School of Sustainable Food and Farming

Developing a low-cost method to monitor the feed efficiency of beef cattle at farm level

Final report

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1.0 Study budget

£34,967.00

2.0 Introduction

One of the most influential factors affecting the profitability of beef cattle production is the provision of feed, which is estimated to account for up to 75% of enterprise variable costs (Nielson *et al.*, 2013). Feed efficiency is generally used to describe the relationship between feed inputs and growth outputs (Haskell *et al.*, 2019), although there are many definitions of feed efficiency at the animal level (Berry and Crowley, 2013). Traditionally, feed conversion efficiency (FCE; gain: feed), or it's mathematical inverse, feed conversion ratio (FCR; feed: gain) have been utilised widely (Kenny *et al.*, 2018). More recently however, the preferred measurement for feed efficiency has become residual feed intake (RFI), defined as the difference between intake and the animal requirements for growth and maintenance (Savietto *et al.*, 2014). This method allows the underpinning biological mechanisms to be considered in more detail (Berry and Crowley, 2013). In addition to affecting profitability, the efficiency of feed utilisation has consequences for the environmental impact of beef production, where it is estimated that selection for cattle with a low RFI may reduce enteric methane emissions by 15 to 25%. Given the direct link between efficiency and productivity, it is unsurprising that most beef cattle feed efficiency research to date has focused on the effects of diet and breed type (Kenny *et al.*, 2018). However, conclusive physiological and behavioural mechanisms underlying differences in feed efficiency have so far remained elusive (Haskell *et al.*, 2019), although there is some evidence to suggest a relationship between feed efficiency and behaviour. Nkrumah *et al.* (2007) reported greater efficiency in steers with a higher frequency of feeding events, and Haskell *et al.* (2019) noted relationships between standing behaviour and residual feed intake.

It has already been determined that genomic selection for feed efficiency is possible (Bolormaa *et al.*, 2013), but its implementation has been hindered by the lack of an appropriate phenotypic reference population (Fitzsimons *et al.*, 2017). The main obstacle preventing the generation of this database is hypothesised to be the cost associated with measuring the trait using automated feed intake recording systems (Nielson *et al.*, 2013). Alternatively, the use of behavioural monitoring technologies such as activity sensors potentially provides a lower cost alternative to facilitate the measurement of beef cattle feed efficiency at farm level. Indeed, the advent of growth monitoring applications such as the 'Breedr App' means that growth outputs are being increasingly monitored. The potential addition of a low-cost feed efficiency monitoring system to these readily available applications may provide the phenotypic database required for feed efficiency selection at a genomic level. There is subsequently a need to determine if activity sensors can be used as a potential lower cost alternative to automated feed intake recording systems to estimate feed efficiency in beef cattle.

3.0 Objectives

- To determine if activity sensors can be used to accurately predict feed efficiency in beef cattle, thereby increasing profitability and reducing emissions intensity.
- To determine the effect of RFI status upon animal physiology and behaviour

4.0 Materials and methods

4.1 Animals, housing, and experimental design

The study was conducted between October and December 2021 using 24 Hereford steers with an initial bodyweight (BW) of (mean ± SE) 285 ± 3.4 kg at 7.4 ± 0.42 months of age. The cattle were housed at the Harper Adams beef unit in straw yards (6 animals per pen), and fed a concentrate diet *ad-libitum* which contained rolled barley (718 g/kg of dry matter; DM), molassed sugar beet pulp (106 g/kg of DM), rapeseed meal (52 g/kg of DM), wheat distillers' dark grains (52 g/kg of DM), molasses (50 g/kg of DM), and intensive beef minerals (22 g/kg of DM; Table 1). The concentrate diet was provided by Wynnstay Ltd, and fed as a coarse blend. Drinkers provided *ad-libitum* access to water, and all animals had free access to fresh straw provided in racks. All four pens were fitted with Growsafe feeders which facilitated the measurement of individual feed intakes for all 24 animals on a daily basis. Fresh feed was offered at approximately 0900 h daily, and diet refusals were removed once per week. Prior to commencing the study, all of the steers were subject to a 4-week adaptation to allow the animals to adapt to the pens, automatic feeders, social group, and finishing diet. All four pens were also bedded 3 times per week with wheat straw.

