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Triaxial accelerometers for recording grazing and ruminating time in dairy cows: An alternative to visual observations

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Abstract

The aim of this study was to validate the recordings of a commercial triaxial accelerometer (HOBO Pendant G data loggers) with respect to visual observations of grazing and ruminating time of dairy cows. Seven lactating Holstein cows with a mean body weight of 602 ± 45 kg were used for the study. Grazing and ruminating times were recorded using HOBO loggers (31.5 hours of total observations for grazing and ruminating) that were attached to the lateral-medial side of the jaw using a strap attached to the head of each cow in a position such that the X-axis was parallel to the ground, the Y-axis was perpendicular to the ground pointing upward, and the Z-axis was parallel to the ground pointing away from the sagittal plane; these relative positions were defined when the cow was in a natural head-up position. Median acceleration (m/s^2) readings in the X-axis >0.175 and <0.95 indicated grazing activity, whereas readings in the Z-axis >-0.275 and <0.0875 indicated ruminating activity. The degree of vertical tilt (° Y-axis) was used to determine grazing position (readings >0° and <61°) and ruminating (readings >0° and <25.8°). Results showed a significant ($P < 0.001$) relationship of estimated grazing time against visual observations when acceleration (X-axis) was used only; nonetheless acceleration (Z-axis) was not significant ($P > 0.05$) for estimating ruminating time. When acceleration and tilt were used for estimating grazing (X- and Y-axis) and ruminating (Z- and Y-axis) time, the slope in both showed a significant ($P < 0.001$) relationship. The prediction R2 in both activities indicated that acceleration (X- and Z-axis) and tilt (Y-axis) of HOBO loggers explained 0.961 and 0.945 of the variance in visual observations per cow/day. Therefore, the validation of the HOBO loggers was successful on a per cow/day and per day basis.

Keywords: validation; triaxial accelerometer; HOBO Pendant G; grazing; ruminating; dairy cows

Introduction

Studies of grazing behavior may improve the understanding of how the animals take advantage of the vegetation on offer and may enable improved herd management (Moreau et al., 2009). Time spent by animals in grazing activities such as grazing, rumination, and resting reflects climatic and pasture (availability and quality) conditions and physiological states of animals and thus relate to the performance of animals (Hirata et al., 2002; Aikman et al., 2008). Rumination has been considered as a key component of digestion and intake by ruminants and has a significant effect in the chemical composition of milk (Gregorini et al., 2013). Recurrent methods to investigate grazing behavior are found in literature, as animal weighting, measuring sward height (SH), esophageal fistulated animals, fecal markers, individual feeding stations, and visual observations (also used to validate other methods). Such methods are valid, although might be laborious and time expensive (Castelán-Ortega et al., 2017). Direct visual observations of grazing behavior to obtain information regarding grazing patterns are time consuming and not an option in modern dairy husbandry or for large-scale grazing experiments for research purposes (Nielsen, 2013). The development of technologies in the field of precision livestock farming has, to date, been largely focused toward intensive animal production. However, there is no fundamental reason why precision technologies should not be used in grasslands systems (Rutter, 2014).
Inspired by precision agriculture, a farming practice of precision livestock farming is under development (Pascual-Alonso et al., 2017). Recent advances in sensor technology offer electronic devices that allow higher sensitivity and larger storage capacity that opens up new scenarios for recording feeding behavior of dairy cows (Oudshoorn et al., 2013). Miniaturization of acceleration sensors into 3-axis micro-electromechanical systems has reduced the size, weight, and power consumption to allow easier mounting on animals without affecting animal behavior (Alvarenga et al., 2016). In this context, wireless tridimensional accelerometers provide a noninvasive and objective method of measuring cows' behavior under extensive conditions. Accelerometers may offer a viable system to monitor changes in grazing behavior, which in turn could be used to document animal health and welfare (Rushen et al., 2012). Before the implementation of such devices for detecting changes in grazing behavior, health, and welfare status, initial work must be done to validate the ability of the devices to describe grazing patterns accurately and precisely. The triaxial accelerometers HOBO Pendant G data loggers have been previously used in cattle to assess the gait patterns of dairy calves (De Passille et al., 2010), lying behavior in both dairy calves (Bonk et al., 2013) and dairy cows (Mattachini et al., 2013), and grazing versus no-grazing in dairy cows (Nielsen, 2013). Grazing studies are more challenging to conduct than the ones in confinement because of less controlled conditions. However, for both types of experiments results are sometimes extrapolated to other settings without plenty justification of little or no impact of differing conditions (Askar et al., 2015). Until now, there is no significant research that investigates the ability of the triaxial accelerometers for measuring feeding activity under free grasslands conditions. Therefore, the aim of this study was to validate the recordings of commercial triaxial accelerometer HOBO Pendant G data loggers with respect to direct visual recording of grazing and ruminating time of grazing dairy cows.

