Characterization of milk composition and somatic cell count estimates from automatic milking systems sensors

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Summary

Adoption of automatic milking systems (AMS) is increasing rapidly in Canada. Some AMS are equipped with sensors to estimate milk components (i.e., fat, protein and lactose) and somatic cell count (SCC). However, the accuracy of the estimates produced by these sensors is unknown. For these data to be used for herd management, benchmarking and genetic evaluations, it is important to get a better understanding of how this data compares with traditional milk recording laboratory analyses.

Milk samples were collected from all milkings and from all the AMS in use on each farm (2.7 ± 1.0 milkings per cow) during a period of 24-h each on 10 farms using Lely Astronaut A4 AMS. The manufacturer's automatic sampling device was used to collect samples. Samples were analysed for fat, protein, lactose and SCC (n=10, 10, 7 and 6 farms, respectively). All herds were comprised of mostly Holstein cows and herd size was on average 74 ± 15 milking cows. Samples were analysed in the Valacta laboratory for milk components and SCC (CombiFoss FT+, Foss, Hillerød, DK). Data on milk production, milk composition estimates and number of milkings were also extracted from the AMS T4C software for the corresponding period. Milk composition derived from laboratory analyses was calculated as 24-hr average weighted by milk yield at the corresponding milking and was compared to the 24-hr estimate provided by the AMS. Only records comprised of three or more samples were considered in the comparison, leaving 501 records (i.e., cows) from the original 939 for statistical analysis.

On four farms with DeLaval VMS equipped with OCC sensors for SCC, sensors were programmed to measure samples of all milkings during a 12-h period. As visits were scheduled the same day of the monthly DHI test, comparisons were made between the AMS estimates and the DHI test results, matching the samples by the time they were taken (n=199). Since SCC estimates were available for each milking, only one sample was collected for each cow, as per regular DHI testing protocol, and results from the AMS sensors and the milk-recording laboratory for the corresponding milking were compared for each cow.

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On average, the mean differences between the results of the Lely AMS MQC sensors and the laboratory for fat and protein percentage were small (-0.05 ± 0.5 % and -0.001 ± 0.23 %, respectively). However, mean absolute errors (MAE) were larger (0.38 and 0.18 %, respectively). Moreover, differences among herds were greater for fat percentage, ranging from -0.22% to 0.14% (MAE = 0.47 to 0.28 %). Similar variations were found within herds, where the average difference for a 24-h period was small, but differences between cows were larger. Results from a concordance correlation coefficient analysis (CCC) between milk component estimations from the AMS and the laboratory analysis also showed variability in the level of agreement between the two measurements (CCC= 0.43 to 0.74 and 0.31 to 0.71, for fat and protein, respectively). In general, differences of milk components followed the same trend, i.e., when the fat was underestimated, there was an underestimation for the other components.

Differences between SCC laboratory measurement and (x1000) for DeLaval or Lely sensors were similar (-66 ± 364 and -61 ± 255, respectively), as well as the MAE (101 and 99, respectively). However, concordance with laboratory measurement of SCC differed between Lely and DeLaval sensors with a CCC 0.52 and 0.91, respectively. Likewise, the range of correlations within herd also varied for DeLaval and Lely farms (CCC= 0.84 to 0.98 and 0.14 to 0.80, respectively). These differences can be explained by the fact that sensors are using different technologies to measure SCC.

Future research will be important to better understand the influence of calibration procedure of AMS sensors, and evaluate the benefits of performing calibration using individual cow samples on a regular basis. It would be then possible to make recommendations to producers with AMS regarding calibration procedures and frequency. Finally, as AMS generate large amounts of data and information, it will be necessary to establish validation mechanisms and thresholds according to the different possible data usages (e.g., farm management, genetic evaluations), in order to enhance data usage from these systems.

Keywords: automatic milking systems, milk composition, sensors.

Introduction

In Canada, the number of farms implementing automatic milking systems (AMS) is increasing rapidly. The implementation of AMS affects milking management on the farm, where the two major aspects that change are the number of milkings per day and the frequency of milkings. Whereas in a conventional system, cows are milked two or three times a day with a fixed frequency, in the AMS cows enter voluntarily, so they can be milked at any time. Although permissions to be milked can be established by the producer for each cow, the consequence is that intervals between milkings are irregular. The range of milkings per day per cow reported in the literature goes from 1.5 to 5.0 with an average of 2.8 ± 0.2 (Bouloc *et al.*, 2001, Tremblay *et al.*, 2016).

