Journal of Animal Science, 2020, 1–11

doi:10.1093/jas/skaa005
Advance Access publication February 3, 2020
Received: 20 October 2019 and **Accepted:** 11 January 2020
Economics of Animal Production

ECONOMICS OF ANIMAL PRODUCTION

An evaluation of the economic effects of bovine respiratory disease on animal performance, carcass traits, and economic outcomes in feedlot cattle defined using four BRD diagnosis methods

Claudia Blakebrough-Hall,[*,1] Joe P. McMeniman,[†] and Luciano A. González[*,‡]

[*]School of Life and Environmental Sciences, Faculty of Science, University of Sydney, Camden, NSW 2570, Australia, [†]Feedlot Research, Meat & Livestock Australia, Brisbane, QLD 4006, Australia, [‡]Sydney Institute of Agriculture, University of Sydney, Sydney, NSW 2015, Australia

[1]Corresponding author: claudia.blakebrough-hall@sydney.edu.au

Abstract

Bovine respiratory disease (**BRD**) causes significant economic losses to the feedlot industry due to decreased production and increased costs associated with treatment. This study aimed to assess the impacts of BRD on performance, carcass traits, and economic outcomes defined using four BRD diagnosis methods: number of BRD treatments an animal received, pleural lesions at slaughter, lung lesions at slaughter, and clinical BRD status defined using both treatment records and lung and pleural lesions. Crossbred steers (n = 898), with an initial body weight of 432 kg (± SD 51), were followed from feedlot entry to slaughter. Veterinary treatment records were collected and lungs scored at slaughter for lesions indicative of BRD. There was an 18% morbidity rate and a 2.1% BRD mortality rate, with an average net loss of AUD$1,647.53 per BRD mortality. Animals treated ≥3 times for BRD had 39.6 kg lighter carcasses at slaughter and returned an average of AUD$384.97 less compared to animals never treated for BRD (P < 0.001). Animals with severe lung lesions at slaughter grew 0.3 kg/d less, had 14.3 kg lighter carcasses at slaughter, and returned AUD$91.50 less than animals with no lung lesions (P < 0.001). Animals with subclinical and clinical BRD had 16.0 kg and 24.1 kg lighter carcasses, respectively, and returned AUD$67.10 and AUD$213.90 less at slaughter, respectively, compared to healthy animals that were never treated with no lesions (P < 0.001). The severity of BRD based on the number of treatments an animal received and the severity of lung and pleural lesions reduced animal performance, carcass weight and quality, and economic returns. Subclinical BRD reduced animal performance and economic returns compared to healthy animals; however, subclinical animals still had greater performance than animals with clinical BRD. This information can be used to plan for strategic investments aimed at reducing the impacts of BRD in feedlot cattle such as improved detection methods for subclinical animals with lesions at slaughter and BRD treatment protocols.

Key words: Bovine respiratory disease, carcass traits, economic return, feedlot health, performance

Introduction

Bovine respiratory disease (BRD) is the single largest health issue faced by the feedlot industry, causing substantial economic and productive losses. The disease accounts for approximately 75% of morbidity (Edwards, 1996) and 50% to 70% of mortality in feedlots (Loneragan et al., 2001). It has been estimated to cost the American feedlot industry between $800 and $900 million annually due to decreased animal production and increased

Abbreviations

BRD	Bovine respiratory disease
CALA	computer-assisted lung auscultation
DOF	days on feed
IBR	infectious bovine rhinotracheitis
MSA	Meat Standards Australia

veterinary treatment costs (Chirase and Greene, 2001). It has been demonstrated that animal performance and carcass traits such as average daily gain (ADG), marbling, hot carcass weight (HCW), and carcass value at slaughter decrease as both the number of BRD treatments (Holland et al., 2010; Thompson et al., 2012; Cernicchiaro et al., 2013) and lung lesion severity at slaughter increase (Schneider et al., 2009; Tennant et al., 2014). Previous research has estimated that around 50% of animals with lung abnormalities at slaughter exhibit no clinical signs of BRD, indicating the potentially significant proportion of animals with subclinical BRD that could go undetected (White and Renter, 2009).

Although there is substantial literature on the subject, previous studies have predominantly examined the economic effects of BRD defined using the number of BRD treatments an animal received or lung lesions at slaughter (Jim et al., 1993; Schneider et al., 2009; Cernicchiaro et al., 2013), with few studies examining the economic effects of using multiple BRD definitions. Additionally, there appears to be limited research on the economic effects associated with clinical vs. subclinical BRD. The current study aimed to evaluate the economic effects of BRD using the number of BRD treatments an animal received, pleural lesions at slaughter, lung lesions at slaughter, and clinical BRD status defined using both treatment records and lung and pleural lesions at slaughter. We hypothesized that animal performance, carcass traits, and economic outcomes would decrease as the severity of BRD increased (defined by the number of BRD treatments, severity of pleural lesions, and severity of lung lesions) and that the costs associated with subclinical BRD would be less than clinical BRD due to the increased treatment costs associated with clinical disease.

Materials and Methods

This experiment was reviewed and approved by the Institutional Animal Ethics Committee from the Research Integrity and Ethics Administration of The University of Sydney, Australia (Approval #1118).

Animals and management

This experiment was conducted at a commercial feedlot in Southern NSW, Australia. Four pens of mixed-breed 1- to 2-year-old steers (n = 898) were followed from feedlot entry to slaughter. Economic data for individual animals were obtained directly from the feedlot and abattoir at the completion of the trial in July 2017. Animals were sourced from multiple saleyards (n = 788) or direct consignment from farms (n = 110). Steers were a mix of Angus (n = 187), Angus cross (Hereford × Angus; n = 156), *Bos indicus* cross (n = 29), British cross (British breed mix, less than 75% Angus; n = 82), European (Simmental, Charolais, or Limousin; n = 123), Hereford (n = 226), Murray Grey (n = 59), and Shorthorn (n = 36) assigned at feedlot entry based on the visual observation of coat color and body conformation. Due to the animals in this study being predominantly sourced from saleyards, no information on treatments or vaccination for BRD prior to feedlot entry was available. At feedlot entry, cattle had initial body weight (BW) recorded (mean ± SD induction weight; 432 ± 51 kg) and were administered a hormonal growth promotant implant (Revalor S; Coopers Animal Health, Macquarie Park, Australia), vaccination for respiratory disease caused by *Mannheimia haemolytica* (Bovilis MH, Coopers Animal Health, Macquarie Park, Australia), modified live intranasal vaccine for Infectious Bovine Rhinotracheitis (**IBR**) (Rhinogard, Zoetis Animal Health, Rhodes, Australia), 5-in-1 vaccination for clostridial diseases (Tasvax 5 in 1, Coopers Animal Health, Macquarie Park, Australia), and antiparasitic injection (Bomectin, Bayer, Leverkusen, Germany). Following feedlot entry, animals were sent to four production pens for the remainder of their time on feed. Pen allocation was based on pen availability and, therefore, pen sizes differed. Pen 1 housed 300 animals, pen 2 housed 266 animals, pen 3 housed 91 animals, and pen 4 housed 241 animals. Animals were fed to allow for ad libitum feed consumption and were transitioned through three starter diets to a steam-flaked barley-based finisher diet over an 18-d period. Animals remained on this diet until slaughter unless they were sent to hospital pens for disease treatment, in which case they received a high roughage (lucerne and barley hay) steam-flaked barley starter diet.

