Devices used by automated milking systems are similarly accurate in estimating milk yield and in collecting a representative milk sample compared with devices used by farms with conventional milk recording

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ABSTRACT

Information on accuracy of milk-sampling devices used on farms with automated milking systems (AMS) is essential for development of milk recording protocols. The hypotheses of this study were (1) devices used by AMS units are similarly accurate in estimating milk yield and in collecting representative milk samples compared with devices used by certified milk recording providers on farms with conventional milking systems (CMS) and (2) devices used on both AMS and CMS comply with accuracy criteria described by the New Zealand Standard and by the International Committee of Animal Recording (ICAR). Milk recording data from 5 AMS farms were collected during 13 milk recording test days between December 2011 and February 2013. Milk yield was estimated by ICAR-approved milk meters on AMS units. Milk samples were collected over a 48-h period and submitted to an off-site certified laboratory for milk composition analysis. Data were also collected manually from 5 to 10 cows per AMS unit; a complete milking of a cow was weighed to serve as gold standard for milk yield, and 3 milk samples per cow milking were collected and analyzed in the laboratory to serve as gold standards for milk composition. A similar procedure was used during 6 milk recording occasions with devices used during conventional milk recording at a CMS research farm. Farm type, breed, season, and region did not appear to affect accuracy of devices used on AMS units. Milk meters used by AMS units complied with ICAR limits in 12.5 and 25% of the milk recording test days for test bucket weights between 2 and 10 kg and for test bucket weights >10 kg, respectively. These percentages were 52 and 42%, respectively, for devices used on CMS. Analyzing all samples as one milk recording test day, 1.4% fell outside the 20% difference band for AMS compared with 1.1%

of the milk samples for CMS. Devices used by AMS complied with ICAR in 73% of the milk recording test days for fat percentage, compared with 42% of the milk recording test days by devices used at the CMS farm. When analyzing all milk samples as one milk recording test day, 3.5% of the milk samples fell outside the 99% ICAR limit for AMS compared with 17.2% of the milk samples for CMS. Applying the ICAR standards for fat percentage to crude protein percentage and SCC, devices used on AMS were accurate in estimating crude protein percentage but not in estimating SCC. Thus, devices on AMS units did not comply with national nor ICAR standards with regard to milk yield and fat percentage. However, devices used on AMS were similarly or more accurate compared with devices used during conventional milk recording. It is proposed that devices used on AMS units, when calibrated regularly and when set up according to the manufacturer's instruction, have similar or improved accuracy compared with CMS devices. Because the New Zealand industry accepts data from devices currently used by certified providers for milk recording on CMS farms, results imply that the AMS devices should also be permitted to be used for milk recording.

Key words: robotic milking, milk recording data, milk-sampling device, accuracy

INTRODUCTION

Robotic or automated milking systems (AMS) were introduced in 1992 (Bottema, 1992). Adoption of this technology was slow at first (De Koning, 2010) and initially took place in countries with high-yielding cows, high milk prices, high labor costs, and family-run farms (Lind et al., 2000). Adoption rates increased from the year 2000 onward (De Koning, 2010) and included countries with lower-input, pasture-based dairying systems (e.g., Jago et al., 2004). As of today, it is estimated that well over 10,000 farms worldwide use one or more AMS units to milk their herd (Rodenburg, 2013). One of the key characteristics of AMS is that the cow itself initiates the milking, and thus, milking intervals vary within and between cows.

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Milk recording data are valuable for farmers to make management decisions regarding feeding, reproduction, and culling. For breeding companies, milk recording data are essential to identify sires and cows that will contribute to the genetic gain of future generations of dairy cattle. Collecting milk recording data on farms with conventional milking systems (CMS), where cows are milked as one batch with more or less fixed milking intervals (e.g., in herringbones and rotary parlors), is clearly defined in milk recording standards. Farms with CMS are often offered flexible options in terms of collecting milk recording data, including the frequency of milk recording (from 1- to 12-wk intervals), full or alternate milk recording or both, and supervised or unsupervised milk recording (Miglior et al., 2002). However, standards generally lack protocols for collecting milk recording data from systems where cows in the herd are milked 24 h per day and where milking intervals may vary between and within cows, as is the case in AMS. Consequently, different countries apply different methods to collect and handle milk recording data from AMS farms (Miglior et al., 2002).

