Cattle feeding in the Great Plains: Economic and environmental impacts of cattle performance and disease management

by

Merri Elizabeth Day

B.S., Auburn University, 2018
M.S., University of Arkansas, 2021

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Agricultural Economics
College of Agriculture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2025

Abstract

The United States Roundtable for Sustainable Beef (USRSB) is credited with developing a framework that provides specific targets for achieving sustainability throughout all sectors of the U.S. beef industry. Livestock operations have been identified as important contributors to greenhouse gas emissions, and the U.S. beef industry is under considerable pressure to reduce its environmental footprint, specifically within the feedyard sector. The USRSB aims to reduce feedyard greenhouse gas emissions by 10% per pound of beef produced by 2030. The USRSB also identifies animal health and well-being, which includes assurance of proper veterinary care, as a top priority for beef feedyards. In beef cattle feedyards, challenges related to animal health and disease management are compounded by space and density, and even the most treatable illnesses can have considerable harmful effects on both herd health and economic returns.

Innovations in feeding technologies such as growth implants and feed additives have shown potential for reducing greenhouse gas emissions. Advancements in veterinary diagnostics and use of antimicrobials have proven effective in improving outcomes for diseased cattle in feedyards. However, economic viability of these management practices is paramount to achieving feedyard sustainability goals set forth by the USRSB.

The first study examines how alternative cattle feeding management decisions impact both net returns and greenhouse gas emissions. We use established procedures to estimate the effects of changes in mortality and growth implant protocols on feedyard net returns. We then propose new methods for estimating concurrent impacts to feedyard greenhouse gas emissions. Using operational feeding data, we find that reducing mortality consistently increases net returns while reducing greenhouse gas emissions intensity. Additionally, our findings indicate that using

two growth implants compared to one has potential for simultaneous improvement of both net returns and greenhouse gas emissions intensity.

The second study estimates net returns from feedyard cattle identified with acute interstitial pneumonia (AIP) ante-mortem and post-mortem. A decision tree framework is implemented to estimate net returns for cattle that finished with their cohort, were culled, or died following an AIP diagnosis. Using comprehensive data, we find that economic outcomes vary across sex, placement weight, and number of AIP treatments. Findings generally indicate that expected returns from treating cattle identified with AIP are favorable to estimated returns from culling.

The third study examines predictors of terminal outcomes for feedyard cattle diagnosed with AIP ante-mortem. Using comprehensive data, mixed-effects logistic models are employed to estimate the probabilities of first AIP treatment failure and failure to finish for cattle treated at least once for AIP. Findings from this analysis indicated that sex, weight, AIP treatment timing, and prior bovine respiratory disease treatment were significantly associated with the probability of first AIP treatment failure and probability of failure to finish.

Building upon findings from the second and third studies, a spreadsheet-based decision aid was developed to support the management of feedyard cattle identified with AIP. Following methods described in the second study, the decision aid prepares a comparison of expected returns from treating an animal compared with estimated returns to culling the animal without AIP treatment, along with probabilities of AIP treatment outcomes as described in the third study.

Cattle feeding in the Great Plains: Economic and environmental impacts of cattle performance and disease management

by

Merri Elizabeth Day

B.S., Auburn University, 2018
M.S., University of Arkansas, 2021

A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Agricultural Economics
College of Agriculture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2025

Approved by:

Co-Major Professor
Dr. Ted C. Schroeder

Approved by:

Co-Major Professor
Dr. Dustin L. Pendell

Copyright

Abstract

The United States Roundtable for Sustainable Beef (USRSB) is credited with developing a framework that provides specific targets for achieving sustainability throughout all sectors of the U.S. beef industry. Livestock operations have been identified as important contributors to greenhouse gas emissions, and the U.S. beef industry is under considerable pressure to reduce its environmental footprint, specifically within the feedyard sector. The USRSB aims to reduce feedyard greenhouse gas emissions by 10% per pound of beef produced by 2030. The USRSB also identifies animal health and well-being, which includes assurance of proper veterinary care, as a top priority for beef feedyards. In beef cattle feedyards, challenges related to animal health and disease management are compounded by space and density, and even the most treatable illnesses can have considerable harmful effects on both herd health and economic returns.

Innovations in feeding technologies such as growth implants and feed additives have shown potential for reducing greenhouse gas emissions. Advancements in veterinary diagnostics and use of antimicrobials have proven effective in improving outcomes for diseased cattle in feedyards. However, economic viability of these management practices is paramount to achieving feedyard sustainability goals set forth by the USRSB.

The first study examines how alternative cattle feeding management decisions impact both net returns and greenhouse gas emissions. We use established procedures to estimate the effects of changes in mortality and growth implant protocols on feedyard net returns. We then propose new methods for estimating concurrent impacts to feedyard greenhouse gas emissions. Using operational feeding data, we find that reducing mortality consistently increases net returns while reducing greenhouse gas emissions intensity. Additionally, our findings indicate that using

two growth implants compared to one has potential for simultaneous improvement of both net returns and greenhouse gas emissions intensity.

The second study estimates net returns from feedyard cattle identified with acute interstitial pneumonia (AIP) ante-mortem and post-mortem. A decision tree framework is implemented to estimate net returns for cattle that finished with their cohort, were culled, or died following an AIP diagnosis. Using comprehensive data, we find that economic outcomes vary across sex, placement weight, and number of AIP treatments. Findings generally indicate that expected returns from treating cattle identified with AIP are favorable to estimated returns from culling.

The third study examines predictors of terminal outcomes for feedyard cattle diagnosed with AIP ante-mortem. Using comprehensive data, mixed-effects logistic models are employed to estimate the probabilities of first AIP treatment failure and failure to finish for cattle treated at least once for AIP. Findings from this analysis indicated that sex, weight, AIP treatment timing, and prior bovine respiratory disease treatment were significantly associated with the probability of first AIP treatment failure and probability of failure to finish.

Building upon findings from the second and third studies, we develop a spreadsheet-based decision aid to support the management of feedyard cattle identified with AIP. Following methods described in the second study, the decision aid prepares a comparison of expected returns from treating an animal compared with estimated returns to culling the animal without AIP treatment, along with probabilities of AIP treatment outcomes as described in the third study.

Table of Contents

List of Figures

List of Tables

Acknowledgements

First, I would like to acknowledge my co-major advisors, Dustin Pendell and Ted Schroeder, and offer my sincerest gratitude for their patience, support, and guidance throughout my time at Kansas State. It has been a privilege to learn from you, and I cannot thank you enough for your mentorship and encouragement in all things. I would also like to thank my committee members, Glynn Tonsor and Phillip Lancaster, for their guidance and support throughout the writing of this dissertation. I would also like to extend my thanks to the Beef Cattle Institute and Center for Outcomes Research and Epidemiology for providing opportunities to network and expand my research. Finally, I would like to express my appreciation for my family and friends, especially my parents. I feel so blessed to have had your love and support, and I truly could not have done this without you.

1 Introduction

Cattle production is a major contributor to the U.S. agricultural economy, accounting for more than $108 billion in cash receipts in 2024 (USDA ERS, 2024). Approximately 11.8 million head of cattle were on feed in U.S. feedyards as of January 1, 2025 (USDA NASS, 2025), and most of these are located in the U.S. Great Plains region. In addition to being one of the leading countries in beef production, the U.S. is among the top beef exporters. Through the use of feeding technologies and improvements in animal health care, the U.S. cattle feeding industry has increased production efficiency. However, livestock disease, increasing cost of inputs, and regulatory policy still pose significant challenges for U.S. cattle feedyards. There remains a need for scientific and economic research providing timely insights for operators and feedyard managers to ensure the sustainability of the U.S. cattle feeding industry.

Environmental sustainability has become a large focus in agricultural research and policy, with the U.S. EPA reporting that production agriculture accounts for approximately 9.4% of U.S. greenhouse gas (GHG) emissions (U.S. EPA, 2025). Because cattle have been identified as a major source of agricultural GHG emissions, the U.S. beef industry is under pressure to reduce supply chain emissions. Feedyards primarily contribute to carbon dioxide, methane, and nitrous oxide emissions. In an effort to reduce beef supply chain emissions, the United States Roundtable for Sustainable Beef (USRSB) has set a target to reduce feedlot GHG emissions intensity by 10% by 2030 (U.S. Roundtable for Sustainable Beef, 2022). One recent study suggests that reducing disease prevalence has the potential to reduce GHG emissions intensity (Capper, 2023). Feeding technologies such as growth implants have also been shown to improve feed efficiency and reduce GHG emissions intensity (Cooprider et al., 2011; Crawford et al., 2022). However, in order to remain profitable, these technologies must be managed effectively.

The USRSB also identifies animal health as a key component of sustainability in beef feedyards. Effective management of feedyard diseases, such as respiratory illnesses, is imperative to reduce death loss and increase efficiency of cattle production. Bovine respiratory disease (BRD) is by far the most common and costly feedlot disease, affecting approximately 16% of U.S. feedlot cattle each year (USDA APHIS, 2013). Caused by viral and bacterial pathogens, BRD typically affects younger cattle early in the feeding period and is often managed with antimicrobials. Another respiratory illness faced in cattle feedyards is acute interstitial pneumonia (AIP). Approximately 3% of U.S. feedyard cattle are affected by AIP annually, and AIP is described as being the second-most important respiratory illness impacting cattle feedyards (Amosson et al., 2006). Unlike BRD, AIP typically occurs in cattle later in the feeding period. Additionally, the cause of AIP is largely unknown, making it difficult to effectively treat.

Concerns surrounding GHG emissions intensity, feeding efficiency, and animal health are exacerbated by the concentration of cattle in feedyards. This dissertation explores the economic implications of cattle performance and disease management in feedyards in the U.S. Great Plains. Specifically, we estimate the effects of cattle performance management strategies on net returns and greenhouse gas emissions, concurrently. Additionally, we estimate returns from cattle diagnosed ante-mortem and post-mortem with AIP and conduct a retrospective study of risk factors associated with probability of treatment outcomes, including prior BRD treatment. Finally, we develop a spreadsheet-based decision aid to assist operators with management of cattle diagnosed with AIP.

While previous research has linked cattle performance to feedyard net returns and greenhouse gas emissions, none have evaluated concurrent economic and environmental effects of combined management practices. Chapter 2 uses operational feeding data from nine Midwestern feedyards, collected from 2018 through 2021, to examine how alternative cattle feeding management decisions impact both net returns and greenhouse gas emissions. We use established procedures to estimate the effects of changes in mortality and growth implant protocols on feedyard net returns. We then propose new methods for estimating concurrent impacts to feedyard greenhouse gas emissions. We find that reducing mortality consistently increases net returns while reducing greenhouse gas emissions intensity. Additionally, our findings indicate that using two growth implants compared to one has potential for simultaneous improvement of both net returns and greenhouse gas emissions intensity. Differentiating practices that increase net returns with the added benefit of reducing greenhouse gas emissions within the feedyard will provide industry leaders with information that could allow for achievement of both economic and environmental targets.

There is limited research evaluating the economic impacts of AIP, despite potential for great economic losses due to late occurrence in feedyard cattle. Chapter 3 uses operational feeding data and individual treatment records from nine Central U.S. high plains feedyards, collected from 2019 through 2023, to estimate net returns from feedyard cattle identified with AIP. A decision tree framework is implemented to estimate net returns for cattle that were identified with AIP ante-mortem and post-mortem. Cattle evaluated in this study were either found dead in the pen, finished with their cohort, were culled, or died following AIP treatment. We find that expected returns from cattle receiving any number of AIP treatments are less than expected returns for healthy cattle. On average, heifers finishing with their cohort following AIP treatment remain profitable across all placement weights. Expected returns from treating cattle identified with AIP are largely negative, but still greater than estimated returns from culling. However, this analysis only considers variation in economic outcomes and does not evaluate factors that rationalize differences in specific treatment outcomes. We address this challenge in Chapter 4.

The cause of AIP is widely unknown, and few studies have investigated risk factors associated with outcomes from AIP. Chapter 4 utilizes operational feeding data and individual treatment records from nine Central U.S. high plains feedyards, collected from 2019 through 2023, to examine predictors of treatment outcomes for cattle diagnosed with AIP ante-mortem. Mixed-effects logistic models are employed to estimate the probability of first AIP treatment failure (PFTF) and the probability that an animal would fail to finish with its cohort following AIP treatment (PDNF). We find that steers and lightweight cattle had increased PFTF and PDNF. We also find that prior BRD treatment, days on feed at first AIP treatment, and risk days remaining are significantly associated with PFTF and PDNF. While this analysis provides valuable insights into factors associated with terminal outcomes of feedyard cattle treated for AIP, additional clinical parameters and metaphylaxis treatment were not available in the data used for this analysis and should be considered in future evaluation of risk factors linked to AIP treatment outcomes.

Chapter 5 describes a spreadsheet-based decision aid developed based on the methods and findings from Chapter 3 and Chapter 4. This decision aid is developed to support the management of feedyard cattle identified with AIP. Using operational information provided by the user, this decision aid computes probabilities of first AIP treatment failure and failure to finish as described in Chapter 4. Following methods outlined in Chapter 3, the output from this decision aid prepares a comparison of expected returns from treating an animal compared with estimated returns to culling the animal without AIP treatment. This decision aid was developed specifically for use in cattle feedyards by operators for the management of AIP.

Each of the chapters contributes to the existing literature on the economics of cattle feeding and feedyard disease management as stand-alone studies. However, it is the intent of these studies to show the harmonizing nature of economic efficiency, animal health, and environmental sustainability in cattle feeding. This dissertation seeks to provide practical information to assist in the rationalization of common management decisions faced by cattle feedyard managers or decision makers. This information taken together can be used to justify the use of feeding technologies to improve production efficiency and strategies to reduce morbidity in cattle feedyards.

2 Effects of Mortality and Growth Implant Use on Feedlot Net Returns and Greenhouse Gas Emissions

2.1 Introduction

Sustainability has become a prevalent topic in agricultural research and policymaking, focusing on the intersection of environmental impacts, economic profitability, and social preferences. With air quality and greenhouse gas (GHG) emissions leading the conversation, major food industry firms have committed to reducing supply chain emissions and pledged to become carbon neutral within the next two decades (JBS Foods, n.d.; McDonald’s, n.d.; Tyson Foods, 2021). Additionally, livestock have been identified as important contributors to methane and nitrous oxide emissions (U.S. EPA, 2024c). The United States leads the world in beef production, and beef cattle production consistently accounts for the largest share of total cash receipts for U.S. agricultural commodities (USDA ERS, 2023). The value of beef production in the United States bring the social and environmental impacts of these operations to the forefront of agricultural sustainability. Industry goals to reduce beef value chain emissions affect every segment of the supply chain, especially producers. How production practices and technologies simultaneously affect economic viability and environmental sustainability of feedlot operations is essential information for producers managing emissions. Further, assessing incremental effects of altering management strategies is important to ensure that feedlots remain profitable while supporting industry goals for emissions reduction. This study is designed specifically to address this issue.

While previous research has linked cattle performance to feedlot net returns and GHG emissions, none have evaluated the concurrent economic and environmental effects of combined management practices (Brooks et al., 2011; Cooprider et al., 2011; Crawford et al., 2022; Irsik et al., 2006; Jones et al., 1996; Mark, Schroeder & Jones, 2000; Stackhouse-Lawson et al., 2013; Swanson & West, 1963; Trapp & Cleveland, 1989). The primary objective of this study is to estimate how mortality and growth implant use affect economic returns and GHG emissions intensity of cattle feeding.

Practices that advance cattle performance, such as improved health outcomes or growth implants used in animal production to stimulate growth and increase efficiency, may improve both economic and environmental robustness of cattle feeding operations. Practices that increase net returns through improved cattle performance may also reduce GHG emissions intensity in cattle feeding. This analysis utilizes methods established in the literature to estimate the effects of changes in mortality and growth implant protocols on net returns and proposes methods for estimating concurrent impacts to feedlot GHG emissions per pound of dressed beef produced.

Meeting industry goals to reduce supply chain emissions requires an understanding of how operational decisions impact net GHG emissions. However, demonstrating potential emissions reductions may not be enough to incentivize producers to alter management strategies or implement new protocols. Investigating concurrent impacts to net returns and GHG emissions could incentivize producers to pursue emissions-reducing practices. This analysis illustrates combined economic and environmental impacts of mortality and growth implant strategies. Results reveal that reducing mortality and using growth implants can simultaneously increase feedlot net returns and reduce GHG emissions per pound of dressed beef produced.

2.2 Background

The U.S. Environmental Protection Agency categorizes GHG emissions as Scope 1, Scope 2, and Scope 3 (U.S. EPA, 2024a; U.S. EPA, 2024b). Scope 1 and 2 emissions are those produced directly and indirectly, respectively, from sources owned or controlled by the organization. Scope 3 emissions are the result of activities within the organization's value chain that are not directly within the control of the organization[1] (U.S. EPA, 2024a; U.S. EPA, 2024b). For beef processors and retailers, on-farm activities are Scope 3 emissions. Thus, industry goals to reduce beef value chain emissions inevitably affect each segment of the supply chain, including producers and stakeholders. The most notable greenhouse gases in beef cattle production are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). GHG emissions can be described as carbon dioxide equivalents (CO_2e), an aggregate measure of GHG emissions in terms of the 100-year global warming potential (GWP) of carbon dioxide (Lynch, 2019). Identifying environmentally friendly management practices that are economically feasible and measuring impacts of these practices are essential for ensuring the continuity of the beef supply chain.

The United States Roundtable for Sustainable Beef (USRSB) has developed industry-wide sustainability goals and identified metrics for monitoring continuous improvement in beef production. Further, the USRSB has set a goal to reduce feedlot GHG emissions by 10% per pound of dressed beef produced before 2030 (U.S. Roundtable for Sustainable Beef, 2022). Economic viability and optimized animal productivity are central to the mission of the USRSB. In feedlots, improved closeout performance and healthier animals are indicative of achieving desired outcomes (U.S. Roundtable for Sustainable Beef, 2022). Feeder cattle performance metrics, such as average feed conversion (AFC) and average daily gain (ADG), are highly dependent upon animal health and diet (Irsik et al., 2006; Belasco Cheng & Schroeder, 2015). Although feeder and fed cattle prices account for much of the variation in net returns to cattle feeding, research has long linked cattle performance to returns to management (Brooks et al.,

[1] The term organization is used here to generally refer to the entity, business, firm, etc. whose emissions are being identified.

2011; Irsik et al., 2006; Jones et al., 1996; Mark, Schroeder & Jones, 2000; Swanson & West, 1963; Trapp & Cleveland, 1989). Researchers have also shown that more efficient cattle create fewer emissions (Broocks et al., 2016; Cooprider et al., 2011; Stackhouse-Lawson et al., 2013).

The implications of using growth implants are of particular interest in this study. Use of growth implants increases feed efficiency and average daily gain (Crawford et al., 2022; Smith & Johnson, 2020; Wileman et al., 2009). Additionally, growth promoting technologies may reduce feedlot GHG emissions per pound of dressed beef produced (Crawford et al., 2022; Stackhouse-Lawson et al., 2013; Stackhouse-Lawson et al., 2012; Webb et al., 2020). In June 2023, the U.S. Food and Drug Administration implemented a clarification concerning the use of growth implants in beef cattle production systems. The clarification states that cattle may be administered only one growth implant per production phase unless the implant is specifically labelled for reimplantation (US FDA, 2023a). As of August 2023, there were 20 commercial implants labelled for use in growing beef cattle fed in confinement for slaughter. However, only five implants were labelled for reimplantation at the time, and approved reimplantation programs do not allow for use of more than two growth implants in cattle fed in confinement for slaughter (US FDA, 2023b). Thus, producers opting for use of multiple implants during the feeding phase are limited in the selection of implants available for use in a reimplantation program. Findings from this study have important implications for policymakers and producers regarding the number and potencies of growth implants used to manage beef cattle fed in confinement for slaughter.

2.3 Data and Methods

This study utilizes proprietary pen-level closeout data for cattle from nine Midwestern feedlots from 2018 through 2021. The data are stratified by placement weight and sex, including

7,813 pens (960,658 head) of beef steers and heifers entering the feedlot between 400 and 1,000 lbs. Mean descriptive statistics are reported in Table 2.1. Summary statistics for data stratified by sex are reported in Appendix Table A.1. Weight categories are determined to evaluate lightweight (400-599 lbs.) and heavyweight (900-1000 lbs.) placed cattle. Steers placed at 400-599 lbs. and heifers placed at 900-1000 lbs. are excluded from the analysis due to insufficient observations[2].Cattle purchase and sale prices are not available in the feedlot data, so average prices for the closeout period were used as proxies. Feeder cattle purchase prices, dressed carcass prices, and 5-area carcass premiums and discounts are obtained from the Livestock Marketing Information Center (LMIC, 2023). Weekly corn prices for the corresponding states where cattle were fed serve as a proxy for feed prices, and feed prices used to calculate net returns are based on week of arrival (LMIC, 2023). Annualized quarterly interest rates were used to estimate interest costs (Federal Reserve Bank of Kansas City, 2024). Yardage cost was assumed at \$0.40/head/day (Dennis et al., 2020).

[2] Cattle were grouped by sex and placement weight for this analysis. Groups of cattle with fewer than 250 observations (pens) were excluded from this analysis to ensure statistical reliability and stability of models. Pens of steers placed at 400-599 lbs. (n = 146) and heifers placed at 900-1000 lbs. (n = 215) were excluded from this analysis.

Table 2.1. Mean Descriptive Statistics for Pen-Level Operational Feedlot Data

	Placement Weight (lbs.)					
Variable Description	400-599	600-749		750-899		900-1000
	Heifers	Heifers	Steers	Heifers	Steers	Steers
Observations (pens)	346	1987	927	2085	1895	573
Placement Weight (lbs.)	553	688	690	807	824	939
Sale Weight (lbs.)	1181	1232	1358	1281	1421	1460
Days on Feed	206	165	189	138	158	136
Average Daily Gain (lbs./day)	2.97	3.22	3.45	3.34	3.71	3.78
Feed Conversion (lbs. feed/lbs. gain)	6.21	6.35	6.10	6.57	6.18	6.35
Health Cost ($/head)	33.02	24.25	28.06	19.43	19.88	17.72
Mortality (proportion)	0.029	0.020	0.024	0.013	0.014	0.009
Cull (proportion)	0.007	0.007	0.008	0.004	0.004	0.003
Carcass Weight (lbs.)	759	789	871	818	906	929
One Implant (0, 1)	0	0.03	0.03	0.03	0.03	0.12
Two Implants (0, 1)	0.40	0.91	0.95	0.97	0.97	0.88
Three or more Implants (0, 1)	0.60	0.06	0.02	0	0	0
Moderate Potency Implant Protocol (0,1)	0.997	0.98	0.68	0.98	0.87	0.77
High Potency Implant Protocol (0,1)	0.003	0.02	0.32	0.02	0.13	0.23
Feeder Price ($/lb.)	1.47	1.36	1.49	1.31	1.41	1.36
Dressed Price ($/lb.)	1.89	1.89	1.85	1.89	1.85	1.85
Yardage Cost ($/head)	82.49	66.04	75.65	55.28	63.18	54.23
Feeding Cost ($/head)	278.75	273.89	295.74	262.56	283.08	261.24
Interest Cost ($/head)	33.88	29.17	37.47	26.43	34.16	31.29
Net Return ($/head)	158.24	136.55	114.00	109.74	90.53	65.49

Cattle performance metrics vary modestly across placement weights, with mean average daily gain (ADG) ranging from 2.97-3.34 lbs./head/day for heifers and 3.45-3.78 lbs./head/day for steers. Average feed conversion (AFC) ranges from 6.21-6.57 lbs. of feed dry matter per lb. gain for heifers and 6.10-6.35 for steers. Average health costs per head are reported for each pen, however the allocation of health costs across preventative vs. treatment measures is unknown. Health costs and mortality are higher for lightweight cattle, which is expected due to increased health risk and time spent in the feedlot.

Implant potency protocol refers to the dose and combination of hormones in the implants used. Implant potency is defined as low (< 200mg progesterone/testosterone), moderate (≥ 200mg progesterone/testosterone or < 200mg trenbolone acetate), or high (≥ 200mg trenbolone acetate). These potencies were determined following Beck et al., (2022) in addition to consultation with veterinary professionals. Low potency implants are rarely utilized by the feedlots represented in this data; thus, only cattle receiving moderate and high potency implants are included in this study (Appendix Table A.2). Most cattle received two implants in the feedlot, with the exception of heifers placed at 400-599 lbs., and a larger proportion of steers received high potency implants compared to heifers (Table 2.1).

Feedlot GHG emissions were estimated by UpLook v1.0, a commercially available GHG emissions modeling software, using IPCC guidelines. The Integrated Farm Systems Model (IFSM) was used to validate emission estimates used, using a random sample of 500 pens from the data. GHG emissions estimates reported in the data and those estimated using the IFSM are highly correlated (0.96), providing confidence in the use of pen-level feedlot GHG emissions estimates given in the data for our analysis.

