The Effect of Milking System on Milk Production and Quality in Québec Dairy Herds

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ABSTRACT

The objective of this study was to investigate the effect of milking system (automated versus parlour or milk-line) on milk production and quality in Québec dairy herds. Lactation milk, energy-corrected milk, fat, and protein yields (kg) were analysed as indicators of production, while lactation average somatic cell score was analysed as an indicator of quality. The analysed data consisted of 67,440 lactation records for 48,018 animals in 1,065 herds (712, milk-line, 216 parlour, and 137 robot). The records covered eleven geographic regions of Québec, and represented Holsteins (84%), Ayrshire (10%), Jersey (5%) and Brown Swiss (1%), over four parities. The model for analysis of each dependent variable accounted for fixed effects of milking system, breed, parity, year of calving, and geographical region of Québec, as well the random effect of herd, nested within milking system and region. Interactions between Breed x Parity and Milking System x Parity were significant in all production models, as was Milking System x Breed with the exception of Lactation Fat Yield. The three-way interaction (Milking System x Breed x Parity) was only significant for lactation average somatic cell score.

Within milking system, all production traits increased with parity (the majority of the increases were significant). Within breeds, results indicated that Holsteins on robotic milking systems had higher levels of production than Holsteins milked in either conventional milking system, with the exception of fat yield from robotic milking systems (which was not significantly higher than from parlours, but was still higher

than milk-lines). The only other within-breed comparison that was significant applied to Jerseys where lactation milk yield was higher from robots than milk-lines. Somatic cell score tended to increase with increasing parity, but those increases were only significant across the three milking systems in the case of Holsteins, and only for parities 1 through 3. Very few of the other parity differences were significant within breed and milking system and, in fact, Jersey least squares means for robotic milking systems seemed to decrease with parity. While the least squares means for somatic cell score tended to be slightly higher for robotic milking than conventional milking, there were no significant differences for any breed/parity combination. Results for Holstein data (which formed the vast majority of the data) would seem to indicate that robotic milking systems can provide higher production than conventional milking systems, without necessarily compromising on milk quality.

RÉSUMÉ

L'objectif de cette étude était d'investiguer l'effet de système de traite (systèmes de traite automatisée versus salle de traite et/ou « Lactoduc ») sur la production et la qualité du lait dans les troupeaux laitiers du Québec. La quantité de lait produite (kg par lactation), le lait corrigé, la matière grasse (kg) et la protéine (kg) ont été analysés en tant qu'indicateurs de production, tandis que le score de cellules somatiques moyen pour la lactation a été analysé comme un indicateur de qualité. Pour ce faire, nous avons analysé les données de 67,440 lactations, pour 48,018 animaux, provenant de 1 065 troupeaux (712 « Lactoduc », 216 salons de traite, 137 systèmes robotisés). Les données provenaient de onze régions du Québec et incluaient quatre parités pour chacune des races Holstein (84 %), Ayrshire (10 %), Jersey (5 %) et Suisse Brune (1 %). Le modèle d'analyse statistique comprenait le système de traite, la race, la parité, l'année de vêlage et la région géographique du Québec comme effets fixes, ainsi que le troupeau, imbriqué dans la région et le système de traite, comme effet aléatoire. Les interactions race x parité et système de traite x parité ont été significatives pour tous les modèles de production, de même que l'interaction système de traite x race, sauf dans le cas de la production de matière grasse. L'interaction système de traite x race x parité a été significative seulement pour le score de cellules somatiques moyen.

Pour ce qui est de l'effet du système de traite, tous les caractères de production ont augmenté avec la parité (la majorité des augmentations étant significatives). Au sein des races, les résultats ont révélé chez les Holstein traites avec des systèmes

robotisés des indicateurs de production supérieurs à ceux des Holstein traites dans l'un des deux systèmes de traite dits conventionnels, à l'exception de la production de matière grasse, pour laquelle la différence avec les salons de traite n'était pas significative. La seule autre comparaison significative au sein d'une race retrouve chez la Jersey, où la production de lait par lactation était supérieure pour la traite robotisée comparativement au Lactoduc. Le score de cellules somatiques moyen pour la lactation tendait à augmenter avec la parité, chez les Holstein, pour tous les systèmes de traite, mais seulement pour les parités 1 à 3. Ces différences entre les parités n'ont pas été observées pour les autres races, peu importe le système de traite. En fait, pour les sujets Jersey traits par des systèmes robotisés, les différences entre les moindres carrés semblaient au contraire diminuer avec l'augmentation de la parité. Bien que les moyennes obtenues par la méthode des moindres carrés tendaient à être légèrement plus élevées chez les systèmes de traite robotisée (par rapport aux systèmes conventionnels), aucune différence significative n'a été démontrée parmi les combinaisons de race et parité. Les résultats pour les données de la Holstein (qui formaient la grande majorité des données) semblent indiquer que les systèmes de traite robotisée peuvent amener une production plus élevée que les systèmes de traite dits conventionnels, sans nécessairement compromettre la qualité du lait.

1. General Introduction

As a result of the increase in world population, and the corresponding need for more milk products, the global dairy industry has changed significantly over the past few decades. World milk production has increased by more than 50% over the last 30 years, with global milk production by cows standing at 636 million tons in 2013 (AHDBDairy 2015). In 2015, the United States was the world's largest milk producer, with 14% of global production, followed by India, China and Brazil (CDIC(G) 2016). (Table 1-1)

Table 1-1. World Top 10 Milk Producing Countries in 2015 (Tg) (CDIC(G) 2016)

USA	India	China	Brazil	Germany	Russia	France	New Zealand	Turkey	Pakistan
94,364	73,656	37,547	35,329	32,685	30,522	25,831	21,575	16,933	15,529

Some countries in the developing world have a long tradition of milk consumption, and milk, or its products, play an important role in their inhabitants' diets. Finland has the greatest *per capita* milk consumption at 128.5 L and followed by Ireland (120.1 L), Estonia (118.5 L), Australia (110.5 L) and New Zealand (108.5 L). In Canada, *per capita* milk consumption was 73.3 L in 2014 (CDIC(f) 2015). New Zealand, the United States of America, Germany, France, Australia and Ireland have the greatest milk surpluses, whereas China, Italy, the Russian Federation, Mexico, Algeria and Indonesia have the greatest milk deficits in the world (FAO 2016).

Changes in the dairy industry, brought on by increases in world population and milk consumption, have mainly arisen through important advances in genetics, nutrition, reproductive physiology, and better farm management (Wade *et al.,* 2004). Improvements in animal housing and health, and improved efficiency through milking machines have also contributed (Jacobs and Siegford 2012). Together, these innovations have created the modern dairy farming industry we know today.

In Canada dairy farming is one of the largest contributors to the agricultural sector and, while present in all provinces, is particularly important in Quebec and Ontario. In 2015, there were 953,200 dairy cows on 11,683 farms across the country, with an average of 82 cows per farm. However, Quebec and Ontario are the major dairy-producing provinces with 49% and 32% of the farms, respectively (CDIC(a) 2015). In 2014, Canadian dairy farms produced 9,012 Tg of milk (CDIC(c) 2015), with each dairy cow producing, on average, 30.76 L d^{-1} at 3.90% fat and 3.19% protein content (Bisson 2015). Quebec is home to the most dairy farms – 5,766 – each housing an average of 61 cows (CDIC(a) 2015). In 2014, Quebec dairy farms produced 2.907 Tg of milk (CDIC(d) 2016), with an average milk production per cow of 30.48 L d^{-1}, at 3.93% fat and 3.22% protein (Bisson 2015).

Milk-payment systems are frequently based on milk quality and composition, and consumer expectations have ensured that both are a major goal of modern dairy farming (De Koning 2011). In Canada, dairy farming uses a supply-management (“quota”) system that regulates the overall milk production, based largely on the kilograms of butterfat produced. Moreover, not only is the milk price based on components, but maximum prices can only be obtained if a specific ratio of the different milk components is respected (Ferland 2008). Considering the importance of fat, protein and overall quality as factors influencing milk payments, these parameters represent critical concerns for modern dairy farms.

A number of important production parameters may influence milk composition. These include nutrition (Looper 2012; Buttchereit *et al.,* 2012), genetics (Hanuš *et al.,* 2011; Looper 2012), cow energy status (Friggens *et al.,* 2007), season, age and parity (Looper 2012), and milking systems (Tousova *et al.,* 2014). Some of these aspects can permanently alter milk composition (*e.g.*, genetics), while others (*e.g.*, milking routines) may influence milk production and quality over a short period of time. Advances in dairy farming technology over the last few decades have seen milking routines and techniques emerging among the most important elements of dairy production technology and management, with respect to their effects on milk production and quality (Heikkilä and Myyrä 2014).

In many developed countries, including Canada, both conventional milking systems (milk-line and milking parlour) and automated milking systems (AMS) are being used. Some of the cited benefits of using AMS, such as reduced (or restructured) labor, more flexible lifestyle, improvement of management performance, and increases in milk production, have led to a significant increase in their use, and their growth in popularity has led to a number of studies, investigating their effects on the yield and quality of milk (Klungel *et al.,* 2000; Hillerton *et al.,* 2004; Abeni *et al.,* 2005; Speroni *et al.,* 2011; Tousova *et al.,* 2014; Tremblay *et al.,* 2016; Wirtz *et al.,* 2004). However, results have been far from conclusive, and relatively few of these studies have been conducted in North America.

Given the growing questions involved in implementation of (or conversion to) an AMS, and the resulting impact on farm management, hygiene and health, and quantity and quality of milk produced, the main objective of this study was to compare CMS (milk-line and milking-parlour) with AMS in terms of lactation measures of milk production, components, and milk quality.

2. Literature Review

2.1 Introduction

Type of milking system is one of the key components of dairy farming, affecting not only the lifestyle of dairy-farm families, but also having a significant impact on the economic, technical and management aspects of dairy farming (Moyes *et al.*, 2014; Rodenburg 2008; Maršálek *et al.*, 2012). Around 380 B.C, Egyptians, in addition to what we consider traditional milking by hand, are reputed to have inserted wheat straws into cows' teats in order to draw milk. The first milking machines were introduced in the early 20th century with the advent of rural electrification: this innovation was an extension of the traditional milking pail, which later developed into the Surge hanging milker (Van Vleck 1998).

Ideal for small dairy farms, the next innovation in milking machines was the low-cost Milkline® milking machine (Milkline Srl, Piacenza, Italy), introduced in the late 20th century. Reducing milking time significantly, compared to traditional methods, this device, which was mostly used on farms with tie-stall barns, includes a vacuum line and milking units, equipped with milking buckets (Milkline 2017). Milk collected in buckets must then be transferred manually to the milk cooling tank (Milkline 2017). As herd size continued to increase, such devices evolved into the more efficient milking parlour. The main reason for this innovation was to maximize the number of cows per operator, and simplify the milking process in commercial dairy farms. This kind of milking system is based on group-milking management. Managing labour, milking equipment, as well as monitoring and evaluating parlour performance are key factors in the operation of a milking system (VanBaale *et al.*, 2007).

As labour costs became one of the major concerns for 20th century dairy-farm operators, an effort to reduce these costs, and alleviate time management constraints in conventional dairy farming, led to a sustained research effort throughout the 1970s, and the introduction of AMS in dairy farming.

Nowadays, AMS are replacing milk-lines and milking parlours on many farms. The first AMS was implemented in 1992 on a commercial farm in The Netherlands, after which their implementation progressed slowly until the end of the 1990s. However, from 2000 onward, AMS became an accepted technology in many developed countries in Europe, North America, as well as Japan (De Koning 2011). This led to a significant increase in the number of AMS-equipped farms, which is now estimated to be 30,000 worldwide (Bisson 2015; Merlo 2015) (Figure 2-1).

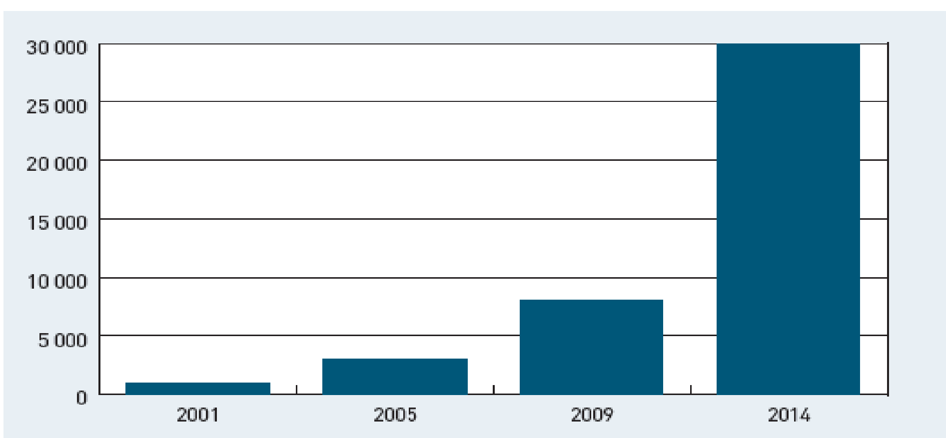

Figure 2-1 Evolution of Robotic Milking Systems Worldwide (Bisson 2015)

Automated milking systems are also termed voluntarily milking system, where the actual milking of dairy cows, requires no human labour. Representing a revolutionary innovation in dairy farming, this type of AMS has altered the entire farm system. Since the main concept of such systems is to allow for the complete automation of the milking process through the use of a "robot", automated milking is therefore also termed Robotic Milking. The most common systems depend on the use of computers and special herd-management software. A robotic milking system includes a milking stall, teat cleaning system, teat detection system, robotic arms, a milking machine and a control system, comprising sensors and computer software. Such a system is also equipped with electronic cow identification. (Figure 2-2). An AMS includes a single stall system which is able to milk 55-65 cows several times a day, or multi-stall systems with 2 to 4 stalls and a moving robotic device which allows the system to milk 80 to 150 cows up to three times a day (De Koning 2011).

Figure 2-2 Electronic Cow Identification in robotic milking (Lotfi Abardeh 2015)

In North America, the first robotic milking system was installed in Ontario, Canada in 1999 (Rodenburg 2008; OMAFRA 2016). By 2015, the breakdown (percent and numbers) of milking systems in Quebec/Canada were 213/493 (4.7%/5.6%) AMS, 289/1,981 (6.4%/22.7%) parlour milking, and 4,005/6,264 (88.9%/71.0%) milk-line systems, respectively (CDIC (b) 2015). Quebec – Canada's largest milk-producing province – accounted for 51.9% of dairy farms in Canada (CDIC(H) 2017), and 41.6% of robotic farms in Canada (CDIC(H) 2017). Figure 2-3 shows the average number of animals in Quebec dairy herds (2015) by barn type (tie-stall or free-stall). In addition, it shows the average herd size for farms with robotic milking systems: most of these are assumed to be free-stall systems (although AMS exist for tie-stall systems as well) (CDIC(H) 2017).