Milk composition and somatic cell count (SCC) are of crucial importance for cow and herd nutritional and health management, genetic evaluation and milk payment. Milk composition and SCC can be affected by numerous factors including nutrition, genetics, management, health, stage of lactation and environment (Seegers *et al.*, 2003, Jenkins and McGuire, 2006, Quist *et al.*, 2008, Forsbäck *et al.*, 2010). Studies have shown that milking frequency and milking intervals affect milk composition and SCC. Increasing milking frequency from two to three times result in a fixed increase of 3.5 kg/day in milk yield and 92 g/day of fat yield independently of parity (Erdman and Varner, 1995). Increasing milking frequency also has shown to reduce SCC (Smith *et al.*, 2002, Dahl *et al.*, 2004). Studies on AMS indicated that milk yield could increase by 5 to 10%

(Bach *et al.*, 2007, Bijl *et al.*, 2007). Results comparing AMS with conventional systems showed that SCC increase by implementing AMS (Klungel *et al.*, 2000, Hovinen and Pyörälä, 2011). Milk composition (i.e., fat, protein and lactose contents) does not seem to be influenced by the type of milking system (Jacobs and Siegford, 2012); it appears that the length of the interval since the previous milking and the variation of milk yield per milking are more important factors (Friggens and Rasmussen, 2001).

Milk recording is challenging in irregular time intervals for milk sampling and 24-h predictions. Furthermore, some AMS are equipped with sensors to estimate milk components (i.e., fat, protein and lactose) and SCC. There are no published reports of the accuracy of the estimates produced by these sensors. For these data to be used for herd management, benchmarking and genetic evaluations, it is important to get a better understanding of how this data compares with traditional milk recording data based on regular milking time intervals and laboratory analyses. The aim of this study was to characterise and compare the results from the AMS sensors and the milk-recording laboratory.

Material and methods

On ten farms equipped with Lely AMS, milk samples were collected from all milkings (2.7 ± 1.0 milkings per cow) during a period of 24 hours starting at midnight on all AMS in use on each farm. The manufacturer's automatic sampling device was used to sample each cow for fat, protein, lactose and SCC (n=10, 10, 7 and 6, respectively).

On four farms with DeLaval AMS equipped with OCC sensors for SCC, OCC sensors were programmed to measure SCC of all milkings during a 12-h period. As sampling was scheduled to occur on the same day of the monthly DHI test, comparisons were made between the AMS estimates and the DHI test results, matching the samples by the time they were taken (n=199). All herds were comprised of mostly Holstein cows and herd size was on average 74 ± 15 milking cows.

Samples were analysed in the Valacta laboratory for milk components and SCC (CombiFoss FT+, Foss, Hillerød, DK). Data on milk production, milk composition estimates, number of milkings and milking description were extracted from the AMS software for the same time period.

For Lely farms, milk composition derived from laboratory analyses was calculated as 24-hr average weighted by milk yield at the corresponding milking and was compared to the 24-hr estimate provided by the AMS (i.e., calculated as the weighted average of the last five milkings for each cow). As the estimate of SCC by the AMS is the geometric mean of the last three milkings, for comparison purposes, the geometric mean of SCC from the laboratory analyses was also calculated. Only records comprised of three or more samples were considered in the comparison, leaving 501 records (i.e. cows) from the original 939 records for statistical analysis.

Data from the AMS was exported in Microsoft Excel. Differences were calculated as the results given from the AMS minus the laboratory results. Mean absolute errors (MAE) were computed, and concordance correlation coefficient (CCC) and Bland Altman analysis were done using the R program version 3.4.1 (R Development Core Team, 2017). The CCC and the Bland Altman analyses quantify the agreement and the reliability between two quantitative measurements, and help establishing the validity of a new technique (Kwiecien *et al.*, 2011; Giavarina, 2015). The CCC analysis was preferred over the Pearson correlation because the latter only provides a measure of the extent to which the points conform to the best fit line. The CCC analysis modifies

the Pearson correlation coefficient by assessing not only how close the data is from the best fit line, but also how far that line is from the perfect agreement line (i.e., 45-degres line through the origin) (Watson and Petrie, 2010).