Bovine respiratory disease diagnosis and monitoring

Following feedlot entry animals were monitored in their production pens for visual signs of BRD by trained feedlot pen riders once daily at approximately 0600 hours. Any animal exhibiting visual signs of BRD, including nasal or ocular discharge, cough, lethargy, depression, labored breathing, and depleted rumen fill (McGuirk, 2008; Blakebrough-Hall et al., 2019), was pulled from their pens and taken to the feedlot hospital shed for clinical measurements and treatment if required. In order to be pulled for BRD based on visual symptoms, animals had to have one or more of the visual symptoms specific to BRD (nasal or ocular discharge, or labored breathing or cough). Animals were part of a case–control trial (Blakebrough-Hall et al., 2019), whereby for every animal exhibiting visual signs of BRD, a control animal exhibiting no visual signs of BRD was pulled from the same pen each day and taken to the hospital for sampling. Rectal temperatures were recorded using a GLA M750 rectal thermometer (GLA Agricultural Electronics, San Luis Obispo, CA, USA). Lung auscultation scores were recorded using a Whisper computer-assisted lung auscultation (**CALA**) system (Geissler Corporation, Plymouth, MA, USA). The Whisper program assigns a CALA score of 1 to 5 based on the severity of the animal's lung sounds, where 1 = normal, 2 = mild acute, 3 = moderate acute, 4 = severe acute, and 5 = chronic. Animals exhibiting elevated rectal temperature or lung auscultation score, or both, were treated for BRD according to the feedlot's veterinary treatment protocol (Table 1). Animals pulled initially as healthy controls exhibiting no visual signs of BRD in the pen but that had elevated rectal temperature or lung auscultation score (n = 63) upon sampling at the hospital were treated for BRD. For the purposes of analysis, these animals were assigned to a separate category defined as visually healthy but treated. These animals were assigned to a separate category because, under normal non-trial conditions, they would not have been pulled and treated for BRD and, therefore, including them with the visually sick treated animals would be an overrepresentation of the number of animals treated for BRD. Necropsies of any BRD mortalities were performed by trained feedlot personnel with the date and reason of death recorded.

Table 1. Treatment protocol for first and subsequent BRD treatments

BRD treatment sequence	Treatment decision cutoffs	Treatment
No treatment	Visual signs of BRD, rectal temperature <40°C and CALA score <2	No treatment
First treatment-less severe BRD, <60 DOF	Visual signs and CALA score 2, or no visual signs and CALA score 2, or visual signs and rectal temperature ≥40°C, or no visual signs and rectal temperature ≥40°C	Tilmicosin (Micotil, Elanco Animal Healthy, West Ryde, Australia)
First treatment-severe BRD, <60 DOF	CALA score 3 with or without visual signs, or rectal temperature ≥ 40°C and CALA score ≥2 with or without visual signs	Tulathromycin (Draxxin, Zoetis Animal Health, NJ, USA)
Second treatment	Pulled for BRD a second time or received Tulathromycin for the first BRD treatment	Oxytetracycline (Engemycin, MSD Animal Health, Wellington, New Zealand)
Third treatment	Pulled for BRD a third time	Florfenicol (Nuflor, Merck Animal Health, Madison, NJ, USA) and Meloxicam (Troy Laboratories, Glendenning, Australia)
First treatment ≥60 DOF, or fourth BRD treatment	Treated regardless of rectal temperature of CALA score, or pulled for BRD a fourth time	Ceftiofur (Excede, Zoetis Animal Health, Lincoln, NE, USA)

Slaughter and lung scoring

Animals were followed through to slaughter at 112 to 122 d on feed (**DOF**). All lungs were scored by two personnel trained by an experienced veterinarian prior to the commencement of the trial. Lungs were visually and physically examined for the degree of consolidation and pleurisy. Lung consolidation was recorded using a previously described scoring method (Theurer et al., 2013), where the consolidation on each lobe was summed to form a total percentage of lung consolidation. Pleurisy was recorded using a scoring system of normal, mild, moderate, and severe pleural lesions as described previously (Blakebrough-Hall et al., 2019). Briefly, normal animals were those with no pleurisy or pleuritic tags; mild animals were those exhibiting pleuritic tags between lobes or small pleuritic tags on lung surface; moderate animals were those with significant pleuritic tags on lung surface, small pieces adhered to thoracic wall or tags on lung margins or between lobes (fringing); and severe animals were those with the whole lung adhered to thoracic wall of carcass with no lung present on offal table. The use of the term pleuritic tags refers to the adhesion of the lung to the rib cage or adhesion between lung lobes by fibrous tags. No lung consolidation score was recorded for animals with severe pleural lesions as there was no lung present on the offal table. Lung lesions were categorized into normal (N), moderate (M), and severe (S) based on both the degree of lung consolidation and severity of pleural lesions (Table 2).

Grading occurred on all carcasses at approximately 24 h after slaughter by the processing plant's accredited meat inspectors. Carcasses were graded using the Meat Standards Australia (**MSA**) grading system (Polkinghorne et al., 2008). Data collected at slaughter included kill date, body number, MSA marbling, MSA index, fat depth at the P8 site (at the crest of third sacral vertebra), rib fat depth, and HCW.

Table 2. Lung lesion severity categories of normal (N), moderate (M), and severe (S) based on percentage of lung consolidation and pleural lesions

	Pleurisy score[1]			
Lung consolidation	Normal	Mild	Moderate	Severe
0–1%	N	N	M	S
2–9%	N	M	M	S
10–55%	M	M	S	S
No Score	–	–	–	S

[1]Pleural lesion categories: Normal, no pleurisy or pleuritic tags, Mild, pleuritic tags between lobes or small pleuritic tags on lung surface; Moderate, significant pleuritic tags on lung surface, small pieces adhered to thoracic wall or tags on lung margins or between lobes (fringing); Severe, the whole lung adhered to thoracic wall of carcass with no lung present on offal table. The use of the term pleuritic tags refers to the adhesion of the lung to the rib cage or adhesion between lung lobes by fibrous tags.

Clinical BRD status

The clinical BRD status was defined using a combination of treatment records and lung and pleural lesions present at slaughter (Table 3). Clinical BRD was defined as an animal that showed visual signs and had elevated rectal temperature or CALA score, was treated for BRD, and had severe lung lesions present at slaughter. Subclinical BRD was defined as an animal that showed no visual signs of BRD and was not treated for BRD but had severe lung lesions present at slaughter. An animal that expressed visual signs of BRD and was treated for BRD but had no lesions present at slaughter was defined as treated with no lesions. An animal that was pulled as a visually healthy control but was then treated for BRD due to elevated rectal temperature or lung auscultation score, but had no severe lung lesions at slaughter was defined as visually healthy but treated, with no lung lesions at slaughter. An animal that exhibited no visual signs of BRD was not treated for BRD and had no severe lung lesions at slaughter was defined as healthy.

Statistical analysis

Mixed-effects linear regression models using the MIXED procedure in SAS 9.4 (SAS, 2017) were used to estimate the effects of BRD on animal performance, carcass traits, and economic outcomes using four BRD diagnosis methods. Animal within pen was considered as the experimental unit. Dependent variables analyzed are outlined in Table 4. Breed was considered as a fixed effect and pen as a random effect. In-weight was used as a covariate for exit weight, ADG, and HCW. Main effects were considered significant at $P \leq 0.05$ and tendencies discussed at

Table 3. Classification of clinical BRD status in feedlot cattle using a combination of visual signs detected by pen riders, veterinary treatment records, and lung and pleural lesions of the respiratory tract at slaughter

Clinical BRD status	Description
Clinical	Visual signs of BRD[1], treated for BRD due to rectal temperature ≥40°C or lung auscultation ≥2, with severe lung lesions at slaughter
Subclinical	No visual signs of BRD, never treated for BRD but with severe lung lesions at slaughter
Treated with no lesions	Visual signs of BRD, treated for BRD, and with no severe lung lesions at slaughter
Visual control, treated, no lesions	No visual signs of BRD but treated for BRD due to elevated rectal temperature or lung auscultation score, with no lesions at slaughter
Healthy	No visual signs and normal rectal temperature and lung auscultation score, and normal or moderate lung lesions at slaughter

[1]Visual signs, presence of one or more of the following detected by pen riders; lethargy, abnormal animal carriage, labored breathing, cough, nasal or ocular discharge, anorexia. Animals had to have one or more of the visual symptoms specific to BRD (nasal or ocular discharge, or labored breathing or cough).