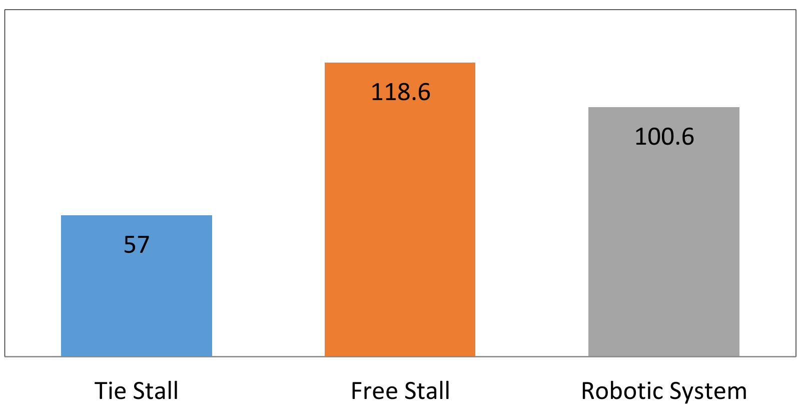

Figure 2-3 Mean animals per farm by barn type in tie and free stall and average of cows in robotic milking system farms that could include free or tie stall farms (mostly assumed to be free stall) in Quebec. Adopted from CDIC(H) (2017)

In 2014, Quebec dairy herds, using an AMS, produced, on average, more milk per cow per day (32.2 L) than herds using other milking systems (30.48 L) (Bisson 2015). The seemingly greater milk yield on robotic farms, along with the estimated labour saving of 25% to 35% (De Koning 2011), has made AMS an interesting possibility for dairy farming. In general, producer surveys have indicated very positive results when switching from a previous milking system to an AMS system (Bentley *et al.,* 2013). Reduction of labour, a more flexible lifestyle, improvement of management performance, and increases in milk production due to more frequent milking are the most-commonly cited benefits of using AMS (Rotz *et al.,* 2003; De Koning 2011; Woodford *et al.,* 2015). Other surveys have shown that improved herd management and better organization of family time are the most influential motivations for switching from CMS to AMS (Moyes *et al.,* 2014).

2.2 Management and Labour Aspects of AMS.

Aside from the labour savings it offers, robotic milking represents a revolutionary innovation in dairy farming, particularly with respect to the overall farm-management system. Although robotic milking helps free up the farm manager to do more true managing of the dairy (*e.g.*, better planning, record keeping and analysis), this kind of system does require some change in management system, and brings on certain challenges. Physical work is replaced with new management tasks: frequent (2 or 3 times a day) checking of computer-generated attention lists, visual control of cows, fetching of cows having exceeded their maximum milking intervals, and control and cleaning of the AMS (Rodenburg 2013; Maršálek *et al.,* 2012). Flexibility and discipline in system and cow-herd control, as well as the ability to work with computers are key factors in successful robotic herd management, especially during the transition phase (De Koning 2011).

Large variations in hours of labour can exist among farms using AMS: while automatic milking might take extra time in the transition phase (De Koning 2010), it appears to be more labour-saving than CMS once established (Hansen 2015). Figure 2-4 shows the results of a study by Rodenburg (2012), looking at the daily labour requirements for milking 60, 120, 240 and 480 cows, respectively for basic parlours (2 x 8 or swing parlour with minimal automation), automated parlours (fully automated 2 x 12 parlour), and AMS.

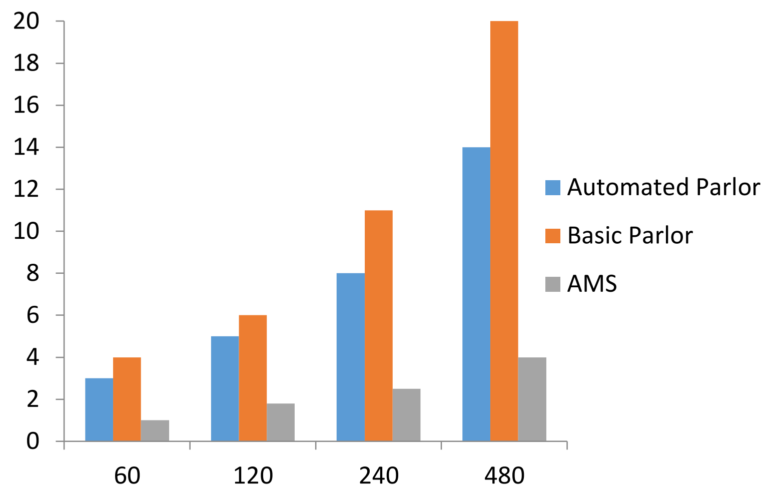

Figure 2-4. Estimated hours of daily milking labour with three different milking systems at four herd sizes. (Rodenburg 2012)

A comparison of 1,590 Quebec dairy farms, looking at daily working minutes per cow in three different milking systems would seem to indicate significant labour efficiencies by AMS (Table 2-1; Valacta, 2013). A study by Fleischmannová *et al.*, (2005) in the Czech Republic, as quoted by Maršálek *et al.*, (2012), reported that robotic milking led to a saving of 30% - 40% in physical labour as compared to conventional milking.

Table 2-1 Mean daily minutes work per cow under different milking systems in Quebec (Baillargeon *et al.*, 2013)

Milking System	Herd Size	No. of Herds	Average Min/Cow/day
Milk-Line	< 50	727	14.4
	50-100	646	12.2
	>100	65	10.9
Milking Parlour	< 50	18	12.5
	50-100	49	11.3
	>100	44	9.1
Robotic Milking	< 50	4	7.1
	50-100	26	8.3
	>100	15	7.4

In terms of labour costs, robotic farms offer the potential for "family farms" to expand to 100 to 150 cows without hiring outside labour (Rodenburg 2008). In large dairy herds, robotic milking technology has a great impact on labour efficiency, and could provide a sustainable solution for labour concerns on large commercial farms. Table 2-2 (Rodrigues 2013) presents examples of different AMS farm sizes, and the required number of employees under actual North American conditions.

Table 2-2 Labour efficiency under robotic milking (Rodriguez 2013)

No. of Robots	Total No. of Cows	No. of Employees	Robots/Employee	Cows/Employee
1	60	1	1.0	60
2	120	1.5	1.3	80
4	240	2	2.0	120
8	480	3	2.7	160
20	1200	5	4.0	240

2.3 Production Aspects

Robotic milking has an influence on production efficiency and increasing milk yield and, given that voluntary robotic milking significantly alters cow to cow milking frequency, it also influences milk composition (De Koning 2011). Comparative statistics for Canada in 2014 showed that AMS farms with Holstein herds produced more milk in 305 days (9,955 kg) than CMS farms (9,384 kg), with correspondingly higher values for fat (380 kg *vs.* 365 kg) and protein (318 kg *vs.* 300 kg) (Bisson 2015)(Table 2-3).

Table 2-3. Comparative statistics-Robotic milking in Holstein Herds in Canada 2014. Adopted from Bisson (2015)

	Canada		Quebec		Ontario	
	Robotic	Others	Robotic	Others	Robotic	Others
305 Days Milk (kg)	9,955	9,384	9,825	9,199	9,930	9,344
305 Days Fat (kg)	380	365	379	365	384	362
305 Days Protein (kg)	318	300	315	300	316	295

2.3.1 Milk yield

Increased milk yield, due to more frequent milking, is one of the benefits often claimed for robotic milking (Devir *et al.,* 1997; Kuipers and Van Scheppingen 1992; De Koning 2011). In such a system cows can be milked more than twice per day, providing a significant yield improvement in the case of high performance animals. Erdman and Varner (1995) observed an increase between 6% and 25% in complete lactation when milking frequency increased from two times to three times per day. Similarly, a 5-10% increase of milk production in AMS (*vs.* CMS) herds was noted across Europe (De Koning and Rodenburg 2004; Bijl *et al.,* 2007; De Koning 2011).

The AMS milking system differs from the other two other milking systems (Milk-Line and Parlour Milking) in terms of milk frequency, since milking frequency varies among cows and days. On AMS farms, the mean milking frequency is 2.2 to 3.2 per day (Rodenburg 2013). Similarly, De Koning (2011) mentions a mean of 2.5 to 3.0 milkings per day under AMS. Thrice-a-day milking is common on many large dairy herds, equipped with highly automated parlour milking in the United States (De Koning *et al.,* 2004), and was associated with an increase in milk production. While the study by De Koning (2011) showed a higher milking frequency for AMS farms over CMS farms, there was significant variation in milking intervals: under an AMS single stall system for a period of two year, almost 10% of the cows showed milking frequencies of twice or less per day.

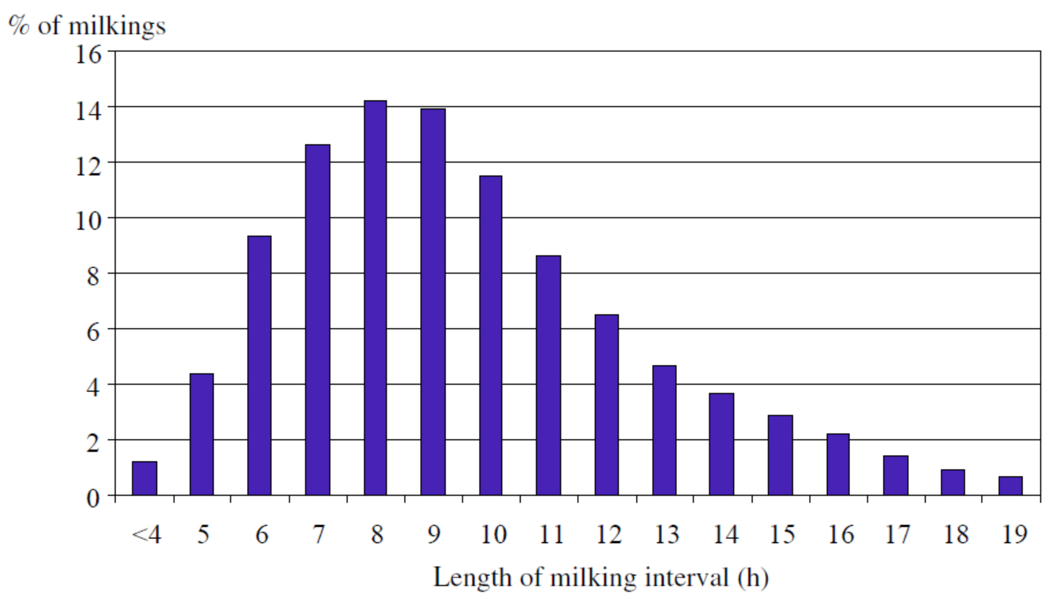

Figure 2-5 Frequency distribution of milking intervals in hours over a two years period (De Koning 2011)

Speroni *et al.,* (2011) conducted a two-year study in Cremona (Italy) examining milk yield, milking interval and frequency under an AMS with 94 cows. Daily mean-milking intervals were calculated in concert with mean milk yield and daily milking frequency. On average, 40 cows were milked each day, with a mean milk yield per milking of 9.6 kg, and visited the AMS 2.5 times per day (although some were as low as 1.5 and as high as 3.7). Almost 50% of cows had a mean milking frequency of 2.5 - 3.0, more than 30% had a frequency of 2.0 – 2.5, 12% had a frequency less than 2.0, and only 6.6% of cows were milked more than 3 times per day.

Rotz *et al.,* (2002) conducted a study to compare long-term farm profitability using traditional milking (Parlour) systems and AMS on farm sizes of 30 to 270 Holstein cows (lactating and dry) in Pennsylvania. The study compared milk yield between AMS and parlour (both 2X and 3X) and found a similar yield (12,200 kg) for both AMS and Parlour (3X). However, they also concluded that while both those systems were similar, in terms of production, labour costs were lower in the case of AMS.

As quoted by Tousova *et al.,* (2014) Dolezal (2000) reported a positive effect of increased milking frequency on milk yield for high-performing cows. He found that increasing milking frequency of cows with a production exceeding 35 kg d^{-1}, led to an 18.9% increase in yield, whereas, for lower performance cows yielding less than 25 kg d^{-1}, the increase was only 1.4%. Similarly, Tousova *et al.,* (2014) mentioned, because milk yield increases from first to fifth lactation, that an increase in milking frequency (due to use of an AMS) can help maximize milk production in AMS.

A study, conducted by Gygax *et al.,* (2007) on twelve Swiss farms, compared 2X parlour milking with AMS. They concluded that the average frequency of milkings on

AMS was 2.4 – 2.5 visits per day. Although many studies (Kuipers *et al.,* 1992; Erdman *et al.,* 1995; Devir *et al.,* 1997; De Koning 2011) indicated an increase in milk yield due to increased milking frequency, the result of the Swiss study revealed that milk yield did not differ on the twelve farms investigated.

In AMS, voluntary attendance is a key element to increasing milking frequency. The main motivation for this is the supply of feed ("concentrates") in the milking box during the milking process. However, success of an AMS through increased voluntary attendance also (necessarily) results in greater cow traffic in the barn. While potentially problematic, it can be facilitated by designing the barn to provide optimum access to milking stalls (De Koning 2011). Tremblay *et al.,* (2016) also mention that on AMS-equipped farms, aspects such as stall type, feeding area, and traffic type (*e.g.*, free *vs*. forced) can contribute to greater milk production.

Besides milking frequency, there are also some important functional aspects of AMS that can influence milk yield: milking interval, length of the milking procedure, and teat cup attachment success rate (Gygax *et al.,* 2007). While most studies agree that the generation of greater milk yields in AMS is the result of greater milking frequencies, large fluctuations in milking interval can decrease milk yield (Bach and Busto 2005). Accordingly, Rodenburg (2013) recommends that both frequent and uniform milking intervals should be considered as goals in AMS. Milking capacity limit in AMS (the possible number of milkings per day) may also have a negative effect on milk yield: Artmann (2004) mentioned a decrease in number of visits when more than 45 high-performance cows were milked in an AMS. Castro *et al.,* (2012) found that when AMS milking operations have different numbers of cow with varying milk yield, changes in milking frequency can affect both the capacity limits and efficiency of the AMS. They further showed that, under an AMS, number of cows and flow rate had the greatest influence on milk yield, which could be maximized by milking the maximum number of cows per AMS with a value of between 2.40 and 2.60 milking per cow per day.

In large herds the number of robots per pen can also influence milk production in AMS farms. Analysing 635 North American dairy farms, Tremblay *et al.,* (2016) conducted a study examining the risk factors associated with increased milk production per cow per day and milk production per robot per day. They found that the presence of two robots per pen was associated with increased milk production per robot per day compared to a pen with a single robot.