Total GHG emissions are described as non-feedlot emissions (emissions from cow-calf/backgrounding phase of production) and feedlot emissions. Average feedlot GHG emissions (kg CO_2e) per head are reported in Figure 2.1 (Appendix Table A.3). Animals of the same sex placed at lighter-weights, naturally have larger feedlot GHG emissions due to longer time on feed and greater feed consumption compared to heavy-weight placements. For example, for heifers, feedlot GHG emissions per head decline by 11% in going from 400-599 lb. to 600-749 lb. placement weights and another 9% from 600-749 lb. to 750-899 lb. placement. Steers tend to have higher feedlot GHG emissions per head than heifers of similar placement weight.

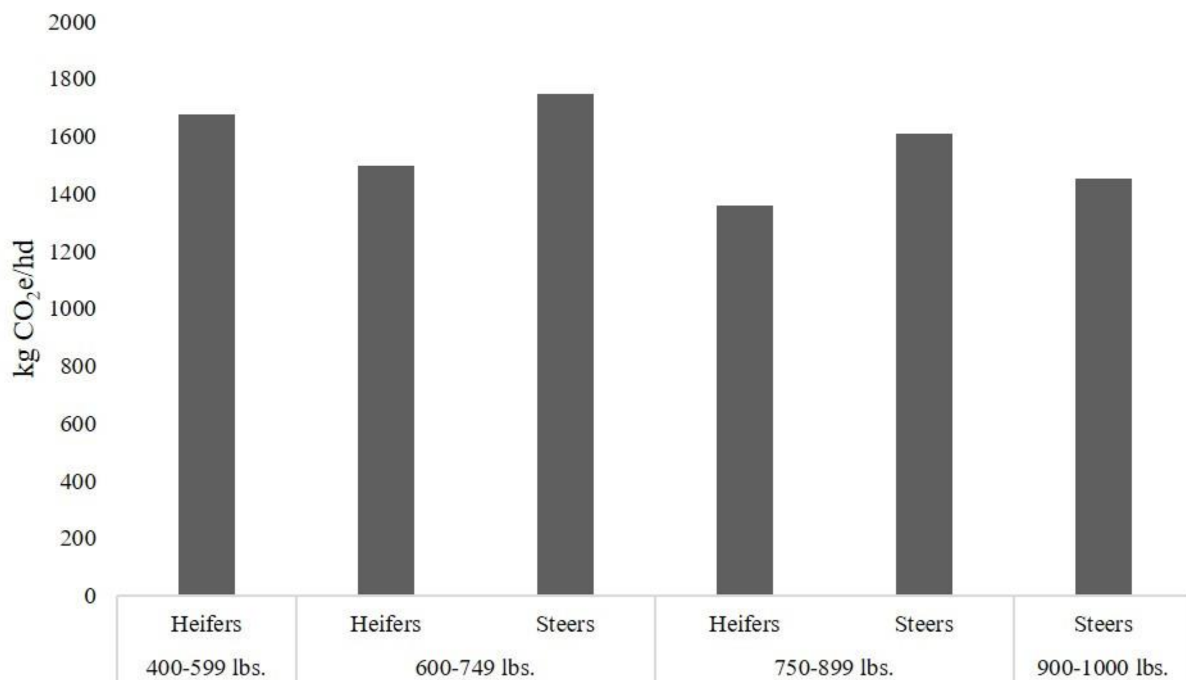

Figure 2.1. Average Feedlot GHG Emissions (kg CO2e) per head, by placement weight and sex. GHG emissions are estimated by Uplook v1.0.

Average feedlot GHG emissions (kg CO_2e) per pound of dressed beef produced are reported in Figure 2.2 (Appendix Table A.3). Consistent with per head values, feedlot GHG emissions intensity is higher for steers compared to heifers of similar placement weight when assessed on a per pound of dressed beef produced. For animals of the same sex, feedlot GHG emissions intensity decreases as placement weight increases. For example, for heifers, feedlot GHG emissions per pound of dressed beef produced decline by 15% in going from 400-599 lb. to 600-749 lb. placement weights and another 13% from 600-749 lb. to 750-899 lb. placement.

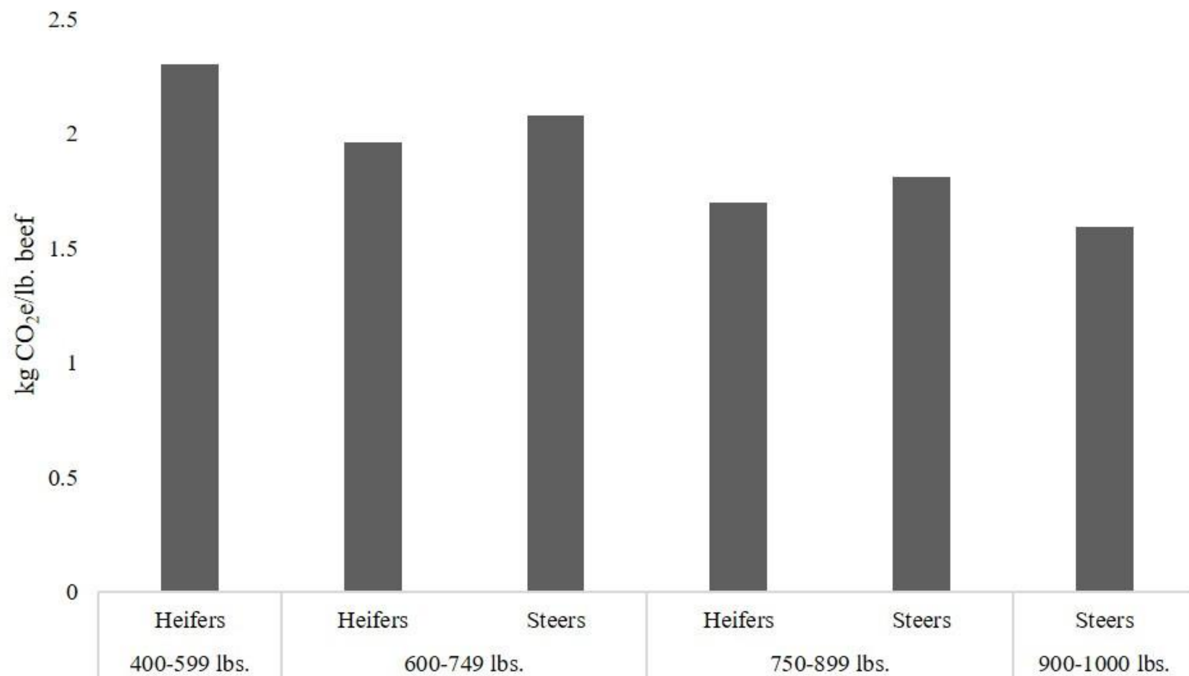

Figure 2.2. Average Feedlot GHG Emissions (kg CO2e) per pound of dressed beef produced, by placement weight and sex. GHG emissions are estimated by Uplook v1.0.

While it is well established that cattle feeding net returns vary across management and animal health protocols, the impacts of management practices on GHG emissions and other environmental factors are less documented. This study estimates the effects of mortality and growth implant protocol on average feed conversion (AFC) and average daily gain (ADG), as well as effects of cattle performance on feedlot GHG emissions intensity. Estimated AFC and ADG are used to calculate net returns and predict GHG emissions per pound of dressed beef produced for various management scenarios. Varying levels of mortality are used to illustrate changes in animal health management, and changes in the number of implants used and implant potency are used to illustrate changes in animal productivity management. This analysis is concerned with the potency of the final two implants received in the feeding phase. Moderate potency protocol indicates an animal received a moderate potency implant followed by a moderate or high potency implant. High potency protocol indicates an animal received a high potency implant followed by a moderate or high potency implant. Irsik et al. (2006) estimated AFC and ADG models and assessed impacts of different treatments on performance of feedlot cattle. Here, the primary effects of interest are mortality, number of implants used, and potency of implants used. Building from the methods in Irsik et al. (2006), we model AFC and ADG as (individual pen subscripts *i* are omitted for simplicity):

$$AFC = \beta_0 + \beta_1 \ln(CPW) + \beta_2(MORT \cdot 100) + \beta_3 HC + \beta_4 T_1 + \beta_5 T_3 + \alpha_m \cdot P_m + \sum_{n=2}^{9} \gamma_n \cdot F_n + \sum_{j=2}^{4} \delta_j \cdot D_j + \varepsilon \tag{2.1}$$

$$ADG = \beta_0 + \beta_1 \ln(CPW) + \beta_2(MORT \cdot 100) + \beta_3 HC + \beta_4 T_1 + \beta_5 T_3 + \alpha_m \cdot P_m + \sum_{n=2}^{9} \gamma_n \cdot F_n + \sum_{j=2}^{4} \delta_j \cdot D_j + \varepsilon \tag{2.2}$$

Variables included in AFC, ADG, and Net Return (NR) equations are defined in Table 2.2. The natural logarithm of CPW, cattle placement weight, is used in the models following prior research (Belasco et al., 2009) and because we expect a nonlinear relationship between placement weight and these independent variables. Because most cattle receive two implants in the feedlot, we evaluate the effects of receiving one growth implant (T_1) and three growth implants (T_3) compared to receiving two growth implants (T_2 = base). There is little variability in the implant potency protocol for heifers as nearly all received two implants. Implant potency protocol is not included in estimation of cattle performance metrics for heifers, due to multicollinearity between implant potency protocol and number of implants received. For steers, inclusion of implant potency protocol does not introduce multicollinearity and is thus included in model estimation. One limitation of this analysis is lack of genetic information for cattle included in the data. We include fixed effects to account for variation across feedlots, as well as placement quarter fixed effects to account for seasonality. Expected changes in AFC (Eq. 1) are used to predict changes in net returns. The methods of Dennis et al. (2020) are modified to calculate net returns per head as:

$$NR = TR - FDRC - YC - FC - HC - IC \tag{2.3}$$

where total revenue (TR), feeder cattle cost (FDRC), yardage cost (YC), feeding cost (FC), and interest cost (IC) are defined as (HC, health costs are used directly as reported in the data set):

$$TR = DP \cdot avgcarcwt \cdot (1 - MORT - CULL) + (CULL \cdot CULLW \cdot CULLP) \tag{2.4}$$

$$FDRC = FRP \cdot CPW \tag{2.5}$$

$$YC = 0.4 \cdot DOF \tag{2.6}$$

$$FC = FEED \cdot (AFC \cdot (CSW \cdot (1 - MORT - CULL) - CPW)) \tag{2.7}$$

$$IC = (0.5 \cdot (YC + FC + HC) + FDRC) \cdot DOF \cdot \left(\frac{IR}{365}\right) \tag{2.8}$$

Researchers have linked cattle performance to GHG emissions, and recent literature has established more efficient cattle produce fewer emissions (Crawford et al., 2022; Cooprider et al., 2011; Stackhouse-Lawson et al., 2013). We estimate feedlot GHG emissions per pound of dressed beef produced (FLGHG) as a function of AFC, ADG, and days on feed (DOF). Expected changes in AFC and ADG due to altered management practices (Eq. 1-2) are used to predict changes in FLGHG. Feedlot fixed effects are included to account for differences in GHG emissions intensity across feedlots such as energy use.

$$FLGHG = \beta_0 + \beta_1 DOF + \beta_2 AFC + \beta_3 ADG + \sum_{n=2}^{9} \gamma_n \cdot F_n + \varepsilon \tag{2.9}$$

Table 2.2. Feeding Net Return Variables

Variables	Description	Calculation
ADG	Average daily gain during feeding (lb./head/day)	
AFC	Average pounds of feed consumed per pound of weight gain (lbs. feed/lbs. gain)	
T_k	Number of growth implants (*k*=one, two (base), three or more)	
P_m	Implant potency protocol (*m*=moderate, high (base))	
F_n	Feedlot fixed effects (*n*=1(base) to 9)	
D_j	Placement quarter effects (*i*=1 (base) to 4)	
DOF	Number of days on feed (days)	
FC	Feed cost ($/head)	See Eq. 2.7
HC	Animal health care cost ($/head)	
IC	Interest cost ($/head)	See Eq. 2.8
MORT	Mortality as a proportion	
Mortality	Mortality as a percentage	
CULL	Proportion culled from pen	
CULLW	Average sale weight of culled (lb./head)	
CULLP	Average sale price of culled ($/lb.)	
TR	Total revenue from cattle sales ($/head)	See Eq. 2.4
YC	Yardage cost of feeding cattle ($/head)	See Eq. 2.6
CPW	Cattle placement weight (lb./head)	
CSW	Finished animal weight (lb./head)	
avgcarcwt	Average dressed carcass weight (lb./head)	
FDRC	Feeder cattle purchase cost ($/head)	See Eq. 2.5
FRP	Feeder cattle purchase price ($/lb.)	
FEED	Corn price when cattle are on feed ($/lb.)	
DP	Dressed carcass price ($/lb.)	
IR	Annualized interest rate	
NR	Net returns to cattle feeding ($/head)	See Eq. 2.3

2.4 Results and Discussion

Analyses are conducted across four placement weight categories.[3] Average placement weight for the entire sample is approximately 750 lbs. Most observations (88%) fall into weight categories of 600-749 lbs. and 750-899 lbs. Regression results for each model are reported in the following sections. Robust standard errors are estimated to account for potential heteroskedasticity.

Feed Conversion and Average Daily Gain Models

Table 2.3 and Table 2.4 provide parameter estimates for the average feed conversion (2.1) and average daily gain (2.2) models. Complete results including feedlot fixed effects and quarterly placement effects for AFC and ADG models are reported in Appendix Table A.4 and Table A.5, respectively. The effect of placement weight on AFC is positive and statistically significant for heifers and steers placed at 600-749 lbs. and 750-899 lbs., indicating that cattle placed at lighter weights are more efficient than heavier placements over their time on feed. The effect of placement weight on ADG is greater for heifers placed at 400-599 lbs. compared to heifers placed at heavier weights; however, a greater proportion of these cattle received three or more implants compared to other groups of cattle. As expected, AFC increases with mortality, while ADG decreases. For heifers and steers placed at 750-899 lbs., a one percentage point increase in mortality (e.g., increase from 1% to 2%) is associated with a 0.09 lb. decrease in ADG.

Effects of health costs on AFC and ADG vary across sex and placement weight. For example, a one dollar increase in health cost per head is associated with a 0.001 lb. decrease in

[3] Analyses were also conducted using head-weighted data, which yielded results that were qualitatively identical to those presented here.

ADG for heifers placed at 600-749 lbs. However, a one dollar increase in health cost per head is associated with a 0.003 lb. increase in ADG for steers placed at 750-899 lbs.

Table 2.3. Results for AFC (feed conversion) model (lb. dry feed/lb. gain)[a]

	Placement weight (lbs.)					
	400-599	600-749		750-899		900-1000
	Heifers	Heifers	Steers	Heifers	Steers	Steers
ln(CPW)	0.707**	1.432***	1.491***	1.881***	1.637***	1.101
	(0.278)	(0.187)	(0.272)	(0.236)	(0.198)	(0.808)
MORT·100	0.133***	0.114***	0.108***	0.172***	0.158***	0.174***
	(0.013)	(0.008)	(0.008)	(0.013)	(0.013)	(0.026)
HC	-0.006***	0.0003	-0.004***	-0.003	-0.004**	-0.009
	(0.002)	(0.001)	(0.001)	(0.003)	(0.002)	(0.006)
One implant		0.435***	0.484**	0.269**	0.335***	0.231*
		(0.091)	(0.188)	(0.137)	(0.118)	(0.120)
Three or more implants	-0.037	-0.021	0.082			
	(0.062)	(0.061)	(0.104)			
Moderate potency protocol			-0.112**		0.056	0.107
			(0.052)		(0.037)	(0.077)
Feedlot Fixed Effects	Y	Y	Y	Y	Y	Y
Placement Quarter Fixed Effects	Y	Y	Y	Y	Y	Y
Constant	1.414	-3.093**	-3.785**	-6.027***	-4.902***	-1.106
	(1.767)	(1.237)	(1.772)	(1.598)	(1.344)	(5.534)
R^2	0.581	0.391	0.443	0.344	0.459	0.320
RMSE	0.398	0.430	0.420	0.479	0.429	0.484
Observations	346	1987	927	2085	1895	573

[a] Standard error in parentheses = * p<0.10, ** p<0.05, *** p<0.01.

Most cattle received two implants in the feedlot. However, the updated U.S. FDA ruling on use of growth implants in cattle production states that cattle may be administered only one growth implant per production phase unless the implant is specifically labelled for reimplantation (US FDA, 2023a), and there are few approved reimplantation programs for cattle grown in confinement for slaughter (US FDA, 2023b). Including effects of one implant versus two implants provides insight on potential impacts to cattle performance of the number of implants administered to feedlot cattle. AFC increases and ADG decreases for cattle receiving one implant compared to two implants, indicating that a second implant may improve performance of feedlot cattle. On average, steers placed at 600-749 lbs. or 750-899 lbs. receiving one implant gain 0.2 lbs. less per day compared to those receiving two implants. However, a third implant is not associated with an improvement in cattle performance. On average, steers placed at 600-749 lbs. receiving three or more implants gain 0.18 lbs. less per day compared to those receiving two implants.

Table 2.4. Results for ADG (average daily gain) model (lb. per day)[a]

	Placement weight (lbs.)					
	400-599	600-749		750-899		900-1000
	Heifers	Heifers	Steers	Heifers	Steers	Steers
ln(CPW)	0.838***	0.683***	0.906***	0.299*	0.587***	0.869
	(0.182)	(0.123)	(0.222)	(0.168)	(0.165)	(0.672)
MORT·100	-0.060***	-0.066***	-0.064***	-0.095***	-0.091***	-0.113***
	(0.006)	(0.003)	(0.005)	(0.006)	(0.005)	(0.017)
HC	-0.00001	-0.001**	-0.0001	0.002	0.003***	0.008**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.004)
One implant		-0.199***	-0.203**	-0.122	-0.204***	-0.121
		(0.054)	(0.091)	(0.075)	(0.068)	(0.085)
Three or more implants	-0.048	-0.033	-0.182**			
	(0.041)	(0.029)	(0.080)			
Moderate potency protocol			0.071*		-0.131***	-0.124**
			(0.037)		(0.031)	(0.057)
Feedlot Fixed Effects	Y	Y	Y	Y	Y	Y
Placement Quarter Fixed Effects	Y	Y	Y	Y	Y	Y
Constant	-2.036*	-1.095	-2.263	1.356	-0.061	-2.172
	(1.163)	(0.808)	(1.446)	(1.127)	(1.117)	(4.601)
R^2	0.471	0.340	0.397	0.247	0.253	0.186
RMSE	0.269	0.297	0.313	0.342	0.365	0.414
Observations	346	1987	927	2085	1895	573

[a] Standard error in parentheses = * p<0.10, ** p<0.05, *** p<0.01.

Implant potency protocol is excluded from heifer performance estimation due to multicollinearity. Reduced potency of implants used in the feedlot is associated with a 0.07 lb. increase in ADG and 0.1 lb. decrease in AFC for steers placed between 600-749 lbs. However, reduced potency of implants is associated with a 0.13 decrease in ADG and an insignificant increase in AFC for steers placed between 750-899 lbs.

2.4.1 Greenhouse Gas Emissions Model

Results for feedlot greenhouse gas emissions models ((2.9) are reported in Table 2.5.[4] To maintain confidentiality of third-party provided emissions predictive models, only signs and statistical significance of coefficients of interest can be reported. The models each explain 79% or more of variation in GHG across pens of cattle. Coefficients for days on feed (DOF), average feed conversion (AFC), and average daily gain (ADG) are all positive and statistically significant ($p<0.01$) across placement weight and animal sex models.

Table 2.5. Sign of Coefficients and Goodness of Fit Measures for Feedlot GHG Emissions Models[a]

	Placement Weight (lbs.)					
	400-599	600-749		750-899		900-1000
	Heifers	Heifers	Steers	Heifers	Steers	Steers
DOF	+	+	+	+	+	+
AFC	+	+	+	+	+	+
ADG	+	+	+	+	+	+
Feedlot Fixed Effects	Y	Y	Y	Y	Y	Y
R^2	0.83	0.82	0.82	0.79	0.79	0.87
RMSE	0.092	0.081	0.079	0.075	0.075	0.059
Observations	346	1987	927	2085	1895	573

[a] Effects of DOF, AFC, and ADG are statistically significant at $p<0.01$ across all placement weights. Coefficients are not reported to maintain confidentiality of third-party provided emissions predictive models.

[4] Variance inflation factor tests were conducted for each model to check for concerning levels of multicollinearity. The results of the VIF test indicate that there are not concerning levels of multicollinearity present.

Additional days on feed are associated with a net increase in feedlot emissions per pound of dressed beef produced. The effect of an additional day on feed increases with placement weight as heavier cattle consume more feed, increasing total GHG emissions per day. Higher feed conversion indicates reduced feed efficiency as heavier cattle generally require more feed to maintain weight. Therefore, positive effects of both AFC and ADG on feedlot GHG emissions intensity are as expected.

2.4.2 Effects of Reducing Mortality and Using Growth Implants

Incremental effects are estimated to determine how changes in management practices impact cattle performance metrics, feedlot net returns, and GHG emissions intensity. A one-at-a-time (OAT) method is preferred for this analysis, as it allows for investigation of the effects of changing one independent variable and increases comparability of results across models. A drawback of using OAT is that it fails to consider other input shifts that may occur simultaneously with management practice changes. As a result, point-estimates of changes in variables of interest may be understated or overstated, depending on correlations.

A baseline is established by calculating net returns and estimating GHG emissions intensity for each pen, with dummy variables set to defaults. Point estimates for cattle performance metrics, net returns, and feedlot GHG emissions intensity are calculated using methods previously described in equations 1-9 for various changes in mortality and implant use. Mortality is shocked (25% and 50% decrease) to predict impacts on AFC and ADG, causing changes in net returns and GHG emissions intensity. Similarly, changes in growth implant programs are also evaluated. Since implant potency protocol is concerned with the final two implants received in the feedlot, and the default for number of implants received is two, effects of changing implant potency protocol are compared to the baseline. Health costs are adjusted for scenarios evaluating changes in implant protocol, accounting for cost differences between using one less (more) implant or using implants with reduced potency.[5] Additionally, DOF is adjusted to account for changes in ADG, assuming placement weight and sale weight remain constant.

Incremental effects of reducing mortality and growth implant protocol on net returns and GHG emissions intensity for heifers placed between 750-899 lbs. are reported in Figure 2.3 and Figure 2.4. Incremental effects of reducing mortality for steers placed between 750-899 lbs. are reported in Figure 2.5 and Figure 2.6. Effects for other placement weights are reported in the Appendix (Appendix Figure A.1-Appendix Figure A.8). Reducing mortality simultaneously increases net returns and reduces feedlot GHG emissions intensity, regardless of sex or placement weight. Impacts of changing implant protocol varies between heifers and steers, and across placement weight.

For heifers placed between 750-899 lbs., reducing mortality by 25% and 50% is associated with a $4.64 and $9.37 increase in net returns per head, respectively. As mortality decreases by 25%, associated GHG emissions intensity decreases by approximately 0.003 kgCO_2e/lb. beef or 0.2%. Decreasing the number of implants from two to one is associated with a decrease in net returns of roughly $7.27 per head and an increase in GHG emissions intensity of approximately 0.14 kgCO_2e/lb. beef or 8%. These findings suggest that using a second implant reduces GHG emissions per pound of dressed beef produced. These findings are consistent with Crawford et al. (2022), which finds that although using growth implants may increase total GHG emissions per head, growth implants decrease GHG emissions per pound of hot carcass weight.

[5] Adjustments to health costs were determined by average cost of implant used. Market prices of implants used were obtained from PBS Animal Health (Appendix Table A.2), and chute cost was assumed to be $1.50.

