detect other changes in milk quality are not available.
Previous research has elucidated that the milk quality on farms with an automatic milking system was significantly poorer when compared to the milk quality in the period before the introduction of the AM-system and compared to the milk quality of farms with conventional milking parlours (Billon, 2001; Klungel *et al*, 2000; Justesen and Rasmussen, 2000; Pomies and Bony, 2000; Van der Vorst and Hogeveen, 2000). All the studies showed an increase in the total plate count (TPC). Results on bulk milk somatic cell count (BMSCC) were not always consistent. The study by Van der Vorst and Hogeveen (2000), showed a significant increase in TPC, free fatty acids (FFA), bulk milk somatic cell count (BMSCC) and the freezing point (FP) after the introduction of the AM-system. Justesen and Rasmussen (2000) found similar effects.
Experience with automatic milking, built up over several years, may allow adjustments by the dairy, the robot industry and the farmer, resulting in a better overall milk quality.

As part of work package 4 within the European project 'Implications of the Introduction of Automatic Milking on Dairy Farms' recent milk quality data of farms with an AM-system were analysed. The development of the milk quality on farms with an AM-system in three countries and installed at different times over a number of years, was studied.

1 Material and Methods

1.1 Selected farms

All farms using an AM-system between February 2001 and October 2001 were selected in Denmark (DK), Germany (G) and The Netherlands (NL). These countries represent respectively partners 3, 2 and 1 of the EU project and were chosen based on the considerable number of farms with an AM-system present at the start of this study (January 2001). The farm addresses were collected with help of the suppliers of automatic milking systems (partners 8, 9 and 10 and three additional partners) and the dairy industry. For Denmark, Germany and The Netherlands respectively, 110, 123 and 325 addresses were received. The groups represented more or less all of the farms with an AM-system in these countries. With the consent from involved farmers, the milk quality data were collected from available databanks (Denmark) and with the help of regional (Germany) and national (The Netherlands) milk control stations or laboratories. In total 99 Danish, 33 German and 262 Dutch farms were included in this study, representing approximately 90%, 25% and 80% of the total population of AM farms in the selected countries. The percentage of German farms was low. In spite of much effort from researchers and industry, it was difficult to find German farms to co-operate. So, those excluded were farms either not willing to co-operate, were misidentified (improper farm numbers) or milked both with a conventional milking parlour and an AM-system.

1.1.1 Grouping

In the study of Van der Vorst and Hogeveen (2000) different 'generations' were defined. These generations referred to the date of installation of the AM-system on the farm. Because differences between the generations were found, and to be able to compare the outcomes found by Van der Vorst and Hogeveen (2000), similar groupings were used in this study. However, instead of 'generations' the term 'groups' is used throughout this report. The word ‘generations’ is not the correct terminology since the division into groups does not cover consequent time spans of installation dates. The groups are presented below, based on their installation dates:

AM1) Before January 1, 1998
AM2) January 1, 1998 - March 31, 1999
AM3) April 1, 1999 - June 30, 2000
AM4) July 1, 2000 - December, 2000

The fourth group of farms represented a group that recently switched to AM. These farms were still in a transition period and only a maximum of 6 months of data, after the introduction of the AM-system, was available (with exception of Danish BMSCC data, 9 months were available). Therefore, results presented on this group (AM4) should be interpreted with care. Furthermore, it must be said that for all German farms, only a maximum of 6 months of data before the introduction of the AM-system was available, while for Danish and Dutch data a maximum of 4 years was available. Other remarks to be made was that no farms introduced an AM-system in Denmark before 1998. Regarding the German data only one of the selected farms introduced its AM system before 1998. Both AM1 groups for Denmark and Germany will for this reason not be presented in the results of model [2] (analysis differentiating between AM1…AM4), however the one specific German farm is included in the overall statistical analysis of model [1] (comparison before vs. after introduction). For the Dutch farms the AM1 group, including 27 farms, is presented and used in the analyses. However, only a maximum of 12 months of data before the introduction of the AM-system was available. Due to these limitations for groups AM1 and AM4, most attention should be focussed on the AM2 and AM3 groups, which have a fairly comparable time-interval before and after introduction of the AM-system. The models are described in paragraph 1.3.

Two control groups were used. One group of 295 Dutch farms, milking two times a day (C2), was randomly selected. The second control group consisted of all Dutch farms (n=40) milking three times a day (C3) with a conventional milking parlour. Data from comparable control groups for Denmark and Germany were not freely accessible and therefore difficult to collect. As a result, it was chosen to present the national averages of all dairy farms in these countries as a reference to the outcomes of the AM farms. For the Danish averages of TPC and BMSCC the overall average was calculated from the monthly national averages from 1997 until 2000 supplied by the Danish Institute of Agricultural Sciences. For the German averages of TPC and BMSCC the overall average was calculated from the yearly national averages from 1997 until 2000 taken from the surveys from Arbeitsgemeinschaft Deutscher Rinderzüchter. These calculated averages were not included in the statistical analysis.

1.2 Data collection

Bulk milk quality data from January 1997 until December 2000, were collected for every selected farm (for German farms only max. 6 months before introduction - see paragraph 1.1). Milk quality parameters were: total plate count (TPC), bulk milk somatic cell count (BMSCC), freezing point (FP) and free fatty acids (FFA).

The TPC is a measurement for the bacteria present in the milk, the BMSCC a measurement of udder health status of cows delivering milk to the bulk tank, the FP provides an indication of the amount of water in the milk and the FFA is an indication for the amount of enzymatic or mechanical damage of milk fat. Low levels of these parameters stand for good milk quality.

In each country, the sampling frequencies and methods to analyse milk differ. Table 1 provides a summary of these differences.

Table 1 Available milk quality data, frequency of sampling and determination method per country involved

	Denmark		Germany		The Netherlands	
	Frequency	Determination*	Frequency	Determination*	Frequency	Determination*
TPC	Every wk	BC 8000	Every 2 wks	BC-8000 or BC-FC	Every 2 wks	BC 8000
BMSCC	Every wk	Fossomatic	at least every 4 wks	Fossomatic	Every 4 wks	Fossomatic
FFA	-		-		Every 6 mnths	Titration
FP	-		Every 2-4 wks	Milk composition/ Cryoscopic	Every 6 mnths	Cryoscopic

*BC 8000/BC-FC=Bactoscan 8000 and Bactoscan FC = fluorescence method; Fossomatic = fluoro-opto-electronic method; Titration = titration according to provisional Dutch standards (NEN 6854, 1988); Cryoscopic = cryoscopic determination with 22 seconds constant plateau-time (ISO 5784, 1986)

To inform table 1:

1) In Denmark and Germany milk is collected every day or every second day. This depends on the different dairies (Knappstein, 2001; Rasmussen, 2001). In The Netherlands milk is collected every third day. The time of storing and cooling of milk before determining the milk quality will influence the type of flora in the milk, and thus the TPC. In general when storing milk for a longer period of time below 4 ^{o}C, more psychotrophic bacteria will be found in the milk. Therefore different conversion factors for calculating TPC from bactocounts are applied in the three countries.
2) During the data collection period (01-'97 till 12-'00) the determination procedure for TPC (Bactoscan) in Germany changed from BC-8000 to BC-FC. Conversion factors between the two methods have been established to provide comparable results within Germany (Suhren et al., 2000). However, this change in methods over time makes it very difficult to compare the TPC of Germany with Denmark and The Netherlands. Denmark and The Netherlands both use BC-8000 which makes their results comparable, however the difference in milk collecting interval and thus the differences in flora should still be taken into account.
3) Due to the conversion characteristics for Bactocounts into colony forming units (cfu), in Germany the TPC below 10.000 cfu/ml is not differentiated. For Danish and Dutch data, TPC below 10.000 cfu/ml are differentiated.
4) In this study it is assumed that the methodology behind somatic cell count figures is comparable between the countries (Van den Bijgaart, 2001).