2.4 Milk Composition

2.4.1 Fat and Protein

Many countries employ a multiple pricing system that pays dairy producers on the basis of milk components (*e.g.*, fat and protein). In general, the solids content of cow milk includes 3-4% fat and about 3.5% protein. Many factors such as nutrition, breed, genetics and environment, management, parity and disease (mastitis) influence milk fat and protein contents (Looper 2012; Buttchereit *et al.,* 2012; Hanuš *et al.,* 2011; Harmon 1994). Moreover, milk composition varies widely among breeds; the components of fat and protein being the most variable (Table 2-4). Milk produced by Jersey cows has the greatest percentage of fat and protein, followed by Brown Swiss, Ayrshire and Holstein cows.

Table 2-4 Breed averages for percentages of milk fat, total protein, true protein and total solids

Breed	**Percent**			
	Total Fat	Total Protein	True Protein	Total Solids
Ayrshire	3.88	3.31	3.12	12.69
Brown Swiss	3.98	3.52	3.33	12.64
Holstein	3.64	3.16	2.97	12.24
Jersey	4.46	3.73	3.54	14.04

Adopted from Looper (2012)

Diseases, such as mastitis, can lead to reduction in milk fat and protein contents (Harmon 1994). Changes in milk fat and protein content are also associated with elevated somatic cell counts (SCC), which are an indicator of milk quality (Table 2-5).

Table 2-5 Change in milk fat & protein associated with high level of Somatic Cell Count (SCC)

Constituent	Normal Milk, %	High SCC Milk, %
Fat (%)	3.5	3.2
Total Protein (%)	3.61	3.56

Adopted from Harmon (1994)

While milk fat tends to remain constant, milk protein content decreases slightly with advancing parity. According to (DHIA) lactation records, milk protein content typically decreases 0.10 to 0.15 units over a period of five or more parities or 0.02 to 0.05 units per lactation (Looper 2012).

2.4.2 Effect of Milking System on Composition

Although previously-discussed factors such as nutrition, genetics and management can influence milk fat and protein, milking systems have been recognized as one of the most influential factors of milk composition (De Koning 2011; Tousova *et al.,* 2014), and while both CMS and AMS use the same milking principle, they present major differences. Under an AMS, the system is continually in use over a 24 h period but lacks continuous visual control at all times during the milking process.

In such a system, voluntary milking can result in a large variation in milking frequency from cow to cow and, therefore, an influence on milk quality and compositions should be expected (De Koning 2011). Since the introduction of AMS in the early 1990s, studies looking at the effects of automated milking systems on milk composition (fat and protein) have been far from conclusive; some studies have shown no effect of AMS on fat and protein [e.g., Abeni *et al.,* (2005) found no effect of milking system on milk fat content], whereas other studies have shown significant effects of milking system on milk composition (Klungel *et al.,* 2000). Since cows can be milked more than twice daily under AMS, some studies have also looked at the effect of milking frequency and interval on milk fat and protein content.

Klungel *et al.,* (2000) found milk quality, in terms of fat and protein content, to be inversely related to milking frequency. As quoted by Tousova *et al.,* (2014), Spolders (2000) reported that a greater milking frequency, under either CMS or AMS, resulted in a lower fat content in milk. In contrast, (Wiking *et al.,* 2006) found an increase in milking frequency to have no effect on fat content. Milking interval time and variation in milk yield per milking also appear to influence fat content (Bruckmaier *et al.,* 2001; Friggens and Rasmussen 2001). Hamann *et al.,* (2004) reported that shorter intervals between milking events under AMS led to an increase in milk fat content. Conducting a study on milk composition and quality on 28 Dutch dairy farms before and after the implementation of AMS, as CMS herds (49 farms with twice-a-day milking and 28 farms with thrice-a-day milking), Klungel *et al.,* (2000) found milk composition, particularly fat and protein contents, to depend on milking frequency and milking system. They found higher milk fat (4.45% vs. 4.19%) and protein (3.47% vs. 3.42%) under twice-a-day milking in CMS. They also reported significantly higher milk fat and protein percentages after the implementation of an AMS (4.41% and 3.49% versus 4.37% and 3.42%, respectively).

In contrast, Tousova *et al.,* (2014) showed a positive effect of introducing an AMS on percentage of fat and protein in the milk. Comparing the effect of the implementation of CMS (300 cows) and AMS (200 cows) on Czech Fleckvieh cows' milk quality and composition, both the fat content (+ 0.16%; $P \leq 0.01$) and protein content (+ 0.06%; $P \leq 0.01$) of AMS-milked cows were higher than those of conventional parlour-milked cows (Table 2-6). Their results concurred with those of Vorobjovas *et al.,* (2010) who reported higher milk fat and protein (+0.09 and +0.08; $P \leq 0.05$, respectively) under AMS versus CMS.

Table 2-6 The effect of milking systems on milk composition and quality

Milking System	Fat (%)	Protein (%)	SCC (1000*ml)
	LSM ± SE	LSM ± SE	LSM ± SE
CMS	4.05±0.022	3.46±0.007	222.3 ± 7.63
AMS	4.21±0.022	3.52±0.006	163.86±7.44

Adopted from Tousova *et al.,* (2014)

2.5 Milk Quality

High expectations by consumers, regarding milk quality and safety, along with the current milk payment system in developed and most developing countries are a main reason why milk quality has become a major concern for dairy farmers (De Koning 2011). Among indicators of milk quality are the Total Bacterial Count (TBC) and SCC, representing, respectively, measurements of the total number of bacteria and white blood cells in a milk sample. Somatic cell count – one of the most common indicators of milk quality – can indicate reduced udder health due to mastitis, and may be affected by several factors, including cow age and stage of lactation (Sandrucci *et al.,* 2014; Laevens *et al.,* 1997; Koc and Kizilkaya 2009), stress (Koc *et al.,* 2009), milking management and hygienic conditions (Sandrucci *et al.,* 2014; Koc *et al.,* 2009), seasonal and environmental conditions (Sandrucci *et al.,* 2014), and breed (Koc *et al.,* 2009). Many studies have also shown an effect of milking system on milk quality (Castro *et al.,* 2012; Tousova *et al.,* 2014; Steeneveld *et al.,* 2015; Klungel *et al.,* 2000).

2.5.1 Somatic Cell Count

An indicator of milk quality, SCC increases in response to pathogenic bacteria (*e.g.,* *Staphylococcus aureus* – a significant cause of mastitis). When $\mathrm{SCC} < 1.0 \times 10^5 \mathrm{cells\,ml^{-1}}$ of milk, the cow producing the milk is normally deemed non-infected, whereas if $\mathrm{SCC} > 2.5 \times 10^5 \mathrm{cells\,ml^{-1}}$ of milk the cow is deemed to be potentially suffering from a significant pathogen infection (Schukken *et al.,* 2003; Schwarz *et al.,* 2010).

2.5.2 Dairy Milk SCC Standard

Among the major factors having an impact on milk quality are national regulations and payment systems to farmers. The latest Canadian Quality Milk program regulation (effective August 2012) lowered the SCC threshold for acceptance from 5.0×10^5 cells mL^{-1} (SCS 5.3) to 4.0×10^5 cells mL^{-1} (SCS 5.0) (Brodhagen 2012). This regulatory standard is comparable to that of the E.U. and other countries such as Australia, New Zealand, Norway and Switzerland. In contrast, the current regulatory limit is 7.5×10^5 cells mL^{-1} (SCS 5.9) in the United States (Brodhagen 2012). In 2014, the mean SCC on Canadian dairy farms was 2.0×10^5 cells mL^{-1}, with the lowest and highest levels found on British Columbia and Manitoba farms, respectively – see Figure 2-7 – (CDIC(e) 2016).

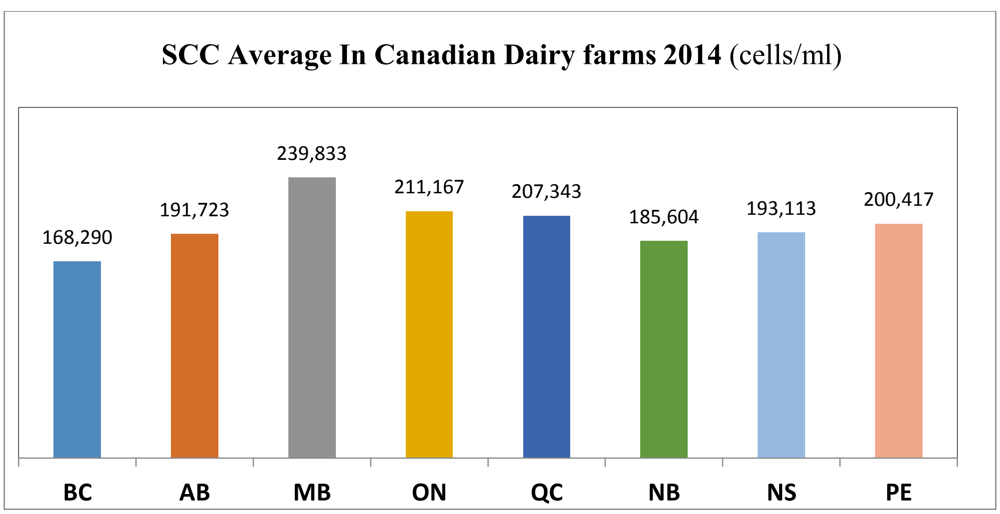

Figure 2-7 Mean Somatic Cell Count (SCC) in milk produced on Canadian farms by province. (CDIC (e) 2016)

2.5.3 Genetic Evaluation of Mastitis Resistance

Herd-health management and disease prevention are both a priority on dairy farms. As clinical mastitis is the most frequent and most reported dairy farm disease, genetic evaluations for mastitis resistance can be a useful tool for any mastitis control strategy. In promoting udder health, SCC, Udder Depth and Fore Udder Attachment are commonly-used traits for selection. However, these three traits only explain 46% of the genetic variation in resistance to mastitis (Beavers and Van Doormal 2013). Accordingly, in December 2013, a new routine evaluation for Mastitis Resistance was officially implemented by the Canadian Dairy Network (CDN) for the Holstein, Ayrshire and Jersey breeds. This evaluation is the first product of a Canadian National Health initiative, begun in 2007 (Beavers *et al.,* 2013). This new genetic evaluation for mastitis resistance combines the three predictive traits mentioned above as well as recorded mastitis, Body Condition Score and several other measurements associated with somatic cell count. Together these explain 72% of the genetic variation in mastitis resistance, thereby increasing the accuracy of genetic evaluations in Canadian dairy herds (Beavers *et al.,*2013).

2.5.4 Factors Influencing SCC

Somatic cell count may be affected by several factors, including the number of milkings, hygienic conditions, age, stage of lactation, stress, breed, and seasonal and environmental conditions (Laevens *et al.,* 1997; Koc *et al.,* 2009; Sandrucci *et al.,* 2014; Helgren and Reinemann 2006). With respect to seasonal and geographic effects on SCC, some studies have shown the highest SCC occurring in the spring (Allore *et* *al.,* 1997; Yoon *et al.,* 2004) and summer (Helgren *et al.,* 2006). The last study found significantly higher values for SCC during the summer months (July, August and September) than during the remainder of the year. In terms of effect of age and parity, many studies show a lower SCC in primiparous versus multiparous cows: Sandrucci *et al.,* (2014) speculated that the effect of parity might be associated with the difference in production level between primiparous and multiparous cows, and their resulting different milking durations and stages of lactation. They also noted certain environmental and management factors to be significant in influencing the risk of high SCC in milk. Clean udders and pre-dipping are associated with a reduced risk of high levels of SCC in herds. Although these factors influence milk quality, many studies have also reported the effect of milking systems on milk quality and SCC (Klungel *et al.,* 2000; Castro *et al.,* 2012; Tousova *et al.,* 2014).

2.5.5 Effect of Milking System on Milk Quality

Early studies, published soon after the introduction of AMS, indicated that herds milked by AMS had higher SCC levels than conventionally-milked herds (Klungel *et al.,* 2000; De Koning *et al.,* 2004; Rasmussen *et al.,* 2002; Reinemann 2002). Comparing milk quality parameters, particularly SCC, on 105 Dutch dairy farms (28 AMS, 49 CMS with twice daily milking, and 28 CMS with thrice daily milking), Klungel *et al.,* (2000) found SCC on AMS farms (196 cells L^{-1}) to be higher than on CMS farms with the twice and thrice daily milking (185 cells L^{-1} and 166 cells L^{-1}, respectively). They also noted that, within the CMS group, a lower SCC was found on the farms with thrice daily milking, confirming the work of Klei *et al.,* (1997) who found lower SCC levels when milking more than twice a day.

Jacobs *et al.,* (2012) suggested that one of the elements which may have led to greater SCC in milk from AMS farms in early studies was the longer machine-attachment times compared with more recent AMS models. De Koning (2011) found that AMS herds showed slightly higher SCC than under CMS, but the differences were relatively small, and within dairy industry standards. In contrast with earlier studies, a number of recent studies have shown no negative effect of AMS on SCC and milk quality, with some studies even showing positive effects on SCC and milk quality from using AMS. (Helgren *et al.,* 2006) conducted a study examining the effect of milking system on milk quality. Daily records from milk bulk tank SCC were analysed and compared to corresponding records from a cohort of CMS farms as well as from a new AMS installation. The geometric mean SCC for all farms was 2.68×10^5 cells mL^{-1}. They reported no significant difference in SCC between AMS farms and CMS farms.

In the Czech Republic, using milk-quality data from second to third lactation Holstein cows on one AMS and two CMS farms in order to assess the effect of milking system on SCC, Janštová *et al.,* (2011) found SCC to be higher in the two CMS farms compared to the AMS farm (Figure 2-8).

