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Using automated in-paddock weighing to evaluate the impact of intervals between liveweight measures on growth rate calculations in grazing beef cattle

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ABSTRACT

Animal liveweight (LW) data collection is key to monitor health, nutrition, and reproduction of cattle. However, this is challenging in grazing systems using traditional technology due to the need of mustering animals into handling facilities with the required frequency. Such practical constraints make it difficult to gather frequent LW data to study the effects of different intervals between LW measures (ILW) to accurately describe the growth pattern of animals. However, nowadays, frequent LW data can be acquired remotely using in-paddock technologies without the need to handle the animals. Thus, the aim of this study was to quantify the impacts of ILW to capture LW and growth patterns of three beef cattle categories (calves, weaners, and cows). Liveweight data were collected using in-paddock walk-over-weighing scales (WOW), placed before the access to the water trough. The lengths of continuous LW data records were 112, 224 and 1460 days (4 years) for calves, weaners and mature cows, respectively. These datasets were then subsampled to simulate different ILW with one LW record every: (a) 1, 2, 4, 8 and 16 weeks for calves; (b) 1, 2, 4, 8, 16 and 32 weeks for weaners; and (c) 1, 2, 4, 8, 16, 26, 32, 52 (1 year) and 208 weeks (4 years) for cows. Daily LW change (LWC) was calculated as the difference between two consecutive LW observations divided by the number of days elapsed. The minimum (Min), mean, maximum (Max), standard deviation (STD) and coefficient of variation (CV) for LW and LWC were calculated for each animal and ILW. Minimum and Max LWC, and STD and CV of LW were affected ($P < 0.05$) by ILW in all animal categories whereas no effects ($P > 0.05$) were observed for the rest of the variables. The relationship between ILW and LW variability (STD, CV) was quadratic for calves and weaners but linear for cows ($P < 0.05$). In comparison to daily data, the minimum frequency required to capture Min and Max LWC was 2 weeks for calves and weaners, and 8 weeks for cows. In addition, an ILW of 4 (calves and weaners) and 8 (cows) weeks was needed to achieve similar STD and CV of LW and LWC compared to daily ILW. These results, obtained in grazing conditions, suggest that WOW could be used more strategically within and between farms, as LW data need to be captured at regular intervals but not necessarily daily.

1. Introduction

Monitoring cattle liveweight (LW) is critical to calculate daily LW change (LWC) and both parameters are directly linked to productivity, animal health, and welfare (Alawneh et al., 2011, González et al., 2014). However, measuring LW often requires mustering cattle to central facilities to individually weigh animals. This labor-intensive task could produce adverse impacts on productivity and welfare (Petherick et al., 2009), rendering it impractical to frequently collect LW data. Additionally, mustering and handling could exacerbate variations in LW as a result of modifying their ruminal fill (Watson et al., 2013). As a result, the frequency of LW data collection achievable by conventional weighing may not be enough to capture LW variability existing across different animal categories (e.g. calves, weaners, cows). Thus, decreasing LW data collection frequency would increase the interval between LW measures (ILW) for each animal.

Nowadays, cattle LW data can be obtained remotely using digital technologies such as in-paddock walk-over-weighing scales (WOW) and then analyzed to manage LW variations (González et al., 2014). Recent studies in sheep, beef and dairy cattle reported on the use of WOW to

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describe LW and LWC patterns of cattle without human handling (Charmley et al., 2006, Alawneh et al., 2011, Brown et al., 2015, González-García et al., 2018). Thus, in-paddock weighing showed the ability to monitor LW patterns of cattle with maximum level of detail (daily frequency) which can then be used to study the impact of ILW on LW and LWC calculations. Also, using such approach would help to assess the variability in LW and LWC using descriptive statistics for individual animals rather than averaging groups of animals. Otherwise, studying the effects of ILW of grazing cattle for long periods (e.g. years) could not be possible due to the impracticality and constraints of mustering and weighing cattle constantly.

Liveweight varies according with the animal category (e.g. calves, mature cows) and temporal scale (e.g. within and between days, months and seasons), possibly affecting the results of simulating different ILW. Detecting periods of minimum and maximum LW and LWC may be essential for timely management (e.g. introduce feed supplementation) and to detect large variations in LW (e.g. pre- and post-parturition in cows). Similarly, detecting deviations from the average LW and LWC (e.g. standard deviation, coefficient of variation) would allow managers to identify animals' responses to environmental conditions and nutrition. To our knowledge, no studies have previously been published assessing ILW in different beef cattle categories using LW data from in-paddock weighing systems.

The aim of this study was to quantify the effects of the interval between LW measures (i.e. ILW) on the calculation of LW and LWC of individual animals in three cattle categories (calves, weaners and breeding cows). We hypothesized that ILW affects LW and LWC calculations. The minimum ILW required to capture the highest variability in LW and LWC would depend on the ability of a given ILW to detect extreme values (peaks and troughs) of the growth patterns for each animal category.

2. Materials and methods

All experimental procedures were approved by the institutional Animal Ethics Committee from The University of Sydney (Approval 2014/615 and 2017/1162).

2.1. Experimental details

The study was conducted at John Pye Farm (latitude: 33°56′93″S, longitude: 150°40′47″E, Greendale, NSW, The University of Sydney) where LW measurements were obtained using a WOW on three different cattle categories: calves, weaners (steers and heifers), and mature breeding cows.