Table 1. Raw material and chemical composition of the finishing concentrate.

	Concentrate
Raw materials (g/kg of fresh weight)	
Rolled barley	721
Sugar beet pulp (Molassed)	102
Rapeseed meal	51
Wheat distillers	50
Molasses (cane)	57
Min/vits	19
Chemical composition (g/kg of DM)	
Dry matter	863
Crude protein	141
ERDP (0.5)	103
DUP (0.5)	20
Ether extract	25
Ash	60
NDF	238
Starch + sugars	494
ME (MJ/kg of DM)	12.8
FME (MJ/kg of DM)	10.9
ERDP/FME	9.41
MP (<10.0 g/kg of DM)	**86**
MP (>10.0 g/kg of DM)	90

4.2 Experimental routine

The initial (day 0) and final (day 70) BW of each animal was monitored using the mean of two BW measurements taken on consecutive days at the beginning and end of the study respectively. Throughout the duration of the study, all cattle were weighed on a weekly basis, with all BW measurements being taken at 1400 h each day. This process complies with the Beef Improvement Federation (BIF) recommendations regarding intake and performance data collection. Prior to commencing the study, all steers were fitted with IceQube 3-axis accelerometers (IceRobotics Ltd, Edinburgh, UK) above the fetlock joint. Data relating to the number of steps taken, standing, lying and overall motion was extracted from the accelerometers using CowAlert for Researchers (IceRobotics, Queensferry, UK). Lying bouts of ≤ 15 s were removed as suggested by Kok *et al.* 2015. Data was then summarised across the study period to produce the behavioural parameters shown in Table 3. Motion index can be defined as absolute acceleration against gravity throughout the course of the day, and is the parameter from which step count is derived.

Diet digestibility was determined in week 8 of the study using acid insoluble ash (AIA) as an indigestible marker according to Block *et al.* (1981). Faecal samples were collected from each of the 24 animals over a five-day period. These faecal samples were subsequently bulked, mixed, and sub-sampled on an individual animal basis prior to freeze-drying and chemical analysis.

4.3 Chemical analysis

Fresh samples of the concentrate diet were taken on a fortnightly basis and stored at -20^{o}C prior to subsequent analysis. At the end of the study, feed samples were bulked on a bi-monthly basis and sub-sampled for analysis by wet chemistry for dry matter (DM), crude protein (CP), ether extract (EE), ash, AIA, neutral detergent fibre (NDF), acid detergent fibre (ADF), starch and gross energy (GE). Bulked faecal samples taken during week 8 of the study were subsequently analysed on an individual animal basis for DM, CP, EE, ash, AIA and GE.

4.4 Calculations and statistical analysis

Feed efficiency traits for the study animals were calculated according to Crowley *et al.* (2010). The average daily gain (ADG) of each animal throughout the study period was calculated by fitting a linear regression model through all of the BW measurements collected for each steer. Mid-test BW was calculated as the animal's BW 35 days after commencing the study, and was estimated from the regression line, and slope for each steer. Similarly, to calculate mid-test metabolic BW ($BW^{0.75}$), a linear regression line was fitted through all of the metabolic BW observations, of which the slope, and intercept were used to calculate the mid-test $BW^{0.75}$. Daily dry matter intake (DMI), was calculated as the mean of the steer's daily intakes throughout the 70-day study period. Average daily metabolisable energy (ME) intake was calculated by multiplying each animal's DMI by the predicted ME concentration of the finishing concentrate (AFRC, 1993). The FCR for each animal was calculated as the mean DMI divided by ADG. Kleiber ratio (KR) and relative growth rate (RGR) were calculated using the following equations:

$$KR = ADG/\text{mid-test } BW^{0.75}$$

$$RGR = RGR = 100x\ [\log_e(\text{end BW}) - \log_e(\text{Start BW})]\ /\text{days on test.}$$

Residual feed intake was calculated as the residuals produced from a multiple linear regression model which regressed MEI on $BW^{0.75}$ and ADG. Similarly, residual BW gain was calculated as the residuals from a multiple linear regression model regressing ADG on $BW^{0.75}$ and MEI.