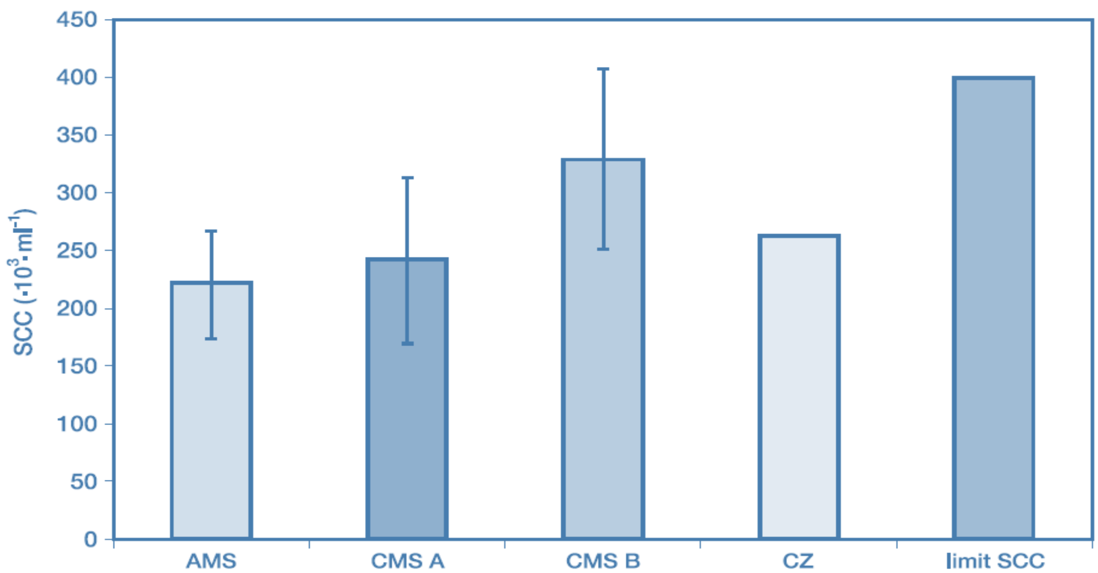

Figure 2-8 Comparison of the somatic cell count in milk from a farm using an automatic milking system (AMS), and two farms using a conventional milking system (CMS A, CMS B) and the 2008-CZ report (Janštová *et al*., 2011) AMS- automatic milking system, CMS A - conventional milking system - farm A, CMS B - conventional milking system - farm B, CZ - mean for Czech Republic, limit SCC – limit somatic cells count.

Similarly Tousova *et al.,* (2014) detected lower SCC values in milk from Czech Fleckvieh cows, milked by AMS (Table 2-6), and Berglund *et al.,* (2002) reported higher SCC values with increasing lactation days under CMS parlour milking (*vs.* AMS), which may reflect the greater difficulty in controlling SCC values in parlour milking. Despite the varying effects of milking systems on milk quality, and especially on SCC, there are some important factors which improve milk quality in both milking systems.

De Koning (2011) suggests that under AMS conditions, teat cleaning, and the cleaning of the teat cups and milking machines, should receive greater attention. Improvement of hygienic conditions in the cow's environment (Sandrucci *et al.*, 2014), hygiene management, and general hygiene standards in the barn (De Koning 2011) are key to success in achieving milk quality performance in both AMS and CMS.

2.6 Effect of Transition Period on Milk Quality and Production

Transitioning from CMS to AMS is a critical process that can influence milk yield and quality. However, every dairy farm begins the transition process from a different starting point. According to Rodriguez (2014), approximately 60% of AMS installations are constructed new and 40% retrofitted, where cows remain in the same environment before and after start up. Given the lower stress levels imposed on cows, when surrounded by familiar environments, retrofitted installations have a lower impact after start up on milk production and cow behaviour (Rodriguez 2014).

In terms of milk quality, the transition period to AMS also represents a period of higher risk to health that begins weeks before installation, when resources start to be diverted from cow management (Hillerton *et al.,* 2004). Some studies indicate that an increase in SCC is one of the main risk factors which influences milk quality during the transition period (Hillerton *et al.,* 2004; Neijenhuis *et al.,* 2010; De Koning 2011). Although udder health status, before the transition to AMS, is an important factor in explaining udder health afterwards (Neijenhuis *et al.,* 2010; De Koning 2011), some other factors such as management strategies, and use of information and data from the AMS, could help to reduce risk factors to udder health during this period (De Koning 2011).

Neijenhuis *et al.,* (2010) recommended that specific attention to cows and their inspection in terms of hygiene, milking intervals and health, along with the improvement of farmers' professional skills could improve udder heath during the transition period to AMS. Changing health-management methods in AMS (*vs.* CMS) herds was also recommended by Tse *et al.,* (2017).

Conducting a national survey across Canada (217 AMS producers from 8 Canadian provinces), Tse *et al.*, (2017) studied the effect of transition to AMS on producers' "perception of farm management and cow health on Canadian dairy farms". They found that, after transition to AMS, 66% of producers changed their health management methods, and reported either a decrease or no change in the rate of clinical mastitis.

As discussed above, studies looking at the effects of AMS on production and milk quality have been far from conclusive. In addition, few surveys have addressed these issues in Canada or, specifically, in Quebec. Our main objective, therefore, was to analyse Quebec dairy data for differences in milk production and milk quality, associated with using the CMS (milk-line, milking-parlour) *vs*. AMS. Lactation values for milk, energy-corrected milk, fat, and protein yield (kg) were considered as indicators of milk production, while somatic cell score was used as an indicator of milk quality.

3. Material and Methods

3.1 Data Collection

Data for this study were obtained from the Quebec Dairy Herd Improvement Agency – Valacta – and covered the 3-year period, starting January 2013 and ending December 2015. They contained 253,847 lactation records, representing 179,403 animals in 4,204 herds across all regions of the province of Quebec. The Valacta files provided region, herd, milking system, animal, parity, and lactation dates, as well as lactation values for milk, fat, and protein (kg), and SCC linear score (SCS).

3.2 Data Editing

SAS (ver. 9.4; SAS Institute Inc., Cary, NC) was used for sorting and basic editing of the milk-recording data files. Initial steps included the elimination of duplicate records, and the removal of abnormal values for lactation milk yield, milk yield per day and missing/negative lactation lengths, resulting in a loss of 2,546 lactations.

While ten different breeds plus Cross Breeds were represented in the data, only Ayrshire, Brown Swiss, Holstein, and Jersey were considered since the other breeds represented less than 1% of the data (a breakdown is shown in Appendix 1). Edits were performed for *age at first calving* less than or equal to 21 months. This was considered as reasonable, given that most average values for this parameter in Quebec are more than 26 months. It was initially decided to analyse up to and including Parity 6 (see Table 3-1); however, subsequent edits for parity parameters

(Table 3-2), as well as computational limitations with the overall size of the data set, resulted in the retention of only parities 1 through 4.

Table 3-1. Lactation records in different Parities

Lactation No	Lactations	Percent
1	103,600	41.23
2	68,217	27.15
3	40,872	16.26
4	21,323	8.49
5	9,909	3.94
6	4,351	1.73
7	1,824	0.73
8	762	0.30
9	278	0.11
10	108	0.04
11	37	0.01
12	10	0.00
13	3	0.00
14	5	0.00
15	2	0.00

Edits were performed for each of the four parities in order to account for potential mismatches in age at calving and parity number. In addition, lactation lengths less than 180 days or greater than 500 days were excluded. The parity-specific edits were carried out, based on excluding ± 4 standard deviations, for lactation milk yield (kg), fat yield (kg), protein yield (kg), and SCS (see Table 3-2).

Table 3-2: Parity-specific Edits.

Editing Criteria	Parity1	Parity2	Parity3	Parity4
Records after initial editing	101,145	68,010	40,720	21,250
Age at calving &	>22 and < 33 months	>33and < 50 months	>45 and < 65 months	>57 and < 80 months
Lactation length (>180 days and < 500 days)	88,881	61,983	37,416	19,448
Milk Yield in lactation period	± 4 Standard deviations (2000 < Milk (Kg) < 17000)	± 4 Standard deviations (2000 < Milk (Kg) < 20000)	± 4 Standard deviations (2000 < Milk (Kg) < 22000)	± 4 Standard deviations (2000 < Milk (Kg) < 23000)
	88,699	61,901	37,390	19,445
Fat in lactation period	± 4 Standard deviations (100 < Fat (Kg) < 750)	± 4 Standard deviations (100 < Fat (Kg) < 800)	± 4 Standard deviations (100 < Fat (Kg) < 900)	± 4 Standard deviations (100 < Fat (Kg) < 900)
	88,474	61,681	37,286	19,399
Protein in lactation period	± 4 Standard deviations (100 < Protein (Kg) < 600)	± 4 Standard deviations (100 < Protein (Kg) < 650)	± 4 Standard deviations (100 < Protein (Kg) < 680)	± 4 Standard deviations (100 < Protein (Kg) < 700)
	88,434	61,655	37,257	19,390
Average of SCC linear score	(0.2 <SCLS< 7)	(0.2 <SCLS< 7.5)		
	88,169	61,533	37,186	19,364
Dataset after combining four parities				**206,252**

Since the main objective of this study was the comparison of AMS (Robots) with CMS (Milk-line and Parlour), and given that Region was considered as playing a potential role in milk production and quality, a breakdown of milking system was examined across regions (Appendix 2). Three of the regions (Gaspesie-Iles-de-la-Madeleine; Laval; and Outaouais) contained no AMS herds, while the region of Abitibi-Temiscamingue contained only one. These four regions were, therefore, excluded from the analyses.

In terms of the herds with Milk-Line system, there are 3793 herds in different regions of Quebec. Since inclusion of all herds (and their corresponding lactations) would have been computational challenging for the model, a random selection of milk-line herds – the most abundant milking system – was chosen for each of the eleven remaining regions. As a result, 712 milk-line herds were selected randomly from across the selected regions. The final edit removed any herd that had less than ten lactations, producing a dataset of 67,440 lactations for analyses with the following characteristics (Table 3-3). The resulting data set comprised 1,065 herds (712, milk-line, 216 parlour, and 137 robot) and 48,018 animals.

Table 3-3: Final data set (Numbers of lactations) for breeds by parity and by milking system.

	Ayrshire	Brown Swiss	Holstein	Jersey		Totals	
Parity 1	2,562	341	24,518	1,244		28,665	42.50%
Parity 2	1,944	269	17,015	937		20,165	29.90%
Parity 3	1,221	168	10,207	626		12,222	18.12%
Parity 4	717	90	5,230	351		6,388	9.47%
Milk-line	5,455	707	24,457	2,368		32,987	48.91%
Parlour	554	93	22,467	302		23,416	34.72%
Robot	435	68	10,046	488		11,037	16.37%
Breed Totals	6,444	868	56,970	3,158		**67,440**	**100.00%**
	9.56%	1.29%	84.48%	4.68%			

3.3 Statistical analysis and prediction model construction

In addition to the three lactation production measurements (kg of milk, fat and protein), energy-corrected milk yield (ECMY) was also calculated for the final dataset as [0.323*Kg Milk + 12.82*Kg Fat + 7.13*Kg Protein] (Gozho *et al.*, 2007). Somatic cell score was analysed as an indicator of milk quality. Using the SAS ® software (SAS Inst., Inc. Cary, NC) mixed-model analyses were carried out under the following model:

$$y = \mu + Milking\_System_i + Breed_j + Parity_k + Year\_of\_Calving_l + Region_m + Herd_{imn} + Breed_j \times Parity_k + Milking\_System_i \times Breed_j + Milking\_System_i \times Parity_k + Milking\_System_i \times Breed_j \times Parity_k + e_{ijklmn}$$

- Where y is the dependent variable [lactation milk yield, ECMY, fat, or protein (kg) or SCS];
- μ is the overall mean; with
- Fixed effects of Milking System, Breed, Parity, Year of Calving and Region;
- Random effect of Herd, nested within Milking System and Region; and
- Fixed effects of the following interactions:
    - Breed by Parity;
    - Milking System by Breed;
    - Milking System by Parity; and
    - Milking System by Breed by Parity.

For all dependent variables, the random effect of herd was tested for statistical significance using the Bayesian information criterion (BIC). Once found to be significant in the model (using F-test), the fixed effects of the models, least squares means and estimates of differences were evaluated. A significance level of $P < 0.05$ was used to evaluate differences among groups. If none of the modelled interactions was found to be significant, the main effects are reported. Otherwise, the interaction effects are presented.

4. Results and Discussion

4.1 Descriptive statistics

An overview of the dataset, in terms of lactation record per breed, parity, and milking system was previously presented in Table 3-3. The proportions of observations in each of the four parities were 43%, 30%, 18% and 9.5%, respectively. Of the four breeds analysed, 84.5% of the lactations were Holstein, followed by Ayrshire (9.6%), Jersey (4.7%) and Brown Swiss (1.3%). Descriptive statistics for the four breeds are shown in Table 4-1.

Table 4-1: Descriptive statistics (LSM) for the four breeds (across all four parities).

	Ayrshire (n = 6,444)				Brown Swiss (n = 868)				Holstein (n = 56,970)				Jersey (n = 3,158)			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Lactation Milk (kg)	8,096	1.79	2,886	18,148	8,526	2.22	3,283	17,864	10,312	2.45	2,601	21,231	6,947	1.83	2,515	15,864
Lactation ECMY (kg)	8,967	1.98	3,384	21,098	9,609	2.54	3,341	21,229	10,996	2.56	3,163	22,743	8,609	2.23	3,132	20,055
Lactation Fat (kg)	341	0.79	131	886	365	1.00	118	832	410	1.00	102	880	348	0.69	101	663
Lactation Fat (%)	4.21%				4.28%				3.98%				5.01%			
Lactation Protein (kg)	276	0.61	105	609	304	2.96	105	671	338	0.79	101	680	266	0.69	101	663
Lactation Protein (%)	3.41%				3.57%				3.28%				3.83%			
Lactation Average SCS	2.19	1.23	0.20	7.20	2.40	1.40	0.20	7.30	2.31	1.29	0.20	7.50	2.80	1.35	0.20	7.50

On average Holstein cows produced the highest lactation yields (10,312 kg) while Jersey had the highest percentage components of fat and protein. All these averages fall into the normally observed values for the respective groups of dairy cows on commercial farms in Quebec and can, therefore, be considered a representative samples for use in further analyses.

4.1.1 Variances of the predictive models

In all predictive models, the effect of milking systems on milk production and quality indicators were evaluated in 1st, 2nd, 3rd and 4th parities in four breeds (Ayrshire, Brown Swiss, Holstein, and Jersey). In all predictive models, the random effect of herd was nested within milking system and region (see Section 3.3). The random effect of herd (within milking system and region) was found to be statistically significant and therefore, there was variability among herds. Table 4-2 shows the variance estimates of the random effect of herd, nested within milking system and region, as well as the variance of the residual effect under all models. Existence of large variation among herds within milking system and region indicates that the effect of herd, as a random effect in the model, cannot be ignored. Under the models for production, Herd accounted for a considerable amount of the total variation (approximately 25%) whereas the model for quality (SCS) saw a much smaller contribution by Herd to the total variation.

Table 4-2: Variance estimates for Herd (within milking system and region) and Residual for the five models (000 000 kg^2 for Milk Yield and ECMY; 0 000 kg^2 for Fat and Protein).