In New Zealand, milk recording standards were developed before AMS technology was an option. Therefore, the standards only allow submission of milk recording data into the national database from herds that are milked in CMS. Consequently, New Zealand farmers that currently use AMS ($n = 15$ herds; J. Jago, DairyNZ Ltd., Newstead, Hamilton, New Zealand, personal communication, 2014) are unable to submit milk recording data. A protocol for collecting milk recording data on AMS farms in New Zealand has been suggested by Jago and Burke (2013). This protocol involved the automated collection of milk samples of every cow milked by the AMS units during a 48-h time period. Although Jago and Burke (2013) suggested that their applied 48-h sampling period might be reduced to 24 h, to be accepted by New Zealand milk recording standards, validation of the approach described in the 48-h protocol was essential. This validation required data from AMS farms representing a variety of milking frequencies and typically representative of farms that varied in intensity (e.g., pasture-based, low supplementary feed input vs. housed, high supplementary feed input dairy systems), breeds, season, and region. Part of the validation involved assessing the accuracy of the milk meters in estimating milk yield and of the automatic milk-sampling devices used to collect a representative sample of the complete milk of a cow. The accuracy of these milk meters and the automatic milk-sampling devices should meet the accuracy criteria described in the New Zealand Standard (2007) and preferably also the standards described by the International Committee of Animal Recording (ICAR, 2012).

The hypotheses of this study were (1) milk-sampling devices (milk meters and automatic milk-sampling devices) used on AMS units are similarly accurate in estimating milk yield and in collecting a representative milk sample compared with devices used by certified milk recording providers on CMS farms and (2) milk-sampling devices used on AMS and CMS comply with accuracy criteria described by the New Zealand Standard (2007) and by ICAR (2012).

MATERIALS AND METHODS

Data used for this study originated from 2 separate but parallel running studies and, therefore, will be described in 2 separate sections.

Data Collection from Farms with Automated Milking Systems

Data were collected between December 2011 and February 2013 at 5 New Zealand farms located in the North ($n = 2$) and South Island ($n = 3$). The 2 main AMS suppliers in New Zealand were represented, with 2 farms using a total of 6 DeLaval units (from the 2010 model with ICAR-approved milk meters; DeLaval International AB, Tumba, Sweden) and the remaining 3 using Lely units (Lely Industries NV, Rotterdam, the Netherlands; 8 A3 units with a jar-type milk-meter system and 6 A4 units with load cells to estimate milk yield; both milk-meter devices were ICAR approved). The selected farms represented a range of New Zealand farm systems of varying herd sizes and breeds, including one farm milking a Jersey herd, one farm milking a Holstein-Friesian herd, and the others milking predominantly Friesian and Friesian-Jersey crossbred cows (Table 1). The total number of milk recording test days conducted was 13, ranging between 1 and 5 milk recording test days per farm (Table 1).

Before the start of each milk recording test day, one of the AMS suppliers confirmed that AMS units and milk-sampling devices used for milk recording were installed and conformed to operational specifications. This included the installation of an automatic milk-sampling device to each AMS unit on farm by a representative of the AMS supplier or by a trained representative of the local farm service center. For the other supplier of AMS, farmers were responsible for the installation of the automatic milk-sampling device and testing that they were operational before milk recording started. Automatic milk-sampling devices collected milk samples into vials similar to those used by 1 of 2 certified providers for milk recording on CMS farms. Vials were preloaded with 3 drops of a 10% solution of the preservative Bronopol (BP2000, Chemiplas, Auck-

Table 1. Characteristics of participating farms with automated milking systems (AMS)

Farm	Herd size (no.)	Farm system	AMS units (no.)	Milk recording test day (no.)
1	180	Predominantly pasture fed, organic, herds with spring and autumn calving, Friesian–Jersey crossbred herd	2	5
2	320	Predominantly pasture fed, seasonal calving, Friesian–Jersey crossbred herd	4	4
3	180 ¹	Housed, predominantly silage and TMR fed, herds with spring and autumn calving, Holstein–Friesian herd	4	1
4	500	Housed, predominantly silage and TMR fed, herds with spring and autumn calving, Jersey herd	8	1
5	150	Predominantly pasture fed, seasonal calving, Friesian–Jersey crossbred herd	2	2

¹Started with AMS during the 2012 to 2013 milking season and was expanding herd size to 320.

land, New Zealand) and stayed uncapped to allow the preservative to dry, requiring no volume adjustments when milk samples were analyzed for milk composition.

Each milk recording test day was conducted according to the 48-h protocol described by Jago and Burke (2013). This involved continuous data collection from the AMS management system (Process 1, Figure 1), including identification numbers of the AMS unit, the automatic milk-sampling device and the cow, date and time of each cow milking, date and time of the previous milking of that same cow, milking interval as the time difference between current and previous milking, milk yield as recorded by the milk meters installed on each AMS unit, and whether or not the current milking had been successful according to AMS software. During milk recording, automatic milk-sampling devices collected a 25-mL milk sample from every cow milking over a 48-h time period (Process 2, Figure 1). Full vials were capped manually and recorded with a unique number, identifying the order in which the milk samples were collected and later used to match with data from the AMS management system. The full vials were removed from the automatic milk-sampling device at regular intervals, replaced with empty ones, transferred into a sample tray (Sample Tray I; Figure 1), and refrigerated at 4°C until transportation to the laboratory.

