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Economic impacts of lameness in feedlot cattle[1]

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ABSTRACT: Lameness is an important health issue in feedlot cattle; however, there is a paucity of information regarding its economic impact. Decision tree models are excellent tools for assessing costs of disease such as the net return (net return = benefit – cost). Models were developed using expert opinion, literature and retrospective feedlot data provided by Vet-Agri Health Services (VAHS, Airdrie, Alberta, Canada) collected from 2005 to 2015 on individually treated cattle (n = 30,940) from 28 feedlots. The objective was to estimate net return of various lameness diagnoses and impacts of cattle type, season of treatment, and extreme high and low cattle prices. Cattle were diagnosed as lame according to the following categories: foot rot, foot rot in heavy cattle (BW > 363 kg at treatment), injury, lame with no visible swelling, and joint infection. Records consisted of arrival and treatment weight, cost of treatment, and cattle deaths. Records included cattle types classified as: fall calves (heifer and steer), winter calves (heifer and steer) and yearling cattle (heifer and steer). Lastly, variables ADG, days on feed (DOF), and Season (spring, summer, fall, and winter) were created. Models estimated net return using cattle slaughter prices for healthy cattle that reached a slaughter weight of 635 kg and for three possible outcomes for each diagnosis after final treatment: cattle that recovered after treatment and reached a slaughter weight of 635 kg; cattle that were removed before they reached slaughter weight; or cattle that died. Compared to undiagnosed cattle with 1.36 kg/d ADG, cattle diagnosed with foot rot and foot rot heavy cattle had the highest ADG until first treatment (1.14 and 1.57 kg/d, respectively) and differed significantly (P < 0.05) compared to cattle diagnosed with injuries (0.87 kg/d), lame with no visible swelling (0.64 kg/d), and joint infections (0.53 kg/d). Yearling steers had the most positive returns compared to all other cattle types. Cattle with lighter arrival weight had lower ADG and increased economic losses after treatment compared to heavier weighted cattle on arrival. Based on average slaughter prices over a 10-yr period for healthy cattle, return was $690. Return after final treatment for cattle with foot rot was $568, foot rot in heavy cattle was $695, and injury was $259. However, joint infections and lame with no visible swelling had negative returns of –$286 and –$701, respectively.

Key words: animal health, cattle, cost, economic, feedlot, lameness

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INTRODUCTION

Lameness is an important concern from both humane and economic perspectives. In a review of > 1.8 million U.S. cattle, 13.1% of cattle had health issues during the feeding period, with 16% of those associated with lameness (Griffin et al., 1993). Lameness is a clinical sign for foot, leg, and upper body issues

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that disrupt the normal gait in response to pain, injury, disease or abnormal structure (Van Amstel and Shearer, 2006). Examples of infectious causes of lameness include foot rot, joint infections, and digital dermatitis (Greenough, 2007), whereas examples of non-infectious causes include toe tip necrosis, trauma, injury, and musculoskeletal disorders (Jelinski et al., 2016).

Lameness has negative impacts on cattle welfare, health, production (Terrell et al., 2014), and it can cause pain and discomfort that can reduce mobility and social interactions (Desrochers et al., 2001). Lame cattle often have reductions in feeding periods at the bunk, body condition score (BCS), and overall health (Vermunt and Greenough, 1994). Negative effects on cattle can lead to substantial economic impacts through inability of cattle to recover, increased days on feed (DOF), cost of treatments, premature removal from feeding and death losses (Terrell et al., 2014). Correctly diagnosing and administering prompt treatment are essential to improve the health and recovery of a lame animal to return or to remain on feed and reach an optimal weight.

Decision tree models are an effective tool to assess the economic impact of lameness. However, descriptive costs, losses specific to various lameness diagnoses, cattle types, and season are insufficiently described for the current feedlot industry. Therefore, the objective was to estimate the net return of various lameness diagnoses and the impact of various cattle types, season of treatment, and extreme low and high cattle prices.

MATERIALS AND METHODS

A dataset was created using health records collected (from 2005 to 2015) chute side by VAHS (Vet-Agri Health Services, Airdrie, Alberta, Canada) from 28 southern Alberta feedlots, ranging in size from 800 to 20,000 head one-time capacity. Collectively, the total annual feedlot capacity was n = 140,000 cattle. The study consisted of producer-collected data compiled in a computer software program (Medlogic, Vet-Agri Health Services, Airdrie, Alberta, Canada). The program was updated throughout the study with the addition of one lameness category (i.e., lame with no visible swelling).

The dataset used for the study included health records from cattle diagnosed as lame in the following categories: foot rot (n = 23,442), foot rot in heavy cattle (> 363 kg at date of treatment; n = 147), injury (n = 893), lame with no visible swelling (n = 4,697), and joint infection (n = 1,761). Foot rot in heavy cattle was categorized differently from foot rot, due to differences in the antibiotics they are treated with which have choices of antibiotics with shorter pre-slaughter withdrawal periods. Records provided the following information: cattle identification, feedlot identification, arrival date, weight on date of arrival, treatment date, weight on date of treatment, treatment type (each treatment was recorded in the dataset as a new record), relapses (treated multiple times for a new case of the same condition), sex (heifer or steer), deaths, and cattle type. The latter category included fall steer calves (FSC), fall heifer calves (FHC), winter steer calves (WSC), winter heifer calves (WHC), yearling steers (YS), and yearling heifers (YH). Within the dataset, there were multiple treatment records that included the list of treatments that an animal received, which were unique to one individual animal. Treatment of cattle was based on veterinary treatment recommendations as provided by the feedlots own veterinarian (Table 1).

In the dataset, a case was defined as an animal diagnosed and treated for one lameness condition. Foot rot and foot rot heavy cases were defined as 1 case within 7 d after initial treatment. A relapse was defined as a new case for the same condition. There were multiple cases for injury, lame with no visible swelling, and joint infection. However, no relapses were defined for injury, lame with no visible swelling, or joint infection due to the chronic nature of the diseases and the unlikeliness of complete recovery (Miskimins, 1994; Hirsbrunner and Steiner, 1998).

Data Cleaning

Exact copies of cattle health records were considered duplicates and therefore omitted. Similarly, some cattle types were uncommon to the feedlot setting; cows (n = 440), breeding heifers (n = 149), bulls (n = 153), bull calves (n = 256), and natural beef (n = 40). Therefore, those cattle types were omitted to focus on more common feedlot cattle types such as fall, winter, and yearling placed cattle (heifers or steers). Additionally, individual cattle that had a recorded weight of < 136 kg on the date of arrival and/or on date of treatment were omitted. Feedlot cattle rarely to have such low body weights on arrival (Greenwood and Cafe, 2007) and are likely due to data input error.

