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Associations between management, climate, and *Escherichia coli* O157 in the faeces of feedlot cattle in the Midwestern USA☆

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Abstract

Our objective was to generate hypotheses for potential on-farm control strategies for *Escherichia coli* O157 by identifying associations between management practices and climate, and the presence of *E. coli* O157 in feedlot cattle. Faeces were obtained from 10,622 cattle in 711 pens on 73 feedlots between May and August 2001. Management and climate information was obtained by questionnaire and observation at the time of sampling. The prevalence of *E. coli* O157 was 10.2% at the sample level, 52.0% at the pen-level, and 95.9% at the feedlot-level. The factors associated with the presence of *E. coli* O157 in cattle faeces were the frequency of observing cats in the pens or alleys (most common when observed daily), the presence of *E. coli* O157 in the water tanks (positive association), the historical use of injectable mass medication (positive association), the use of antibiotics in the ration or water (negative association), the wetness of the pen, number of cattle in

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the pen (negative association), wind velocity (positive association), and height of the feed bunk (positive association).

Keywords: *E. coli* O157; Feedlot; Management; Climate; Associations

1. Introduction

Escherichia coli O157 is an important foodborne pathogen that has been estimated to cause 62,458 illnesses, 1843 hospitalizations, and 52 deaths annually in the US (Mead et al., 1999). Many cases of human illness have been traced to beef products or other food products and water contaminated with bovine faeces (Armstrong et al., 1996). A percentage of cattle shed *E. coli* O157 in their faeces (Galland et al., 2001; Hancock et al., 1997a; Chapman et al., 1993), although faecal shedding in individual cattle is transient (Shere et al., 1998; Besser et al., 1997; Rahn et al., 1997). *E. coli* O157 does not appear to cause clinical symptoms in cattle (Armstrong et al., 1996). Attempts to prevent exposure of humans to these bacteria encompass a ‘‘farm-to-fork’’ approach, with each component of the food industry attempting to control the pathogen. However, at the farm level, there is currently insufficient knowledge of potential risk factors for *E. coli* O157 to allow the design and implementation of effective control strategies. Previous studies in feedlot cattle have identified some management factors that might be associated with increased faecal shedding of the bacteria (Dargatz et al., 1997; Smith et al., 2001). However, the results have not been consistent across studies (Hancock et al., 1997b), or have not allowed for practical, effective control strategies to be proposed.

Over time, the reported prevalence of *E. coli* O157 in cattle has increased due (at least in part) to improved diagnostic procedures (Meyer-Broseta et al., 2001; Rasmussen and Casey, 2001). This can lead to reduced misclassification and increased statistical power to identify risk factors in epidemiological studies. Therefore, our objective was to use sensitive culture techniques to investigate associations between management and climate factors, and *E. coli* O157 in feedlot cattle close to market weight, to generate hypotheses for on-farm control strategies.

2. Materials and methods

2.1. Feedlot selection and sample collection

The study group consisted of commercial feedlots located in Kansas, Nebraska, Texas, and Oklahoma, USA. Complete details of feedlot selection, sample collection, and laboratory methods have been described previously (Sargeant et al., 2003). Briefly, feedlot owners were identified by extension persons and feedlot veterinarians, and feedlots were selected from this group based on willingness to participate. Each feedlot was visited once between May and August 2001. A total of up to 10 pens, within ~1 month of finishing and on the final finishing ration, were selected for sampling. If <10 pens met this criterion, all eligible pens were selected. If >10 pens met this criterion, the 10 pens closest to anticipated market date were selected. In each selected pen, 15 faecal samples were collected from individual cattle observed to defecate and three water samples were obtained from a single water tank. Following collection of the water samples, two water-tank-sediment samples were collected from the same water tank by scraping the sides of the tank with a putty knife and storing the sediment in a small amount of the tank water. If there was more than one water tank within a pen, the tank nearest to the feed bunk was selected for sampling. The samples were stored on ice following collection and during transportation to a single laboratory at Kansas State University. Sample processing began within 24 h of collection.