Results

Lely AMS MQC sensors

On average, mean differences between the results of the Lely MQC sensors and the laboratory for fat, protein and lactose percentages and fat and protein yields and linear score were small (Table 1). However, mean absolute errors (MAE) were larger for fat and protein percentages, but not for lactose (Table 1).

Results from the Bland Altman analysis indicate that the fat percentage had the highest mean bias of the milk components estimated by the AMS, followed by protein and lactose (0.05, 0.04, and 0.001, respectively). The mean bias for the SCC and linear score was 61 and -0.05, respectively. Similarly, the results of the CCC analysis between milk component estimations from the AMS sensors and the laboratory analysis showed the variability in the lack of agreement between the two measurements. On average, the CCC were 0.61, 0.59, and 0.69 for fat, protein and lactose percentages, respectively. The CCC for SCC and linear score was 0.52 and 0.32, respectively.

Table 1. Mean differences and standard deviations of milk components generated for the ten farms by the Lely AMS MQC sensors and the milk recording laboratory.

Item	% fat	% protein	% lactose	Fat yield (kg/d)	Protein yield (kg/d)	SCC (cells/mL)[1]	Linear score
AMS	3.76 (0.57)	3.19 (0.21)	4.65[2] (0.11)	1.63 (0.40)	1.40 (0.33)	71[3] (145)	2.11 (0.87)
Laboratory	3.81 (0.55)	3.19 (0.28)	4.68 (0.16)	1.67 (0.40)	1.39 (0.30)	133 (340)	2.11 (1.68)
Differences	-0.05 (0.50)	-0.001 (0.23)	-0.04 (0.1)	-0.04 (0.23)	0.01 (0.10)	-61 (255)	0.01 (1.56)
MAE[4]	0.38	0.18	0.09	0.17	0.08	99	1.31

[1] Geometric mean of the last three milkings (x1000)
[2] Data available only for seven farms
[3] Data available only for six farms
[4] Means absolute error

Differences among herds (Table 2) were larger for fat percentage than from protein and lactose percentages, ranging from -0.22% to 0.14% (MAE = 0.47 to 0.28%). The same pattern was seen for fat and protein yields. Similar variations were found within herds, where the average difference for a 24-h period was small, but differences between cows were larger. The variation between farms was also seen on the results from the Bland Altman analysis by the range of the bias. For example, for fat percentage the bias range was between -0.14 to 0.25.

Similarly, CCC analysis for each farm also showed variability in the level agreement between sensor results and laboratory measurements. The CCC analyses of fat and protein percentages by farms are presented in Figures 1 and 2. In general, differences of milk components followed similar patterns, i.e., when the fat was underestimated, there was an underestimation for the other components.

Table 2. Accuracy of milk components and SCC estimates by Lely AMS MQC on ten farms.

