https://doi.org/10.17221/180/2022-CJAS

Using precision livestock farming for dairy herd management

Radko Loučka[1], Filip Jančík[1], Dana Kumprechtová[1], Veronika Koukolová[1], Petra Kubelková[1], Yvona Tyrolová[1], Alena Výborná[1], Miroslav Joch[1], Václav Jambor[2], Hana Synková[2], Soňa Malá[2], Jan Nedělník[3], Jaroslav Lang[3], Petr Homolka[1,4]*

[1]*Institute of Animal Science, Prague-Uhříněves, Czech Republic*
[2]*NutriVet Ltd, Pohořelice, Czech Republic*
[3]*Agricultural Research Ltd Troubsko, Troubsko, Czech Republic*
[4]*Department of Microbiology, Nutrition and Dietetics, Czech University of Life Sciences Prague, Prague, Czech Republic*

**Corresponding author: jancik.filip@vuzv.cz*

Citation: Loučka R., Jančík F., Kumprechtová D., Koukolová V., Kubelková P., Tyrolová Y., Výborná A., Joch M., Jambor V., Synková H., Malá S., Nedělník J., Lang J., Homolka P. (2023): Using precision livestock farming for dairy herd management. Czech J. Anim. Sci., 68: 111–121.

Abstract: The aim of this study was to validate selected precision livestock farming (PLF) methods of nutrition and feeding management of high-yielding Holstein dairy cows. In a feeding trial with 36 dairy cows, the effect of replacing 0.1 kg of sodium bicarbonate in the control total mixed ration (TMR-C) with 1 kg of wheat straw in the experimental total mixed ration (TMR-S) on the physiological status of cows and the amount of milk produced (milk yield, MY) was investigated. Feed intake time (FT), as measured using tensometric feed troughs (TFT), was significantly longer with TMR-S (188 min) than with TMR-C (157 min). Differences between TMR-C and TMR-S were not significant for FT or rumination time (RT), as measured by a sensor in the collar (VSC). There was only a weak correlation between the two technologies (TFT vs. VSC) for FT (r = 0.27). Differences between TMR-C and TMR-S were not significant for values measured in rumen fluid (pH, acid and ammonia levels) nor for values measured by sensors in the milking parlour (MY, fat and protein percentage of milk). Milk analysis in the laboratory showed that the cows fed TMR-C had higher urea (26.6 vs. 22.7 mg/100 ml) and free fatty acid (0.87 vs. 0.33 mmol/100 g) levels in milk. Moderate correlations were between TMR intake and MY (r = 0.55); between MY and milk fat (r = –0.46); between milk fat and milk protein (r = 0.63); and between milk fat and milk protein measured by sensors and in the laboratory (r = 0.47 and r = 0.42, respectively). In view of the above results, further research and data validation for each technology are needed.

Keywords: ruminant nutrition; rumination; rumen pH measuring bolus; milk yield

Precision livestock farming (PLF) aims to provide real-time monitoring and management tools to farmers. The idea behind PLF is to generate real-time alerts when something goes wrong so that farmers can take immediate action to resolve the problem (Berckmans 2017). Various PLF systems using tech-

Supported by the Czech Ministry of Agriculture (Projects No. QK1810137 and No. MZE-RO0723).

https://doi.org/10.17221/180/2022-CJAS

nologies such as sensors, cameras or microphones can alert farmers via connected devices (e.g. cell phones, PCs, tablets) on anomalies detected, allowing them to intervene at an early stage. Research shows a great potential of these 'smart technologies' to help livestock farmers monitor the welfare of their animals. Precision farming technologies are based on imaging (2D or 3D cameras, computer vision, optical flow, thermal imaging), sonic tools (microphones or sonars), sensors (accelerometers, pressure and infrared sensors), radio-frequency identification or wireless transmission.

The PLF technologies are designed to support farmers in livestock management by monitoring and controlling animal productivity, environmental impacts, as well as health and welfare parameters in a continuous, real-time and automated manner. However, there is still a lack of confidence among the farming community in the adoption of PLF technologies in practice. This may be related to the lack of validation of some technologies, which may result in a low level of confidence among farmers, but also the possibility that technologies overlook issues that compromise welfare. Furthermore, the adoption of technologies does not guarantee that the technologies will be used in an optimal way in relation to welfare.

Technology validation is usually required to predict how a system would perform under realistic operating conditions, and in the case of PLF, development must take into account the complexity of living organisms, which are 'individually distinct, temporally variable and dynamic'. This complexity may explain why a wide range of PLF technologies still require further validation. Even commercially available PLF technologies, such as the use of accelerometers, pressure or infrared sensors, still need validation. In order to actively use milk monitoring technologies to detect early behavioural changes, technologies must first be validated for their ability to accurately measure dairy cattle behaviour (Borchers et al. 2016; Borchers et al. 2021).

According to Lovarelli et al. (2020), PLF is spreading worldwide and it is increasingly used in both intensive and extensive livestock farming. When assessing the benefits of PLF, it is also necessary to consider health, animal welfare, performance, animal behaviour, housing conditions and the impact of all these aspects on environmental, economic and social sustainability. The analysis of PLF technologies by Krampe et al. (2021) revealed some common concerns of PLF users, and the analysis by Morrone et al. (2022) ascertained several ethical issues raised by PLF.

