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ABSTRACT

The aim of this study was to compare different statistical methods for the estimation of daily and 305-day lactation milk, fat and protein yields of Holstein and Simmental cattle breeds using an alternative milk recording scheme. Data included 6,824 individual test-day milk yield records collected according to the A4 milk recording method on 668 cows reared on 15 family farms. Daily milk, fat and protein yields were estimated using several statistical methods with regard to breed. The 305-day lactation yields were calculated from estimated daily yields using the Test Interval Method. The correlation between estimated and true yields, as well as the mean difference among estimated and true yield were used as the evaluation criteria for estimation methods. The linear regression of daily to partial milk, fat and protein yields while taking into account the interval between successive milkings was shown to be the most accurate model for estimating daily values, either from morning or evening records. The simple doubling of morning or evening records overestimated and underestimated the daily yields, respectively. When 305-day lactation milk, fat and protein yields were compared no difference between evaluated methods were found. Also, a separate estimation of daily and 305-day lactation yields according to breeds did not result in increased estimation accuracy.

Key words: Holstein and Simmental cattle, Alternating morning-evening milkings, Daily (24 h) milk yields, 305-day lactation milk yields, Estimation.

RIASSUNTO

STIMA DELLA PRODUZIONE DI LATTE GIORNALIERA E DELLA INTERA LATTAZIONE UTILIZZANDO SCHEMI DI CONTROLLO FUNZIONALE ALTERNATIVI IN BOVINE DI RAZZA HOLSTEIN E SIMMENTAL

Scopo del lavoro è stato quello di comparare differenti metodi di controllo funzionale per la stima della produzione giornaliera e a 305-d per il latte, grasso e proteina in bovine di razza Holstein e Simmental. Un totale di 6824 produzioni individuali giornaliere sono state raccolte utilizzando il metodo di controllo A4 *su 668 bovine allevate in 15 allevamenti. Le produzioni giornaliere di latte, grasso e proteina sono state stimate utilizzando diversi metodi statitici per ciascuna delle due razze. Le produzioni a 305-d sono state calcolate dalle produzioni giornaliere impiegando il metodo del controllo intermedio. I criteri per valutare i metodi a confronto sono stati la correlazione tra le produzioni stimate e reali e la media delle differenze tra le produzioni stimate e reali. La regressione lineare della produzione giornaliera e di una singola mungitura per le produzioni di latte, grasso e proteina, corretta per l'intervallo di mungitura, ha dimostrato di essere la procedura più accurata nella stima delle produzioni giornaliere, sia per le mungiture del mattino che per quelle della sera. Il semplice raddoppio delle produzioni del mattino o della sera hanno rispettivamente sovrastimato e sottostimato le produzioni giornaliere. Le produzioni di latte, grasso e proteina a 305-d stimate con i diversi metodi non hanno evidenziato differenze significative. L'applicazione separata dei vari metodi tra le due razze non ha evidenziato incrementi nelle accuratezze di stima nelle produzioni giornaliere e a 305-d.*

Parole chiave: *Bovine di razza Holstein e Simmental, Mungiture mattina-sera alternate, Produzione gioranliera di latte (24h), Produzione della lattazione (305-d), Stima.*

Introduction

Milk recording enables data acquisition on animals that are under selection. These data are the basis for the calculation of breeding values as well as for the improvement of herd management of dairy animals. The referent milk recording method by the International Committee for Animal Recording (ICAR, 2003) is the A4 method which implies the recording of the milk yield of two consecutive milkings (in the evening of the test day and the following morning) per animal every four weeks. With the aim of reducing the cost of milk recording in recent decades several alternative milk recording methods have been developed (Porzio, 1953; Putman and Gilmore, 1968; McDaniel, 1969; Wiggans, 1981). Increased participation in milk recording and cost reduction could be achieved by extending the interval between successive milk recordings by measuring only one milking per test-day (alternative milk recording method - AT) or by their combination. The implementation of the AT method, in addition to cost reduction (Everett and Wadell, 1970; Hargrove and Gilbert, 1984; Aleandri and Tondo, 2003), also results in faster genetic gain from selection due to potentially increased intensity of selection (Cassandro *et al.*, 1995, Cassandro *et al.*, 2003), greater flexibility in organizing the work of supervisors, increased number of herds served by one supervisor and less disruption of the milking routine. According to the AT method, milk recording is undertaken alternatively, either at morning or at evening milking; therefore, milk, fat and protein yields measured at each milking should be corrected by adequate coefficients. In other words, daily yields are estimated by a statistical model previously developed and tested (ICAR, 2003). Different genetic and environmental factors such as breed, season, herd management, health status, lactation stage and parity can be the cause of alternation in milk yields. According to numerous studies (Putnam and Gilmore, 1970; Everett and Wadell, 1970; Lee and Wardrop, 1984; Hargrove, 1994; Harding, 1995; Klopčič *et al.*, 2001, 2003; Jovanovac *et al.*, 2005; Gantner *et al.*, 2006), the interval between successive milkings is one of the most important effects on milk yield and content at each milking. The accuracy of daily milk, fat and protein yield estimation depends on how successfully the mentioned factors are taken into account;. this means that on the method used for estimation (Hargrove, 1994; Liu *et al.*, 2000) if estimation accuracy of total lactation yields is considered, a noticeable difference has not been detected between different estimation methods for daily yields (Cassandro *et al.*, 1995). In Croatia, milk recording performs according to the AT4 (and BT4) milk recording method by the field officers of the Croatian Livestock Centre (HSC, 2004). During milking on the test day, with the purpose of computing the interval between successive milkings, the initial time of current milking and the initial time of previous milking for each cow are recorded.

