Have your steak and eat it too: Precision beef management to simultaneously reduce eCH$_4$ and increase profit

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Abstract

Achieving carbon net zero is a clear priority, with beef farmers under significant scrutiny from food system stakeholders. Tools are available to assess greenhouse gas emissions (GHGe), yet adoption is low, and producers are not currently financially incentivized to change management practices. This study used cattle performance data from a commercial beef operation to model the optimal age and weight at slaughter to maximize profit and reduce enteric methane (eCH$_4$) emissions at the individual animal and herd level, compared to heuristic management on farm.

Performance data, including age at farm arrival and slaughter; sex; breed; days spent on pasture; entry and staged liveweight; carcass weight (CW); killing out percentage; conformation score and fat grade were sourced from 777 growing and finishing cattle at the ABP Bromstead Farm (UK) for the period between July 2017-June 2020. Using GrowSafe feeder data, daily lifetime growth efficiency was estimated. Using liveweight data, growth equations were fitted for each individual animal (adjusted R^2 >0.963 for 99.2% of cattle) and daily feed intake was estimated. eCH4 emissions were calculated based on feed intake, daily liveweight gain and ration formulation. Thus, we accounted for expected daily changes in lifetime costs, revenue (with prices based on age, CW and EUROP grid premiums and discounts) and profitability of lifetime profit profile (£ hd^{-1}) for each individual animal. This enabled the identification of individual optimal age at slaughter to maximize gross margins for both a single cycle and when lifetime profit (as NPV hd^{-1}) is maximized in perpetuity (multi-cycle optimal management accounts for opportunity cost of capital).

Average realized profit was £210 hd^{-1} (SD £148.60, range -£369 to £589 hd^{-1}). When comparing actual management to single cycle optimal management, improving the management of the lowest 10% of performing cattle achieved increases in profitability of between £100 and £331 hd^{-1} and increased average profit to £259 hd^{-1} (SD £118.29, range -£183 to £589 hd^{-1}). Optimal individual animal management using a multi-cycle approach generated on average a 5% profit gain (an extra £339 hd^{-1} in perpetuity) compared to optimized management in a single cycle. When comparing optimal multi-cycle management to actual on-farm performance, an average profit gain of 45% was expected (£2278 more per head in perpetuity). Concurrently, eCH$_4$

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emission intensity per kg beef CW was reduced by 28% (single cycle) or 32% (multi-cycle) under optimal management. For the 777 head of finished cattle, it represents a total of 15.93t and 18.5t reduction in eCH_4 emissions for optimal single and multi-cycle management.

This study showed that individual animal performance data can be used to improve economic returns whilst reducing greenhouse gas emissions from beef cattle. This approach can be used to forecast the optimal age at slaughter in real-time. It demonstrates a significant opportunity for the beef industry to identify, develop and adopt on-farm precision management practices and technologies to capture the economic and environmental efficiencies identified here.

Keywords.
Enteric methane emissions, feed efficiency, slaughter age, optimization.

Introduction

The sustainability of farming systems is of paramount importance to all food system stakeholders. A sustainable future may only be achieved by balancing economic viability, environmental responsibility, and social acceptability, both at an individual farm level and throughout an industry and supply chain. All three pillars of sustainability are equally important, but a clear and immediate need exists for the UK beef sector to demonstrate effort to reducing negative environmental impacts, and to do so in an evidence-based manner that allows progress to be benchmarked and communicated, with greenhouse gas (GHG) emissions being the most urgent area of focus. Emissions from UK beef production is affected by efficiency within each sector, and at each point from feed production through to retail and consumption. Although marginal gains can and should be achieved post-slaughter in terms of transport, processing, retail and consumption, the greatest opportunities for sector decarbonization occur at the individual animal level (Beauchemin et al., 2010; Samsonstuen et al., 2020; Thompson & Rowntree, 2020).