In addition to the automated collection of milk samples, trained DairyNZ research technicians manually collected 3 reference milk samples from each of 5 to 10 cows per AMS unit during each milk recording test day between 0700 and 2200 h (Process 3, Figure 1). To collect the 3 reference samples, AMS units were programmed to divert all milk into a test bucket after a cow finished milking. This test bucket was weighed before and after the milk was collected to estimate total milk yield for that cow milking, including an adjustment to account for the 25 mL of milk collected by the automatic milk-sampling device. The test bucket milk was mixed and subsampled manually to collect the 3 reference milk samples (Process 3, Figure 1) using similar vials, preloaded with preservative, as used by

the automatic milk-sampling devices. The 3 reference milk samples were transferred to a second sample tray together with their corresponding sample collected by the automatic milk-sampling device (Sample Tray II, Figure 1) and refrigerated at 4°C until transportation to the laboratory. The manually sampled cows included at least one high-producing cow, one low-producing cow, one cow with a high milking frequency, one with a low milking frequency, and one randomly selected cow. Farm-specific performance indicators (e.g., milk yield and number of milkings per day) were used to identify these manually sampled cows.

Both sample trays (Sample Tray I and II, Figure 1) were sent to TestLink Laboratory (located in Hamilton, New Zealand, for milk samples collected in the North Island and in Christchurch, New Zealand, for milk samples collected in the South Island) for milk composition analysis including fat and CP percentage and SCC. Milk samples in Sample Tray II (Figure 1) were analyzed twice; following the first analysis, the tray was retained until the results were printed. The tray was then tested again through the same machine, and the second set of results was generated. Results from the first and second analysis of Sample Tray II were used in the current study for the milk samples collected manually (6 milk composition results). Results from the first milk composition analysis only were used for the milk sample that was collected by the automatic milk-sampling device of that same cow milking (Process 3; Figure 1).

Data Collection from a Conventional Milking System

Data were collected at DairyNZ's Lye Research Farm (Newstead, Hamilton, New Zealand). Forty Friesian and Friesian–Jersey crossbred cows were selected from the entire herd to provide a subherd with a representative range of milk yields and SCC levels. The cows were managed as a single herd and milked twice daily using an 8-bail herringbone parlor. A familiarization period of 8 milkings enabled the cows, normally milked in a

Figure 1. Schematic approach of collecting milk samples manually and by automatic milk-sampling devices on farms with automated milking systems (AMS). Color version available online.

rotary parlor, to get accustomed to milking in the small herringbone parlor.

Milk recording test days were conducted by 2 providers certified for milk recording (CRV Ambreed, PO Box 176, Hamilton, New Zealand; LIC, Private Bag 3016, Hamilton, New Zealand). Temporary installation of the milk-sampling devices was completed by a certified-provider's representative using routine procedures for milk recording on CMS farms. Each certified provider collected milk recording data on 3 occasions (early, peak, and late lactation) in the 2012 to 2013 milking season. Each milk recording occasion comprised 4 consecutive milkings, equal to 2 consecutive milk recording test days each starting with the first milk sample collected at a p.m. milking. Milk samples collected by the certified-provider's representative were weighed by DairyNZ technicians (Process 1; Figure 2). These samples were then split into 1 to 5 preloaded vials, depending on the volume of the collected milk sample, and stored in a sample tray (Sample Tray 1;

Figure 2) refrigerated at 4°C until transportation to the laboratory. During each milk recording occasion, cows were milked into test buckets at every milking session using the same principle as with AMS systems; the test bucket was weighed before and after the milk was collected to estimate milk yield for that specific milking for that cow, including adjustment for the milk sample collected by the certified-provider's representative. The test bucket milk was mixed and subsampled manually to collect 4 reference milk samples using preloaded vials similar to those used with AMS (Process 2; Figure 2). The reference milk samples were transferred into the same sample tray as milk samples collected from the certified-provider's milk sample (Sample Tray 1; Figure 2). All milk samples were analyzed twice for milk composition by the TestLink Laboratory (Hamilton, New Zealand) using the same procedure as used for the AMS. Results from the first run only were used in the current study, including 4 milk composition results for each cow-milking that was manually collected (Process

2; Figure 2) and 1 to 5 milk composition results from the milk sample that was collected by the milk-sampling device used by the certified providers (Process 1; Figure 2).

Before the current study commenced, certified providers were requested to install the milk-sampling devices as used in the field without any special preparations. One certified provider, however, did calibrate these devices specifically for this study.