2.2. Identification of E. coli O157 in faeces and water

For each faecal sample, 1 g of faeces was added to 9 ml of Gram-negative broth containing 0.05 μg/ml cefixime, 10 μg/ml cefsulodin, and 8 μg/ml vancomycin, and incubated at 37 °C for 6 h. Following incubation, samples were vortexed and 1 ml was transferred to a microcentrifuge tube containing 20 μl Dynabeads (Dynal Inc., Lake Success, NY) for immunomagnetic separation (IMS), as per manufacturer recommendation. Fifty microliters of separated sample was spread onto Sorbitol–McConkey agar supplemented with cefixime and sodium tellurite (CT–SMAC) and incubated for 18 h at 37 °C. Following incubation on CT–SMAC, up to six non-sorbital fermenting colonies with morphology typical of *E. coli* O157 were transferred to blood agar plates and incubated for 18–24 h at 37 °C. After incubation, indole testing was performed. Indole-positive colonies were tested for O157 latex agglutination (Oxoid, Basingstoke, Hampshire, UK). Colonies positive for agglutination were confirmed as *E. coli* by Rapid A.P.I. tests (bioMerieux, Hazelwood, MO).

Water and water–sediment samples were vortexed and then 5 ml of water or sediment–water mix were added to 5 ml double-strength Tryptic Soy Broth (Difco, Detroit, MI) and incubated at 44 °C for 24 h. Following incubation, 1 ml was transferred to a microcentrifuge tube containing 20 μl Dynabeads (Dynal Inc., Lake Success, NY) for IMS. After IMS, the culture process followed the procedures outlined above for faecal culture.

2.3. Management and ancillary data collection

Management information was obtained by use of a questionnaire. The questions pertained to feedlot and cattle demographics, health-management practices, feed components and storage, wildlife management, and pen and water management. The questionnaire was administered face-to-face with the feedlot owner or manager by one of six field-sampling persons at the time of the sampling visit. Depending on the nature of the question, the information was obtained at the feedlot-level or at the pen-level for each pen. The questions were primarily closed, with an inclusive and mutually exclusive list of responses provided. The producers were asked to select the most-appropriate answer from the available responses, or to answer yes or no to each choice. To ensure that questions were inclusive, some questions offered the chance to respond as ‘‘other, please specify’’. Several of the questions consisted of two parts, wherein the second part of the question was asked of a sub-group of the respondents to obtain more detail on a specific response.

A second part of the questionnaire was completed by the feedlot samplers and consisted of pen-level observations and measurements, and climate information. Water pH was tested using a hand-held pH meter (pHep®3, Hanna Instruments, Woonsocket, RI) in each of the water tanks sampled for *E. coli* O157. Weather conditions at the start of sampling at each feedlot visit were recorded as sunny, partly cloudy, mostly cloudy, light rain, or heavy rain. Temperature, humidity, and heat index were calculated at the start of sampling at each feedlot visit using a hand-held weather meter (Kestrel 3000, Nielsen-Kellerman, Chester, PA). Heat index was provided automatically by the weather meter, using a regression function which combines information on temperature and humidity (the standard heat-index formula may be viewed at http://www.srh.noaa.gov/bmx/tables/hindex.html). Using the same instrument, the average wind speed over a 30 s period was measured in the feed-bunk area of each pen. The date of the last precipitation prior to the sampling date, and the total amount of precipitation during the previous week, were obtained at the five-digit zip-code level after the sampling visit using web-based information (http://www.wunderground.com/).

The questionnaire was pre-tested on four individuals familiar with feedlot management and the feedlot industry. The wording of several questions was modified based on their suggestions. A copy of the questionnaire is available on request from the first author.

2.4. Statistical analysis

Prevalence of *E. coli* O157 in faecal samples was defined at the individual-sample, pen, and feedlot-levels. A positive pen was defined as a pen with one or more faecal samples positive for *E. coli* O157, and a positive feedlot was defined as a feedlot with one or more positive faecal samples. Multiple water and water–sediment samples were collected from a single water tank to increase the sensitivity to detect *E. coli* O157 if present. Therefore, prevalence of *E. coli* O157 in water tanks was not described at the individual-sample level. The same definitions were used with the water and water–sediment samples to define a positive pen or feedlot.