Variance parameters	Estimates				
	Milk Yield	ECMY	Fat	Protein	SCS
$\sigma^2_{Herd\ (Milking\ system\ and\ Region)}$	1.1249	1.4059	0.2232	0.1319	0.1441
σ^2_e	3.6581	4.0756	0.6489	0.3940	1.4619

ECMY: Energy Corrected Milk Yield
SCS: Average Somatic Cell Score

In Table 4-3 the fixed effects of the models (by using F-test), least squares means and estimates of differences were evaluated.

Table 4-3: Probabilities of significant differences (Type 3 Tests) among the fixed effects for the five dependent variables

	Type 3 Tests of Fixed Effects								
	Milking System	Breed	Parity	Year of Calving	Region	Breed x Parity	Milking System x Breed	Milking System x Parity	Milking System x Breed x Parity
Lactation Milk (kg)	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.0014	0.0347	**0.6884**
Lactation ECMY (kg)	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.0429	0.0141	**0.3738**
Lactation Fat (kg)	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	**0.1471**	0.0266	**0.1988**
Lactation Protein (kg)	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.0119	0.0059	**0.4790**
Average Lactation SCS	**0.5158**	<.0001	<.0001	**0.2529**	0.0306	<.0001	0.0237	**0.3350**	0.0004

A P-value of 0.05 was chosen for significance testing.

4.1.2 Estimated differences.

The least squares means for the four predictive models, related to production, are presented in Appendix 3 (main effects and two-way interactions only), and those for the three-way interactions only for SCS are presented in Table 4-8. In all predictive models, Scheffé's Method was used to assess multiple comparisons. Probabilities of significant differences among the fixed effects for the five dependent variables are shown in Table 4-3. Plots of the two-way interactions (see Figures 4-1 – 4-4) showed that, despite their significance, some of the main effects could also be interpreted in a meaningful manner (Table 4-4). The analysis of average lactation SCS showed a significant three-way interaction among Milking System, Breed, and Parity (Table 4-3) and is treated separately under Section 4.3.

Table 4-4: Estimates of differences among main effects of milking system, parity and breed

	Milk Yield (kg)			Fat Yield (kg)			Protein Yield (kg)			ECMY (kg)		
	Estimate	SE	Adj P	Estimate	SE	Adj P	Estimate	SE	Adj P	Estimate	SE	Adj P
Milking System												
M - P	-349.50	138.50	0.0350	-13.08	5.97	0.0859	-7.29	4.55	0.2782	-306.00	147.30	0.1158
M - R	-803.40	145.20	<.0001	-25.77	6.30	0.0001	-25.24	4.90	<.0001	-782.30	158.80	<.0001
P - R	-453.90	185.90	0.0440	-12.69	8.02	0.3418	-17.95	6.21	0.0153	-476.20	200.80	0.0117
Parity												
P1 - P2	-1090.60	73.74	<.0001	-45.53	3.11	<.0001	-41.34	2.42	<.0001	-1230.60	77.88	<.0001
P1 - P3	-1545.80	89.46	<.0001	-62.33	3.77	<.0001	-54.65	2.94	<.0001	-1688.00	94.48	<.0001
P1 - P4	-1955.90	120.30	<.0001	-78.76	5.07	<.0001	-65.48	3.95	<.0001	-2108.70	127.00	<.0001
P2 - P3	-455.30	91.18	<.0001	-16.80	3.84	0.0003	-13.31	2.99	0.0002	-457.40	96.28	<.0001
P2 - P4	-865.30	122.00	<.0001	-33.23	5.14	<.0001	-24.14	4.01	<.0001	-878.10	128.80	<.0001
P3 - P4	-410.10	131.40	0.1314	-16.43	5.54	0.0180	-10.83	4.32	0.0977	-420.70	138.80	0.0269
Breed												
AY - BS	-860.90	1176.90	<.0001	-46.09	7.48	<.0001	-45.49	5.82	<.0001	-1192.70	187.40	<.0001
AY - HO	-2267.10	94.13	<.0001	-71.71	3.98	<.0001	-65.40	3.10	<.0001	-2115.30	99.90	<.0001
AY - JE	527.00	128.60	0.0008	-22.16	5.45	0.0009	-7.47	4.24	0.3762	-169.10	136.60	0.6748
BS - HO	-1406.10	152.30	<.0001	-25.62	6.43	0.0012	-19.91	5.01	0.0012	-922.60	161.20	<.0001
BS - JE	1387.90	178.80	<.0001	23.93	7.56	0.0183	38.02	5.88	<.0001	1023.60	189.40	<.0001
HO - JE	2794.00	95.43	<.0001	49.55	4.04	<.0001	57.93	3.15	<.0001	1946.30	101.40	<.0001

M= Milk-Line, P=Parlour, R=Robot (AMS)
P1 to P4= Parity one to Parity Four
AY=Ayrshire, BS=Brown Swiss, HO= Holstein and JE= Jersey
ECMY= Energy corrected milk yield

4.2 Effect of milking system on milk-production traits

Using a significance level of $P<0.05$, the interactions of Breed x Parity, Milking System x Breed, and Milking System x Parity were found to be significant effects in all of the predictive models for production except for the effect of Milking System x Breed for fat yield (Table 4-3). The three-way interaction was not found to be significant in any of four production models.

Significant differences were found for lactation milk yield between AMS and CMS in the four major breeds. The least squares mean for lactation milk yield from herds that were using robotic milking was 9,292 kg, whereas the values for parlour milking and milk-line records were 8,838 kg and 8,489 kg respectively (Appendix 3).

These results generally agree with the findings of previous studies (Bijl *et al.*, 2007; De Koning *et al.*, 2004; De Koning 2011; Tousova *et al.*, 2014), reporting a 5-10% increase in milk production in AMS herds compared to CMS.

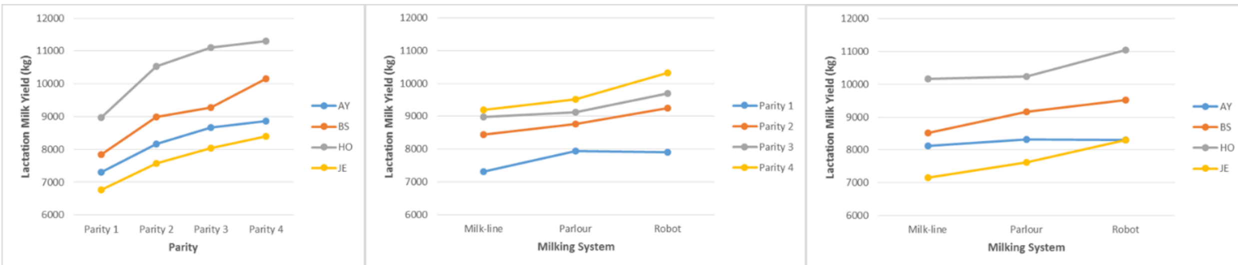

Figure 4-1: Plots of Lactation Milk Yield (LSM) for the three 2-way model interactions (a, b, and c).

In all three milking systems significant differences were found among different parities, and milk yield per lactation increased with parity. The maximum milk production was found for fourth-lactation Holsteins on robotic milking systems. This finding agrees with observations made by Maršálek *et al.*, (2012), where increased milk yields on AMS from first to fifth lactation (through an increased milking frequency), suggested a maximizing of milk production in dairy herds using AMS. There was a slight decrease in parity one when comparing robotic milking with parlour milking, but no significant difference was found between those two milking systems (see Appendix 3 for LSM and Figure 4-2b). In parities two and four, AMS had a significantly higher milk yield ($P < 0.05$) compared to the milk-line.

Table 4-5: Estimates of differences among milking systems within parity.

		Milk Yield (kg)			ECMY (kg)			Fat Yield (kg)			Protein Yield (kg)		
		Estimate	SE	Adj P	Estimate	SE	Adj P	Estimate	SE	Adj P	Estimate	SE	Adj P
Parity 1	M - P	-628	149	0.087	-666	161	0.104	-25	6	0.162	-19	5	0.194
	M - R	-591	175	0.410	-515	189	0.761	-16	8	0.945	-16	6	0.772
	P - R	38	214	1.000	151	231	1.000	9	9	1.000	3	7	1.000
Parity 2	M - P	-312	153	0.965	-348	165	0.955	-14	7	0.950	-9	5	0.989
	M - R	-795	174	0.036	-786	188	0.095	-27	7	0.287	-25	6	0.069
	P - R	-483	215	0.928	-438	231	0.980	-13	9	0.998	-16	7	0.930
Parity 3	M - P	-145	202	1.000	-107	216	1.000	-4	9	1.000	-1	7	1.000
	M - R	-712	191	0.239	-658	205	0.505	-21	8	0.835	-22	6	0.358
	P - R	-568	261	0.943	-552	279	0.972	-17	11	0.997	-21	9	0.866
Parity 4	M - P	-313	279	1.000	-240	296	1.000	-9	12	1.000	-3	9	1.000
	M - R	-1116	248	0.042	-1109	264	0.092	-39	11	0.262	-35	8	0.078
	P - R	-803	355	0.925	-869	377	0.915	-30	15	0.973	-32	12	0.756

M= Milk-Line, P=Parlour, R=Robot (AMS)
ECMY= Energy corrected milk yield

No significant difference was found in milk yield for Ayrshire and Brown Swiss (see Appendix 3 for LSM and Figure 4-1c), and in Jersey, a significant difference was found only between AMS and Milk-Line herds. The Holstein breed showed significant differences between AMS and both CMS.

Table 4-6: Estimates of differences among milking systems within breed.

		Milk Yield (kg)			ECMY (kg)			Fat Yield (kg)			Protein Yield (kg)		
		Estimate	SE	Adj P	Estimate	SE	Adj P	Estimate	SE	Adj P	Estimate	SE	Adj P
Ayrshire	M - P	-194	228	1.000	-283	244	1.000	-15	10	0.997	-4	8	1.000
	M - R	-174	219	1.000	-193	235	1.000	-8	9	1.000	-5	7	1.000
	P - R	19	300	1.000	90	321	1.000	7	13	1.000	-1	10	1.000
Brown Swiss	M - P	-647	358	0.987	-707	381	0.983	-27	15	0.990	-21	12	0.987
	M - R	-1008	330	0.592	-1195	351	0.396	-48	14	0.383	-35	11	0.501
	P - R	-362	455	1.000	-488	483	1.000	-21	19	1.000	-14	15	1.000
Holstein	M - P	-79	89	1.000	-133	99	0.999	-8	4	0.970	-1	3	1.000
	M - R	-878	107	<.0001	-789	119	<.0001	-25	5	0.004	-27	4	<.0001
	P - R	-799	122	<.0001	-656	136	0.016	-17	5	0.562	-26	4	<.0001
Jersey	M - P	-479	213	0.929	-238	228	1.000	-3	9	1.000	-6	7	1.000
	M - R	-1153	231	0.009	-891	248	0.300	-23	10	0.921	-32	8	0.113
	P - R	-675	295	0.918	-654	316	0.961	-19	13	0.997	-26	10	0.809

M= Milk-Line, P=Parlour, R=Robot (AMS)
ECMY= Energy corrected milk yield

Energy corrected milk yield (ECMY) determines the amount of energy in milk based on milk's weight, as well as the fat, adjusted to 3.5 per cent, and the protein, adjusted to 3.2 per cent. It has already been defined in Section 3.3 as [0.323*Kg Milk + 12.82*Kg Fat + 7.13*Kg Protein]. The utility of ECMY is that it provides a standardized milk production value that can be used to compare milk with different fat and protein levels (Linington *et al.*, 2016).

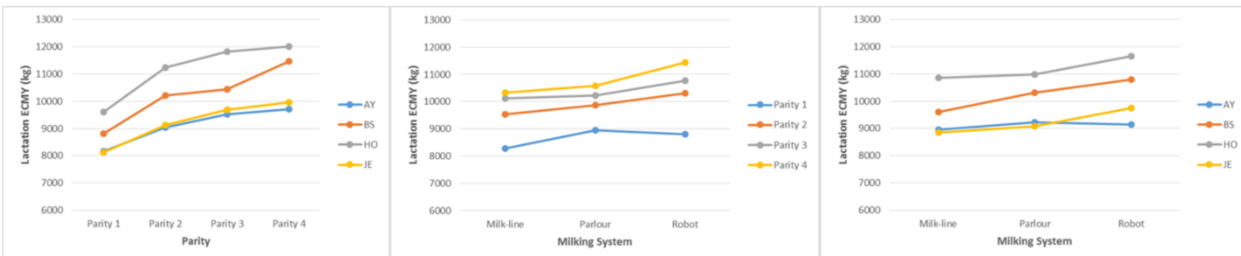

Figure 4-2: Plots of Lactation ECMY (LSM) for the three 2-way model interactions (a, b, and c).

There were significant differences (P<0.05) among ECMY for the four breeds for AMS and CMS (Figure 4-2c). The value of ECMY was highest in AMS (10,333 kg) versus 9,906 kg and 9,506kg for parlour and milk-line respectively. This finding agrees with observations made by Oudshoorn *et al.*, 2012, who found higher ECMY in AMS as compared to CMS.

In terms of the comparison between parlour milking and milk-line in all breeds, although there was an increase in ECMY in parlour milking, no significant difference was found between the conventional milking systems. Table 4-6 shows that for Ayrshire, Brown Swiss and Jersey breeds, no significant differences were found between robotic and parlour milking (P<0.05). In the Holstein breed significantly higher ECMY for AMS farms was observed (P<0.05) compared to milk-line. Higher standard errors and lower number of observations for Ayrshire, Brown Swiss and Jersey, Holsteins could help to explain these lacks of significance, while the fact that Holsteins represented the majority of the observations may contribute to the significance of several effects for that breed.

Significant differences were found in ECMY among all four parities (ECMY increased with parity). Also, significant differences were observed in first, second and fourth parities when comparing milk-line and robotic milking systems. There was a slight decrease in parity one when comparing robotic milking with parlour milking but the difference was not significant. Maximum performance of ECMY was found in the herds using AMS in 4^{th} parity (Appendix 3) which agrees with observations made by (Maršálek *et al.,* 2012), reporting that the higher the parity in AMS farms, the higher the performance in milk yield.

Numerous studies (Devir *et al.,* 1997; Kuipers *et al.,* 1992; De Koning 2011; Gygax *et al.,* 2007) have shown that AMS herds have a greater milk yield than CMS herds. The main explanation for this higher performance in milk production in AMS herds is that the increase in milk yield is due to more frequent milking (Erdman *et al.,* 1995). These authors also observed an increase between 6% and 25% over complete lactations when milking frequency increased from two times to three times per day. In addition, Österman and Bertilsson (2003) observed that ECMY was higher in cows milked three times per day compared to those milked twice per day. As AMS milking systems differ from the two other milking systems (milk-line and parlour), and cows can be milked more than two (several) times per day, this increase in milking frequency can explain the increase in milk production (Atashi 2015). On AMS farms the mean milking frequency is 2.2 to 3.2 per day (Rodenburg, 2013). Similarly, De Koning (2011) mentions a mean of 2.5 to 3.0 milking per day under AMS. The key element in increasing milking frequency, under an AMS, is voluntary attendance. The main motive for this is the supply of concentrates in the milking box during the milking process. Another important key factor of high voluntary attendance in AMS is greater cow traffic in the barn, which can be achieved by providing easy access to milking stalls, and selecting gates and traffic flows in the barn that are conducive to voluntary attendance (De Koning 2011).