Several factors in cattle production can impact GHG emissions, including daily liveweight gain (DLWG), slaughter age, carcass weight, feed efficiency, feed/forage choice, health and genetics (Beauchemin et al., 2010; Capper, 2011). However, to improve decision making UK farmers need and want clear guidance on how to improve their carbon footprint through simple efficiency changes under practical conditions on farms, while maintaining their profitability. The use of precision livestock farming (PLF) approaches has the potential to help farmers achieve these objectives (Van Hertem et al., 2016). The overall aim of this research was to determine the potential of PLF, through data-driven decision support based on real-life commercial data, to reduce GHG emissions, meet carcass and slaughter age targets, and improve the economic performance of beef finishing.

Methodology

This research used real cattle performance data from a commercial beef unit, to identify relationships between cattle genetics, feed efficiency and finishing system, on GHG emissions and economic efficiency. Data relating to cattle performance was collected from Bromstead Farm (Shropshire, UK), an independent commercial beef finishing enterprise working closely with ABP. The farm bought in batches of mixed sex cattle at around 120 days of age, growing them through to slaughter at target weights and ages, and finished for ABP Ellesmere. Performance data included date of birth; age and weight at farm arrival and slaughter; sex; sire breed and name; batch number; time/dates spent on pasture; carcass weight and killing out percentage; conformation score and grade; and fat grade and score (based on EUROP guidelines (Ford & Powdrill, 2019)). Information on individual animal feed efficiency was obtained through a 70 d (plus acclimatisation) experimental period of indoor feeding using the GrowSafe system (GrowSafe Systems Ltd, Airdrie, AB, Canada). Data from 12 intake batches, a total of 857 cattle, was collected, with 80 animals removed from the analysis due to missing data components, leaving 777 head for analysis (Table 1, Figure 1).

Table 1. Individual animal performance data for Bromstead cattle (n=777).

Parameter	Mean	Range
Arrival weight (kg Lwt)	149	99.5-284
Slaughter liveweight (kg)	612	463-754
Slaughter deadweight (kg)	313	219-419
Age at slaughter (mo)	16.2	13.3-20.0
Killing out %	51.1	46.1-62.7
DLWG (kg/d)	1.53	0.61-2.32
Dry Matter Intake (kg DM/d)	10.54	6.02-15.31
Kg DM feed/kg Lwt gain	6.96	4.27-13.10

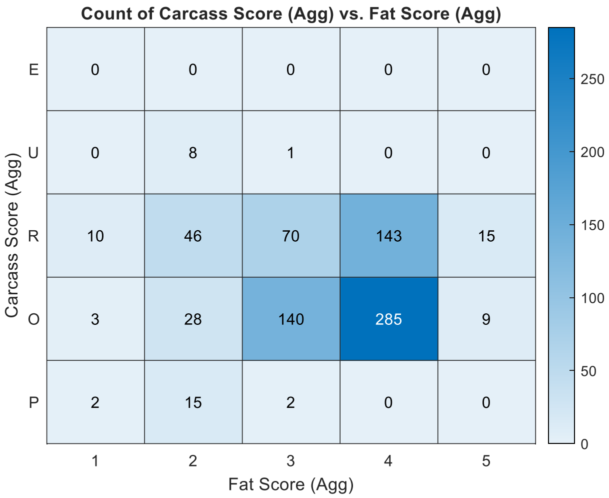


Fig 1. Distribution of cattle numbers across carcass confirmation scores and fat grades.

Modelling individual animal performance

A standard Gompertz equation (Thornley & France, 2007) was used to fit growth curves for all individual animals, such that:

$$LW_t = k\left(\frac{A}{k}\right)^{\exp(-r.t)} \tag{1}$$

where LW_t is liveweight (kgs) at age t days, k is the maximum mature liveweight (kg), A is the birth weight (kg), and r is the growth rate parameter. The maximum mature liveweight for all animals (parameter k in equation1) was set at 912.6kg liveweight based on the maximum recorded slaughter weight from a sample of 2338 head of similar genotype provided by ABP (Behrendt et al., 2021). The growth rate parameter value, r, is estimated for each individual animal and represents how the animal was managed and/or it's phenotypic expression of its genetic potential. This value can change if feeding changes or more measurements are provided to revise growth predictions. Birth weight was set at 39kg for all steers/bulls and 36kg for heifers (parameter A in equation 1).