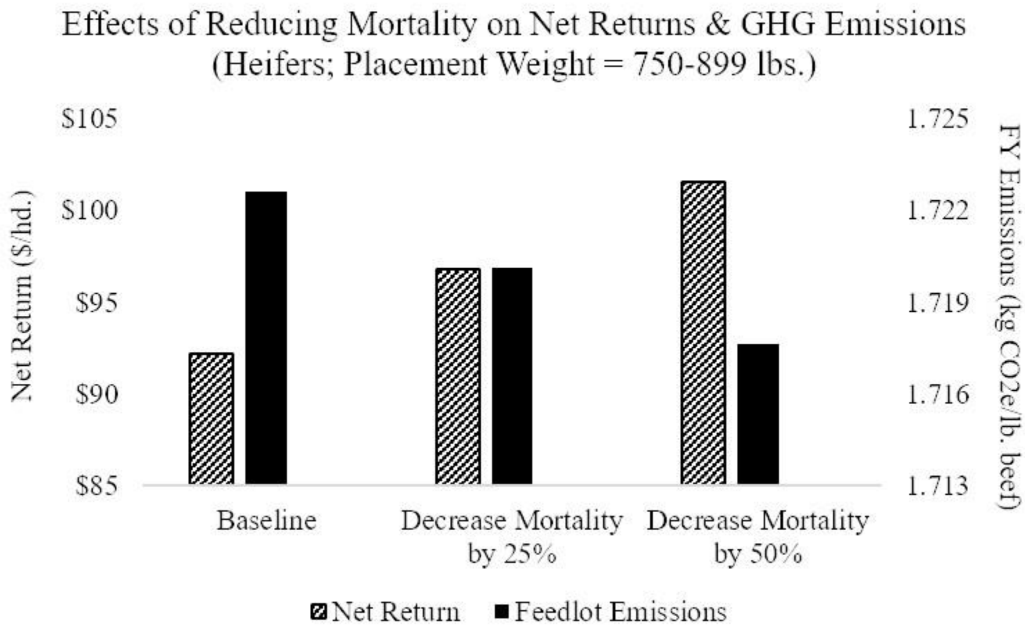

Figure 2.3. Incremental effects of reducing mortality on feedlot net returns and GHG emissions per pound of dressed beef for heifers placed between 750-899 lbs.

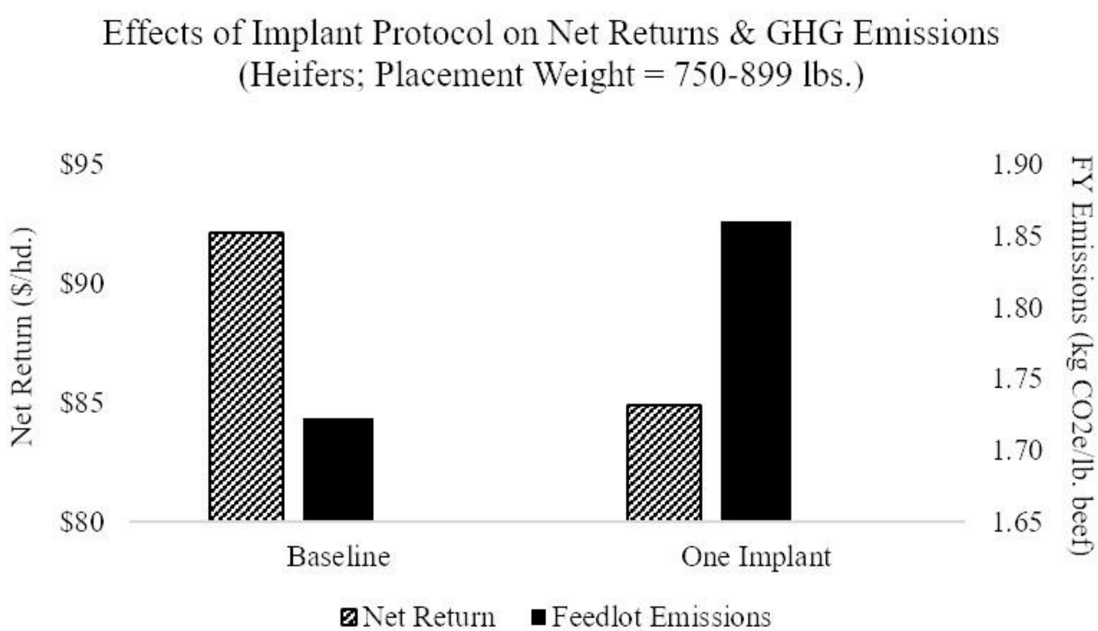

Figure 2.4. Incremental effects of changing the number of growth implants on feedlot net returns and GHG emissions per pound of dressed beef for heifers placed between 750-899 lbs.

For steers placed between 750-899 lbs., reducing mortality by 25% and 50% is associated with a \$5.59 and \$11.31 increase in net returns per head, respectively. As mortality decreases by 25%, GHG emissions intensity decreases by approximately 0.004 $kgCO_2e$/lb. beef or 0.2%. Decreasing the number of implants from two to one is associated with a decrease in net returns of approximately \$10.97 per head, and an increase in GHG emissions intensity of 0.1 $kgCO_2e$/lb. beef or 5%. Moderate potency protocol is associated with approximately a \$2.36 decrease in net returns per head and a 0.02 $kgCO_2e$, or 1%, reduction in GHG emissions intensity, compared to high potency protocol.

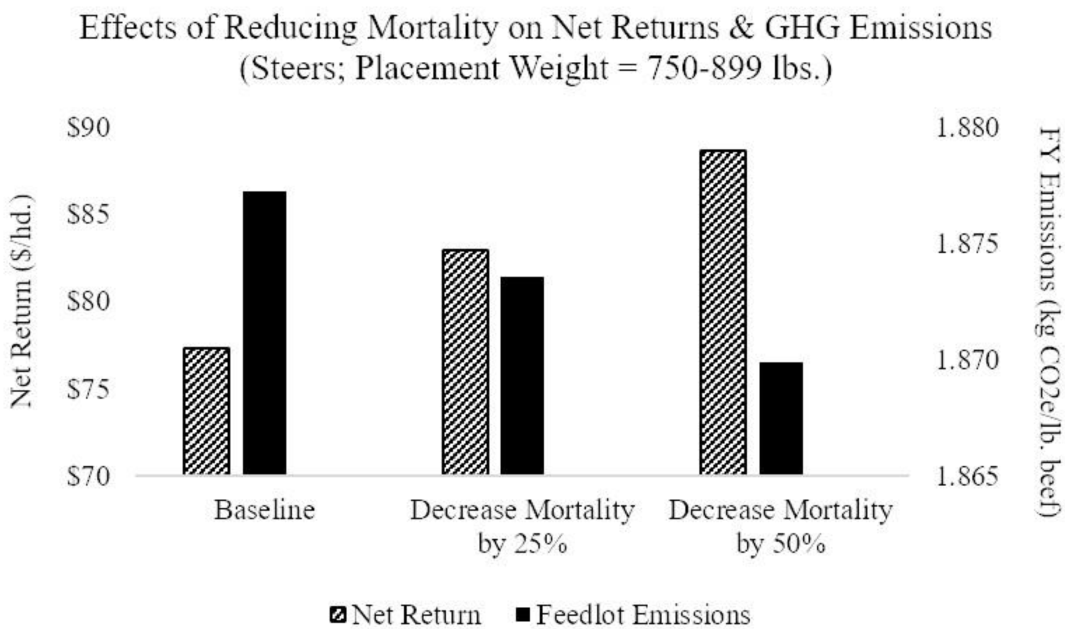

Figure 2.5. Incremental effects of reducing mortality on feedlot net returns and GHG emissions per pound of dressed beef for steers placed between 750-899 lbs.

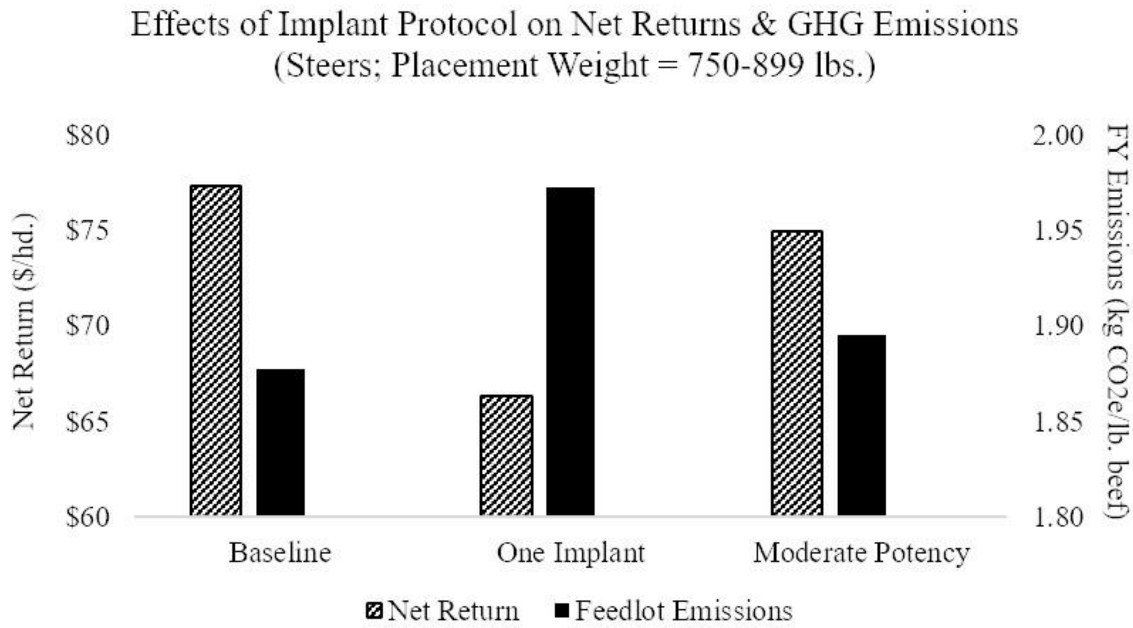

Figure 2.6. Incremental effects of changing the number of growth implants and implant potency on feedlot net returns and GHG emissions per pound of dressed beef for steers placed between 750-899 lbs.

2.5 Conclusions and Policy Implications

Beef industry sustainability goals may affect producer management decisions, which will in turn affect economic and environmental health of the beef value chain. Recent emphasis placed on reducing greenhouse gas emissions in the U.S. beef supply chain creates a need for information regarding emissions-reducing potential of practices enabling producers to remain profitable. The novelty of this analysis is quantification of economic together with environmental impacts of feedlot management strategies. Changes in GHG emissions per pound of dressed beef produced through implementation of various management practices have important implications for policymakers and stakeholders alike.

This study analyzes concurrent effects of mortality and use of growth implants in Midwestern feedlots. Reducing mortality simultaneously increases feedlot net returns and reduces GHG emissions per pound of dressed beef produced. Enhanced cattle health to decrease mortality is one way that GHG emissions intensity might be reduced through better identification, diagnosis, and treatment of sick or injured animals, or procurement strategies to prioritize healthy cattle upon arrival. However, added costs of greater emphasis on animal health must be assessed relative to savings from increased animal performance. For example, our findings illustrate that for heifers placed at 750-899 lbs., reducing mortality by 25% could improve returns to management and reduce emissions intensity if accomplishing this lower mortality costs less than $4.64 per head, on average. Enhancement of proactive health programs, such as for animal preconditioning or antimicrobial metaphylaxis, also may reduce mortality.

All observed associations between use of growth implants and cattle performance in this study are based on operational data. Decisions on the number and type of implants used are dependent upon factors that may not be included in this analysis. Impacts of changing growth implant programs vary between steers and heifers, and across placement weight, but using at least two implants, as compared to just one, increased net returns per head and reduced feedlot GHG emissions per pound of dressed beef produced. Using multiple moderate potency implants may further reduce feedlot GHG emissions intensity. The 2023 FDA ruling indicates that only five commercially available implants are currently labelled for reimplantation in cattle grown in confinement for slaughter (US FDA, 2023), and only two of the five implants are moderate potency. Increased regulation of growth technologies used in cattle production may limit producers' abilities to reduce GHG emissions intensity in a cost-effective manner.

Despite a unique and detailed data set employed, this study certainly has limitations. The analysis completed here relies upon observational data. Although rich in numbers of observations and reflective of animal performance observed in commercial production settings, we estimate models using data with associated endogenous or unobserved management decisions. For example, a pen of cattle that may have had a different implant protocol from another pen that appear similar in the data, could have been different in ways we cannot observe. Likewise, we do not know if health costs are preventative or reactive to diagnosed health ailments. Additionally, cattle prices and costs of other inputs are not collected as part of the data. Coupled with the unobservable characteristics of these pens, this makes net returns our best estimates. These and related limitations of the data must be considered as implications are drawn. Additionally, the methods implemented here only investigate the changes in net returns and emissions intensity associated with mostly changing one input at a time. Future research investigating effects of management practices and feedlot GHG emissions intensity could include further variation of inputs. Utilizing methods which allow for modification of multiple inputs at once may allow for more detailed analysis, although adding to model complexity.

Funding Statement:

This work was supported by partial funding from the Kansas State University Global Food Systems Seed Grant

3 Economic outcomes associated with acute interstitial pneumonia in Central U.S. High Plains feedyards

3.1 Introduction

Research indicates health outcomes are correlated with animal performance (Irsik et al., 2006; Belasco, Cheng & Schroeder, 2015). Agricultural economists have also linked cattle health and performance to net returns (Brooks et al., 2011; Mark, Schroeder, & Jones, 2000). Further research has shown that timing of disease events and number of treatments also impact net return to cattle feeding (Babcock et al., 2010; Davis-Unger et al., 2017). Economic costs may stem from death loss due to treatment failure, foregoing culling for treatment, or culling cattle that would have finished profitably. Common feedyard diseases such as respiratory illnesses, though treatable, may have sizable adverse effects on health and economic returns if not effectively managed.

Acute interstitial pneumonia (AIP) is a respiratory illness that affects approximately 3% of U.S. feedyard cattle (USDA APHIS, 2013) and has been identified as one of the most important feedyard respiratory diseases (Amosson et al., 2006). While other respiratory illnesses such as bovine respiratory disease (BRD) often affect cattle early in the feeding phase (<40 days on feed) (Griffin, 2014), AIP is typically identified later in the feeding phase (>45 days on feed) (Woolums, 2015; Woolums, 2003). Since AIP often affects cattle near harvest, there is potential for great economic losses from investment in feed, yardage, and interest, in addition to the cost of the animal (Loneragan et al., 2001a). However, there is little research quantifying the economic impacts of AIP. The objective of this analysis was to estimate net returns for cattle identified with AIP ante-mortem and post-mortem in feedyards and evaluate economic outcomes across sex, placement weight, and number of treatments.

3.2 Materials & Methods

Data was collected from existing records maintained by cooperating operations; therefore, IACUC approval was not acquired for this study. An initial dataset was created using retrospective feedyard records and individual cattle health records collected from 9 Central U.S. high plains feedyards, along with economic information. Cohort level feedyard data included average placement weight, placement date, average finishing weight, harvest date, average daily gain, and average feed consumption. Cattle health data included diagnosis, date of treatment, weight at treatment, and outcome of treatment and was matched with cohort level feedyard data using cohort identification numbers. Economic information came from the Livestock Marketing Information Center and Federal Reserve Bank of Kansas City.

3.2.1 Data Cleaning

Inclusion and exclusion criteria for the final dataset are described in Figure 3.1. Exact copies of individual health records were considered duplicates and therefore omitted, leaving 196,393 unique observations. Observations with negative days on feed (DOF) were removed. Uncommon cattle types and observations from mixed-sex pens were removed from the dataset to focus on heifers and steers. Observations for which feed data were unavailable were removed from the dataset. Cattle with placement dates or closing dates in 2024 were removed from the dataset, leaving beef steers and heifers placed in nine Central U.S. high plains feedyards from 2019 through 2023.

Only AIP cases, which represented approximately 3.5% of treated cattle from the initial dataset, were evaluated in this study. These data were further refined by excluding those with unreliable treatment dates (treatment date reported as being prior to placement or after shipping). Cattle on feed for more than 300 days were considered outliers and excluded from the analysis. Observations with reported pen-level morbidity greater than 100% were removed. Cattle placed in the feedyard weighing less than 226 kg or more than 454 kg were excluded due to inconsistent availability of price records for lightweight and heavyweight cattle. For similar reasons, cattle finishing at less than 499 kg or greater than 725 kg were also excluded. Cattle weighing less than 204 kg at first AIP treatment or when culled were considered outliers and removed. The final dataset for this analysis included 5,339 feedyard cattle from 3,216 cohorts that were identified with AIP (Figure 3.1).

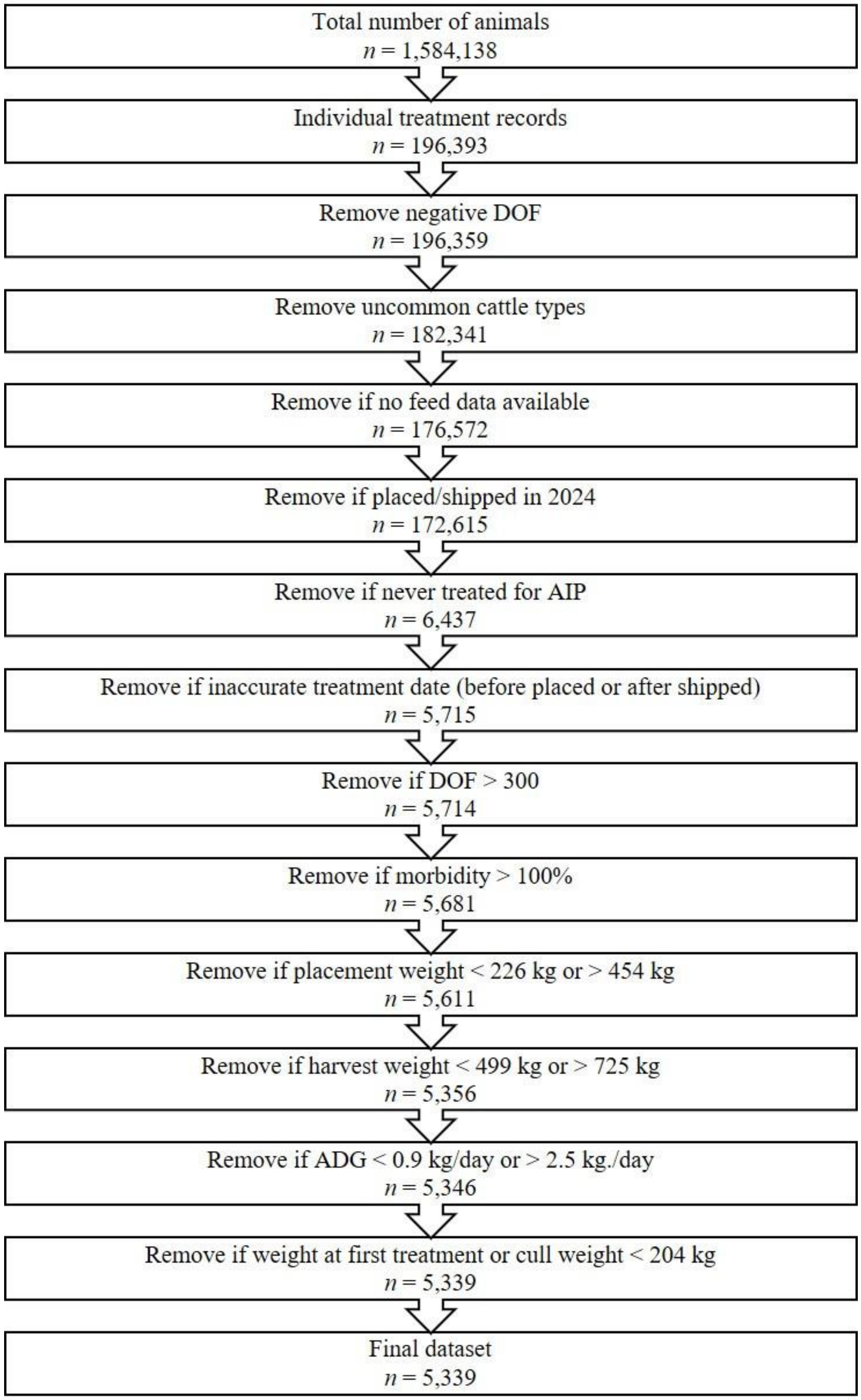

Figure 3.1. Data cleaning process to identify cattle with acute interstitial pneumonia (AIP) in health and cohort records from nine Central U.S. high plains feedyards from 2019 to 2023.

3.2.2 Data Management

Days on feed (DOF) for each animal were determined by subtracting placement date from estimated harvest date. Placement weight, harvest weight, morbidity, and mortality were cohort-level recorded variables. Average daily gain (ADG) of the cohort was determined by dividing total weight gained during the feeding period by days on feed. Average feed conversion (AFC) of the cohort was determined by dividing dry feed consumption by total weight gained during the feeding period.

In the dataset, healthy cattle were defined as those having no record of a disease event in the feedyard, while treated cattle were defined as those receiving treatment following a disease event diagnosis. An AIP event was defined as having been treated for or died from AIP. Additional variables indicating AIP event outcomes were created for this analysis. The number of AIP treatments was determined by the number of events designated as AIP with a "Treatment" outcome. AIP events with a "Death" outcome without prior AIP treatment were indicated as having been found dead in the pen. Event outcomes beyond the first AIP treatment were defined as Death (died in the feedyard), Cull (culled prior to harvest), and Finish (finished with cohort). Deaths and Culls were not necessarily attributed specifically to AIP, but rather denoted outcomes following at least one AIP treatment.

3.2.3 Data Analysis

A decision tree framework was implemented to estimate the net returns of cattle with various disease outcomes at multiple decision points. A decision tree framework includes decision nodes, which represent a choice made by the producer, and branches, which represent potential outcomes following a decision. Decision nodes were selected based on how feedyard managers make decisions following cattle treatment in the feedyard. As seen in Figure 3.2, the initial decision was whether or not to treat cattle for AIP after the first identification. Following initial treatment, cattle that remained in the feedyard may have finished with or without further disease events, culled or died after additional diagnosis and treatment.

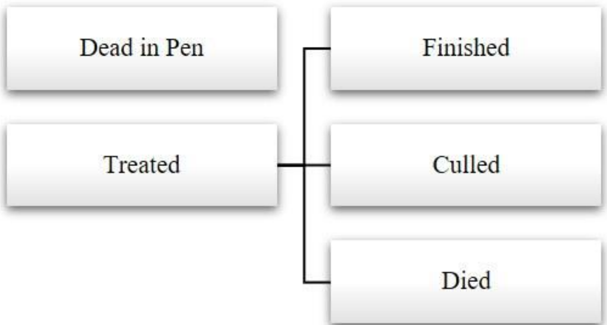

Figure 3.2. Example Decision Tree Framework. Dead in Pen = never treated for AIP; Treated = treated at least once for AIP; Finished = harvested with cohort; Died = died prior to harvest; Culled = culled prior to expected harvest.

Weekly feeder cattle prices and dressed carcass prices were collected from the Livestock Marketing Information Center (LMIC). Dressed cull cow prices have been found to be significantly correlated with prices received for feedyard culls, and thus were used as a proxy for feedyard cull prices (Horton et al., 2021). Cattle prices were matched with the existing data set based on placement date and harvest date. Weekly corn prices, obtained from the LMIC, served as a proxy for cost of feed. Corn prices were matched with the existing data based on placement date, assuming that feed was purchased prior to placement. Annualized interest rates were obtained from the Federal Reserve Bank of Kansas City.

Building upon methods from Dennis et al. (2020) and Dennis et al. (2018), estimated net returns (NR) to cattle feeding after an AIP diagnosis were determined by:

$$NR = TR - FDRC - FC - YC - IC - (TxC \cdot Tx) - (ChC \cdot Tx) \tag{3.1}$$

where *TxC* is the cost of treatment ($23.60/animal), *Tx* is number of treatments, and *ChC* is chute cost ($1.50/animal). Total revenue (*TR*) and feeder cattle cost (*FDRC*) were estimated using pen-level data, defined as:

$$TR = DP \cdot avgcarcasswt \tag{3.2}$$

$$FDRC = FRP \cdot CPW \tag{3.3}$$

where *DP* is dressed carcass price ($/kg), *FRP* is feeder cattle price ($/kg), and *CPW* is feeder cattle purchase weight. A dressing percentage of 64% was assumed to calculate average carcass weight (*avgcarcasswt*) from shipping weight. Yardage cost (*YC*) and interest cost (*IC*) were defined as:

$$YC = 0.4 \cdot DOF \tag{3.4}$$

$$IC = (0.5 \cdot (YC + FC) + FDRC) \cdot DOF \cdot \left(\frac{IR}{365}\right) \tag{3.5}$$

where *DOF* is days on feed and *IR* is annualized interest rate. Because many cattle in our data do not finish with their cohort, average feeding cost is estimated by:

$$FC = FEED \cdot \big(AFC \cdot (CSW - CPW)\big) \tag{3.6}$$

where *FEED* is the price of corn ($/kg), *AFC* is average feed conversion, and *CSW* is an adjusted individual finishing weight. *CSW* is estimated by:

$$CSW = TreatmentWeight + (ADG_T \cdot DaystoHarvest) \tag{3.7}$$

where *TreatmentWeight* is the weight recorded at AIP treatment[6], ADG_T is the estimated average daily gain after AIP treatment, and *DaystoHarvest* is days on feed after AIP treatment. The difference in weight gain between AIP treatments for cattle that received more than one AIP

[6] The last recorded treatment weight is used to estimate CSW. Cull weight and death weight are estimated in a similar manner, using last recorded treatment weight and estimated days to cull or death.

treatment was used to determine an average ADG_T for cattle that received any number of AIP treatments.