Table 1. Hospital treatment protocol provided by Vet-Agri Health Services (VAHS) of initial treatment therapy administered to cattle based on lameness diagnosis

Diagnosis	Initial treatment therapy
Foot rot	LA-200
Foot rot Heavy	Excenel and Dexamethasone
Injury	No treatment given unless there is evidence of an infection
Joint Infection	Resflor
Lameness – No Swelling	Resflor

Negative DOF (n = 7) were also removed, as the number of DOF was considered 0 on arrival to the feedlot. The criteria above resulted in elimination of 1,350 cattle health records, resulting in n = 30,940 cattle health records from 28 feedlots used in the study (Fig. 1).

Data Management

Data were compiled in a commercial spreadsheet (Microsoft Excel, v.15; Microsoft Corporation, Redmond, WA). Two continuous variables were created. The first variable represented DOF (d; treatment date minus arrival date). The second variable was defined as ADG [(kg/d) until treatment; weight on date of treatment minus the weight on date of arrival divided by DOF]. A categorical variable (Season) was created for classification of lameness occurrence throughout the year. The categories were spring (March 20 through June 20), summer (June 21 through September 21), fall (September 22 through December 20), and winter (December 21 through March 19).

Cattle records included multiple treatments for each lameness diagnosis as a protocol defined treatment or relapse. The lameness diagnoses foot rot and foot rot heavy consisted of 4 and 2 treatments, respectively. However, treatments were only included until the third treatment for foot rot and 1 treatment for foot rot heavy. The limit on the number of treatments was to ensure that there were > 10 observations per treatment (which did not have a major impact on results).

The dataset did not have a category that included proportion of cattle that were railed (removed from the

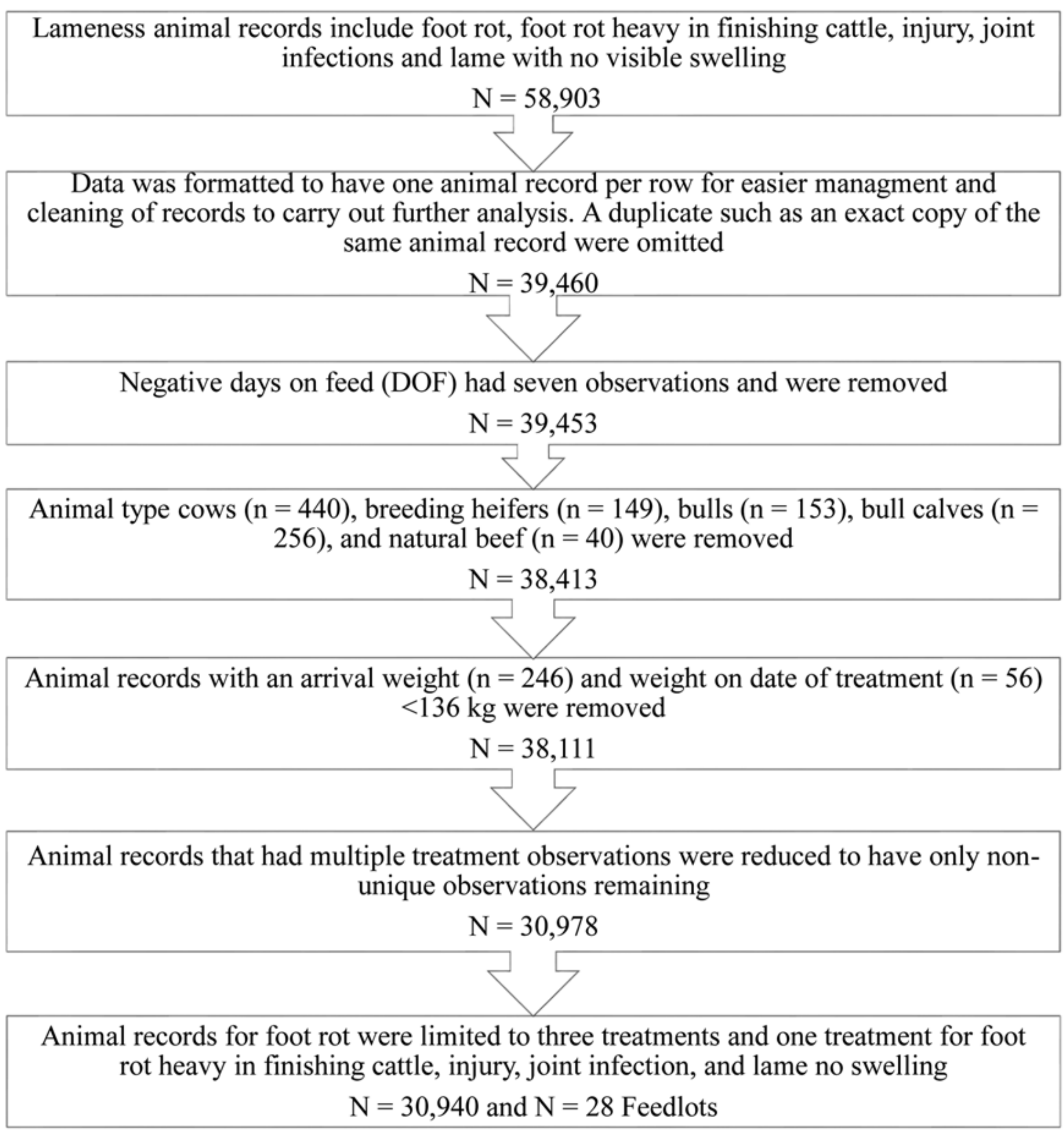

Figure 1. Flow chart diagram illustrating data management and cleaning process of cattle health records used within the lameness diagnose categories and cattle type.

feeding period before they reach their optimal slaughter weight). Producers make decisions based on management and treatment protocols to rail cattle if there are no apparent improvements in treatment recovery, weight gain or overall body condition. Therefore, the proportion of cattle commonly railed was obtained from expert opinion in the feedlot cattle industry. Based on expert opinion, the proportion was estimated to be 0.42%. The proportion of cattle railed over the total feedlot capacity therefore consisted of 595 cattle. The number of cattle railed was kept constant at 0.42% per lameness category and equal among seasons. In addition, railing cattle is based on live animal weight where the minimum average railing weight is estimated to be 453 kg. In the dataset, cattle that were > 453 kg at time of treatment to be railed were removed from the feeding period at that point in time. However, cattle that were < 453 kg at time of treatment remained on feed until they reached 453 kg and then removed from the feeding period.

From the total available records used for this study, 3.80% of all cattle diagnosed with lameness died in the feedlot. Of the 3.80%, the percentage of cattle that died after being diagnosed with foot rot was 1.30%, 0.00% for foot rot heavy cattle, 0.38% for injuries, joint infections were 1.80%, and lame with no visible swelling was 0.35%.

Data Analysis

Descriptive statistics were generated for each lameness diagnose category stratified by cattle type and season using STATA (Version 14; StataCorp LP, College Station, TX). The median value was used to calculate the appropriate measure, as data were not normally distributed. Median value outputs were generated for the following variables: weight on date of arrival, weight on date of treatment, DOF, ADG, and cost of treatment.