5) Comparable methods are used to determine FP in the Netherlands and Germany. However, the FP seems to have a constant difference of 0,005 degrees Celsius when comparing the two countries (Buchberger, 1994; Van den Bijgaart, 2001; Slaghuis, 2001). Though, no scientific studies have been published to prove this difference and explain the causes. Therefore, it was chosen to present the original values of both countries, thus not correcting for the 0,005 degrees. This is possible since the three analyses are performed per country anyhow.

1.3 Data analysis

Before analyses, all data were checked for unlikely values (farms without data, incorrect sample dates, etc.). To approximate the normal distribution, TPC, BMSCC and FFA were transformed with a natural logarithm (Ln). For FP the absolute values were used.
Descriptive analysis was accomplished by tabulation of the data. Using the method of residual maximum likelihood (REML), the relationship between the selected milk quality parameters and milking with an AM-system was modelled. The REML algorithm is a linear mixed model with both fixed and random effects. All statistical analyses were performed using Genstat™ statistical software (Genstat version 4.2, 2000). Both, for the descriptive analyses as for the REML, individual values were used (with exception of model [3], see below).
In general the differences in flora, determination procedure and apparatus for several milk quality parameters (see paragraph 1.2) in the three countries involved make it improper to analyse the results from all the AM farms in all countries as one group. Therefore, all three analyses are performed per country. The following models were fitted:

$$Y_{ijklm\,(AM\,farms)} = \mu + BA_k + FTB_{ijlm} + \varepsilon_{ijklm} \quad \textbf{[1]}$$

$$Y_{ijklm\,(all\,farms)} = \mu + TYPE_k + FTB_{ijlm} + \varepsilon_{ijklm} \quad \textbf{[2]}$$

$$Y_{ijklm\,(all\,farms)} = \mu + PERIOD_k + TB_{ijm} + \varepsilon_{ijklm} \quad \textbf{[3]}$$

Where:

Y_{ijklm}	= Level of milk quality parameters TPC, BMSCC, FP and FFA
μ	= Overall mean
BA_k	= Fixed effect of the time before and after the introduction of the AM-system k (k = <0 or >0, resp. before or after introduction)
$TYPE_k$	= Fixed effect of farm type k (k = AM1, AM2, AM3, AM4, 2x farms (C2) or 3x farms (C3))
$PERIOD_k$	= Fixed effect of period in days after introduction (k=0…183, 184…365, 366…548)
FTB_{ijlm}	= Random effect of month of milk sampling i (i = 1, 2…12) times year of sampling j (j = 1997, 1998, 1999, 2000), within farm l (l = 1, 2…729 for all farms and i = 1, 2…394 for AM farms) plus make m of AM system (m = AMS liberty, Galaxy, Lely Astronaut, Leonardo, Manus, Merlin, VMS and Zenith for AM farms).
TB_{ijm}	= Random effect of month of introduction i (i = 1, 2…12) times year of introduction j (j = 1995…2000) plus make m of AM system (m = AMS liberty, Galaxy, Lely Astronaut, Leonardo, Manus, Merlin, VMS and Zenith for AM farms).
ε_{ijklm}	= Rest variance

The relative importance of the fixed and random effects included in the model was evaluated by means of the level of significance and the percentage of explained variance. The inclusion of the random effects month, year, farm and make of the AM-system within FTB_{ijlm}, corrects for constant variations caused by one of these factors. Effects per random factor are thus not modelled and therefore not estimated.
In model [1] the period before (milking conventionally) and after the introduction of the AM-system is compared with the milk quality in those periods.
In model [2] the milk quality is modelled for the period after the introduction of the AM-system per group (AM1…AM4) compared to the conventional farms (C2, C3). This is done based on the components of variance within and between farms, relative to the total variance of the data-set.

In model [3] every milk quality parameter is estimated, every 6 months after the introduction of the AM-system with a maximum of 2 years. This provides more insight into significant changes over time after the introduction of the AM-system. To use this model the conventional farms were all given a fictitious date of installation to correct for the influence of year effects.
All three models were calculated per country.

2 Results and Discussion

2.1 Model [1] - 'before vs. after'

The results from model [1] are presented and described in the paragraphs below. The results are given as predicted means (PM) from the models (calculated from individual Ln transformed values) and the recalculated means (RM) (inv Ln of predicted mean). The results from model [1] are presented in Table 2. The average of conventional farms are also presented as a reference however are not statistically tested in model [1], this is done, where possible, in model [2] (see paragraph 2.2).

2.1.1 Before introduction versus conventional milking

Before introduction of the AM-system all farms had similar milk quality considering the different AM groups amongst each other (AM1…AM4) and comparing the AM groups to the farms with parlour milking (latter comparison only analysed for Dutch farms).
Before introduction of the AM-system the TPC was comparable in Denmark and The Netherlands to that on conventional farms (farms milking with a parlour). For Germany the TPC appeared lower before the introduction of the AM-system than the given national average, however this could not be analysed statistically, since the underlying data were not available. Furthermore, it must be considered that only an estimate of about 25% of all German farms with an AM-system were included in this study, and thus it cannot be concluded that this is a representative group of all German AM farms.
Both in Denmark and in Germany the BMSCC of the AM-farms before introduction seemed to be slightly higher than the national average BMSCC. Unfortunately, as with TPC, no data were available to analyse this difference for these countries. However, the Dutch BMSCC of the AM farms before the introduction in comparison to the conventional of Dutch conventional farms, showed no significant difference.
The Dutch farms using parlour milking do mutually not distinct between their milk quality parameter levels, with exception FFA. The Dutch conventional farms that milked three times daily had a higher level of milk FFA than those milking twice per day. This was also concluded in earlier studies by Van der Vorst and Hogeveen (2000). It is known, that the milking frequency can influence the FFA level in the milk (Klei *et al,* 1997).
For, the freezing point only the figures of conventional Dutch farms were available. Before introduction, the freezing point of the test farms (going to switch to AM) was comparable to that on the Dutch conventional farms.