Reports on the use of PLF methods for dairy herd management are increasingly covered by scientific literature, also in terms of nutrition and feeding of high-producing Holstein dairy cows. The aim of several earlier studies was to compare cow behaviour measured by motion sensors (usually placed in the neck collar) with visual observations. Several studies have confirmed a high agreement between these two methods. For instance Grinter et al. (2019) found Pearson correlation coefficients (Prion and Haerling 2014) of 0.99, 0.93 and 0.94 for rumination, feeding and resting times, respectively, in lactating dairy cows. Another important PLF method is the real-time measurement of milk yield (MY) and milk quality. Such information is provided by the Afimilk system. According to Caria et al. (2019), the tested AfiFarm technology gave promising results showing reliability and efficiency in real-time measurement of milk.

As the milk yield of dairy cows increases, the risk of developing health disorders such as ruminal acidosis is growing, which affects both the overall health and the quantity and quality of milk produced. Therefore, it is essential to have good herd management practices in place (Valente et al. 2017). While many dairy farmers include straw or hay in total mixed rations (TMR) for preventing ruminal acidosis, others prefer TMR-buffering products such as sodium bicarbonate.

We hypothesized that PLF technologies are able to detect even small differences between the two types of TMR used in this study, based on monitoring the buffering effect on rumen contents to prevent ruminal acidosis that may adversely affect performance, health and well-being of high-producing dairy cows. By good management of the dairy herd and quick response to alerts issued by sensors, negative effects can be identified and subsequently eliminated, or at least nipped in the bud before they fully develop into clinical manifestations of the problem (acidosis in particular) and before milk yield declines. Among the many types of PLF technologies, the Vitalimeter sensor mounted on a cow collar (VSC) and AfiFarm sensors in a milking parlour to aid dairy cow feeding management undoubtedly belong to the most promising ones. We concluded that these PLF methods would be well complemented in the study

https://doi.org/10.17221/180/2022-CJAS

by the use of TFT, and by sampling and laboratory analysis of rumen fluid, cow faeces and milk.

The aim of the study was to validate and compare precision livestock farming (PLF) methods for nutrition and feeding management of high-yielding Holstein dairy cows.

MATERIAL AND METHODS

Design of experiment

The experiment was carried out on the Experimental Farm of the Institute of Animal Science in Prague (50°05''N and 14°27''E; altitude 287 meters above sea level; 8.4 °C daily mean; 526 mm average precipitation). The feeding experiment was carried out in accordance with the practices outlined in Act No. 183/2017 Coll., on the Protection of Animals against Cruelty and with Directive 2010/63/EU on the protection of animals used for scientific purposes. The experimental methodology was approved by Ministry of Agriculture of the Czech Republic.

The experiment started on January 14, 2022. During the 3-week preparatory period, dairy cows were acclimated to the barn and feeding technology. Two experimental periods (P1, P2) followed, each lasting three weeks.

A total of 36 Holstein dairy cows were included in the experiment. The cows were divided into two groups (A, B) by the pairing method according to parity, days in milk (DIM) and milk yield, so that each cow pair was comparable at the beginning of the first experimental period (Table 1).

Dosing of TMR components was controlled by software in the Husky DS 90 mixer wagon. Cows in both experimental groups had an unrestricted access to feed and water. Chemical composition of the diet was estimated by the nutrition software (AgroKonzulta Žamberk s.r.o., Czech Republic) which complies with NRC (2001). The components of the control and experimental total mixed rations (TMR-C and TMR-S, respectively) and their chemical composition are shown in Table 2. Maize silage was made using the additive Formasil® Maize

Table 1. Description of dairy cow groups at the beginning of the experiment

Parameter	Group A		Group B		SEM	*P*-value
	mean	SD	mean	SD		
MY kg/day	40.9	9.31	41.0	7.74	2.02	0.960
DIM	65.4	28.3	65.6	24.5	6.24	0.980
Parity	2.28	1.13	2.33	1.08	0.26	0.881

DIM = days in milk; MY = milk yield; SD = standard deviation; SEM = standard error of the mean

Table 2. Composition of control total mixed ration (TMR-C) and experimental total mixed ration (with straw) (TMR-S)

Components (kg)	TMR-C	TMR-S
Maize silage	17.5	16.0
Alfalfa silage	9.00	9.00
WMG	5.00	5.00
WBG	7.00	7.00
MGP	3.50	3.50
DO1	8.50	9.00
$NaHCO_3$	0.10	0.00
Wheat straw	0.00	1.00
Daily intake (kg of DM)*		
Maize silage	5.51	4.80
Alfalfa silage	2.45	2.33
WMG	3.10	2.95
WBG	1.62	1.54
MGP	3.47	3.30
DO1	7.48	7.54
$NaHCO_3$	0.09	0.00
Wheat straw	0.00	0.82
Analytical constituents		
DM (g/kg)	452	459
CP (g/kg DM)	174	173
CF (g/kg DM)	134	146
ADF (g/kg DM)	158	171
NDF (g/kg DM)	290	306
Starch (g/kg DM)	296	287
NEL (MJ/kg DM)	7.55	7.49
PDIA/CP	30.2	30.4

ADF = acid detergent fibre; CF = crude fibre; CP = crude protein; DM = dry matter; DO1 = concentrate for fresh dairy cows; MGP = liquid energy booster – a mixture of glycerol and molasses at a ratio of 1 : 1, and net energy lactation 8.7 MJ/kg; NDF = neutral detergent fibre; NEL = net energy lactation; PDIA = dietary protein undegraded in the rumen but truly digestible in the small intestine; WGB = wet brewers' grains; WMG = wet maize grain