The Adjusted R-squared values from the fitted models indicated that the majority of cattle growth curves have over 98% accuracy, and that the 'best fit' mature weight (k value) for the majority of animals is expected to have a mature weight in the vicinity of 900-920kg Lwt. Inaccuracies can occur due to insufficient measurements or measured liveweights and weight gains between measurements being irregular (e.g. due to a period of illness, a change in feeding, inaccuracy in weigh scales, or just the effect of different levels of gut fill between measurements).

A series of equations were then used to calculate the feed intake of individual animals. The growth efficiency of animals (kg weight gain per kg of feed consumed) is assumed to asymptotically approach zero as cattle approach maturity. This corresponds to well established cattle growth models such as those detailed by Freer et al. (1997) and Tedeschi et al. (2004). The base equation for daily growth efficiency, GE_t used in this analysis is:

$$GE_t = \alpha_G . exp(\beta_G . A_t) \tag{2}$$

where A_t is the age of the animal in days, and α_G and β_G are specific to a given breed and feed type. In this simple model we assume β_G = -0.0042 (based on typical maturity patterns in British cattle) and α_G is calibrated for each individual animal. The model uses the measured Average Dry Matter Intake (DMI kg day^{-1}) during the feed efficiency measurement period to calibrate the α_G parameter for each individual animal, given each individual animal's modelled daily liveweight gain and actual feed intake adjustment ratio (which is the ratio of Actual Feed Intake to Predicted

Feed Intake during the feed testing period). The feed consumed per day by each individual animal, F_t (kgs DM head^{-1}), is calculated using the following equation:

$$F_t = \frac{DLWG_t}{GE_t} . FI_A \tag{3}$$

where $DLWG_t$ is the daily liveweight gain (kgs) of an animal on day t, and FI_A is the Actual Feed Intake Ratio which is the Average DMI ÷ Predicted DMI during the feed efficiency trial period. The Predicted DMI is derived using the reported batch level Residual Feed Intake (RFI in kgs) and Average DMI, such that *Predicted DMI = -(RFI – Ave DMI)*.

To predict level of enteric methane emissions from individual cattle, the Monte-Carlo simulation corrected equation specific to beef cattle finished on high-forage diets published by Escobar-Bahamondes et al. (2016) was selected as the most appropriate for the cattle and systems being investigated. The equation for enteric methane emissions, eCH_4 (g d^{-1}), is as follows:

$$\mathrm{eCH_4} = 25.9 + 0.13\mathrm{LW_t} + 145.4\mathrm{F} + 10.3(\mathrm{NDF} - \mathrm{ADF})^2 + 0.1\mathrm{DMI}^3 - 27.4(\mathrm{S{:}NDF}) \tag{4}$$

where *ADF* is acid detergent fibre intake (kg d^{-1}), *DMI* is F_t (kg DM d^{-1}), *NDF* is neutral detergent fibre intake (kg d^{-1}), *F* is fat intake (kg d^{-1}), and *S* is starch intake (kg d^{-1}). All data curation, modelling and analysis is undertaken using Matlab® (Mathworks, 2019).

Beef Finishing Profitability

Using the modelled lifetime performance of all individual animals and their individual feed intake (based on RFI measurements and calibration with actual intake data), the expected changes in daily costs, revenue and profitability over the life of the animal is calculated. This allows the identification of the optimum time to slaughter/sell an animal based on its growth efficiency, RFI, and growth curve. The assumed prices of inputs and outputs are shown in Table 2.