2.2. Weaner cattle management

Forty-one Charolais × Angus weaners (24 steers and 17 heifers) between 6 and 7 months of age were tagged with electronic identification (EID) and fed with a sequence of forages for 224 days (from 12 April to 22 November 2017). Cattle were grazed rotationally on 24.7 ha of temperate pastures and oat crops divided into 18 paddocks. Concentrate supplementation was offered infrequently (Monday, Wednesday and Friday) at a rate of 1.25 kg/hd per day from 07 of August to 22 of November due to drought. Over the grazing period, animals were moved to a fresh paddock when forage availability to the base of 5 cm was approximately 1000 and 750 kgDM/ha for pastures and oat-crop paddocks, respectively. Average stocking rate was 2.5 hd/ha ranging from 13.7 dry sheep equivalents (DSE)/ha to 23.2 DSE/ha.

2.3. Cow-calf herd management

Eighteen multiparous Charolais cows were tagged with EID and grazed native pastures from 01 September 2014 to 31 August 2018 (1460 days, 4 years). Predominant forage species included kangaroo grass (*Themeda australis*) and weeping grass (*Microlaena stipoides*). Lucerne and oaten hay and silage were fed intermittently over this 4-year period to cover seasonal pasture deficits and because of drought. Cow ID, birth date and sex of the calf at calving were recorded. Twelve Charolais × Angus calves from the cows born within one season were selected for this study with an average birth weight of 48.13 ± 8.20 kg (mean ± SD) and the earliest birth was recorded on 19 of August 2017 and the latest on 27 September 2017. Calves were selected based on those showing the highest number of LW records and the lowest minimum interval between LW records during the period of study (112 days).

2.4. In-paddock measurements of live weight

A central yard (15 m × 25 m) located at the sole water point was built for each herd (weaners, calves and cows). An in-paddock WOW station was placed at the entry of each yard to record LW, EID, date and time (Precision Pastoral Ltd, Alice Spring, Northern Territory, Australia for weaners and Tru-test Ltd, Auckland, New Zealand for cows). The WOW consisted of a platform (0.8 width × 2.4 m length) placed over two load bars and mounted along steel and wooden panels (3 m-long × 2 m-height) on both sides. Spear gates were used at the entry of the WOW and each exit gate to allow animals to move in only one direction. Animals were previously trained to use the WOW following the procedure proposed by González et al. (2014).

2.5. Data processing and statistical analysis

Data recorded by the WOWs were filtered for outlying data and then smoothed using penalised b-splines using the methods described by González et al. (2014). Briefly, Gonzalez et al. (2014) first deleted extreme weights outliers which were biologically implausible. Then, data were fitted to penalised B-spline for each individual animal and LW outliers were deleted if greater than 1.5 times below or above of residuals obtained from the smoothed mean of each animal. After outliers' deletion, the penalised B-spline was fitted again to obtain the predicted LW for each individual animal. Daily liveweight change (g/hd per day) was calculated from the smoothed data as the first derivative of the predicted LW curve. The resulting LW and LWC data were averaged by date for each animal if more than one measurement per day and animal existed. Table 1 shows that days with usable LW records represented 42, 69 and 51% of the full-length period for calves, weaners and cows, respectively. This resulted in average intervals between consecutive records (days) ranging from 1.45 (weaners) to 2.48 (calves). Days without records were interpolated considering a linear change in LW and LWC between the previous and the next record. This process originated a dataset with all days having LW and LWC measurements for all animals with calves, weaners and cows having records for 112, 224 and 1460 days, respectively. The first day considered for each calf was the date of the appearance of the first usable LW record after smoothing and deletion of outliers (González et al., 2014). This complete dataset was then used to create subsets of data simulating different ILW for each animal according to the length of the data collection period. Thus, from day 1 until the last day of the period considered, one LW record was selected for each animal every 1 (1W), 2

Table 1
Descriptive statistics (Mean ± SD) of liveweight (LW) data for each animal category.

Items (days)	Calves	Weaners	Mature cows
Period length	112	224	1460
Days with valid LW records	47.1 ± 6.5	155.4 ± 11.7	755.2 ± 57.6
Average of the interval between valid LW records	2.48 ± 0.35	1.45 ± 0.11	1.94 ± 0.14

(2W), 4 (4W), 8 (8W) and 16 weeks (16W). The latter resulted in calves having 1 LW record at the beginning and 1 LW record at the end of the entire period. Because the period of data collection was longer for weaners and cows, records at 32 weeks (32W) apart were selected for weaners and cows. Cows also had 1 LW record selected every 26 and 52 weeks, and 1 LW record at the beginning and at the end of the entire 4-year period (208 weeks). Liveweight change was then re-calculated for each dataset as the difference between two consecutive LW observations divided by the number of days between both observations.

Data from each animal and each ILW was then used to calculate the minimum (Min) LW and LWC; maximum (Max); standard deviation (STD) for LW and LWC and coefficient of variation (CV) for LW (the CV of LWC for cows was not analysed due to negative values). The objective of these calculations was to obtain extreme values or peaks and troughs (Min and max) and measures of variability (STD, CV) over the entire period. Calculations of STD and CV for calves and weaners and Min LWC for weaners and cows were $\log_{10}$ -transformed to normalise data prior to the analysis. Data were analysed for each animal category separately using a linear model including ILW as a fixed factor and each summary statistic as response variables, i.e. Min, Max, STD and CV. In addition, linear and quadratic effects of increasing ILW data were tested for every response variable. Means were separated using Bonferroni adjustment for multiple comparisons. Statistical significance was declared at $P < 0.05$. All statistical procedures were done using SAS/STAT software (SAS Institute Inc., Cary, NC, USA).

3. Results

3.1. Calves

Increasing ILW resulted in a linear increase of the Min LWC measured ($P < 0.001$; Table 2). Maximum LWC decreased quadratically when increasing ILW ($P < 0.001$) because the largest drop in Max LWC was observed at 4W. Both the STD and CV of LWC decreased linearly with increasing ILW ($P < 0.001$). These results were reflected in Fig. 1 which shows that the peaks and troughs of the LWC trajectory tend to disappear as ILW increases, whereas LW does not seem to be affected. However, STD and CV of LW increased quadratically with increments of ILW ($P < 0.001$).