Because of the non-parametric distribution and non-paired observations of the dataset, the Kruskal–Wallis and the Wilcoxon rank-sum test were used. First, the Kruskal–Wallis test was used to determine by rank if there was a difference for the following variables; weight on date of arrival, weight on date of treatment, and ADG. If there was a difference by rank for each variable, a Wilcoxon rank-sum test was applied. The Wilcoxon rank-sum test determined the individual differences between each variable and lameness diagnoses at final treatment. A priori significance level was set at P-value < 0.05.

Modeling software (TreeAge Pro, TreeAge Software Inc., Williamstown, MA) was used to construct a decision tree model to estimate net return for each lameness diagnosis and impact of various cattle types and season of treatment. In a decision tree model, a decision node, represented by a square in Fig. 2 and 3, represents the initial decision within the tree (e.g., if the animal is lame or not lame). From a decision node, there are branches that lead to chance nodes, represented by circles, which represent all the possible outcomes for that event (e.g., diagnosed as lame and being treated). The branches from chance nodes to the outcome represent the probability of that event occurring in the model. Finally, the terminal node, represented by a triangle, represents the overall outcome and the net return from that decision in the model. There were 2 different models generated based on relapses; Figure 2 illustrates the decisions and outcomes for cattle that were diagnosed with foot rot in heavy cattle, injury, joint infection, or lameness with no visible swelling. The second model shown in Figure 3 illustrates the multiple relapses and outcomes for cattle diagnosed with foot rot, however, results of this study focus on the portion of the model presented in the rectangle.

The various decision tree models were generated using the available dataset, such as the probabilities of each event occurring at the branches. The total popu-

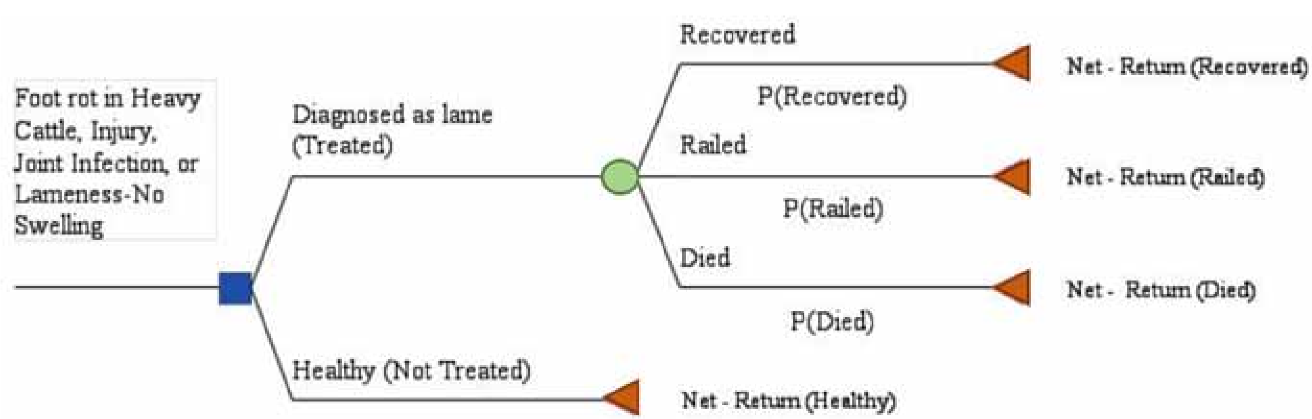

Figure 2. Decision tree model describing the probability of cattle at each event and the overall the net-return for cattle diagnosed with foot rot in heavy animals (> 363 kg), injury, joint infections, or lameness with no visible swelling for the outcomes recovered, railed and died.

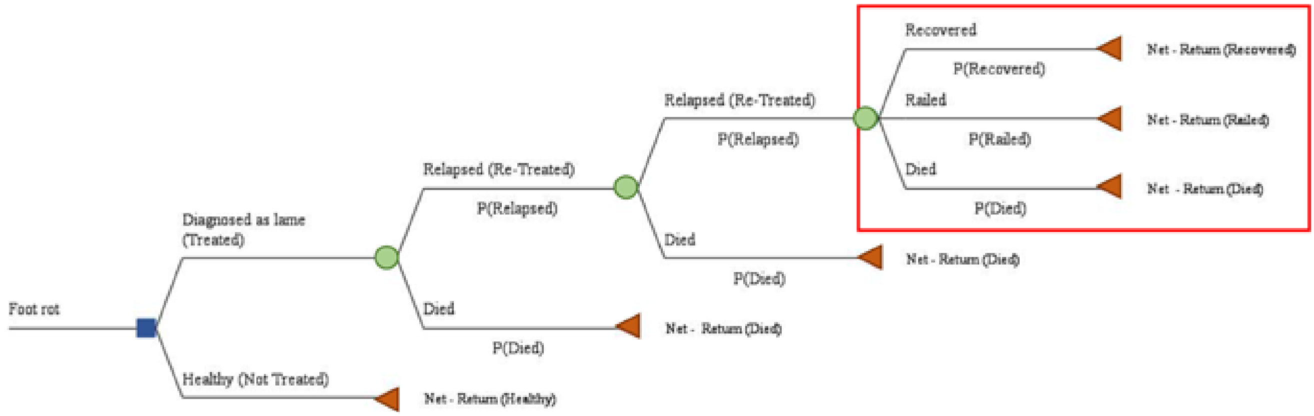

Figure 3. Decision tree model describing the probability of cattle at each event and the overall the net-return for cattle diagnosed with foot rot for the outcomes recovered, railed and died at final treatment (rectangle outline).

lation of healthy (not diagnosed as lame) and animals diagnosed as lame was $N = 140{,}000$. The probability of cattle being diagnosed and receiving an initial treatment with foot rot was (21,988/140,000). The probability of that animal relapsing was (2,060/21,988), and the final relapse was (169/2,060). In a different model for heavier cattle, the probability of an animal being diagnosed with foot rot was (147/140,000). The probability of an animal being diagnosed with an injury was (893/140,000), while joint infections were (4,697/140,000), lastly, lameness with no swelling (1,761/140,000).

The first-time an animal was diagnosed with lameness was identified as an initial treatment. For initial treatment of lameness, 4 possible outcomes were included in the model: healthy cattle (not diagnosed with lameness), cattle diagnosed and recovered, cattle diagnosed and relapsed, and cattle diagnosed and died. Model outcomes after the initial treatment for foot rot heavy, injury, lame with no visible swelling and joint infection did not include relapses, and therefore included diagnosed and recovered, diagnosed and railed, and diagnosed and died (Figure 2). Model outcomes after the initial treatment for cattle diagnosed with foot rot were diagnosed and relapsed and, diagnosed and died (Figure 3). These options were modeled for up to 3 treatments; outcomes of the model after the third and final treatment included diagnosed and recovered, diagnosed and railed, and diagnosed and died. All economic results were reported in Canadian dollars ($). Net return was calculated using the following formula [Eq. 1].

$$\text{Net return} = \text{benefit} - \text{cost}. \quad [1]$$

Net return did not include the cost of the calf or the cost of rendering. The cost of the calf was not included, due to fluctuating cattle prices throughout the year.