Table 2. Cost and price assumptions for economic analysis

Category	Item	Value	Source & Notes
Outputs			
	Steers	362.9 p/kg Dwt	AHDB (2022) nominal prices for Great Britain 5th January 2019 to 29th January 2022
	Heifer	362.9 p/kg Dwt	
	Young Bull	347.6 p/kg Dwt	
	Carcass Premiums & Discounts	-150 to 35 p/kg Dwt	ABP UK Price Grid for 6th April 2020
Inputs			
	Calf purchase price	184 p/kg Lwt	Redman (2020)
	Animal health and other upfront costs (e.g. transport etc)	£4.31 /head	Redman (2020)
	Pasture Feed Costs	£0.0632/kg DM	See Appendix Table 1A
	TMR Feed costs	£0.1515/kg DM	See Appendix Table 2A
	Bedding Costs	£0.14 /head/day	Redman (2020)
Assumptions			
	Discount Rate	3%	HM Treasury (2018) >30 year discount rate
	Birth weights	Steers & Bulls – 39 kg Heifers – 36 kg	
	Age at arrival	120 days	

The cumulative Gross Margin for each individual animal is calculated and aggregated on a daily basis to provide insight into their evolving lifetime costs, income and profit changes out to an age of 1000 days. Costs are based on the predicted daily feed intake of both total mixed ration (TMR) and pasture, arrival weight at 120 days of age, and other costs. Income is based on each animals' carcass attributes (position on grid, price premiums & discounts) and predicted slaughter weights. The derived lifetime profit profile (£ hd^{-1}) is used to identify the age and weight at which gross margins are maximized (i.e. single-cycle optimal management). This is compared against the actual management gross margin, which is based on the animals' actual age and weight at slaughter.

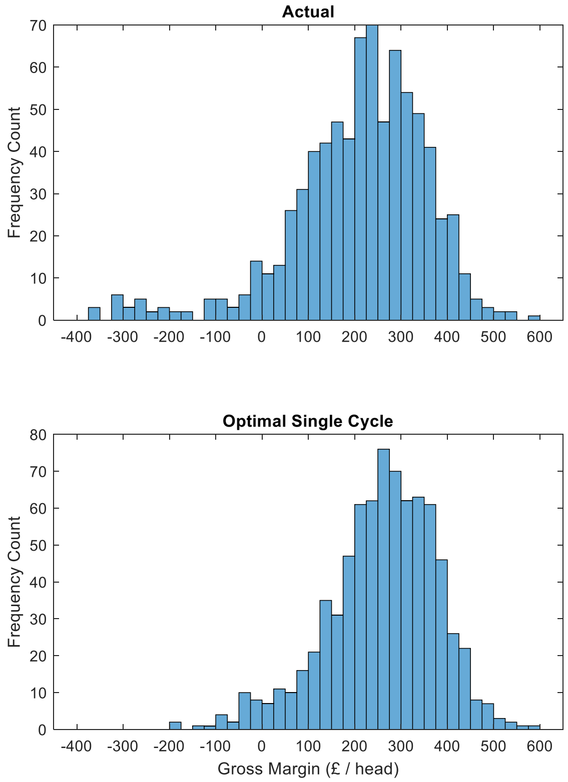
We also considered the opportunity cost of delaying income and revenue from all future finishing cycles, calculating the profitability of each individual animal based on indefinite multiple cycles (finishing cycles in perpetuity). This multi-cycle approach assumes that finishing cattle is not a once-off activity, and that the infrastructure and equipment used for the enterprise is used for more than a single-cycle.

Multi-cycle profit is calculated as the Present Value (PV, £ hd^{-1}) of gross margins using the Faustmann formula (Clark, 2010) that is commonly used in forestry to determine the optimum planting-harvesting interval, using a discount rate to account for the opportunity cost of delayed income. This was calculated daily over the life of the animal and allowed the identification of when lifetime profit in perpetuity is maximised (i.e. multi-cycle optimal management). Although this methodology assumed that each individual animal would be replaced with another identical animal in terms of efficiency and performance potential, it provides the economically optimal management of an individual animal under precision management conditions.