$0.05 < P \le 0.10$. When a significant P-value was detected, means were separated using Bonferroni adjustment for multiple comparisons. Orthogonal contrasts were used to test the linear, quadratic, and cubic responses by increasing the number of BRD treatments and increasing pleural lesion severity. The visually healthy but treated animals were deleted from the orthogonal contrast analysis for a number of BRD treatments an animal received. Data were transformed when necessary using either square root or logarithm to normalize them before statistical analysis when P-values were obtained; however, the mean and standard error presented in tables were obtained from the untransformed data. All economic results are reported in Australian dollars and are based on the actual income the animals received.

Results

Summary statistics for animal performance, carcass traits, and economic outcomes are shown in Table 5. There were only 870 animals slaughtered out of the 898 trial animals because there were 23 mortalities and 5 animals deemed not fit for travel with the main cohort to slaughter due to chronic lameness. The average BW at feedlot entry was 432 ± 51.2 kg. Over an average of 114 DOF, animals gained an average of 208.4 kg. At the exit, animals weighed an average of 640.4 ± 80.54 kg. Treatment costs for BRD ranged from AUD$5.70 for an initial induction BRD vaccination only to AUD$122.26 per animal for animals that were treated ≥3 times. The average BRD treatment cost was AUD$13.31, lower than the average of other veterinary costs at AUD$25.41. There was a 2.5-fold difference between the highest (AUD$1,094.40) and lowest (AUD$2,570.53) value at slaughter resulting in a range of AUD$1,476.13. Estimated net return showed a broad range of AUD$1,292.32, with the lowest net return being –$688.01 and the highest net return being AUD$604.31. The number of animals with an MSA index recorded (n = 853) was reduced due to 17 animals failing to meet all MSA requirements due to a high pH and being recorded as an MSA un-grade.

Out of the 23 mortalities, 18 were attributed to BRD upon necropsy, accounting for 73.3% of the mortalities and resulting in a 2.1% BRD mortality rate. Based on the number of animals treated for BRD before death (once, twice, or ≥3 times) and with the visually healthy but treated animals included, the BRD case fatality rate was 8.7% (Table 6). Interestingly, 11 out of the 30 steers treated three or more times for BRD died (36.7%; Table 6). Prior to succumbing to BRD and dying, animals lost an average of –1.5 kg/d on average and died between 14 and 82 DOF (Table 5). Treatment costs associated with BRD (including an initial BRD vaccination) averaged AUD$74.21 per BRD mortality. Body removal costs were estimated at AUD$60.00 per animal and this combined with losses attributed to costs associated with purchase, induction, transport, feed, yardage, and treatment for BRD contributed to an average net loss of AUD$1,647.53 per dead animal.

Number of treatments for BRD

The effects of the number of BRD treatments an animal received on performance, carcass traits, and economic outcomes are presented in Table 7. This table also presents results for the visually healthy animals that were treated for BRD because of elevated rectal temperature or lung auscultation score upon clinical examination at the hospital, representing 7.2% (n = 63) of the animals slaughtered. With mortalities and reject animals excluded from analysis (n = 870) and not including the visually healthy but treated animals, 18.0% (n = 145) of animals were treated for BRD (either once, twice, or ≥3 times). With the visually healthy but treated animals included, 23.9% (n = 208) of animals were treated for BRD. There were 76.0% (n = 662) of animals never treated for BRD, 11.5% (n = 100) treated once for BRD, 3.0% (n = 26) treated twice for BRD, and 2.2% (n = 19) treated ≥3 times for BRD.

There was a linear decrease in exit weight, ADG, HCW, MSA marble score, P8 fat depth, and rib fat depth as the number of BRD treatments increased ($P < 0.001$; Table 7). Animals treated for BRD ≥3 times grew 0.7 kg/d less and had carcasses that were 39.6 kg lighter at slaughter compared to animals that were never treated for BRD ($P < 0.001$). Feed costs and total value at slaughter also decreased linearly ($P < 0.001$) as the number of BRD treatments increased. A cubic trend was observed for BRD treatment cost ($P < 0.001$) because the largest difference was found between healthy animals and those treated once or twice, and then for animals treated ≥3 times. A quadratic trend was observed for other treatment costs ($P < 0.001$), price received ($P = 0.004$), and net return ($P < 0.001$) because the largest reduction was found for animals treated ≥3 times for BRD. No effects of the number of BRD treatments were found on induction weight or MSA index ($P > 0.100$).

Pleural lesions

There were only 10.9% (n = 95) of animals that exhibited no pleural lesions at slaughter, 36.2% (n = 315) with mild pleural lesions, 42.2% (n = 367) with moderate pleural lesions, and 10.7% (n = 93) exhibiting severe adhesion of the lungs to the thoracic cavity (Table 8). Induction weight, exit weight, ADG, HCW, MSA marble score, MSA index, P8 fat depth, rib fat depth, purchase price, feed cost, total value at slaughter, and net return showed a quadratic decrease as the severity of pleural lesions increased ($P < 0.005$). This quadratic effect was due to the minimal differences found between normal, mild, and moderate animals but the significant differences of these groups compared with severe animals. The exception was in-weight which was similar

Table 4. Performance and economic outcome variables, with descriptions and formulas

Variable	Description
In-weight, kg	Individual full body weight taken at feedlot entry
Exit weight, kg	Carcass weight per dressing %, per lot basis
Dressing, % body weight, per lot basis	Carcass weight as a percentage of body weight[1], used to calculate exit weight from carcass weight
ADG, kg/d	Average daily gain
ADG to first BRD pull, kg/d	Average daily gain to time of first BRD pull
Carcass weight, kg/carcass	AUS-MEAT hot standard carcass weight once the live animal has been slaughtered, with hide, feet, tail, head, and innards removed (Polkinghorne et al., 2008)
MSA (Meat Standards Australia) marble score	MSA marbling score (range 100–1,190)(Polkinghorne et al., 2008)
MSA index	Prediction of eating quality potential of a carcass based on carcass measurements (range 30–80) (McGilchrist et al., 2019)
P8 fat depth	Fat depth at the P8 site at crest of third sacral vertebra measured on the hot carcass
Rib fat depth	Subcutaneous depth of fat over the quartered rib site between the 5th and 13th ribs measured on the chilled and quartered carcass
Purchase price, $/animal	Cost to purchase each animal for feedlot entry. Calculated based on market prices at the time of purchase (range: AU$2.75 to $3.50 $/kg)
Feed cost, $/animal	Estimated cost of feed consumed for each animal on a DM basis based on $270/tonne
BRD treatment cost, $/animal	Individual drug cost for animals treated for BRD. Includes BRD vaccination cost at feedlot entry of $5.67/animal plus the cost of drug treatments
Other treatment cost, $/animal	Individual drug cost for treatments of ailments other than BRD. Ailments include lameness, acidosis, and polioencephalomalacia
Price received, $/kg carcass weight (cwt)	Price received at slaughter per kg of carcass weight. Price paid by abattoir according to pricing grid
Slaughter value, $/animal	Price received × carcass weight
Net return, $/animal	Slaughter value—purchase price—induction processing cost[3]—feed cost—BRD treatment cost—other veterinary treatment cost—yardage cost[4]—transport cost[5]—buyers commission—levy
Body removal cost[6]	Average cost of body removal per animal. Estimated at AU$60/mortality according to time and labor units required

[1]Lot dressing percentage calculated based on lot exit body weights by the feedlot, however only dressing % data were obtained for this study to calculate exit weight.
[2]Weight days = average weight of animal x total DOF. Pen weight days = ∑DOF of all animals in pen × ∑average weight of all animals in pen.
[3]Induction processing cost: $7.30/animal includes labor, ear tags, hormonal growth promotant implant, 5-in-1 clostridial vaccination, and antiparasitic injection.
[4]Yardage cost: Total DOF × yardage cost (approximately AUD$1.05/d/animal).
[5]Transport cost: flat load rate of AU$635/load with a load weight limit of 35,500 kg/load.
[6]Body removal cost calculated using an average time of 30 min per dead using two labor units at a labor rate of AUD$35/h plus fuel and machinery costs of $42.50/h.

for animals with no lesions and those with severe pleural lesions ($P = 0.062$). Animals with severe pleural lesions grew 0.3 kg/d less ($P < 0.001$), had 19.7 kg lighter carcasses at slaughter ($P < 0.001$), and returned AUD$137.45 less than the average of no lesions, mild lesions, and moderate lesions. A cubic trend was observed for BRD treatment cost ($P < 0.001$) and other treatment costs ($P < 0.001$), with severe animals exhibiting AUD$16.31 higher BRD treatment costs compared to the average of no lesions, mild lesions, and moderate pleural lesions.