The objectives of this study were to compare methods for estimating daily (24 h) and 305-day lactation milk, fat and protein yields of Holstein and Simmental cattle breeds from alternative milk recording schemes (single morning and evening milking records) in the Croatian dairy system.

Material and methods

Data

Data were collected from November 2004 to November 2006 in a milk recording experiment designed to calculate factors for the estimation of daily milk, fat and protein yields (D), as well as fat and protein content. Milk recording was performed according to the A4 milk recording method by the field officers of the Croatian Livestock Centre. Analysed data included 7815 individual test-day milk of 769 cows reared on 15 family farms in Croatia. More than 50% of all cows were Holstein (58.9%), while the rest of the cows (41.1%) belonged to the Simmental breed. Regarding the parity 41.74% of cows calved for the first time, 23.77%, were in second lactation, 13.64% in the third, 9.37% in the fourth while the rest of the cows (11.48%) were in the class of fifth and later lactations. Measurements at each test-day included measurement of milk yield and taking one sample for analysis of milk composition at each milking (evening and morning). Also, at each milking, the initial time of current milking and the initial time of previous milking for each animal were recorded. The interval between successive milkings was computed as the time from the beginning of previous milking to the beginning of current milking. Daily yields (milk, fat and protein) were computed as evening (P) plus morning (A) yields. As proposed by Cassandro et al. (1995), the direct factors (D/A and D/P) were computed as the ratio of daily (D) to single milking in the morning or evening, and the indirect factors (A/D and P/D) as ratio of single milking to daily milk yield. With the purpose of estimating direct and indirect factors, milking interval (daily or nightly) was divided into 60-min (methods M_{2A} and M_{3A}) and 15-min (methods M_{2B} and M_{3B}) classes. Additionally, a linear regression of daily to evening or morning records was fitted in order to detect outliers. Residuals over three standard deviations were taken as outliers and deleted from the dataset. Also, logical control of data was performed according to ICAR standards (2003). Test-day records with missing evening or morning milk yields and milking interval, as well as with unreasonable lactation stage (<5; >500 days), lactation number (<1, >5), and ordinal number of milk recording (<1) were deleted from the database. The final dataset consisted of 6,824 test-day records from 668 cows. This dataset (dataset 1) was used for the estimation of daily milk yields according to six statistical methods. In order to calculate 305-day lactation milk yields, a subset of records of cows with 10 consecutive test-day records per lactation was created (dataset 2). This dataset contained test-day records of a total of 94 cows from which 34 were Simmental, while 60 were Holstein breed.

Estimation of daily (24 h) milk yields (dataset 1)

A preliminary analysis of variance showed that the interval between successive milkings, had a highly significant effect (P<0.001) on the variation of single milking (morning and evening) milk, fat and protein yields (Jovanovac *et al.*, 2005; Gantner *et al.*, 2006). Therefore, when daily milk, fat and protein yields were estimated from morning or evening records, the interval between successive milkings was taken into account as a covariate (method M_1) or as classed fixed effect (methods M_{2A}, M_{2B}, M_{3A} and M_{3B}). Daily milk, fat and protein yields were estimated according to the following methods:

1 - regression of daily to single milking of milk, fat or protein yields:

$$y_i = \mu + b_1 m_i + b_2 t_i + e_i$$

where:
y_i - daily milk/fat/protein yield;
μ - intercept;
m_i - evening or morning milk/fat/protein yield;
t_i - interval between successive milkings;
e_i - residual.