Results and Discussion

The distribution of individual ‘actual’ and ‘optimal single cycle’ gross margin performance for all cattle analysed is shown in Figure 2. The average actual realized gross margin was £210 hd^{-1} (SD £148.60, range -£369 to £589 hd^{-1}). When comparing actual management to single cycle optimal management, improving the management of the lowest 10% of performing cattle achieved increases in profitability of between £100 and £331 hd^{-1} and increased overall average gross margin to £259 hd^{-1} (SD £118.29, range -£183 to £589 hd^{-1}). Through this comparison it is apparent that the more prevalent downside tail under the actual gross margin distribution indicates that more optimal systems do tend to reduce the incidence of poor performing cattle, i.e. those that have a low or negative gross margin, with a concurrent increase in the mean gross margin per head when managed optimally. The challenge to producers is to identify these poor performing cattle early, maximise their profit potential within their cycle, and look to replace them in the future with more profitable cattle. This may be achieved through the adoption of PLF by increasing the amount of data recording, analysis, and benchmarking. Routinely weighing cattle would provide a foundation for improved data collection and analysis, especially if combined with regular assessment of growing cattle condition. Such relatively simple changes in management practice could have a significant benefit in the adoption of data-driven, evidence-based PLF production systems, with a concurrent focus on economic and environmental sustainability.

Fig 2. Distribution of individual ‘actual’ and ‘optimal single cycle’ gross margin performance.



The expected performance of all cattle analysed in perpetuity when comparing multi-cycle optimisation to single-cycle optimisation and actual performance are shown in Table 3. Optimal individual animal management using a multi-cycle approach generated on average a 5% profit gain (an extra £339 hd^{-1} PV) compared to optimized management in a single cycle. When comparing optimal multi-cycle management to actual on-farm performance, an average profit gain of 45% was expected (£2278 more PV per head finished in perpetuity). These potential benefits come about through identifying individual animal phenotypes and then managing their growth and finishing time to maximise long-run profits. By taking time more into account (i.e., the opportunity cost of delaying income and revenue from all future finishing cycles) in on-farm decision making we focus on the realizable net marginal gains from feeding animals longer and achieving a higher weight or different carcass specification. We also consider that we can off-load an animal and replace it with another. The replaced animal should also be genetically superior if the genetics of our animals are improving over time. Under such a system the more optimal strategy would be to turn off cattle much younger and at a lighter weight than is typically done in industry, and that increasing fat depth may not be a profitable strategy as it does not attract sufficient premiums to compensate for increasing costs of DLWG and delays in future sales. As such, a greater focus on improving both conformation score and feed efficiency would lead to higher prices and potentially higher profits.

Table 3. Mean NPVs and associated weight and age at slaughter for actual, single and multiple cycle management.

Cycle	Present Value (£ hd^{-1} – finishing in perpetuity)		Weight at slaughter (kg Lwt hd^{-1})		Age at slaughter (Days)	
	Mean	StDev	Mean	StDev	Mean	StDev
‘Actual’	5094	3662	612	44	500	34
‘Single’	7033	3442	531	53	438	44
‘Multiple’	7372	3620	511	32	422	50

Given the need for economic and environmental parameters to balance within sustainable operations, it’s essential to consider potential trade-offs between enteric CH_4 emissions and economic profitability. Previous studies have reported improvements in both environmental impacts and economic viability conferred by efficiency gains in beef production overseas (e.g. Capper & Hayes, 2012; Pashaei Kamali et al., 2016; Stackhouse-Lawson et al., 2013), yet there are few studies that have investigated these effects in UK beef systems.