Material and methods

The study was carried out in the experimental farm of the Faculty of Veterinary Medicine, Autonomous University of the State of Mexico in the central highlands of Mexico (19° 24’ 52” N and 99° 41’ 20” W, and 2667 m above sea level). The climate is temperate subhumid dominated by summer-fall (June to October) rainfalls. The annual rainfall and mean annual temperature is 750-990 mm and 13.5°C with a range of -5°C to 25°C, respectively. The handling of animals was done according to Mexican bioethical standards (NOM-062-ZOO-1999). All cows were under the care of a veterinarian and monitored for signs of lameness or disease at the beginning and end of the study. No other signs of disease or lameness were observed.

Animals

Seven multiparous and lactating Holstein cows, clinically healthy, with a mean liveweight of 602 kg (±45), 200 (±25) days of lactation, and 23 (±2.9) kg of milk/cow/day, were used for the study. The cows were in a continuous grazing system during 12 hours, starting at 7:00 and finishing at 19:00 hours; after grazing, the cows were housed during 12 hours overnight and fed with 14.6 kg dry matter (DM) as a totally mixed ration that consisted in maize grain (13.1%), soybean meal (13.4%), wheat bran (4.1%), rapeseed (5.9%), soybean oil (3%), oat hay (26.8%), maize silage (32.7%), CaCO3 (0.8%), and premix of vitamins and minerals (0.2%).

Pasture composition, availability of dry matter, and SH

Measurements were carried out in a ryegrass-white clover pasture from 1 to 30 July, 2014. Thirty individual samples per hectare were collected from the ryegrass-white clover pasture at the beginning of the study and the sward composition was: Lolium perenne (53%), Trifolium repens (29%), Pennisetum clandestinum (9%), Festuca arundinacea (7%), and weeds (2%). Samples were collected using a quadrant of 0.25 m2, which was thrown 30 times on the pasture following a “W” pattern; all standing plants within the quadrant were cut above ground level with shears and then the material was weighed, placed into plastic bags, labeled, and then taken to the laboratory. In the laboratory, the weight was recorded after drying the samples at 60

C until constant weight was achieved. To measure the SH at pregrazing and postgrazing, 6 sampling days were established at days 2, 3, 4, 22, 23, 24 of July 2014. Linear regression equations were obtained by plotting the SH using a rising plate meter within a 0.5 m^2 quadrant and the DM harvested from the quadrants, and additionally 300 SH measurements of the pasture were taken in the sampling days, and the average SH was used in the regression equation to estimate the available DM of pasture at pregrazing and postgrazing (Dobos et al., 2009).

Direct visual observations

Three observers were given identical training before the study to standardize observation criteria and recordings of grazing time and ruminating time as much as possible (Ortiz-Plata et al., 2012). Bouts of 30 minutes were established to get detailed information from cows’ behavior at pasture such as counting and recording the number of bites/cow/minute during effective grazing and the number of chewing when the cows were ruminating (data not presented here because they are part of a second paper). In addition, the observers were recording the seconds that cows were just smelling and walking with a head-down position relative to the ground, the seconds that were just playing with other cows, drinking, or doing nothing. These activities were recorded by HOBO loggers as well and therefore were useful to distinguish between effective grazing and other activities.

This approach was followed because the visual observations of grazing and ruminating time recorded during short periods at different times of the day were more accurate than recordings of 1 hour or more because the observers felt tired after 30 minutes of observations, especially for grazing observations. The recordings were carried out as follows: throughout the recording days (RD), observer 1 carried out a direct visual observation bout of 30 minutes/ cow/day in the morning until he completed the visual observations for 7 cows. In the next RD, observer 2 recorded the visual observations at noon, and in the next RD, observer 3 recorded the visual observations at afternoon following the same procedure of observer 1 until they completed 9 RD.