Lung lesions

Out of 870 animals slaughtered, 32.4% ($n = 282$) had no lung lesions at slaughter, 51.7% ($n = 450$) had moderate lung lesions, and 15.9% ($n = 138$) displayed severe lung lesions (Table 9). Animals with severe lesions grew 0.3 kg/d less than animals with no lung lesions ($P < 0.001$) and had 14.3 kg lighter carcasses at slaughter ($P < 0.001$). Animals with severe lesions had AUD$13.77 higher BRD treatment costs than animals with no lung lesions ($P < 0.001$) and returned AUD$91.50 less at slaughter. Animals with severe lesions also had AUD$8.64 higher other treatment costs than animals with no lung lesions ($P < 0.001$). No differences were found between animals with no lung lesions and moderate lung lesions for any of the outcome variables except for purchase price which was higher for animals with moderate lung lesions ($P = 0.032$).

Clinical BRD status

Defining BRD using the clinical BRD status definition resulted in 6.7% ($n = 58$) of animals with clinical BRD, 8.4% ($n = 73$) with subclinical BRD, 7.2% ($n = 63$) that were visually healthy but treated with no lesions, 10.2% ($n = 89$) that were visually sick and treated with no lesions, and 67.5% ($n = 587$) were healthy (Table 10). Healthy and visually healthy but treated with no lesions animals were the highest performers, with greater ADG, exit weight, HCW, and net returns compared to clinical, subclinical, and visually sick treated with no lesions animals ($P < 0.001$). Clinical BRD animals had the lowest performance gaining 0.4 kg/d less than healthy animals ($P = 0.002$), with 24.1 kg lighter carcasses at slaughter ($P = 0.014$). Subclinical and visually sick treated with no lesions animals had lower ADG, HCW, and net returns compared to healthy animals ($P < 0.001$). There were no differences between subclinical and visually sick treated with no lesions animals ($P \geq 0.05$) except for the higher BRD treatment costs of the latter ($P = 0.023$). Subclinical and visually sick treated with no lesions animals had greater ADG, carcass weight, and net returns compared to clinical BRD

Table 5. Summary statistics for animal performance, carcass traits, and economic outcomes of feedlot steers

Variable	N	Mean	SD	Minimum	Maximum
In-weight, kg/animal	870	432.0	51.24	276.0	576.0
Exit weight, kg/animal	870	640.4	80.54	405.0	927.1
Days on feed (DOF)	870	114	2.9	110	120
ADG, kg/animal/d	870	1.8	0.44	−0.1	3.4
Carcass weight, kg/carcass	870	351.5	44.53	228.0	509.0
MSA marble score, %	870	351.6	75.99	130.0	640.0
MSA Index	853	54.7	1.97	47.7	60.8
P8 fat depth[1]	870	17.1	5.35	2.0	40.0
Rib fat depth	870	8.6	3.48	0	25.0
Purchase value, $/animal	870	1,397.43	159.799	894.50	1,837.12
Feed cost, $/animal	870	324.95	37.910	208.63	442.62
BRD treatment cost, $/animal	870	13.31	17.148	5.67	122.26
Other treatment cost, $/animal[2]	48	25.41	13.175	9.24	75.94
Price received, $/kg cwt	870	5.90	0.261	4.81	6.43
Total slaughter value, $/animal	870	2,059.21	253.301	1,094.40	2,570.53
Net return, $/animal[3]	870	159.01	173.960	−688.01	604.31

[1]P8 fat depth: fat depth at the crest of third sacral vertebra measured on the hot carcass.
[2]Other treatment cost: cost of treatments for ailments other than BRD.
[3]Net return was calculated using slaughter value less the purchase price, induction processing cost of $7.30/animal, feed cost, BRD treatment cost, other veterinary treatment cost, yardage cost of approximately AUD$1.05/animal/d, transport cost (flat load rate of AU$635/load with a load weight limit of 35,500 kg/load), buyers commission, and levy.

Table 6. Summary statistics for animal performance, carcass traits, and economic outcomes for the 18 animals that died due to BRD

Variable	N	Mean	SD	Minimum	Maximum
In-weight, kg/animal	18	434.8	48.71	328.0	492.0
Days on feed at death	18	41	20.8	14	82
ADG to first pull, kg/animal/day	18	−1.5	3.17	−10.0	2.9
Purchase value, $/animal	18	1,403.46	154.016	1,064.88	1,627.11
Feed cost, $/animal	18	94.14	46.128	31.33	178.13
BRD treatment costs, $/animal	18	74.21	37.678	5.70	123.34
Direct cost to death, $/animal	18	1,638.46	1,90.817	1,333.75	1,929.98
Body removal costs, $/animal[1]	18	60.00	0	60.00	60.00
Net loss at death, $/animal[2]	18	−1,647.53	190.981	−1,939.65	−1,334.85

[1]Body removal cost: Average cost of body removal per animal. Estimated at AU$60/mortality according to time and labor units required.
[2]Net loss at death includes losses associated with purchase price of animal, induction, transport, feed, yardage, treatment, and body removal costs. Induction costs were AUD$7.30/animal. Transport costs were calculated using a flat load rate of AU$635/load with a load weight limit of 35,500 kg/load. Yardage costs were approximately AUD$1.05/animal/d.

animals ($P < 0.001$). Clinical BRD animals had the highest BRD treatment costs and lowest net returns of all groups ($P < 0.001$), returning an average of AUD$213.94 less than healthy animals and AUD$146.79 less than subclinical animals ($P < 0.001$). Clinical BRD animals were the only group of animals that resulted in an economic loss partly due to lower carcass value and higher BRD treatment costs compared to the other groups ($P < 0.001$). No significant differences were found for induction weight, MSA Index, purchase price, or other treatment cost ($P \geq 0.183$).

Discussion

The current study evaluated the effects of BRD defined through multiple BRD diagnosis methods on animal performance, carcass traits, and economic outcomes in feedlot cattle with an average arrival BW of 432.0 kg and an average feeding duration of 114 d. Economic effects of BRD were evaluated using four BRD diagnosis methods: the number of BRD treatments an animal received, pleural lesion severity, lung lesion severity, and clinical BRD status. Much of the previous research evaluating the economic effects of BRD has defined BRD using either the number of BRD treatments an animal received (Holland et al., 2010; Cernicchiaro et al., 2013; Wilson et al., 2016) or lung lesion severity at slaughter (Schneider et al., 2009; Tennant et al., 2014). Due to the lack of a gold standard for BRD diagnosis, the current study evaluated multiple BRD diagnosis methods to compare the economic effects of BRD using different BRD definitions. There is also a lack of published data on the effects of lung lesion severity on carcass value and net returns. Only one study could be found reporting actual economic figures associated with lung lesion severity at slaughter (Tennant et al., 2014). Literature on the economics of clinical vs. subclinical BRD also appears to be minimal (Thompson et al., 2006). In the present study, the largest difference in net returns between groups was found using the number of times an animal was treated for BRD, with a difference of AUD$410.54 between animals that were never treated compared to those treated ≥3 times. Defining BRD using lung lesions at slaughter had the smallest difference in net returns between animals with severe lung lesions and those with no or moderate lung lesions, with a AUD$90.97