2.1.2 Before introduction versus after introduction

For all three countries and all milk quality parameters (TPC, BMSCC, FP, FFA) the milk quality was slightly but significantly poorer after introduction of the AM-system in comparison to before, with exception of the German BMSCC. Here no significant difference was found between before and after introduction. An average increase (deterioration) for most parameters has been shown before by several authors (Billon, 2001; Klungel *et al*, 2000; Justesen and Rasmussen, 2000; Pomies and Bony, 2000; Van der Vorst and Hogeveen, 2000).
With regard to TPC the largest relative increase was found in The Netherlands and Denmark. Germany showed the smallest increase. Furthermore, since the level of TPC after the introduction on German AM-farms was close to the average German TPC for conventional farms it cannot be concluded that German AM-farms had a higher TPC than German conventional farms. However, this was not tested statistically. Furthermore, it appeared that the absolute TPC levels were higher than of the other two countries involved. This may be due to the differences in determination and conversion methods as described in paragraph 1.2.
As mentioned above, the BMSCC on German farms showed no significant difference between the period before and after the introduction of the AM-system. The largest relative increase of BMSCC was found in The Netherlands. However the Dutch level after introduction was equal to the German

level after introduction. The Danish farms showed a relatively small but significant increase. Since all countries use similar determination methods for BMSCC it may be concluded that the average level of BMSCC in Denmark of both conventional and AM farms is highest of all countries analysed. Denmark has recently introduced a self-monitoring program to reduce the BMSCC. This will be discussed further in paragraph 2.3.
The FP increased significantly after introduction of the AM-system both in Germany and The Netherlands by about 0,005 °C. It can be concluded that the dry matter content is lower in milk produced on farms milking automatically. One cause can be that more water gets into the milk. This may be a continuation of the higher number of cleanings and less drainage time when milking automatically. However, more factors may influence the FP of milk, examples are, lack of energy or protein in feed can increase FP but also season and stage of lactation have its effects on FP (Braathen, 1976).
The FFA in the Netherlands showed a significant increase after introduction. It is known that an increase of the milking frequency increases the levels of FFA (Klei *et al*, 1997; Jellema, 1975). On average the milking frequency increases from two times daily to 2,3-3 times daily when milking automatically. Besides this effect of milking frequency, other factors such as air inlet, freezing of milk, older cows and late lactating cows, may increase FFA (Jellema, 1975; Jellema 1980)
Besides an increase of the averages for most levels for practically all parameters the variance increases after introduction, both within and between farms. This was also found in earlier studies (Van der Vorst and Hogeveen, 2000).

Table 2 Predicted (PM) and recalculated means (RM) before versus after the introduction of the AM system (model [1]), with figures from conventional farms as reference.

Country	Group	No. of farms	No. of values	TPC Cfu/ml		BMSCC Cells/ml		FP °C	FFA Mmol/100 g fat	
				PM	RM	PM	RM	PM	PM	RM
DK	C2*	All	-	-	9.000	-	246.000	-	-	-
	Before	99	9731	$2{,}080^x$	8.000	$5{,}558^x$	259.000	-	-	-
	After	99	5654	$2{,}633^y$	14.000	$5{,}633^y$	279.000	-	-	-
G	C2*	All	-	-	21.000	-	181.000	-	-	-
	Before	33	1263	$2{,}835^x$	17.000	$5{,}302^x$	201.000	$-0{,}526^x$	-	-
	After	33	4207	$3{,}033^y$	21.000	$5{,}313^x$	203.000	$-0{,}521^y$	-	-
NL	C2*	295	28741	1,995	7.000	5,169	176.000	-0,521	-0,8142	0,44
	C3*	40	3786	2,016	8.000	5,214	184.000	-0,522	-0,5870	0,56
	Before	262	15739	$2{,}006^x$	7.000	$5{,}138^x$	170.000	$-0{,}522^x$	$-0{,}9310^x$	0,39
	After	262	9111	$2{,}559^y$	13.000	$5{,}320^y$	204.000	$-0{,}517^y$	$-0{,}5569^y$	0,57

*shaded sections not included in model / x and y = averages with different superscripts within each column and country differ significantly ($p<0{,}05$)

2.1.3 Penalty points before versus after introduction

The European limit for TPC (100.000 cfu/ml) and BMSCC (400.000 cells/ml) are laid down in legislation (Council Directive 92/46/EEC). Several countries employ their limits based on geometric averages over 2 or 3 months. The German penalty limit for FP is dependent on the dairy company (usually -0,515°C). The Dutch limit is -0,505°C. The Dutch limit for FFA is 1,0 mmol/100 g fat. From the figures in table 2 it can be concluded that, the milk quality in all three countries slightly deteriorates after the introduction of the AM-system. Analogous to this is the percentage of milk deliveries exceeding the European or National penalty limits after the introduction of the AM-system in comparison to before introduction as is presented in table 3. These figures are based on individual bulk tank milk samples.

Table 3 Percentage (%) of samples of individual bulk tank milk samples exceeding penalty limits before versus after the introduction of the AM-system

Country	Group	TPC Cfu/ml	BMSCC Cells/ml	FP °C	FP °C	FFA Mmol/100 g fat
		>100.000	>400.000	>-0,505 (NL)	>-0,515 (G)	>1,0
DK	Before	0,8%	9,1%	-	-	-
	After	2,5%	11,1%	-	-	-
G	Before	2,9%	6,0%	-	3,1%	-
	After	7,7%	9,3%	-	7,5%	-
NL	Before	0,8%	2,4%	0,4%	-	1,6%
	After	2,8%	5,5%	1,4%	-	7,3%

2.1.4 Evaluation of effects

For all countries similar effects within model [1] can generally explain the variation in the levels of TPC, BMSCC, FP and FFA. After introduction, on average 27 % percent of the variation in TPC could be explained by differences between farms and 22% by the interaction of farm and time effect. Almost 50% could not be explained by variables included in the model. With regard to BMSCC, an average of 34% of the variation could be explained by the farm differences and 36% could be explained by the interaction of farm and time effect. For FP 69% could be explained by farm effects and 23% by the interaction of farm and time effects. For the last parameter, FFA, 41% could be explained by farm effects and 26% by the interaction of farm and time effect.
Therefore, farm and time differences seem to have significant affects on the milk quality. The farm effects can be considered as the most complicated effect. Numerous factors are included in this effect such as, management aspects, housing aspects, type of make, milk yield, etc. The variation between farms indicates that improvement is possible.

2.2 Model [2] – 'differences between groups'

Practically no significant differences were found between the four AM groups (AM1…AM4) as analysed using model [2]. However, comparing the AM and the conventional groups significant differences were found.

2.2.1 Averages of four AM groups and conventional farms

Table 4 provides more insight into the course of the milk quality after the introduction of the AM-system depending on the time of installation (model [2]).