The benefit value was calculated for the following 4 outcomes: healthy cattle, diagnosed and recovered, diagnosed and railed, and diagnosed and died. The benefit value of healthy cattle (not diagnosed with lameness) and diagnosed and recovered was calculated using an average slaughter weight for finished cattle of 635 kg (CanFax, 2013) multiplied by Canadian slaughter prices of heifers and steers (StatisticsCanada, 2016). The benefit value of cattle that were diagnosed and railed was calculated using the estimated rail slaughter price multiplied by the weight on date of treatment. Cattle that are railed have reduced backfat and muscle due to a lower BCS (Apple et al., 1999). Lame cattle that are classified as railer's are unlikely to recover, finish the feeding period and therefore would be railed at a lighter weight. It is difficult to market cattle for slaughter that are < 453 kg, therefore, cattle are kept on feed until they reach an average marketable rail weight of 453 kg. The rail slaughter price was given a conservative estimate to be half of the slaughter price for cattle that reach the optimal slaughter weight. In line with a previous study, 5 large western U.S. feedlots estimated that salvageable lame animals were only 53% of their original value (Griffin et al., 1993). The benefit value of diagnosed and died was $0.

The cost value for healthy cattle consisted of the following formula [Eq. 2].

$$\text{Cost (healthy cattle)} = [(\text{BW \{slaughter\}} - \text{BW \{arrival\}})\ \text{ADG}]\ \ \text{cost (finish)}. \quad [2]$$

Where BW (slaughter) = slaughter weight of 635 kg; BW (arrival) = weight on date of arrival for a healthy animal of 313 kg; ADG = ADG of 1.36 kg/d for a healthy animal; and cost (finish) = cost to finish cattle ($3/d).

The cost value of cattle that were diagnosed and died after initial treatment of foot rot or cattle that were diagnosed and railed or died after first and only treatment of lameness consisted of formula [Eq. 3].

Cost (diagnosed and railed or diagnosed and died) = {[(BW {treatment} – BW {arrival}) ADG (healthy)] cost (finish)} + cost (chute and labor) + cost (treatment). [3]

Where BW (treatment) = weight on date of treatment; BW (arrival) = weight on date of arrival; ADG = ADG of 1.36 kg/d for a healthy animal; cost (chute and labor) = cost of chute and labor ($2/animal); and cost (treatment) = cost of initial treatment. There were additions to the formula [Eq. 3] for consecutive treatments of diagnosed and died and for diagnosed and railed after final treatment. First, the cost to finish cattle was multiplied by the difference in weight on date of treatment for the various treatments, then divided by ADG on date of treatment between treatment dates. Lastly, the equation had the addition of treatment cost, and chute and labor cost per treatment to determine overall cost.

Cost value of cattle diagnosed and recovered after initial treatment of lameness consisted of formula [Eq. 4].

Cost (diagnosed and recovered) = {[(BW {treatment} – BW {arrival}) ADG (healthy)] cost (finish)} + {[(BW {slaughter} – BW {treatment}) ADG (treatment)] cost (finish)} + cost (chute and labor) + cost (treatment). [4]

Where BW (treatment) = weight on date of treatment; BW (arrival) = weight on date of arrival; ADG (treatment) = ADG on date of treatment; cost (chute and labor) = cost of chute and labor ($2/animal); and cost (treatment) = cost of initial treatment. There was the addition to the formula [Eq. 4] for consecutive treatment for cattle diagnosed with foot rot. The difference in weight on date of treatment between treatments was divided by the ADG for each, then multiplied by the cost to finish was added.

The net return of treating lame cattle was calculated for the average slaughter price from 2005 to 2015, for exceptionally high slaughter prices in 2015, and low slaughter prices in 2009.

RESULTS

Impact of Cost of Cattle Diagnosed and Treated for Foot Rot, Foot Rot in Heavy Cattle, Joint Infections, Injuries, or Lameness with No Swelling

The average cost of a healthy animal that was finished to 635 kg was $710 compared to $861 for cattle diagnosed and recovered from foot rot after final treatment. The median cost of treatment for cattle with foot rot was $11.80 at final treatment (Table 2). However, based on cattle type with foot rot, WHC had the lowest cost of treatment compared to FSC (Table 3). Foot rot in heavy cattle had the overall highest ADG compared to all other diagnoses; furthermore, the average cost of treatment

Table 2. Descriptive statistics used to estimate average net return of cattle diagnosed and treated as lame stratified by treatment number

Diagnosis	Treatment	Arrival weight, median kg	Treatment weight, median kg	DOF[1] at treatment, median d	ADG[2] at treatment, median kg/d	Cost of treatment, median $[3]
Foot rot	1	296[a]	492[h]	130	1.34*	10.9
	2	303[b]	503[i]	141	1.27*	11.6
	3	299[c]	499[j]	133	1.14*	11.8
Foot rot Heavy	1	318[d]	591*	177	1.57*	15.2
Injury	1	281[e]	354*	49	0.871*	9.3
Joint Infection	1	261[f]	295*	39	0.644*	25.0
Lame No Swelling	1	258[g]	279*	26	0.526*	21.6

*Significant with all other values within column ($P < 0.05$).

[a]Not significant compared to c ($P = 0.223$).

[b]Not significant compared to c and d ($P = 0.613$ and 0.340, respectively).

[c]Not significant with d ($P = 0.265$).

[d]Significant compared to a, e, and f ($P = 0.0001$).

[e]Significant compared with all other values within column ($P <0.05$).

[f]Significant compared with a, b, c, d, and e ($P = 0.0001$).

[g]Not significant with f ($P = 0.652$).

[h]Not significant with j ($P = 0.452$).

[i]Not significant with j ($P = 0.073$).

[j]Significant compared with all other values within column ($P <0.05$).

[1]DOF = Days on Feed.

[2]ADG = Average Daily Gain.

[3]All costs of treatment are in $CAN.