2 - multiplying single milking of milk, fat or protein yields (A or P) by direct factors estimated for each milking interval class (M_{2A} method - 6 classes, and M_{2B} method - 18 classes),

3 - dividing single milking of milk, fat or protein yields (A or P) by indirect factors estimated for each milking interval class (M_{3A} method - 6 classes, and M_{3B} method - 18 classes),

4 - doubling single milking of milk, fat or protein yields (A or P),

5 - method of DeLorenzo and Wiggans (1986) - used only for estimation of daily milk yield.

Estimation of 305-day lactation milk yields (dataset 2)

The real and estimated daily milk, fat and protein yields were used for the calculation of 305-day lactation milk, fat and protein yields (LMY) for each cow that had 10 consecutive test-day records per lactation simulating an alternate recording scheme (using first evening then morning record). The lactation milk, fat and protein yields were calculated using the Test Interval Method that is the reference method by ICAR (ICAR, 2003).

$$LMY = I_0 M_1 + I_1 \frac{M_1 + M_2}{2} + I_2 \frac{M_2 + M_3}{2} + \ldots + I_{n-1} \frac{M_{n-1} + M_n}{2} + I_n M_n$$

where:

$M_1, M_2, \ldots, M_n$ - milk, fat and protein yielded in 24 hours of the recording day, kg (real or estimated);

$I_1, I_2, ,,,, I_{n-1}$ - the intervals between recording dates, days;

I_0 - the interval between the lactation period start date and the first recording date, days;

I_n - the interval between the last recording date and the 305th lactation day, days.

Previous studies (McDaniel, 1969; Anderson *et al.*, 1989; Aleandri *et al.*, 2003; Berry *et al.*, 2005) show that estimation error of A4 milk recording method was negligible which means that the A4-estimated 305-day lactation yield could be taken as the most accurate reflection of the actual 305-day lactation yield.

The evaluation criteria for comparison methods were: correlation between estimated and true milk yields, as well as the mean and standard deviation of differences between estimated and true milk, fat and protein yields. Data were analyzed using SAS/STAT (SAS Institute Inc., 2000).

Results and discussion

Descriptive statistics

Descriptive statistics of the analysed traits according to breeds are reported in Table 1. Differences in traits means and variances between breeds indicate the necessity of diverging the estimation by breed. Relationship between daily, morning and evening milk traits, determined through correlation analysis according to breeds is shown in Table 2. All determined correlations between daily and single milking (morning and evening) of milk, fat and protein yields were high (in interval from +0.89 to +0.98) and different from zero (P<0.001). The strongest correlation was observed between daily and evening protein content in the Simmental breed, while the weakest correlation was between daily and evening fat content also in Simmental cows. Generally, if yields are considered, correlations between daily and morning yields are higher than those between daily and evening records indicating increased accuracy of estimated daily yields from morning records. The opposite was true for fat and protein content.

Table 1. Description of data.

Trait		S (n = 2726)		H (n = 4098)		All (n = 6824)	
		$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
Milk, kg	D	18.0	5.9	21.4	6.8	20.0	6.7
	A	9.6	3.2	11.3	3.8	10.6	3.7
	P	8.4	2.9	10.0	3.3	9.4	3.3
Fat, kg	D	0.75	0.3	0.94	0.3	0.86	0.3
	A	0.39	0.1	0.48	0.2	0.45	0.2
	P	0.36	0.1	0.45	0.2	0.41	0.2
Protein, kg	D	0.63	0.2	0.73	0.2	0.69	0.2
	A	0.34	0.1	0.39	0.1	0.37	0.1
	P	0.30	0.1	0.34	0.1	0.33	0.1
Interval	NI min	772.5	54.9	762.0	58.3	766.2	57.2
	DI "	670.4	56.7	680.6	57.0	676.5	57.1

D: daily yield; A: morning yield; P: evening yield; NI: interval from p.m. to a.m. milking; DI: interval from a.m. to p.m. milking; S: Simmental; H: Holstein.

Table 2. Correlation among milk traits according to breeds.

Trait		S (n = 2726)			H (n = 4098)			All (n = 6824)		
		D A	D P	A P	D A	D P	A P	D A	D P	A P
Milk	kg	0.97	0.96	0.87	0.96	0.95	0.83	0.97	0.96	0.85
Fat	"	0.93	0.93	0.72	0.94	0.93	0.75	0.94	0.94	0.76
Protein	"	0.96	0.94	0.81	0.95	0.94	0.79	0.96	0.94	0.81

P<0.001. D: daily yield; A: morning yield; P: evening yield; S: Simmental; H: Holstein.