Table 4 Predicted (PM) and recalculated means (RM) of every milk quality parameter after introduction (AM1…AM4) of the AM system in comparison to conventional farms

Country	Group	No. of farms	No. of values	TPC Cfu/ml		BMSCC Cells/ml		FP °C	FFA Mmol/100 g fat	
				PM	RM	PM	RM	PM	PM	RM
DK	C2*	All	-	-	9.000	-	246.000	-	-	-
	AM2	23	2402	2,707[a]	15.000	5,624[a]	277.000	-	-	-
	AM3	44	3252	2,868[a]	18.000	5,657[a]	286.000	-	-	-
	AM4	32	615	2,677[a]	15.000	5,745[a]	312.000	-	-	-
G	C2*	All	-	-	21.000	-	181.000	-	-	-
	AM2	12	1978	2,930[a]	19.000	5,286[a]	198.000	-0,521[a]	-	-
	AM3	18	1768	3,140[a]	23.000	5,383[a]	218.000	-0,520[a]	-	-
	AM4	2	22	2,690[a]	15.000	5,306[a]	202.000	-0,520[a]	-	-
NL	C2*	295	28741	1,995[a]	7.000	5,169[a]	176.000	-0,521[a]	-0,8142[bd]	0,44
	C3*	40	3786	2,016[a]	8.000	5,214[a]	184.000	-0,522[a]	-0,5870[ac]	0,56
	AM1	27	2335	2,733[b]	15.000	5,264[ab]	193.000	-0,519[a]	-0,5576[ab]	0,57
	AM2	56	3071	2,531[b]	13.000	5,250[a]	191.000	-0,519[a]	-0,5706[ab]	0,57
	AM3	122	3323	2,690[b]	15.000	5,382[b]	217.000	-0,519[a]	-0,6405[ab]	0,53
	AM4	57	382	2,625[b]	14.000	5,401[b]	222.000	-0,518[a]	-0,8355[cd]	0,43

*shaded sections not included in model / x and y = averages with different superscripts within each column and country differ significantly ($p<0{,}05$)

The averages of all studied parameters after introduction of the AM-system on farms with different installation dates (groups AM1…AM4), showed no significant differences for the Danish and German dairy farms. This is similar for TPC and FP on the Dutch farms. The Dutch BMSCC was significantly higher for the AM3 and AM4 farms compared to the AM2 and the conventional farms. Furthermore, after introduction the BMSCC of Dutch AM1 and AM2 showed no difference to the conventional farms.

No significant difference was seen between the FP of the conventional farms and the AM farms. The fact that no significant differences were found can most probably be explained by the increase of variation after the introduction of the AM system. Working with smaller numbers, by dividing the AM farms into four groups, and due to the fact that FP is determined less frequently than TPC and BMSCC (see table 1) the variance is relatively higher and therefore results in non-significant differences. However, the tendency could be seen that FP is slightly higher for AM farms (as corresponding with model [1]).

Furthermore, the Dutch AM4 group showed a significantly lower FFA than AM1, AM2 and AM3. The FFA level in milk from the conventional farms was similar to the levels of all AM groups. However, as with FP, the FFA appeared to show a tendency to be higher for AM1…AM3 in comparison to the conventional farms that milk twice daily. The low level for AM4 was unexpected and does not compare with more recent results from the Dutch Milk Control station. When comparing this figure with the Dutch FFA level average of 0,75 mmol/100 g fat for all AM farms in the autumn of 2001 (Van den Bijgaart, 2001), AM4 does not indicate an improvement of FFA. The lower level of the AM4 group is based on a very limited number of data. A maximum of one measurement per farm was in included in this group. Therefore, a sensible conclusion on the course of FFA over the different groups should be drawn without considering AM4.

Less differences were found between the different groups of farms (AM1…AM4) according to their date of installation in contradiction to earlier results where difference were shown between the AM1 and AM2 group (Van der Vorst and Hogeveen, 2000). In comparison to that study, the present study had more data available over a longer period before and after introduction of the AM-system (max. 4 years). To gain more insight into the period after introduction, the patterns for every parameter were studied further. These are presented in paragraph 2.3.

2.3 Model [3] – 'courses after introduction'

Within model [3] the averages for three 6-month periods after the introduction of the AM-system were calculated by group and by country. These averages were corrected for time effects. Before discussing the results, it must be noted that the AM4 group could only be tested during the first 6 months due to limited available data after that period. The limited data result in larger standard errors, making it difficult to indicate significant differences. If tendencies were seen, these are mentioned for each quality parameter and each country. Furthermore, it must be noted that due to differences in determination methods, the levels of the German TPC differ, resulting in different scales used in figure 1. The scales of the Danish BMSCC (figure 2) also differ since levels are overall higher. These different scales were chosen to increase the overview of the courses of both parameters.

The graphs are used to illustrate model [3]. In the graphs the geometric mean of individual farm samples is calculated for every month from the day of introduction of the AM-system. The courses are shown per group. For the AM3 and AM4 groups not all dots in the graph, representing the averages, are based on the same number of farms. All farms are present in the first measurement (during installation). However, as the course regresses the average is based on lesser farms depending on their exact date of installation. For example, if an AM3 farm installed its AM-system in May 2000 only data of a maximum of 8 months after installation was available (up to December 2000). For AM1 and AM2 a minimum of 1,5 years of data after installation was available and therefore for these two groups, the course is based on a constant number of farms equal to the number in table 3.
Where possible, the mean values for conventional farms, C2 and C3, are also given. Of course, in practice these courses also show variation however, since these conventional farms have no date of installation the overall mean is presented in the graphs.

2.3.1 Course of total plate count (TPC)

No significant differences were found in the average TPC between the different AM groups (AM1-AM4) after introduction of the AM-system for all countries (table 4). However, differences in the patterns were found. To illustrate this, the course of TPC is presented for each country in Figure 1.

The only significant effect to be found for Denmark was that the AM4 group had a lower TPC during the first 6 months than AM2 and AM3. After these 6 months all groups had comparable levels. The TPC of the AM farms was always slightly above the level of the conventional farms. Unfortunately, this difference with the conventional farms could not be statistically tested.
For the German AM farms no significant differences could be found. However, during the second half of the first year after introduction (days 178…365) the AM2 seemed to have a lower TPC than the AM3 group. The same tendency was found for the third period of six months (days 366…548). Even though no comparison could be made with the conventional farms, practically no difference between this group and the AM farms could be found.
The Dutch AM farms were statistically compared to the conventional farms. For both the first half year and the second half year after introduction, TPC of all AM groups was higher than the C2 (2x daily conventional) group. Furthermore, during the first six months the AM4 group showed a significantly lower TPC than the AM1, AM2 and AM3 group. For the second half year the AM3 had a significantly lower TPC than the AM1 and AM2 group. No data of the AM4 group were available for this period. For the third half year (days 366-548) no significant differences were seen between the AM-groups. However, only the AM2 group had a TPC comparable to the conventional C2 group at this stage, AM1 and AM3 still had a higher TPC.