3.2. Growing weaner cattle

All calculations except mean daily LWC, and the mean, minimum and maximum LW were affected by ILW (Table 3, $P < 0.05$). Variables affected by ILW showed a quadratic decrease ($P < 0.05$) except Min LWC which increased linearly from −104 to 530 g/hd per day as ILW increased from Daily to 32W ($P < 0.05$). For Min and Max LWC, 2W data was the longest ILW that did not differ from daily LWC ($P > 0.05$). Frequencies lower than 4W were not able to capture negative Min LWC. The graphical presentation of these results in Fig. 2 indicates that ILW could largely affect LWC calculations ranging from the visualisation of peaks and troughs (Daily) to a flattened line (16 Weeks). In addition, max LWC detected by Daily ILW was 63% greater than 32W ($P < 0.05$). Standard deviation of LWC decreased significantly by 28% at 16W compared to Daily ($P < 0.05$) but no differences were found between Daily until 8W ($P > 0.05$). A similar reduction and statistical significance were observed for the CV of LWC however differences with Daily were noticed from 4W and beyond ($P < 0.05$). In contrast to LWC, only the variability of LW was affected by ILW ($P < 0.05$) with increasing STD and CV of LW as ILW increased with differences starting to differ from Daily at 4W ($P < 0.05$).

3.3. Mature cows

The Min and Max LWC of mature cows were affected by ILW and quadratic effects were observed (Table 4, $P < 0.05$). Calculations from Daily and Weekly data showed that cows lost up to 1081 g/hd per day and such values of Min LWC were also captured using ILW up to 8W ($P > 0.05$). No differences were detected until 16W for STD of LWC which decreased quadratically ($P < 0.05$) by 23% and 77% from Daily to 16W and Year frequencies (Fig. 3). Mean, Min, and Max LW were not affected by ILW ($P > 0.05$); however, STD of LW increased linearly with ILW (Table 4, $P > 0.05$). Graphical representation of these data in Figs. 3 and 4 demonstrates that increasing ILW reduces the ability to capture periods of high weight gain or loss such as during calving.

4. Discussion

The objective of the present study was to determine the minimum frequency required to monitor LW and LWC without losing critical

Table 2
Average of the mean, minimum, maximum and STD of liveweight change (LWC) and liveweight (LW) of calves calculated at daily; weekly; fortnightly; 4-week; 8-week; or 16-week intervals between liveweight measures (ILW).

LWC (g/hd per day)	Mean	Minimum	Maximum	STD	CV (%)
Daily	1022 ± 20.0 a	825 ± 35.9 b	1284 ± 26.3 a	126 ± 12.2 a	12 ± 1.3 a
1W	1025 ± 20.0 a	830 ± 35.9 b	1266 ± 26.3 ab	129 ± 12.2 a	12 ± 1.3 a
2W	1025 ± 20.0 a	851 ± 35.9 b	1221 ± 26.3 ab	120 ± 12.2 a	12 ± 1.3 a
4W	1025 ± 20.0 a	899 ± 35.9 ab	1156 ± 26.3 b	98 ± 12.2 ab	10 ± 1.3 ab
8W	1025 ± 20.0 a	967 ± 35.9 ab	1084 ± 26.3 cd	58 ± 12.2 b	6 ± 1.3 b
16W	1026 ± 20.0 a	1026 ± 35.9 a	1026 ± 26.3 d	0 ± 12.2 c	0 ± 1.3 c
P-value					
Model	1	< 0.001	< 0.001	< 0.001	< 0.001
Linear	1	< 0.001	< 0.001	< 0.001	< 0.001
Quadratic	1	0.26	< 0.01	0.73	0.73
LW (kg/hd)					
Daily	138 ± 5.1 a	82 ± 4.9 a	197 ± 5.3 a	33 ± 0.9 e	23 ± 0.8 e
1W	138 ± 5.1 a	82 ± 4.9 a	197 ± 5.3 a	36 ± 0.9 de	25 ± 0.8 de
2W	138 ± 5.1 a	82 ± 4.9 a	197 ± 5.3 a	39 ± 0.9 d	27 ± 0.8 d
4W	139 ± 5.1 a	82 ± 4.9 a	197 ± 5.3 a	45 ± 0.9 c	32 ± 0.8 c
8W	139 ± 5.1 a	82 ± 4.9 a	197 ± 5.3 a	57 ± 0.9 b	40 ± 0.8 b
16W	139 ± 5.1 a	82 ± 4.9 a	197 ± 5.3 a	80 ± 0.9 a	56 ± 0.8 a
P-value					
Model	0.99	1	1	< 0.001	< 0.001
Linear	0.99	1	1	< 0.001	< 0.001
Quadratic	0.99	1	1	< 0.01	< 0.01