Estimation of daily (24 h) milk, fat and protein yields

Table 3 shows results from the comparison of several methods for daily (24h) milk yield estimation from morning or evening records for each breed. The method with the highest correlation between estimated and true daily milk yields and the lowest mean difference between estimated and true daily milk yield could be taken as the most accurate one. When daily milk yield was estimated based on morning record, correlations were around 98% with the exception of M_5 that is simply doubling single records, which resulted in correlations around 97%. Estimation based on evening milk yield resulted in slightly lower correlations. Similar relationships between estimated and true daily milk yield were determined by Liu *et al.* (2000); in their study correlations ranged from 97.6% to 97.7% when estimated from morning milkings, and from 95.8% to 97.4% when estimated from evening milkings. The highest mean differences between estimated and true daily milk yield i.e. bias in amount over 1 kg per day was determined in the ap-

Table 3. Accuracy of different methods to estimate daily milk yield (DMY) from morning or evening milking.

DMY, kg	$\bar{x}$			$r(\hat{y},y)$[1]			$\bar{x}(\hat{y}-y)\pm\sigma(\hat{y}-y)$[2]		
	S	H	All	S	H	All	S	H	All
Morning milking (nS = 2695; nH = 4061; n = 6756)									
$\hat{y}$ (M_1)	17.93	21.30	19.96	97.90	98.19	98.21	$3.5*10^{-15} \pm 1.20$	$1.2*10^{-15} \pm 1.29$	$7.8*10^{-16} \pm 1.25$
$\hat{y}$ (M_{2A})	18.04	21.39	20.05	97.96	98.12	98.20	0.10 ± 1.21	$8.4*10^{-2} \pm 1.33$	$9.7*10^{-2} \pm 1.28$
$\hat{y}$ (M_{2B})	18.03	21.39	20.05	98.05	98.23	98.29	$9.8*10^{-2} \pm 1.18$	$8.0*10^{-2} \pm 1.29$	$9.4*10^{-2} \pm 1.25$
$\hat{y}$ (M_{3A})	17.93	21.30	19.96	97.96	98.11	98.19	$-6.3*10^{-5} \pm 1.21$	$-8.9*10^{-3} \pm 1.33$	$-9.3*10^{-4} \pm 1.28$
$\hat{y}$ (M_{3B})	17.93	21.30	19.96	98.06	98.23	98.29	$-5.4*10^{-4} \pm 1.18$	$-7.2*10^{-3} \pm 1.29$	$8.5*10^{-6} \pm 1.24$
$\hat{y}$ (M_4)	18.06	21.88	20.32	97.77	98.11	98.13	$2.0*10^{-2} \pm 1.26$	0.136 ± 1.35	$8.8*10^{-2} \pm 1.32$
$\hat{y}$ (M_5)	19.09	22.63	21.21	97.01	96.90	97.12	1.16 ± 1.58	1.33 ± 1.93	1.25 ± 1.80
y	17.93	21.31	19.96						
Evening milking (nS= 2699; nH= 4047; n= 6746)									
$\hat{y}$ (M_1)	17.94	21.25	19.92	97.32	97.69	97.64	$-3.0*10^{-15} \pm 1.36$	$-5.9*10^{-17} \pm 1.43$	$-9.3*10^{-16} \pm 1.42$
$\hat{y}$ (M_{2A})	18.12	21.39	20.07	97.21	97.53	97.54	0.18 ± 1.46	0.14 ± 1.55	0.15 ± 1.52
$\hat{y}$ (M_{2B})	18.10	21.38	20.06	97.31	97.73	97.69	0.16 ± 1.43	0.14 ± 1.49	0.14 ± 1.47
$\hat{y}$ (M_{3A})	17.97	21.26	19.93	97.21	97.54	97.55	$2.9*10^{-2} \pm 1.45$	$1.5*10^{-2} \pm 1.54$	$1.4*10^{-2} \pm 1.50$
$\hat{y}$ (M_{3B})	17.97	21.26	19.93	97.32	97.74	97.70	$2.5*10^{-2} \pm 1.42$	$1.8*10^{-2} \pm 1.48$	$1.4*10^{-2} \pm 1.46$
$\hat{y}$ (M_4)	18.06	21.55	20.12	96.67	97.46	97.36	$1.4*10^{-2} \pm 1.54$	-0.12 ± 1.54	$-6.8*10^{-2} \pm 1.54$
$\hat{y}$ (M_5)	16.81	19.96	18.70	96.35	95.97	96.33	-1.13 ± 1.59	-1.29 ± 1.89	-1.23 ± 1.77
y	17.94	21.25	19.92						