Accuracy of Milk Meters (AMS) and Milk-Sampling Devices (CMS) in Assessing Milk Yield

The accuracy of milk meters used in AMS and milk-sampling devices used in CMS were assessed using accuracy standards described in Section 11 of ICAR (2012) and Appendix D of the New Zealand Standard (2007). According to ICAR (2012), the standard deviation and the bias of the estimated yield should be within 0.5 and 0.2 kg, respectively, for reference yields between 2 and 10 kg and less than 5 and 2%, respectively, for reference yields >10 kg. Appendix D of the New Zealand Standard (2007) states that 95 and 99%

of the milk yield estimations must be within ± 15 and $\pm 20\%$, respectively, of the reference milk yield. In the current study, milk yield estimation refers to the yield assessed by the in-line milk meter on the AMS units and recorded by the herd management software (Process 1; Figure 1) or by the milk yield estimation derived from samples taken by the milk-sampling devices used by the 2 certified providers (Process 1; Figure 2). The reference yield refers to the milk yield assessed by manual weighing of test buckets, adjusted for milk collected by certified providers at CMS (Process 2; Figure 2) and the 25-mL milk sample collected by the automatic milk-sampling devices at AMS farms (Process 3; Figure 1). One AMS supplier recorded milk yield in liters, and therefore, results were converted to kilograms by multiplying the recorded milk yield by 1.03.

Accuracy of Milk-Sampling Devices in Collecting Representative Milk Samples

The subsampling requirements for milk components found in Appendix D of the New Zealand Standard (2007) state analyses to be applied to fat percentage

Figure 2. Schematic approach of collecting milk samples manually and by certified milk recording providers at DairyNZ Lye Research Farm (Hamilton, New Zealand). Color version available online.

only and require 95 and 99% of all milk samples to be within ± 0.1 and $\pm 0.2\%$ of the mean of the 2 reference samples, respectively. These requirements are more rigorous than those stated by ICAR (2012). Moreover, these accuracy requirements for subsampling are being revised and currently under public consultation (New Zealand Standard, 2014). Therefore, accuracy of automatic milk-sampling devices used on AMS units and the milk-sampling devices used by certified providers in CMS in collecting representative milk samples was assessed using ICAR (2012) standards only. The current study applied the limits set for milk recording devices with a sampler. For these types of samplers, ICAR (2012) only presents limits for fat percentage. The current study applied these limits also to CP percentage and SCC, and presented the results for all milk components with indications of the 95 and 99% confidence intervals around the limit for standard deviation. This means that 95% of the milk samples should be within 1.96 times the standard deviation limit and 99% of the milk samples should be within 2.57 times the standard deviation limit, where the standard deviation limit is 0.10% (ICAR, 2012).

Results of the composition analyses of the reference samples ($n = 6$) collected manually at AMS units (Process 3, Figure 1) were averaged to serve as gold standards. The composition result of the first run for milk samples collected by the automatic milk-sampling device was compared with this gold standard. Milk samples in Sample Tray I (Figure 2) collected at CMS were also analyzed in duplicate, but only results of the first run were used. Thus, the first results of the 4 reference samples collected manually per milk sample (Process 2, Figure 2) were averaged to serve as gold standard for CMS. The first results of the 1 to 5 milk samples that were collected from the milk-sampling device used by certified providers (Process 1; Figure 2) were also averaged (if applicable) to compare with this gold standard.

Data analyses were conducted in GenStat (VSN International, 2013). Graphs were created with the package lattice 0.20–24 (<http://lattice.r-forge.r-project.org/index.php>) in R version 3.0.2 (www.R-project.org). Results for SCC were $\log_{10}$ transformed before the analyses. Because the current study's focus is on accuracy of milk-sampling devices (milk meters and automatic milk-sampling devices) used on AMS, results of AMS are presented per milk recording test day. By doing this, potential differences between farm type, season, breeds, and region would be made visible. Results for milk-sampling devices used by certified providers are merged together in the creation of plots. This was done to provide results for comparison with AMS and not to demonstrate the accuracy of each certified provider separately.

RESULTS

Accuracy of Milk Meters (AMS) and Milk-Sampling Devices (CMS) in Assessing Milk Yield

A total of 189 milk samples were analyzed to assess the accuracy of milk meters used by AMS units in estimating milk yield, and 943 milk samples were analyzed to assess accuracy of milk-sampling devices used by certified providers for CMS (Table 2).

Evaluating the accuracy according to ICAR (2012), milk meters used by AMS units complied for both standard deviation and bias in 1 out of 8 milk recording test days (12.5%) for test bucket weights between 2 and 10 kg and in 2 out of 8 milk recording test days (25%) for test bucket weights >10 kg (Table 3). In comparison, milk-sampling devices used by certified providers complied for both standard deviation and bias in 11 out of 21 milking sessions (52%) with test bucket weights between 2 and 10 kg and in 8 out of 19 milking sessions (42%) with test bucket weights >10 kg (Table 4). For CMS milk-sampling devices, for the majority of milk recording occasions, the bias was <0.4 kg with a standard deviation of <0.5 kg for test bucket weights between 2 and 10 kg, and <4 and $<5\%$ for bias and standard deviation, respectively, for test bucket weights >10 kg. If these limits were applied to milk meters used by AMS units, then one more milk recording test day would comply for both bias and standard deviation (test d 12; Table 3) for both milk yield categories.