Diet digestibility coefficients were calculated as follows:

$$\text{DM digestibility} = \frac{\text{AIA faeces (g/kg DM)} - \text{AIA feed (g/kg DM)}}{\text{AIA faeces (g/kg DM)}}$$

$$\text{Faecal DM output} = \text{DMI} - (\text{DMI} \times \text{DM digestibility})$$

$$\text{Nutrient digestibility} = \frac{(\text{DMI} \times \text{nutrient (g/kg DM)}) - (\text{DMO} \times \text{nutrient (g/kg DM)})}{(\text{DMI} \times \text{nutrient (g/kg DM)})}$$

There were two stages to the subsequent statistical analysis. First, all 24 animals were ranked according to RFI status, and eight were selected from each extreme to form low (n = 8) and high (n = 8) RFI treatments respectively. Performance, digestibility and feed efficiency parameters were analysed by analysis of variance with RFI status (low versus high) as the treatment effects. $P < 0.05$ was considered the threshold for significance, whilst $P < 0.1$ was used to denote statistical trends. Means are presented with their associated standard error of the mean.

Secondly, Linear Mixed Models for RFI, FCR and ADG were constructed with appropriate performance and activity parameters as explanatory variables. Each potential explanatory variable was first analysed in isolation as a univariate, and subsequently became a candidate for the multivariate model if an association was noted ($P < 0.2$). These variables were then added into the multivariate models in a forward-stepwise manner, with order of inclusion determined by the Wald statistic. Akaike Information Criterion (AIC) values, significance levels at inclusion ($P < 0.05$), and R^2 values were used to further guide the modelling process. The relationships between continuous variables were examined by Pearson correlations. The effect of pen was also included in each model as a random effect. All of the statistical analyses were undertaken using Genstat version 21 (VSN International Ltd., Oxford, UK).

5.0 Results

5.1 Feed efficiency and nutrient digestibility

The performance of the steers separated into groups based on RFI is summarised in Table 1. There was an effect of RFI status upon residual feed intake, where low RFI steers had 9.74 MJ/d lower ($P < 0.001$) residual feed intake than steers in the high RFI group. In contrast, there was no effect ($P > 0.05$) of RFI status on ADG, with a mean value of 1.52 kg/d across the two groups. There was however, an effect of RFI status on DMI and MEI, where low RFI steers consumed 0.7 kg/d less dry matter, and 9.1 MJ/d less metabolisable energy than high RFI steers respectively. Low RFI steers also had a 0.59 kg/kg lower FCR, and a 0.13 kg/d superior residual BW gain compared to high RFI steers. There was however no effect ($P > 0.05$) of RFI grouping on any other feed efficiency or performance trait.

The nutrient digestibility of the steers separated into groups based on RFI is presented in Table 2. Low RFI steers had a 1.1, 1.1, and 0.2 kg/d lower ($P < 0.001$) intake of DM, OM, and CP, compared to high RFI steers respectively. There was also an effect ($P < 0.001$) of RFI grouping on EE and GE intakes, which were 14 g/d, and 19 MJ/d lower for low compared to high RFI steers respectively. In contrast, there was no effect ($P > 0.05$) of RFI grouping on the faecal output or digestibility of any nutrient.