Table 3. Descriptive statistics used to estimate average net return of cattle diagnosed and treated as lame stratified by cattle type: fall heifer calves (FHC), fall steer calves (FSC), winter heifer calves (WHC), winter steer calves (WSC), yearling heifers (YH), and yearling steers (YS)

Diagnosis	Cattle type	Arrival weight, median kg	Treatment weight, median kg	DOF[1] at treatment, median d	ADG[2] at treatment, median kg/d	Cost of treatment, median $[3]
Foot rot	FHC	263	481	174	1.31	10.7
	FSC	267	503	164	1.37	11.6
	WHC	281	417	124	1.22	8.9
	WSC	286	454	102	1.27	9.6
	YH	395	490	62	1.35	11.3
	YS	422	510	59	1.48	11.1
Foot rot Heavy	FHC	227	482	266	1.02	11.9
	FSC	318	593	177	1.57	15.2
	YH	345	590	144	1.70	14.1
Injury	FHC	236	293	58	0.72	9.8
	FSC	274	322	44	0.90	10.7
	WHC	239	349	91	0.92	5.0
	WSC	218	279	77	0.74	0.9
	YH	369	411	39	0.75	9.6
	YS	420	465	49	1.02	7.7
Joint Infection	FHC	233	272	43	0.56	24.9
	FSC	261	286	37	0.58	25.7
	WHC	235	272	42	0.65	21.8
	WSC	221	277	62	0.73	23.8
	YH	376	426	30	0.77	25.1
	YS	398	454	50	0.99	20.8
Lame No Swelling	FHC	241	264	23	0.54	23.5
	FSC	253	272	26	0.45	22.2
	WHC	215	288	67	0.87	8.5
	WSC	244	298	56	0.63	10.2
	YH	383	406	19	0.71	13.2
	YS	372	445	61	0.95	11.9

[1]DOF = Days on Feed.
[2]ADG = Average Daily Gain.
[3]All costs of treatment are in $CAN.

was higher than cattle diagnosed with foot rot (Table 2). All cattle types differed significantly in arrival weight, except when foot rot treatment 3 was compared to foot rot treatment 1 and 2 ($P = 0.223$ and 0.613, respectively; Table 2). Arrival weight for cattle diagnosed with foot rot fat was not significantly different from foot rot treatment 2 and 3 ($P = 0.340$ and 0.265, respectively; Table 2).

Cattle with chronic cases of lameness had the lowest arrival and treatment weight, DOF and ADG, which increased the overall cost. Arrival weight of cattle diagnosed as lame with no visible swelling was not significantly different from cattle diagnosed with joint infections ($P = 0.652$; Table 2). All cattle types differed significantly in weight on date of treatment, except when foot rot treatment 3 was compared to foot rot treatment 1 and 2 ($P = 0.452$ and 0.073, respectively; Table 2). All cattle types differed significantly in ADG ($P < 0.05$; Table 2). The cost of treatment and recovery for cattle diagnosed with joint infections was $1,674. The cost of treatment for all cattle types with joint infections was the highest compared to all other diagnoses (Table 3). In addition, cost of treatment for cattle with joint infections was highest in fall compared to all other seasons (Table 4). The cost for cattle diagnosed with injuries was $1,138 after final treatment and recovery. Furthermore, animals treated for injuries in the spring had the highest cost per treatment compared to all other seasons of treatment (Table 4). Cattle that were lame with no swelling had the highest overall cost ($2,087). Finally, animals treated as lame with no visible swelling in fall was the season with the highest cost per treatment ($22.80; Table 4).

Impact of Cattle Type and Lameness Diagnoses on Average Net Return (2005 to 2015)

Input values utilized in the calculation of net return for several outcomes are shown (Table 5). Based on average slaughter prices, healthy cattle had a net re-

Table 4. Descriptive statistics used to estimate average net return of cattle diagnosed and treated as lame stratified by season of treatment: spring, summer, fall, and winter

Diagnosis	Season of treatment	Arrival weight, median kg	Treatment weight, median kg	DOF[1] at treatment, median d	ADG[2] at treatment, median kg/d	Cost of treatment, median $[3]
Foot rot	Spring	295	519	160	1.43	11.6
	Summer	308	499	144	1.30	11.7
	Fall	363	454	52	1.17	9.0
	Winter	276	408	106	1.08	8.6
Foot rot Heavy	Spring	318	596	177	1.58	15.2
	Sumer	224	490	255	1.08	11.9
	Fall	345	590	144	1.70	14.1
Injury	Spring	272	413	125	0.95	9.9
	Summer	274	450	99	1.13	4.4
	Fall	280	306	24	0.69	9.6
	Winter	288	361	68	0.89	8.8
Joint Infection	Spring	261	372	78	0.92	18.2
	Summer	276	397	112	0.92	21.4
	Fall	257	272	28	0.41	25.8
	Winter	262	315	63	0.75	25.1
Lame No Swelling	Spring	315	406	78	0.93	9.8
	Summer	309	395	23	0.58	11.7
	Fall	254	267	21	0.37	22.8
	Winter	260	312	62	0.78	19.1

[1]DOF = Days on Feed.

[2]ADG = Average Daily Gain.

[3]All costs of treatment are in $CAN.

Table 5. Variable inputs used within the net return modeling tree to calculate the estimated net return of non-treated healthy cattle, cattle that recovered, were railed, or died for each lameness diagnose category stratified by treatment, cattle type and season

Variable	Value	Unit[1]	Source
Cost to finish cattle	3	$/d	Expert Opinion
Average 2005 to 2015 slaughter price	100	$/45.4 kg	(StatisticsCanada, 2016)
Average 2005 to 2015 rail price	50	$/45.4 kg	Estimate
High 2015 slaughter price	174	$/45.4 kg	(StatisticsCanada, 2016)
High 2015 rail price	87	$/45.4 kg	Estimate
Low 2009 slaughter price	76	$/45.4 kg	(StatisticsCanada, 2016)
Low 2009 rail price	38	$/45.4 kg	Estimate
Average railed cattle annually of total feedlot capacity (n = 140,000)	0.42	%	Expert Opinion
Average daily gain of healthy cattle	1.36	kg/d	(CanFax, 2013)
Optimum slaughter weight	635	kg	(CanFax, 2013)
Minimum rail weight	453	kg	Estimate
Minimum arrival weight	136	kg	(Cernicchiaro et al., 2013)
Minimum weight at date of treatment	136	kg	(Cernicchiaro et al., 2013)

[1]All values in $CAN.

turn of $690 (net return = benefit– cost; $690 = $1,400 to $710). When stratified by cattle type, the average net return for healthy FHC was $567, FSC was $600, WHC was $750, WSC was $700, YH with $867 and YS with $940. All cattle deaths resulted in negative returns. Yearling steers had the highest return after treatment compared to all other cattle types. Compared to healthy cattle, cattle treated for foot rot resulted in a decreased net return after final treatment and if they were railed (Table 6). A single treatment for foot rot heavy cattle resulted in a net return higher than the average return for healthy cattle (Table 6).