*Daily intake was calculated according to tensometric feed trough measuring

https://doi.org/10.17221/180/2022-CJAS

[0.5 g/t; *Lactobacillus buchneri* (NCIMB 40788) 2 × 1 011 CFU/g; *Pediococcus pentosaceus* (NCIMB 12455) 7.5 × 1 010 CFU/g] and lucerne silage was made using the additive Formasil® Alfa [1 g/t; *Lactobacillus plantarum* (CNCM MA 18/5U) 1.5 × 1 011 CFU/g; *Pediococcus pentosaceus* (NCIMB 12455) 1.5 × 1 011 CFU/g; enzymes: beta-glucanase; activity > 150 000 nkat/g; xylanase, activity > 136 000 nkat/g]. To avoid the intake of straw not included in TMRs, the stalls were embedded with sawdust. DO1 complementary feed (concentrate) contained 38% wheat grain, 15% barley grain, 35% extracted rapeseed meal, 3% C-16 (rumen protected fat), 8% MKD (mineral supplement) and 1% PROTE-N (protected urea; 90% urea; 41% N; 9.9% fat; 1.2% ash) and chemical composition: DM 866 g/kg, crude protein 240 g/kg DM, starch 367 g/kg DM, ash 113 g/kg DM, NEL 8,17 MJ/kg DM.

The samples of TMR were collected during the last week of each experimental period. The chemical composition of TMRs was repeatedly analysed three times. Fresh samples were dried for 24 h at 50 ± 2 °C and subsequently milled to pass through a 1-mm sieve. Dry matter (#934.01), ash (#942.05), crude protein (#976.05), starch (#920.40), neutral detergent fibre (#2002.04), acid detergent fibre (#973.18) were determined according to the methods of the Association of Official Analytical Chemists (AOAC 2005), crude fibre content according to the Weende gravimetric method (Jung 1997). Energy (MJ NEL/kg DM) was calculated based on the measured chemical composition and nutrient digestibility values using the equations of Vencl et al. (1991). PDIA was calculated based on INRA Ruminant Nutrition System (Verite and Peyraud 1989).

Precision livestock farming methods used

The cows were stabled in an experimental barn equipped with TFT (Insentec BV, Marknesse, the Netherlands) connected to a computer system. Using this system, the consumption of feed, duration of TMR eating and number of visits to the feed bunk were continuously monitored and recorded during the experiment, separately for each cow. The TMRs were given to the TFT six times per day.

The dairy cows in the barn were equipped with 'collars', a precision farming technology which continuously records the above information via the 'Vitalimeter' device (AGROSOFT Tábor, Czech Republic), i.e. the duration of feed ingestion (feeding time, FT) and rumination (rumination time, RT).

One dairy cow in each group received a pH measuring bolus, inserted into the rumen with a special applicator (SmaXtec Classic Bolus SX.2; Animal Care GmbH, Graz, Austria) to measure pH values and temperature every 10 minutes.

The milk yield (MY) and composition of milk of all the cows were recorded twice a day by the herd management system AfiFarm v5.5 (Afimilk Ltd, Afikim, Israel). MY was measured by an electronic lactometer module (Afimilk), fat and protein content of milk by a milk analysis module (Afilab).

The samples of milk, rumen fluid and cow faeces were collected during the last week of each period from seven selected cows from each group at the same time. Milk quality was analysed in an accredited (ČSN EN ISO/IEC 17025:2005, 2018) laboratory (MILCOM a.s. Prague, Czech Republic). Infrared spectrophotometry (ČSN 57 0530, 2010; ČSN 57 0536, 1999) was used to analyse fat, protein, lactose and non-fat dry matter of milk; casein, urea and free fatty acids (FFA) by the indirect MIR-FT method (Hanus et al. 2008).

Rumen fluid was sampled using a stomach tube (length 240 cm; diameter 2.5 cm; insertion depth 180 cm) four hours after morning feeding. Each time 250 ml of rumen fluid was taken and 1 ml of toluene was added for conservation. Then the samples were transported to the laboratory, pH was measured and rumen fluid was centrifuged at 1 200 rpm for 5 minutes. The supernatant was transferred into a PE bottle and frozen until analysis. Rumen fermentation properties were analysed as follows: pH potentiometrically using inoLab Level 1 (inoLab, Kladno, Czech Republic), volatile fatty acids (mmol/l of rumen fluid) by capillary electrophoresis method (Kvasnicka 2000) using an ITP/CZE analyser IONOSEP 2003 (RECMAN, Ostrava-Hrabuvka, Czech Republic) and ammonia nitrogen (mg N/100 g rumen fluid) spectrophotometrically using Biochrom Libra s22 (Biochrom Ltd, Cambridge, UK).

Faeces were sampled using rectal palpation in an amount of 0.8 kg and DM (#934.01) and starch (#920.40) were determined according to AOAC (2005). pH was measured with a laboratory pH meter inoLab Level 1 (inoLab, Kladno, Czech Republic) from a solution of 15 g faeces mixed in 100 ml of distilled water.

https://doi.org/10.17221/180/2022-CJAS

All the cows were daily monitored for health indicators, especially for clinical signs of acidosis, both visually and by the above PLF methods.

Statistical analysis

The experimental design was as follows: TMR-C or TMR-S were fed to 18 dairy cows in each period, similarly 18 cows were fed in each group (A, B). Each of the two periods lasted 21 days, the periods were not included in the evaluation. Analysis of variance (ANOVA) with multivariate design was used (STATISTICA v10 software; StatSoft, Inc., Tulsa, OK, USA). The statistical model for the results was:

$$Y_{ij} = \mu + T_i + G_j + TG_{ij} + e_{ij} \quad (1)$$

where:

T_{ij} – the dependent variable;

μ – the overall mean;

T_i – the effect of the factor TMR (i = 1 to 2);

G_j – the effect of the factor group (j = 1 to 2);

TG_{ij} – the interaction of TMR with group;

e_{ij} – the error term.