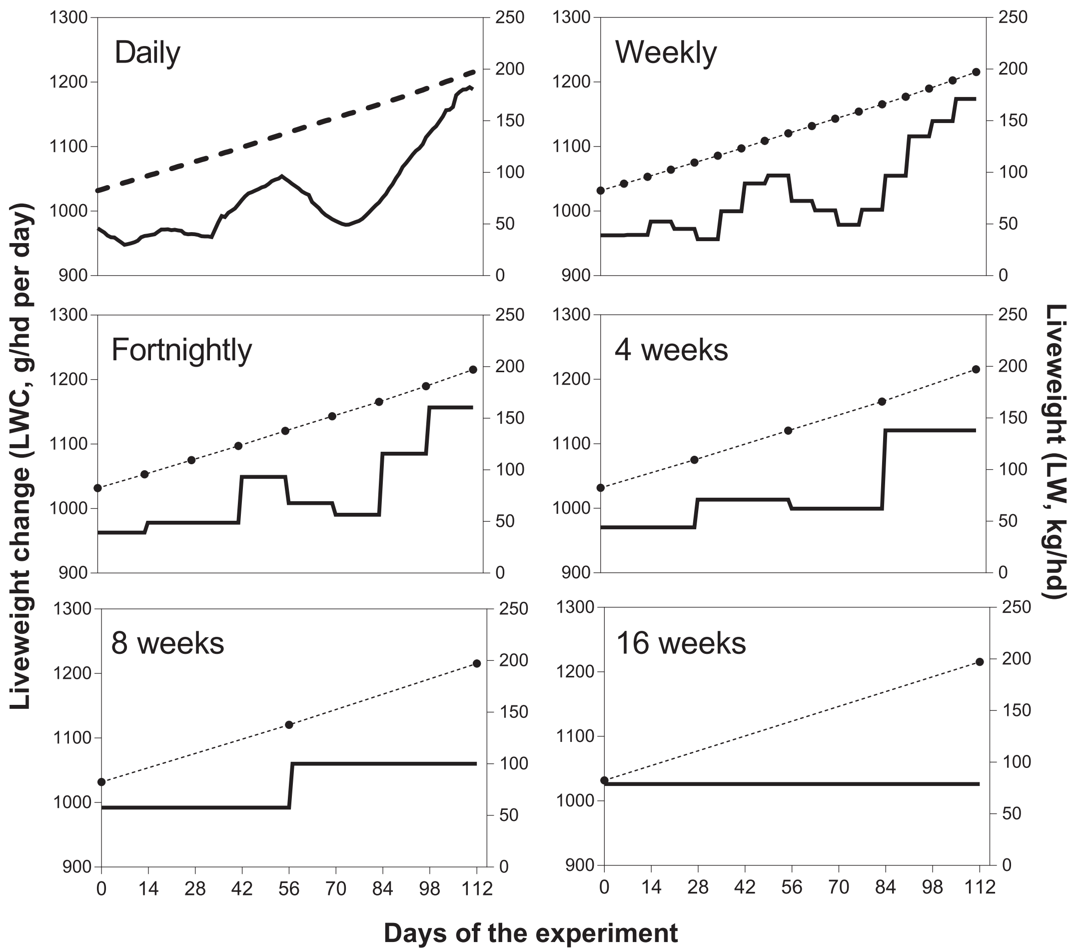

Fig. 1. Liveweight change (LWC, solid line) and liveweight (LW, discontinuous line) of calves calculated from daily observations or from observations every 1, 2, 4, 8 and 16 weeks. Dots indicate LW records selected.

Table 3
Average of the mean, minimum, maximum and STD of liveweight change (LWC) and liveweight (LW) of growing weaners calculated at daily; weekly; fortnightly; 4-week; 8-week; 16-week; and 32-week intervals between liveweight measures (ILW).

LWC (g/hd per day)	Mean	Minimum	Maximum	STD	CV (%)
Daily	531 ± 13.5 a	−104 ± 17.2 e	1439 ± 28.9 a	459 ± 10.2 a	87 ± 1.7 a
1W	529 ± 13.5 a	−88 ± 16.1 e	1436 ± 28.5 a	458 ± 10.2 a	86 ± 1.7 a
2W	529 ± 13.5 a	−56 ± 16.5 de	1370 ± 28.1 ab	446 ± 10.2 a	84 ± 1.7 ab
4W	529 ± 13.5 a	−2 ± 15.1 d	1253 ± 28.1 b	421 ± 10.1 ab	79 ± 1.7 b
8W	529 ± 13.5 a	83 ± 15.1 c	1041 ± 28.1 c	377 ± 10.1 b	70 ± 1.7 c
16W	529 ± 13.5 a	208 ± 15.1 b	852 ± 28.1 d	329 ± 10.2 c	62 ± 1.7 d
32W	530 ± 13.5 a	530 ± 15.1 a	530 ± 28.1 e	0 ± 10.1 d	0 ± 1.7 e
P-values					
Model	1	< 0.001	< 0.001	< 0.001	< 0.001
Linear	0.99	< 0.001	< 0.001	< 0.001	< 0.001
Quadratic	0.92	0.51	< 0.001	< 0.001	< 0.001
LW (kg/hd)					
Daily	233 ± 5.9 a	188 ± 5.3 a	308 ± 6.7 a	36 ± 1.2 e	16 ± 0.6 e
1W	233 ± 5.9 a	188 ± 5.3 a	308 ± 6.7 a	38 ± 1.2 e	16 ± 0.6 e
2W	234 ± 5.9 a	188 ± 5.3 a	308 ± 6.7 a	39 ± 1.2 de	17 ± 0.6 de
4W	235 ± 5.9 a	189 ± 5.3 a	308 ± 6.7 a	43 ± 1.2 d	18 ± 0.6 d
8W	237 ± 5.9 a	189 ± 5.3 a	308 ± 6.7 a	50 ± 1.2 c	21 ± 0.6 c
16W	236 ± 5.9 a	189 ± 5.3 a	308 ± 6.7 a	64 ± 1.2 b	27 ± 0.6 b
32W	248 ± 5.9 a	189 ± 5.3 a	308 ± 6.7 a	86 ± 1.2 a	34 ± 0.6 a
P-values					
Model	1	1	1	< 0.001	< 0.001
Linear	0.035	0.89	0.93	< 0.001	< 0.001
Quadratic	0.66	0.92	0.96	0.02	< 0.01