For this study, the bout of 30 minutes/cow included grazing activity or ruminating activity or both activities. A total of 63 direct visual observations for grazing and ruminating activity were obtained (7 cows × 9 days × 1 observer/day); nonetheless, 50 and 28 recordings from visual observations were obtained for grazing and ruminating time, respectively. In terms of time, from a total of 31.5 hours ([63 × 30 minutes]/60 minutes), 11 hours were related to effective grazing, 8 hours related to ruminating, and 12.5 hours to other activities (not presented here). After this, a database was created in Microsoft Excel with the visual observations registered during the RD, and these were tested against recordings obtained with HOBO loggers.

Data loggers

The HOBO Pendant G Acceleration Data logger is a waterproof 3- channel logger with 8-bit resolution, which can record up to approximately 21,800 combined acceleration readings or internal logger events. The logger uses an internal triaxis (X, Y, Z) accelerometer with a range of ±3 g (accuracy ± 0.075 g at 25°C with a resolution of 0.025 g) based on micromachined silicon sensors consisting of beams that deflect with acceleration (Mattachini et al., 2013). Grazing timewas recorded using HOBO loggers (dimensions: height 58 mm × width 33 mm × depth 23 mm; weight: 18 g) that were attached consistently to the lateral-medial side of the jaw using a strap attached to the head of each cow (Figure 1) in a position such that the X-axis was parallel to the ground, the Y-axiswas perpendicular to the ground pointing upward, and the Z-axis was parallel to the ground pointing away from the sagittal plane; these relative positions were defined when the cow was in a natural head-up position.

Figure 1. Data loggers were attached consistently in a harness to the lateral-medial side of the jaw using a strap attached to the harness head of each cow

The loggers have the option of setting the measurement intervals at 1 second, 30 seconds, 10 minutes, 15 minutes, 1 hour, and so forth. The HOBO loggers were programmed to record the acceleration (m/s^2) on the X-, Y-, and Z-axis at 30-second intervals because this setting allowed us to record during 24 hours during 9 days and they were permanently and consistently attached to the strap fastened to the same position during the RD. After 9 RD, the data loggers were removed from the cows for downloading the data using Onset HOBO-ware software (Onset Computer Corporation, Bourne, MA, USA) by means of a coupler and an optical base station with a USB interface for transferring the data to a computer, and then these data were exported into Microsoft Excel (Microsoft Corporation, Redmond,WA). The degree of vertical tilt (

Y-axis)was used to determine the ruminating and grazing activity of the animal. When the visual observations carried out during 9 days (reference method) were contrasted with recordings of data loggers, we found that readings >0° and <180° indicated the cow was head-up ruminating, whereas readings >0° and <234.4° indicated the cow was head-down in grazing position. Acceleration (m/s^2) readings in the X-axis >-1.96 and <11.28 indicated grazing activity, whereas readings in the Z-axis >-3.19 and <1.132 indicated ruminating activity. Median values for acceleration and tilt are presented in Table 1, and Figure 2 shows the frequencies for acceleration and tilt.

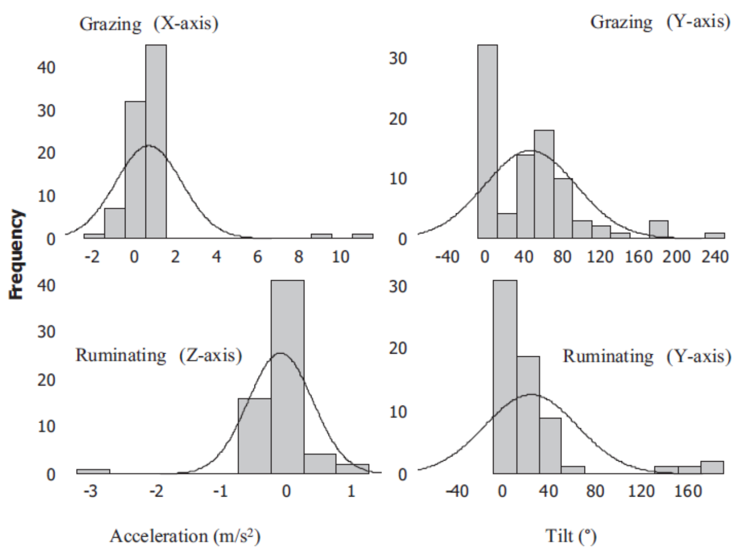

Figure 2. Frequency of acceleration and tilt values obtained with the data loggers for grazing and ruminating time during the recording days.