Table 1. Mean growth and efficiency traits of Hereford cross dairy steers ranked as low or high for residual feed intake

	Residual feed intake group			
Trait	Low	High	SEM	P-value
Residual feed intake, MJ/d	-4.74	5.00	1.189	<0.001
Start BW[1], kg	284	286	3.4	0.813
Final BW, kg	391	389	5.9	0.755
DMI[2], kg/d	7.4	8.1	0.15	0.007
MEI[3], MJ/d	94.9	104.0	1.92	0.007
Mid-test BW, kg	338	338	4.5	0.986
Mid-test $BW^{0.75}$, kg	78.7	78.7	0.78	0.998
ADG[4], kg/d	1.54	1.50	0.058	0.663
Feed conversion ratio, kg/kg	4.84	5.43	0.143	0.014
Relative growth rate	0.46	0.44	0.014	0.436
Kleiber ratio	0.020	0.019	0.0006	0.593
Residual BW gain, kg/d	0.09	-0.04	0.036	0.028

[1] BW: bodyweight
[2] DMI: Dry matter intake
[3] MEI: Metabolisable energy intake
[4] ADG: Average daily gain

Table 2. Nutrient digestibility of Hereford cross dairy steers ranked as low or high for residual feed intake

	Residual feed intake group			
	Low	High	SEM	P-value
Dry matter, kg/d				
Intake	8.3	9.4	0.18	<0.001
Faecal output	1.4	1.5	0.11	0.643
Digestibility, kg/kg	0.833	0.845	0.0111	0.476
Organic matter, kg/d				
Intake	8.2	9.3	0.17	<0.001
Faecal output	1.4	1.4	0.11	0.640
Digestibility, kg/kg	0.835	0.846	0.011	0.481
Crude protein, kg/d				
Intake	1.3	1.5	0.03	<0.001
Faecal output	0.020	0.022	0.0028	0.429
Digestibility, kg/kg	0.804	0.814	0.0135	0.595
Ether extract, g/d				
Intake	107	121	2.3	<0.001
Faecal output	20	24	2.1	0.232
Digestibility, g/g	0.803	0.795	0.0171	0.730
Gross energy MJ/d				
Intake	148	167	3.2	<0.001
Faecal output	24.8	26.3	2.1	0.605
Digestibility, MJ/MJ	0.832	0.843	0.0118	0.550

5.2 Feed efficiency and steer behaviour

The mean behaviours of the steers separated into groups based on RFI are shown in Table 3. There was no effect (P > 0.05) of RFI status on any activity parameter, with mean activity values of 4542 for motion index, and 805 steps/d respectively. There was however, a trend (P < 0.1) for low RFI steers to have 1.7 fewer lying bouts per day compared to high RFI steers, with each bout tending (P < 0.1) to be 6.5 mins longer in duration for low RFI steers. In contrast, there was no effect (P > 0.05) of RFI status on any other lying behaviour. Likewise, there was no effect (P < 0.05) of steer RFI status on any activity behaviour, although, steers in the low RFI group tended (P < 0.05) to have 1.6 fewer standing bouts per day compared to high RFI steers.

Table 3. Mean behaviours of Hereford cross dairy steers ranked as low or high for residual feed intake

	Residual feed intake group			
Behaviour[1]	Low	High	SEM	P-value
Activity- movement				
MI	4581	4504	234.5	0.821
sdMI	1232	1082	13.6	0.271
nSteps	810	800	40.3	0.857
sdSteps	189	183	15.5	0.769
Activity- lying				
LyingTime	918.0	908.0	18.91	0.724
dLyingBout	59.0	52.5	2.11	0.051
MinLyingBout	8.7	6.6	0.85	0.107
MaxLyingBout	114.3	115.7	4.12	0.811
nLyingBouts	15.7	17.4	0.58	0.064
Activity- standing				
StandTime	522.3	532.0	18.91	0.724
dStandBout	34.0	31.6	1.83	0.369
MinStandBout	3.0	3.2	0.55	0.736
MaxStandBout	114.3	115.7	4.1	0.811
nStandBouts	15.5	17.1	0.59	0.075