Table 7. Performance, carcass traits, and economic outcomes according to the number of treatments for BRD in feedlot cattle

Variable	Number of BRD treatments					P-value
	0	1	2	≥3	Visually healthy treated[1]	
N	662	100	26	19	63	Chi = <0.001
Mortalities	1	3	3	11	0	
In-weight, kg/animal	428.2 ± 5.97	421.3 ± 7.24	418.4 ± 11.39	414.0 ± 12.85	437.4 ± 8.52	0.260
Exit weight, kg/animal	634.6 ± 5.23[a]	625.5 ± 6.35[a]	581.5 ± 9.97[b]	560.4 ± 11.51[b]	651.3 ± 7.48[c]	<0.001[L]
ADG, kg/d	1.8 ± 0.05[ab]	1.7 ± 0.06[b]	1.3 ± 0.09[c]	1.1 ± 0.10[c]	1.9 ± 0.07[a]	<0.001[L]
Carcass weight, kg/carcass	347.9 ± 2.89[ab]	344.4 ± 3.51[b]	320.6 ± 5.51[c]	308.3 ± 6.36[c]	356.4 ± 4.12[a]	<0.001[L]
MSA marble score	347.5 ± 8.07[a]	331.2 ± 9.78[ab]	303.8 ± 15.37[b]	300.2 ± 17.35[b]	345.2 ± 11.53[ab]	<0.001[L]
MSA Index	54.3 ± 0.21	54.3 ± 0.26	53.4 ± 0.42	54.1 ± 0.48	54.1 ± 0.30	0.100
P8 fat depth[2]	16.3 ± 0.58[ab]	15.0 ± 0.70[bc]	12.2 ± 1.11[cd]	11.3 ± 1.25[d]	17.9 ± 0.83[a]	<0.001[L]
Rib fat depth	7.9 ± 0.38[a]	7.0 ± 0.46[ab]	6.3 ± 0.72[ab]	5.3 ± 0.81[b]	7.6 ± 0.54[ab]	<0.001[L]
Purchase price, $/animal	1,405.25 ± 18.592	1,377.37 ± 22.115	1,371.65 ± 34.475	1,344.94 ± 38.955	1,416.80 ± 26.081	0.140
Feed cost, $/animal	327.54 ± 1.426[a]	314.25 ± 3.648[b]	304.14 ± 7.191[bc]	285.83 ± 8.412[c]	335.20 ± 4.619[a]	<0.001[L]
BRD treatment cost, $/animal	5.67 ± 0.225[a]	31.32 ± 0.578[b]	43.07 ± 1.138[c]	91.86 ± 1.332[d]	28.86 ± 0.731[b]	<0.001[C]
Other treatment cost, $/animal[3]	25.95 ± 2.230[a]	21.49 ± 4.139[a]	21.67 ± 5.553[a]	49.67 ± 8.780[b]	13.86 ± 12.417[a]	<0.001[Q]
Price received, $/kg cwt	5.86 ± 0.029[a]	5.89 ± 0.036[a]	5.79 ± 0.056[ab]	5.66 ± 0.064[b]	5.85 ± 0.042[a]	0.004[Q]
Total slaughter value, $/animal	2,072.98 ± 6.230[a]	2,044.90 + 15.956[a]	1,929.62 ± 32.039[b]	1,759.83 ± 37.799[c]	2,115.22 ± 20.211[a]	<0.001[L]
Net return, $/animal[4]	182.86 ± 6.049[a]	118.07 ± 15.451[b]	−6.34 ± 31.056[c]	−227.68 ± 35.624[d]	198.10 ± 19.564[a]	<0.001[Q]

[1]Visually healthy treated animals were initially pulled as visually healthy controls but exhibited elevated rectal temperature or lung auscultation score and therefore were treated for BRD.
[2]P8 fat depth: fat depth at the crest of third sacral vertebra measured on the hot carcass.
[3]Other treatment cost: cost of treatments for ailments other than BRD.
[4]Net return was calculated using slaughter value less the purchase price, induction processing cost of $7.30/animal, feed cost, BRD treatment cost, other veterinary treatment cost, yardage cost of approximately AUD$1.05/animal/d, transport cost (flat load rate of AU$635/load with a load weight limit of 35,500 kg/load), buyers commission, and levy.
[a–c]Within a row, means without a common superscript letter differ ($P < 0.05$).
[L,Q,C]The effect of increasing the number of BRD treatments was linear, quadratic, or cubic ($P < 0.05$).

difference between severe animals and the average of no lung lesions and moderate lung lesions.

In the present study, 73.3% of mortalities were attributed to BRD, resulting in a 2.1% BRD mortality rate. These figures are comparable to those reported in previous studies (Loneragan et al., 2001; Gagea et al., 2006). The BRD incidence based on the number of BRD treatments an animal received was 23.9% with the inclusion of the visually healthy but treated animals and 16.7% without these animals. This is higher than the figure of 8.2% reported in a previous study (Schneider et al., 2009), which could be due to different BRD outcomes and relapse rates associated with differing trial conditions between studies. The present study had a shorter feeding cycle compared to previous studies (Schneider et al., 2009; Cernicchiaro et al., 2013) which may have contributed to lighter carcass weights at slaughter. In addition, Cernicchiaro et al. (2013) reported that the number of days an animal spent on feed in their dataset increased from 158 to 204 as the number of BRD treatments increased from 0 to ≥3. Similarly, Thompson et al. (2006) reported that days on feed increased for both animals that were treated for BRD and animals with lung lesions. Although the reasons for such increases in days on feed was unclear in those studies, it is likely that BRD cases are left on feed for longer to counterbalance their lower performance and to allow them to reach similar carcass endpoint to their healthy counterparts. Unlike other studies (Waggoner et al., 2007; Holland et al., 2010; Wilson et al., 2016), cattle in the present study were slaughtered at a common DOF rather than a common body composition endpoint such as fat thickness. Consequently, BRD animals in this study were not fed longer to achieve the same carcass weights or quality characteristics as their healthy counterparts, which could partially explain the larger impacts of BRD seen in the present study compared to previous studies.

Animal performance, carcass traits, and economic returns decreased as the number of BRD treatments increased in the present study. Animals treated more than once for BRD indicate a potential lack of initial treatment effectiveness and are likely to be more severe BRD cases. A quadratic trend was observed for net return, which decreased considerably in animals treated for BRD ≥ 3 times. This appears to be consistent with previous reports of a reduction in performance and economic outcomes associated with increasing disease severity (Gardner et al., 1999; Schneider et al., 2009; Brooks et al., 2011). This trend is also supported in the current study by the fact that animals treated 0, 1, 2, and ≥3 times for BRD had mortality rate increase by 0.2%, 2.9%, 10.3%, and 36.7%, respectively. Similar to the findings of previous studies (Waggoner et al., 2007; Thompson et al., 2012), average daily gain decreased linearly with increasing treatments for BRD. Reductions in appetite and hence dry matter intake (DMI), decreased feed efficiency, or the extra energy expenditure associated with the immune response could explain the decline in ADG and consequently carcass weight as the number of BRD treatments increased (van der Mei and van den Ingh, 1987; Sowell et al., 1999).