The Tukey HSD (honestly significant difference) test at a significance level $P < 0.05$ was used to evaluate the results.

The associations for each item among factors (Table 3 and Table 4) were evaluated using a bivariate correlation analysis (STATISTICA v10 software; StatSoft, Inc., Tulsa, OK, USA). The probability of correlation (P-value) was calculated and Pearson bivariate correlations (Puth et al. 2014) were considered significant at $P < 0.05$. The r coefficient values for correlation were interpreted according to Prion and Haerling (2014): very strong correlation (± 0.91 to ± 1.00); strong correlation (± 0.68 to ± 0.90); moderate correlation (± 0.36 to ± 0.67); weak correlation (± 0.21 to ± 0.35); and negligible correlation (0 to ± 0.20).

Table 3. Correlation table ($P < 0.05$) of tensometric feed trough (TFT) and Vitalimeter sensor mounted on the collar (VSC) data

Index	ITMR	FT of TFT	FT of VSC	RT	MY
ITMR	–	0.03	0.04	0.05	0.55
FT of TFT	0.03	–	0.27	0.09	–0.03
FT of VSC	0.04	0.27	–	0.05	–0.05
RT of VSC	0.05	0.09	0.05	–	–0.01
MY	0.55	–0.03	–0.05	–0.01	–

FT = feeding time; RT = rumination time; ITMR = intake of total mixed ration

Table 4. Chart of correlations ($P < 0.05$) between AfiFarm sensor data and laboratory milk analysis

Indicator	Data from AfiFarm			Analytical results	
	MY	fat	protein	fat	protein
MY AfiFarm	–	–0.46	–0.13	–0.34	–0.32
Fat AfiFarm	–0.46	–	0.63	0.47	0.36
Protein AfiFarm	–0.13	0.63	–	0.33	0.42
Fat analytical	–0.34	0.47	0.33	–	0.23
Protein analytical	–0.32	0.36	0.42	0.23	–

MY = milk yield

RESULTS AND DISCUSSION

Feeding and rumination time

As can be seen from Table 2, both groups were balanced in their parameters, or there were no significant differences between them. The addition of 1 kg of wheat straw to the experimental TMR-S resulted in an increase of 12 g/kg DM in CF, 13 g/kg DM in ADF and 16 g/kg DM in NDF. TMR-S then had a NEL lower by 0.06 MJ/kg DM. Table 5 shows the FT and RT values obtained by the Vitalimeter Sensor in the collar of dairy cows (VSC), while Table 6 compares the values obtained from the TFT. Table 3 gives the correlations between the two technologies (VSC vs. TFT), supplemented by the correlation with MY obtained by Afimilk.

Table 5. Comparison of values obtained by Vitalimeter sensor in the collar of dairy cows

Parameter	TMR		Group		SEM	P-value	
	C	S	A	B		TMR	group
FT (min)	214	243	230	227	11.9	0.084	0.823
SD	65.1	77.6	76.9	69.2	–	–	–
RT (min)	485	482	482	485	9.20	0.852	0.867
SD	61.1	49.9	57.1	54.4	–	–	–

FT = feeding time; RT = rumination time; SD = standard deviation; TMR-C = control total mixed ration; TMR-S = experimental total mixed ration with straw

https://doi.org/10.17221/180/2022-CJAS

Table 6. Comparison of the values obtained from tensometric feed troughs

Parameter	TMR		Group		SEM	P-value	
	C	S	A	B		TMR	group
ITMR (kg/day)	52.5	50.7	52.2	51.0	1.03	0.230	0.419
SD	6.17	6.10	6.46	5.86	–	–	–
FT (min)	157	188	169	176	6.12	0.001	0.444
SD	34.8	38.4	40.7	38.9	–	–	–
FA	79.1	89.2	83.0	85.3	3.86	0.068	0.666
SD	22.1	23.6	21.1	25.5	–	–	–

FA = accesses to the feed trough; FT = feeding time; ITMR = intake of total mixed ration; SD = standard deviation; TMR-C = control total mixed ration; TMR-S = experimental total mixed ration with straw

FT tended ($P < 0.1$) to be longer for TMR-S than for TMR-C, consistent with the hypothesis because TMR-S contained more fibre. This trend was not confirmed for RT (Table 5). For either FT or RT, other differences between TMR-C and TMR-S or between the cow groups (A vs. B) were not significant ($P \geq 0.05$).

FT, as detected by VSC technology, tended ($P < 0.1$) to be longer when TMR-S was fed compared to TMR-C, consistently with the hypothesis based on TMR-S containing more fibre. This trend was not confirmed for rumination time. FT, as determined from the TFT data, was significantly ($P < 0.001$) longer for TMR-S than for TMR-C, which was accompanied by a trend ($P = 0.07$) of more frequent cow visits to tensometric feed troughs, i.e. the cows inserting their heads into the automatic device of each TFT. Differences between the groups were not significant in any parameter. Surprisingly, RT showed a lower than weak correlation with all other assessed indicators.

Beauchemin (2018) points out that dairy cows have changed significantly in recent decades, as have the types of feed and production systems used. The abundance of literature published in recent years has reportedly provided new insights into feeding and rumination in dairy cows. Measurement of RT is based on periodic jaw movements during regurgitation and subsequent chewing of the cud (bolus) in both the recumbent and standing positions. Measurement of TMR intake is based on specific movements of the cow's head while eating. Chewing increases salivary secretion in dairy cows, which helps reduce the risk of acidosis. Lactating cows spend about 4.5 h/day (270 min) eating (range: 2.4–8.5 h/day) and 7 h/day (420 min) ruminating (range: 2.5–10.5 h/day), with a maximum total chewing time of 16 h/day (960 min).