[1]*Correlation between estimated and true DMY (multiplied by 100).*
[2]*Mean and standard deviation of differences between estimated and true DMY (kg).*
S: Simmental, H: Holstein.

plication of method M_5. Doubling morning milking on an average overestimated the true daily milk yield, while doubling evening milking resulted in the underestimation. The lowest bias was observed when daily milk yield was estimated by method M_1. Although method M_1 exhibits the highest estimation accuracy, differences between estimation methods were small, with the exception of method M_5 which gives the lowest accuracy for both the estimation based on morning and evening records. Research results of Schaeffer and Rennie (1976), Cassandro *et al.* (1995), Lee and Wardrop (1984), Wangler *et al.* (1996), Liu *et al.* (2000), Jovanovac *et al.* (2005), Gantner *et al.* (2006), as well as of Jovanovac and Gantner (2007) confirm that the doubling method is the less accurate one and that different estimation methods based on regression technique, which take into account various factors that influence milk production, give higher estimation accuracy. These studies also confirm that estimates based on morning records are more accurate than those based on evening ones. Interval between successive milkings is the factor that has the highest influence on the quantity of milk yield milked in the morning or in the evening (Ormiston *et al.*, 1967; Putnam and Gilmore, 1969; Everett and Wadel, 1970; Shook *et al.*, 1973; DeLorenzo and Wiggans, 1986; Trappmann *et al.*, 1998; Kawahara *et al.*, 2000). There are several ways in which milking interval could be taken into account, e.g. as covariate or as classed fixed effect in which classification could be differently designed. In this study milking interval was taken into account as covariable (M_1), and as classed effect with 6 (M_{2A}, M_{3A}) or 18 (M_{2B}, M_{3B}) levels. The results showed that the differences in accuracy between above mentioned methods were negligible indicating use of method M_1 for estimation. Moreover, correct data on milking interval are necessary when daily milk yield is estimated from morning or evening records. Cassandro *et al.* (1995) reported that if milking interval data are questionable, doubling single milking of yields could guarantee better estimates of daily milk yield. Although breed was shown to have a significant effect on analysed traits, separate estimation according to breeds did not result in increased estimation accuracy.

Results from comparison of methods for daily (24h) fat and protein yields estimation from morning or evening records separate for each breed are shown in Table 4 and 5, respectively. Correlation between daily fat yields estimated from morning records and the true one were around 94.8% for the Simmental breed, while for Holstein cows they were slightly higher at around 95.2%. When evening records were used for estimation, correlations were slightly lower for both breeds. Liu *et al.* (2000) reported correlations ranging from 92.6% to 94.3% when estimated from morning milkings, and from 93.3% to 94.0% when estimated from evening milkings. Similar to estimation of daily milk yields, method M_1 was also shown to be the least biased in the estimation of daily fat yield. Slightly higher correlations between estimated and true daily protein yield as well as slightly lower bias were determined if estimation was based on morning records (Table 5). Determined correlations, regardless of estimation method or breed, were high and statistically highly significant ($P<0.0001$), indicating the adequacy of using method M_1 in routine work. Similar correlations were obtained by Liu *et al.* (2000), while Wiggans' study (1986) showed higher projection error in Holstein cattle than in the Jersey breed.

Estimation of 305-day lactation milk, fat and protein yields

Overestimation and underestimation of daily milk, fat and protein yields observed when estimation was based on morning

Table 4. Accuracy of different methods to estimate daily fat yield (DFY) from morning or evening milking.