Table 8. Performance, carcass traits, and economic outcomes according to severity of pleural lesions in feedlot cattle

	Pleural lesions				
Variable	No lesions	Mild	Moderate	Severe	*P*-value
N	95	315	367	93	Chi = <0.001
In-weight, kg/animal	415.1 ± 7.48[b]	428.1 ± 6.30[ab]	431.6 ± 6.07[a]	416.3 ± 7.64[b]	0.005[Q]
Exit weight, kg/animal	623.5 ± 6.78[a]	637.6 ± 5.69[a]	633.9 ± 5.49[a]	598.9 ± 6.94[b]	<0.001[Q]
ADG, kg/d	1.7 ± 0.06[a]	1.8 ± 0.05[a]	1.8 ± 0.05[a]	1.4 ± 0.06[b]	<0.001[Q]
Carcass weight, kg/carcass	347.4 ± 3.78[a]	349.9 ± 3.13[a]	347.7 ± 3.01[a]	328.6 ± 3.76[b]	<0.001[Q]
MSA marble score, %	337.6 ± 10.00[a]	351.8 ± 8.41[a]	344.2 ± 8.09[a]	311.4 ± 10.23[b]	0.0002[Q]
MSA Index	53.8 ± 0.27[b]	54.5 ± 0.23[a]	54.3 ± 0.22[ab]	53.9 ± 0.28[b]	0.004[Q]
P8 fat depth[1]	16.2 ± 0.74[ab]	17.0 ± 0.62[a]	15.6 ± 0.60[b]	14.0 ± 0.76[c]	<0.001[Q]
Rib fat depth	8.1 ± 0.48[a]	8.0 ± 0.40[a]	7.6 ± 0.39[a]	6.2 ± 0.49[b]	<0.001[Q]
Purchase price, $/animal	1,394.54 ± 16.543[ab]	1,416.40 ± 9.321[ab]	1,421.70 ± 8.391[a]	1,370.42 ± 15.991[b]	0.020[Q]
Feed cost, $/animal	320.94 ± 3.962[a]	327.90 ± 2.221[a]	327.62 ± 2.001[a]	305.71 ± 3.812[b]	<0.001[Q]
BRD treatment cost, $/animal[2]	10.92 ± 1.682[a]	11.23 ± 0.924[a]	12.02 ± 0.861[a]	27.70 ± 1.701[b]	<0.001[C]
Other treatment cost, $/animal[3]	20.45 ± 6.464[a]	20.30 ± 3.586[a]	27.39 ± 3.232[ab]	31.17 ± 3.586[b]	<0.001[C]
Price received, $/kg cwt	5.90 ± 0.037[a]	5.87 ± 0.031[a]	5.86 ± 0.030[a]	5.78 ± 0.038[b]	0.004[L]
Total slaughter value, $/animal	2,042.11 ± 24.943[a]	2,050.92 + 20.591[a]	2,032.32 ± 19.854[a]	1,906.52 ± 24.803[b]	<0.001[Q]
Net return, $/animal[4]	177.91 ± 16.541[a]	187.20 ± 8.980[a]	170.60 ± 8.352[a]	41.12 ± 16.813[b]	<0.001[Q]

[1]P8 fat depth: fat depth at the crest of third sacral vertebra measured on the hot carcass.
[2]Data were log transformed to obtain *P*-value due to non-normality.
[3]Other treatment cost: cost of veterinary treatments for ailments other than BRD.
[4]Net return was calculated using slaughter value less the purchase price, induction processing cost of $7.30/animal, feed cost, BRD treatment cost, other veterinary treatment cost, yardage cost of approximately AUD$1.05/animal/d, transport cost (flat load rate of AU$635/load with a load weight limit of 35,500 kg/load), buyers commission, and levy.
[a–c]Within a row, means without a common superscript letter differ ($P < 0.05$).
[L,Q,C] The effect of increasing the number of BRD treatments was linear, quadratic, or cubic ($P < 0.05$).

Table 9. Effect of the severity of lung lesions at slaughter on performance, carcass traits, and economic outcomes of feedlot steers

	Lung lesions severity			
Variable	No lesions	Moderate	Severe	*P*-value
N	282	450	138	Chi < 0.001
In-weight, kg/animal	422.1 ± 6.35	430.6 ± 6.04	422.8 ± 7.09	0.050
Exit weight, kg/animal	632.8 ± 5.57[a]	636.6 ± 5.29[a]	603.8 ± 6.22[b]	<0.001
ADG, kg/d	1.8 ± 0.05[a]	1.8 ± 0.05[a]	1.5 ± 0.06[b]	<0.001
Carcass weight, kg/carcass	347.2 ± 3.11[a]	349.5 ± 2.95[a]	332.9 ± 3.47[b]	<0.001
MSA marble score, %	341.7 ± 8.42[a]	350.7 ± 8.00[a]	313.3 ± 9.42[b]	<0.001
MSA Index	54.2 ± 0.23	54.4 ± 0.21	54.0 ± 0.25	0.090
P8 fat depth[1]	16.4 ± 0.63[a]	16.2 ± 0.60[a]	14.2 ± 0.70[b]	<0.001
Rib fat depth	8.0 ± 0.40[a]	7.7 ± 0.38[a]	6.6 ± 0.45[b]	0.002
Purchase price, $/animal	1,352.01 ± 19.671[a]	1,388.23 ± 18.73[b]	1,368.32 ± 21.97[ab]	0.009
Feed cost, $/animal	323.54 ± 2.373[a]	329.04 ± 1.852[a]	311.62 ± 3.122[b]	<0.001
BRD treatment cost, $/animal[2]	10.91 ± 0.983[a]	11.31 ± 0.772[a]	24.72 ± 1.401[b]	<0.001
Other treatment cost, $/animal[3]	21.81 ± 3.771[a]	24.10 ± 3.168[a]	30.45 ± 3.168[b]	<0.001
Price received, $/kg cwt	5.93 ± 0.032[a]	5.90 ± 0.030[a]	5.81 ± 0.035[b]	0.010
Total slaughter value, $/animal	2,041.72 ± 20.944[a]	2,045.32 ± 19.791[a]	1,936.32 ± 22.964[b]	<0.001
Net return, $/animal[4]	181.30 ± 7.421[a]	180.30 ± 7.422[a]	89.83 ± 13.712[b]	<0.001

[1]P8 fat depth: fat depth at the crest of third sacral vertebra measured on the hot carcass.
[2]Data were log transformed to obtain *P*-value due to non-normality.
[3]Other treatment cost: cost of veterinary treatments for ailments other than BRD.
[4]Net return was calculated using slaughter value less the purchase price, induction processing cost of $7.30/animal, feed cost, BRD treatment cost, other veterinary treatment cost, yardage cost of approximately AUD$1.05/animal/d, transport cost (flat load rate of AU$635/load with a load weight limit of 35,500 kg/load), buyers commission, and levy.
[a–c]Within a row, means without a common superscript letter differ ($P < 0.05$).

The linear decrease in HCW and marbling associated with increasing BRD treatments that was observed is consistent with other studies (Schneider et al., 2009; Brooks et al., 2011). However, the magnitude of the effects in the present study are larger than those reported by Brooks et al. (2011) which could be explained by the longer days on feed as the number of BRD treatments increased. As the number of BRD treatments increased, net returns decreased by 35.0%, 104.2%, and 211.1% in cattle treated once, twice, or ≥3 times, respectively, compared to cattle never treated. A reduction in animal value and net returns as the number of BRD treatments increased have been previously reported although these reductions were smaller

Table 10. Performance, carcass traits, and economic outcomes of feedlot steers classified according to clinical BRD status