The values we obtained for both foraging time and rumination time are within the range of values published by Beauchemin (2018), as well as Souza et al. (2022), Krpalkova et al. (2022) and others. Their results also suggest that RT is influenced by many factors, especially NDF intake. The use of recently developed low-cost sensors that monitor the rumination activity of dairy cows in commercial facilities can provide information that is useful in management decisions, especially when combined with other factors such as feed management, cow variability and cow health. These effects are not accounted for in RT prediction equations. Chewing is critical for promoting salivation, particle size reduction, microbial digestion, and passage of undigested material out of the rumen, but the effect of changing RT on these functions is difficult to quantify (Beauchemin 2018).

A meta-analysis by Souza et al. (2022), which included 130 studies, showed that RT averaged 444 min/day (range 151–638 min/day). RT increased with increasing milk fat yield ($R^2 = 0.27$) and milk fat percentage ($R^2 = 0.17$). RT also increased with increasing MY, DM intake and rumen pH and was related to dietary neutral detergent fibre (NDF) and total tract NDF digestibility ($R^2 = 0.10–0.27$). Similar relationships were observed for rumination per unit of DM and NDF intake.

Data obtained by sensors were compared with the observations by Krpalkova et al. (2022). The aim of their study was to identify associations between RT and MY measurements using data collected from 2 777 dairy cows on nine commercial dairy farms in several European countries between 2017 and 2019. The database included behavioural and daily MY data. Cows averaged (mean ± standard deviation) 2.7 ± 1.6 lactations, 153 ± 81 days in milk and 23.2 ± 7.5 kg/day MY during the observation period. Krpalkova et al. (2022) concluded that high-yielding cows may have better feed efficiency and/or faster feed intake. This is consistent with previously published research. Behavioural data included RT (504 ± 93 min/day), FT (479 ± 110 min/day), rest time (360 ± 94 min/day), and activity time (96 ± 45 min/day). The coefficient of variation for RT (min/day) was 18.5%. High-producing dairy cows in early lactation achieved ($P < 0.05$) MY ≥ 23 kg/day,

https://doi.org/10.17221/180/2022-CJAS

RT 522 ± 3.54 min/day and FT 457 ± 4.69 min/day. The study showed that more productive cows spent a greater proportion of their time eating and ruminating.

Juhas et al. (2019) aimed to evaluate the change and interindividual stability of rumination characteristics in dairy cattle after a change of TMR composition between the first month after calving (TMR1) and the fourth month after calving (TMR2). RT of one cud of TMR2 was longer (TMR1 = 54.0 ± 8.2 s, TMR2 = 57.6 ± 6.3 s) than that of TMR1 cud ($P < 0.001$).

To complement the presented results, we provide an example of the application of FT and RT measurements for herd management evaluated e.g. by Codl et al. (2020). Evaluation of the parameters obtained from Vitalimeter 5P was performed on 719 dairy cows within one farm. Data collection lasted one year. A detailed evaluation by the GLM procedure was used. Parity, season of the year and animal genetics had a significant effect on the FT, RT, increased activity and the sum of activities. Within the effect of parity, a certain discrepancy was evident when the longest FT was observed in the first parity cows (293 min/day), while the longest RT was measured in the 3rd (485 min/day), 4th and other parity cows (482 min/day). The lowest values were recorded in the exactly opposite ways, namely the lowest FT in older cows and the lowest RT in the youngest cows. In terms of the season, differences were noted in summer FT and RT compared to the rest of the year.

In the middle of the experiment, TMRs were exchanged abruptly between the groups. This decision was based on the research findings of Schingoethe (2017). They imply that abrupt changes in TMR composition may result in reduced feed intake or milk production, but this effect does not always occur, especially if the dietary changes are not fundamental.

As expected, in group A the change from TMR with straw to fine TMR-C resulted in a reduction in feeding time, whereas in group B the change from TMR-C to coarse TMR-S led to an increase in feeding time. When measuring the feeding time, the differences between groups based on the data from feed troughs were even more pronounced than those based on the sensors in the collar data.

Rumination time increased gradually with ongoing lactation in the first part of the experiment. After the transition from TMR-C to TMR-S in group A, the rumination time increased, while in group B it decreased after the transition from TMR-S to TMR-C. After one week, the rumination time of both groups of cows equalized and remained stable until the end of the experiment.

Indicators of cow health and welfare

The values of rumen fluid pH and acids in seven selected dairy cows from each group are given in Table 7. The pH, DM and starch content of the faecal solids are shown in Table 8.

Deviations from the physiological state are evaluated clinically and by using selected parameters from the examination of rumen fluid, faeces and milk. As regards the addition of sensor data for the measurement of feeding and rumination time, the measurement of parameters in rumen fluid or faeces is rarely reported in the literature. An example is the meta-analysis by Souza et al. (2022). This meta-analysis provides baseline data for comparison with our inputs and results. According to it, for example, the mean rumen pH was 6.1 (range: 5.3–7.0) in 292 treatments reporting the observation.

In the study presented here, no statistically significant differences were found between TMR-C and TMR-S in terms of acid content and ratio. The rumen fluid pH values (6.09 and 5.99 for TMR-C and TMR-S, respectively) indicate that they were on average higher than the critical value (pH 5.8) reported by, for example, Valente et al. (2017) for the development of subclinical acidosis.