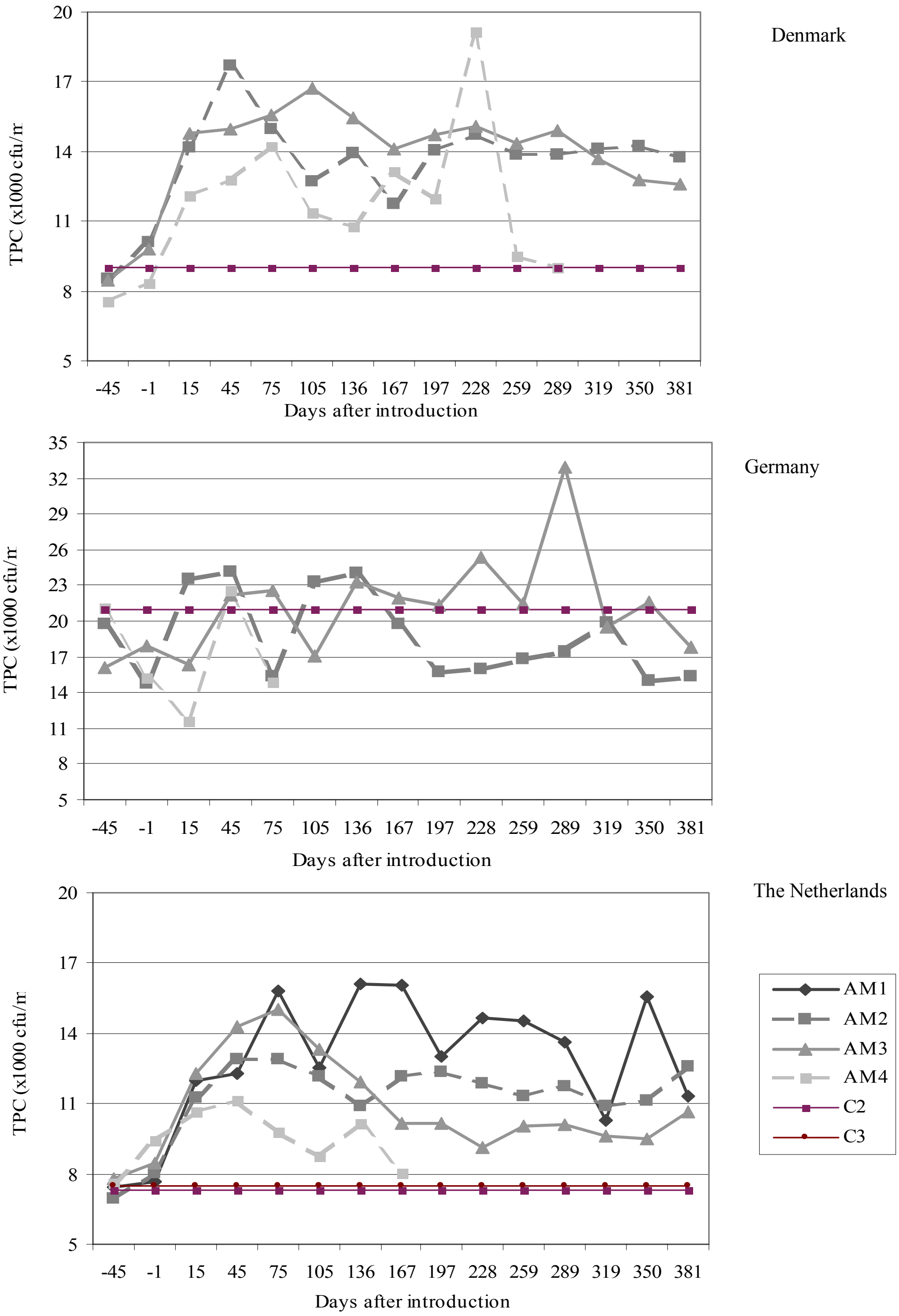

Figure 1 Course of TPC of four AM groups after introduction of the AM-system, in 3 countries.

The German farms showed practically no differences between the different AM groups. The standard errors were large. This was mainly affected by the limited number of farms used within this study. The Danish and Dutch farms look alike. Both countries showed a rapid increase of TPC after introduction of the AM system, to above the level of conventional farms. After about 6 months stabilisation was seen and after a period of about a year some AM groups approached or reached the level of conventional farms. Moreover, it appeared in general that farms that switched to AM more recently had a lower initial increase of TPC immediately after the introduction and showed a quicker recovery of TPC. This was found especially on Dutch farms. Perhaps experience of farmers and cooling- and AM-suppliers have resulted in more insight of the effect on TPC and resulted in a better control. However, since the level of TPC is still above conventional levels, attention should still be paid to this item.

2.3.2 Course of bulk milk somatic cell count (BMSCC)

The overall averages of BMSCC for all AM groups, as presented in table 4, showed no or little mutual differences. To gain more insight, the courses of BMSCC were studied further. After introduction the courses of BMSCC showed similar patterns as for TPC; just after introduction the BMSCC increased. Furthermore, after some time the BMSCC seemed to decrease in all countries to a level comparable to the conventional farms (C2). This is illustrated in figure 2 and discussed below.