	Clinical BRD status					
Variable	Clinical	Subclinical	Treated no lesions	Visually healthy, treated no lesions	Healthy	*P*-value
N	58	73	89	63	587	Chi = <0.001
In-weight, kg/animal	416.0 ± 8.66	425.1 ± 8.13	424.1 ± 7.45	437.4 ± 8.48	428.0 ± 5.98	0.183
Exit weight, kg/animal	593.3 ± 7.72[c]	611.3 ± 7.17[bc]	620.1 ± 6.59[b]	652.1 ± 7.51[a]	639.4 ± 5.28[a]	<0.001
ADG, kg/d	1.4 ± 0.07[c]	1.6 ± 0.07[b]	1.6 ± 0.06[b]	1.9 ± 0.07[a]	1.8 ± 0.05[a]	<0.001
Carcass weight, kg/carcass	328.2 ± 4.53[c]	336.3 ± 4.22[b]	339.0 ± 3.90[b]	356.1 ± 4.48[a]	352.3 ± 3.23[a]	<0.001
MSA marble score	299.4 ± 11.47[c]	326.2 ± 10.88[b]	340.2 ± 9.95[ab]	344.4 ± 11.26[ab]	349.1 ± 7.92[a]	<0.001
MSA Index	54.0 ± 0.31	54.0 ± 0.29	54.1 ± 0.27	54.0 ± 0.30	54.1 ± 0.21	0.191
P8 fat depth[1]	12.9 ± 0.85[c]	15.2 ± 0.80[bc]	14.9 ± 0.73[bc]	17.9 ± 0.83[a]	16.5 ± 0.59[ab]	<0.001
Rib fat depth	6.0 ± 0.55[b]	7.2 ± 0.51[ab]	7.1 ± 0.47[ab]	7.6 ± 0.54[ab]	8.0 ± 0.38[a]	<0.001
Purchase price, $/animal	1,346.21 ± 27.02	1,364.31 ± 25.26	1,375.22 ± 23.17	1,406.12 ± 26.35	1,374.41 ± 18.60	0.290
Feed cost, $/animal[2]	301.32 ± 4.773[b]	315.91 ± 4.260[b]	313.24 ± 3.903[b]	334.51 ± 4.633[a]	329.11 ± 1.724[a]	<0.001
BRD treatment cost, $/animal	44.50 ± 1.144[a]	5.71 ± 1.003[d]	35.21 ± 0.922[b]	27.81 ± 1.091[c]	5.72 ± 0.353[d]	<0.001
Other treatment cost, $/animal[3]	31.41 ± 5.426	29.92 ± 4.007	21.93 ± 4.430	13.86 ± 13.291	24.22 ± 3.049	0.423
Price received, $/kg cwt	5.70 ± 0.043[b]	5.83 ± 0.041[ab]	5.90 ± 0.043[a]	5.82 ± 0.042[ab]	5.91 ± 0.032[a]	0.003
Total slaughter value, $/animal	1,876.21 ± 27.944[d]	1,976.32 ± 26.132[c]	2,005.02 ± 24.184[bc]	2,080.11 ± 27.344[a]	2,049.32 ± 19.684[ab]	<0.001
Net return, $/animal[4]	−24.72 ± 21.063[d]	122.11 ± 18.450[c]	98.61 ± 17.203[c]	198.14 ± 19.862[a]	189.22 ± 6.523[a]	<0.001

[1]P8 fat depth: fat depth at the crest of third sacral vertebra measured on the hot carcass.
[2]Data were square transformed to obtain *P*-values due to non-normality.
[3]Other treatment cost: cost of veterinary treatments for ailments other than BRD including vaccinations at induction.
[4]Net return calculated using slaughter value less the purchase price, induction processing cost of $7.30/animal, feed cost, BRD treatment cost, other veterinary treatment cost, yardage cost of approximately AUD$1.05/animal/d, transport cost (flat load rate of AU$635/load with a load weight limit of 35,500 kg/load), buyers commission, and levy.
[a–c]Within a row, means without a common superscript letter differ ($P < 0.05$).

compared to the present study (Schneider et al., 2009; Brooks et al., 2011; Cernicchiaro et al., 2013). Schneider et al. (2009) reported a reduction in total value at slaughter of US$23.23 (2% less), US$30.15 (3% less), and US$54.01 (5% less) for animals treated once, twice, and ≥3 times compared to animals that were never treated. Schneider et al. (2009) calculated slaughter value based on carcass premiums and the actual price received but did not account for treatment costs and, therefore, their figures are likely an underestimation of the economic losses. For this reason, caution should be taken when comparing studies based on carcass value and net return figures because the methodologies employed could have large implications on the results.

Reductions in performance and carcass quality variables such as ADG, marbling, and final BW associated with increasing lung lesion severity have been described previously, although with a lesser magnitude of the relationship and using different lung scoring methods (Wittum et al., 1996; Gardner et al., 1999; Schneider et al., 2009). These papers describe the negative relationship between lung lesions and animal performance and carcass traits such as ADG, marbling, and HCW (Wittum et al., 1996; Thompson et al., 2006; Schneider et al., 2009); however, only one peer-reviewed study could be found on the effects of lung lesion severity on actual monetary animal value or net return figures (Tennant et al., 2014). The authors reported a difference of US$112.60 in net return between animals with severe lung lesions and animals with no lung lesions which is comparable with the results of this study. A quadratic response to increasing pleural lesions was also observed for animal value and net returns, which, similar to lung lesions, fell significantly in animals with severe pleural lesions.

Previous estimations of the incidence of clinical and subclinical BRD in feedlots have varied widely (Thompson et al., 2006; Schneider et al., 2009). Thompson et al. (2006) reported that subclinical BRD occurred in 29.7% and clinical BRD in 22.6% of animals out of 2,036 animals. The much lower incidences of clinical and subclinical BRD found in the present study may be due to including animals with severe lesions only for the clinical and subclinical definitions, rather than including the presence of any lesions as done previously (Schneider et al., 2009). There were more subclinical than clinical BRD animals in the current study, suggesting that either more than half of the animals infected with BRD went undetected in the feedlot or that these animals acquired infection before arrival to the feedlot, or possibly a combination of both. It is important to note, however, that the experimental design of the present study did not allow for differentiation between animals that developed lesions prior to feedlot entry and those that developed lesions after entering the feedlot. This demonstrates the complexities of BRD diagnosis methods and the challenges of BRD diagnosis. In addition, this raises the question as to whether further efforts are required to reduce subclinical BRD cases by improving BRD detection methods (White and Renter, 2009; Leruste et al., 2012).

Animals with clinical BRD had 0.2 kg/d lower ADG compared to animals with subclinical BRD in the present study. This is similar to the 0.1 kg/d reduction reported by Thompson et al. (2006). Carcass quality traits such as marbling were lower in both clinical and subclinical animals compared to healthy animals, which has been seen previously (Schneider et al., 2009). The reduction in performance, HCW, and carcass quality attributes associated with clinical and subclinical BRD contributed to these animals having lower slaughter value and net returns compared to healthy animals. Interestingly, only clinical BRD animals resulted in an economic loss whereas all other groups resulted in an economic gain. This loss can predominantly be attributed to the increased treatment costs and lower carcass value of clinical animals. No differences in performance or animal value were found between animals that were treated but showed no lesions at slaughter, and animals with subclinical BRD which could have several explanations. Either the subclinical animals developed and resolved the BRD infection prior to feedlot entry but still had evidence of lung damage at slaughter, or treatment for BRD did not increase performance compared to animals with subclinical BRD or a combination of these. The fact that the treated no lesions animals had lower performance than the healthy animals suggests that these animals were not false positives for BRD.

The results of the present study indicate that BRD morbidity and mortality have substantial impacts on animal performance and carcass traits, and that considerable economic losses occur as a result. The study demonstrated that animals suffering from more severe BRD (≥2 treatments), clinical BRD, and those with severe lung lesions and pleurisy had lower performance and economic returns when compared with animals that suffered less severe or no BRD. Animals that received one treatment for BRD showed similar slaughter value and net return to animals that were never treated for BRD, but animals treated for BRD two or more times showed a dramatic reduction in slaughter value and net return. These results highlight the importance of effective and timely first treatments for BRD and indicate that efforts to increase the effectiveness could have positive impacts on economic return. Little scientific information is available identifying and quantifying the factors affecting the effectiveness of first BRD treatments and further research is warranted. Additionally, the results of the current study indicate that subclinical BRD reduces ADG, slaughter value, and net returns compared to healthy animals with no evidence of BRD. We estimate that the detection and treatment of these animals could improve profitability by up to $67.11 per animal. Economic return figures are affected by prices of inputs and beef and this figure is subject to change according to prevailing market prices. Nevertheless, productivity losses reported in the present study can be used to estimate potential economic losses under changing conditions. Data collected at the feedlot and abattoir such as the number of BRD treatments and pleurisy score provide valuable information to quantify the economic impacts of the disease and monitor factors that can reduce disease severity. These data can be used to improve feedlot BRD management strategies surrounding treatment protocol decision-making and enhanced the detection of animals suffering from subclinical BRD.