Estimated net returns, as described in equations (1-7), offer an approximation of value for an animal with a given treatment outcome. However, expected net returns can provide long-term insights by accounting for the probability of different treatment outcomes. The expected net return is different than the estimated net return, in that the expected net return is determined by computing the sum of the products of estimated net returns for terminal outcomes and probability of occurrence of each outcome from the data distribution.

A simple linear mixed model and Wald Chi-Square test was implemented to test the association of sex, placement weight, and number of AIP treatments with whether an animal finishes with its cohort. A p-value ≤ 0.05 indicated that sex, placement weight, and number of AIP treatments were statistically associated with whether an animal finishes with its cohort. While not central to the findings of this study, this analysis validates the relevance of sex, placement weight, and number of treatments in the examination of net returns for feedyard cattle identified with AIP.

3.3 Results

Table 3.1 provides mean descriptive statistics generated for performance variables used in net return estimation for cohorts of feedyard cattle that had at least one animal identified for treatment with AIP. These data consisted of beef heifers (n = 3,483) and steers (n = 1,496). On average, cattle included in this analysis spent 132 days on feed, gaining 1.56 kg/day at 6.14 kg feed/kg gain. The average pen mortality was 4.1% and 3.3% for heifers and steers, respectively.

Table 3.1. Mean descriptive statistics of performance variables for cohorts from which Central U.S. high plains feedyard cattle with acute interstitial pneumonia (AIP) were identified, overall and stratified by sex.

Variable	All	Heifers	Steers
Days on Feed	132	129	139
Placement Weight, kg	336	330	351
Harvest Weight, kg	581	562	629
Morbidity, %	24.97	25.59	23.39
Mortality, %	3.89	4.10	3.33
Average Daily Gain, kg	1.56	1.51	1.70
Average Feed Conversion, kg feed/kg gain	5.35	5.42	5.16
Number of animals identified with AIP	5,339	3,483	1,496

Of the cattle identified with AIP (n = 5,339), approximately 50% died in the feedyard, and 29% of cattle with a designated AIP event were found dead in the pen and never received treatment for AIP (Figure 3.3). Of the cattle that were found dead in the pen, approximately 35% were previously treated for BRD. Approximately 50% of the cattle identified with AIP were treated once, 14% were treated twice, and 6% were treated three or more times (Figure 3.3).

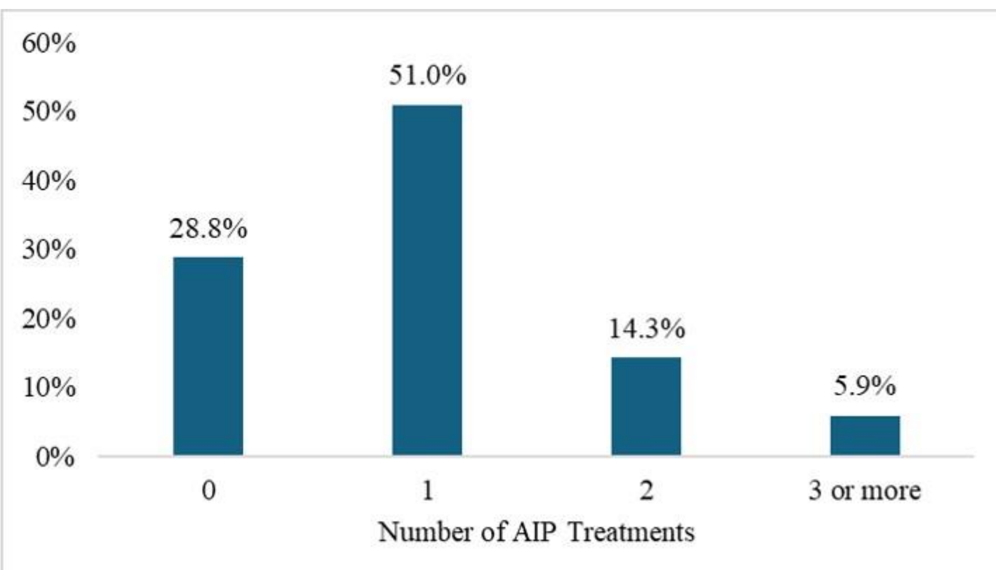

Figure 3.3. Percentage of Central U.S. high plains feedyard cattle identified with acute interstitial pneumonia (AIP) receiving zero, one, two, and three or more AIP treatments.

Most cattle identified as morbid with AIP received the first treatment within 50 days of expected harvest regardless of placement weight. Similarly, cattle that were found dead in the pen and designated as an AIP case were, on average, identified around 25 days prior to expected harvest. Nearly 25% of cattle identified with AIP were previously treated for BRD. Of those cattle previously treated for BRD and later identified with AIP, 21% finished with their cohort, 56% died, and 23% were culled.

Costs associated with cattle feeding varied modestly by sex (Table 3.2). Feeder cattle cost was higher for steers compared to heifers, likely due to heavier weight at purchase. On average, steers had greater DOF, and therefore had higher yardage and interest costs. However, feed costs were lower for steers than heifers, likely due to better performance (higher ADG, lower AFC). The dressed carcass price received was $4.65/kg for heifers and $4.56/kg for steers. Carcass information was not available for the cattle in this study; therefore, yield grade and quality grade premiums and discounts were not accounted for in net return estimation. Due to higher costs of feeding and lower dressed prices, it was anticipated that average net return could be considerably lower for steers placed during the time period evaluated in this study (2019-2023).

Table 3.2. Mean descriptive statistics of economic variables used in net return estimation for Central U.S. high plains feedyard cattle identified with acute interstitial pneumonia (AIP), stratified by sex.

Variable	**All**	**Heifers**	**Steers**
Feeder Cattle Cost, $/animal	1,048.13	1,001.59	1,167.68
Feed Cost, $/animal	274.32	273.10	277.47
Yardage Cost, $/animal	52.82	51.67	55.75
Interest Cost, $/animal	24.87	23.16	29.28
Dressed Carcass Price, $/kg	4.63	4.65	4.56
Number of animals identified with AIP	5,339	3,483	1,496

Estimated net returns for various outcomes of cattle identified with AIP during the feeding phase are presented in Figure 3.4. On average, estimated net returns were positive for cattle that finished with their cohort even after multiple treatments, although estimated net returns were lower for cattle that received a greater number of AIP treatments. Estimated net returns were \$98.70/animal for cattle that finished with their cohort after one treatment, \$85.60/animal for those that finished after two treatments, and \$46.33/animal for those that finished after three or more treatments.

Of the cattle identified with AIP, 29% were found dead in the pen (identified post-mortem) and never received treatment. No cattle were identified with AIP and culled without receiving at least one AIP treatment. Of the cattle treated once for AIP, approximately 30% recovered and finished with their cohort without further treatment for AIP (Figure 3.4).

Of those treated once, approximately 28% relapsed and were treated at least one more time, while 42% did not remain in the feedyard. Of the 42% that did not finish after the first AIP treatment, 62% died and 38% were culled. The probability of not finishing was greater for cattle receiving a second AIP treatment, and even greater for cattle receiving a third AIP treatment.

Estimated returns for cattle identified with AIP vary by sex, placement weight, and number of AIP treatments (Figure 3.5; Figure 3.6). On average, heifers that finish after AIP treatment were estimated to bring positive returns across all placement weights. Heifers placed between 226-271 kg that finished after two AIP treatments were estimated to bring the highest net return of \$147.17/animal, on average (Figure 3.5). Heifers that finished after three or more AIP treatments were generally estimated to bring higher returns if placed at heavier weights. There was little variation in estimated net returns from culling heifers after one or two AIP treatments; however, estimated net returns from culling heifers were slightly higher following three or more AIP treatments. Estimated economic losses were greatest for heifers placed between 408-454 kg that died after two AIP treatments. Steers that finished after two treatments and were placed between 363-407 kg were estimated to bring the highest return at $96.60/animal (Figure 3.6).

Steers placed between 408-454 kg and treated more than once for AIP were not estimated to bring positive returns, even if they recovered and finished with their cohort. Similar to heifers, there was little variation in estimated net returns from culling steers after one or two AIP treatments. Estimated economic losses were greatest for steers that die after two AIP treatments.

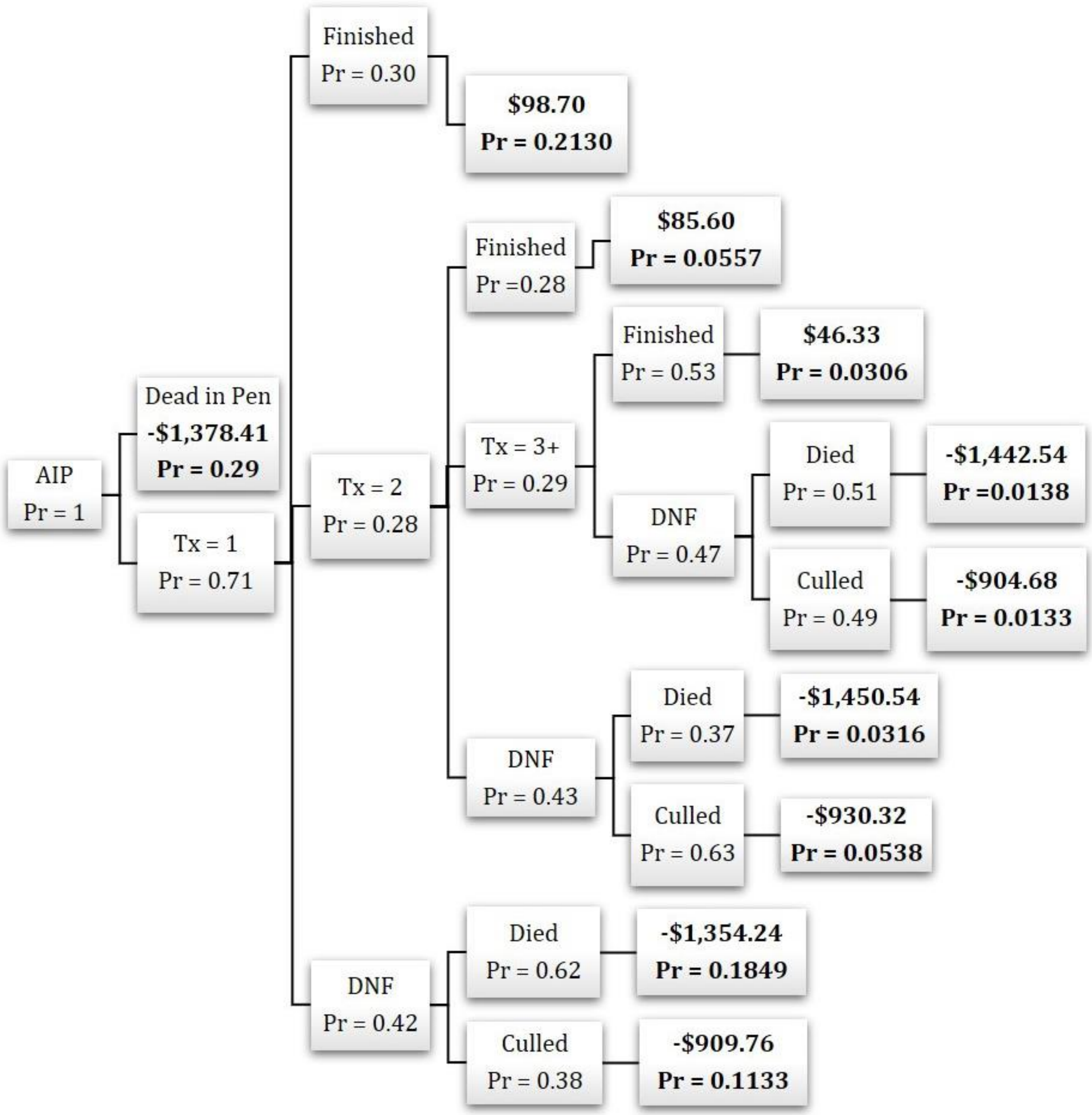

Figure 3.4. Decision Tree Framework describing probability of outcome occurrence and estimated net return for Central U.S. high plains feedyard cattle identified with acute interstitial pneumonia (AIP). Dead in Pen = never treated for AIP; Tx = treatment; Finished = harvested with cohort; DNF = Did Not Finish; Died = died prior to harvest; Culled = culled prior to expected harvest; Pr = within data probability of each outcome.

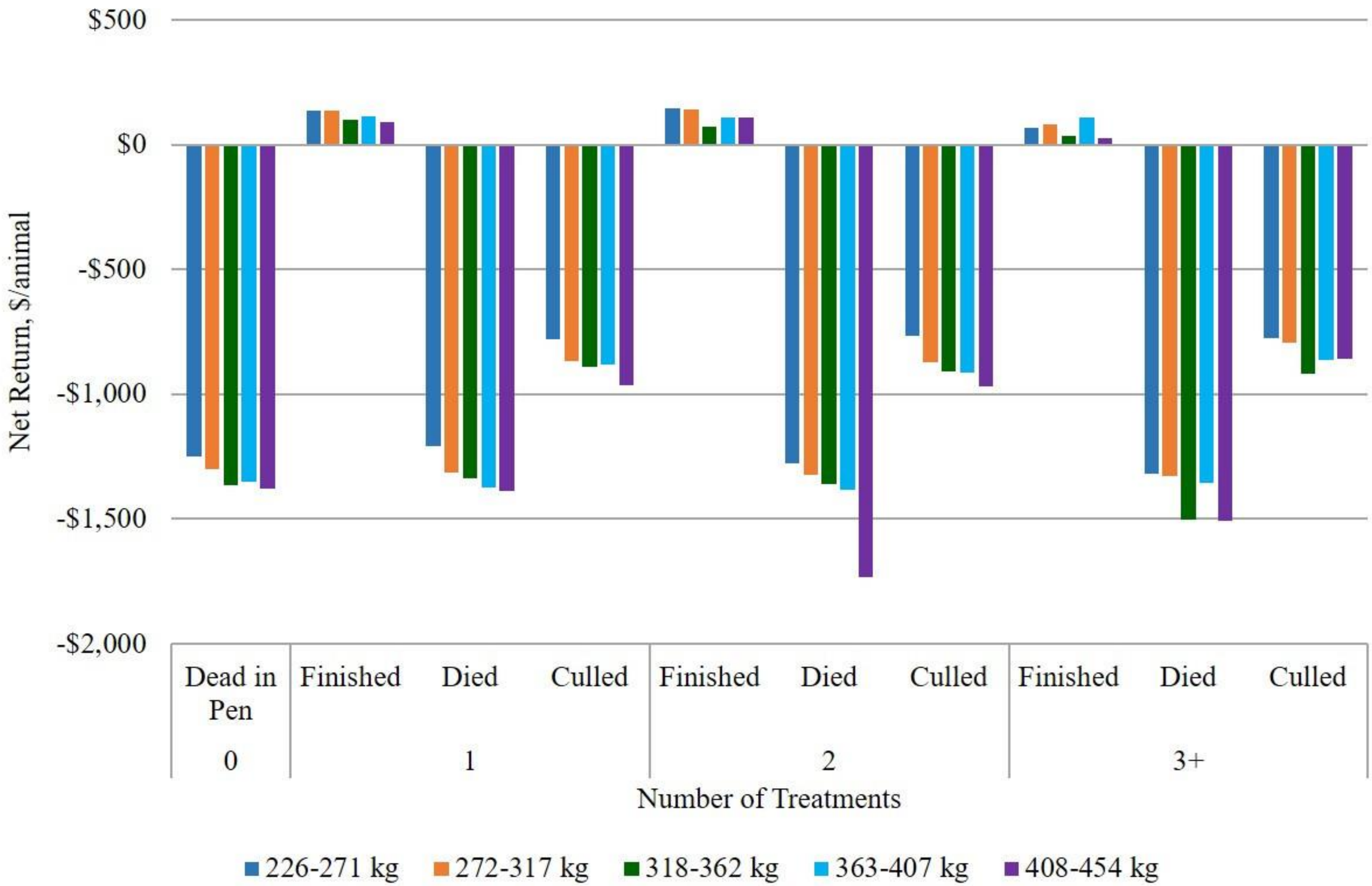

Figure 3.5. Estimated net returns for heifers from Central U.S. high plains feedyards identified with acute interstitial pneumonia (AIP). Finished = harvested with cohort; Died = died prior to harvest; Culled = culled prior to expected harvest.

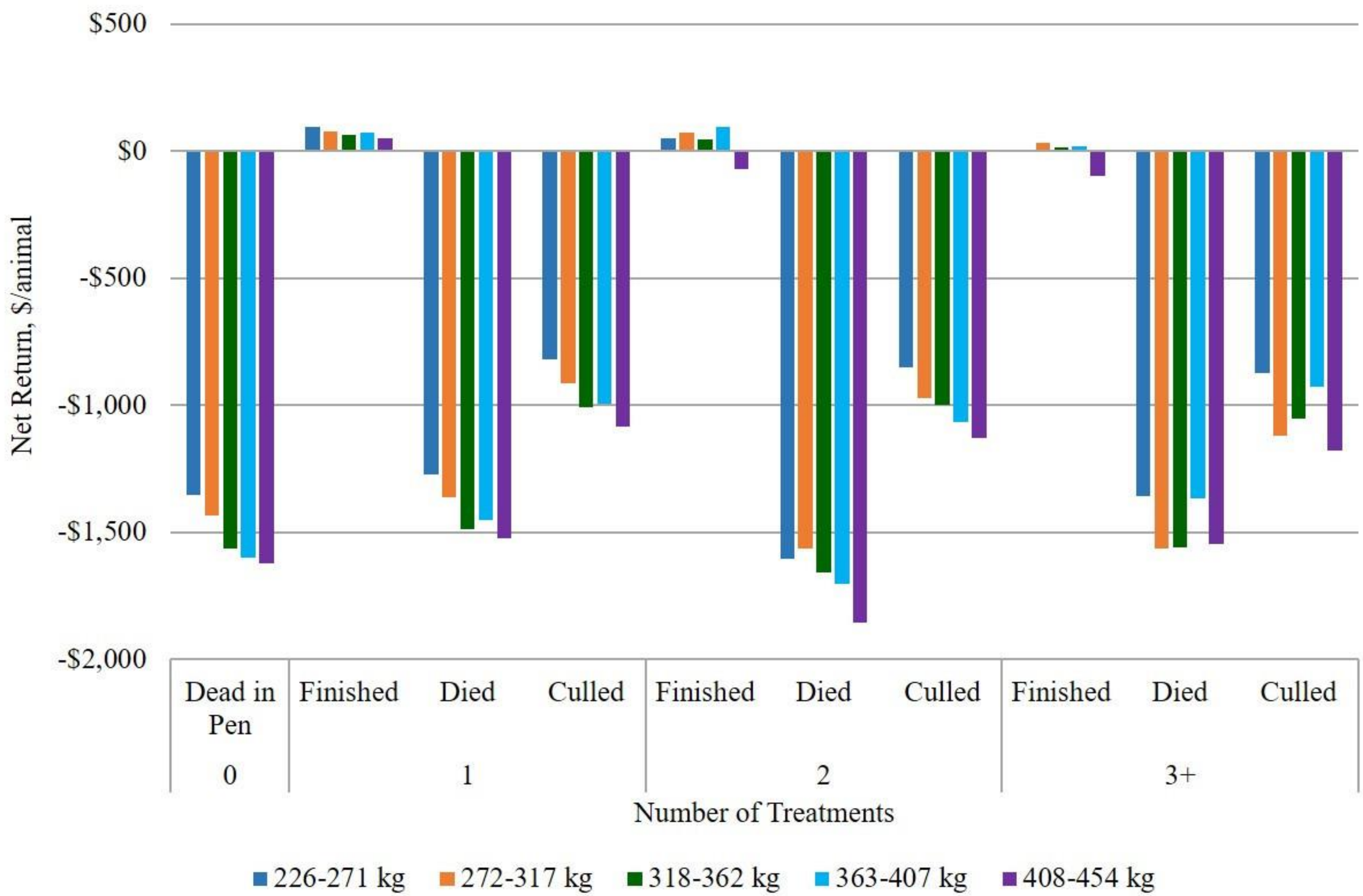

Figure 3.6. Estimated net returns for steers from Central U.S. high plains feedyards identified with acute interstitial pneumonia (AIP). Finished = harvested with cohort; Died = died prior to harvest; Culled = culled prior to expected harvest.

Probabilities of treatment outcomes from the data distribution were used to calculate expected returns for cattle identified with AIP at each decision node. The expected net return to feeding healthy cattle was $193.67/animal, and the expected net return for cattle identified with AIP was -$853.83/animal. Expected returns were greater, on average, for cattle receiving more AIP treatments. The expected net return was -$639.71/animal for cattle treated once for AIP, -$612.41/animal for those treated twice for AIP, and -$529.57/animal for those treated three or more times for AIP.

3.4 Discussion

These data represented beef heifers (*n* = 3,483) and steers (*n* = 1,496), which is consistent with previous studies finding that AIP tends to occur more often in heifers (Valles et al., 2016; Loneragan et al., 2001a; Ayroud et al., 2000). The majority of cattle treated for AIP received the first AIP treatment within 50 days of expected harvest, which is consistent with previous studies of AIP in cattle feedyards (Loneragan & Gould, 2000; Loneragan et al., 2001a; Loneragan et al., 2001b; Bortoluzzi et al., 2023). This analysis offers insights for returns from cattle identified with AIP on the basis of sex, placement weight, and number of AIP treatments. Estimated net returns were lower for steers treated for AIP compared to heifers, regardless of placement weight and number of treatments. This is likely attributed to higher investment and lower dressed carcass prices for steers during this time period. As expected, estimated net returns were generally lower for cattle receiving more AIP treatments and cattle placed in the feedyard at heavier weights. Estimated net returns remained positive for cattle that were successfully treated for AIP and finished with their cohort, with the exception of steers placed between 408-454 kg that were treated more than once for AIP. On average, estimated returns were $98.70/animal for cattle that finished with their cohort after one AIP treatment, $85.60/animal for those that finished after two AIP treatments, and $46.33/animal for those that finished after three or more AIP treatments. Although net returns were estimated to remain positive for cattle that finish with their cohort after multiple AIP treatments, the probability of each outcome should be considered when making the decision to cull or treat cattle that have been identified with AIP. The expected net return for cattle identified with AIP (-$853.83/animal) was considerably lower than the expected net return from healthy feedyard cattle ($193.67/animal).

Cattle culled after an AIP diagnosis were not estimated to bring positive net return, even if culled after the first treatment. Negative returns for culls are likely due to increased feeding costs for animals culled late in the feeding period. Decisions to cull or keep cattle in the feedyard after treatment are largely based on cull prices. If expected return from treating the animal is greater than estimated return from culling, the animal should remain in the feedyard. In this analysis, expected returns are greater for cattle treated for AIP compared to cattle that are culled before or after AIP treatment. For example, expected net returns for cattle treated once for AIP were -$639.71/animal, while estimated net returns from culling after one AIP treatment were -$909.76/animal. Similarly, expected net returns were -$612.41/animal from cattle treated twice for AIP and -$529.57/animal for those treated three or more times, while estimated net returns from culling were -$930.32/animal and -$904.68, respectively. Although largely negative, expected net returns from keeping and treating cattle identified with AIP were still greater than estimated net return from culling at each decision point, implying that cattle identified with AIP should not be culled extemporaneously. However, returns from culls are greater than returns from animals that died in the feedyard, suggesting that culling would be preferable in some cases. The decision to cull versus treat an animal should incorporate the probability of treatment success for that particular animal. While not included in this analysis, additional factors such as individual and cohort risk level, previous illness, and treatment timing should be considered in culling decisions.

Although data were based on field observations from U.S. Central high plains feedyards, we have demonstrated that economic returns from cattle identified with AIP vary across sex, placement weight, and treatment outcome. However, this analysis is not without limitations. Chute-side diagnosis of AIP is not perfect, and consideration of other health indicators and risk factors not evaluated in this study may contribute to the decision to cull cattle identified with AIP. Metaphylaxis treatment and incoming health status were not included in the data; therefore, we are unable to evaluate differences in returns from high-risk and low-risk cattle treated for AIP. A more detailed look at the effects of treatment timing on treatment outcomes may be beneficial for producers deciding whether to treat or cull cattle identified with AIP. The majority of feedyard cattle identified with AIP are first treated for AIP within 50 days of expected harvest, and only 30% of cattle in this data, excluding those found dead in the pen, recovered and finished after the first AIP treatment. A greater understanding of factors associated with the probability of first AIP treatment success is imperative for producers making decisions regarding management of feedyard cattle identified with AIP. Association between expected AIP treatment outcomes and prior disease management is another area for future analysis. In our data, approximately 25% of cattle identified with AIP were previously treated for BRD, of which 56% died and 23% were culled. Cohort and individual demographics such as BRD morbidity may provide more insight into the risk associated with prior respiratory diagnoses and AIP treatment outcomes. Further analysis with predictive modeling of economic and treatment outcomes are necessary for determining best management of AIP cases identified in cattle feedyards.

Funding Statement:

Research funded by Foundation for Food and Agriculture Research International Consortium on Antimicrobial Stewardship Grant ID 22-000564.