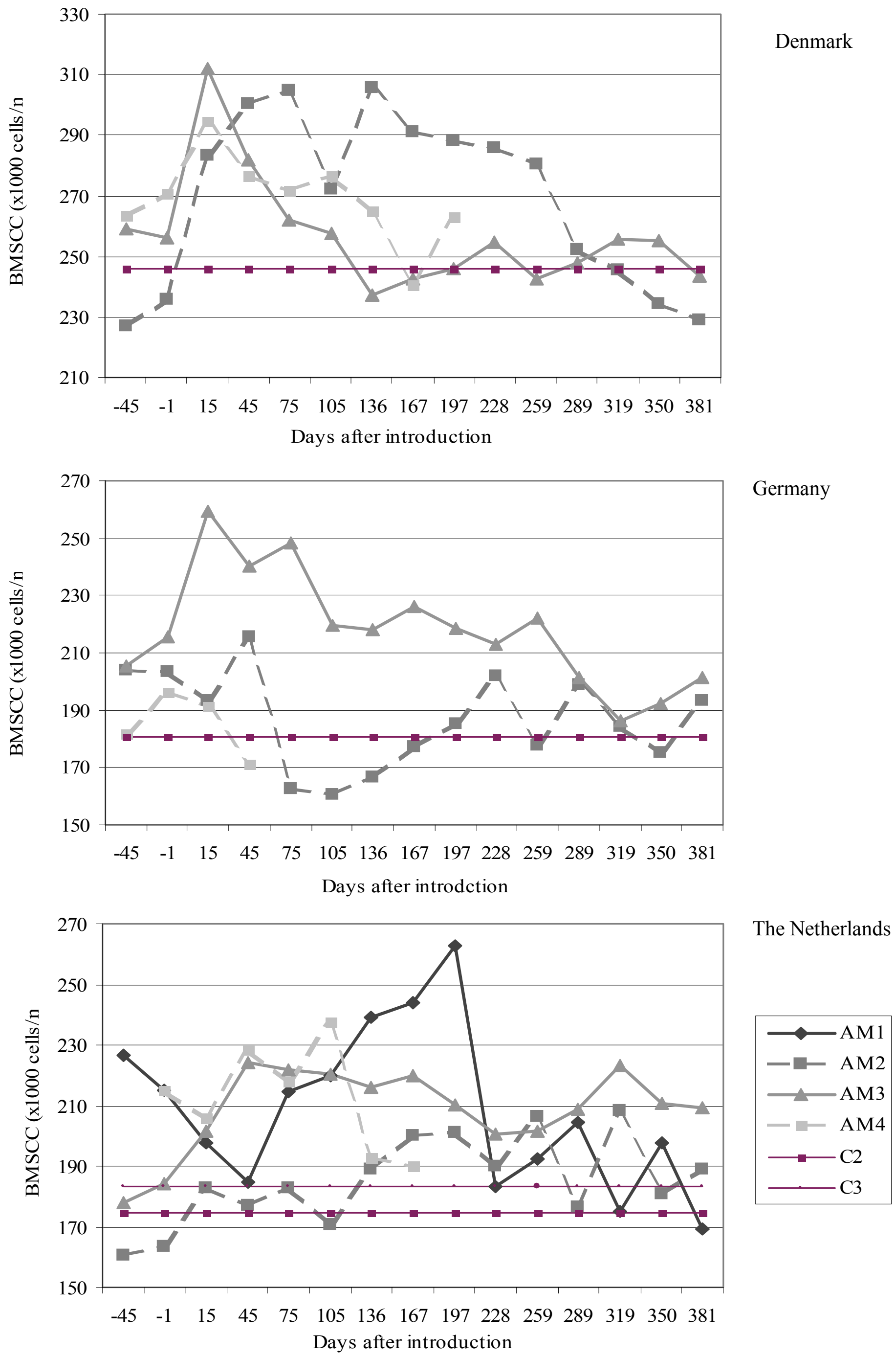

Figure 2 Course of BMSCC of four AM groups after introduction of the AM system, in 3 countries.

For the Danish farms no significant differences could be found between the AM groups over time. However, during the first six and second six months the AM3 group seemed to have a lower BMSCC than AM2 and AM4, although the AM2 group seemed to have a lower level before introduction (not significant, $p<0,05$). As explained already, the differences with the conventional farms could not be tested statistically. It appeared however, that in the 12 months after introduction both AM2 and AM3 reached the level of conventional farms.
No significant differences for the German farms could be found. AM4 was only based on two farms so, no attention will be paid to that group. AM2 had the tendency to be lower than AM3 and appeared to have a comparable level as the conventional farms (C2). This difference between AM2 and AM3, however, was due to a limited number of farms and large standard errors not significant.
As for the Dutch farms, all AM groups had a significantly higher BMSCC during the first six months when compared to the C2 group, with the exception of AM2. This latter group was similar to the conventional farms during the first six months ($p<0,05$). During the second six months (days 184…365) AM2 was significantly higher than C2. Apparently the farmers and cows were not fully adjusted to the AM-system. During months 12 to 18 after introduction, AM2 was comparable again to the C2 group. The AM3 group stayed significantly higher from the beginning until 1,5 years after the introduction of the AM system. Also the AM4 group showed significantly higher levels than C2. The AM1 group approached the level of conventional C2 farms during the second half year after introduction.
The significantly higher levels for BMSCC on the Dutch AM3 and AM4 in comparison to C2, might be explained by the change in the Dutch penalty system for BMSCC at the beginning of 2000. From that time on the penalties were based on the geometric averages of three months compared to the absolute values used before 2000. Using geometric averages will result in fewer penalties given, since one tank >400.000 cells/ml does not result in a violation, only the geometric average of 3 consecutive tank samples will.
As for comparison of the Dutch AM farms among themselves, no differences could be found during the first, second and third six months after introduction between the AM groups. The AM1 and AM3 groups tended to be higher than AM2 and AM4 during the first six months, however this was not a significant difference.

It must be noted that the overall BMSCC level in Denmark was clearly higher than found on German and Dutch farms. However, the strongest decrease 6 months after introduction was also seen in Denmark (see figure 2). Even though the AM groups could not be compared statistically to the conventional farms, the BMSCC of the Danish farms seemed comparable to the conventional farms from 6 to 12 months after introduction. Little can be said of the German farms due to the limited number involved and due to the large differences between AM2 and AM3. It cannot be concluded in general that farms that switched more recently to AM had a better BMSCC. For the Danish farms an improvement was seen on the 'newer' farms, however, not in Germany and The Netherlands. Very probably, the Danish compulsory self-monitoring program (Justesen and Rasmussen, 2000) has contributed to an improved control of BMSCC.
Overall, probably the most important remark is that after about 1,5 years the BMSCC on all AM farms was comparable to conventional farms, independent of their date of installation. Only the time it takes the different groups to reach the conventional level, differs. This means also that improvement could be made to prevent the initial increase during the first 12 months. Apparently cows and farmers adjust to the AM-system in a way that the BMSCC can be lowered after the initial increase.

2.3.3 Courses of freezing point (FP)

Only German and Dutch data were available for FP patterns (figure 3). FP, as TPC and BMSCC, increased immediately after introduction of the AM-system. However, in contrast to what was (partly) seen for the first two parameters discussed, the FP appeared to remain higher than conventional levels during a longer period of time after introduction (up to 18 months). So, no 'recovery' was seen. During the first 12 months this higher level was not found to be significant. For the period of 12 to 18 months after introduction a significant higher level of FP was seen in The Netherlands in comparison to conventional farms.