DFY, kg	$\bar{x}$			$r(\hat{y},y)$[1]			$\bar{x}(\hat{y}-y)\pm\sigma(\hat{y}-y)$[2]		
	S	H	All	S	H	All	S	H	All
Morning milking (nS = 2403; nH = 3627; n = 6030)									
$\hat{y}$ (M_1)	0.74	0.93	0.86	94.78	95.25	95.40	$-3.4*10^{-15} \pm 0.08$	$-2.8*10^{-15} \pm 0.09$	$1.2*10^{-15} \pm 0.09$
$\hat{y}$ (M_{2A})	0.76	0.94	0.87	94.84	95.20	95.35	$1.3*10^{-2} \pm 0.09$	$9.3*10^{-3} \pm 0.10$	$1.2*10^{-2} \pm 0.09$
$\hat{y}$ (M_{2B})	0.76	0.94	0.87	94.85	95.25	95.43	$1.3*10^{-2} \pm 0.09$	$9.0*10^{-3} \pm 0.10$	$1.1*10^{-2} \pm 0.09$
$\hat{y}$ (M_{3A})	0.74	0.93	0.86	94.85	95.20	95.36	$4.7*10^{-4} \pm 0.08$	$-1.4*10^{-3} \pm 0.10$	$-2.4*10^{-4} \pm 0.09$
$\hat{y}$ (M_{3B})	0.74	0.93	0.86	94.88	95.27	95.44	$3.5*10^{-4} \pm 0.08$	$-1.5*10^{-3} \pm 0.09$	$-3.4*10^{-4} \pm 0.09$
$\hat{y}$ (M_4)	0.77	0.97	0.82	94.65	94.77	94.77	$2.3*10^{-2} \pm 0.09$	$4.1*10^{-2} \pm 0.11$	$3.5*10^{-2} \pm 0.10$
y	0.74	0.93	0.86						
Evening milking (nS = 2414; nH = 3640; n = 6054)									
$\hat{y}$ (M_1)	0.74	0.93	0.86	94.19	95.44	95.40	$-2.4*10^{-15} \pm 0.08$	$1.6*10^{-16} \pm 0.09$	$-4.2*10^{-15} \pm 0.09$
$\hat{y}$ (M_{2A})	0.76	0.95	0.87	94.14	95.33	95.35	$1.5*10^{-2} \pm 0.09$	$1.4*10^{-2} \pm 0.10$	$1.4*10^{-2} \pm 0.10$
$\hat{y}$ (M_{2B})	0.76	0.95	0.87	94.18	95.43	95.43	$1.4*10^{-2} \pm 0.09$	$1.4*10^{-2} \pm 0.10$	$1.4*10^{-2} \pm 0.10$
$\hat{y}$ (M_{3A})	0.75	0.94	0.86	94.15	95.34	95.36	$7.9*10^{-4} \pm 0.09$	$3.1*10^{-3} \pm 0.10$	$1.5*10^{-3} \pm 0.10$
$\hat{y}$ (M_{3B})	0.75	0.94	0.86	94.21	95.45	95.44	$8.3*10^{-4} \pm 0.09$	$3.3*10^{-3} \pm 0.10$	$1.7*10^{-3} \pm 0.10$
$\hat{y}$ (M_4)	0.71	0.89	0.82	93.74	94.50	94.77	$-3.1*10^{-2} \pm 0.09$	$-4.2*10^{2} \pm 0.10$	$-3.8*10^{-2} \pm 0.10$
y	0.74	0.93	0.86						

[1]*Correlation between estimated and true DFY (multiplied by 100).*

[2]*Mean and standard deviation of differences between estimated and true DFY (kg).*

S: Simmental; H: Holstein.

and on evening records, respectively, could be partially avoided by the alternate use of AM and PM for calculation of lactation milk yields (Schaeffer and Rennie, 1976; Webb, 1980; Smith and Pearson, 1981; Liu *et al.*, 2000). Results from the comparison of different estimation methods for 305-day lactation milk, fat and protein yields are presented in Tables 6 to 8. According to correlations between estimated and true (A4) 305-day lactation milk, fat as well as protein yields, negligible differences were observed among estimation methods as well as between breeds as all correlation coefficients were around 99%. Doubling single milking of yields (method M_5) resulted in underestimation on average less than 1% of true yield. The highest estimation accuracy was gained with application of estimated indirect factors (method M_3.). Similar bias in the use of estimated direct (method M_2) and indirect (method M_3) factors were obtained by Cassandro *et al.* (1995). In conformity with comparison results it could be said that there are no notable differences between the tested estimation methods which could be explained by the balance of estimation error of daily yields from morning milking with those from evening milking. It could also be concluded that separate estimation according to cattle breed did not result in increased estimation accuracy.

Table 5. Accuracy of different methods to estimate daily protein yield (DPY) from morning or evening milking.