	Farms									
Item	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**
Fat %										
AMS	3.54	3.80	3.57	3.61	3.80	3.82	3.64	3.74	3.85	4.09 .
	(0.62)	(0.55)	(0.61)	(0.52)	(0.49)	(0.53)	(0.53)	(0.49)	(0.53)	(0.53)
Laboratory	3.60	4.02	3.63	3.60	3.94	3.75	3.63	3.93	3.74	3.94
	(0.58)	(0.47)	(0.46)	(0.50)	(0.42)	(0.43)	(0.59)	(0.56)	(0.55)	(0.67)
Difference	-0.06	-0.22	-0.06	0.004	-0.14	0.08	0.01	-0.17	0.11	0.14
	(0.43)	(0.40)	(0.58)	(0.37)	(0.38)	(0.50)	(0.46)	(0.47)	(0.44)	(0.59)
MAE[1]	0.30	0.35	0.47	0.28	0.33	0.40	0.37	0.34	0.34	0.45
Protein %										
AMS	3.23	3.31	3.07	3.14	3.12	3.09	3.18	3.15	3.16	3.33
	(0.18)	(0.18)	(0.18)	(0.14)	(0.21)	(0.19)	(0.24)	(0.23)	(0.13)	(0.23)
Laboratory	3.25	3.29	3.09	3.18	3.14	3.13	3.20	3.16	3.18	3.26
	(0.16)	(0.27)	(0.23)	(0.27)	(0.25)	(0.25)	(0.39)	(0.27)	(0.27)	(0.34)
Difference	0.02	-0.02	-0.02	-0.03	-0.02	-0.04	-0.02	-0.01	-0.02	0.07
	(0.20)	(0.20)	(0.20)	(0.25)	(0.24)	(0.23)	(0.25)	(0.20)	(0.24)	(0.24)
MAE	0.16	0.16	0.15	0.20	0.19	0.18	0.17	0.15	0.20	0.22
Lactose *%a*										
AMS	4.61	4.70	n.a.[2]	4.64	4.54		4.61		4.62	4.71
	(0.09)	(0.09)		(0.10)	(0.09)	-	(0.09)	-	(0.10)	(0.08)
Laboratory	4 70	4.70	4.64	4.75	4.60	4.67	4.71	4.68	4.66	4.68
	(0.12)	(0.18)	(0.17)	(0.15)	(0.15)	(0.18)	(0.12)	(0.14)	(0.15)	-0,15
Difference	-0 09	-0.02		-0.11	-0.06		-0.09		-0.04	0.01
	(0.08)	(0.10)	-	(0.09)	(0.09)	-	(0.09)	-	(0.10)	(0.09)
MAE	0.098	0.083	-	0.12	0.081	-	0.11	-	0.083	0.073
Fat yield (kg/d)										
AMS	1.29	1.61	1.86	1.57	1.55	1.28	1.38	1.63	1.81	1.77
	(0.30)	(0.30)	(0.47)	(0.36)	(0.35)	(0.26)	(0.19)	(0.30)	(0.37)	(0.40)
Laboratory	1.34	1.71	1.96	1.60	1.63	1.27	1.40	1.71	1.78	1.72
	(0.33)	(0.33)	(0.44)	(0.42)	(0.32)	(0.24)	(0.23)	(0.30)	(0.43)	(0.33)
Difference	-0.05	-0.10	-0.10	-0.03	-0.08	0.01	-0.02	-0.08	0.03	0.05
	(0.15)	(0.19)	(0.29)	(0.19)	(0.18)	(0.18)	(0.18)	(0.18)	(0.22)	(0.26)
MAE	0.11	0.16	0.25	0.13	0.15	0.14	0.15	0.15	0.16	0.20
Protein yield (kg/d)										
AMS	1.18	1.41	1.62	1.37	1.28	1.04	1.22	1.37	1.51	1.47
	(0.22)	(0.25)	(0.39)	(0.29)	-27	(0.18)	(0.21)	(0.24)	(0.39)	(0.30)
Laboratory	1.19	1.40	1.62	1.38	1.28	1.05	1.23	1.37	1.50	1.44
	(0.21)	(0.23)	(0.36)	(0.26)	(0.23)	(0.18)	(0.22)	(0.25)	(0.31)	(0.26)
Difference	-0.01	0.01	0.004	-0.005	0.0001	0.01	-0.01	-0.003	0.01	0.03
	(0.07)	(0.09)	(0.11)	(0.10)	(0.09)	(0.08)	(0.10)	(0.09)	(0.12)	(0.12)
MME	0.06	0.068	0.083	0.083	0.074	0.062	0.07	0.066	0.097	0.098
SCC (cells/mL)										
AMS	139 (67.8)	42.3	51.9	-	83.7	-	-	66.2	-	
		(27.9)	(36.7)		(106.5)			(24.2)		
Laboratory	80.5	119	156	114	209	393	105	96.3(178)	86'7	134
	(90.6)	-176	-260	-254	-630	-675	-275		-131	-440
Difference	58.22	-77.01	-103		-126.1			-21.28		-40.5
	(78.2)	-161	-252	-	(535.9)	-	-	-146	-	-227
MME	84.8	94.2	123	-	160	-	-	63.2	-	86.1
Linear Score										
AMS	3.34	1.72	1.90		2.32			2.29		2.28
	(0.62)	(0.71)	(0.72)	-	(0.90)	-	-	(0.62)	-	(0.60)
		2 19	2.50	2.19	2.16	3.68	1.65	1.91	1.84	1.81
Laboratory	2.0 (1.39)	(1.68)	(1.68)	(1.46)	(1.93)	(1.85)	(1.61)	(1.52)	(1.56)	(1.70)
Difference	1.34	-0.57	-0.54		0.16			0.34		0.48
	(1.03)	(1.60)	(1.58)	-	(1.48)		-	(1.38)	-	(1.38)
MAE	1.48	1.43	1.32	-	1.24	-	-	1.18	-	1.25