Associations between *E. coli* O157 in faeces and management characteristics were determined using generalized linear models for analyses of feedlot factors, pen factors, climate factors, and all factors combined. The outcome for each group of factors was a binary variable corresponding to the presence or absence of *E. coli* O157 in each faecal sample. For each analysis, a series of steps was used to create the generalized linear models. Initially, univariable associations between *E. coli* O157 and each of the management variables were performed as a screening step. To test the assumption of constancy of odds ratios for continuous variables, each continuous variable was categorized by quartiles and tested as a categorical variable (Hosmer and Lemeshow, 1989). If there was evidence of non-linearity (quartile-variable effects non-linear over quartile intervals), then the factor was assessed using the quartile-variable coding. Otherwise, the factor was offered as a continuous variable. Factors which were associated significantly with the outcome at $p < 0.2$ were considered for further analysis. These variables were offered into a logistic-regression model (Proc Logistic, SAS Version 8.0, SAS Institute Inc., Cary, NC) using a forward-stepwise approach with a p-value of <0.2 to enter and a p-value of ≤ 0.05 to remain. The variables selected in the stepwise logistic-regression models were included in a generalized linear model with pen and feedlot controlled as random variables (Proc Glimmix, SAS Version 8.0, SAS Institute Inc., Cary, NC). Initially, all of the selected variables were entered. Variables were removed using a backward-selection approach until all variables remaining in the mixed effect models were significant at $p \leq 0.05$. For clarity in the modeling steps and interpretation of results, all significance testing was two-sided. No interactions were tested.

To check for collinearity, associations (two-sided p-value <0.05) between factors in the final model containing feedlot, pen, and climate factors and independent variables that passed the initial screening and were significant at $p < 0.2$ in univariable associations with the feedlot effect controlled but were not included in the final model were examined using chi-square, correlation coefficient, and Spearman's correlation for binary and nominal variables, continuous variables, and ordinal variables, respectively. The direction of significant associations was provided for comparisons between continuous variables and comparisons between ordinal variables.

3. Results

Faecal samples ($n = 10{,}662$) were collected from 711 pens on 73 feedlots. Complete details of the prevalence and distribution of *E. coli* O157 are available elsewhere (Sargeant et al., 2003). Briefly, 10.2% of the individual faecal samples were positive for *E. coli* O157, with 95.9% of feedlots and 52.0% of pens having at least one positive faecal sample. The percentage of positive samples per pen ranged from 0 to 93.3%, and the percentage of positive pens per feedlot ranged from 0 to 100%. Thirteen percent of the pens and 60% of the feedlots had at least one water or water–sediment sample positive for *E. coli* O157.

Descriptive statistics, stratified by *E. coli* O157 status, for the herd- and pen-level variables obtained from primary questions and the climatic factors are included in Tables 1–3. All feedlots reported that they routinely cleaned water tanks, and therefore, the secondary questions for this management factor also are included. None of the pen rations contained barley, re-constituted grains, wheat, or chicken waste at the time of sampling.

In the regression analyses of herd-level variables only, variables from 71 feedlots were included; the remaining two feedlots had missing data for many of the variables. In the final multivariable herd-level model which controlled for multiple samples at the feedlot and pen-levels, month of sampling and the frequency with which stray cats were seen in the pen or alley area were associated with the presence of *E. coli* O157 in cattle faeces (Table 4). The highest prevalence of *E. coli* O157 was associated with stray cats observed in the pens or alleys at least daily. However, the relationship did not decrease monotonically.

Data were available for inclusion in the regression models of pen-level variables only for 701 of the 711 pens sampled (Table 5). The remaining pens were from a feedlot that changed ownership prior to marketing. There were positive associations between *E. coli* O157 in faeces and the presence of *E. coli* O157 in the water tank, the addition of new cattle to the pen during the feeding period, the use of injectable mass medication, wind velocity, and the height of the feed bunk. *E. coli* O157 was associated negatively with treatment for external parasites and the number of cattle in the pen. There was a significant association with pen condition. However, the relationship was not monotonic in either direction;

Table 1
Descriptive statistics for feedlot-level management factors obtained by survey from 71 feedlots in four states in the US between May and August 2001, stratified by feedlot-level *E. coli* O157 status