DPY, kg	$\bar{x}$			r(ŷ,y)[1]			$\bar{x}$ (ŷ-y)±σ (ŷ-y)[2]		
	S	H	All	S	H	All	S	H	All
Morning milking (nS = 2424; nH = 3652; n = 6076)									
ŷ (M_1)	0.63	0.73	0.69	97.41	97.51	97.62	$-1.6*10^{-15}$ ± 0.04	$-7.8*10^{-16}$ ± 0.05	$6.2*10^{-16}$ ± 0.05
ŷ (M_{2A})	0.64	0.74	0.70	97.46	97.37	97.57	$4.7*10^{-3}$ ± 0.04	$3.5*10^{-3}$ ± 0.05	$4.1*10^{-3}$ ± 0.05
ŷ (M_{2B})	0.64	0.74	0.70	97.55	97.50	97.67	$4.5*10^{-3}$ ± 0.04	$3.3*10^{-3}$ ± 0.05	$4.0*10^{-3}$ ± 0.04
ŷ (M_{3A})	0.63	0.73	0.69	97.46	97.37	97.57	$9.2*10^{-4}$ ± 0.04	$-2.9*10^{-5}$ ± 0.05	$4.8*10^{-4}$ ± 0.05
ŷ (M_{3B})	0.63	0.73	0.69	97.55	97.51	97.67	$8.2*10^{-4}$ ± 0.04	$-3.7*10^{-5}$ ± 0.05	$4.4*10^{-4}$ ± 0.04
ŷ (M_4)	0.67	0.78	0.74	96.53	96.10	96.45	$4.2*10^{-2}$ ± 0.06	$4.5*10^{-2}$ ± 0.07	$4.4*10^{-2}$ ± 0.06
y	0.63	0.73	0.69						
Evening milking (nS = 2425; nH = 3660; n = 6085)									
ŷ (M_1)	0.63	0.73	0.69	96.53	96.68	96.79	$-3.7*10^{-16}$ ± 0.05	$-1.0*10^{-15}$ ± 0.05	$-2.4*10^{-15}$ ± 0.05
ŷ (M_{2A})	0.64	0.79	0.70	96.43	96.55	96.70	$5.0*10^{-3}$ ± 0.05	$4.9*10^{-3}$ ± 0.06	$4.9*10^{-3}$ ± 0.05
ŷ (M_{2B})	0.64	0.79	0.70	96.54	96.77	96.87	$4.7*10^{-3}$ ± 0.05	$4.7*10^{-3}$ ± 0.05	$4.7*10^{-3}$ ± 0.05
ŷ (M_{3A})	0.63	0.73	0.69	96.44	96.56	96.70	$-8.9*10^{-5}$ ± 0.05	$2.8*10^{-4}$ ± 0.06	$-3.8*10^{-6}$ ± 0.05
ŷ (M_{3B})	0.63	0.73	0.69	96.56	96.78	96.88	$-1.6*10^{-4}$ ± 0.05	$4.0*10^{-4}$ ± 0.05	$3.8*10^{-5}$ ± 0.05
ŷ (M_4)	0.59	0.69	0.65	95.27	94.52	95.09	$-4.2*10^{-2}$ ± 0.06	$-4.6*10^{-2}$ ± 0.07	$-4.4*10^{-2}$ ± 0.06
y	0.63	0.73	0.69						

[1]*Correlation between estimated and true DPY (multiplied by 100).*

[2]*Mean and standard deviation of differences between estimated and true DPY (kg).*

S: Simmental; H: Holstein.

Table 6. Accuracy of different methods to estimate 305-day lactation milk yield (nS = 34; nH= 60; n = 94).

LMY, kg	$\bar{x}$			r(ŷ,y)[1]			$\bar{x}$ (ŷ-y)±σ (ŷ-y)[2]		
	S	H	All	S	H	All	S	H	All
ŷ (M_1)	5798	6831	6415	99.57	99.36	99.44	-13.80 ± 137.0	-26.10 ± 143.9	-18.77 ± 143.6
ŷ (M_{2A})	5865	6896	6480	99.50	99.34	99.40	53.66 ± 114.7	39.26 ± 155.4	46.13 ± 142.9
ŷ (M_{2B})	5769	6895	6478	99.59	99.41	99.47	57.10 ± 106.0	37.53 ± 144.4	44.19 ± 134.1
ŷ (M_{3A})	5824	6860	6441	99.50	99.33	99.40	12.73 ± 116.2	2.91 ± 153.3	7.47 ± 141.8
ŷ (M_{3B})	5829	6862	6442	99.59	99.41	99.47	17.47 ± 107.0	4.57 ± 143.1	8.21 ± 133.5
ŷ (M_4)	5894	6867	6502	99.51	99.39	99.47	6.21 ± 119.8	-14.39 ± 143.0	-8.45 ± 137.1
ŷ (M_5)	5848	6831	6463	99.37	99.19	99.32	-39.71 ± 137.6	-50.31 ± 161.0	-47.59 ± 153.8
y	5888	6881	6510						

[1]*Correlation between estimated and true LMY (multiplied by 100).*

[2]*Mean and standard deviation of differences between estimated and true LMY (kg).*

S: Simmental; H: Holstein.