Table 1. Acceleration and tilt values obtained using the data loggers

Acceleration an tilt value	Grazing				Rumiating			
	X		Y		Z		Y	
	Min	Max	Min	Max	Min	Max	Min	Max
Median	0.175	0.95	0	61.6	-0.275	0.0875	0	

Statistical analysis

Two methods were tested; visual observations and HOBO loggers. HOBO recorded the acceleration (m/s^2) and tilt on the X-, Y-, and Z-axis; therefore, the evaluations of grazing time were as follows: (a) visual observations, (b) acceleration in X-axis, and (c) acceleration in X-axis and tilt in Y-axis. The evaluations of ruminating time were as follows: (a) visual observations, (b) acceleration in Z-axis, and (c) acceleration in Z-axis and tilt in Y-axis, any other combination of axes did not improve the accuracy and precision of estimations (data not shown). The grazing and ruminating time were tested using data from visual observations and HOBO loggers (a) per observation, (b) per day, and (c) per cow basis: (a) per observation basis included 50 and 28 recordings, respectively, (b) per day basis included the average of 7 cows/day, and (c) per cow basis the average of 9 days/cow.

Linear regression was used to evaluate the relationship between visual observations and HOBO sensors' estimations which is implemented in MINITAB Release 14.1 (Minitab Inc. 2003 Statistical Software). To evaluate the accuracy, the mean prediction error (MPE) in equation (2) was used (Stergiadis et al., 2016).

$$\mathrm{MSPE} = \frac{1}{\mathrm{n}}\sum(\mathrm{P} - \mathrm{A})^2 \qquad (1)$$

$$\mathrm{MPE} = \frac{\sqrt{\mathrm{MSEP}}}{\sum \mathrm{A}/\mathrm{n}} \qquad (2)$$

Where MSPE is the mean-square prediction error and MPE is the mean prediction error. P and A represent the predicted (HOBO) and actual values (visual observations), respectively, and n is the number of pairs of P and A values compared. To evaluate the agreement and precision between visual observations and HOBO sensors, the Bland-Altman plot was used (MedCalc Statistical Software). As is mentioned by Giavarina (2015), the correlation coefficient (r) and regression technique can be misleading when assessing agreement because they evaluate only the linear association of 2 sets of observations. The r measures the strength of a relation between 2 variables, not the agreement between them. Similarly, the coefficient of determination only tells us the proportion of variance that the 2 variables have in common. Bland and Altman (1999) established a method to quantify agreement between 2 quantitative measurements by constructing limits of agreement. These statistical limits are calculated by using the mean and the standard deviation of the differences between 2 measurements. In other words, the difference of the 2 paired measurements is plotted against the mean of the 2 measurements. Bland-Altman plot is implemented in MedCalc Statistical Software trial version 15.4 (MedCalc Software bvba, Ostend, Belgium; https:// www.medcalc.org; 2015).

Results and discussion

Table 2 shows the SH and the availability of DM at pregrazing and postgrazing. In general, SH and availability of DM remained constant throughout the RD, although an increase was observed from RD1 to RD9. The average pregrazing and postgrazing SH was 6.9 cm and 5.4, representing a decrease of 0.116 kg DM/m^2. No significant ($P > 0.05$) correlation was observed between grazing or ruminating time and SH.

Table 2. Sward height (cm) of pasture, pregrazing, and postgrazing dry matter (kg/m2) of pasture during the evaluation period

Evaluation period	RD1	RD2	RD3	RD4	RD5	RD6	RD7	RD8	RD9
Pregrazing SH	5.3 ± 1.3	7.2 ± 1.9	8.3 ± 2.9	6.0 ± 1.4	6.7 ± 2.7	5.2 ± 1.5	7.8 ± 3.1	8.7 ± 3.7	7.5 ± 3.6
Postgrazing SH	4.8 ± 1.9	4.9 ± 1.6	5.3 ± 1.7	5.2 ± 1.5	5.0 ± 1.6	4.5 ± 1.4	6.4 ± 3.3	6.8 ± 3.1	6.3 ± 3.2
Pregrazing DM	0.28 ± 3.4	0.38 ± 5.1	0.44 ± 7.7	0.70 ± 8.2	0.80 ± 15.5	0.60 ± 8.5	0.36 ± 5.8	0.60 ± 9.5	0.72 ± 13.5
Posgrazing DM	0.24 ± 4.9	0.26 ± 4.3	0.28 ± 4.5	0.60 ± 8.5	0.60 ± 0.90	0.52 ± 8.1	0.28 ± 6.1	0.46 ± 8.1	0.60 ± 10.1

RD, recording day; SH, sward height measured with a racing plate meter; DM, dry matter; (_), standard deviation values when the measurements were averaged in a recording day.