4 A retrospective analysis of predictors of first treatment failure and failure to finish in Central U.S. High Plains feedyard cattle treated for acute interstitial pneumonia

4.1 Introduction

Respiratory disease remains a challenge for the livestock industry with significant herd health and economic impacts (Smith, 1998; Panciera & Confer, 2010; Johnson & Pendell, 2017; Smith et al. 2020). Acute interstitial pneumonia (AIP) is a common respiratory illness, which researchers have described as the second-leading cause of economic loss in U.S. cattle feedyards following bovine respiratory disease (BRD) (Loneragan et al., 2001a; Woolums et al., 2005), affecting approximately 3% of cattle in U.S. feedyards (USDA APHIS, 2013). However, the etiology of AIP remains uncertain (Haydock et al., 2022; Valles et al., 2023). Clinical signs of AIP include acute dyspnea, open-mouthed breathing, and grunting (Doster, 2010). Heat stress, exposure to dust and toxins, and parasites are a few factors associated with AIP (Sorden et al., 2000; Doster, 2010). Studies have found AIP is more common in heifers (Bortoluzzi et al., 2023; Stanford et al., 2006; Woolums et al., 2005; Loneragan et al., 2001b), and AIP is often identified in cattle closer to harvest than other respiratory illnesses (Loneragan et al., 2001a; Woolums, 2003; Woolums, 2015; Bortoluzzi et al., 2023).

Feedyard disease treatment outcomes are commonly evaluated using metrics such as first treatment success or case fatality risk. Characteristics at time of placement have been used to predict health outcomes for feedyard cattle (Marti et al., 2021), including treatment outcomes for respiratory diseases such as BRD (Neal et al., 2024; Rojas et al., 2022; Smith et al., 2022; Amrine et al., 2019; Avra et al., 2017). Previous studies also evaluated the effect of treatment timing and other factors on respiratory treatment outcomes (Neal et al., 2024; Bortoluzzi et al., 2023; Avra et al., 2017; Babcock et al., 2009; Woolums et al., 2004; Loneragan et al., 2001a). Research shows calf health, environmental conditions, and treatment timing are among the top risk factors associated with BRD treatment outcomes in the feedyard (Babcock et al., 2009; Cernicchiaro et al., 2013; Avra et al., 2017; Smith et al., 2022); however, there is relatively little work dedicated to the identification of potential risk factors associated with AIP treatment outcomes. Bortoluzzi et al. (2023) found that sex and days on feed at death were significantly associated with the probability of being diagnosed with AIP at necropsy; however, this study did not evaluate risk factors associated with the probability of clinical AIP treatment outcomes.

Coupled with late incidence, negative outcomes following AIP treatment may have severe economic consequences (Loneragan et al., 2001a; Woolums et al., 2005; Amosson et al., 2006). Even if identified early in the feeding period, AIP diagnoses and treatments may affect productivity and treatment outcomes. Identification of risk factors associated with AIP treatment outcomes is essential to further the understanding of how feedyard cattle diagnosed with AIP should be managed. The objective of this analysis was to identify risk factors associated with first AIP treatment failure (*FTF;* relapse of AIP requiring additional treatment and mortalities and culls following AIP treatment) and failure to finish (*DNF*; mortalities and culls attributed following AIP treatment). Risk factors evaluated in this study include characteristics at time of placement and treatment, timing of AIP treatment, and history of prior BRD treatment.

4.2 Materials & Methods

Kansas State University Institutional Animal Care and Use Committee (IACUC) approval was not acquired for this study due to data being obtained from existing databases maintained by cooperating feedyards. Operational feeding data and individual treatment records were obtained from nine Central U.S. high plains feedyards. Cohort level data included average placement weight, placement quarter, and estimated harvest date. Individual treatment records included diagnoses, treatment dates, treatment weights, and treatment outcomes. Individual treatment records were matched with cohort level feeding data using feedyard and lot (cohort) identification numbers to create a comprehensive initial dataset for analysis.

4.2.1 Feedyard Data

The initial dataset contained 196,393 unique treatment records for feedyard cattle (Day et al., 2025). Exclusion criteria and dataflow are presented in Figure 4.1. Data errors (negative days on feed (DOF), inaccurate treatment date, morbidity >100%). Cattle with >300 DOF, ADG <2 lbs./day or ADG >5.5 lbs./day, and cull weight or weight at first AIP treatment <450 lbs. were removed. The data set was further limited to steers and heifers placed in the feedyard from January 2019 through December 2023, with placement weights between 500-1000 lbs. Only cattle diagnosed with AIP ante-mortem were considered for analysis. The final dataset for analysis included 3,800 unique observations treated for AIP.

Variables included for analysis are described in Table 4.1. Placement quarter and quarter of first AIP treatment were defined based on recorded placement dates and treatment dates (Q1 = January, February, March; Q2 = April, May, June; Q3 = July, August, September; Q4 = October, November, December). Placement weight categories (500-599 lbs.; 600-699 lbs.; 700-799 lbs.; 800-899 lbs.; 900-1000 lbs.) and first AIP treatment weight categories (< 1000 lbs.; 1000-1250 lbs.; > 1250 lbs.) were identified based on the distribution of data.

Unique treatment records (n = 196,393)

↓

DOF greater than 0 (n = 196,359)

↓

Only steers and heifers (n = 182,341)

↓

Feeding data available (n = 176,572)

↓

Placed and harvested between January 2019 and December 2023 (n = 172,615)

↓

Diagnosed with AIP ante-mortem or post-mortem (n = 6,437)

↓

Day of treatment between placement date and harvest date (n = 5,715)

↓

Less than 300 DOF (n = 5,714)

↓

Pen-level morbidity less than 100% (n = 5,681)

↓

Placement weight between 500 lbs. and 1000 lbs. (n = 5,611)

↓

Harvest weight between 1100 lbs. and 1600 lbs. (n = 5,356)

↓

ADG between 2 lbs./day and 5.5 lbs./day (n = 5,346)

↓

First AIP treatment weight or cull weight greater than 450 lbs. (n = 5,339)

↓

Received at least one AIP treatment (n = 3,800)

Figure 4.1. Data workflow and exclusion criteria to identify cattle treated for acute interstitial pneumonia (AIP) from nine Central U.S. high plains feedyards from 2019 to 2023.

Variables were calculated to designate prior diagnosis and treatment, as well as timing of the first AIP treatment. A calf level indicator variable was generated to specify whether cattle were treated for BRD prior to receiving the first AIP treatment. Days on feed (DOF) at first AIP treatment (*first AIP treatment date – placement date*) and risk days remaining after the first AIP treatment (*expected harvest date – first AIP treatment date*) were designated as factors. Levels for DOF at first AIP treatment and risk days remaining were selected based on definition of treatment timing from previous feedyard respiratory disease studies (Avra et al., 2017; Theurer et al., 2021; Smith et al., 2022) and the distribution of data used for analysis. Days on feed at first AIP treatment and risk days remaining were categorized as: < 40 days, 40-100 days, and >100 days.

The outcomes of interest in this study were first AIP treatment failure (*FTF*) and did not finish (*DNF*). Cattle that received more than one AIP treatment were designated *FTF*. Cattle that were culled, died, or finished after receiving more than one AIP treatment were described as *FTF*. Cattle that failed to finish with their cohort following any number of AIP treatments, and cattle that were culled or died after receiving any AIP treatment, were designated *DNF*.

Table 4.1. Variables used in the working dataset for analysis of risk factors associated with probability of first AIP treatment failure and probability of not finishing after AIP treatment.

Variable	**Description**
Feedyard ID	Indicates feedyard
Sex	Heifer or Steer
Placement Quarter	Q1 = January, February, March; Q2 = April, May, June; Q3 = July, August, September; Q4 = October, November, December
Placement Weight	500-599 lbs.; 600-699 lbs.; 700-799 lbs.; 800-899 lbs.; 900-1000 lbs.
First AIP Treatment Quarter	Q1 = January, February, March; Q2 = April, May, June; Q3 = July, August, September; Q4 = October, November, December
First AIP Treatment Weight	< 1000 lbs.; 1000-1250 lbs.; > 1250 lbs.
Treated for BRD First	0/1; Calf level variable indicating if animal was treated for bovine respiratory disease prior to receiving first AIP treatment; 0 = No, 1 = Yes
DOF at First AIP Treatment	< 40 days; 40-100 days; > 100 days
Risk Days Remaining	< 40 days; 40-100 days; > 100 days
First AIP Treatment Failure (*FTF*)	0/1; Calf level variable indicating if animal finished with cohort after receiving just one AIP treatment; 0 = finished, 1 = failed
Failure to Finish (*DNF*)	0/1; Calf level variable indicating if animal died in the feedyard or was culled following any AIP treatment; 0 = finished, 1 = died or culled

4.2.2 Statistical Analysis

Mixed-effects regression models have been used in recent studies to evaluate risk factors associated with respiratory disease outcomes in feedyard cattle (Neal et al., 2024; Smith et al., 2022; Avra et al., 2017). Here, a mixed-effects logistic model was employed to estimate the probability of first AIP treatment failure (*PFTF*) and the probability that an animal would fail to finish with its cohort following any AIP treatment (*PDNF*):

$$log\left[\frac{Pr(Y_{ij}=1)}{1-Pr(Y_{ij}=1)}\right] = \beta_0 + X_{ij}\beta + Z_{ij}\mu_j \tag{4.1}$$

where Y_{ij} is a binary outcome for animal *i* in feedyard j, $Pr(Y_{ij}=1)$ denotes probability of the outcome occurring (*FTF, DNF*) for animal *i* in feedyard j, and $X_{ij}\beta$ is a linear combination of fixed effects predictors. The random effects component is written as $Z_{ij}\mu_j$, where Z_{ij} is a design matrix for random feedyard effects, and μ_j is a random intercept for feedyard j, assumed to be normally distributed with mean 0 and variance σ_u^2.

Final models for examining risk factors associated with probability of *FTF* and probability *DNF* were determined using a backwards stepwise function to select predictors, where the best fit model was determined by the lowest Akaike Information Criterion (AIC). In the backwards stepwise function for model selection, all independent variables in the working dataset were included in the initial models (sex, placement quarter, placement weight category, first AIP treatment quarter, first AIP treatment weight category, treated for BRD first, DOF at first AIP treatment category, risk days remaining category). Previous research has established that AIP is more prevalent in heifers compared to steers (Ayroud et al., 2000; Day et al., 2025), thus 'Sex' remained in the final model. Two-way interactions were tested throughout the model selection process, but none were included in the final. Strong correlations resulting in multicollinearity were not identified between any two independent variables[7].

4.3 Results

Summary statistics are reported in Appendix Table B.1. Following exclusion criteria and derived variable generation, the final dataset consisted of 3,800 animals with a 70.5% cumulative incidence of *FTF* and 58.3% cumulative incidence of *DNF* (Table 4.2). Nearly 43% of cattle were placed between 700-799 lbs., and the average placement weight was 745 lbs. More than half were first treated for AIP between 1000-1250 lbs., and average weight at first AIP treatment was 1093 lbs. Approximately 21% of feedyard cattle were treated for BRD prior to receiving the first AIP treatment. Of those cattle that received BRD treatment prior to receiving AIP treatment, 34% finished with their cohort, 32% were culled , and 34% died following AIP treatment. The majority of feedyard cattle were first treated for AIP at greater than 100 DOF (70.8%). Comparatively, only 26.3% of cattle received the first AIP treatment between 40 and 100 DOF, and even fewer received the first AIP treatment within the first 40 DOF (2.9%). Approximately 67.3% of cattle received the first AIP treatment with <40 risk days remaining (Figure 4.2). Approximately 12.7% of cattle had more than 100 risk days remaining in the feedyard when first treated for AIP, and 20% of cattle were first treated for AIP with between 40 and 100 risk days remaining.

[7] Multicollinearity was assessed using variance inflation factor tests.

Table 4.2. Description of animals treated for acute interstitial pneumonia (n = 3,800) and percent of the sample represented.

Variable	Number of animals	Percent
Sex		
Heifer	2,634	69.32
Steer	1,166	30.68
Placement Quarter		
1	1,420	37.37
2	1,153	30.34
3	530	13.95
4	697	18.34
Placement Weight (lbs.)		
500-599	257	6.76
600-699	887	23.34
700-799	1,631	42.92
800-899	857	22.56
900-1000	168	4.42
First AIP Treatment Quarter		
1	411	10.82
2	1,504	39.58
3	1,254	33.00
4	631	16.60
First AIP Treatment Weight (lbs.)		
< 1000	977	25.71
1000-1250	2,193	57.71
> 1250	630	16.58
Treated for BRD First		
No	2,994	78.79
Yes	806	21.21
DOF at First Treatment		
< 40	111	2.92
40-100	998	26.26
> 100	2,691	70.82
Risk Days Remaining		
< 40	2,557	67.29
40-100	760	20.00
> 100	483	12.71
First AIP Treatment Failure	2,679	70.50
Did Not Finish	2,215	58.29

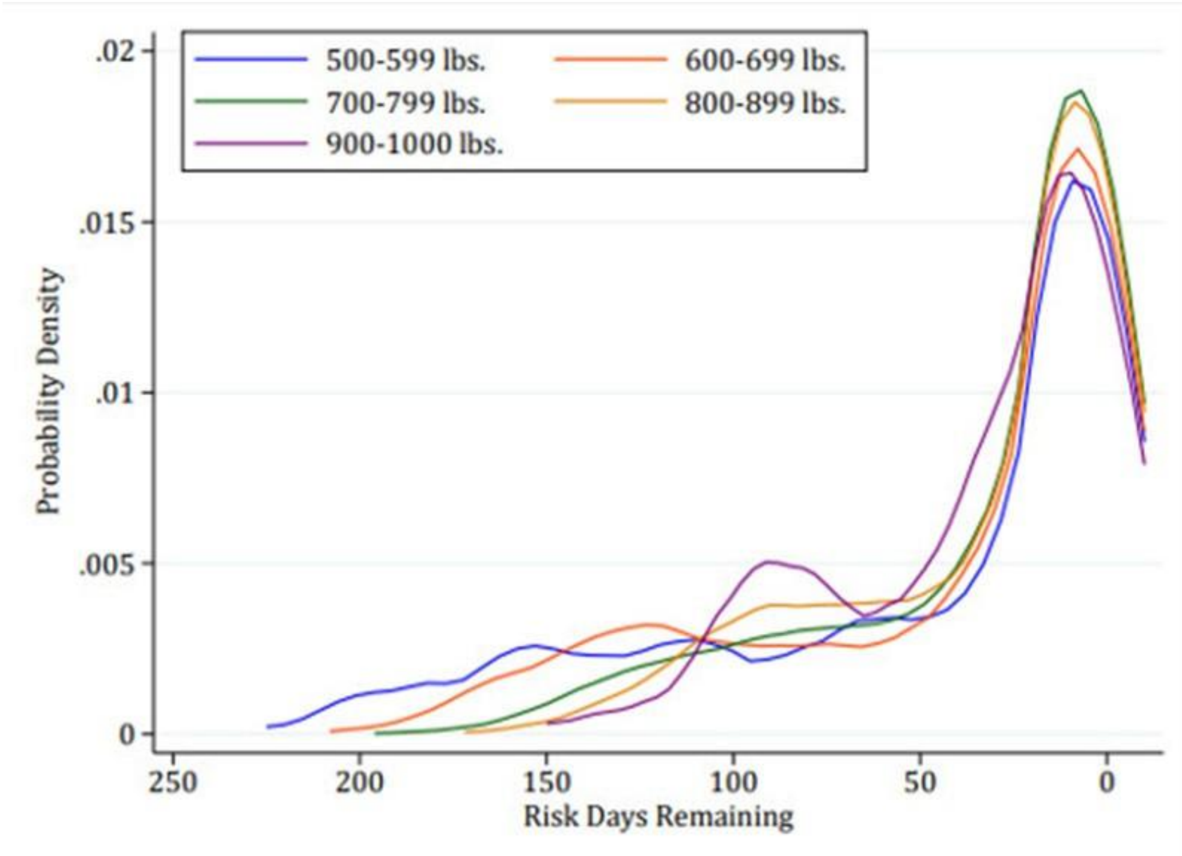

Figure 4.2. Distribution of risk days remaining at first AIP treatment for Central U.S. high plains feedyard cattle treated for AIP.

Mixed effects logistic regression results are reported in Appendix Table B.2 Model adjusted probability estimates and statistics for *FTF* and *DNF* are reported in Table 4.3. The final multivariable model for factors associated with the probability of first AIP treatment failure (*PFTF*) included fixed effects for sex, placement weight category, quarter of first AIP treatment, first AIP treatment weight category, prior BRD treatment, DOF category at first AIP treatment, and risk days remaining category ($p \leq 0.05$). The final multivariable model for factors associated with the probability of failure to finish after AIP treatment (*PDNF*) included the same fixed effects, except for quarter of first AIP treatment ($p \leq 0.05$). Placement quarter was not statistically associated with either outcome, so it was not included in the final models. Both models also included random feedyard effects.

Table 4.3. Model adjusted probability estimates and statistics from mixed-effects logit models for first AIP treatment failure (FTF) and failure to finish (DNF) in feedyard cattle treated for acute interstitial pneumonia (AIP).

	FTF		**DNF**	
	Prob	**SE**	**Prob**	**SE**
Sex				
Heifer	0.65[a]	0.06	0.48[a]	0.03
Steer	0.69[b]	0.06	0.52[b]	0.03
Placement Weight (lbs.)				
500-599	0.74[a]	0.06	0.60[a]	0.05
600-699	0.71[a]	0.06	0.55[a]	0.04
700-799	0.69[a]	0.06	0.51[a]	0.03
800-899	0.62[b]	0.07	0.48[ab]	0.03
900-1000	0.57[b]	0.08	0.36[b]	0.05
First AIP Treatment Quarter				
1	0.61[a]	0.07		
2	0.70[b]	0.06		
3	0.69[ab]	0.06		
4	0.68[ab]	0.06		
First AIP Treatment Weight (lbs.)				
< 1000	0.80[a]	0.05	0.70[a]	0.03
1000-1250	0.68[b]	0.06	0.49[b]	0.03
> 1250	0.50[c]	0.07	0.31[c]	0.03
Prior BRD Treatment				
No	0.54[a]	0.07	0.30[a]	0.03
Yes	0.78[b]	0.05	0.70[b]	0.03
DOF at First AIP Treatment				
<40	0.70[a]	0.06	0.55[a]	0.03
40-100	0.70[ab]	0.08	0.52[ab]	0.07
>100	0.62[b]	0.06	0.44[b]	0.02
Risk Days Remaining				
<40	0.87[a]	0.03	0.84[a]	0.02
40-100	0.54[b]	0.07	0.31[b]	0.03
>100	0.51[b]	0.07	0.29[b]	0.03

Different superscripts (a, b ,c) within among covariate levels indicate statistically significant ($p \leq 0.05$) differences in probabilities.

4.3.1 First AIP Treatment Failure

Steers had greater *PFTF* (69% ± 6)[8] compared to heifers (65% ± 6). Probability of *FTF* was greater for cattle placed in the feedyard at 500-599 lbs. (74% ± 6), 600-699 lbs. (71% ± 6) or 700-799 lbs. (69% ± 6) compared to those placed at 800-899 lbs.(62% ± 7) or 900-1000 lbs. (57% ± 8). Cattle that received the first AIP treatment in Q2 had greater *PFTF* (70% ± 6) compared to those receiving the first AIP treatment in Q1 (61% ± 7); however, *PFTF* for cattle that were first treated for AIP in Q3 (69% ± 6) or Q4 (68% ± 6) was not significantly different from *PFTF* for cattle treated in Q1 or Q2.Cattle that were first treated for AIP at <1000 lbs. had greater *PFTF* (80% ± 5) compared to those first treated for AIP between 1000-1250 lbs. (68% ± 6) and >1250 lbs. (50% ± 7). Cattle that were treated for BRD prior to receiving the first AIP treatment had greater *PFTF* (78% ± 5) than those that had not previously been treated for BRD (54% ± 7). Cattle first treated for AIP at <40 DOF had greater *PFTF* (70% ± 6) compared to those first treated for AIP at >100 DOF (62% ± 6). Cattle that were first treated for AIP with <40 risk days remaining had greater *PFTF* (87% ± 3) compared to those treated with between 40-100 (54% ± 7) and >100 risk days remaining (51% ± 7).

4.3.2 Failure to Finish

Steers had greater *PDNF* (52% ± 3) compared to heifers (48% ± 3). Probability of *DNF* was greater for cattle placed in the feedyard at 500-599 lbs. (60% ± 5), 600-699 lbs. (55% ± 4) or 700-799 lbs. (51% ± 3) compared to those placed at 900-1000 lbs. (36% ± 5). Probability of *DNF* for cattle placed at 800-899 lbs. (48% ± 3) was not significantly different from that of cattle placed at other weights. Cattle that were first treated for AIP at <1000 lbs. had greater *PDNF*

---

[8] Values in parentheses refer to probability of outcome ± standard error.

(70% ± 3) compared to those first treated for AIP between 1000-1250 lbs. (49% ± 3) and >1250 lbs. (31% ± 3). Cattle that were treated for BRD prior to receiving the first AIP treatment had greater *PDNF* (70% ± 3) than those that had not previously been treated for BRD (30% ± 3). Cattle first treated for AIP at <40 DOF had greater *PDNF* (55% ± 3) compared to those first treated for AIP at >100 DOF (44% ± 2). Cattle that were first treated for AIP with <40 risk days remaining had greater *PDNF* (84% ± 2) compared to those treated with between 40-100 (31% ± 3) and >100 risk days remaining (29% ± 3).

4.4 Discussion

Studies have found that AIP is more common in heifers (Bortoluzzi et al., 2023; Stanford et al., 2006; Woolums et al., 2005; Loneragan et al., 2001b). Nearly 70% of the observations retained for analysis were heifers, which is consistent with the population of cattle at feedyards included in this study, as well as previous studies of AIP (Ayroud et al., 2000; Day et al., 2025). Interestingly, we found that steers had greater probability of first AIP treatment failure compared with heifers ($p \leq 0.05$). We also found that steers were significantly ($p \leq 0.05$) less likely to finish with their cohort following AIP treatment compared with heifers. Bortoluzzi et al. (2023) found that the probability of being diagnosed with AIP at necropsy was significantly ($p \leq 0.05$) higher for heifers compared with steers.

Increased *PFTF* and *PDNF* for lightweight placements and those treated early in the feeding period could be indicative of age or overall health upon arrival. Neal et al. (2024) found that cattle placed at lighter weights generally had higher case fatality risk for BRD than cattle placed at heavier weights. We found that *PFTF* and *PDNF* were higher for cattle placed at lighter weights compared with those placed at heavier weights, and cattle receiving the first AIP treatment at <1000 lbs. had higher *PFTF* and higher *PDNF* compared with those receiving the first AIP treatment at heavier weights. Approximately two-thirds of cattle received the first AIP treatment with <40 risk days remaining , which is consistent with previous studies of AIP incidence in U.S. cattle feedyards (Loneragan & Gould, 2000; Loneragan et al., 2001a; Bortoluzzi et al., 2023).We found that first AIP treatment failure is more likely in cattle first treated for AIP at <40 DOF compared to those first treated for AIP at >100 DOF. Others have found that cattle that died between 100-150 DOF had higher probability of an AIP diagnosis at necropsy than those that died between 0-50 DOF (Bortoluzzi et al., 2023). Younger cattle may have naïve immune systems or experience high stress levels during transportation, making them more susceptible to AIP than older cattle placed at heavier weights. However, pre-arrival processing information and additional clinical parameters were not available for cattle included in this study.

Our data is consistent with other studies showing that AIP is typically identified in cattle closer to harvest than other respiratory illnesses (Loneragan et al., 2001a; Woolums et al., 2004; Bortoluzzi et al., 2023). Cattle that were first treated for AIP with <40 risk days remaining had higher *PFTF* and *PDNF* compared to those that had >100 risk days remaining at first AIP treatment. A novel finding of this study is the significant ($p \leq 0.05$) association of prior BRD treatment with AIP treatment outcomes. Current findings illustrate increased *PFTF* and *PDNF* for cattle treated for BRD prior to the first AIP treatment. Although we find a significant link between prior BRD morbidity and AIP treatment outcomes, we cannot establish causality. Cattle treated for BRD may be more susceptible to AIP later on; however, this study did not investigate clinical indicators for cattle treated for both BRD and AIP. Additionally, we evaluated prior BRD treatment as a binary response (0/1) and did not consider multiple BRD treatments prior to AIP treatment. Further examination of risk factors associated with AIP treatment outcomes following BRD morbidity is necessary to gain better understanding of how these cattle are managed.