With the exception of 2 milk recording test days, milk meters were accurate in estimating milk yield when evaluated according to accuracy criteria of the New Zealand Standard (2007; Figure 3). When aggregating all AMS milk samples and analyzing them as one milk recording test day on 189 cows, 15 out of 189 milk samples (7.9%) fell outside the 20% difference band from the gold standard, compared with the 1% that are allowed to fall outside this limit. Excluding the 2 milk recording test days where the milk meters were clearly inaccurate resulted in 2 out of 139 samples (1.4%) falling outside the 20% difference band. In comparison, milk-sampling devices as used by certified providers were slightly more accurate in estimating milk yield (Figure 4) when evaluated according to the New Zealand Standard (2007); 10 out of 943 milk samples (1.1%) fell outside of the 20% difference band from the gold standard.

The 2 milk recording test days where milk meters were clearly inaccurate in estimating milk yield happened to occur on the same farm. Results from the other milk recording test days suggest that farm type (housed vs. pasture based, high vs. low input), breeds, season, and region do not influence the accuracy of milk meters in estimating milk yield (Figure 3).

Table 2. Number of milk samples included to assess the accuracy of milk meters in estimating milk yield and automatic milk-sampling devices in collecting a representative milk sample for the 5 farms with automated milking systems (AMS) and to assess the accuracy of milk-sampling devices used by certified providers at farms with conventional milking systems (CMS)

Item	AMS: Number of milk samples used for assessing the accuracy of		CMS: Number of milk samples used for assessing the accuracy of	
	Milk meters in estimating milk yield ¹	Automatic milk-sampling device in collecting a representative milk sample ¹	Milk-sampling device in estimating milk yield ¹	Milk-sampling device in collecting a representative milk sample ¹
Milk recording test day				
1	—	10		
2	—	10		
3	—	10		
4	18	20		
5	18	20		
6	—	10		
7	—	10		
8	18	18		
9	32	33		
10	21	21		
11	42	40		
12	20	—		
13	20	—		
Total	189	202		
Milk recording occasion				
1			156	153
2			160	160
3			152	148
4			159	160
5			160	158
6			156	155
Total			943	934

¹Reasons why milk samples were not analyzed for milk composition or where the number of milk samples used for analyses is different between yield and milk composition include milk samples having no reference milk yield, milk samples received no laboratory results for milk composition, and milk composition results received from the laboratory were deemed invalid because sample identification numbers did not match.

Accuracy of Milk-Sampling Devices in Collecting Representative Milk Samples

To assess the accuracy of the automatic milk-sampling devices on AMS units and milk-sampling devices used by certified providers at CMS in collecting a representative milk sample for milk composition analysis,

202 milk samples were analyzed for AMS and 934 milk samples for CMS (Table 2). Not all CMS milk samples, however, had results for fat and CP percentage and SCC, as some SCC analyses were missed or sample identification numbers did not match and, therefore, results were deemed invalid. A total of 841, 934, and 633 milk samples for fat percentage, CP percentage,

Table 3. Accuracy of milk meters on automated milking systems (AMS) in estimating milk yield when evaluated against the standard described by the International Committee of Animal Recording (ICAR, 2012)¹

Milk recording test day ²	Test bucket milk yield 2–10 kg			Test bucket milk yield >10 kg		
	Samples (no.)	Bias ³ <0.2 kg	SD ⁴ <0.5 kg	Samples (no.)	Bias ³ <2%	SD ⁴ <5%
4	2	0.86	0.05	16	10.1	3.3
5	5	1.04	0.26	13	9.9	5.7
8	5	0.85	1.35	13	15.2	8.2
9	21	1.16	1.54	11	12.5	12.9
10	9	−0.02	0.56	12	−1.4	3.5
11	32	−0.07	0.39	10	−1.1	1.6
12	2	0.27	0.14	18	3.8	3.2
13	15	0.58	0.67	5	6.7	1.3

¹Values in bold indicate that the milk yield estimate is in agreement with the ICAR (2012) standard.

²Milk recording test day refers to the same milk recording test day listed in Table 2.

³Average of the difference in milk yield estimated by milk meters on AMS units and the milk yield from weighing the test buckets.

⁴Standard deviation of the difference in milk yield estimated by milk meters on AMS units and the milk yield from weighing the test buckets.