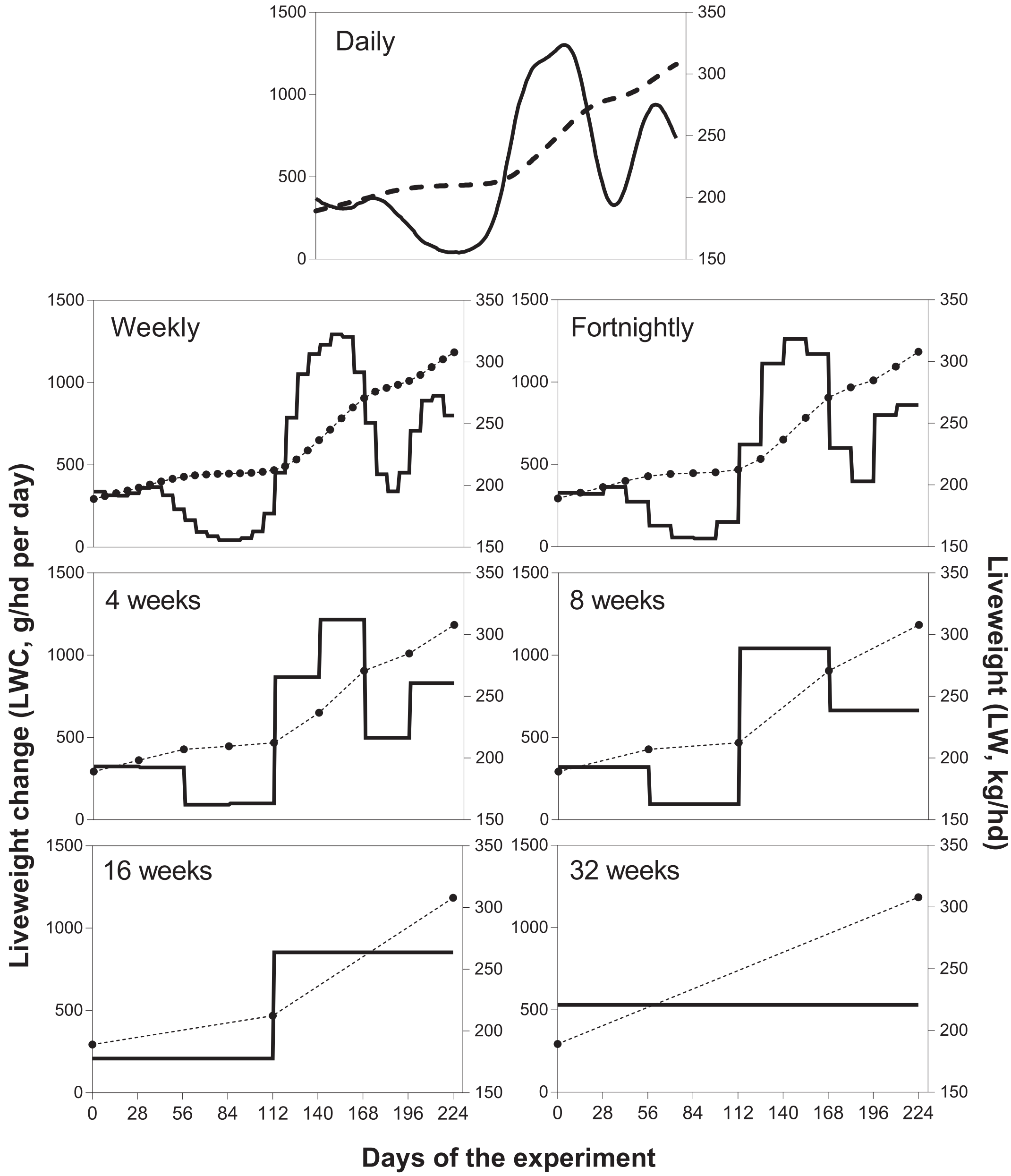

Fig. 2. LWC (solid line) and LW (discontinuous line) of growing weaners calculated from daily observations or from observations every 1, 2, 4, 8, 16 and 32 weeks. Dots indicate LW records selected.

information that may be important for timely management decisions (e.g. feeding, prevention of disease, reproduction management, calving). With this aim, we explored the effects of different ILW among cattle categories (calves, weaners and mature cows). Our results indicate that the minimum interval required to capture Min and Max LWC was 2 weeks for calves and weaners, and 8 weeks for cows, in comparison with daily data. Additionally, similar variability (STD and CV of LW and LWC) to that using daily LW data was detected with ILW of 4 weeks for calves and weaners and 8 weeks for cows.

Studies reporting on similar findings are limited. Currie et al. (1989) compared daily LW collected by WOW with LW data obtained by conventional weighing every 6 weeks over approximately 90 days. They concluded that LWC patterns calculated from conventional weighing data largely differed from those provided by continuous LW measurements in grazing beef steers. Other studies (Alawneh et al., 2011; González et al., 2014) used daily LW from WOW but did not directly compare ILW. Working with dairy cattle, Alawneh et al. (2011) suggested the collection of daily LW for earlier detection of illness events or changes in feed management, which would not be possible using ILW longer than 1 week. Similarly, González et al. (2014) showed that nutritional management of grazing beef steers to avoid LW loss could not be achievable by using ILW longer than 4 weeks. The present study demonstrates graphically (Figs. 1–4) and statistically (Tables 2–4) that the ability of monitoring LWC and LW was reduced as ILW increased, due to a progressive flattening of LWC patterns.

The quantification and detection of periods with relatively poor or good animal performance could improve management decisions. For example, monitoring LWC could help to identify periods of decreasing rates of positive LWC or severe weight loss which has implications on productivity, reproduction and survival. In the present study, the Min and Max LW and LWC throughout trials and animal categories demonstrated the ability of these measurements to identify and quantify the extent of periods of undernutrition and of compensatory growth when on-farm decisions may be needed. Similarly, STD and CV of LWC

Table 4
Average of the mean, minimum, maximum and STD of liveweight change (LWC) and liveweight (LW) of beef cows calculated at daily; weekly; fortnightly; 4-week; 8-week; 16-week; 26-week; 1-year; or 4-year intervals between liveweight measures (ILW).