[1] MI: mean daily motion index; sdMI: mean standard deviation of the motion index; nSteps: mean number of steps/d; sdSteps: mean standard deviation of steps/d; LyingTime; mean time lying (minutes/d); dLyingBout: mean lying bout duration (minutes/bout); MinLyingBout: mean minimum lying bout duration (minutes/bout); MaxLyingbout: mean maximum lying bout duration (minutes/bout): nLyingbouts: mean number of lying bouts/d; StandTime; mean time standing (minutes/d); dStandBout: mean standing bout duration (minutes/bout); MinStandingBout: mean minimum standing bout duration (minutes/bout); MaxStandbout: mean maximum standing bout duration (minutes/bout): nStandingbouts: mean number of standing bouts/d

5.3 Univariate and multivariate models

Variables that demonstrated associations ($P < 0.2$) with RFI, FCR, and ADG are shown in Table 4. The final multivariate models for ADG and RFI are presented below Table 4, with the model R^2 value in parentheses. Steers with a higher ADG, had higher intakes ($F = 15.21$; $r = 0.63$), and a higher minimum daily standing bout ($F = 1.51$; $r = 0.17$). In contrast, there were no associations ($P > 0.05$) between any behavioural variables and FCR. Steers that had a more efficient RFI, had a longer daily minimum lying bout ($F = 2.86$; $r = 0.05$), and experienced fewer lying ($F = 0.53$; $r = 0.32$) and standing bouts ($F = 0.50$; $r = 0.31$) each day.

Table 4. Variables included in the Linear Mixed Models for average daily gain, feed conversion ratio, and residual feed intake. Variables with a P-value of < 0.200 were considered as candidates for the multivariate analysis. The variables are presented in ascending order of the Wald statistic.

Average daily gain			Residual feed intake		
Variable[1]	Wald	P-value	Variable[2]	Wald	P-value
DMI	15.61	<0.001	MinLyingBout	3.02	0.105
MinStandBout	3.09	0.094	nLyingBouts	2.79	0.112
			nStandBouts	2.65	0.120

[1] DMI: Dry matter intake (kg/day); MinStandBout; minimum standing bout duration (minutes/bout)
[2] MinLyingBout: minimum lying bout duration (minutes/bout); nLyingBouts: mean number of lying bouts/day; nStandBouts: mean number of standing bouts/day

ADG: DMI + MinStandBout (0.44)

RFI: MinLyingBout + nLyingBouts + nStandBouts (0.28)

6.0 Discussion

6.1 Performance, feed efficiency traits, and nutrient digestibility

The observed trends in feed efficiency and performance between the different RFI groups in this study are consistent with the findings of others who have reported on the grouping of animals according to RFI status (Basarb *et al.*, 2004; Baker *et al.*, 2006). Steers that were classified as low RFI on the current study, consumed 8% less feed per day than those in the high RFI group, resulting in a lower FCR for low RFI steers. Grouping according to RFI status also did not alter ADG, RGR, or indeed KR in the present study, reflecting the lack of phenotypic correlation with RFI, and supports the findings of previous studies (Baker *et al.*, 2006; Crowley *et al.*, 2010).

It is generally accepted within literature that increasing the quantity of feed consumed, results in decreased diet digestibility, as a result of decreased ruminal residency time (Kenny *et al.*, 2018). Therefore, as a result of the increased intake associated with high RFI steers in the present study, a reduction in apparent digestibility would have been expected. The literature however, does not support this speculation, as dry matter digestibility remains unaltered when monitored in beef cattle grouped according to RFI status (Richardson *et al.* 2004; Fitzsimons *et al.*, 2014), an observation which was also noted in the present study. The reasons for this lack of difference in digestibility are unclear, but may relate to the homogeneity of the diet offered (Herd *et al.*, 2004a), differences in the digestion characteristics of different feed types (Kenny *et al.*, 2018), or differences in nutrient use efficiency post-absorption (Fitzsimons *et al.*, 2017).