Table 7. Accuracy of different methods to estimate 305-day lactation fat yield (nS = 34; nH = 60; n = 94).

LFY, kg	$\bar{x}$			$r(\hat{y},y)^1$			$\bar{x}(\hat{y}-y)\pm\sigma(\hat{y}-y)^2$		
	S	H	All	S	H	All	S	H	All
$\hat{y}$ (M_1)	245.11	297.88	279.34	98.93	98.75	98.84	-5.36 ± 11.21	-1.04 ± 9.71	-2.44 ± 9.55
$\hat{y}$ (M_{2A})	252.17	303.80	285.80	99.03	98.71	98.80	1.70 ± 7.51	4.88 ± 9.79	4.02 ± 9.23
$\hat{y}$ (M_{2B})	252.36	304.06	285.85	99.10	98.80	98.84	1.88 ± 7.44	5.14 ± 9.47	4.07 ± 9.03
$\hat{y}$ (M_{3A})	247.76	300.25	281.75	99.05	98.72	98.81	-2.71 ± 7.72	1.34 ± 9.56	-0.03 ± 9.01
$\hat{y}$ (M_{3B})	248.03	300.65	281.92	99.10	98.80	98.84	-2.45 ± 7.65	1.73 ± 9.28	0.14 ± 8.87
$\hat{y}$ (M_4)	245.52	298.13	279.54	98.97	98.73	98.82	-4.95 ± 8.00	-0.78 ± 9.33	-2.24 ± 8.90
y	256.94	301.37	286.42						

[1]*Correlation between estimated and true LFY (multiplied by 100).*
[2]*Mean and standard deviation of differences between estimated and true LFY (kg).*
S: Simmental; H: Holstein.

Table 8. Accuracy of different methods to estimate 305-day lactation protein yield (nS = 34; nH = 60; n = 94).

LPY, kg	$\bar{x}$			$r(\hat{y},y)^1$			$\bar{x}(\hat{y}-y)\pm\sigma(\hat{y}-y)^2$		
	S	H	All	S	H	All	S	H	All
$\hat{y}$ (M_1)	208.45	229.52	221.99	99.57	99.08	99.27	-0.69 ± 4.81	-0.57 ± 4.92	-0.92 ± 4.91
$\hat{y}$ (M_{2A})	211.23	231.47	224.22	99.55	99.11	99.29	2.09 ± 3.87	1.38 ± 5.04	1.31 ± 4.54
$\hat{y}$ (M_{2B})	211.30	231.42	224.23	99.56	99.19	99.34	2.17 ± 3.87	1.33 ± 4.80	1.32 ± 4.38
$\hat{y}$ (M_{3A})	209.76	230.18	222.83	99.55	99.10	99.28	0.63 ± 3.88	0.09 ± 4.99	-0.09 ± 4.56
$\hat{y}$ (M_{3B})	209.88	230.24	222.93	99.57	99.18	99.34	0.75 ± 3.84	0.15 ± 4.77	0.01 ± 4.38
$\hat{y}$ (M_4)	207.81	228.37	221.02	99.34	99.93	99.10	-1.33 ± 4.72	-1.72 ± 5.26	-1.90 ± 5.09
y	212.21	230.22	223.22						

[1]*Correlation between estimated and true LPY (multiplied by 100).*
[2]*Mean and standard deviation of differences between estimated and true LPY (kg).*
S: Simmental; H: Holstein.

Conclusions

Several statistical methods were developed and used to estimate daily milk, fat and protein yield in dairy cattle from part day samples. In estimating daily yields, either from morning or evening records, method M_1, which is the linear regression of daily to partial yields while taking into account the interval between successive milkings, proved to be the most accurate model. The use of estimated direct and indirect factors, as well as the use of the method by DeLorenzo and Wiggans (1986) resulted in slightly lower estimation accuracy. Usage of simply doubling method gives overestimation and underestimation of daily yields when estimating based on morning or evening records, respectively. In general, the estimates based on morning records were more accurate than those based on evening samples regardless of estimation method. Eventually, when daily yields are estimated from AT recording scheme, method M_1 is recommended for routine use.

Results from the comparison of calculated 305-day lactation milk, fat as well as protein yields indicate that there are no notable differences between evaluated methods and breeds.

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