[1]Mean absolute error
[2]Data was not available on the AMS

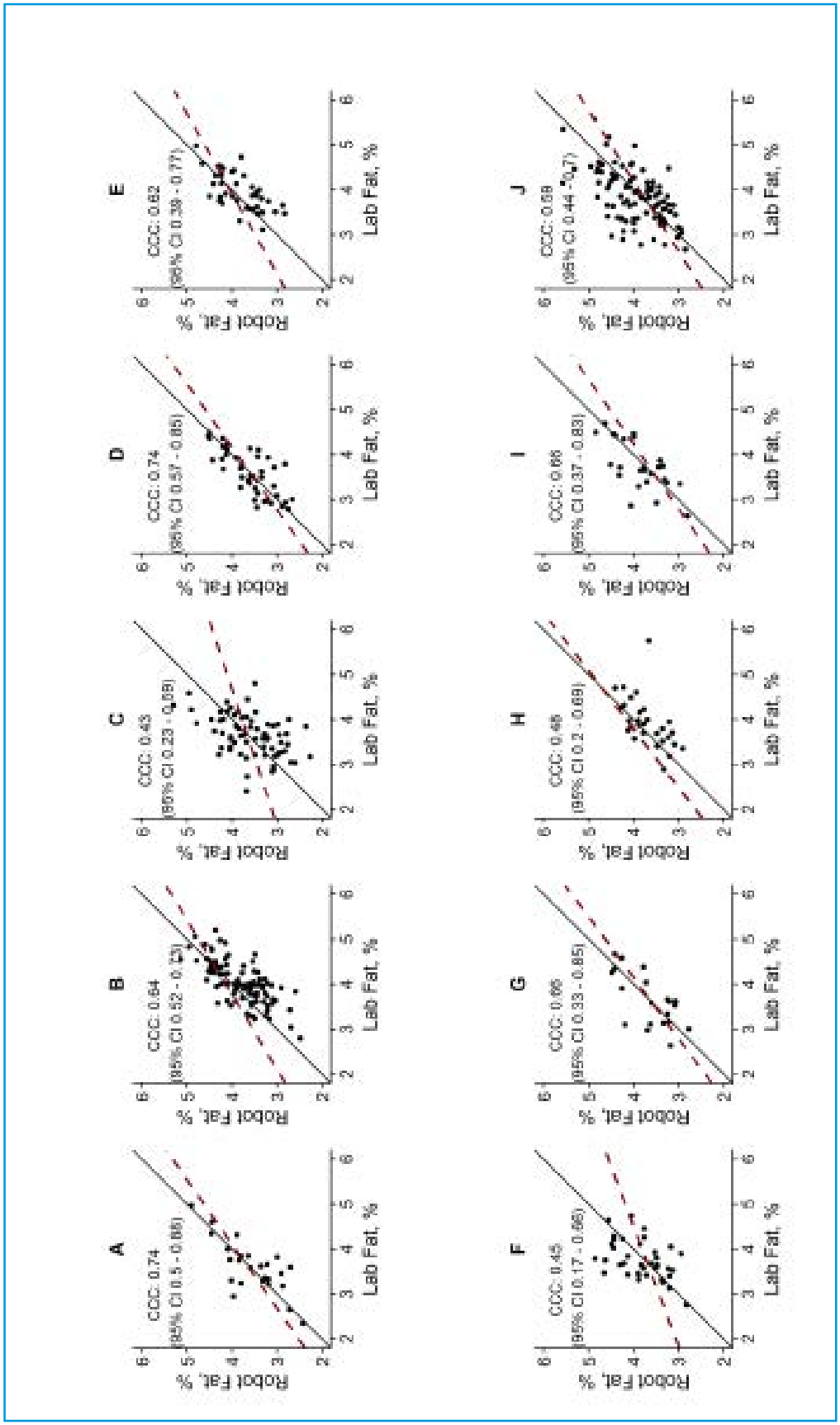

Figure 1. Concordance correlation coefficient (CCC) between milk fat percentages from the AMS sensors and the laboratory analysis of the 10 farms.