Variable	#Feedlots per category and (number samples positive/total number of samples) (categorical variables) or #feedlots and value for each quartile (continuous variables)	
	Faecal-positive feedlots[a]	Faecal-negative feedlots
Feedlot demographics		
Month of sampling[b]		
May	12 (336/1769)	1 (150)
June	21 (285/3118)	1 (150)
July	27 (404/3898)	1 (75)
August	8 (55/1202)	0
State where sampled[b]		
Kansas	30 (381/4499)	0
Nebraska	17 (359/2340)	3 (375)
Oklahoma	9 (196/1348)	0
Texas	12 (144/1800)	0
#On-feed, past 12 months[b]	68 (25,750; 46,300; 76,560)	3 (14,000; 30,000; 32,000)
#Marketed, past 12 months ($n = 69$)[b]	66 (24,750; 45,300; 75,000)	3 (14,000; 30,000; 32,000)
Same holding pens for receiving and shipping		
Yes	61 (961/8968)	1 (150)
No	7 (119/1019)	2 (225)
#Pens on site ($n = 70$)[b]	67 (114; 180; 276)	3 (44; 90; 150)
%Pens occupied on day of visit[b]	68 (85; 90; 99)	3 (90; 90; 90)
#Cattle on site on day of visit ($n = 70$)[b]	67 (11,500; 20,000; 32,715)	3 (6800; 17,000; 21,000)
Acreage of feedlot[b]	68 (160; 300; 473)	3 (400; 480; 640)
Health management		
Treat sick cattle in hospital pens (hold 24+ h)[b]		
Always	51 (858/7440)	3 (375)
Usually	15 (212/2247)	0
Sometimes	2 (10/300)	0
Never	0	0
Treat sick cattle in hospital pens and return to pen[b]		
Always	0	0
Usually	1 (11/150)	0
Sometimes	27 (377/4047)	0
Never	40 (692/5790)	3 (375)
Treat sick cattle in home pen or alley[b]		
Always	0	0
Usually	1 (28/149)	0
Sometimes	21 (357/3148)	0
Never	46 (695/6690)	3 (375)

Table 1 (*Continued*)

Variable	#Feedlots per category and (number samples positive/total number of samples) (categorical variables) or #feedlots and value for each quartile (continuous variables)	
	Faecal-positive feedlots[a]	Faecal-negative feedlots
Feed management		
Method of storage of mineral supplements[b]		
Bags	12 (142/1800)	0
Sealed containers/bins	47 (711/6838)	3 (375)
Uncovered bunks/pits	0	0
Covered bunks/pits	3 (81/449)	0
Not applicable	6 (146/900)	0
Method of storage of protein supplements[b]		
Bags	0	0
Sealed containers/bins	64 (1039/9388)	3 (375)
Uncovered bunks/pits	1 (1/150)	0
Covered bunks/pits	3 (40/449)	0
Not applicable	0	0
Method of storage of fat supplements[b]		
Bags	0	0
Sealed containers/bins	55 (779/8202)	2 (225)
Uncovered bunks/pits	0	0
Covered bunks/pits	1 (18/150)	0
Not applicable	12 (283/1635)	1 (150)
Method of storage of feed additives[b]		
Bags	15 (258/2248)	0
Sealed containers/bins	50 (796/7289)	3 (375)
Uncovered bunks/pits	0	0
Covered bunks/pits	1 (18/150)	0
Not applicable	2 (8/300)	0
Method of storage of energy concentrates[b]		
Bags	1 (3/150)	0
Sealed containers/bins	49 (762/7140)	3 (375)
Uncovered bunks/pits	1 (33/150)	0
Covered bunks/pits	12 (236/1797)	0
Not applicable	5 (46/750)	0
Method of storage of roughage[b]		
Bags	0	0
Sealed containers/bins	1 (18/150)	0
Uncovered bunks/pits	17 (191/2548)	0
Covered bunks/pits	49 (851/7139)	3 (375)
Not applicable	1 (20/150)	0
Method of feeding[b]		
Ad libitum	2 (66/300)	0
Slick bunk	40 (677/5788)	3 (375)
Program feeding	8 (74/1198)	0
Bunk scoring	18 (263/2701)	0

Table 1 (*Continued*)

Variable	#Feedlots per category and (number samples positive/total number of samples) (categorical variables) or #feedlots and value for each quartile (continuous variables)	
	Faecal-positive feedlots[a]	Faecal-negative feedlots
Same machinery used for feeding/cleaning?		
Yes	11 (170/1545)	0
No	57 (910/8442)	3 (375)
Water management		
Are water tanks routinely cleaned?		
Yes	68 (1080/9987)	3 (375)
No	0	0
Frequency of water tank cleaning	68 (3.5; 7; 7)	3 (7; 10; 10)
Method of water tank cleaning		
Chlorine		
Yes	1 (18/150)	0
No	67 (1062/9837)	3 (375)
Empty and re-fill[b]		
Yes	27 (486/3840)	3 (375)
No	41 (594/6147)	0
Scrubbed while full		
Yes	31 (518/4439)	3 (375)
No	37 (562/5548)	0
Scrubbed while empty[b]		
Yes	64 (1044/9389)	3 (375)
No	4 (36/598)	0
Biosecurity practices		
Restriction of people onto feedlot[b]		
Yes	38 (656/5491)	3 (375)
No	30 (424/4496)	0
Restriction of horses onto feedlot		
Yes	42 (693/6088)	3 (375)
No	26 (387/3899)	0
Method of fly control		
Manure removal		
Yes	68 (1080/9987)	3 (375)
No	0	0
Predatory insects		
Yes	34 (466/5099)	0
No	34 (614/4888)	3 (375)
Insecticide ear tags[b]		
Yes	5 (47/750)	0
No	63 (1033/9237)	3 (375)
Environmental sprays		
Yes	51 (769/7468)	1 (75)