Another explanation for higher milk yield by automatic milking systems may be a higher management ability in herds using AMS versus herds with conventional milking systems. Although this study did not attempt to evaluate management skill among herds, differences observed in milk yield might be associated with better management practices, related to freeing up the farm manager to do more true managing of the dairy (*e.g.*, better planning, record keeping and analysis in AMS herds). Tranel *et al.,* (2012) hypothesised that AMS allow for an increased management ability by collecting individual cow milk production, milk conductivity, cow activity, and rumination data. They were also of the opinion that AMS represent a high-level management system, not just a tool to milk cows.

High-performing herds not only need superior milking cows; they also need to have a high level of management skills. This is in agreement with Wade *et al.,* (2004) who mentioned that milk production on dairy farms in greatly dependent on management. One could postulate, therefore, that milk-yield performance could be used as an indicator of the management quality of herds.

Table 4-7: Estimates of differences among parities in milking systems.

		Milk Yield (kg)			ECMY (kg)			Fat Yield (kg)			Protein Yield (kg)		
		Estimate	SE	Adj P	Estimate	SE	Adj P	Estimate	SE	Adj P	Estimate	SE	Adj P
Milk-line	P1 - P2	-1129	53	<.0001	-1248	56	<.0001	-46	2	<.0001	-42	2	<.0001
	P1 - P3	-1671	61	<.0001	-1831	65	<.0001	-68	3	<.0001	-59	2	<.0001
	P1 - P4	-1887	75	<.0001	-2053	80	<.0001	-77	3	<.0001	-65	2	<.0001
	P2 - P3	-542	64	<.0001	-583	67	<.0001	-22	3	<.0001	-17	2	<.0001
	P2 - P4	-758	78	<.0001	-806	82	<.0001	-31	3	<.0001	-23	3	<.0001
	P3 - P4	-216	82	0.8050	-223	87	0.8306	-9	3	0.8530	-6	3	0.9452
Parlour	P1 - P2	-813	140	0.0004	-930	148	<.0001	-35	6	0.0003	-32	5	<.0001
	P1 - P3	-1187	189	<.0001	-1271	200	<.0001	-47	8	0.0003	-40	6	<.0001
	P1 - P4	-1571	261	0.0002	-1627	276	0.0003	-60	11	0.0015	-48	9	0.0008
	P2 - P3	-374	194	0.9778	-341	205	0.9934	-12	8	0.9975	-9	6	0.9986
	P2 - P4	-758	268	0.7106	-697	283	0.8671	-26	11	0.9178	-17	9	0.9784
	P3 - P4	-384	296	0.9993	-356	312	0.9998	-14	12	0.9999	-8	10	1.0000
Robot	P1 - P2	-1333	164	<.0001	-1518	173	<.0001	-57	7	<.0001	-51	5	<.0001
	P1 - P3	-1792	181	<.0001	-1973	191	<.0001	-73	8	<.0001	-65	6	<.0001
	P1 - P4	-2411	239	<.0001	-2647	252	<.0001	-99	10	<.0001	-84	8	<.0001
	P2 - P3	-459	182	0.8499	-455	192	0.8982	-16	8	0.9576	-14	6	0.8945
	P2 - P4	-1078	239	0.0399	-1128	252	0.0443	-43	10	0.0836	-33	8	0.0899
	P3 - P4	-620	249	0.8610	-673	263	0.8345	-26	11	0.8479	-19	8	0.9206

P1, P2, P3, and P4 represent parities 1 through 4
ECMY= Energy corrected milk yield

Lactation fat yield showed significant differences among AMS and milk-lines, and was highest in herds using and AMS (393 kg) versus 380 kg and 367 kg in herds using a parlour and milk-line, respectively. The results of this study are in general agreement with the study by Vorobjovas *et al.*, (2010) and Tousova *et al.*, (2014) who reported higher milk fat in AMS compared to CMS. However, an earlier study, done by Abeni *et al.*, (2005), concluded that milking system did not influence milk fat content. In fact, a study reported by Wirtz *et al.*, (2004), reported lower fat content in AMS compared to CMS.

When comparing parlour and milk-line, the former was higher (although not significantly so), and no significant difference was found between parlour and AMS. Despite the seeming drop of AMS in parity 1 (compared to CMS), the difference was not significant, nor where there any significant differences for milking system within parity (Table 4-5; Figure 4-3b).

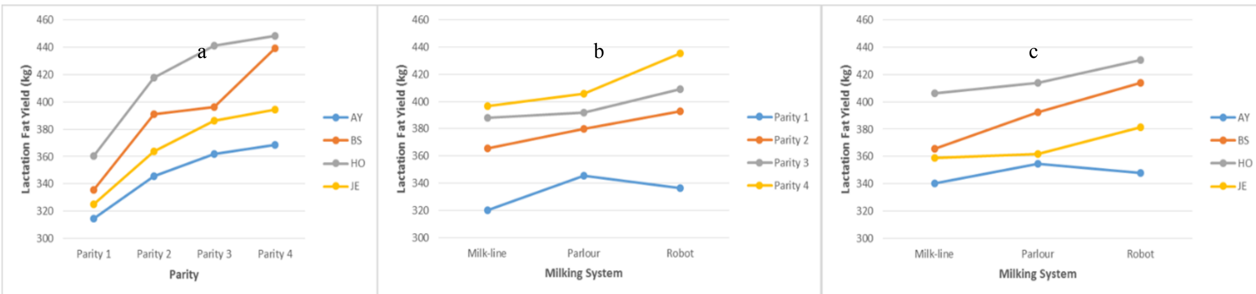

Figure 4-3: Plots of Lactation Fat Yield (LSM) for the three 2-way model interactions (a, b, and c).

In general, there were significant differences for lactation fat yield among all four parities (an increase). In the case of both parlour and robot milking, there were no significant differences for lactation fat yield among parities 2, 3, and 4, but all three later parities were significantly higher than parity 1 (Table 4-7; Figure 4-3b). In the case of milk-line records, all parity comparisons were significantly different for fat except for parities 3 and 4 (P<0.05).

Milk fat curves display different patterns depending on the type of milking system and parity. This finding agrees with result obtained by Looper (2012) who reported an effect of age and parity on milk-fat content. This finding is also in agreement with Vorobjovas *et al.*, (2010); De Koning (2011); Tousova *et al.*, (2014); Klungel *et al.*, (2000) who reported that milking system has a significant effect on milk-fat content. However, the study by Abeni *et al.*, (2005) observed no effect of milking system on milk fat content. Since cows can be milked more than twice daily under AMS, the effect of milking frequency and interval, on milk fat content, could explain the influential effects of milking system. As mentioned, AMS differs from the two other milking systems (milk-line and parlour milking) and, since cows can be milked more than two (several) times per day, this increase in frequent milking can lead to change in milk composition. In this study, the lactation milk fat yield of herds, which were using AMS, showed an increase – perhaps due to the higher frequency of milking in AMS. There seems to be quite variable results in the literature regarding the effect of milking frequency on fat content: Wiking *et al.,* (2006) found no effect on fat content with increased milking frequency, whereas Klungel *et al.,* (2000) found that higher milking frequency in AMS resulted in a reduction of fat and protein content in milk. As quoted by Tousova *et al.,* (2014), Spolders (2000) also reported that more frequent milking, in both CMS and AMS, resulted in a decreased fat content in milk.

The length of the interval since the previous milking, and variation in milk yield per milking, also appears to be more important for fat content (Bruckmaier *et al.*, 2001; Friggens *et al.*, 2001). Hamann *et al.,* (2004) reported that shorter intervals between milking events in AMS led to increased fat content in milk. Rodenburg (2013) recommended that both frequent milking and uniform milking intervals should be considered as a goal in AMS. As mentioned previously, milk production in greatly dependent on management skills (Wade *et al.,* 2004). Since lactation milk fat yield is directly linked to lactation milk yield, it could be argued that higher milk fat yield observed in AMS would also be associated with better management skills in these herds.

Lactation protein yield showed significant differences among AMS and CMS, and was highest in herds using an AMS (320 kg) versus 302 kg and 295 kg in herds using a parlour and milk-line, respectively. This result agrees with the finding by Vorobjovas *et al.*, (2010) and Tousova *et al.*, (2014). In both studies, higher milk protein yield was reported in AMS as compared to CMS herds.

In all three milking systems milk protein yield increased with parity. Table 4-11 shows the least squares means of lactation milk protein yield for the four parities and three milking systems. Appendix 3 shows that, as was the case for fat in parity 1, robotic milking and parlour milking were basically identical (the value for parlour was actually higher) and no significant difference was found between the two milking systems (P< 0.05). In fact, across breeds, the same trend for lactation protein yield was found in the comparison of parities as was found for fat (Figure 4-4b). Within breed, the only significant effects of milking system were found in Holstein, where AMS had significantly higher lactation protein yield than either parlour or milk-line. None of the other comparisons for any breed was significantly different (Table 4-6).

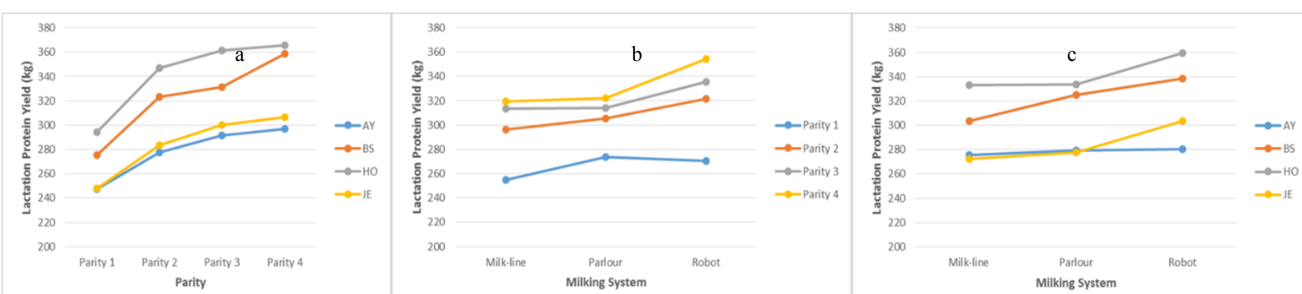

Figure 4-4: Plots of Lactation Protein Yield (LSM) for the three 2-way model interactions (a, b, and c).

As in the case of fat yield, this finding is also in agreement with Vorobjovas *et al.*, (2010); De Koning (2011); Tousova *et al.*, (2014); Klungel *et al.*, (2000), who reported a significant effect of milking system on milk protein content, and the same arguments for potentially increased milking frequency hold for protein as well.

4.3 Effect of milking system on milk quality

Lactation average somatic cell score was used as an indicator of milk quality in this study, and, as was the case for the production traits, the effect of milking system on SCS was evaluated in four parities and four breeds (Ayrshire, Brown Swiss, Holstein, and Jersey). The random effect of herd was found statistically significant; i.e. there were differences among the herds. The fixed effect of the three-way interaction (Milking System x Breed x Parity) was found to be significant (Table 4-3), as were the two-way interactions of Breed x Parity and Breed x Milking System, but not the interaction between Milking System x Parity (P< 0.05). As the fixed effect of the three way interaction was found to be significant, the effects of these three variables on SCS were analyzed. Least squares means for the three-way interactions are shown in Table 4-8.

Table 4-8: Estimates of least squares means (and standard errors) for SCS for milking system within breed and parity.

		Milk-line		Parlour		Robot	
		Estimate	SE	Estimate	SE	Estimate	SE
Ayrshire	Parity 1	2.006	0.051	1.929	0.137	2.198	0.140
	Parity 2	2.270	0.053	2.157	0.144	2.480	0.145
	Parity 3	2.395	0.058	2.431	0.159	2.622	0.161
	Parity 4	2.468	0.066	2.636	0.194	2.830	0.205
Brown Swiss	Parity 1	2.121	0.094	1.970	0.218	1.711	0.281
	Parity 2	2.550	0.103	2.295	0.222	2.456	0.274
	Parity 3	2.689	0.118	3.077	0.375	2.775	0.315
	Parity 4	3.006	0.149	3.618	0.556	3.754	0.465
Holstein	Parity 1	2.118	0.039	1.943	0.046	2.141	0.053
	Parity 2	2.427	0.040	2.296	0.047	2.413	0.054
	Parity 3	2.697	0.041	2.606	0.049	2.706	0.057
	Parity 4	2.834	0.045	2.737	0.053	2.894	0.064
Jersey	Parity 1	2.702	0.060	2.484	0.134	3.019	0.137
	Parity 2	2.796	0.064	2.503	0.151	2.286	0.142
	Parity 3	2.962	0.072	2.644	0.180	2.626	0.157
	Parity 4	3.049	0.086	2.548	0.264	2.573	0.199

While interpretation of the simple effect of milking system is not obvious (given the three-way interaction), there were no significant difference in SCS (although AMS was numerically the highest (2.59) versus 2.57 for milk-line and 2.49 for parlour. Helgren *et al.,* (2006) concluded that there was no significant difference in SCC between AMS farms and the cohort of conventional farms. De Koning (2011) mentioned that, in general, AMS herds show slightly higher SCC compared to CMS but the differences were relatively small and well within the dairy industry requirements. Klungel *et al.,* (2000) observed higher SCC in AMS compare to CMS. It is, perhaps, worth noting that the technology of AMS has evolved with time and may explain some of the differing results in early studies that observed a negative effect of AMS on SCS. The similarity of SCS among milking systems in this study is borne out by Table 4-9 where there were no significant differences among milking systems within breed and parity.

Table 4-9: Estimates of differences in SCS among *milking systems* within breed and parity.