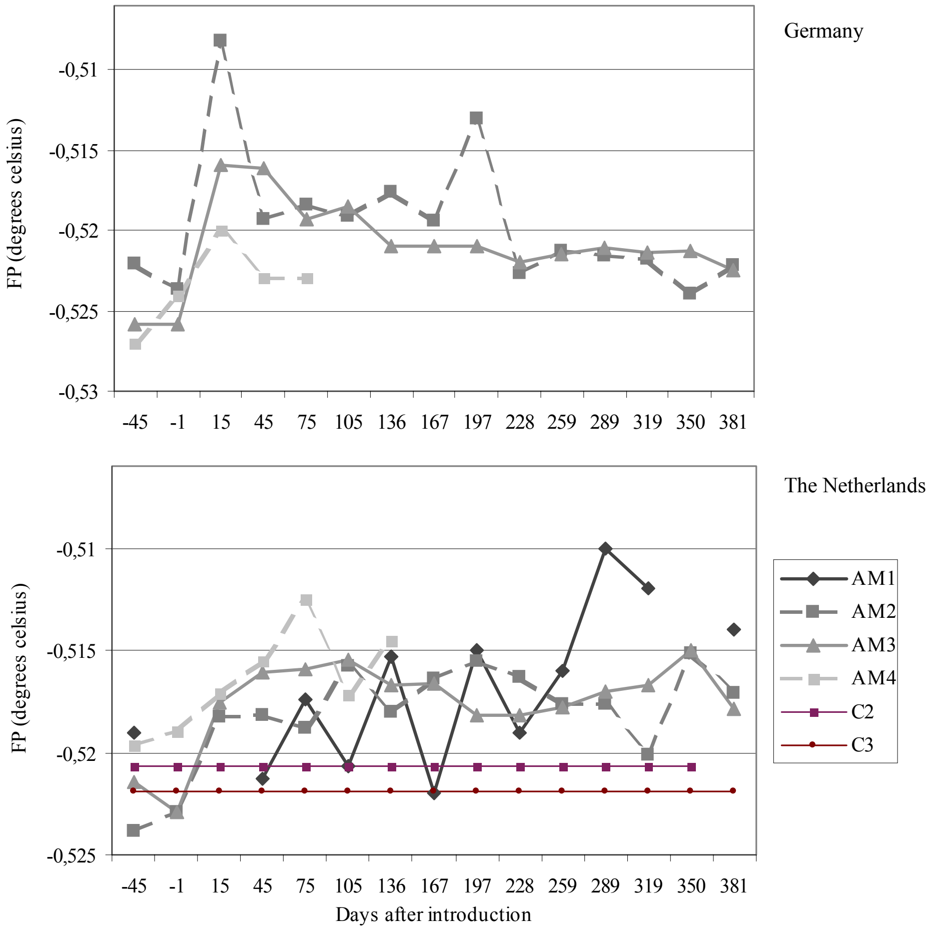

Figure 3 Course of FP of four AM groups after introduction of the AM system in 2 countries.

For Germany the number of farms was limited. For the Netherlands the number of Dutch farms was relatively large, however, the FP was only measured once every 6 months (see also table 1). To provide an overview of the pattern of the average Dutch FP in figure 3, the average was calculated per month. However, this results in different data of different farms per calculated average. For model [3] the averages were calculated every six months within the same farms. So comparing the within farm patterns.

Due to the limited number of data for FP, the only significant difference in comparison to C2 was found for the Dutch AM2 and AM3 group one year after introduction. This can be explained looking at the standard errors, and thus the variation in the data. During the first year the standard errors were too large to point out a significant higher level of FP in comparison to the Dutch conventional farms, even though the averages in figure 3 indicate this. Twelve months after introduction less variation influenced the data, making a significant difference. FP did not seem to recover after some time and thus FP stayed above conventional levels.

In The Netherlands, the rise was relatively small and far from the penalty levels (-0,505 ^{o}C). With regard to the German penalty levels, more problems could be expected, since the penalty levels are more strict (-0,515 ^{o}C).

2.3.4 Course of free fatty acids (FFA)

Only Dutch data were available on milk FFA. FFA was only measured once every six months resulting in limited data. This data was calculated the same way as the Dutch FP as described in the previous paragraph. The Dutch AM1 group had the smallest number of farms and showed a course of

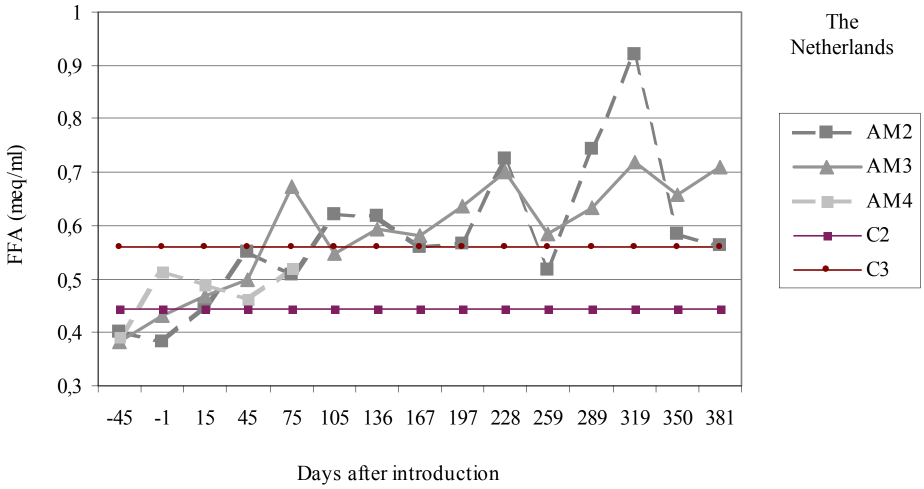

Figure 4 Course of FFA of four AM groups after introduction of the AM system, in The Netherlands.

FFA which was very variable and did not correspond with the AM2 and AM3 group which represent much a much larger number of farms. Therefore, AM1 is not shown in figure 4.

As for AM2, AM3 and AM4 the increase was less obvious after introduction than was seen for TPC and BMSCC. It appeared to rise slowly, which also might explain the low FFA for the AM4 group as presented in table 4. After 6 months the FFA of the AM2 and AM3 group was significantly higher than the conventional farms that milk twice daily (C2). No difference was found when comparing with the C3 group during 1,5 years after introduction. The significant difference with the C2 group, on the other hand, was still found at the end of year 2 after introduction of the AM system. It is known that increased milking frequency increases FFA (Klei *et al*, 1997). However, on the AM farms it appeared as if the FFA kept increasing. No equilibrium was seen after 12 months. More study is necessary on this parameter to study the causes of the increase and to evaluate whether the increase is ongoing, and when it reaches an equilibrium.

2.4 Individual farm figures

Figures 1 and 2 show the averages of TPC and BMSCC for all farms analysed. Naturally, individual farm figures often agree with the averages however, much variation is seen. For all parameters in the three countries the variation in average milk quality increased after introduction of AM in comparison to the time before introduction. The farmer obviously needs time to adjust to the new milking system, the techniques and the interpretation of its data. After some time the milk quality levels stabilise as the management adjusts to the AM-system.

As already explained in section 2.1.4, all parameters were to a certain extent influenced by farm effects. Figure 5 shows the course of TPC of an individual Dutch farm before and after introduction. Besides an increase in TPC an increase in variation was seen directly after the introduction of the system. This appeared to decrease after one year resulting in a comparable level of TPC as before introduction.

Even though, many differences were found between farms most farms show the pattern for TPC as shown in figure 5. Differences can be found mainly in the time farms need before they recover after the initial rise, as was also seen in figures 1-4, and the number of peaks they show before they stabilise.