Acknowledgments

The authors would like to acknowledge Meat & Livestock Australia for the funding of this project, the feedlot personnel, and Bell Veterinary Services for their assistance throughout the experiment.

Literature Cited

Blakebrough-Hall, C., A. Dona, M. D'occhio, J. McMenimal, and L. A. Gonzalez. 2019. Diagnosis of bovine respiratory disease in feedlot cattle using blood 1H NMR metabolomics. *Sci. Rep.* **10**(1):115. doi:10.1038/s41598-019-56809-w

Brooks, K. R., K. C. Raper, C. E. Ward, B. P. Holland, C. R. Krehbiel, and D. L. Step. 2011. Economic effects of bovine respiratory disease on feedlot cattle during backgrounding and finishing phases 1: 1. *Prof. Anim. Sci.* **27**(3):195. doi:10.15232/S1080-7446(15)30474–5

Cernicchiaro, N., B. J. White, D. G. Renter, and A. H. Babcock. 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. *Am. J. Vet. Res.* **74**:300–309. doi:10.2460/ajvr.74.2.300

Chirase, N. K., and L. W. Greene. 2001. Dietary zinc and manganese sources administered from the fetal stage onwards affect immune response of transit stressed and virus infected offspring steer calves. *Anim. Feed Sci. Technol.* **93**(3):217–228. doi:10.1016/S0377-8401(01)00277-2

Edwards, A. J. 1996. Respiratory diseases of feedlot cattle in the central USA. *Bovine Practioner* **30**:5–7.

Gagea, M. I., K. G. Bateman, T. van Dreumel, B. J. McEwen, S. Carman, M. Archambault, R. A. Shanahan, and J. L. Caswell. 2006. Diseases and pathogens associated with mortality in Ontario beef feedlots. *J. Vet. Diagn. Invest.* **18**:18–28. doi:10.1177/104063870601800104

Gardner, B. A., H. G. Dolezal, L. K. Bryant, F. N. Owens, and R. A. Smith. 1999. Health of finishing steers: effects on performance, carcass traits, and meat tenderness. *J. Anim. Sci.* **77**:3168–3175. doi:10.2527/1999.77123168x

Holland, B. P., L. O. Burciaga-Robles, D. L. VanOverbeke, J. N. Shook, D. L. Step, C. J. Richards, and C. R. Krehbiel. 2010. Effect of bovine respiratory disease during preconditioning on subsequent feedlot performance, carcass characteristics, and beef attributes. *J. Anim. Sci.* **88**:2486–2499. doi:10.2527/jas.2009-2428

Jim, G. K., C. W. Booker, C. S. Ribble, P. T. Guichon, and B. E. Thorlakson. 1993. A field investigation of the economic impact of respiratory disease in feedlot calves. *Can. Vet. J.* **34**:668–673.

Leruste, H., M. Brscic, L. F. Heutinck, E. K. Visser, M. Wolthuis-Fillerup, E. A. Bokkers, N. Stockhofe-Zurwieden, G. Cozzi, F. Gottardo, B. J. Lensink, *et al.* 2012. The relationship between clinical signs of respiratory system disorders and lung lesions at slaughter in veal calves. *Prev. Vet. Med.* **105**:93–100. doi:10.1016/j.prevetmed.2012.01.015

Loneragan, G. H., D. A. Dargatz, P. S. Morley, and M. A. Smith. 2001. Trends in mortality ratios among cattle in US feedlots. *J. Am. Vet. Med. Assoc.* **219**:1122–1127. doi:10.2460/javma.2001.219.1122

McGilchrist, P., R. J. Polkinghorne, A. J. Ball, and J. M. Thompson. 2019. The meat standards Australia index indicates beef carcass quality. *Animal* **13**:1750–1757. doi:10.1017/S1751731118003713

McGuirk, S. M. 2008. Disease management of dairy calves and heifers. *Vet. Clin. North Am. Food Anim. Pract.* **24**:139–153. doi:10.1016/j.cvfa.2007.10.003

van der Mei, J., and T. S. van den Ingh. 1987. Lung and pleural lesions of veal calves at slaughter and their relationship with carcass weight. *Vet. Q.* **9**:203–207. doi:10.1080/01652176.1987.9694101

Polkinghorne, R., R. Watson, J. M. Thompson, and D. W. Pethick. 2008. Current usage and future development of the Meat Standards Australia (MSA) grading system. *Aus. J. Exp. Agric.* **48**(11):1459–1464. doi:10.1071/EA07175

SAS 9.4. 2017. Cary, NC: SAS Institute Inc.

Schneider, M. J., R. G. Tait, Jr, W. D. Busby, and J. M. Reecy. 2009. An evaluation of bovine respiratory disease complex in feedlot cattle: impact on performance and carcass traits using treatment records and lung lesion scores. *J. Anim. Sci.* **87**:1821–1827. doi:10.2527/jas.2008-1283

Sowell, B. F., M. E. Branine, J. G. Bowman, M. E. Hubbert, H. E. Sherwood, and W. Quimby. 1999. Feeding and watering behavior of healthy and morbid steers in a commercial feedlot. *J. Anim. Sci.* **77**:1105–1112. doi:10.2527/1999.7751105x

Tennant, T. C., S. E. Ives, L. B. Harper, D. G. Renter, and T. E. Lawrence. 2014. Comparison of tulathromycin and tilmicosin on the prevalence and severity of bovine respiratory disease in feedlot cattle in association with feedlot performance, carcass characteristics, and economic factors. *J. Anim. Sci.* **92**:5203–5213. doi:10.2527/jas.2014-7814

Theurer, M. E., D. E. Anderson, B. J. White, M. D. Miesner, D. A. Mosier, J. F. Coetzee, J. Lakritz, and D. E. Amrine. 2013. Effect of *Mannheimia haemolytica* pneumonia on behavior and physiologic responses of calves during high ambient environmental temperatures. *J. Anim. Sci.* **91**:3917–3929. doi:10.2527/jas.2012-5823

Thompson, D. U., E. S. Moore, B. J. White, and C. D. Reinhardt. 2012. Case study: effects of undifferentiated bovine respiratory disease on performance and marbling deposition in feedlot steers fed to a common yield grade endpoint. *Bov. Pract.* **46**:52–58.

Thompson, P. N., A. Stone, and W. A. Schultheiss. 2006. Use of treatment records and lung lesion scoring to estimate the effect of respiratory disease on growth during early and late finishing periods in South African feedlot cattle. *J. Anim. Sci.* **84**(2):488. doi:10.2527/2006.842488x

Waggoner, J., C. Mathis, C. Löest, and J. Sawyer. 2007. CASE STUDY: impact of morbidity in finishing beef steers on feedlot average daily gain, carcass characteristics, and carcass value. *Prof. Anim. Sci.* **23**(2):174–178.

White, B. J., and D. G. Renter. 2009. Bayesian estimation of the performance of using clinical observations and slaughter lung lesions for diagnosing bovine respiratory disease in post-weaned beef calves. *J. Vet. Diagn. Investig.* **21**(4):446–453. doi:10.1177/104063870902100405

Wilson, B. K., D. L. Step, C. L. Maxwell, C. A. Gifford, C. J. Richards, and C. R. Krehbiel. 2016. Effect of bovine respiratory disease during the receiving period on steers finishing performance, efficiency, carcass characteristics, and lung scores. *Prof. Anim. Sci.* **33**:24–36. doi:10.15232/pas.2016-01554

Wittum, T. E., N. E. Woollen, L. J. Perino, and E. T. Littledike. 1996. Relationships among treatment for respiratory tract disease, pulmonary lesions evident at slaughter, and rate of weight gain in feedlot cattle. *J. Am. Vet. Med. Assoc.* **209**(4):814–818.