Table 3 shows the parameters of the linear regression model of direct observations and HOBO loggers for grazing and rumination time per cow/day. The loggers have 3 axes in which they can record data (X, Y, and Z). When grazingwas estimated using the data of the X-axis, only, there was a significant relationship for grazing time. However, the MPE decreased when X- and Y-axis were used for grazing activity and Z- and Y-axis for ruminating activity. We observed that MPE and the standard deviation of grazing activity was lower than ruminating activity, suggesting superior accuracy and precision of the Hobo loggers in detecting effective grazing time. The predicted R^2 in both activities indicated that acceleration (X- and Z-axis) and tilt (Y-axis) of HOBO loggers explained 96.1% and 94.5 % of the variance in visual observations. These R^2-predicted values were superior to those reported by Nielsen (2013), in which the accelerometer correctly recognized the grazing activity for 77.6% of the variance during 5-minute interval of observations.

Table 3. Parameters of the linear regression model of direct observations and HOBO loggers (n ¼ 63) for grazing and rumination time per cow/day

Recordings	Intercept	P-value	Slope	P-value	R^2	MPE
Grazing						
Acceleration (X-axis)	6.2 (59.5)	0.917	0.812 (0.108)	0.001	0.6027	0.153
Acceleration (X-axis) an tilt (Y-axis)	5.8 (27.3)	0.832	1.01 (0.02)	0.001	0.9614	0.113
Ruminating						
Acceleration (Z-axis)	750 (170. 3)	0.001	-0.276 (0.309)	0.381	0.0000	0.362
Acceleration (X-axis) an tilt (Y-axis)	-84.9 (53.8)	0.126	1.02 (0.04)	0.001	0.9452	0.268

MPE, mean prediction error; R2-pred, R2 of prediction.

Figure 3 shows a Bland-Altman plot to compare HOBO loggers' agreement of grazing or ruminating time and visual observations. The bias was computed as the value determined by the HOBO loggers minus the value determined by the visual observations. The mean black line is slightly different from zero and the observations were wide spread, indicating that HOBO loggers systematically produced different recordings for grazing and ruminating activities when only the X- or Z-axis were used for estimations. A superior agreement was observed when X- and Y-axis or Z- and Y-axis were used for estimations because deviations were reduced.

Table 4 presents the parameters of the linear regression model when mean values of HOBO loggers were used as predictors for grazing and ruminating time either per day or per cow, and Figure 4 shows the fits of the estimated values against visual observations per cow/day, per day, and per cow. We observed that the accuracy of estimations for grazing time per day was higher than per cow because MPE and the standard deviations were lower than per cow. In terms of R^2, the results were similar to the study carried out by Ruuska et al. (2016) that reported $R^2 = 0.94$ for grazing time. Delagarde and Lamberton (2015) reported a higher value per day ($R^2 = 0.98$), and earlier studies have reported varying correlations between different automated rumination measurement techniques and visual observations. Our results showed a prediction $R^2 = 0.90$ per day which is higher than the 0.74, reported by Büchel and Sundrum (2014). Burfeind et al. (2011) reported R^2 between 0.22 to 0.79 depending on the age of the animals. In our study, when ruminating time is assessed per cow, the predicted R^2 was lower than that reported by Delagarde and Lamberton (2015) who observed an $R^2 = 0.99$ per cow. According to Tedeschi (2006), accuracy and precision are 2 key concepts for evaluating the relationship of a model (observed against predicted). Accuracy measures how closely model-estimated values are to the true values and precision measures how closely individual model predicted values are within each other. Figure 4 showed that HOBO logger readings were accurate because they were consistently distributed along regression line, but they were slightly imprecise when estimations of grazing and ruminating time were evaluated per cow. MPE was higher than per day. A possible reason for this could be attributed to the bias introduced by the observer. When a cow is walking in a head-down position relative to the ground the observer could have considered such activity as effective grazing. When a cow is ruminating, she sometimes makes soft movements to clean her body, so the HOBO loggers registered the acceleration as if were a harvest movement.