This retrospective study examined risk factors associated with terminal outcomes for Central U.S. high plains feedyard cattle following treatment for AIP, including characteristics at time of placement and treatment, timing of AIP treatment, and prior BRD treatment. This analysis provides valuable insights into factors associated with terminal outcomes of feedyard cattle treated for AIP, but it is not without limitations. This study utilized retrospective operational data maintained by feedyards, and chute-side diagnosis of AIP is not perfect. The potential for bias and errors should be considered when interpreting these results. While these findings are valid for the feedyards included in this analysis, there are unobserved differences in production and management which might make these results less applicable to other feedyards. For example, metaphylaxis treatment and other processing information were not obtainable in the data used for this analysis. Therefore, we are unable to directly evaluate the differences in probabilities of treatment outcomes for low-risk and high-risk cattle from varying sources.

Further research is needed to understand additional factors associated with the probability of first treatment failure and failure to finish for cattle treated for AIP. This study utilized available data to analyze the effects of individual characteristics at time of placement and time of treatment on AIP treatment outcomes. Findings from this analysis indicated that sex, weight, treatment timing, and prior BRD treatment were significantly associated with the *PFTF* and the *PDNF* for feedyard cattle treated for AIP. Analyses of larger databases including clinical parameters and risk ratings could provide more insight into factors associated with terminal outcomes for cattle treated for AIP.

Funding Statement:

Research funded by Foundation for Food and Agriculture Research International Consortium on Antimicrobial Stewardship Grant ID 22-000564.

5 Decision aid for feedyard operators managing cattle diagnosed with acute interstitial pneumonia

5.1 Introduction

Animal health and productivity are essential to the success of cattle feedyards. Operators and managers are tasked with determining how morbid animals should be handled in the feedyard, with the goal of maintaining adequate herd health and remaining a profitable enterprise. Decisions regarding how to handle morbid animals are a series of complex questions, and generally there is no single 'right' answer. These complex decisions often require cooperation among veterinary and other industry professionals to determine the best course of action. However, before deciding how the individual animal should be treated, operators must decide whether or not to treat the animal at all.

Livestock operators may forego treatment and decide to cull the animal, usually with the goal of minimizing economic loss and/or greater herd health impacts. Retaining and treating morbid animals could result in additional herd health impacts, depending on the diagnosis, and there is a possibility that the animal could die even after receiving treatment. On the other hand, there is an economic risk in culling animals that would have otherwise finished with their cohort. For beef cattle in the feedyard, returns from culled animals are generally much lower than returns from animals that finish with their cohort. Additionally, individual animals present with characteristics which might make them more or less susceptible to disease, and these factors must be accounted for when attempting to evaluate the risk of treating a particular animal. Further, the diagnosis of the animal must be examined in conjunction with the individual risk factors.

This Excel-based decision aid was developed with the goal of providing a resource for feedyard managers and operators deciding whether to cull or treat individual animals identified with acute interstitial pneumonia (AIP). Building upon findings from previous analyses in Chapters 3 and 4, this decision aid tool combines economics and the likelihood of treatment outcomes in a spreadsheet format to provide additional information to operators making culling decisions (Figure 5.1).

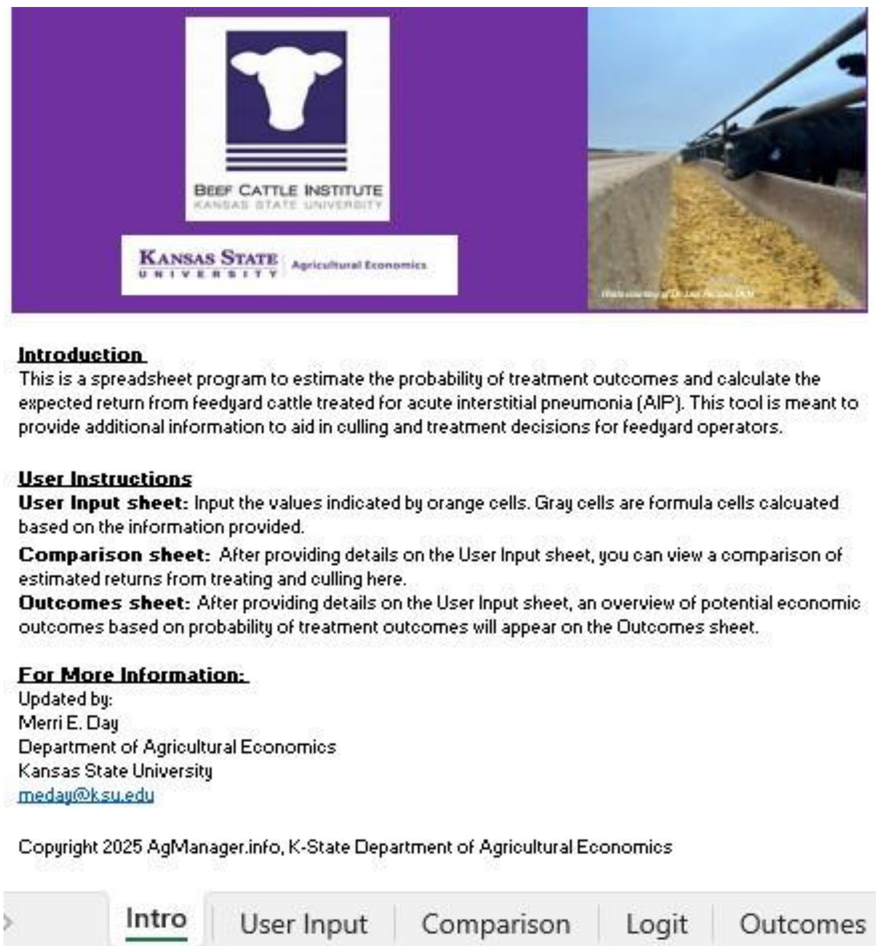

Figure 5.1. Introduction Sheet from the spreadsheet-based decision aid for feedyard operators managing feedyard cattle diagnosed with AIP.

5.2 User Input Sheet

The first section of this tool is the User Input sheet (Figure 5.2). All data necessary for estimating the probability of treatment outcomes and calculating estimated returns from culling versus treating are collected on the User Input sheet. Users are able to input characteristics of the individual animal, along with price and other operational feeding information, to estimate returns for the animal under a culling scenario and a treatment scenario. Animal inputs include sex (a dropdown selection for heifer or steer), placement weight, current weight, expected outweight, and average daily feed consumption. The decision aid will automatically generate 'Today's date', but users must enter placement date and expected shipping date. Users must input all feeding costs, including the interest rate. Users will input number of AIP treatments, AIP treatment cost ($/hd), and chute cost ($/hd). 'Treated for BRD first' is a dropdown list with yes/no selection.

All cells under 'Culling Calculations' and 'Finishing Calculations' headings contain formulas. Current days on feed and estimated days to harvest are calculated based on dates input by the user. Average feed conversion and average daily gain are calculated based on user inputs for weight and feeding information, following methods described in Chapter 3 of this dissertation.

Animal	
Sex	Steer
Weight of animal at purchase, lbs/hd	725.00
Weight of animal today, lbs/hd	1320.00
Expected outweight, lbs/hd	1358.00
Average daily feed consumption, lbs/hd	21.00

Dates	
Placement date	11/15/24
Today's date	02/17/25
Expected shipping date	04/15/25

Feeding Costs	
Purchase price of animal, $/lb	$ 2.64
Cull price, $/lb	$ 1.35
Expected sale price, $/lb	$ 2.04
Yardage cost, $/head/day	$ 0.40
Feed cost, $/lb	$ 0.07
Interest rate, %	6%

AIP Treatment Cost	
Number of AIP treatments	1
AIP treatment cost, $/hd	$ 23.60
Chute cost, $/hd	$ 1.50
Treated for BRD first	Yes

Culling Calculations	
Current days on feed	94
Estimated days to harvest	0
Average feed conversion, lbs feed/lb gain	3.32
Average daily gain, lbs/hd/day	6.33

Finishing Calculations	
Current days on feed	94
Estimated days to harvest	57
Average feed conversion, lbs feed/lb gain	5.01
Average daily gain, lbs/hd/day	4.19

Intro | User Input | Comparison | Logit | Outcomes | +

Figure 5.2. User Input sheet from the spreadsheet-based decision aid for feedyard operators managing feedyard cattle diagnosed with AIP.

5.3 Comparison Sheet

Costs and benefits associated with culling animals identified with AIP can be found on the Comparison sheet (Figure 5.3). All cells on the Comparison sheet contain formulas. Weight of the animal today, cull price, expected outweight, and expected sale price are automatically populated from the User Input sheet. Data provided by the user for cattle feeding costs are pulled from the User Input sheet to calculate feeder cattle costs, total feeding costs, total yardage cost, and interest cost. Estimated Net Return is calculated as the difference between Total Revenue (weight in lbs. x $/lb.) and Total Cost (sum of feeder cattle costs, total feeding costs, total yardage cost, and interest cost). All calculations in this sheet follow the methods described in Chapter 3 of this dissertation.

Cull value is calculated based on user inputted cull weight and cull price. Because estimated costs are restricted to feeding costs of the animal up to the point that the decision aid is implemented, benefits from culling should be interpreted as the value of the animal if sold today. User inputs to estimate costs and benefits from culling should be adjusted based on when the decision aid is implemented.

Unlike the culling scenario, estimated costs from treating an animal identified with AIP are not restricted to feeding costs up to the point that the decision aid is implemented. User inputs for the benefit of treating and finishing include harvest weight and sale price, and harvest value of the animal is calculated based on these inputs. Finally, net returns are calculated by subtracting total cost from the harvest value of the animal. It is imperative to note that the net returns in this scenario are estimated under the assumption that the animal will recover and finish with its cohort following AIP treatment.

Cost/Benefit of Culling Today

Revenue	
Weight of animal today, lbs/hd	1320.00
Cull price, $/lb	$ 1.35
Total Revenue	**$ 1,782.00**
Cost	
Feeder Cattle Cost	$ 1,914.00
Total Feeding Cost	$ 138.18
Total Yardage Cost	$ 37.60
Interest Cost	$ 30.93
Total Cost	**$ 2,120.71**
Estimated Net Return from Culling	
Estimated Net Return	**$ (338.71)**

Cost/Benefit of Treating & Finishing

Revenue	
Expected outweight	1358.00
Expected sale price, $/lb	$ 2.04
Total Revenue	**$ 2,770.32**
Cost	
Feeder Cattle Cost	$ 1,914.00
Total Feeding Cost	$ 221.97
Total Yardage Cost	$ 60.40
Interest Cost	$ 51.01
Total AIP Treatment Cost	$ 25.10
Total Cost	**$ 2,272.48**
Estimated Net Return from Finishing	
Estimated Net Return	**$ 497.84**

Intro | User Input | Comparison | Logit | Outcomes | +

Figure 5.3. Comparison sheet from the spreadsheet-based decision aid for feedyard operators managing feedyard cattle diagnosed with AIP.

5.4 Logit Sheet

Probabilities of treatment outcomes are estimated on the Logit sheet (Figure 5.4). Logit model coefficients for first AIP treatment failure and failure to finish are obtained from statistical models described in Chapter 4. The Logit Model Estimations section of the Logit sheet indexes coefficients based on the data from the User Inputs sheet to calculate the log odds. Log odds are then converted to a probability using the inverse logit function (Equation 5.1). The Logit sheet will be hidden for users of this decision tool.

$$P = \frac{1}{1+ e^{-\log odds}} \tag{5.1}$$

Predictor	Level	Logit Model Coefficients: First AIP Treatment Failure	Logit Model Coefficients: Failure to Finish
Intercept		0.3924437	-0.3035005
Sex	Heifer	0	0
Sex	Steer	0.1853893	0.1749403
Placement Weight	500-599 lbs.	0	0
Placement Weight	600-699 lbs.	-0.1432779	-0.1794689
Placement Weight	700-799 lbs.	-0.236494	-0.3499299
Placement Weight	800-899 lbs.	-0.5395953	-0.4746174
Placement Weight	900-1000 lbs.	-0.7646011	-0.9876284
First AIP Treatment Quarter	Q1	0	
First AIP Treatment Quarter	Q2	0.3795515	
First AIP Treatment Quarter	Q3	0.3362053	
First AIP Treatment Quarter	Q4	0.3018043	
First AIP Treatment Weight	< 1000 lbs.	0	0
First AIP Treatment Weight	1000-1250 lbs.	-0.6036162	-0.8850812
First AIP Treatment Weight	> 1250 lbs.	-1.387527	-1.608202
Treated for BRD first	No	0	0
Treated for BRD first	Yes	1.105705	1.717205
DOF at First AIP Treatment	< 40 days	0.000021	-0.1043421
DOF at First AIP Treatment	40-100 days	0	0
DOF at First AIP Treatment	> 100 days	-0.3583232	-0.44335533
Risk Days Remaining	< 40 days	1.763569	2.438753
Risk Days Remaining	40-100 days	0	0
Risk Days Remaining	> 100 days	-0.1441168	-0.1327863

Logit Model Estimations	FTF	DNF
Sex	0.185389	0.17494
Placement Weight	-0.23649	-0.34993
First AIP Treatment Quarter	0	0
First AIP Treatment Weight	-1.38753	-1.6082
Treated for BRD first	1.105705	1.717205
DOF at First AIP Treatment	0	0
Risk Days Remaining	0	0
Log-Odds	0.059517	-0.36949
Probability	**0.514875**	**0.408665**

Intro | User Input | Comparison | Logit | Outcomes | +

Figure 5.4. Logit sheet from the spreadsheet-based decision aid for feedyard operators managing feedyard cattle diagnosed with AIP.

5.5 Outcomes Sheet

The final segment of this decision tool is the Outcomes sheet, which allows users to explore the risk associated with treating an individual animal with AIP (Figure 5.5). Data are pulled from the User Input sheet to estimate the probabilities of first AIP treatment failure and failure to finish for an animal identified with AIP. Methods for estimating probabilities of first AIP treatment failure and failure to finish are established in Chapter 4 of this dissertation and presented on the Logit sheet.

Because the probability of first AIP treatment failure is represented as a percentage, the value in this cell will be a value between 0% and 100%. This value should be interpreted as the likelihood that the animal described by the data inputted on the User Input sheet will experience first AIP treatment failure. First AIP treatment failure is defined as any outcome in which the animal is re-treated for AIP or fails to finish with its cohort. Like the probability of first AIP treatment failure, the probability of failure to finish, represented as a percentage, should be interpreted as the likelihood that the animal described by the data inputted on the User Input sheet will fail to finish with its cohort.

Estimated returns from finishing, estimated returns from culling, estimated returns from death, and expected returns from treating are also reported on the Outcomes sheet. A gauge chart (or speedometer chart) is included to provide a visual for the range of economic outcomes for the individual animal described by the user selected levels of predictors.

Probability of First AIP Treatment Failure	51%
Probability of Failure to Finish	41%

Estimated Return from Finishing	$ 294.39
Estimated Return from Culling	$ (338.71)
Estimated Return from Death	$ (2,120.71)
Expected Return from Treating	$ 35.66

Intro User Input Comparison Logit Outcomes

Figure 5.5. Outcomes sheet from the spreadsheet-based decision aid for feedyard operators managing feedyard cattle diagnosed with AIP.

5.6 Summary

This Excel-based decision aid was developed to assist feedyard operators in decisions regarding the management of cattle identified with AIP. Combining estimation of economic returns and estimation of probabilities of treatment outcomes, this decision aid provides the user with an overview of expected returns for an individual animal identified with AIP. Additionally, the user is able to compare the expected net return from treating the animal to the estimated return from culling the animal. This decision tool is not meant to offer any recommendations on whether an animal should be culled or treated, but rather provide the user with additional information which may be considered for management of AIP.

Generally, if expected net returns from treating the animal are greater than estimated returns from culling the animal, then the animal should be retained for treatment. However, the decision to cull or treat based on information provided by this decision aid along with other factors will likely differ between operators based on multiple factors, including individual risk preferences. A risk-loving operator may opt to keep and treat an animal, while a risk-averse operator might opt to cull the same animal when the same information is considered.

The methods used to develop this decision aid are based on operational data collected from Central U.S. high plains feedyards from 2019 through 2023. Users of this decision aid should use their own discretion when interpreting the validity of outputs for their own operation based on production year, geographic location, and other potential management differences. There are many potential risk factors associated with AIP treatment outcomes that are not accounted for in this decision aid. Because this decision aid is built upon the methods and findings from Chapter 4, we are likewise unable to include metaphylaxis treatment or other clinical parameters as user inputs for this decision aid. Factors not included in this decision aid should not be ignored when determining whether or not to cull or treat, but rather should be considered in conjunction with the information provided by this decision aid.

6 Conclusions

This dissertation is a series of essays examining economic outcomes associated with various management decisions in cattle feedyards. In particular, this dissertation is concerned with feedyard management decisions which may directly or indirectly influence progress toward sustainability goals set by the United States Roundtable for Sustainable Beef (USRSB) to reduce greenhouse gas (GHG) emissions and improve animal health and welfare.

Chapter 2 focuses on performance-based decision making in feedyards which affect both economic productivity and GHG emissions. This study utilizes operational feeding data from nine Midwestern feedyards, from 2018 through 2021, consisting of beef steers and heifers placed in the feedyard between 400 and 1000 lbs. We estimate the effects of reducing mortality (25% and 50%) and changing implant protocol (number, potency) on feedyard net returns and greenhouse gas emissions. Quantification of simultaneous economic and environmental impacts of changes in feedyard management practices is a novelty of this study. Results indicate that reducing mortality consistently increases net returns and reduces GHG emissions intensity in the feedlot regardless of sex or placement weight. Additionally, we find that use of two implants in the feedlot may increase net returns and reduce GHG emissions intensity, compared to using just one growth implant. The effect of changing implant potency varies across placement weight for steers; we were unable to evaluate changes in implant potency for heifers. The findings of this analysis imply that there is potential economic and environmental benefit from reducing mortality and utilizing growth implants. However, added costs of emphasizing animal health or implementing feeding technologies, in addition to the regulation of such practices, must be considered.

Chapters 3 and 4 concentrate on health-based decisions in feedyards, specifically focusing on the management of acute interstitial pneumonia (AIP). Using operational data and individual treatment records from nine Central U.S. high plains feedyards, Chapter 3 estimates net returns for feedyard cattle identified AIP ante-mortem and post-mortem. A decision tree framework is implemented to examine economic outcomes from cattle that either finished with their cohort, were railed, or died following AIP treatment. We find that estimated net returns for feedyard cattle identified with AIP vary by sex, placement weight, and number of AIP treatments. The expected net return to feeding healthy cattle was $193.67/animal, while the expected net return for an animal diagnosed with AIP at the time it was first pulled for treatment was -$853.83. Estimated net returns, which assume the animal finished with its cohort following AIP treatment, were $98.70/animal for cattle treated once for AIP, $85.60/animal for those treated twice for AIP, and $46.33/animal for those treated three or more times for AIP. However, expected returns, which account for the probabilities of treatment outcomes, were -$639.71/animal, -$612.41/animal, and -$529.57/animal for cattle treated for AIP once, twice, and three or more times, respectively. Although expected returns from treating AIP were negative, they were still greater than estimated returns from culling, on average. Similarly, returns from culls remain higher than returns from cattle that died, implying that culling is preferable in some cases. This study did not evaluate clinical factors or risk of individual cattle, which should be considered in culling decisions.

Chapter 4 used statistical models to examine AIP treatment outcomes, utilizing operation feeding data and individual treatment records from nine Central U.S. high plains feedyards. Mixed-effects logit models were employed to estimate the probability of first AIP treatment failure (PFTF) and failure to finish (PDNF) for feedyard cattle treated for AIP. Results reveal that sex, weight, AIP treatment timing, and prior bovine respiratory disease (BRD) were significantly associated with PFTF and PDNF. Steers have higher PFTF and PDNF compared to heifers, and cattle that are placed or treated at lighter weights have higher PFTF and PDNF than those placed or treated at heavier weights. Most notably, cattle that receive BRD treatment prior to the first AIP have higher PFTF and PDNF than those that were not treated for BRD prior to AIP. We also find that cattle treated for AIP within the first forty days on feed, or within forty days of expected harvest, have higher PFTF and PDNF. While this study examines some of the factors associated with AIP treatment outcomes, clinical factors that are unobservable in the data could not be evaluated and should be considered in future research.

Chapter 5 describes the development of an Excel-based decision aid for feedyard operators deciding whether to cull or treat cattle identified with AIP. This spreadsheet tool allows the user to enter information on the User Input worksheet and then, using methods described in Chapter 3 and Chapter 4, estimates potential economic and treatment outcomes. The Comparison worksheet allows the user to compare estimated returns from culling today versus estimated returns from treating the animal, under the assumption that the animal will finish. The Logit worksheet, which will be hidden from users, contains estimated Logit coefficients and formulas for estimating the probabilities of first AIP treatment failure and failure to finish. The Outcomes worksheet provides an overview of potential economic outcomes, along with the likelihood of first AIP treatment failure and failure to finish for the animal defined on the User Input worksheet. This tool is not meant to make recommendations, but rather to provide additional information to be considered in the decision of culling versus treating feedyard cattle diagnosed with AIP.

Chapter 2 takes on a new approach to examining the simultaneous economic and environmental benefits associated with reducing mortality and using growth implants in cattle feedyards. However, future research should consider the economic and environmental effects of other management strategies in cattle feedyards such as metaphylaxis treatment. Chapters 3 and 4 provide valuable insights into the economics of AIP and factors associated with terminal outcomes of feedyard cattle treated for AIP; however, additional clinical parameters and metaphylaxis treatment were not available in the data and should be considered in future evaluation of risk factors linked to AIP treatment outcomes. Likewise, the decision aid described in Chapter 5 should be adjusted and updated in accordance with future research findings concerning the economic costs associated with AIP and risk factors associated with AIP in cattle feedyards. The use of observational data is a limitation for each of these studies and should be considered when interpreting the results of these analyses.

References

Albright, M. L., Schroeder, T. C., & Langemeier, M. R. (1994). Determinants of Cattle Feeding Cost-of-Gain Variability. Journal of Production Agriculture, 7(2), 206-210. https://doi.org/10.2134/jpa1994.0206

Amrine, D. E., McLellan, J. G., White, B. J., Larson, R. L., Renter, D. G., & Sanderson, M. (2019). Evaluation of three classification models to predict risk class of cattle cohorts developing bovine respiratory disease within the first 14 days on feed using on-arrival and/or pre-arrival information. Computers and Electronics in Agriculture, 156, 439-446. https://doi.org/10.1016/j.compag.2018.11.035

Amosson, S. H., Guerrero, B. L., & Almas, L. K. (2006). Economic analysis of solid-set sprinklers to control dust in feedlots. Proceedings of the 38th Southern Agricultural Economics Association Annual Meeting, Feb 5-8, Orlando, pp: 1-20. http://dx.doi.org/10.22004/ag.econ.35341

Avra, T. D., Abell, K. M., Shane, D. D., Theurer, M. E., Larson, R. L., & White, B. J. (2017). A retrospective analysis of risk factors associated with bovine respiratory disease treatment failure in feedlot cattle. Journal of Animal Science, 95(4), 1521-1527. https://doi.org/10.2527/jas.2016.1254

Ayroud, M., Popp, J. D., VanderKop, M. A., Yost, G. S., Haines, D. M., Majak, W., Karren, D., Yanke, L. J., & McAllister, T. A. (2000). Characterization of acute interstitial pneumonia in cattle in southern Alberta feedyards. The Canadian Veterinary Journal, 41(7), 547.

Babcock, A. H., White, B. J., Dritz, S. S., Thomson, D. U., & Renter, D. G. (2009). Feedlot health and performance effects associated with the timing of respiratory disease treatment. Journal of Animal Science, 87(1), 314-327. https://doi.org/10.2527/jas.2008-1201

Babcock, A. H., Renter, D. G., White, B. J., Dubnicka, S. R., & Scott, H. M. (2010). Temporal distributions of respiratory disease events within cohorts of feedlot cattle and associations with cattle health and performance indices. Preventive Veterinary Medicine, 97(3-4), 198-219. https://doi.org/10.1016/j.prevetmed.2010.09.003

Beck, P., Reuter, R., & Lalman, D. (2022). Implants and their use in beef cattle production. Oklahoma State University Extension. Retrieved November 14, 2024, from https://extension.okstate.edu/fact-sheets/implants-and-their-use-in-beef-cattle-production.html

Belasco, E. J., Cheng, Y., & Schroeder, T. C. (2015). The impact of extreme weather on cattle feeding profits. Journal of Agricultural and Resource Economics, 285-305.