Cattle with injuries had greater returns when they reached optimal slaughter weight compared to being railed after reaching 453 kg (Table 6). Cattle diagnosed with joint infections were negatively impacted when they

Table 6. Estimated net return of cattle that recovered, were railed or died after final treatment with foot rot, foot rot heavy, injury, joint infection and lame with no visible swelling stratified by cattle type: fall heifer calves (FHC), fall steer calves (FSC), winter heifer calves (WHC), winter steer calves (WSC), yearling heifers (YH) and yearling steers (YS) based on average slaughter and rail prices over the period 2005 to 2015 ($100/45.4 kg and $50/45.4 kg, respectively)

	Cattle	Final treatment[1]		
Diagnosis	type	Recovered	Railed	Died
Foot rot	Average	$568.70	$77.29*	–$472.70
	FHC	$725.30	$300.90*	–$214.00
	FSC	$374.30	–$69.10*	–$587.10
	WHC	$576.10	$33.60*	–$501.30
	WSC	$457.10	$47.80*	–$488.70
	YH	$793.30	$264.50*	–$295.50
	YS	$866.10	$319.60*	–$251.30
Foot rot Heavy	Average	$695.50	$31.50*	–$621.20
Injury	Average	$259.80	–$15.10	–$171.30
	FHC	–$161.30	–$306.60	–$136.80
	FSC	$247.20	–$52.70	–$117.70
	WHC	$219.80	–$88.90	–$249.00
	WSC	–$173.90	–$342.10	–$137.90
	YH	$408.90	$227.50	–$103.60
	YS	$787.00	$401.80*	–$110.70
Joint Infection	Average	–$286.60	–$341.50	–$102.00
	FHC	–$632.90	–$572.90	–$112.90
	FSC	–$473.40	–$443.20	–$82.70
	WHC	–$362.00	–$434.40	–$106.80
0	WSC	–$202.80	–$366.60	–$148.80
	YH	$455.80	$257.60	–$137.10
	YS	$710.40	$354.40*	–$146.80
Lame No Swelling	Average	–$701.40	–$566.90	–$854.60
	FHC	–$703.60	–$611.80	–$893.50
	FSC	–$1,059.20	–$759.20	–$859.20
	WHC	$40.90	–$237.30	–$935.50
	WSC	–$323.30	–$366.20	–$874.20
	YH	$369.70	$234.00	–$571.20
	YS	$626.00	$297.40	–$593.90

*Animals were > 453 kg at time of treatment and then railed; remaining animals were fed to 453 kg and then railed.

[1]All values in $CAN.

completed the period and when they were railed after reaching a minimum 453 kg, except for yearling cattle. Fall placed calves diagnosed as lame with no visible swelling had a reduced loss if they were railed at minimum rail weight compared to completing the feeding period till preferred slaughter weight. Although recovered after treatment, both FHC and WSC diagnosed with injuries had negative net returns, of –$161 and –$173, respectively (Table 6). The net return for recovered cattle with joint infections resulted in negative returns for the average of –$286 (Table 6). The cattle types FHC, FSC, WHC, and WSC, had negative returns after final treatment and recovery, with the lowest return for FHC (Table 6). Cattle diagnosed as lame with no swelling had the lowest average recovered treatment return at –$701 compared to all other lameness diagnoses. There were negative net returns for the recovered treated cattle types FHC, FSC, WSC, with FSC as the lowest return compared to all other cattle types (Table 6).

Impact of High and Low Cattle Slaughter Prices on the Average Net Return

Yearling steers diagnosed and recovered with foot rot had the highest return compared to FSC for years with high or low cattle prices (Table 7). Low cattle prices had a negative net return for cattle types FSC, WHC, and WSC when animals > 453 kg at time of being railed (Table 7). Net returns for foot rot heavy, injury, joint infection and lame with no visible swelling, based on high and low cattle prices, are shown (Table 8). Based on high and low cattle prices, foot rot heavy diagnosed cattle that were railed after treatment and were > 453 kg had a return of $513 compared to a negative net return of –$124 for the average.

Regardless of cattle price, yearling cattle with chronic cases of lameness had the highest returns compared to all other cattle types (Table 8). In years with high cattle prices, cattle with injuries had resulted in positive returns when railed after treatment and reached a minimum of 453 kg. However, in years with low cattle prices, only yearling cattle prices resulted in positive returns after being railed (Table 8). Based on low cattle prices in 2009, cattle that were treated and recovered from joint infections resulted in a negative net return for the average as well as the cattle types FHC, FSC, WHC, and WSC. High cattle prices in 2015 resulted in a negative net return of –$23 for FSC that were treated and recovered as lame with no visible swelling. Low cattle prices in 2009 resulted in a negative net return for the average, and for the cattle types FHC, FSC, WHC, and WSC (Table 8).

Impact of Season at Time of Lameness Diagnoses on the Average Net Return over the Period of 2005 to 2015

The average net return for healthy cattle was $690 (net return = benefit – cost; $690 = $1,400 to $710). However, season had an impact on the net return for all lameness diagnoses. Cattle diagnosed and treated with foot rot in fall had the highest return after final treatment compared to winter with the lowest return (Table 9). Cattle that were ultimately railed after final treatment for foot rot had a reduced positive net return in all seasons, except spring (Table 9). Spring was the only season of treatment recorded for foot rot

Table 7. Estimated net return of cattle that recovered, were railed or died after final treatment with foot rot stratified by cattle type: fall heifer calves (FHC), fall steer calves (FSC), winter heifer calves (WHC), winter steer calves (WSC), yearling heifers (YH) and yearling steers (YS) based on high cattle prices in 2015 (slaughter price $174/45.4 kg and rail slaughter price $87/45.4 kg) and low cattle prices in 2009 (slaughter price $76/45.4 kg and rail slaughter price $38/45.4 kg)

	Final treatment[1]					
	High prices			Low prices		
Cattle type	Recovered	Railed	Died	Recovered	Railed	Died
Average	$1,604.70	$484.20*	–$472.70	$232.70	–$54.70*	–$472.70
FHC	$1,761.30	$682.00*	–$214.00	$389.30	$177.30*	–$214.00
FSC	$1,410.30	$314.20*	–$587.10	$38.30	–$193.40*	–$587.10
WHC	$1,612.10	$429.50*	–$501.30	$240.10	–$94.70*	–$501.30
WSC	$1,493.10	$444.80*	–$488.70	$121.10	–$80.90*	–$488.70
YH	$1,829.30	$678.90*	–$295.50	$457.30	$130.10*	–$295.50
YS	$1,902.10	$742.10*	–$251.30	$530.10	$182.60*	–$251.30

*Animals were > 453 kg at time of treatment and then railed.

[1]All values in $CAN.

Table 8. Estimated net return of cattle that recovered, were railed or died after final treatment with foot rot heavy, injury, joint infection and lame with no visible swelling stratified by cattle type: fall heifer calves (FHC), fall steer calves (FSC), winter heifer calves (WHC), winter steer calves (WSC), yearling heifers (YH) and yearling steers (YS) based on high cattle prices in 2015 (slaughter price $174/45.4 kg and rail slaughter price $87/45.4 kg) and low cattle prices in 2009 (slaughter price $76/45.4 kg and rail slaughter price $38/45.4 kg)