The result of this analysis shows a relationship exists between actual gross margin and enteric methane emission intensity (Figure 3). It demonstrates that win:win solutions can be achieved by concurrently focusing on reducing enteric methane emissions and improving beef finishing profitability, with profitability increasing as emission intensity declines.

Fig 3. Relationship between actual gross margin and enteric CH_4 emission intensity across all analyzed cattle.

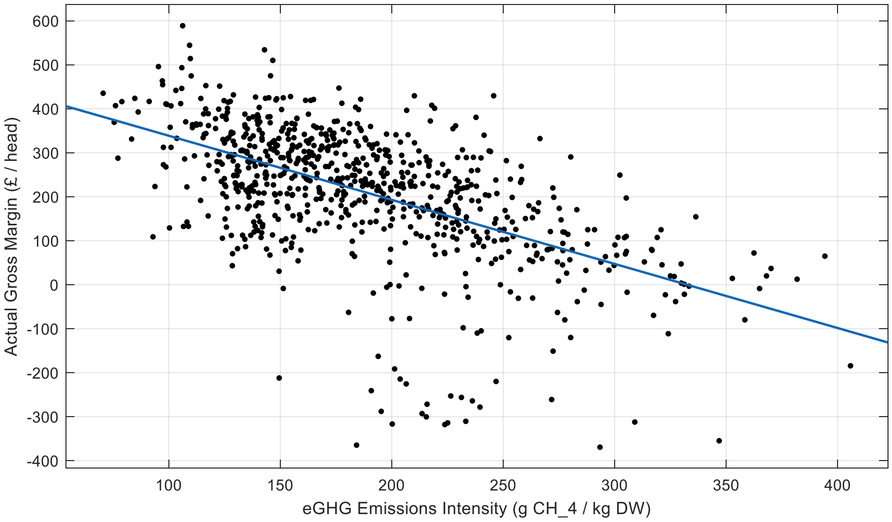
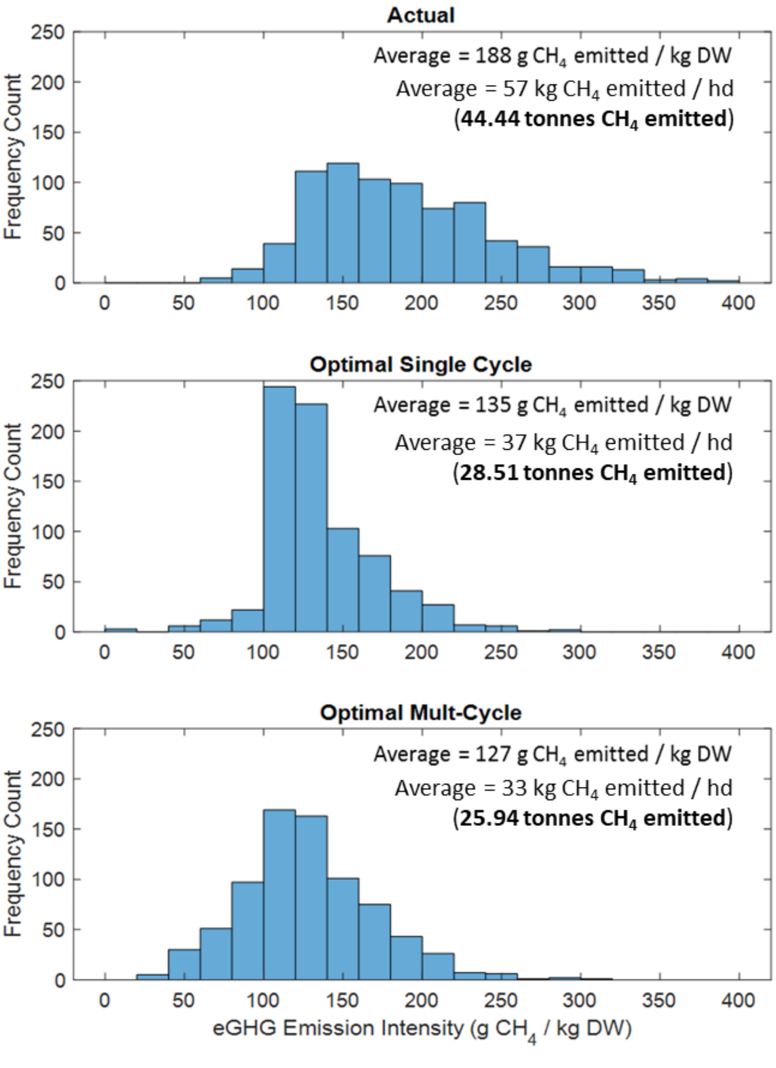