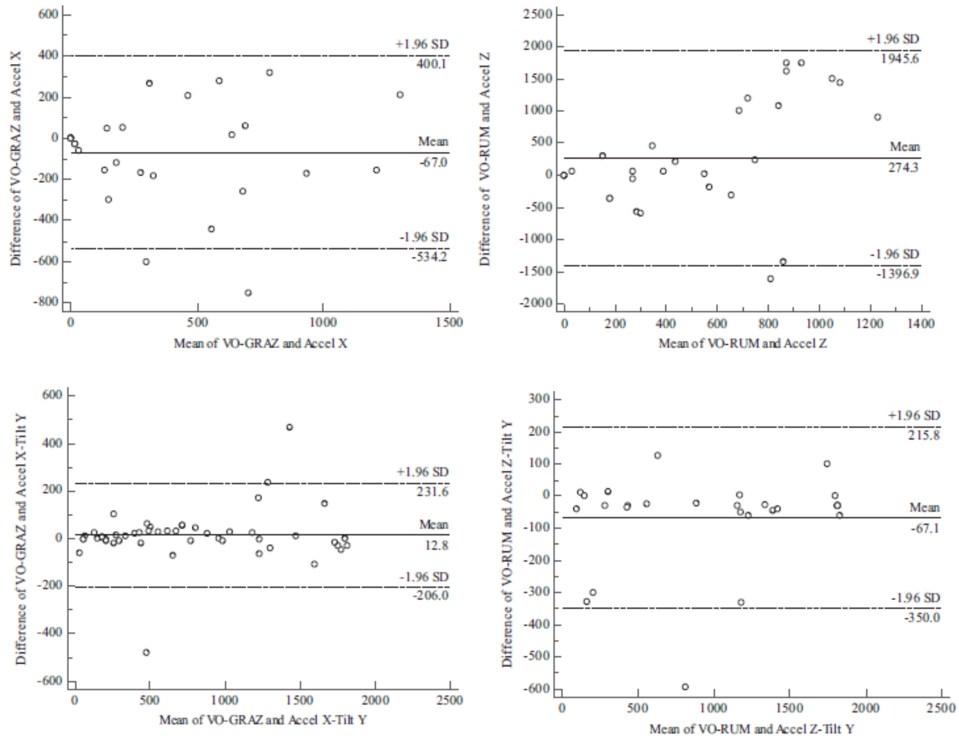

Figure 3. Bland-Altman plot (n = 63) for visual observations, acceleration and tilt on the X-, Y-, and Z-axis. VO-GRAZ, visual observations during grazing; Accel X, acceleration X-axis; VO-RUM, visual observations during rumination; Accel Z, acceleration Z-axis; Tilt Y, tilt Y-axis.

Table 4. Parameters of the linear regression model when mean values of data loggers are used as predictors for grazing and rumination time

Recordings	Sample size	Intercept	P-value	Slope	P-value	R^2	MPE
Grazing[a]							
Day	n=9	-31.5 (35.6)	0.405	1.05 (0.025)	0.001	0.9617	0.047
Cow	n=7	-38.7 (148.1)	0.804	1.04 (0.148)	0.003	0.6668	0.184
Ruminating[b]							
Day	n=9	-131.2 (107.5)	0.262	1.11 (0.049)	0.001	0.9053	0.099
Cow	n=7	61.2 (196.3)	0.768	1.01 (0.182)	0.003	0.6512	0.394

MPE, mean prediction error; R2-pred, R2 of prediction.
a Estimated grazing time using acceleration (X-axis) and tilt (Y-axis).
b Estimated ruminating time using acceleration (Z-axis) and tilt (Y-axis).

Measuring behavior across temporal scales can facilitate understanding of the factors that drive resource selection and coping mechanisms with grasslands conditions (Owen-Smith et al., 2010; Anderson et al., 2013). Therefore, monitoring behavior in near real time can enable more accurate and timely management decisions to optimize animal performance, welfare, and environmental outcomes (González et al., 2015; Teixeira et al., 2013). The present study was carried out to investigate whether the HOBO loggers could be used to measure grazing and ruminating time of dairy cows. In a preliminary study, Miranda-de la Lama et al. (2015) obtained estimates of grazing and ruminating time that explained 75% and 53% of the variability in the visual observations, respectively, indicating that data loggers can be used for estimating grazing behavior of dairy cows. The need for improvement in estimations was clear. Here we showed that improvement of estimates from data logges is possible and can be used to estimate grazing and ruminating time per cow/day and per day accurately. Estimates of grazing and ruminating time per cow should be viewed cautiously, given that Ambriz-Vilchis et al. (2015) reported R^2 between 0.28 to 0.95 that were dependant on the animal.