		Final treatment[1]					
		High prices			Low prices		
Diagnosis	Cattle type	Recovered	Railed	Died	Recovered	Railed	Died
Foot rot Heavy	Average	$1,731.50	$513.90*	–$621.20	$359.50	–$124.90*	–$621.20
Injury	Average	$1,295.80	$354.80	–$171.30	–$76.10	–$135.10	–$171.30
	FHC	$874.60	$63.30	–$136.80	–$497.30	–$426.60	–$136.80
	FSC	$1,283.20	$317.20	–$117.70	–$88.70	–$172.70	–$117.70
	WHC	$1,255.80	$281.00	–$249.00	–$116.10	–$208.90	–$249.00
	WSC	$862.10	$27.80	–$137.90	–$509.90	–$462.19	–$137.90
	YH	$1,444.90	$597.50	–$103.60	$72.90	$107.51	–$103.60
	YS	$1,823.00	$781.00*	–$110.70	$451.00	$278.80*	–$110.70
Joint Infection	Average	$749.40	$28.40	–$102.00	–$622.60	–$461.50	–$102.00
	FHC	$403.00	–$202.95	–$112.90	–$968.90	–$692.90	–$112.90
	FSC	$562.50	–$73.21	–$82.70	–$809.40	–$563.20	–$82.70
	WHC	$673.90	–$64.40	–$106.80	–$698.00	–$554.40	–$106.80
	WSC	$833.10	$3.30	–$148.80	–$538.80	–$486.60	–$148.80
	YH	$1,491.80	$627.60	–$137.10	$119.80	$137.60	–$137.10
	YS	$1,746.40	$724.80*	–$146.80	$374.40	$233.90*	–$146.80
Lame No Swelling	Average	$334.50	–$196.90	–$854.60	–$1,037.40	–$686.90	–$856.60
	FHC	$332.40	–$241.80	–$893.50	–$1,039.60	–$731.80	–$893.50
	FSC	–$23.20	–$389.25	–$859.20	–$1,395.20	–$879.20	–$859.20
	WHC	$1,076.90	$132.70	–$935.50	–$295.00	–$357.30	–$935.50
	WSC	$712.60	$3.70	–$874.20	–$659.30	–$486.20	–$874.20
	YH	$1,405.70	$604.00	–$571.20	$33.70	$114.00	–$571.20
	YS	$1,662.00	$667.40	–$593.90	$290.00	$177.40	–$593.90

*Animals were > 453 kg at time of treatment and then railed; remaining animals were fed to 453 kg and then railed.

[1]All values in $CAN.

heavy cattle, and so, the net return was higher than healthy cattle after final treatment (Table 9). There was a loss of $667 in return if foot rot heavy cattle were railed after treatment instead of reaching an optimal slaughter weight of 635 kg.

Cattle diagnosed with injuries had a positive net return in every season, except in fall (Table 9). Cattle with injuries that were railed resulted in reduced positive net returns than cattle that were treated and had recovered, except in spring and fall, with a loss of $15 and $206,

Table 9. Estimated net return of cattle that recovered, were railed or died after final treatment with foot rot, foot rot heavy, injury, joint infections and lame with no visible swelling stratified by season of treatment based on the average slaughter and rail prices over the period 2005 to 2015 ($100/45.4 kg and $50/45.4 kg, respectively)

Diagnosis	Season of treatment	Final treatment[1]		
		Recovered	Railed	Died
Foot rot	Spring	$518.90	–$12.20*	–$572.20
	Summer	$528.20	$71.79*	–$488.20
	Fall	$655.20	$272.50*	–$227.40
	Winter	$419.20	$40.98	–$344.20
Foot rot Heavy	Spring	$694.90	$27.75*	–$627.20
Injury	Spring	$259.20	–$15.70	–$171.90
	Summer	$513.00	$244.90	–$395.40
	Fall	–$91.20	–$206.80	–$69.60
	Winter	$309.30	$18.40	–$170.80
Joint Infection	Spring	$278.10	–$30.70	–$266.20
	Summer	$334.10	$25.30	–$291.40
	Fall	–$1,299.10	–$880.50	–$61.80
	Winter	–$11.30	–$42.80	–$143.10
Lame No Swelling	Spring	$448.60	$133.90	–$717.80
	Summer	–$34.30	–$4.00	–$731.70
	Fall	–$1,587.80	–$1,042.00	–$864.80
	Winter	$37.20	–$173.00	–$847.10

*Animals were > 453 kg at time of treatment and then railed; remaining animals were fed to 453 kg and then railed.

[1]All values in $CAN.

respectively, in return. Cattle diagnosed with joint infections had a positive net return, except in fall and winter where the return was negative (Table 9). Cattle treated and recovered from being diagnosed as lame with no swelling had negative net returns in summer and fall (Table 9). However, spring was the only season with a reduced positive return for cattle that were lame with no visible swelling and railed after reaching 453 kg.

DISCUSSION

Lameness as diagnosed in the feedlot is a common and costly disorder. Lameness has been evaluated from datasets of multiple feedlots over a single year as well as from a single feedlot over multiple years (Griffin et al., 1993; Tibbetts et al., 2006). However, in this study, the objective was to estimate the economic impact of lameness on multiple feedlots over multiple years using decision tree models. Foot rot has been commonly diagnosed in feedlots across North America (Kruse et al., 2013). Initial and consecutive treatments for cattle correctly diagnosed with foot rot were beneficial for the animal and resulted in positive returns. Early detection of foot rot resulted in less effects on BW gain or days to reaching an optimal slaughter weight (Tibbetts et al., 2006). Furthermore, treating heavy cattle with foot rot near the end of the feeding period reflected positive returns. Cattle with lighter arrival weights between 258 and 285 kg, were negatively impacted by injuries, joint infections and lameness with no visible swelling. Retreating cattle with chronic cases of lameness that have been diagnosed, treated, and failed to recover may result in increased net losses. Fall and winter placed calves diagnosed with joint infections or lame with no visible swelling such as toe tip necrosis, will require additional preventative strategies such as quieter, low-stress handling during processing and earlier detection and administration of treatment therapy due to the fact that keeping and/or railing those animals at a marketable slaughter weight of a minimum 453 kg can both result in substantial economic losses. For cattle diagnosed with injuries, railing those animals resulted in increased losses compared to keeping the animal on feed until slaughter. Therefore, depending on the type of injury and the required treatment therapy, it is important to identify whether keeping or railing the animal is the most beneficial decision for the animal and for the producer. Heavier yearling cattle had lower overall costs, which allowed for a higher return after final treatment.

The most common cattle types with lighter arrival weights were fall and winter placed calves compared to yearling placed calves. Fall placed calves that were just weaned have been reported to be 16.1% more susceptible to disease than yearlings (11.6%; Hendrick and Abeysekara, 2014). Earlier lameness detection along with correct diagnosis and prompt treatment for fall and winter placed calves could improve recovery and allow calves to remain on feed. Calves that respond to treatment more quickly and remain on feed are more likely to finish to an optimal slaughter weight, therefore, reducing economic losses (Booker et al., 2006).