Table 1 (*Continued*)

Variable	#Feedlots per category and (number samples positive/total number of samples) (categorical variables) or #feedlots and value for each quartile (continuous variables)	
	Faecal-positive feedlots[a]	Faecal-negative feedlots
No	17 (311/2519)	2 (300)
Animal sprays, powder, pour-on[b]		
Yes	16 (293/2397)	0
No	52 (787/7590)	3 (375)
Larvalcide feed additives[b]		
Yes	1 (3/150)	0
No	67 (1077/9837)	3 (375)
Fly traps		
Yes	19 (313/2834)	1 (75)
No	49 (767/7153)	2 (300)
Fly bait[b]		
Yes	57 (878/8340)	3 (375)
No	11 (202/1647)	0
Frequency of vermin seen in pens/alleys		
Dogs, foxes, coyotes[b]		
At least daily	5 (73/750)	0
At least weekly	13 (254/1918)	0
At least monthly	3 (49/450)	2 (300)
Occasionally	37 (592/5368)	1 (75)
Never	10 (112/1501)	0
Stray cats[b]		
At least daily	10 (282/1499)	0
At least weekly	6 (23/900)	0
At least monthly	6 (42/899)	0
Occasionally	28 (532/3989)	3 (375)
Never	18 (201/2700)	0
Deer, elk[b]		
At least daily	0	0
At least weekly	0	0
At least monthly	4 (109/570)	2 (225)
Occasionally	22 (363/3120)	1 (150)
Never	42 (608/6297)	0
Rodents[b]		
At least daily	24 (439/3434)	3 (375)
At least weekly	20 (355/2953)	0
At least monthly	6 (68/902)	0
Occasionally	17 (212/2549)	0
Never	1 (6/149)	0
Small mammals (e.g. raccoons)[b]		
At least daily	10 (158/1503)	1 (75)
At least weekly	27 (494/3942)	1 (150)
At least monthly	7 (78/1050)	0
Occasionally	21 (322/3043)	1 (150)

Table 1 (*Continued*)

Variable	#Feedlots per category and (number samples positive/total number of samples) (categorical variables) or #feedlots and value for each quartile (continuous variables)	
	Faecal-positive feedlots[a]	Faecal-negative feedlots
Never	3 (28/449)	0
Birds[b]		
At least daily	58 (979/8489)	3 (375)
At least weekly	5 (66/750)	0
At least monthly	1 (15/150)	0
Occasionally	4 (20/598)	0
Never	0	0
Aggressiveness of control measures in pens, alleys		
Dogs, foxes, coyotes[b]		
Aggressive	12 (178/1799)	0
Moderate	9 (85/1275)	1 (75)
Minimal	27 (480/3913)	2 (300)
No control	3 (64/449)	0
Not considered a problem	17 (273/2551)	0
Stray cats[b]		
Aggressive	3 (25/449)	0
Moderate	1 (3/150)	0
Minimal	20 (394/2789)	2 (225)
No control	11 (154/1649)	1 (150)
Not considered a problem	33 (504/4950)	0
Deer, elk[b]		
Aggressive	1 (7/149)	0
Moderate	1 (11/150)	0
Minimal	0	0
No control	26 (460/3688)	3 (375)
Not considered a problem	40 (602/6000)	0
Rodents[b]		
Aggressive	48 (767/7063)	3 (375)
Moderate	10 (120/1500)	0
Minimal	8 (142/1125)	0
No control	2 (51/299)	0
Not considered a problem	0	0
Small mammals (e.g. raccoons)[b]		
Aggressive	13 (146/1873)	0
Moderate	6 (105/900)	0
Minimal	27 (477/3913)	3 (375)
No control	8 (115/1202)	0
Not considered a problem	14 (237/2099)	0
Birds[b]		
Aggressive	9 (133/1350)	0
Moderate	26 (477/3688)	3 (375)
Minimal	8 (87/1203)	0
No control	19 (300/2847)	0
Not considered a problem	6 (83/899)	0