According to the records from the smaXtec ruminal sensors, which measured the rumen pH of one cow per group, the pH value often (in about one quarter of the cases) decreased below 5.8, i.e., according to Valente et al. (2017), below the risk threshold for subacute ruminal acidosis (SARA). At the same time, the cows coped with this decrease in pH quite quickly (e.g., the cow drank and thus the rumen contents became diluted). On average, rumen pH was 5.91 ± 0.27 with TMR-C and 5.83 ± 0.26 with TMR-S. The more important information is the percentage of the time when rumen pH was below 5.8: 6.82% with TMR-C and 17.72% with TMR-S (data are not presented in table). Monitoring rumen acidity with pH ruminal sensors is an important contribution to understanding what happens in the rumen.

https://doi.org/10.17221/180/2022-CJAS

Table 7. Rumen fluid values of selected dairy cows according to total mixed ration or group

Indicator	TMR		Group		SEM	*P*-value	
	C	S	A	B		TMR	group
pH	6.09	5.99	5.97	6.11	0.09	0.462	0.273
SD	0.33	0.32	0.41	0.20	–	–	–
Total acids (mM)	135	138	139	134	3.73	0.618	0.416
SD	13.9	13.5	16.8	9.2	–	–	–
Lactic acid (mol%)	0.57	0.62	0.61	0.59	0.02	0.089	0.428
SD	0.10	0.04	0.09	0.06	–	–	–
Acetic acid (mol%)	62.7	63.0	61.8	63.9	0.38	0.480	0.001
SD	1.43	2.73	1.95	1.81	–	–	–
Propionic acid (mol%)	20.3	20.4	20.8	19.9	0.32	0.898	0.062
SD	1.20	1.83	1.68	1.24	–	–	–
Butyric acid (mol%)	16.5	15.9	16.8	15.6	0.27	0.156	0.005
SD	1.24	1.18	1.21	0.93	–	–	–
Valeric acid (mol%)	0.53	0.57	0.54	0.57	0.02	0.280	0.392
SD	0.09	0.07	0.10	0.07	–	–	–
NH_3 (mg N/100 g)	12.2	12.3	12.2	12.3	0.31	0.848	0.774
SD	0.95	1.34	1.43	0.80	–	–	–

N = nitrogen; NH_3 = ammonia; SD = standard deviation; TMR-C = control total mixed ration; TMR-S = experimental total mixed ration with straw

Not only the pH values in the faeces indicated that dairy cows had problems with acidification of the digestive tract. The starch content also indicated that the digestion of the cows was standard in both groups and with both TMRs. The knowledge of faecal starch levels is useful for monitoring TMR digestibility, especially when changing TMR composition abruptly. Faecal starch content of up to 30 g/kg DM can be considered optimal and between 30 and 50 g/kg DM normal. Increasing total tract starch digestibility can increase milk production, milk protein content and overall TMR efficiency (Fredin et al. 2014).

Table 8. Faecal values from selected dairy cows according to total mixed ration or group

Indicator	TMR		Group		SEM	*P*-value	
	C	S	A	B		TMR	group
pH	6.73	6.69	6.71	6.72	0.02	0.114	0.904
SD	0.11	0.09	0.11	0.09	–	–	–
DM (g/kg)	149	150	154	145	4.24	0.797	0.126
SD	18.9	12.6	10.1	19.2	–	–	–
Starch (g/kg DM)	32.2	32.2	32.5	31.9	0.59	0.980	0.494
SD	2.26	2.12	1.71	2.55	–	–	–

DM = dry matter; SD = standard deviation; TMR-C = control total mixed ration; TMR-S = experimental total mixed ration with straw

Indicators of the health and well-being of dairy cows are also closely related to rumen fluid and faecal values. A review of health-associated traits in current dairy cattle breeding was published by Zavadilova et al. (2021). The review focuses on breeding practices aimed at improving resistance to diseases and health disorders that are associated with better efficiency, welfare and longevity of cows. Cow health is essential because of its effect on the farm economy, animal welfare and food safety. Enhancing cow health is possible by changing environmental conditions and improving management and genetics.

Throughout the experiment (42 days), no major diseases (or signs of rumen acid-base disturbances) occurred in the dairy cows that could have negatively affected the results of the experiment. No cows were treated by a veterinarian or removed from the trial. The same number of cows was present at the beginning and at the end of the experiment.

Milk performance parameters

Data on the average quantity of milk and its main quality parameters (fat and protein content) from

https://doi.org/10.17221/180/2022-CJAS

AfiFarm sensors are presented in Table 9. The milk quality indicators analysed in the laboratory are shown in Table 10. The chart of correlations between the AfiFarm sensor data and the laboratory milk control is given in Table 4.

Laboratory milk analyses showed that cows fed TMR-C had more urea (26.6 vs. 22.7 mg/100 ml) and FFA (0.87 vs. 0.33 mmol/100 g) in their milk. The comparison of urea and fatty acids in Holstein cows with SARA was the focus of a study by Kara (2020). The study showed that dairy cows with lower milk urea nitrogen and milk fatty acids were more likely to develop SARA. This is consistent with our results where both rumen fluid pH and pH measured by smaXtec sensors were higher in TMR-C cows than in TMR-S cows.