LWC (g/hd per day)	Mean	Minimum	Maximum	STD
Daily	134 ± 8.1 a	−1051 ± 54.1 d	1478 ± 149.6 ab	565 ± 25.5 a
Weekly	130 ± 8.1 a	−1081 ± 52.2 d	1575 ± 149.6 a	562 ± 25.5 a
2W	130 ± 8.1 a	−1023 ± 50.5 d	1685 ± 145.4 a	554 ± 25.5 ab
4W	131 ± 8.1 a	−981 ± 49.0 d	1457 ± 145.4 ab	539 ± 25.5 ab
8W	131 ± 8.1 a	−890 ± 47.6 d	1136 ± 145.4 ab	506 ± 25.5 ab
16W	131 ± 8.1 a	−622 ± 47.6 c	926 ± 145.4 b	437 ± 25.5 b
26W	131 ± 8.1 a	−340 ± 47.6 b	581 ± 145.4 c	296 ± 25.5 c
52W (1 year)	129 ± 8.1 a	−54 ± 47.6 a	275 ± 145.4 d	130 ± 25.5 d
208W (4 years)	129 ± 8.1 a	129 ± 47.6 a	129 ± 145.4 e	0 ± 25.5 e
P value				
Model	0.99	< 0.001	< 0.001	< 0.001
Linear	0.74	< 0.001	< 0.001	< 0.001
Quadratic	0.79	< 0.001	< 0.001	< 0.001
LW (kg/hd)				
Daily	675 ± 9.5 a	562 ± 9.2 a	780 ± 13.5 a	52 ± 2.9 c
Weekly	675 ± 9.5 a	562 ± 9.2 a	780 ± 13.5 a	52 ± 2.9 c
2W	675 ± 9.5 a	562 ± 9.2 a	779 ± 13.5 a	52 ± 2.9 c
4W	674 ± 9.5 a	562 ± 9.2 a	778 ± 13.5 a	53 ± 2.9 c
8W	674 ± 9.5 a	562 ± 9.2 a	776 ± 13.5 a	55 ± 2.9 c
16W	673 ± 9.5 a	564 ± 9.2 a	770 ± 13.5 a	59 ± 2.8 c
26W	667 ± 9.5 a	564 ± 9.2 a	758 ± 13.5 a	61 ± 2.8 bc
52W (1 year)	662 ± 9.5 a	564 ± 9.2 a	756 ± 13.5 a	73 ± 2.9 b
208W (4 years)	661 ± 9.5 a	567 ± 9.2 a	755 ± 13.5 a	139 ± 3.3 a
P value				
Model	0.90	0.99	0.76	< 0.001
Linear	0.17	0.59	0.11	< 0.001
Quadratic	0.31	0.89	0.13	0.68

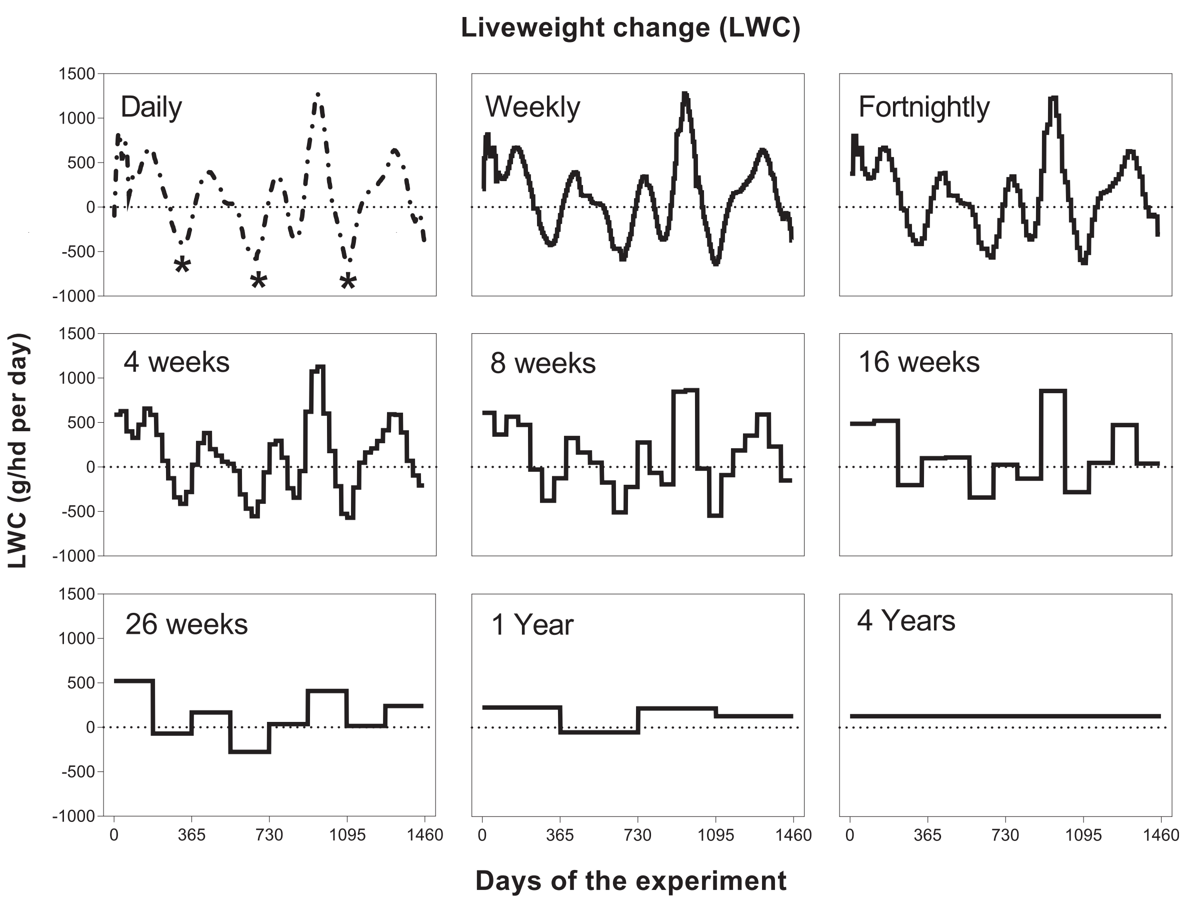

Fig. 3. LWC of beef cows calculated from daily observations or from observations every 1, 2, 4, 8, 16, 26, 52 (1 year) and 208 weeks (4 years). Dots in Daily indicate calving time.