Table 1 (*Continued*)

Variable	#Feedlots per category and (number samples positive/total number of samples) (categorical variables) or #feedlots and value for each quartile (continuous variables)	
	Faecal-positive feedlots[a]	Faecal-negative feedlots
Frequency of vermin seen in feed-storage areas		
Dogs, foxes, coyotes[b]		
At least daily	1 (16/150)	0
At least weekly	2 (51/299)	0
At least monthly	2 (80/300)	0
Occasionally	22 (438/3089)	3 (375)
Never	41 (495/6149)	0
Stray cats[b]		
At least daily	6 (106/899)	0
At least weekly	4 (32/600)	0
At least monthly	5 (98/675)	1 (75)
Occasionally	30 (597/4361)	2 (300)
Never	23 (247/3452)	0
Deer, elk[b]		
At least daily	0	0
At least weekly	1 (21/150)	0
At least monthly	0	0
Occasionally	21 (441/2939)	3 (375)
Never	46 (618/6898)	0
Rodents[b]		
At least daily	24 (502/3433)	3 (375)
At least weekly	15 (226/2205)	0
At least monthly	4 (61/600)	0
Occasionally	20 (243/3000)	0
Never	5 (48/749)	0
Small mammals (e.g. raccoons)[b]		
At least daily	3 (19/449)	0
At least weekly	10 (234/1498)	0
At least monthly	8 (162/1155)	1 (75)
Occasionally	26 (444/3737)	2 (300)
Never	21 (221/3148)	0
Birds[b]		
At least daily	35 (680/5038)	3 (375)
At least weekly	7 (104/1049)	0
At least monthly	3 (82/449)	0
Occasionally	14 (121/2098)	0
Never	9 (93/1353)	0
Aggressiveness of control in feed-storage areas		
Dogs, foxes, coyotes[b]		
Aggressive	6 (62/899)	0
Moderate	2 (21/225)	1 (75)
Minimal	21 (446/3014)	2 (300)
No control	6 (127/899)	0
Not considered a problem	33 (424/4950)	0

Table 1 (*Continued*)

Variable	#Feedlots per category and (number samples positive/total number of samples) (categorical variables) or #feedlots and value for each quartile (continuous variables)	
	Faecal-positive feedlots[a]	Faecal-negative feedlots
Stray cats[b]		
Aggressive	2 (14/299)	0
Moderate	2 (30/300)	0
Minimal	19 (416/2639)	2 (225)
No control	12 (185/1799)	1 (150)
Not considered a problem	33 (435/4950)	0
Deer, elk[b]		
Aggressive	3 (25/449)	0
Moderate	0	0
Minimal	1 (21/150)	0
No control	20 (427/2789)	3 (375)
Not considered a problem	44 (607/6599)	0
Rodents[b]		
Aggressive	50 (829/7289)	3 (375)
Moderate	8 (108/1200)	0
Minimal	3 (50/450)	0
No control	3 (53/448)	0
Not considered a problem	4 (40/600)	0
Small mammals (e.g. raccoons)[b]		
Aggressive	6 (57/899)	0
Moderate	8 (163/1200)	0
Minimal	22 (461/3089)	3 (375)
No control	6 (62/898)	0
Not considered a problem	26 (337/3901)	0
Birds[b]		
Aggressive	8 (137/1200)	0
Moderate	25 (497/3538)	3 (375)
Minimal	6 (110/900)	0
No control	16 (229/2397)	0
Not considered a problem	13 (107/1952)	0
Environmental management		
Use of permanent sprinklers for dust control ($n = 70$)		
Yes	12 (187/1800)	0
No	55 (888/8037)	3 (375)
Use of mobile sprinklers for dust control ($n = 70$)		
Yes	28 (427/4196)	0
No	39 (648/5641)	3 (375)
Use of mechanical scrapers for dust control ($n = 70$)[b]		
Yes	56 (264/7712)	2 (225)
No	11 (811/2125)	1 (150)
Increased cattle density for dust control ($n = 70$)[b]		
Yes	39 (681/5666)	3 (375)
No	28 (394/4171)	0