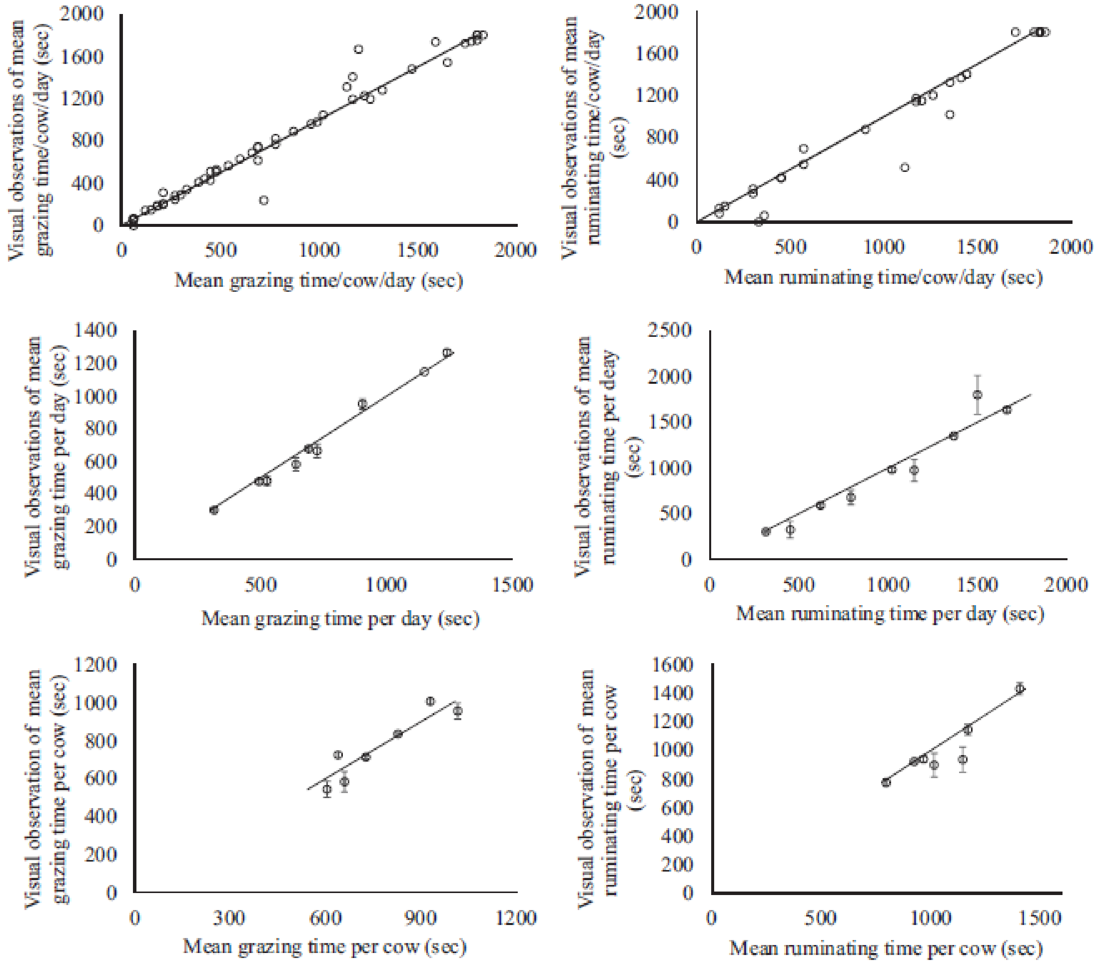

Figure 4. Relationship between visual observations of grazing time and readings of data loggers. Solid black line, X ¼ Y; circles, estimates of grazing and ruminating time against visual observations.

Conclusions and implications

The results showed that validation of the HOBO loggers with respect to visual observations of grazing and ruminating time of dairy cows was successful. The performance of HOBO loggers was superior when the recordings were analyzed on a per cow/day and per day basis than per cow basis. Further research must be conducted to improve the accuracy per cow.

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Conflict of interest The authors wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

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