Table 4. Accuracy of milk-sampling devices used by 2 certified providers at conventional milking systems (CMS) farms in estimating milk yield when evaluated by standards described by the International Committee of Animal Recording (ICAR, 2012)¹

Milk recording occasion ²	Milking session	Test bucket milk yield 2–10 kg			Test bucket milk yield >10 kg		
		Samples (no.)	Bias ³ <0.2 kg	SD ⁴ <0.5 kg	Samples (no.)	Bias ³ <2%	SD ⁴ <5%
1	1	11	0.60	0.96	28	1.26	7.11
	2	1	−0.04	NA ⁵	38	1.80	5.73
	3	9	0.09	0.31	30	2.62	3.35
	4				39	2.05	2.88
2	1	39	0.03	0.76	1	0.85	NA
	2	1	0.18	NA	39	1.41	2.03
	3	27	0.28	0.52	13	2.82	2.19
	4	1	−0.45	NA	39	2.7	2.87
3	1	38	−0.10	0.47			
	2	37	0.00	0.28	1	−1.82	NA
	3	38	0.07	0.16			
	4	32	−0.01	0.25	6	0.05	2.47
4	1	34	−0.27	0.37	5	−4.48	5.92
	2	1	0.11	NA	39	−1.31	2.56
	3	6	−0.05	0.12	34	−0.79	3.20
	4				40	−0.44	2.76
5	1	40	−0.16	0.95			
	2	2	0.09	0.08	38	−0.24	4.29
	3	21	0.01	0.22	19	0.67	1.86
	4				40	1.86	4.15
6	1	39	0.04	0.22			
	2	31	0.24	0.40	8	2.33	3.38
	3 ⁶	38	0.12	0.18			
	4 ⁶	30	0.19	0.28	8	3.08	2.12

¹Values in bold indicate the milk yield estimate is in agreement with ICAR standards (ICAR, 2012).

²Milk recording occasion refers to the same milk recording occasion listed in Table 2.

³Average of the difference in milk yield estimated by milk-sampling devices used by 2 certified providers at CMS farms and the milk yield from weighing the test buckets.

⁴Standard deviation of the difference in milk yield estimated by milk-sampling devices used by 2 certified herd providers at CMS farms and the milk yield from weighing the test buckets.

⁵NA = not applicable.

⁶One milk sample was omitted because milk yield was <2 kg.

and SCC, respectively, were included for further analyses. Results for SCC were reported for 4 milk recording occasions only.

Figure 5 demonstrates that, for fat percentage, in 8 out of 11 AMS milk recording test days (73%), automatic milk-sampling devices were able to collect milk samples where none fell outside the limit set by ICAR (2012). However, when all milk samples were aggregated and analyzed as one milk recording test day on 202 cows, 7 out of 202 (3.5%) milk samples collected by automatic milk-sampling devices fell outside the 99% ICAR limit. Findings for fat percentage were similar for milk-sampling devices used by certified providers in CMS: in 5 out of 12 milk recording test days (42%), milk-sampling devices collected milk samples where none fell outside the limit set by ICAR (2012). Aggregating all milk samples and analyzing them as one milk recording tests day on 841 cows, however, resulted in 145 out of 841 milk samples (17.2%) that fell outside the 99% limit set by ICAR (2012; Figure 6).

Applying the same ICAR accuracy standards for fat percentage to CP percentage, automatic milk-sampling devices on AMS units were able to collect milk samples in 9 out of 11 milk recording test days (82%) without any falling outside the 99% limit (Figure 7). When analyzing all milk recording test days as one, 2 out of 202 milk samples (1%) collected by automatic milk-sampling devices fell outside the 99% limit. For milk-sampling devices used by certified providers for CMS, 11 out of 12 milk recording test days (92%) had no milk samples fall outside the 99% limit. When aggregating all milk samples and analyzing them as one milk recording test day on 934 cows, this comprised 2 out of 934 milk samples (0.2%; Figure 8).

Applying the same ICAR accuracy standards for fat percentage to SCC, 8 out of 11 milk recording test days (73%) conducted on AMS farms had no milk samples that fell outside the 99% limit (Figure 9). This equaled to 6 out of 202 milk samples (2.9%) when all samples were aggregated and analyzed as

Figure 3. Percent difference in estimated milk yield between milk meters used by automated milking systems (AMS) and the gold standard (test bucket weight). Each panel represents milk samples collected during a milk recording test day ($n = 8$ on 5 AMS farms), and panels are numbered such that they are in agreement with milk recording test days reported in Table 2. Appendix D of New Zealand Herd Test Standard 8100.2007 states that 99% of the samples should be within a 20% difference band from the gold standard (dashed lines) and that 95% of the samples should be within a 15% difference band from the gold standard (dotted lines). Color version available online.