6.2 Behaviour, feed efficiency, and small-stature calves

It has been observed previously that lower activity levels are associated with better feed efficiency in beef cattle, as demonstrated by a lower number of steps taken per day (Herd *et al.*, 2004b). In contrast, RFI status did not alter activity in terms of motion index, step count, or total standing time in the current study. Hypothetical reasoning for these contrasting findings between studies thus far remains elusive, but may relate to the environment surroundings within which the animals are kept. It is also unclear why steers in the low RFI group tended to have a lower number of lying bouts, which were of greater duration. The high RFI animals maybe simply standing to access feed, water, or perform other behaviours in short bouts, with no resulting effect on overall standing time.

Overall, some univariate associations were made between behaviour and measures of performance to include ADG and RFI. Despite the feeding of a concentrate diet, which should have allowed the steers to better demonstrate their true phenotype for feed efficiency (Kenny *et al.*, 2018), the associative R^2 values for the multivariate models (0.44 and 0.28 for ADG and RFI respectively) were low, demonstrating limited predictive value of these models in the field. It can therefore be concluded that the monitoring of behaviour in this manner will not adequately predict animal performance on farm to facilitate increased genetic selection for efficiency traits. The importance of feed efficiency to the farmer should not however be disregarded, the 8% decreased intake of low RFI steers observed in the present study, represents a saving of approximately £ 73/head from 3-months of age to slaughter, based on current feed prices (13-month beef production system). Genetics companies are however, starting to select for feed efficiency in beef cattle, and as these metrics become increasingly available, those within supply chains should aim to adopt them. Nevertheless, industry wide acceleration in the selection for more efficient beef cattle is still hindered by the lack of a widespread phenotypic reference population (Fitzsimons *et al.*, 2017). An answer to this problem potentially lies in the use of cameras, images, and machine learning to facilitate the widespread recording of cattle phenotypes, technology which has already proven its prediction accuracy within the pig sector (Fernandes *et al.*, 2019).

Perhaps one of the most important findings involving sustainability in the current study, relates to the role of small-stature calves in the beef supply chain. The animals utilised in the current study were sourced from a local spring-calving dairy herd consisting of small-stature grazing dairy cows. This would not have had any implications upon the behavioural study, where the interaction of behaviour with feed efficiency should not be influenced by breed (Haskell *et al.*, 2019). There is however the perception within the beef industry that these calves are less efficient and not capable of meeting market specifications, leading to reduced calf prices, and historically calf euthanasia on farm. There is however, a commitment from the dairy industry to end the routine euthanasia of bull calves via the Red Tractor Assurance standards by 2023 (James, 2022). One of the suggested solutions to this problem is to increase the size of spring-calving cows, however the performance recorded in this study, suggests that measure to be premature. The overall efficiency of the animals in this is study comparable to that observed historically with typical dairy cross-beef cattle at Harper Adams University (Wilkinson *et al.*, 2021), with finished liveweights exceeding 520 kg for those slaughtered at the time of writing. Indeed, considering the low purchase price of these animals, profit potential maybe greater in comparison to typical dairy cross beef cattle.

7.0 Progress against milestones

Table 5. Milestones and achievements

Project milestones	Initial completion date	Completion status
Recruit all animals onto the study	October 2021	Completed
Finish performance collection and laboratory analyses	February 2022	Completed
Prepare final report	March 2022	Completed

All objectives have been examined and discussed- no changes were made to the objectives

8.0 Achievements and potential outputs

- Final report provided for publication on the School of Sustainable Food and Farming website- Complete
- Evidence surrounding small-stature calves has been used to target further funding in the area- In process
- Three abstracts for publication at the British Society of Animal Science- Target completion date of April 2023
- Target of three peer-reviewed publications to include the following titles (Estimated completion by January 2023):

    1. The effect of feed efficiency upon digestibility in Hereford cross dairy steers
    2. Explaining the influence of effect size in behavioural study models
    3. Producing sustainable beef from small stature dairy cows

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