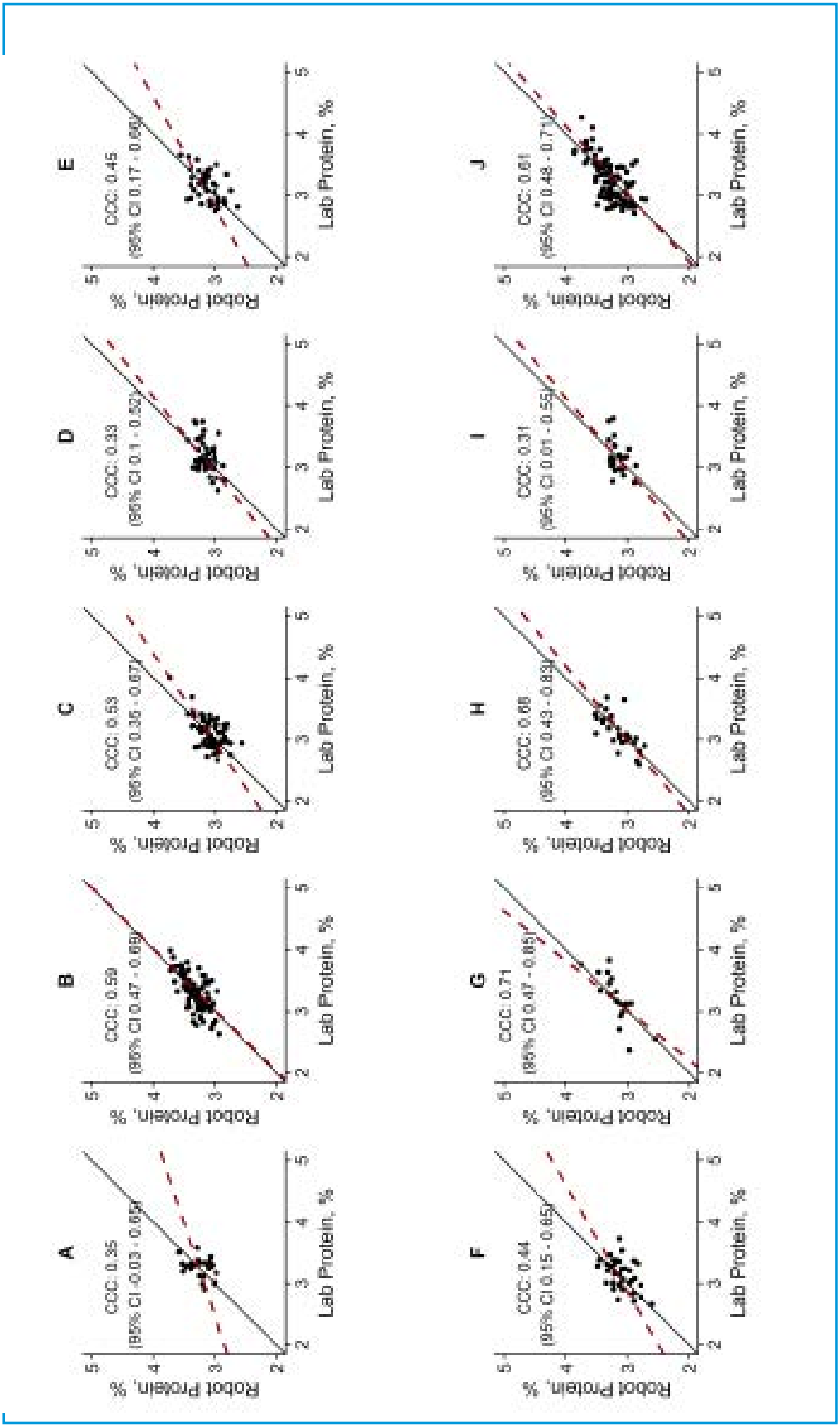

Figure 2. Concordance correlation coefficient (CCC) between milk protein percentages from the AMS sensors and the laboratory analysis of the 10 farms.

DeLaval AMS OCC sensors

Differences between the SCC (x1000) for DeLaval farms were -66 ± 364, and the MAE was 101. The average CCC between SCC estimations from the AMS sensors and the laboratory analysis showed good agreement between the two measurements (CCC= 0.91). Results for each farm are presented on Table 3. Within herds CCC ranged from 0.84 to 0.98.

Table 3. Accuracy of SCC estimates by the DeLaval AMS OCC sensors on four farms.