Figure 4. Percent difference in estimated milk yield between milk-sampling devices used by certified providers and the gold standard (test bucket milk). Each black dot represents a sampled cow. Appendix D of New Zealand Herd Test Standard 8100.2007 states that 99% of the samples should be within a 20% difference band from the gold standard (dashed lines) and that 95% of the samples should be within a 15% difference band from the gold standard (dotted lines). Color version available online.

one milk recording test day on 202 cows. For milk-sampling devices used by certified providers for CMS, 6 out of 8 milk recording test days (75%) had no milk samples falling outside the 99% limit. When aggregating the milk samples and analyzing them as one milk

recording test day on 633 cows, 13 out of 633 milk samples (2.1%) fell outside the 99% limit set by ICAR (Figure 10).

Figures 5, 7 and 9 demonstrate visually that the type of farm, breed, season, and region do not influence the

Figure 5. Difference in fat percentage between milk samples collected by automatic milk-sampling devices at automated milking systems (AMS) and the gold standard (test bucket fat %). Each panel represents milk samples collected during a milk recording test day ($n = 11$ from 5 AMS farms), and panels are numbered such that they are in agreement with milk recording test days reported in Table 2. The dotted and dashed lines represent limits reported in ICAR (2012) standards: 95 and 99% of the milk sample results should fall within these limits, respectively. Color version available online.

accuracy of automatic milk-sampling devices in collecting representative milk samples.

DISCUSSION

This study was conducted to assess the accuracy of milk-sampling devices used by AMS (milk meters and automatic milk-sampling devices) for developing milk recording protocols for AMS farms. This accuracy was compared with New Zealand and ICAR standards and with the accuracy of milk-sampling devices used by certified providers at CMS farms.

Before each milk recording test day started on AMS farms, AMS suppliers were asked to ensure that AMS units and automatic milk-sampling devices were installed and conformed to their standard operating procedures. This was done by a representative of the AMS supplier for one AMS supplier and by farmers who checked the standard operating procedures themselves in the case of the second AMS supplier. According to these latter procedures, milk meters on the AMS units were not required to be calibrated. This lack of calibration clearly influenced results negatively for 2 milk recording test days that happened to be conducted on

Figure 6. Difference in fat percentage between milk samples collected by milk-sampling devices used by certified providers and the gold standard (test bucket fat %). Each black dot represents a sampled cow. The dotted and dashed lines represent limits reported in ICAR (2012) standards: 95 and 99% of the milk sample results should fall within these limits, respectively. Color version available online.

the same AMS farm. Excluding these 2 milk recording test days did improve accuracy from 7.9% of the samples that fell outside the 99% difference band from the gold standard to 1.4% falling outside this limit. Yet, the bias and standard deviation of the milk meters still exceeded the limits set by ICAR (2012). Moreover, the

less strict New Zealand Standards were also not met by the milk meters to estimate milk yield. Results stress the importance that milk meters on AMS units require calibration on a regular basis to ensure they work as accurately as possible. Yet, even with calibration, the milk meters did not meet the accuracy standards.

Figure 7. Difference in CP percentage between milk samples collected by automatic milk-sampling devices at automated milking systems (AMS) and the gold standard (test bucket CP %). Each panel represents milk samples collected during a unique milk recording test day ($n = 11$ from 5 AMS farms), and panels are numbered such that they are in agreement with milk recording test days reported in Table 2. The dotted and dashed lines represent limits similar to those reported for fat percentage in ICAR (2012) standards: 95 and 99% of the milk sample results should fall within these limits, respectively. Color version available online.

The accuracy of automatic milk-sampling devices used by AMS units in collecting representative milk samples was assessed using the limit for standard deviation for fat percentage as described by ICAR (2012) for all components, because of the lack of limits for CP percentage and SCC. The reported percentages that fall outside this limit are likely to be overestimated because these percentages do not take into account potential bias. Still, even when taking bias into account, automatic milk-sampling devices are likely not to meet ICAR (2012) standards for fat percentage and the limit set for SCC. For CP percentage, automatic milk-

sampling devices are likely to fulfil the set requirement when bias is taken into account.

Data used for the current study originated from 2 separate but parallel running studies. Both studies had their own objectives, and as a consequence, data collection and procedures to analyze milk samples differed slightly. These differences are acknowledged together with the fact that data were collected on just one CMS research farm that was not representative of the average CMS farm in New Zealand. Additionally, one certified provider calibrated their milk-sampling devices specifically for this study, despite the request to use their de-

Figure 8. Difference in CP percentage between milk samples collected by milk-sampling devices used by certified providers and the gold standard (test bucket CP %). Each black dot represents a sampled cow. The dotted and dashed lines represent limits similar to those reported for fat percentage in ICAR (2012) standards: 95 and 99% of the milk sample results should fall within these limits, respectively. Color version available online.

vices as they normally would do in the field. Despite all this, data collected at the CMS farm are still useful to demonstrate variation in accuracy of milk-sampling devices currently used by certified providers in estimating milk yield and in collecting representative milk samples

for composition analyses to serve as a comparison for the AMS data.