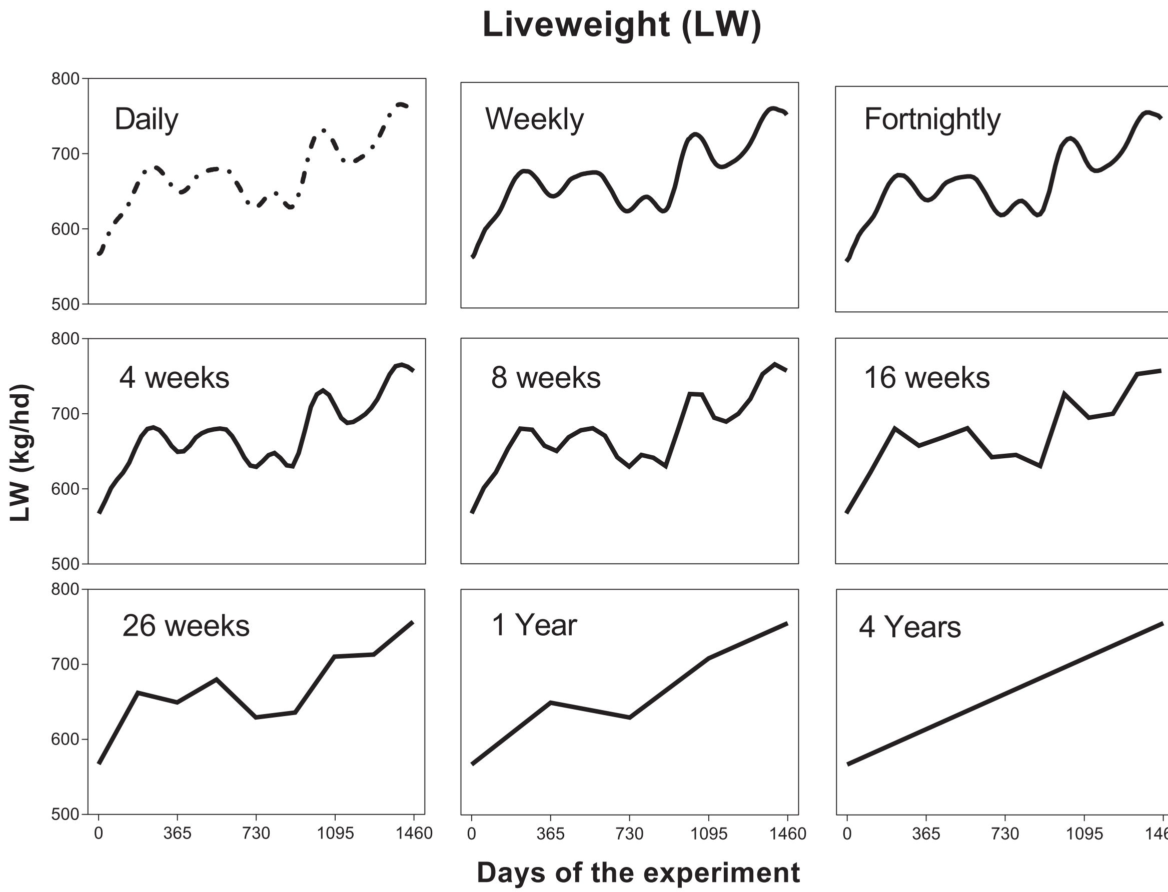

Fig. 4. LW of beef cows calculated from daily observations or from observations every 1, 2, 4, 8, 16, 26, 52 (1 year) and 208 weeks (4 years).

or LW could help in quantifying variability in the ability of animals to cope with changes in environmental and management factors over time. For example, both STD and CV of LWC within the trial period were smaller for calves, medium for weaners and largest for cows, which is also well reflected in the figures. In addition, STD and CV data are in alignment with our hypothesis, which states that the growth trajectory would be different for each animal category with calves showing the least variability in LWC, weaners intermediate and cows the largest variability. This is expected, as calves obtained most of their feed from their mothers during early stages of life (von Keyserlingk and Weary, 2007) which could explain the smaller variability observed on calves' LWC. In agreement with the present study, González et al. (2018) suggested that calves start walking over the WOW by themselves, approximately, at the age of two months and 100 kg of LW, which maybe in concordance with the time of calves being less dependent on their dam nursing. However, these are just speculations and studies are needed to test these hypotheses. On the contrary, mature cows are likely to experience abrupt changes in LW and LWC due to gestation, calving, lactation, weaning and seasonal fluctuations on their nutritional status (Lake et al., 2006, Cooper-Prado et al., 2014).

In line with our findings, results showed that ILW has a significant impact on the quantification and detection of Min and Max LWC and the variability (STD and CV) within a period for all animal classes. However, the mean LWC and LW were not affected by ILW in any animal class. It is important to note that, for example, the mean LWC may be arithmetically affected by ILW during periods of non-linear trajectories; however, it may not differ statistically. Additionally, increasing ILW significantly increased Min LWC and reduced Max LWC across all animal categories until both parameters were similar to each other at the highest ILW.