Cattle that were diagnosed as lame with no visible swelling were treated earlier in the feeding period with a median DOF at treatment of 26 d. The median DOF for cattle with injuries was 49 d after arrival to the feedlot. Injuries related to feedlot cattle are often misdiagnosed and can result from cattle handling, facility design, and management (Stokka et al., 2001). The median DOF at treatment for joint infections was 39 d and ranged between 37 and 62 DOF for all cattle types. Mean DOF at diagnosis for septic joints and upper limb lameness ranged from 44 to 110 d depending on the type and detection of joint infection (Hendrick and Abeysekara, 2014; Terrell et al., 2017). The majority of observations of foot rot was observed later in the feeding period (median DOF of 130 d at first treatment), which was similar to previous reporting of median DOF of 124 d for cattle with foot rot (Hendrick and Abeysekara, 2014).

The later DOF at diagnosis along with treatment and recovery from foot rot resulted in lower overall cost to finish cattle to the optimal slaughter weight of 635 kg.

This resulted in a $121 loss after final treatment per animal compared to a healthy animal. Cattle diagnosed and treated for cases with digital dermatitis or foot rot have accounted for smaller economic losses of $128/case ($USD; van Amstel and Shearer, 2006). Cattle with joint infections had the highest treatment costs ($25 at final treatment) compared to all other diagnoses, which is similar to previous findings that reported an average treatment cost of $23 ($CAN; Hendrick and Abeysekara, 2014). True joint infections or arthritis are often difficult to treat and the prognosis is poor, which can result in substantial economic losses (Radostits et al., 2007). The early DOF and low ADG at time of diagnosis had a negative impact on cost and overall return after final treatment for cattle diagnosed as lame with no visible swelling. On average, cattle diagnosed as lame with no visible swelling that completed the feeding period had a net loss of $700.

Weather conditions (e.g., spring and winter) increased the number of cattle diagnosed with foot rot. This was most likely due to wet and muddy pen conditions occurring when snow accumulated within pens melted quickly, particularly when there was rainfall (common during the spring). Wet conditions could increase spread of infectious bacteria, potentially invading the hoof to cause infection (Tibbetts et al., 2006; Greenough, 2007). Yearling cattle were more commonly treated for foot rot as heavier cattle are more prone to leg and foot injuries in muddy pen conditions (Radostits et al., 2007). Consequently, costs for cattle diagnosed and treated in spring were higher compared to fall. Fall had a negative impact on cattle diagnosed with injuries, joint infections and lameness with no visible swelling. Fall is the most common season where handling and vaccination of cattle occurs within the feedlot. Cattle that are treated earlier on arrival have the remaining feeding period to recover and finish to an optimal slaughter weight, therefore, increasing overall costs. The onset and duration of lameness in auction-derived feeder steer calves was observed immediately after vaccinations and handling up to 3 wk on feed (Green et al., 2012). Cases of toe tip necrosis have been reported to occur most commonly between September and December; early in the feeding period for fall placed cattle (Jelinski et al., 2016). Cattle that were diagnosed as lame with no visible swelling had the highest treatment costs in fall compared to all other seasons, having an impact on overall net return.

In our study, the cost of the calf was excluded from the net returns of the various models due to fluctuation in prices based on the situation that cattle are fed, such as being weaned or being kept on fed until a later period in the year. In addition, the rail slaughter price was a conservative estimate of 50% of the average, high, or low live cattle slaughter price. This will inform producers on the difference in returns for cattle that do not recover from treatment. It is difficult to market live cattle for slaughter < 453 kg, therefore, the models reflect a railing weight of 453 kg or greater. A study of 5 feedlots reported that lameness was the cause of 70% of all sales of non-performing cattle that were railed after treatment (Griffin et al., 1993). Consequently, the same study estimated that salvageable lame animals were only 53% of their original value. Profit margins for feedlot cattle are highly impacted by fluctuations in cattle prices (Crespi et al., 2010). High and low cattle slaughter prices had an impact on the average net return of cattle that were diagnosed and treated as lame. High cattle prices in 2015 resulted in higher returns for recovered cattle diagnosed with foot rot compared to healthy cattle. Extremely low cattle prices in 2009 resulted in large economic losses for cattle diagnosed with chronic cases of lameness that completed the feeding period.

There was limited literature providing specific lameness diagnosis information on the percentage of cattle commonly railed in the feedlot; therefore, values were obtained from 2 experienced experts in the feedlot industry that manage cattle in larger Alberta feedlots. We concluded that of all cattle treated for lameness, 13.00% of cattle with injuries were railed, along with 2.50% for joint infections and 6.80% for lameness with no visible swelling. A previous study reported that 11.00% of cattle diagnosed with upper-limb lameness were prematurely removed from feeding, along with 5.60% for toe and sole ulcer or abscesses, and 5.80% for septic joints (Terrell et al., 2017). In a survey of feedlots belonging to the Alberta Cattle Feeders Association, an average rail rate of 0.48% was reported for all diagnoses (Church and Radostits, 1981), comparable to the estimated railing rate of < 0.50% used in our study.

Quality of data input was a limitation of this study, as there were multiple feedlots and producers inputting data. The lame with no swelling category can include cattle likely affected by toe tip necrosis; currently a more commonly diagnosed disorder, as 0.01 to 1.30% of feedlot cattle could be affected (Gyan et al., 2015). The addition of this lameness category in the study may have caused wrongful classification of some lameness diagnoses (e.g., digital dermatitis). Therefore, recording cattle health characteristics and diagnosing may have been inconsistent. All records were retrieved from clients of VAHS and their recommendations for managing lame cattle may not fully represent what is occurring across Alberta or the North America feedlot industry, limiting external validity.

Feedlots in this study ranged in capacity from 800 to 20,000 head, with one feedlot contributing 78% of the total observations. Individual feedlots impacted results and may have created a bias due to feedlot-specific management protocols for treating lameness cases. Furthermore, omitted cattle types reduced the possibility of presenting the net return for differently managed cattle within a feedlot (e.g., pasture based or feeding mature cattle). Due to the fact that the study data was limited to 28 feedlots, caution is needed when information is extrapolated to the whole industry due to restricted external validity. Although, individual animals were recorded into the Medlogic program chute side, pen-based observations (e.g., outbreak of foot rot) could have been treated by administering medication into the feed, without being recorded in the Medlogic program, thereby resulting in an underestimate of actual occurrences of lameness. Furthermore, it is likely that not all observations of lameness were recorded within the dataset, as some observations were missed or simply not recorded.

Despite the limitations, this was one of the few studies dedicated to describing the economic impact of lameness by cattle type, season of treatment, and extreme cattle prices in southern Alberta feedlots. Retrospective data confirmed that there was limited impact on cattle diagnosed and treated with foot rot compared to cattle diagnosed and treated with injuries, joint infections, and lameness with no visible swelling. Lastly, body weight, environmental (wet) conditions, and season of arrival (e.g., fall) were factors that contributed to the economic impact on the animal within the feedlot. Therefore, implementing prevention and mitigation strategies such as earlier lameness detection and managing different cattle types accordingly may reduce the occurrence of lameness in feedlots. Further research is necessary to assess the total economic impact of lameness in feedlot cattle in feedlots, based on their specific management protocols. These results may provide management tools that more effectively mitigate the economic impact of lameness in feedlot cattle.

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