		Parity 1			Parity 2			Parity 3			Parity 4		
		Estimate	SE	Adj P	Estimate	SE	Adj P	Estimate	SE	Adj P	Estimate	SE	Adj P
Ayrshire	M - P	0.077	0.138	1.000	0.113	0.145	1.000	-0.036	0.162	1.000	-0.168	0.199	1.000
	M - R	-0.192	0.141	1.000	-0.210	0.147	1.000	-0.227	0.164	1.000	-0.362	0.210	1.000
	P - R	-0.269	0.189	1.000	-0.322	0.198	1.000	-0.190	0.221	1.000	-0.194	0.278	1.000
Brown Swiss	M - P	0.151	0.232	1.000	0.255	0.240	1.000	-0.388	0.390	1.000	-0.613	0.574	1.000
	M - R	0.410	0.292	1.000	0.094	0.289	1.000	-0.086	0.333	1.000	-0.748	0.486	1.000
	P - R	0.259	0.352	1.000	-0.161	0.349	1.000	0.302	0.487	1.000	-0.136	0.723	1.000
Holstein	M - P	0.176	0.036	0.998	0.131	0.038	1.000	0.091	0.041	1.000	0.098	0.049	1.000
	M - R	-0.023	0.044	1.000	0.014	0.046	1.000	-0.009	0.051	1.000	-0.059	0.061	1.000
	P - R	-0.199	0.049	1.000	-0.118	0.051	1.000	-0.100	0.055	1.000	-0.157	0.065	1.000
Jersey	M - P	0.219	0.138	1.000	0.292	0.156	1.000	0.318	0.188	1.000	0.501	0.274	1.000
	M - R	-0.317	0.141	1.000	0.510	0.148	1.000	0.336	0.165	1.000	0.476	0.212	1.000
	P - R	-0.535	0.185	1.000	0.218	0.201	1.000	0.018	0.233	1.000	-0.024	0.327	1.000

M= Milk-Line, P=Parlour, R=Robot (AMS)

Estimates of differences in SCS among parities within breed and milking system are shown in Table 4-10. The only significant differences among parities, across all milking systems, were found in Holstein – an increase in SCS over the first three parities. While the tendency of increase in SCS continued into the fourth parity, there was no significant difference between the third and fourth parity of Holsteins under any milking system. The only other significant increases in parities were found in Ayrshire (parity 1 → 3; and parity 1 → 4). No other parity differences were significant in any breed/milking system combination. It is worth reiterating the fact that the Holstein and Ayrshire made up almost 85% and 10% of the records analyzed, respectively (Table 3-3).

Table 4-10: Estimates of differences in SCS among *parities* within breed and milking system.

		Milk-line			Parlour			Robot		
		Estimate	SE	Adj P	Estimate	SE	Adj P	Estimate	SE	Adj P
Ayrshire	P1 - P2	-0.264	0.040	0.592	-0.228	0.124	1.000	-0.282	0.141	1.000
	P1 - P3	-0.389	0.046	0.016	-0.502	0.142	1.000	-0.424	0.159	1.000
	P1 - P4	-0.462	0.056	0.022	-0.706	0.180	1.000	-0.632	0.202	1.000
	P2 - P3	-0.125	0.049	1.000	-0.274	0.149	1.000	-0.142	0.165	1.000
	P2 - P4	-0.198	0.058	1.000	-0.479	0.185	1.000	-0.351	0.207	1.000
	P3 - P4	-0.073	0.062	1.000	-0.204	0.197	1.000	-0.208	0.219	1.000
Brown Swiss	P1 - P2	-0.429	0.111	1.000	-0.324	0.283	1.000	-0.744	0.364	1.000
	P1 - P3	-0.568	0.128	1.000	-1.107	0.412	1.000	-1.064	0.399	1.000
	P1 - P4	-0.885	0.158	0.962	-1.648	0.573	1.000	-2.043	0.531	1.000
	P2 - P3	-0.139	0.133	1.000	-0.782	0.421	1.000	-0.319	0.399	1.000
	P2 - P4	-0.456	0.163	1.000	-1.324	0.585	1.000	-1.298	0.529	1.000
	P3 - P4	-0.317	0.172	1.000	-0.542	0.656	1.000	-0.979	0.550	1.000
Holstein	P1 - P2	-0.308	0.019	<.0001	-0.353	0.019	<.0001	-0.272	0.029	0.000
	P1 - P3	-0.579	0.022	<.0001	-0.664	0.023	<.0001	-0.565	0.034	<.0001
	P1 - P4	-0.716	0.028	<.0001	-0.794	0.030	<.0001	-0.752	0.044	<.0001
	P2 - P3	-0.270	0.023	<.0001	-0.311	0.024	<.0001	-0.293	0.036	0.034
	P2 - P4	-0.408	0.029	<.0001	-0.441	0.031	<.0001	-0.481	0.046	<.0001
	P3 - P4	-0.137	0.031	1.000	-0.130	0.034	1.000	-0.187	0.049	1.000
Jersey	P1 - P2	-0.093	0.061	1.000	-0.019	0.167	1.000	0.734	0.133	0.971
	P1 - P3	-0.259	0.070	1.000	-0.160	0.195	1.000	0.394	0.153	1.000
	P1 - P4	-0.347	0.085	1.000	-0.065	0.272	1.000	0.447	0.194	1.000
	P2 - P3	-0.166	0.073	1.000	-0.140	0.204	1.000	-0.340	0.156	1.000
	P2 - P4	-0.254	0.087	1.000	-0.045	0.278	1.000	-0.287	0.195	1.000
	P3 - P4	-0.087	0.093	1.000	0.095	0.295	1.000	0.053	0.208	1.000

P1, P2, P3, and P4 represent parities 1 through 4

In comparing breeds within parity and milking system (Table 4-11) no significant differences were found for SCS for either parlour or AMS milking. Within milk-line systems, there was some indication that further investigation into the Jersey breed might be warranted: they tended to compare unfavourably to the other three breeds for SCS. However the only significant comparisons involved the Jersey breed with Holsteins and Ayrshires in parity 1.

Table 4-11: Estimates of differences in SCS among *breeds* within parity and milking system.

		Milk-line			Parlour			Robot		
		Estimate	SE	Adj P	Estimate	SE	Adj P	Estimate	SE	Adj P
Parity 1	AY - BS	-0.115	0.094	1.000	-0.041	0.251	1.000	0.487	0.304	1.000
	AY - HO	-0.112	0.041	1.000	-0.013	0.132	1.000	0.057	0.134	1.000
	AY - JE	-0.696	0.061	<.0001	-0.555	0.181	1.000	-0.821	0.181	1.000
	BS - HO	0.002	0.088	1.000	0.027	0.215	1.000	-0.430	0.278	1.000
	BS - JE	-0.582	0.099	0.913	-0.514	0.249	1.000	-1.308	0.306	1.000
	HO - JE	-0.584	0.050	<.0001	-0.541	0.128	1.000	-0.878	0.132	0.595
Parity 2	AY - BS	-0.280	0.104	1.000	-0.137	0.258	1.000	0.024	0.302	1.000
	AY - HO	-0.157	0.044	1.000	-0.138	0.139	1.000	0.066	0.140	1.000
	AY - JE	-0.526	0.067	0.071	-0.346	0.199	1.000	0.194	0.190	1.000
	BS - HO	0.123	0.098	1.000	-0.001	0.219	1.000	0.043	0.271	1.000
	BS - JE	-0.246	0.111	1.000	-0.209	0.262	1.000	0.170	0.303	1.000
	HO - JE	-0.369	0.056	0.614	-0.208	0.146	1.000	0.128	0.139	1.000
Parity 3	AY - BS	-0.294	0.122	1.000	-0.645	0.403	1.000	-0.153	0.346	1.000
	AY - HO	-0.302	0.051	0.903	-0.175	0.155	1.000	-0.085	0.158	1.000
	AY - JE	-0.567	0.078	0.248	-0.212	0.233	1.000	-0.004	0.212	1.000
	BS - HO	-0.008	0.114	1.000	0.470	0.374	1.000	0.069	0.313	1.000
	BS - JE	-0.273	0.129	1.000	0.433	0.412	1.000	0.149	0.346	1.000
	HO - JE	-0.265	0.065	1.000	-0.037	0.177	1.000	0.081	0.154	1.000
Parity 4	AY - BS	-0.538	0.155	1.000	-0.983	0.587	1.000	-0.924	0.504	1.000
	AY - HO	-0.366	0.062	0.915	-0.101	0.193	1.000	-0.063	0.204	1.000
	AY - JE	-0.581	0.097	0.877	0.087	0.323	1.000	0.257	0.275	1.000
	BS - HO	0.172	0.147	1.000	0.882	0.556	1.000	0.860	0.464	1.000
	BS - JE	-0.043	0.165	1.000	1.070	0.613	1.000	1.181	0.502	1.000
	HO - JE	-0.215	0.083	1.000	0.188	0.263	1.000	0.321	0.200	1.000

As mentioned in Section 2, high safety expectations by consumers, and the corresponding milk-payment systems, largely explain why milk quality has become a major concern for dairy farmers (De Koning 2011). As a useful indicator of inflammation in the udder (and potential incidence of mastitis), SCS was used in this study to try and assess the effects of different milking systems on udder health. Numerous studies have shown that SCC may be affected by several factors such as number of milking and management, hygiene conditions, age and stage of lactation, stress, breed and seasonal and environmental conditions (Laevens *et al.,* 1997; Koc *et al.,* 2009; Sandrucci *et al.,* 2014; Helgren *et al.,* 2006). Although these factors have a major influence on milk quality, many studies have also looked at the effect of milking system on milk quality and SCC (Klungel *et al.,* 2000; Castro *et al.,* 2012; Tousova *et al.,* 2014). The results of this study reveal little or no difference in average SCS among the three milking systems. This finding agrees with observations made by Tousova *et al.,* (2014) and Helgren *et al.,* (2006) who reported no significant differences in SCC between AMS and CMS. They also concluded that AMS has no negative effects on SCC and milk quality. De Koning (2011) found that, in general, AMS herds showed slightly higher SCC, compared to CMS, but the differences were relatively small, and the scores themselves were well within the dairy industry requirements (CQM threshold acceptance is 5.0 for SCS or 4.0×10^5 cells mL^{-1} for SCC). In terms of effect of age and parity on SCS, the results of this study show first parity has the lowest average SCS, compared to later parities (Table 4-8). This is in agreement with many studies – for example, Sandrucci *et al.,* (2014) reported that first-parity animals had lower SCC than multiparous ones. Sandrucci *et al.,* (2014) also observed that the effect of parity could be associated with the difference in production level between primiparous and multiparous cows, influenced by different milking durations and stages of lactation. Reported increases in milk yield for AMS herds (due possibly to an increase in milking frequency), and differences in SCC (associated with the difference in production level), may help to explain some reports of higher SCC in AMS, compared to CMS. However, no such difference was found in this study.

5. General Discussion and Conclusions

In this study, data from the Quebec dairy herd improvement agency (Valacta) were used to investigate if there were differences in milk production and milk quality, associated with using conventional milking systems (milk-line, milking-parlour) versus automatic-milking systems, given the growing prevalence of AMS systems in Québec, and the fact that few studies have investigated these issues in Canada. This makes this study unique compared to previous studies. Milk, energy-corrected milk, fat and protein (kg) over complete lactations were considered as indicators of milk production, while somatic cell score was used as an indicator of milk quality. Milk production and quality are affected by several factors such as herd management (Wade *et al.,* 2004), age and parity (Looper 2012), environmental condition (Sandrucci *et al.,* 2014), genetics (Hanuš *et al.,* 2011; Looper 2012), milking systems (Tousova *et al.,* 2014) and breeds (Koc *et al.,* 2009). In this study, by taking account of many of the above-mentioned conditions, models were developed to evaluate the effect of different milking systems on milk production and quality. In addition, in order to examine milk production in a standardized format, ECMY was calculated and analysed from the available data.

In all predictive models, the effect of milking systems on milk production and quality indicators were evaluated in 1st, 2nd, 3rd and 4th parities in four breeds (Ayrshire, Brown Swiss, Holstein, and Jersey). In all predictive models, the random effect of herd was found statistically significant and therefore, there were differences among the herds. For milk yield, the fixed effects of Milking System x Breed, Milking System x Parity and Breed x Parity were found to be significant interactions in the predictive model (Table 4-3). Across the four breeds, lactation milk yield was found to be significantly higher in AMS compared to CMS herds. These results generally agree with the findings of previous studies (Devir *et al.,*1997; Kuipers *et al.,* 1992; Gygax *et al.,* 2007; De Koning 2011; Tousova *et al.,* 2014) who found that AMS herds have a greater milk yield than CMS herds. In all three milking systems significant differences were found among different parities (milk increased with parity). The maximum performance was found for AMS records in the 4th parity. This finding agrees with observations made by Maršálek *et al.,* (2012), where increased milk yields from AMS from first to fifth lactation (through an increased milking frequency), suggested a maximizing of milk production in dairy herds using AMS. In terms of ECMY, the fixed effects of Milking System x Breed, Milking System x Parity, and Breed x Parity were found to be significant, and differences were found between AMS and milk-lines in the Holstein breed. Energy-corrected milk yield was found to be higher in AMS herds compared to CMS herds with a milk-line. This finding agrees with observations made by Oudshoorn *et al.,* 2012, who found higher ECMY in AMS as compared to CMS. For lactation fat yield, the fixed effects of Milking System x Parity and Breed x Parity were found to be significant. Lactation fat yield showed significant differences among AMS and milk-lines, and was higher in herds using an AMS versus herds using a milk-line. These results are in general agreement with the study by Vorobjovas *et al.*, (2010) and Tousova *et al.*, (2014) who reported higher milk fat in AMS compared to CMS. However, the study by Abeni *et al.,* (2005) observed no effect of milking system on milk fat content. For protein content, the fixed effects of Milking System x Breed, Milking System x Parity, and Breed x Parity were found to be significant. Lactation protein yield showed significant differences among AMS and CMS herds. The results showed an increase in AMS herds compared to CMS herds. This result agrees with the finding by Vorobjovas *et al.,* (2010) and Tousova *et al.,* (2014); in both studies, higher milk protein yield was reported in AMS as compared to CMS herds. All of the milk production indicators (milk yield, ECMY, fat, and protein) were higher in parlour, compared to milk-line, but the differences were not significant. The main explanation for this higher performance in milk-production indicators in AMS herds could be argued to be due to more frequent milking.

Overall, the AMS appear to yield better results for production than CMS. Since, in Canada, milk payments are based on amount of milk solids sold (Ferland 2008), the potentially higher production could contribute to higher milk payments. It could be concluded that savings in labor costs, and higher production performance should lead to greater revenues from AMS herds.