Table 9. Values from AfiFarm sensors at mid-trial total mixed ration change according to total mixed ration and group

Indicator	TMR		Group		SEM	*P*-value	
	C	S	A	B		TMR	group
MY (kg/day)	44.3	43.4	44.7	43.0	1.15	0.569	0.306
SD	7.93	7.36	8.25	6.93	–	–	–
Fat (%)	3.17	3.19	3.13	3.23	0.08	0.857	0.397
SD	0.50	0.49	0.53	0.46	–	–	–
Protein (%)	2.59	2.62	2.61	2.61	0.02	0.320	0.943
SD	0.13	0.13	0.13	0.13	–	–	–

MY = milk yield; SD = standard deviation; TMR-C = control total mixed ration; TMR-S = experimental total mixed ration with straw

According to Prion and Haerling (2014), TMR intake showed a moderate correlation with MY (r = 0.55); MY was negatively correlated (r = –0.46) with milk fat content; milk fat content was correlated with protein content (r = 0.63); and fat and protein contents measured by the sensors were correlated with those measured in the laboratory (r = 0.47 and r = 0.42, respectively). These data are fully consistent with the hypotheses that the authors of the present study formulated before planning the experiment and also consistent with data from the literature, e.g., Polakova et al. (2010).

Identifying the association of cow feeding behaviour with MY is important to support the recommendation of strategies that optimize MY (Krpalkova et al. 2022). The behavioural differences observed in this study provide new insights into the effects of RT and FT on MY. MY was positively correlated with RT in early- and mid-lactation dairy cows with correlation coefficients of 0.24 (P < 0.001) and 0.25 (P < 0.001), respectively. High-producing dairy cows in early lactation achieved (P < 0.05) MY ≥ 23 kg/day.

Stone et al. (2017) reported a weak correlation (r = 0.22) between RT and daily MY. There was a negligible correlation (r = 0.17) between RT and MY in the study by Codl et al. (2020).

According to the meta-analysis by Souza et al. (2022), MY averaged 34.3 kg/day (range: 14.2–52.1)

Table 10. Milk quality indicators analysed in the laboratory according to total mixed ration and group

Indicator	TMR		Group		SEM	*P*-value	
	C	S	A	B		TMR	group
Fat (g/100 g)	3.52	3.24	3.38	3.39	0.13	0.132	0.954
SD	0.82	0.70	0.83	0.72	–	–	–
Protein (g/100 g)	3.22	3.27	3.23	3.26	0.05	0.497	0.662
SD	0.28	0.33	0.29	0.32	–	–	–
Lactose (g/100 g)	4.99	5.03	5.04	4.99	0.03	0.344	0.283
SD	0.19	0.18	0.18	0.18	–	–	–
Casein (g/100 g)	2.50	3.68	3.08	3.11	0.55	0.137	0.970
SD	0.25	4.62	3.26	3.39	–	–	–
Urea (mg/100 ml)	26.6	22.7	24.6	24.7	0.84	0.002	0.907
SD	5.43	4.48	5.45	5.25	–	–	–
FFA (mmol/100 g)	0.87	0.33	0.64	0.56	0.05	0.001	0.290
SD	0.33	0.29	0.42	0.41	–	–	–

FFA = free fatty acids; SD = standard deviation; TMR-C = control total mixed ration; TMR-S = experimental total mixed ration with straw

https://doi.org/10.17221/180/2022-CJAS

and milk fat averaged 3.47% (range 2.20–4.60). Dry matter intake averaged 23.1 kg/day (range: 15.3–32.6). Mean rumen pH was 6.1 (range: 5.3–7.0) in 292 treatments reporting the observation. These are the baseline data for comparison with our inputs and results. The conclusion from the meta-analysis by Souza et al. (2022) was that RT was related to MY, milk fat yield and concentration, rumen pH, NDF intake and total tract digestibility. Milk fat yield was maximal at RT of 494 min/day with no additional benefit of increased RT. In a multivariate analysis, a set of variables explained 37% of RT. Overall, RT was mostly associated with milk fat. However, the relationship was only moderate in overall strength, suggesting that rumination is not the only factor important for optimal and stable ruminal fermentation, and therefore factors other than ruminal fermentation influence the milk fat production.

CONCLUSION

This study evaluated different PLF technology from several other studies, but the results are similar, suggesting that the technology works in a similar way. There were only weak correlations between the two technologies (TFT vs. VSC) (r = 0.27). Correlations between the PLF technologies in the milking parlour and the control measurements in the laboratory were moderately high. This is consistent with most other studies, although some studies published higher correlations (however, most were correlations between VSC and behavioural observation data).

Replacing 0.1 kg of sodium bicarbonate in TMR-C by one kg of wheat straw in TMR-S to improve rumen acid-base ratios in dairy cows did not significantly affect the time of feeding or rumination as measured by VSC. Only FT showed the expected trend to be longer in TMR-S because there was more fibre supplied through straw in this TMR. The increased fibre content in TMR-S caused other expected effects, namely that cows fed TMR-S had lower levels of urea and free fatty acids in milk compared to TMR-C.

The TMR intake correlated moderately (± 0.36 to ± 0.67) with milk yield; this correlation was positive. Milk yield negatively correlated with milk fat content. The fat and protein content, as measured by the sensors at a milking parlour, correlated with that measured in the laboratory.

From the above, further research in this area is recommended. The validation of selected PLF methods for nutrition and feeding management of high-yielding Holstein dairy cows is necessary.

Conflict of interest

The authors declare no conflict of interest.

REFERENCES

AOAC – Association of Official Agricultural Chemists. Official methods of analysis. 18th ed. Washington, DC: AOAC International; 2005.

Beauchemin KA. Invited review: Current perspectives on eating and rumination activity in dairy cows. J Dairy Sci. 2018 Jun;101(6):4762-84.

Berckmans D. General introduction to precision livestock farming. Anim Front. 2017 Jan;7(1):6-11.