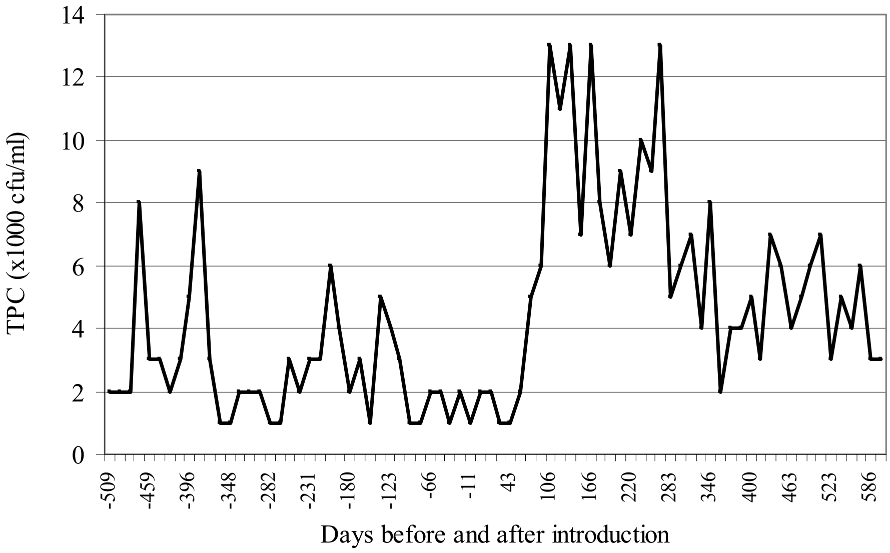

Figure 5 Course of TPC of one Dutch farm before and after introduction of the AM-system.

Figure 6 shows the course of BMSCC of an individual German farm before and after introduction. During introduction a slight rise of BMSCC was seen. After about six months a decline was seen to a level than was general before introduction. Apparently, this farm profited by having a better BMSCC due to milking automatically. However, it is unknown whether this was due to management changes and selection of cows or due to the technical change in milking.

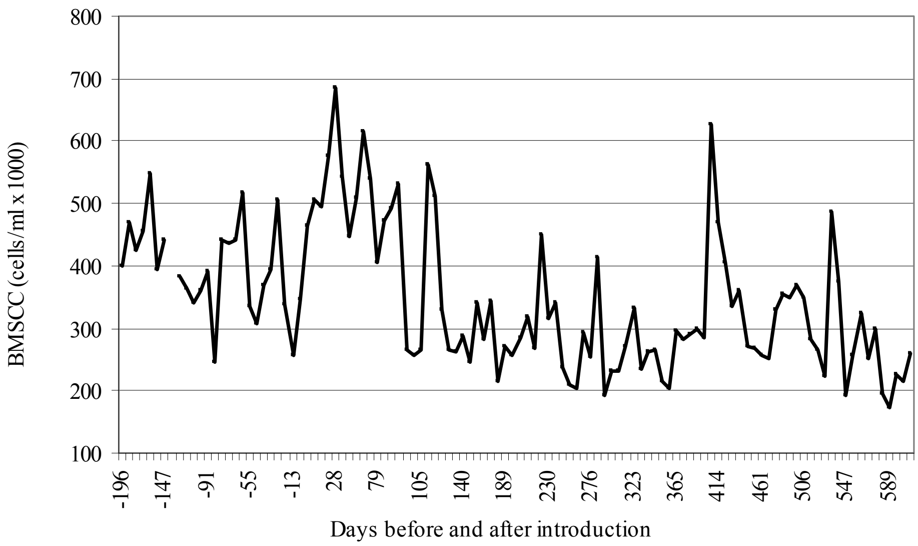

Figure 6 Course of BMSCC of one German farm before and after introduction of the AM-system

2.5 Results summarised

The general reduction in standards of the four milk quality parameters after the introduction of the AM-system are relatively small, especially when compared with the European regulatory requirements, but are important with regard to premium price systems based on lower levels for TPC and BMSCC employed in some European countries. It should not be taken for granted that milk quality improves with AM milking as was generally assumed when the first AM-systems were introduced. For example, automatic milking does not necessarily mean an improved BMSCC, as was expected, following an increased milking frequency (Harmon, 1994; Hogeveen *et al*, 2000) and individual teat cluster detachment. Apparently, more factors play a role. A clear illustration is the variation that could be explained by farm differences (paragraph 2.1.4). A wide range of factors fall within this denominator. Besides farm effects, for several milk quality parameters most variation could also be explained by differences over time. Farm effects are mainly based on management, housing and technique and time effects on changes over time such as seasonal effects. Most probably interaction between these large variance components plays an important role in affecting the milk quality.

Besides a slight decrease of milk quality after the introduction of the AM-system, an increase in variation within and between farms was found. This is also illustrated by table 3. The number of penalty points, given when exceeding maximum limits, increased after introduction. The variation indicates that improvement is possible.

The highest levels for most quality parameters (with exception of FFA) are found during the first six months after introduction. Apparently, the farmer needs to adjust to the innovation on his farm and needs to learn to work with this new system and how to interpret its information. Management needs to be adjusted. It is important that the farmer is guided well (consultants, industry, dairy boards, etc.) during the switch to automatic milking. After about six months most farmers adjust well and the milk quality improves. However, for TPC, FFA and FP levels stay above conventional levels. Most probably, more factors than just management play a role.

3 Conclusion

Milk quality is to a certain degree poorer when milking with an automatic milking system. Data from Denmark, Germany and The Netherlands showed that the poorer levels for all parameters evaluated are found in the first six months after introduction. After this period, the farmers adjusted to the new techniques and the milk quality slightly improved. All farms more or less stabilise their milk quality (with exception of FFA). However, the quality from AM farms was still slightly poorer than from conventional farms (with exception of BMSCC). Differences between farms occurred both in averages and in variance. This, together with the knowledge that the milk quality improves about 6 months after introduction indicates that improvements are possible.

This study presents the analysis of milk quality data performed within the first sub-package of work package 4 of the EU project. The second sub-package will focus on the identification of the risk factors and its quantitative effects on the milk quality. This study is currently under preparation and will be executed during the summer of 2002.

Acknowledgements

All farmers involved in this study are thanked for giving access to their milk quality data. In Germany the regional milk control laboratories are thanked for their contribution in delivering the requested milk quality data. In The Netherlands, the Milk Control Station (MCS, Zutphen) is thanked for their supply of milk quality data. Furthermore all AM-suppliers are thanked for their supply of farm addresses and the Dutch DHIA (NRS) for identifying the farms milking 3 times daily. Johan van Riel is gratefully acknowledged for his assistance in the statistical analyses. Finally, the Dutch Ministry of Agriculture is appreciatively considered for financing 50% of the project costs.

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List of Abbreviations

AM	Automatic Milking
AM1	Group of farms that introduced the AM system before January 1998
AM2	Group of farms that introduced the AM system between 01-01-1998 and 31-03-1999
AM3	Group of farms that introduced the AM system between 01-04-1999 and 30-06-2000
AM4	Group of farms that introduced the AM system between 01-07-2000 and 31-12-2000
C2	Control group of farms milking twice a day with a conventional milking parlour
C3	Control group of farms milking thrice a day with a conventional milking parlour
TPC	Total Plate Count
BMSCC	Bulk Milk Somatic Cell Count
FP	Freezing Point
FFA	Free Fatty Acids
Mmol	Millimol
^{o}C	Degrees Celsius
DK	Denmark
D	Germany
NL	The Netherlands