Similar to the data collected at AMS farms, the variation in accuracy of milk-sampling devices used by certified providers falls outside the limits set by ICAR

Figure 9. Difference in $\log_{10}$ SCC between milk samples collected by automatic milk-sampling devices at automated milking systems (AMS) and the gold standard (test bucket $\log_{10}$ SCC). Each panel represents milk samples collected during a unique milk recording test day ($n = 11$ from 5 AMS farms), and panels are numbered such that they are in agreement with milk recording test days reported in Table 2. The dotted and dashed lines represent limits similar to those reported for fat percentage in ICAR (2012) standards: 95 and 99% of the milk sample results should fall within these limits, respectively. Color version available online.

(2012) and the New Zealand Standard (2007). This variation was much greater for fat percentage compared with the variation reported for the automatic milk-sampling devices used by AMS. Variation in accuracy for milk-sampling devices was comparable to that of milk meters for milk yield and to that of automatic milk-sampling devices for CP percentage and SCC. Although neither of the milk-sampling devices used on AMS units nor those used by certified providers met ICAR (2012) standards, results are encouraging because they are derived from the field, where it will

be much more challenging to meet standards compared with laboratory settings.

Despite the fact that the milk-sampling devices did not meet ICAR (2012) nor the New Zealand Standard (2007) for milk yield, and fat percentage nor the set limits for SCC, data from milk-sampling devices used by certified providers at CMS farms are accepted by breeding companies to calculate breeding values. Moreover, these breeding companies have been able to ensure genetic gain of New Zealand dairy cattle (P. Amer, AbacusBio, Dunedin, New Zealand, personal communi-

Figure 10. Difference in $\log_{10}$ SCC between milk samples collected by milk-sampling devices used by certified providers and the gold standard (test bucket $\log_{10}$ SCC). Each black dot represents a sampled cow. The dotted and dashed lines represent limits similar to those reported for fat percentage in ICAR (2012) standards: 95 and 99% of the milk sample results should fall within these limits, respectively. Color version available online.

cation, 2013). One could argue, therefore, that breeding companies require at least a similar or better accuracy from the milk-sampling devices used on AMS farms for the information to be of value for calculating breeding values. Results of the current study suggest that

the milk-sampling devices (milk meters and automatic milk-sampling devices) used on AMS units are similarly or more accurate than the milk-sampling devices used by certified providers for CMS. When addressing the most variable component (fat percentage), 27% of the

milk recording test days conducted on AMS farms had data outside the 99% limit compared with 58% for milk recording test days conducted at the CMS farm. When all data were analyzed as one milk recording test day, 3.5% of the milk samples were outside the 99% limit for AMS compared with 17.2% for CMS. It can, therefore, be concluded that milk-sampling devices used to collect milk recording data on AMS farms, when calibrated regularly and when installed (including the setup and software used) according to the manufacturer's instructions, have similar or improved accuracy compared with CMS milk-sampling devices. These results imply that milk-sampling devices used on AMS should also be permitted to be used for milk recording. The results also suggest that revision of the subsampling requirements in the New Zealand Standard (2014), to be more aligned with ICAR (2012) guidelines, is appropriate. Future research should study whether performances specified in the revised New Zealand Standard (2014) better reflect the performance of milk-sampling devices used by certified providers on CMS farms for both milk yield and milk composition. Additionally, future research should evaluate whether the 48-h collection of milk recording data as proposed by Jago and Burke (2013) can be reduced to make it a less expensive and a more practical protocol without losing accuracy for estimating standardized 24-h yields.

CONCLUSIONS

Farm type, breed, season, and region do not appear to affect the accuracy of milk-sampling devices (milk meters and automatic milk-sampling devices) used on AMS units to collect milk recording data. Furthermore, milk-sampling devices used on AMS require regular calibration, and the setup of these devices (including software used) has to conform to the manufacturer's instructions. Milk-sampling devices used on AMS units did not comply with national nor ICAR (2012) standards with regard to milk yield and fat percentage. Applying the ICAR (2012) accuracy standards for fat percentage to the milk components CP percentage and SCC, the sampling devices used on AMS were accurate in estimating CP percentage but not in estimating SCC. However, the milk-sampling devices used on AMS were similarly or more accurate compared with the milk-sampling devices currently used by certified providers at CMS farms. Therefore, because the New Zealand industry is currently accepting data from milk-sampling devices used on CMS farms, it is proposed that AMS

milk-sampling devices also should be permitted to be used for milk recording in New Zealand.

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