Figure 4 shows the distributions of aggregated lifetime enteric methane emission intensity for individual cattle and total enteric methane emissions under each management system. Enteric methane emission intensity per kg beef carcase weight produced was reduced by 28% under single cycle optimality or 32% under multi-cycle optimality. The results indicate that for the 777 head of finished cattle analysed, it would be possible to reduce total eCH_4 emissions by 15.93t - 18.5t through the adoption of optimal single or multi-cycle management.

The drivers of the relationships identified in these results embody the phenotypic expression of both the genotype and management of the animals. Identifying genotypes and phenotypes associated with reduced GHG emissions across the entire livestock sector, in combination with a better understanding of the opportunities and limitations of manipulating rumen function will offer GHG mitigation opportunities.

Importantly, whole sector adoption of a data-driven approach also necessitates the ability to manage individual animals in an optimal way (i.e. precision livestock farming). Adopting precision diet formulation, such that diets are specifically targeted not just to species and production level, but according to the variety of nutrients required by the individual animal could also confer significant benefits, although this would have a greater potential impact in intensive than extensive systems (Andretta et al., 2021; Carter & Kim, 2013). Additionally, as shown by the distributions of economic performance for individual cattle (Figure 2), being able to identify the drivers and monitor key attributes through the use of PLF technologies, will enable farmers to identify under-performing cattle and modify their management to ensure they minimise enteric methane emissions and maximize economic outcomes.

Fig 4. Distributions of enteric methane emission intensity for individual cattle and total enteric methane emissions under each management system.



Conclusion or Summary

The results from this work indicate the significant improvements in profitability and reductions in CH_4 emissions that are possible through the adoption of more optimal management strategies. Specifically, the results indicate that producers should focus on improving both genetics and carcass conformation and collect associated data that allows for a data driven PLF management approach. To our knowledge, this research is the first to demonstrate and quantify the relationships between feed efficiency, enteric methane emissions and economic profitability using real-world UK-based beef production data.

A limitation in the current analysis is that we assumed carcase conformation and fat score is held constant around the actual time of slaughter. When this work was undertaken, the predictions based on the available data using machine learning were not sufficiently accurate to include predictions of changing fat and conformation scores with age in these calculations. However, in support of the assumptions and findings in this analysis there is a window around the actual time of slaughter where we would mainly expect fat score to decline with slaughtering at a younger age, and with little impact on conformation score due to plateauing animal maturity. Additionally, the majority of animals within the sample were slaughtered at fat score 3+ to 4+, while the commercially available price grid maintains constant premiums/discounts between fat score 2+ to 4= across all conformation scores. Hence a changing fat score with slaughtering at a younger age has little or no impact on the price received per kg of carcase weight sold and would not be expected to result in significant errors in estimating profitability.

Overall, there remains a need to develop cost-effective autonomous cattle monitoring systems (e.g. that automatically capture changes in feed intake, liveweights and carcass attributes on live animals) and decision support systems capable of adequate prediction based on the phenotyping of individual cattle. This work has shown that this could concurrently increase beef finishing profitability by over 45% and reduce enteric methane emissions by around 30% in the long term compared to current industry practice.

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