Belasco, E. J., Taylor, M. R., Goodwin, B. K., & Schroeder, T. C. (2009). Probabilistic models of yield, price, and revenue risks for fed cattle production. Journal of Agricultural and Applied Economics, 41(1), 91-105. https://doi.org/10.1017/S1074070800002571

Blackman, I. (2021). Stanford Explainer: Social Cost of Carbon. Stanford University News. Retrieved August 18, 2023, from https://news.stanford.edu/2021/06/07/professors-explain-social-cost-carbon/

Bortoluzzi, E. M., White, B. J., Schmidt, P. H., Mancke, M. R., Brown, R. E., Jensen, M., Lancaster, P. A. & Larson, R. L. (2023). Epidemiological Factors Associated with Gross Diagnosis of Pulmonary Pathology in Feedyard Mortalities. Veterinary Sciences, 10(8), 522. https://doi.org/10.3390/vetsci10080522

Broocks, A., Andreini, E., Rolf, M., & Place, S. (2016). Carbon Footprint Comparison Between Grass- and Grain-finished Beef. Retrieved August 18, 2023, from https://extension.okstate.edu/fact-sheets/carbon-footprint-comparison-between-grass-and-grain-finished-beef.html

Brooks, K. R., Raper, K. C., Ward, C. E., Holland, B. P., Krehbiel, C. R., & Step, D. L. (2011). Economic effects of bovine respiratory disease on feedlot cattle during backgrounding and finishing phases. The Professional Animal Scientist, 27(3), 195–203. https://doi.org/10.15232/S1080-7446(15)30474-5

Capper, J. L. (2023). The impact of controlling diseases of significant global importance on greenhouse gas emissions from livestock production. *One Health Outlook*, *5*(1), 17. https://doi.org/10.1186/s42522-023-00089-y

Cernicchiaro, N., White, B. J., Renter, D. G., & Babcock, A. H. (2013). Evaluation of economic and performance outcomes associated with the number of treatments after an initial diagnosis of bovine respiratory disease in commercial feeder cattle. American Journal of Veterinary Research, 74(2), 300-309. https://doi.org/10.2460/ajvr.74.2.300

Cooprider, K. L., Mitloehner, F. M., Famula, T. R., Kebreab, E., Zhao, Y., & Van Eenennaam, A. L. (2011). Feedlot efficiency implications on greenhouse gas emissions and sustainability. Journal of Animal Science, 89(8), 2643-2656. https://doi.org/10.2527/jas.2010-3539

Crawford, D. M., Hales, K. E., Smock, T. M., Cole, N. A., & Samuelson, K. L. (2022). Effects of changes in finishing diets and growth technologies on animal growth performance and the carbon footprint of cattle feeding: 1990 to 2020. Applied Animal Science, 38(1), 47-61. https://doi.org/10.15232/aas.2021-02199

Davis-Unger, J., Pajor, E. A., Schwartzkopf-Genswein, K., Marti, S., Dorin, C., Spackman, E., & Orsel, K. (2017). Economic impacts of lameness in feedlot cattle. Translational Animal Science, 1(4), 467-479. https://doi.org/10.2527/tas2017.0052

Day, M. E., Pendell, D. L., White, B. J., Lancaster, P. L., & Larson, R. L. (2025). Economic outcomes associated with acute interstitial pneumonia in Central U.S. High Plains feedyards. Working paper. Kansas State University.

Dennis, E. J., Schroeder, T. C., Renter, D. G., & Pendell, D. L. (2018). Value of placement metaphylaxis in US cattle industry. Journal of Agricultural and Resource Economics, 43(2), 233-250. http://dx.doi.org/10.22004/ag.econ.273448

Dennis, E. J., Schroeder, T. C., & Renter, D. G. (2020). Net return distributions when metaphylaxis is used to control bovine respiratory disease in high health-risk cattle. Translational Animal Science, 4(2), 1091-1102. https://doi.org/10.1093/tas/txaa020

Doster, A. R. (2010). Bovine atypical interstitial pneumonia. Veterinary Clinics: Food Animal Practice, 26(2), 395-407. https://doi.org/10.1016/j.cvfa.2010.03.002

Federal Reserve Bank of Kansas City. (2024). Ag Credit Survey, Data: Fixed Interest Rates. Federal Reserve Bank of Kansas City. https://www.kansascityfed.org/agriculture/ag-credit-survey/

Griffin, D. (2014). The monster we don't see: subclinical BRD in beef cattle. Animal Health Research Reviews, 15(2), 138-141. https://doi.org/10.1017/S1466252314000255

Haydock, L. A., Fenton, R. K., Sergejewich, L., Squires, E. J., & Caswell, J. L. (2022). Acute interstitial pneumonia and the biology of 3-methylindole in feedlot cattle. Animal Health Research Reviews, 23(1), 72-81. https://doi.org/10.1017/S1466252322000020

Horton, L. M., Depenbusch, B. E., Pendell, D. L., & Renter, D. G. (2021). Description of feedlot animals culled for slaughter, revenue received, and associations with reported US beef market prices. The Bovine Practitioner, 55(1), 65-77. https://doi.org/10.21423/bovine-vol55no1p65-77

Irsik, M., Langemeier, M., Schroeder, T., Spire, M., & Roder, J. D. (2006). Estimating the effects of animal health on the performance of feedlot cattle. The Bovine Practitioner, 65–74. https://doi.org/10.21423/bovine-vol40no2p65-74

JBS Foods. (n.d.). JBS makes global commitment to achieve net-zero greenhouse gas emissions by 2040. JBS Foods. Retrieved December 19, 2022, from https://jbsfoodsgroup.com/articles/jbs-makes-global-commitment-to-achieve-net-zero-greenhouse-gas-emissions-by-2040

Johnson, K. K., & Pendell, D. L. (2017). Market impacts of reducing the prevalence of bovine respiratory disease in United States beef cattle feedlots. Frontiers in Veterinary Science, 4, 189. https://doi.org/10.3389/fvets.2017.00189

Jones, R., Mintert, J., Langemeier, M., & Schroeder, T. (1996). Sources of economic variability in cattle feeding. Proceedings of the NCR-134 Conference on Applied Commodity Price Analysis, Forecasting, and Market Risk Management. Chicago, IL.

Livestock Marketing Information Center. (n.d.). Livestock Marketing Information Center. https://www.lmic.info/

Loneragan, G. H., & Gould, D. H. (2000). Acute interstitial pneumonia in feedlot cattle. In American Association of Bovine Practitioners Conference Proceedings (pp. 129-132).

Loneragan, G. H., Gould, D. H., Mason, G. L., Garry, F. B., Yost, G. S., Miles, D. G., Hoffman, B. W., & Mills, L. J. (2001a). Involvement of microbial respiratory pathogens in acute interstitial pneumonia in feedlot cattle. American Journal of Veterinary Research, 62(10), 1519-1524. https://doi.org/10.2460/ajvr.2001.62.1519

Loneragan, G. H., Gould, D. H., Mason, G. L., Garry, F. B., Yost, G. S., Lanza, D. L., Mile, D. G., Hoffman, B. W. & Mills, L. J. (2001b). Association of 3-methyleneindolenine, a toxic metabolite of 3-methylindole, with acute interstitial pneumonia in feedlot cattle. American Journal of Veterinary Research, 62(10), 1525-1530. https://doi.org/10.2460/ajvr.2001.62.1525

Lynch, J. (2019). Availability of disaggregated greenhouse gas emissions from beef cattle production: A systematic review. Environmental Impact Assessment Review, 76, 69-78. https://doi.org/10.1016/j.eiar.2019.02.003

Mark, D. R., Schroeder, T. C., & Jones, R. D. (2000). Identifying economic risk in cattle feeding. Journal of Agribusiness, 18(3), 331-344. http://dx.doi.org/10.22004/ag.econ.14712

Marti, S., Jelinski, M. D., Janzen, E. D., Jelinski, M. J., Dorin, C. L., Orsel, K., Pajor, J. S., Millman, S. T., & Schwartzkopf-Genswein, K. S. (2021). A prospective longitudinal study of risk factors associated with cattle lameness in southern Alberta feedlots. Canadian Journal of Animal Science, 101(4), 647-654. https://doi.org/10.1139/cjas-2020-0128

McDonald's. Climate Action—McDonald's. (n.d.). McDonald's. Retrieved December 19, 2022, from https://corporate.mcdonalds.com/corpmcd/our-purpose-and-impact/our-planet/climate-action.html

Neal, K. B., White, B. J., Amrine, D. E., Lubbers, B. V., Tessman, R. K., & Larson, R. L. (2024). Risk factors associated with case fatality and treatment success following initial bovine respiratory disease treatment in feedyard cattle. The Bovine Practitioner, 58(2), 1-8. https://doi.org/10.21423/bovine-vol58no2p1-8

Panciera, R. J., & Confer, A. W. (2010). Pathogenesis and pathology of bovine pneumonia. Veterinary Clinics: Food Animal Practice, 26(2), 191-214. https://doi.org/10.1016/j.cvfa.2010.04.001

PBS Animal Health. (n.d.) PBS Animal Health. https://www.pbsanimalhealth.com

Rojas, H. A., White, B. J., Amrine, D. E., & Larson, R. L. (2022). Predicting bovine respiratory disease risk in feedlot cattle in the first 45 days post arrival. Pathogens, 11(4), 442. https://doi.org/10.3390/pathogens11040442

Sanderson, M. W., Dargatz, D. A., & Wagner, B. A. (2008). Risk factors for initial respiratory disease in United States' feedlots based on producer-collected daily morbidity counts. The Canadian Veterinary Journal, 49(4), 373.

Smith, R. A., Step, D. L., & Woolums, A. R. (2020). Bovine respiratory disease: looking back and looking forward, what do we see?. Veterinary Clinics: Food Animal Practice, 36(2), 239-251. https://doi.org/10.1016/j.cvfa.2020.03.009

Smith, K. J., Amrine, D. E., Larson, R. L., Theurer, M. E., & White, B. J. (2022). Determining relevant risk factors associated with mid-and late-feeding-stage bovine respiratory disease morbidity in cohorts of beef feedlot cattle. Applied Animal Science, 38(4), 373-379. https://doi.org/10.15232/aas.2022-02312

Smith, Z. K., & Johnson, B. J. (2020). Mechanisms of steroidal implants to improve beef cattle growth: a review. Journal of Applied Animal Research, 48(1), 133-141. https://doi.org/10.1080/09712119.2020.1751642

Sorden, S. D., Kerr, R. W., & Janzen, E. D. (2000). Interstitial pneumonia in feedlot cattle: concurrent lesions and lack of immunohistochemical evidence for bovine respiratory syncytial virus infection. Journal of Veterinary Diagnostic Investigation, 12(6), 510-517. https://doi.org/10.1177/104063870001200604

Stackhouse, K. R., Rotz, C. A., Oltjen, J. W., & Mitloehner, F. M. (2012). Growth-promoting technologies decrease the carbon footprint, ammonia emissions, and costs of California beef production systems. Journal of Animal Science, 90(12), 4656-4665. https://doi.org/10.2527/jas.2011-4654

Stackhouse-Lawson, K. R., Calvo, M. S., Place, S. E., Armitage, T. L., Pan, Y., Zhao, Y., & Mitloehner, F. M. (2013). Growth promoting technologies reduce greenhouse gas, alcohol, and ammonia emissions from feedlot cattle. Journal of Animal Science, 91(11), 5438-5447. https://doi.org/10.2527/jas.2011-4885

Stanford, K., McAllister, T. A., Ayroud, M., Bray, T. M., & Yost, G. S. (2006). Effect of dietary melengestrol acetate on the incidence of acute interstitial pneumonia in feedlot heifers. Canadian Journal of Veterinary Research, 70(3), 218.

Swanson, E. R., & West, V. I. (1963). Statistical analysis of feeder cattle returns. Journal of Farm Economics, 45(1), 146-150. https://doi.org/10.2307/1235925

Theurer, M. E., Johnson, M. D., Fox, T., McCarty, T. M., McCollum, R. M., Jones, T. M., & Alkire, D. O. (2021). Bovine respiratory disease during the mid-portion of the feeding period: observations of frequency, timing, and population from the field. Applied Animal Science, 37(1), 52-58. https://doi.org/10.15232/aas.2020-02089

Tractor Supply Company. (n.d.) Tractor Supply Company. https://www.tractorsupply.com

Trapp, J. N., & Cleveland, S. D. (1989). An analysis of the sources of profit volatility in cattle feeding. NCR-134 Conference on Applied Commodity Price Analysis, Forecasting, and Market Risk Management, Chicago, IL.

Tyson Foods (2021). Tyson Foods Targets 2050 to achieve net zero greenhouse gas emissions. Tyson. https://www.tysonfoods.com/news/news-releases/2021/6/tyson-foods-targets-2050-achieve-net-zero-greenhouse-gas-emissions

USDA, APHIS. (2013). Feedlot 2011 Part IV: Health and health management on US feedlots with a capacity of 1,000 or more head. NAHMS Feedlot Studies. Fort Collins: National Animal Health Monitoring System. Retrieved September 15, 2024, from https://www.aphis.usda.gov/livestock-poultry-disease/nahms/feedlot

USDA ERS. (2023) U.S. Department of Agriculture Economic Research Service. Retrieved November 15, 2023, from https://www.ers.usda.gov/topics/animal-products/cattle-beef/sector-at-a-glance/

USDA ERS. (2024). U.S. Department of Agriculture, Economic Research Service. Farm Income and Wealth Statistics. Retrieved February 3, 2025, from https://data.ers.usda.gov/reports.aspx?ID=4057

USDA NASS. (2025). U.S. Department of Agriculture, National Agricultural Statistics Service. Retrieved February 3, 2025 from https://usda.library.cornell.edu/concern/publications/m326m174z

U.S. EPA. (2024a). Scope 1 and Scope 2 Inventory Guidance. United States Environmental Protection Agency. Retrieved November 14, 2024, from https://www.epa.gov/climateleadership/scope-1-and-scope-2-inventory-guidance

U.S. EPA. (2024b). Scope 3 Inventory Guidance. United States Environmental Protection Agency. Retrieved November 14, 2024, from https://www.epa.gov/climateleadership/scope-3-inventory-guidance

U.S. EPA. (2024c). United States Environmental Protection Agency. Retrieved November 14, 2024, from https://www.epa.gov/ghgemissions/overview-greenhouse-gases

U.S. EPA. (2025). United States Environmental Protection Agency. Retrieved February 3, 2025, from https://www.epa.gov/ghgemissions/agriculture-sector-emissions

U.S. FDA. (2023a). United States Food and Drug Administration. Retrieved August 18, 2023, from https://www.fda.gov/animal-veterinary/resources-you/fda-letter-industry-provides-additional-information-and-clarification-use-beef-cattle-ear-implants

U.S. FDA. (2023b). United States Food and Drug Administration. Retrieved February 27, 2024, from https://www.fda.gov/animal-veterinary/product-safety-information/fda-provides-list-currently-approved-and-currently-marketed-implants-available-beef-cattle-target.

U.S. Roundtable for Sustainable Beef. (2022). USRSB High-Priority Indicator Goals and Sector Targets. United Stated Roundtable for Sustainable Beef. Retrieved August 18, 2023, from https://www.usrsb.org/Media/USRSB/Docs/usrsbgoalsandtargets_supportingdocument_2022.pdf

Valles, J. A., Apley, M. D., Reinhardt, C. D., Bartle, S. J., & Thomson, D. U. (2016). Pathologies of acute interstitial pneumonia in feedlot cattle. American Journal of Animal and Veterinary Sciences, 11(1), 1-7. https://doi.org/10.3844/ajavsp.2016.1.7

Wang, T., Park, S. C., Bevers, S., Teague, R., & Cho, J. (2013). Factors affecting cow-calf herd performance and greenhouse gas emissions. Journal of Agricultural and Resource Economics, 435-456.

Webb, M. J., Block, J. J., Harty, A. A., Salverson, R. R., Daly, R. F., Jaeger, J. R., Underwood, K. R., Funston, R. N., Pendell, D. L., Rotz, C. A., Olsen, K. C., & Blair, A. D. (2020). Cattle and carcass performance, and life cycle assessment of production systems utilizing additive combinations of growth promotant technologies. Translational Animal Science, 4(4), txaa216. https://doi.org/10.1093/tas/txaa216

Weber, K. M. D. (2022). Essays on fed cattle production and net return risk using stochastic simulation. Kansas State University.

Wileman, B. W., Thomson, D. U., Reinhardt, C. D., & Renter, D. G. (2009). Analysis of modern technologies commonly used in beef cattle production: Conventional beef production versus nonconventional production using meta-analysis. Journal of Animal Science, 87(10), 3418-3426. https://doi.org/10.2527/jas.2009-1778

Woolums, A. R. (2003). An update on feedlot AIP. In American Association of Bovine Practitioners Conference Proceedings (pp. 62-67).

Woolums, A. R., Mason, G. L., Hawkins, L. L., Brown, C. C., Williams, S. M., Gould, J. A., Fox, J. J., Sturgeon, S. D., Anderson, J. L., Duggan, F. E., Sanchez, S., Barrett, P. B., & Chitwood, S. W. (2004). Microbiologic findings in feedlot cattle with acute interstitial pneumonia. American Journal of Veterinary Research, 65(11), 1525-1532. https://doi.org/10.2460/ajvr.2004.65.1525

Woolums, A. R., Loneragan, G. H., Hawkins, L. L., & Williams, S. M. (2005). A survey of the relationship between management practices and risk of acute interstitial pneumonia at US feedlots. The Bovine Practitioner, 125-133. https://doi.org/10.21423/bovine-vol39no2p125-133

Woolums, A. R. (2015). Feedlot acute interstitial pneumonia. Veterinary Clinics of North America: Food Animal Practice, 31(3), 381-389. https://doi.org/10.1016/j.cvfa.2015.05.010

Appendix A

Table A.1. Summary Statistics for Pen-Level Operational Feedlot Data

Variable description	Heifers				Steers			
	Mean	Std. dev.	Min	Max	Mean	Std. dev.	Min	Max
Placement Weight (lbs.)	734	87.48	400	899	807	91.36	600	999
Sale Weight (lbs.)	1251	62.49	990	1503	1410	69.18	1038	1665
Days on Feed	156	25.40	96	266	163	23.35	94	247
Average Daily Gain (lbs./day)	3.26	0.39	1.50	4.75	3.65	0.44	1.66	5.30
Feed Conversion (lbs. feed/lbs. gain)	6.44	0.59	5.02	11.98	6.19	0.58	4.72	13.72
Health Cost ($/head)	22.66	11.83	4.58	127.09	21.75	11.43	5.05	105.02
Mortality (proportion)	0.02	0.02	0	0.29	0.02	0.02	0	0.30
Cull (proportion)	0.01	0.02	0	1	0.01	0.01	0	0.16
Carcass Weight (lbs.)	800	41.10	643	976	900	45.03	686	1049
One Implant (0, 1)	0.03	0.16	0	1	0.05	0.22	0	1
Two Implants (0, 1)	0.90	0.30	0	1	0.94	0.23	0	1
Three or more Implants (0, 1)	0.07	0.26	0	1	0.01	0.07	0	1
Moderate Potency Implant Protocol (0,1)	0.98	0.14	0	1	0.80	0.40	0	1
High Potency Implant Protocol (0,1)	0.02	0.014	0	1	0.20	0.40	0	1
Feeder Price ($/lb.)	1.34	0.06	1.24	1.66	1.42	0.06	1.35	1.64
Dressed Price ($/lb.)	1.89	0.02	1.81	1.97	1.85	0.02	1.76	1.93
Yardage Cost ($/head)	62.25	10.16	38.40	106.40	65.08	9.34	37.60	98.80
Feeding Cost ($/head)	268.92	79.48	-368.90	636.75	282.85	69.55	141.44	672.81
Interest Cost ($/head)	28.24	4.04	17.51	48.48	34.58	4.38	22.49	66.15
Net Return ($/head)	125.59	95.08	-209.01	873.33	92.71	93.80	-383.37	402.20

Table A.2. Relative Potency of Hormonal Growth Implants

Implant	Hormone Combination	Relative Potency [a,b]	Market Price [c] ($/dose)
Component E-H with Tylan	200mg testosterone 20mg estradiol benzoate	Moderate	$1.37
Component E-S with Tylan	200mg progesterone 20mg estradiol benzoate	Moderate	$1.63
Component TE-G with Tylan	40mg trenbolone acetate 8mg estradiol	Moderate	$1.89
Component TE-IH with Tylan	80mg trenbolone acetate 8mg estradiol	Moderate	$3.34
Component TE-IS with Tylan	80mg trenbolone acetate 16mg estradiol	Moderate	$3.34
Component TE-H with Tylan	140mg trenbolone acetate 14mg estradiol	Moderate	$3.65
Component TE-S with Tylan	120mg trenbolone acetate 24mg estradiol	Moderate	$4.43
Revalor G	40mg trenbolone acetate 8mg estradiol	Moderate	$1.75
Revalor H	140mg trenbolone acetate 14mg estradiol	Moderate	$4.08
Revalor S	120mg trenbolone acetate 24mg estradiol	Moderate	$4.08
Revalor IH	80mg trenbolone acetate 8mg estradiol	Moderate	$3.34
Revalor IS	80mg trenbolone acetate 16mg estradiol	Moderate	$3.18
Synovex One Grass	150mg trenbolone acetate 21mg estradiol benzoate	Moderate	$5.47
Synovex Choice	100mg trenbolone acetate 14mg estradiol benzoate	Moderate	$3.24
Synovex H	200mg testosterone propionate 20mg estradiol benzoate	Moderate	$1.37
Synovex S	200mg progesterone 20mg estradiol benzoate	Moderate	$1.37
Component TE-200 with Tylan	200mg trenbolone acetate 20mg estradiol	High	$4.31
Revalor 200	200mg trenbolone acetate 20mg estradiol	High	$4.10
Revalor XS	200mg trenbolone acetate 40mg estradiol	High	$9.35
Revalor-XH	200mg trenbolone acetate 20mg estradiol	High	$8.57
Synovex Plus	200mg trenbolone acetate 28mg estradiol benzoate	High	$4.09
Synovex One-Feedlot	200mg trenbolone acetate 28mg estradiol benzoate	High	$8.26

[a] Moderate potency implants contain ≥ 200mg progesterone/testosterone or < 200mg trenbolone acetate.
[b] High potency implants contain ≥ 200mg trenbolone acetate.
[c] Market prices ($/dose) for growth implants were obtained from PBS Animal Health. Market prices for Component E-H with Tylan and Component TE-H with Tylan were unavailable at PBS Animal Health, and were obtained from Tractor Supply.

Table A.3. Average Net Greenhouse Gas Emissions

	Placement Weight (lbs.)					
	400-599	600-749		750-899		900-1000
	Heifers	Heifers	Steers	Heifers	Steers	Steers
Non-feedlot emissions per head (kg CO_2e/hd.)	5875.17	6184.68	6190.86	6500.78	6547.73	6890.55
Feedlot emissions per head (kg CO_2e /hd.)	1675.86	1498.80	1747.06	1360.89	1606.90	1454.30
Total emissions per head (kg CO_2e /hd.)	7551.03	7683.48	7937.92	7861.67	8154.63	8344.85
Non-feedlot emissions per lb. dressed beef produced (kg CO_2e/lb. beef)	8.10	8.06	7.35	8.11	7.37	7.51
FY emissions per lb. dressed beef produced (kg CO_2e /lb. beef)	2.30	1.96	2.08	1.70	1.81	1.59
Total emissions per lb. dressed beef produced (kg CO_2e /lb. beef)	10.40	10.02	9.43	9.81	9.18	9.10

Table A.4. Results for AFC (feed conversion) model (lb. dry feed/lb. gain) [a]

	Placement Weight (lbs.)					
	400-599	600-749		750-899		900-1000
	Heifers	Heifers	Steers	Heifers	Steers	Steers
Yard 2	0.604***	0.190**	0.417***	0.102*	0.168***	0.061
	(0.154)	(0.083)	(0.077)	(0.056)	(0.060)	(0.154)
Yard 3	-0.075	-0.287***	-0.215***	-0.315***	-0.270***	-0.333***
	(0.085)	(0.037)	(0.054)	(0.035)	(0.033)	(0.066)
Yard 4	0.225	-0.175***	0.029	-0.118***	-0.045	-0.064
	(0.138)	(0.044)	(0.064)	(0.044)	(0.043)	(0.091)
Yard 5	0.665***	0.157***	0.202*	0.357***	0.347***	0.586**
	(0.135)	(0.058)	(0.104)	(0.064)	(0.081)	(0.254)
Yard 6	0.216*	-0.241***	-0.076	-0.373***	-0.099	-0.342***
	(0.110)	(0.053)	(0.072)	(0.051)	(0.066)	(0.124)
Yard 7	0.286	-0.162**	-0.198***	-0.465***	-0.503***	-0.466***
	(0.187)	(0.078)	(0.065)	(0.176)	(0.093)	(0.140)
Yard 8	-0.141*	-0.363***	-0.250***	-0.336***	-0.355***	-0.452***
	(0.083)	(0.036)	(0.044)	(0.035)	(0.031)	(0.065)
Yard 9		0.307**	0.012	0.780***	0.718***	0.713***
		(0.154)	(0.242)	(0.182)	(0.171)	(0.160)
Q2	0.151*	-0.010	0.047	0.014	-0.010	0.026
	(0.079)	(0.026)	(0.049)	(0.028)	(0.026)	(0.060)
Q3	0.253***	0.097***	0.347***	-0.054*	0.179***	-0.003
	(0.076)	(0.028)	(0.043)	(0.030)	(0.028)	(0.061)
Q4	0.054	0.111***	0.095**	0.163***	0.161***	0.208***
	(0.073)	(0.028)	(0.038)	(0.037)	(0.029)	(0.080)
ln(CPW)	0.707**	1.432***	1.491***	1.881***	1.637***	1.101
	(0.278)	(0.187)	(0.272)	(0.236)	(0.198)	(0.808)
MORT · 100	0.133***	0.114***	0.108***	0.172***	0.158***	0.174***
	(0.013)	(0.008)	(0.008)	(0.013)	(0.013)	(0.026)
HC	-0.006***	0.0003	-0.004***	-0.003	-0.004**	-0.009
	(0.002)	(0.001)	(0.001)	(0.003)	(0.002)	(0.006)
One implant		0.435***	0.484**	0.269**	0.335***	0.231*
		(0.091)	(0.188)	(0.137)	(0.118)	(0.120)
Three or more implants	-0.037	-0.021	0.082			
	(0.062)	(0.061)	(0.104)			
Moderate potency protocol			-0.112**		0.056	0.107
			(0.052)		(0.037)	(0.077)
Constant	1.414	-3.093**	-3.785**	-6.027***	-4.902***	-1.106
	(1.767)	(1.237)	(1.772)	(1.598)	(1.344)	(5.534)
R^2	0.581	0.391	0.443	0.344	0.459	0.320
RMSE	0.398	0.430	0.420	0.479	0.429	0.484
Observations	346	1987	927	2085	1895	573

[a] Standard error in parentheses = * p<0.10, ** p<0.05, *** p<0.01.