The impact of ILW was expected to be larger in animal categories that experience larger variability in LWC and LW, i.e. largest in cows and least in calves. For calves, decreasing ILW had a quadratic effect on Max LWC with the largest impact at 4W and longer intervals between LW measurements whereas Min LWC increased linearly with ILW. Findings confirm this hypothesis because the difference in Min LWC between Daily and at 16W was 201, 312 and 429 g/d for calves, weaners and cows, respectively.

Our results indicate that weaners had a linear increase in Min LWC and a quadratic effect on Max LWC because the latter drops sharply at 2W and higher ILW. Results from the present study agree with Currie et al. (1989) who described the growth patterns of yearling steers for two summer periods using in-paddock and conventional weighing (i.e. static scales, three times per year). These authors suggested that growth rates calculated at long weighing intervals failed to describe the growth pattern over the entire season with enough accuracy to specifically identify points in time when live weight was leveling out, increasing or decreasing. However, Currie et al. (1989) did not test ILW and only descriptive LW data were presented in their article.

In contrast to calves and weaners, decreasing ILW of cows resulted in a quadratic effect on both Min and Max LWC. Intervals between measurement up to 8 and 16 weeks were able to capture similar Min and Max LWC, respectively, compared to daily information. An adequate ILW for cows should be able to capture critical time periods affecting LW across seasons as a result of different physiological stages related to the effects of pregnancy, parturition and LW recovery (Cooper-Prado et al., 2014). The present study indicates that cows lost approximately 1.05 kg/hd per day during the calving period whereas the 16W interval only captured an average of 0.62 kg/hd per day. It is possible to speculate that long periods between successive weighing events may have contributed to the lack of success in identifying sources of variability affecting the reproduction and growth of the dam, and its correlation with their offspring performance in a previous study (Osoro and Wright, 1992). However, further research is required to confirm this speculation.

Another important aspect to consider in animal research is the impact that ILW could potentially have on the interpretation of results. For example, looking at the effect of growth rate measured over long periods of time on variables measured from biological samples (e.g. blood plasma or faecal samples) taken at one point in time could lead to severe misinterpretation of results. An example with the weaner data from the present study indicates that LW measured on days 0 and 150 results in an estimated growth rate of 0.40 kg/hd per day however the instantaneous growth rate on day 150 was 1.20 kg/hd per day. Results and conclusions could be very different if measurements made on a blood sample obtained at day 150 are correlated with estimated growth rates from long-interval LW measurements which, in this example, were 3-fold different. Therefore, it is recommended that studies correlating growth and LW with biological traits measure LW as frequently as possible; regarding this, our results provide specific guidance on minimum intervals required for each category.

The use of in-paddock LW measurement enables the collection of frequent data where conventional weighing procedures may not be feasible because it increases labour, reduces productivity and negatively affects animal welfare (Petherick et al., 2009). Furthermore, mustering and handling cattle could affect LW on a short-term basis by altering ruminal fill (Watson et al., 2013). In this regard, there have been multiple attempts to standardize static weighing procedures which included limiting feeding in the previous 3–5 days, weighing on 2 or more consecutive days (Watson et al., 2013) and restricting access to feed and water before weighing (Smith et al., 1982, Kirton et al., 2012). Remote automatic weighing could help farmers and researchers to overcome these constraints by collecting LW data more frequently but without handling animals. Then, data can be analysed and used to minimize LW variability (González et al., 2014) and data streams could be presented in real-time to manage LW and growth rate.

The findings of the present study could enhance cattle weighing procedures using either static scales or in-paddock scales. For example, studies on ILW could aid to select the right frequency to muster animals to central yards while contemplating the ability to capture changes in LW and LWC and minimizing the required labour (Stock et al., 1983). In addition, results from the present study suggest that in-paddock weighing could be used discontinuously for collecting LW data during certain critical periods, although the ideal frequency would depend on each animal category. For instance, the same WOW system could be used to monitor different herds, or farmers could associate to purchase and use the equipment cooperatively as having WOW installed to acquire daily LW on each category of cattle can be too expensive or logistically impractical. However, further research is needed to assess if this option, which implies the use of data collected sporadically, has similar accuracy as the smoothing and outlier detection algorithms used in the present study from daily data points. Finally, our results could be indicative of those expected in other scenarios with similar LWC variability, which do not necessarily include grazing forages. Nevertheless, similar studies should be conducted in other cattle systems, which aim to reduce LWC fluctuations with a more intensive use of supplementary feed.

Determining the optimal ILW could enhance cattle management at different temporal scales and purposes. On a short-term basis, timely decision-making, including precision animal nutrition could be improved (González et al., 2018). For instance, quantifying the duration and extent of weight loss can be critical to determine the introduction of feed supplementation. Grazing management can also be enhanced by moving animals to another paddock based on both changes in feed availability and LWC. On a long-term basis (e.g. the entire production period), an accurate description of growth variability (STD, CV) would allow for the identification of performance boundaries while aiming to reduce such variability.

5. Conclusions

Remote in-paddock weighing offers a platform to study variability in cattle growth and LW patterns over time. The interval between LW measures affects growth rate estimations and the ability to capture and quantify periods with low or high animal performance. Therefore, the present work provides first and specific guidance on minimum intervals required for each animal category (2 weeks for calves and weaners, and 8 weeks for cows). Selecting the appropriate frequency of LW data collection could enhance timely and accurate management interventions on animal nutrition and cattle operations.

CRediT authorship contribution statement

J.A. Imaz: Conceptualization, Methodology, Data curation, Writing - original draft. **S. Garcia:** Visualization, Writing - original draft. **L.A. González:** Supervision, Writing - original draft, Supervision, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.compag.2020.105729.

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