Borchers MR, Chang Y, Tsai I, Wadsworth B, Bewley J. A validation of technologies monitoring dairy cow feeding, ruminating, and lying behaviors. J Dairy Sci. 2016 Sep;99(9):7458-66.

Borchers MR, Gavigan S, Harbers A, Bewley J. An evaluation of a novel device for measuring eating, rumination, and inactive behaviors in lactating Holstein dairy cattle. Animal. 2021 Jan;15(1): 5 p.

Caria M, Todde G, Pazzona A. Evaluation of automated in-line precision dairy farming technology implementation in three dairy farms in Italy. Front Agric Sci Eng. 2019 Jun;6(2):181-7.

Codl R, Duchacek J, Pytlik J, Stadnik L, Vacek M, Vrhel M. Evaluation of the level of length of eating time, chewing and parameters of daily increased activity depending on the breed, the lactation number and the period of the year. Acta Univ Agric Silvic Mendel Brun. 2020 Aug;68(4):659-67.

Fredin SM, Ferraretto LF, Akins MS, Hoffman PC, Shaver RD. Fecal starch as an indicator of total-tract starch digestibility by lactating dairy cows. J Dairy Sci. 2014 Mar; 97(3):1862-71.

Grinter LN, Campler MR, Costa JHC. Technical note: Validation of a behavior-monitoring collar's precision and accuracy to measure rumination, feeding, and resting time of lactating dairy cows. J Dairy Sci. 2019 Apr; 102(4):3487-94.

Hanus O, Vegricht J, Frelich J, Macek A, Bjelka M, Louda F, Janu L. Analyse of raw cow milk quality according to free fatty acids contents in the Czech Republic. Czech J Anim Sci. 2008 Jun 6;53(1):17-30.

Juhas P, Spulerova K, Vavrisinova K, Hozakova K, Strapak P. Changes of the rumination characteristics in dairy cows after change tmr composition. Acta Univ Agric Silvic Mendel Brun. 2019 Oct;67(5):1153-7.

Jung HJG. Analysis of forage fiber and cell walls in ruminant nutrition. J Nutr. 1997 May;127(S5):S810-3.

Kara K. Milk urea nitrogen and milk fatty acid compositions in dairy cows with subacute ruminal acidosis. Vet Med-Czech. 2020 Aug;65(8):336-45.

Krampe C, Serratosa J, Niemi JK, Ingenbleek PTM. Consumer perceptions of precision livestock farming – A qualitative study in three European countries. Animals. 2021 Apr 23;11(5): 13 p.

Krpalkova L, O'Mahony N, Carvalho A, Campbell S, Walsh J. Association of rumination with milk yield of early, mid and late lactation dairy cows. Czech J Anim Sci. 2022 Mar;67(3):87-101.

Kvasnicka F. Application of isotachophoresis in food analysis. Electrophoresis. 2000 Aug;21(14):2780-7.

Lovarelli D, Bacenetti J, Guarino M. A review on dairy cattle farming: Is precision livestock farming the compromise for an environmental, economic and social sustainable production. J Cleaner Prod. 2020 Jul;262: 121409.

Morrone S, Dimauro C, Gambella F, Cappai MG. Industry 4.0 and precision livestock farming (PLF): An up to date overview across animal productions. Sensors. 2022 Jun; 22(12): 25 p.

NRC – National Research Council. Nutrient requirements of dairy cattle. 7th ed. Washington, DC: National Academies Press; 2001. 405 p.

Polakova K, Kudrna V, Kodes A, Hucko B, Mudrik Z. Nonstructural carbohydrates in the nutrition of high-yielding dairy cows during a transition period. Czech J Anim Sci. 2010 Jan 1;55(11):468-78.

Prion S, Haerling KA. Making sense of methods and measurement: Pearson product-moment correlation coefficient. Clin Simul Nurs. 2014 Nov;10(11):587-8.

Puth MT, Neuhauser M, Ruxton GD. Effective use of Pearson's product–moment correlation coefficient. Anim Behav. 2014 Jul;93:183-9.

Schingoethe DJ. A 100-year review: Total mixed ration feeding of dairy cows. J Dairy Sci. 2017 Dec;100(12):10143-50.

Souza JG, Claudio VDM, Ribeiro CVDM, Harvatine KJ. Meta-analysis of rumination behavior and its relationship with milk and milk fat production, rumen pH, and total-tract digestibility in lactating dairy cows. J Dairy Sci. 2022 Jan;105(1):188-200.

Stone AE, Jones BW, Becker CA, Bewley JM. Influence of breed, milk yield, and temperature-humidity index on dairy cow lying time, neck activity, reticulorumen temperature, and rumination behavior. J Dairy Sci. 2017 Mar; 100(3):2395-403.

Valente TNP, Sampaio CB, Lima ES, Deminicis BB, Cezario AS, Santos WBR. Aspects of acidosis in ruminants with a focus on nutrition: A review. J Agric Sci. 2017 Feb; 9(3):90-7.

Vencl B, Frydrych Z, Krasa A, Pospisil R, Pozdisek J, Sommer A, Simek M, Zeman L. The new systems of feed evaluation for cattle. Praha: Czechoslovak Academy of Agriculture; 1991. 134 p. Czech

Verite R, Peyraud JL. Protein: The PDI system. In: Jarrige R, editor. Ruminant nutrition. Paris: INRA and John Libbey; 1989. p. 75-93.

Zavadilova L, Kasna E, Krupova Z, Klimova A. Health traits in current dairy cattle breeding: A review. Czech J Anim Sci. 2021 Jul;66(7):235-50.

Received: October 28, 2022
Accepted: February 15, 2023
Published online: March 20, 2023