For SCS, the fixed effects of Milking System x Breed, and Breed x Parity and also the fixed effect of the three-way interaction of Milking System x Breed x Parity were found to be significant. The results showed that, on average, SCS was slightly higher in AMS herds than CMS herds, but differences were only numerical, and no significant differences were found. In fact, within breed and parity, there were no significant differences in SCS among milking systems. This finding is in agreement with Helgren *et al.,* (2006) who concluded there was no significant difference in the milk quality indicator between AMS farms and a cohort of conventional farms. This finding also agrees with observations made by Tousova *et al.,* (2014) and Helgren *et al.,* (2006) who reported no significant differences in SCC between AMS and CMS. They also concluded that AMS had no negative effects on milk quality, whereas Klungel *et al.*, (2000) observed higher SCC in AMS compared to CMS. It is, perhaps, worth noting that the technology of AMS has evolved with time, and may explain some of the early studies that observed a negative effect of AMS on SCS. The only significant differences among parities, across all milking systems, were found in Holstein – an increase in SCS over the first three parities. This effect of parity on SCS might be associated with difference in production level between first and later parities. Because of the increase in milk yield in AMS herds (potentially due to more frequent milking), it could be argued that slightly higher SCS in AMS, compared to CMS, might be associated with the difference in productivity.

For the main effects examined, conclusions regarding milking system were not conclusive for all of the parities and breeds studied. In three of the breeds (Ayrshire, Brown Swiss and Jersey) the data sets used for developing the predictive models, were much smaller in size, compared to the Holstein breed (almost 85%), and this may have contributed to differences in the results obtained. Also, lower standard errors in Holstein is an indication that the sample means for production and SCS may be a more accurate reflection of the actual population means.

Even though this study did not address management skill, the random effect of herd, nested within milking system and region was significant, and differences, observed in milk yield and milk composition could be associated with better management practices in AMS herds. Also in terms of milk quality, although no significant differences were found for SCS among AMS and CMS herds, all milking systems require a high level of management skill (e.g., general hygiene and environmental managements, and specific attention to cows for hygiene, milking frequency, milking interval, and health). These, along with the improvement of farmers' professional skills, could improve production yields and udder health during the transition period to AMS.

Although this study would seem to indicate that robotic milking systems can provide higher production than conventional milking systems, without necessarily compromising on milk quality, additional research could be conducted to compare milk production, quality, and measures of profitability that have transitioned from CMS to AMS farms.

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Appendix 1: Lactation records from different breeds (Original Data)

Breed	Frequency	Percent
Ayrshire	11,489	4.53
Brown Swiss	1,277	0.50
Canadian	494	0.19
Dutch Belted	9	0.00
Guernsey	8	0.00
Holstein	232,788	91.70
Jersey	7,450	2.93
Montbéliard	3	0.00
Milking Shorthorn	15	0.01
Normande	1	0.00
Cross Breed	313	0.12

Appendix 2: Breakdown of Herds with Parlours and AMS in Quebec by Region.

Region Name	Parlour	Robotic	Total
Abitibi-Temiscamingue	16	1	17
Bas-Saint-Laurent	21	14	35
Centre-du-Quebec	49	39	88
Chaudiere-Appalaches	48	46	94
Estrie	34	26	60
Gaspesie-Iles-de-la-Madeleine	1	0	1
Lanaudiere	17	5	22
Laurentides	17	3	20
Laval	1	0	1
Mauricie	8	7	15
Monteregie-Est	36	15	51
Monteregie-Ouest	55	9	64
Outaouais	4	0	4
Quebec Capitale-Nationale	6	4	10
Saguenay-Lac-Saint-Jean	16	16	32
Total	**329**	**185**	**514**

Appendix 3: Least Squares Means for Lactation Milk Yield, Energy-corrected Milk Yield, Fat Yield, and Protein Yield (kg).

Least Squares Means (Milk)				
Effect	**Breed**	**Milking System**	**Parity**	**Estimate ± SE**
Milking System		Milk-line		8489 ± 103
Milking System		Parlour		8838 ± 158
Milking System		Robot		9292 ± 165
Breed	AY			8254 ± 138
Breed	BS			9067 ± 182
Breed	HO			10479 ± 102
Breed	JE			7691 ± 137
Parity			1	7723 ± 118
Parity			2	8815 ± 118
Parity			3	9273 ± 129
Parity			4	9680 ± 152
Breed x Parity	AY		1	7312 ± 147
Breed x Parity	AY		2	8172 ± 150
Breed x Parity	AY		3	8665 ± 159
Breed x Parity	AY		4	8867 ± 183
Breed x Parity	BS		1	7849 ± 221
Breed x Parity	BS		2	8982 ± 218
Breed x Parity	BS		3	9280 ± 284
Breed x Parity	BS		4	10157 ± 404
Breed x Parity	HO		1	8967 ± 102
Breed x Parity	HO		2	10538 ± 102
Breed x Parity	HO		3	11111 ± 103
Breed x Parity	HO		4	11302 ± 105
Breed x Parity	JE		1	6766 ± 146
Breed x Parity	JE		2	7568 ± 152
Breed x Parity	JE		3	8037 ± 165
Breed x Parity	JE		4	8394 ± 207
Milking System x Breed	AY	Milk-line		8132 ± 112
Milking System x Breed	AY	Parlour		8325 ± 236
Milking System x Breed	AY	Robot		8306 ± 228
Milking System x Breed	BS	Milk-line		8515 ± 152
Milking System x Breed	BS	Parlour		9162 ± 349
Milking System x Breed	BS	Robot		9523 ± 320
Milking System x Breed	HO	Milk-line		10161 ± 98
Milking System x Breed	HO	Parlour		10239 ± 120
Milking System x Breed	HO	Robot		11038 ± 135
Milking System x Breed	JE	Milk-line		7147 ± 117
Milking System x Breed	JE	Parlour		7626 ± 220
Milking System x Breed	JE	Robot		8300 ± 237
Milking System x Parity		Milk-line	1	7317 ± 106
Milking System x Parity		Milk-line	2	8446 ± 108
Milking System x Parity		Milk-line	3	8988 ± 111
Milking System x Parity		Milk-line	4	9204 ± 119
Milking System x Parity		Parlour	1	7945 ± 166
Milking System x Parity		Parlour	2	8758 ± 168
Milking System x Parity		Parlour	3	9132 ± 212
Milking System x Parity		Parlour	4	9516 ± 282
Milking System x Parity		Robot	1	7908 ± 190
Milking System x Parity		Robot	2	9241 ± 188
Milking System x Parity		Robot	3	9700 ± 202
Milking System x Parity		Robot	4	10319 ± 252

Least Squares Means (ECMY)				
Effect	**Breed**	**Milking System**	**Parity**	**Estimate ± SE**
Milking System		Milk-line		9566 ± 114
Milking System		Parlour		9906 ± 173
Milking System		Robot		10333 ± 181
Breed	AY			9109 ± 150
Breed	BS			10236 ± 196
Breed	HO			11169 ± 113
Breed	JE			9227 ± 149
Parity			1	8677 ± 130
Parity			2	9909 ± 130
Parity			3	10369 ± 140
Parity			4	10786 ± 165
Breed x Parity	AY		1	8160 ± 159
Breed x Parity	AY		2	9050 ± 162
Breed x Parity	AY		3	9520 ± 172
Breed x Parity	AY		4	9706 ± 197
Breed x Parity	BS		1	8806 ± 237
Breed x Parity	BS		2	10218 ± 233
Breed x Parity	BS		3	10442 ± 302
Breed x Parity	BS		4	11477 ± 428
Breed x Parity	HO		1	9617 ± 113
Breed x Parity	HO		2	11231 ± 114
Breed x Parity	HO		3	11822 ± 115
Breed x Parity	HO		4	12005 ± 117
Breed x Parity	JE		1	8125 ± 158
Breed x Parity	JE		2	9135 ± 165
Breed x Parity	JE		3	9690 ± 178
Breed x Parity	JE		4	9956 ± 222
Milking System x Breed	AY	Milk-line		8951 ± 124
Milking System x Breed	AY	Parlour		9233 ± 254
Milking System x Breed	AY	Robot		9143 ± 246
Milking System x Breed	BS	Milk-line		9602 ± 165
Milking System x Breed	BS	Parlour		10309 ± 372
Milking System x Breed	BS	Robot		10797 ± 342
Milking System x Breed	HO	Milk-line		10861 ± 110
Milking System x Breed	HO	Parlour		10994 ± 134
Milking System x Breed	HO	Robot		11650 ± 150
Milking System x Breed	JE	Milk-line		8850 ± 128
Milking System x Breed	JE	Parlour		9088 ± 236
Milking System x Breed	JE	Robot		9742 ± 256
Milking System x Parity		Milk-line	1	8283 ± 117
Milking System x Parity		Milk-line	2	9531 ± 119
Milking System x Parity		Milk-line	3	10114 ± 122
Milking System x Parity		Milk-line	4	10336 ± 131
Milking System x Parity		Parlour	1	8949 ± 181
Milking System x Parity		Parlour	2	9879 ± 183
Milking System x Parity		Parlour	3	10220 ± 228
Milking System x Parity		Parlour	4	10576 ± 301
Milking System x Parity		Robot	1	8799 ± 206
Milking System x Parity		Robot	2	10317 ± 204
Milking System x Parity		Robot	3	10772 ± 218
Milking System x Parity		Robot	4	11445 ± 271

Least Squares Means (FAT)				
Effect	**Breed**	**Milking System**	**Parity**	**Estimate ± SE**
Milking System		Milk-line		368 ± 4.53
Milking System		Parlour		381 ± 6.89
Milking System		Robot		393 ± 7.2
Breed	AY			348 ± 5.99
Breed	BS			391 ± 7.82
Breed	HO			417 ± 4.5
Breed	JE			367 ± 5.95
Parity			1	334 ± 5.17
Parity			2	380 ± 5.18
Parity			3	396 ± 5.6
Parity			4	413 ± 6.57
Breed x Parity	AY		1	314 ± 6.35
Breed x Parity	AY		2	346 ± 6.47
Breed x Parity	AY		3	362 ± 6.85
Breed x Parity	AY		4	368 ± 7.85
Breed x Parity	BS		1	336 ± 9.45
Breed x Parity	BS		2	391 ± 9.28
Breed x Parity	BS		3	396 ± 12.04
Breed x Parity	BS		4	440 ± 17.09
Breed x Parity	HO		1	361 ± 4.52
Breed x Parity	HO		2	418 ± 4.53
Breed x Parity	HO		3	441 ± 4.57
Breed x Parity	HO		4	448 ± 4.65
Breed x Parity	JE		1	325 ± 6.31
Breed x Parity	JE		2	364 ± 6.58
Breed x Parity	JE		3	386 ± 7.11
Breed x Parity	JE		4	394 ± 8.84
Milking System x Breed	AY	Milk-line		340 ± 4.93
Milking System x Breed	AY	Parlour		355 ± 10.13
Milking System x Breed	AY	Robot		348 ± 9.8
Milking System x Breed	BS	Milk-line		366 ± 6.57
Milking System x Breed	BS	Parlour		392 ± 14.84
Milking System x Breed	BS	Robot		414 ± 13.64
Milking System x Breed	HO	Milk-line		406 ± 4.37
Milking System x Breed	HO	Parlour		414 ± 5.34
Milking System x Breed	HO	Robot		431 ± 5.97
Milking System x Breed	JE	Milk-line		359 ± 5.11
Milking System x Breed	JE	Parlour		362 ± 9.42
Milking System x Breed	JE	Robot		381 ± 10.22
Milking System x Parity		Milk-line	1	320 ± 4.65
Milking System x Parity		Milk-line	2	366 ± 4.74
Milking System x Parity		Milk-line	3	388 ± 4.88
Milking System x Parity		Milk-line	4	397 ± 5.21
Milking System x Parity		Parlour	1	345 ± 7.2
Milking System x Parity		Parlour	2	380 ± 7.29
Milking System x Parity		Parlour	3	392 ± 9.09
Milking System x Parity		Parlour	4	406 ± 12.02
Milking System x Parity		Robot	1	336 ± 8.22
Milking System x Parity		Robot	2	393 ± 8.15
Milking System x Parity		Robot	3	409 ± 8.7
Milking System x Parity		Robot	4	435 ± 10.8

Least Squares Means (PROTEIN)				
Effect	**Breed**	**Milking System**	**Parity**	**Estimate ± SE**
Milking System		Milk-line		296 ± 3.49
Milking System		Parlour		304 ± 5.33
Milking System		Robot		320 ± 5.56
Breed	AY			278 ± 4.63
Breed	BS			322 ± 6.06
Breed	HO			342 ± 3.47
Breed	JE			285 ± 4.6
Parity			1	266 ± 3.99
Parity			2	308 ± 4
Parity			3	321 ± 4.33
Parity			4	332 ± 5.09
Breed x Parity	AY		1	248 ± 4.91
Breed x Parity	AY		2	277 ± 5.01
Breed x Parity	AY		3	292 ± 5.31
Breed x Parity	AY		4	297 ± 6.09
Breed x Parity	BS		1	276 ± 7.34
Breed x Parity	BS		2	323 ± 7.21
Breed x Parity	BS		3	331 ± 9.36
Breed x Parity	BS		4	359 ± 13.3
Breed x Parity	HO		1	294 ± 3.48
Breed x Parity	HO		2	347 ± 3.49
Breed x Parity	HO		3	362 ± 3.51
Breed x Parity	HO		4	366 ± 3.58
Breed x Parity	JE		1	248 ± 4.88
Breed x Parity	JE		2	283 ± 5.1
Breed x Parity	JE		3	300 ± 5.51
Breed x Parity	JE		4	307 ± 6.87
Milking System x Breed	AY	Milk-line		276 ± 3.8
Milking System x Breed	AY	Parlour		279 ± 7.86
Milking System x Breed	AY	Robot		280 ± 7.6
Milking System x Breed	BS	Milk-line		304 ± 5.09
Milking System x Breed	BS	Parlour		325 ± 11.54
Milking System x Breed	BS	Robot		339 ± 10.6
Milking System x Breed	HO	Milk-line		333 ± 3.36
Milking System x Breed	HO	Parlour		334 ± 4.11
Milking System x Breed	HO	Robot		360 ± 4.59
Milking System x Breed	JE	Milk-line		272 ± 3.94
Milking System x Breed	JE	Parlour		278 ± 7.31
Milking System x Breed	JE	Robot		304 ± 7.92
Milking System x Parity		Milk-line	1	255 ± 3.59
Milking System x Parity		Milk-line	2	296 ± 3.65
Milking System x Parity		Milk-line	3	314 ± 3.76
Milking System x Parity		Milk-line	4	319 ± 4.02
Milking System x Parity		Parlour	1	274 ± 5.57
Milking System x Parity		Parlour	2	305 ± 5.64
Milking System x Parity		Parlour	3	314 ± 7.05
Milking System x Parity		Parlour	4	322 ± 9.34
Milking System x Parity		Robot	1	271 ± 6.36
Milking System x Parity		Robot	2	321 ± 6.31
Milking System x Parity		Robot	3	336 ± 6.74
Milking System x Parity		Robot	4	354 ± 8.38