Table A.5. Results for ADG (average daily gain) model (lb. per day) [a]

	Placement Weight (lbs.)					
	400-599	600-749		750-899		900-1000
	Heifers	Heifers	Steers	Heifers	Steers	Steers
Yard 2	-0.182**	-0.070*	-0.164***	0.008	-0.120***	-0.107
	(0.076)	(0.037)	(0.050)	(0.034)	(0.045)	(0.089)
Yard 3	-0.011	-0.027	-0.025	-0.005	-0.091***	0.007
	(0.059)	(0.025)	(0.039)	(0.025)	(0.027)	(0.052)
Yard 4	-0.043	0.001	-0.040	-0.038	-0.117***	-0.020
	(0.071)	(0.027)	(0.046)	(0.029)	(0.034)	(0.076)
Yard 5	-0.334***	-0.174***	-0.250***	-0.254***	-0.308***	-0.337**
	(0.075)	(0.033)	(0.070)	(0.041)	(0.060)	(0.162)
Yard 6	-0.102	0.014	0.009	0.105***	-0.059	0.181**
	(0.070)	(0.033)	(0.053)	(0.038)	(0.050)	(0.083)
Yard 7	-0.356***	-0.140***	-0.133***	-0.023	-0.023	0.062
	(0.078)	(0.041)	(0.045)	(0.091)	(0.070)	(0.110)
Yard 8	0.023	0.126***	0.129***	0.147***	0.174***	0.216***
	(0.058)	(0.025)	(0.035)	(0.024)	(0.027)	(0.059)
Yard 9		0.099	0.337**	-0.148	0.005	0.012
		(0.086)	(0.145)	(0.099)	(0.094)	(0.158)
Q2	-0.004	0.054***	0.018	-0.024	0.062***	-0.031
	(0.055)	(0.018)	(0.042)	(0.019)	(0.022)	(0.048)
Q3	-0.071	0.038*	-0.175***	0.214***	0.062***	0.179***
	(0.053)	(0.019)	(0.032)	(0.021)	(0.023)	(0.052)
Q4	-0.037	-0.066***	-0.120***	-0.008	-0.065***	-0.142**
	(0.053)	(0.018)	(0.028)	(0.025)	(0.024)	(0.066)
ln(CPW)	0.838***	0.683***	0.906***	0.299*	0.587***	0.869
	(0.182)	(0.123)	(0.222)	(0.168)	(0.165)	(0.672)
MORT · 100	-0.060***	-0.066***	-0.064***	-0.095***	-0.091***	-0.113***
	(0.006)	(0.003)	(0.005)	(0.006)	(0.005)	(0.017)
HC	-0.00001	-0.001**	-0.0001	0.002	0.003***	0.008**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.004)
One implant		-0.199***	-0.203**	-0.122	-0.204***	-0.121
		(0.054)	(0.091)	(0.075)	(0.068)	(0.085)
Three or more implants	-0.048	-0.033	-0.182**			
	(0.041)	(0.029)	(0.080)			
Moderate potency protocol			0.071*		-0.131***	-0.124**
			(0.037)		(0.031)	(0.057)
Constant	-2.036*	-1.095	-2.263	1.356	-0.061	-2.172
	(1.163)	(0.808)	(1.446)	(1.127)	(1.117)	(4.601)
R^2	0.471	0.340	0.397	0.247	0.253	0.186
RMSE	0.269	0.297	0.313	0.342	0.365	0.414
Observations	346	1987	927	2085	1895	573

[a] Standard error in parentheses = * p<0.10, ** p<0.05, *** p<0.01.

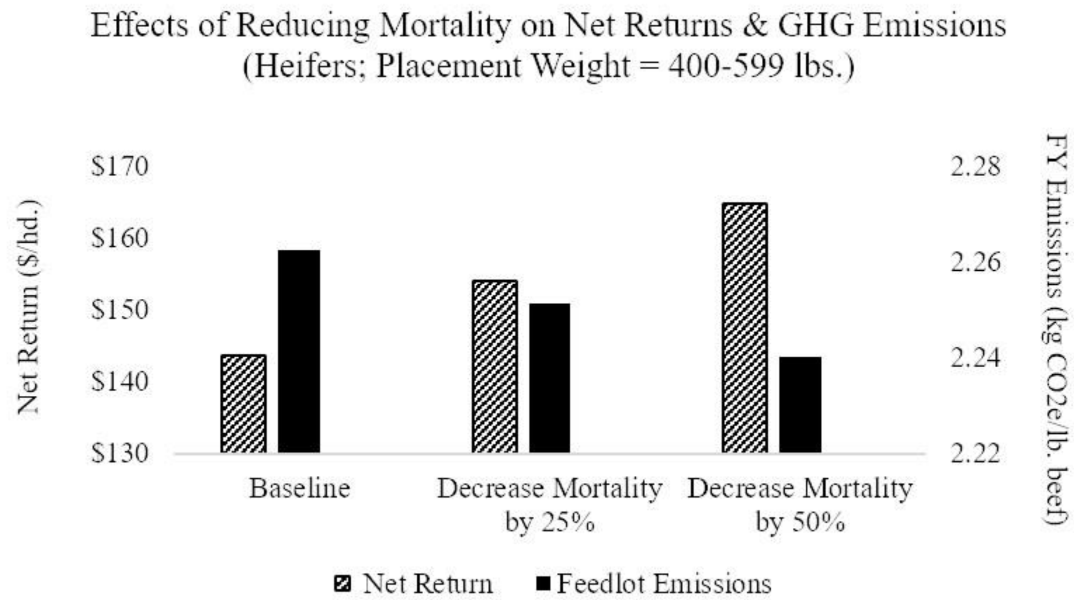

Figure A.1. Incremental effects of reducing mortality on feedlot net returns and GHG emissions per pound of dressed beef for heifers placed between 400-599 lbs.

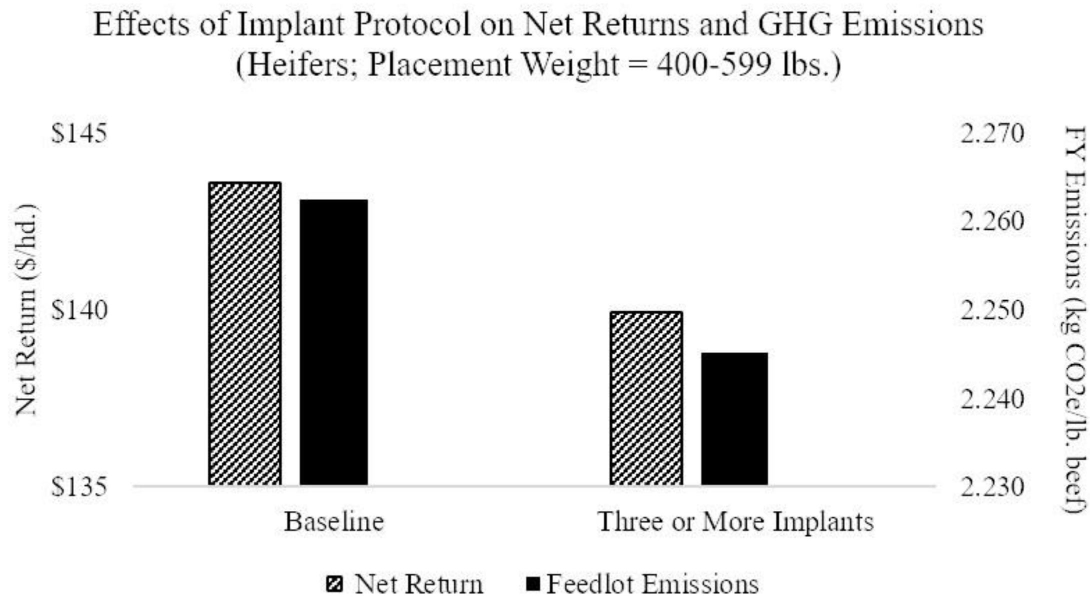

Figure A.2. Incremental effects of changing the number of growth implants on feedlot net returns and GHG emissions per pound of dressed beef for heifers placed between 400-599 lbs.

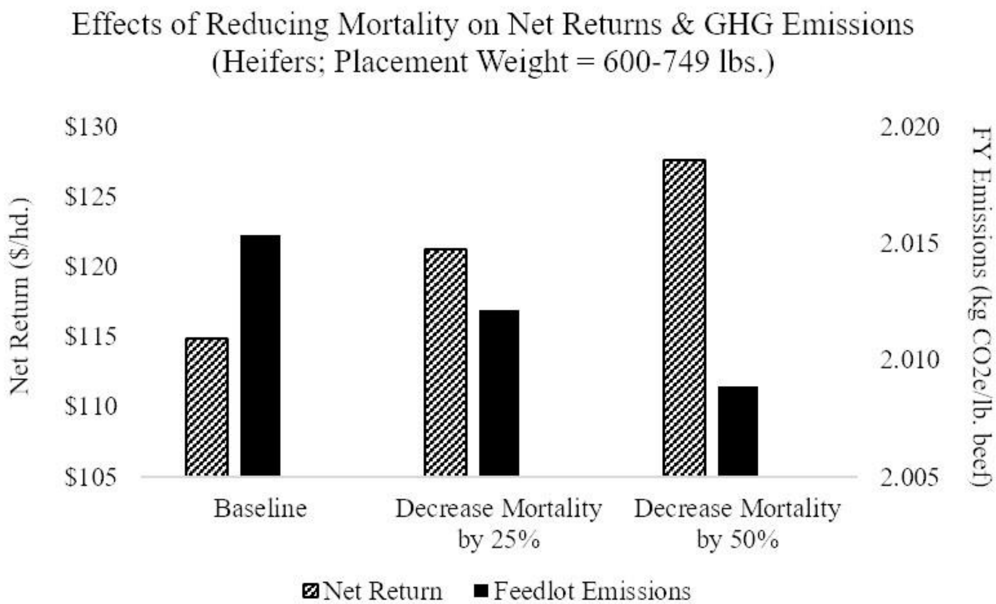

Figure A.3. Incremental effects of reducing mortality on feedlot net returns and GHG emissions per pound of dressed beef for heifers placed between 600-749 lbs.

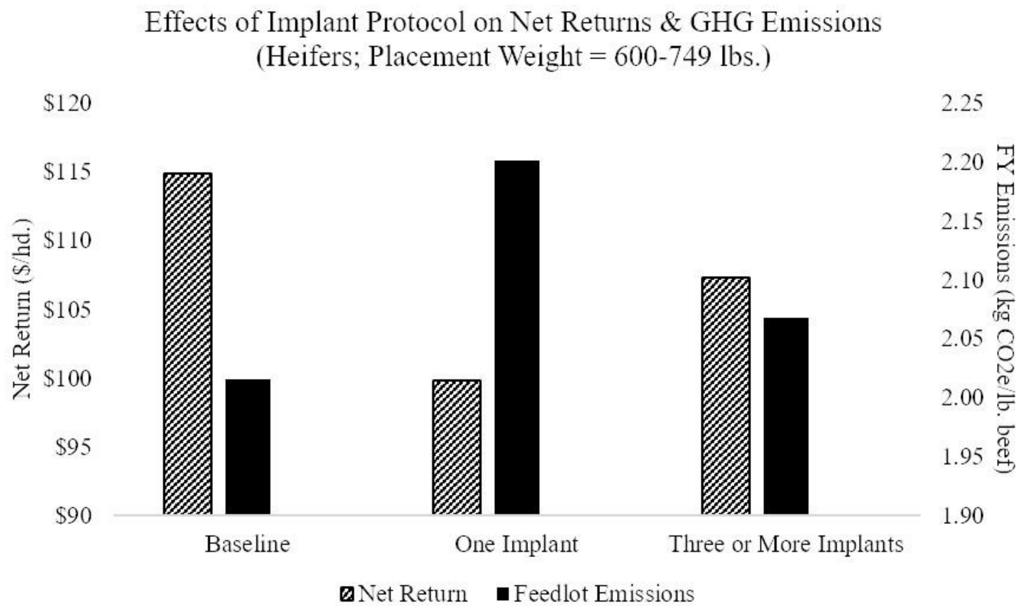

Figure A.4. Incremental effects of changing the number of growth implants on feedlot net returns and GHG emissions per pound of dressed beef for heifers placed between 600-749 lbs.

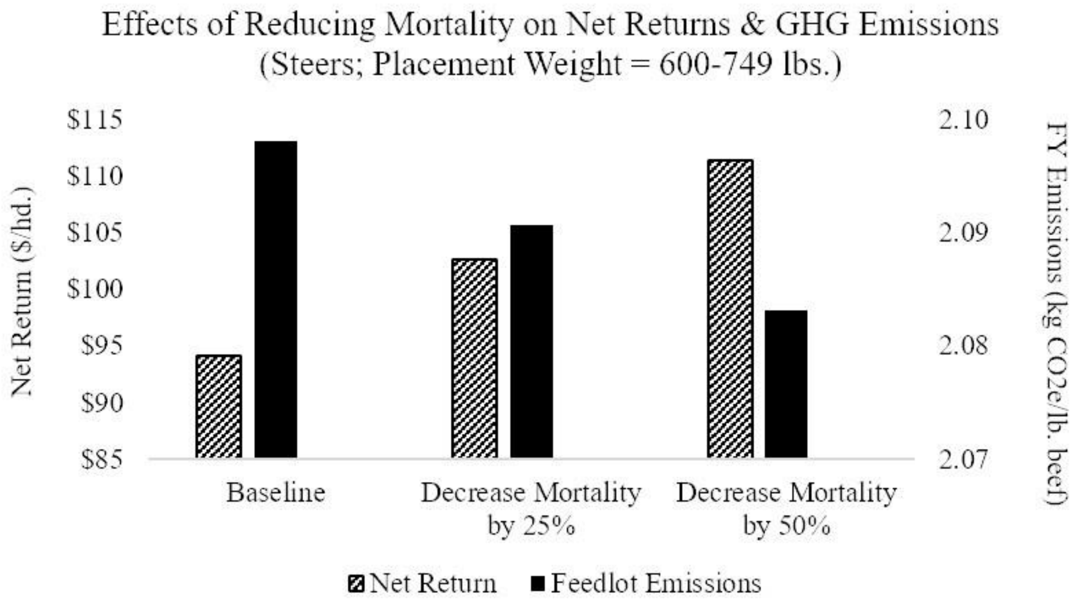

Figure A.5. Incremental effects of reducing mortality on feedlot net returns and GHG emissions per pound of dressed beef for steers placed between 600-749 lbs.

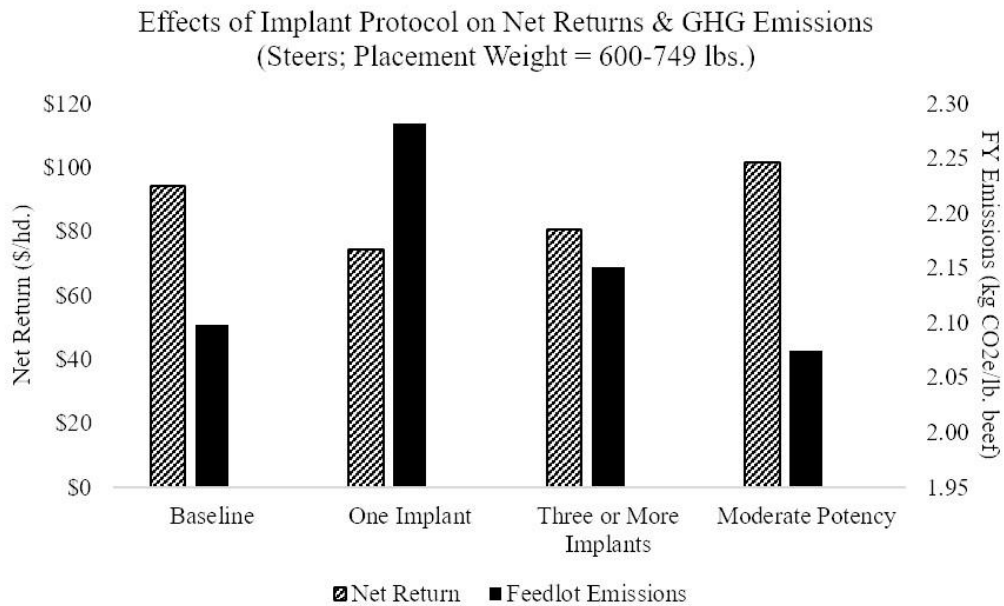

Figure A.6. Incremental effects of changing the number of growth implants and implant potency on feedlot net returns and GHG emissions per pound of dressed beef for steers placed between 600-749 lbs.

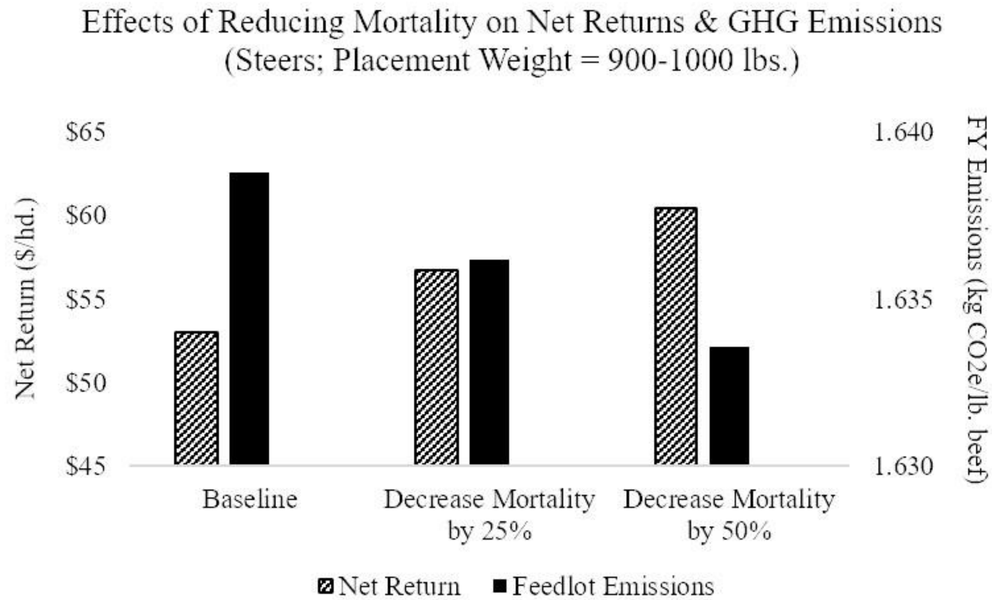

Figure A.7. Incremental effects of reducing mortality on feedlot net returns and GHG emissions per pound of dressed beef for steers placed between 900-1000 lbs.

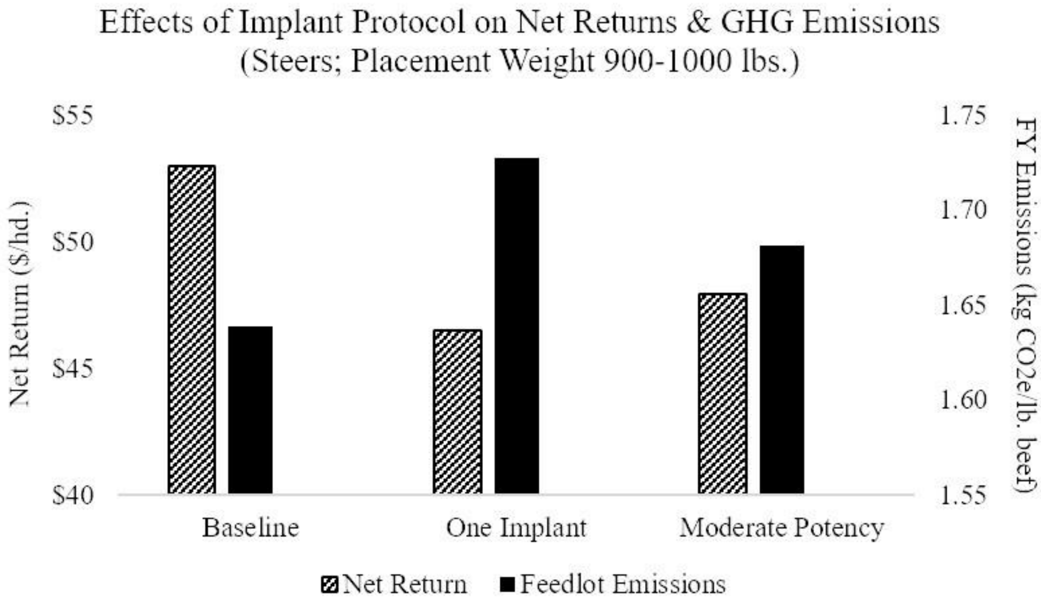

Figure A.8. Incremental effects of changing the number of growth implants and implant potency on feedlot net returns and GHG emissions per pound of dressed beef for cattle placed between 900-1000 lbs.

Appendix B

Table B.1. Summary statistics for nine Central U.S. high plains feedyard cattle treated for acute interstitial pneumonia (AIP) from 2019 through 2023.

	Mean	Std. dev.	Min	Max
Placement Weight (lbs.)	745	91.90	502	1000
DOF	136	34.73	1	251
First AIP Treatment Weight (lbs.)	1093	163.09	518	1895
DOF at First AIP Treatment	117	36.76	1	237
Risk Days Remaining	37	44.89	0	215
Morbidity (%) [a]	25.00	17.51	1	100
Mortality (%) [a]	3.66	3.15	0	25

Notes: [a] Mean cohort morbidity and average cohort mortality for feedyard cattle treated for AIP.

Table B.2. Estimated mixed-effects logistic regression results for first AIP treatment failure (FTF) and failure to finish (DNF) for nine Central U.S. high plains feedyard cattle treated for AIP.

	FTF	DNF
Sex		
Steer	0.185 *	0.175 *
	(0.093)	(0.087)
Placement Weight (lbs.)		
600-699	-0.142	-0.179
	(0.184)	(0.169)
700-799	-0.236	-0.350 *
	(0.178)	(0.164)
800-899	-0.540 **	-0.475 **
	(0.192)	(0.178)
900-1000	-0.765 **	-0.988 ***
	(0.259)	(0.247)
First AIP Treatment Weight (lbs.)		
1000-1250	-0.604 ***	-0.885 ***
	(0.111)	(0.105)
>1250	-1.388 ***	-1.608 ***
	(0.146)	(0.140)
First AIP Treatment Quarter		
2	0.380 **	
	(0.134)	
3	0.336 *	
	(0.137)	
4	0.302 *	
	(0.152)	
Prior BRD Treatment		
Yes	1.106 ***	1.717 ***
	(0.132)	(0.134)
DOF at First AIP Treatment		
<40	0.00002	-0.104
	(0.255)	(0.263)
>100	-0.358 ***	-0.443 ***
	(0.112)	(0.105)
Risk Days Remaining		
<40	1.764 ***	2.439 ***
	(0.114)	(0.122)
>100	-0.144	-0.133
	(0.144)	(0.143)
Constant	0.392	-0.304
	(0.343)	(0.203)
Model Fit	Wald Chi2(15) = 381.48	Wald Chi2(12) = 569.27
	Prob>Chi2 = 0.0000	Prob>Chi2 = 0.0000
Observations	3,800	3,800

Notes: [a] Standard errors in parentheses= * p<0.05, ** p<0.01, *** p<0.001.