	Farms			
Item	**W**	**X**	**Y**	**Z**
SCC (cells/mL)				
AMS	98 (181)[1]	262 (825)	190 (741)	333 (829)
Laboratory	126 (234)	320 (1008)	241 (999)	452 (1404)
Difference	-28 (75)	-58 (190)	-51 (259)	-120 (635)
MAE[2]	38	66	58	128
Linear Score				
AMS	2.14 (1.35)	2.64 (1.73)	2.12 (1.65)	3.03 (2.02)
Laboratory	2.40 (1.43)	2.76 (1.84)	2.16 (1.77)	3.13 (2.14)
Difference	-0.26 (0.68)	0.13 (0.54)	-0.03 (0.34)	-0.11 (0.32)
MAE[2]	0.49	0.39	0.26	0 .25

[1] Number in parentheses is the standard deviation
[2] Mean absolute error

Discussion

Estimates of milk components provided by Lely AMS MQC sensors showed only moderate agreement with laboratory measurements. Furthermore, sensor-based estimates tended to overestimate component levels below average and underestimate high components concentrations.

Within-herd level of agreement differed between farms. One hypothesis to explain the large inter-herd variations between data from the Lely AMS MQC sensors and milk recording laboratories may be the way producers calibrate the sensors. The calibration of the Lely AMS sensors can be done in two ways:

1. Ccalibration at the cow level: using the results of the DHI.
2. Calibration at the herd level: using components results for the bulk tank.

The method of calibration will probably lead to different results but, unfortunately, we did not find publicly available studies on the impact of the calibration method on the results. All farms in the present study calibrated the AMS sensor using bulk tank results.

Another possible explanation for the variation between herds could be the frequency at which the calibration is performed. In the present study producer-declared calibration frequency ranged from every bulk tank pick-up (every other day) to biweekly. However, it was not possible to retrieve records of previous calibrations since only the last calibration date is reported in the AMS software. Another source of variation among herds might be the number of robots at that farm. Most farms that participated in the present study (9 out of 10) had two AMS. Since calibration is based on a single bulk tank value, milk composition of the bulk tank, which is a mixture of the milk from the two AMS the calibration process does not account for differences between the sensors of each AMS. Since the AMS software does not provide the milk components data for each AMS, it is not possible to assess if there are differences in milk components provides by the sensor of each AMS when farms have more than one.

Future research will be important to better understand the influence of calibration procedure of AMS sensors and evaluate, for example, the additional benefits of performing calibration using individual cow samples, on a regular basis. It would be then possible to make recommendations to producers with AMS regarding calibration procedures and frequency.

Milk composition (i.e., fat, protein and lactose) of each milking was not available in the AMS software. The data available for milk composition was, the average of the five last milkings, as calculated at the end of the day. It is known that milking frequency can significantly change from a cow to another and as the lactation progresses (Bouloc *et al.*, 2001). Studies report that milking frequency ranges from 1.5 to 5 milkings per day with an average of 2.8 ± 0.2 (Bouloc *et al.*, 2001, Tremblay *et al.*, 2016). The lactation period covered by each mean can be from one day (with cows with five milkings per day) to 3.3 days (for cows with 1.5 milkings per day). For this study, it would have been necessary to take milk samples during 1.8 days (average milkings was 2.8 ± 0.92). However, sampling was done over a period of 24-hours. Subsequent analyses should be done using sensor data produced at each milking, when this becomes available.

There was a significant difference in the accuracy of the two sensors producing an estimate of SCC. The optical measurement of SCC by the DeLaval OCC sensor provides reasonably accurate estimation of SCC as compared to laboratory measurement (CCC = 0.91). However, the Lely MQC2 sensor, which is based on a modified California mastitis Test reaction had lower accuracy for SCC below 500 (CCC = 0.52).

Conclusions

As AMS generate large amounts of data which could contribute to central databases such as those used by milk recording and genetic evaluation organisations, it will be necessary to establish validation procedures and thresholds according to the different possible data usages (e.g., farm management, genetic evaluations) in order to enhance data usage from these systems.

Future research is required to better understand the influence of calibration procedure and frequency on the accuracy of AMS sensors and evaluate the benefits of performing calibration using individual cow samples on a regular basis. It will be then possible to make recommendations to producers with AMS regarding calibration procedures and frequency.

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