Table 1 (*Continued*)

Variable	#Feedlots per category and (number samples positive/total number of samples) (categorical variables) or #feedlots and value for each quartile (continuous variables)	
	Faecal-positive feedlots[a]	Faecal-negative feedlots
Removal of manure during feeding period		
Yes	49 (777/7135)	3 (375)
No	19 (303/2852)	0
Manure disposal (%)		
Applied to land	68 (0; 15; 79)	3 (0; 50; 100)
Sold	68 (0; 0; 0)	3 (0; 0; 0)
Given away	68 (0; 20; 94)	3 (0; 50; 100)
Paying for removal	68 (0; 0; 0)	3 (0; 0; 0)
Manure stored on feedlot premises ($n = 70$)[b]		
Yes	56 (1005/8188)	3 (375)
No	11 (70/1649)	0
Use of lagoons ($n = 70$)		
Yes	67 (1075/9837)	3 (375)
No	0	0
Use of berms ($n = 70$)[b]		
Yes	59 (964/8637)	3 (375)
No	8 (111/1200)	0
Use of fencing ($n = 70$)[b]		
Yes	28 (321/4124)	2 (225)
No	39 (754/5713)	1 (150)

[a] At least one faecal sample positive for *E. coli* O157.
[b] Significant in univariable statistics at $p < 0.2$, and therefore, offered into final stepwise model.

compared to dry pens, there was a positive association with the presence of mud below the fetlocks, but a negative association with the presence of mud above the fetlocks.

In the model of climate factors (with feedlot and pen-within-feedlot controlled), there was a negative association between heat index and the number of days since the previous rainfall and the presence of *E. coli* O157 in cattle faeces. For each degree-centigrade increase in heat index, the odds ratio of *E. coli* O157 was 0.95 (95% CI = 0.92, 0.99; $p = 0.02$). For each day increase in the number of days since the last recorded rainfall, the odds ratio was 0.94 (0.90, 0.99; $p = 0.02$). The model deviance was 4405 with 9109 d.f.

In the final model containing feedlot, pen, and climate factors, there were significant associations between the presence of *E. coli* O157 in faeces and the frequency with which cats were seen in the pens or alleys, the presence of *E. coli* O157 in the water tank (positive association), the use of injectable mass medication (positive), the use of antibiotics in the ration or water (negative), the wetness of the cattle within pens, the number of cattle in the pen at the time of sampling (negative), wind velocity (positive), and the height of the feed bunk from the surface on which the cattle stood to eat (positive) (Table 6). Statistical associations between variables in the final model and screened variables that were significant at $p < 0.2$ in univariable statistics with the feedlot effect controlled are in

Table 2
Descriptive statistics for pen-level management factors in 701 pens in 72 feedlots sampled in four states in the US between May and August 2001, stratified by pen-level *E. coli* O157 status

Variable	Number of observations	#Pens per category and (number samples positive/total number of samples) (categorical variables) or #pens and value for each quartile (continuous variables)	
		Faecal-positive pens[a]	Faecal-negative pens
Demographic information			
Month of cattle entry[c]	677		
January		113 (369/1694)	95 (1423)
February		70 (173/1049)	51 (765)
March		51 (118/765)	64 (960)
April		15 (30/224)	31 (465)
May		5 (6/75)	15 (228)
June		0	0
July		1 (2/15)	0
August		1 (3/15)	2 (30)
September		2 (28/30)	2 (30)
October		13 (35/195)	5 (75)
November		21 (63/315)	25 (375)
December		58 (214/870)	37 (554)
Days on feed[c]	676	350 (127; 151; 182)	326 (123; 144; 177)
New additions during production[c]	678		
Yes		30 (107/450)	19 (285)
No		320 (934/4797)	309 (4635)
Average arrival weight[c]	657	342 (631; 693; 770)	315 (645; 712; 801)
Were cattle from a single source[c]	689		
Yes		133 (357/1993)	130 (1951)
No		213 (678/3194)	186 (2789)
Don't know		11 (14/165)	16 (240)

Source of majority of cattle[b]	658		
Kansas		52 (121/779)	65 (975)
SE USA		73 (215/1095)	38 (570)
Midwest USA		106 (356/1590)	97 (1455)
SW USA		92 (270/1378)	93 (1395)
Western USA		13 (37/195)	11 (165)
Far West USA		0	0
Mexico		2 (4/30)	4 (60)
Canada		0	0
Other		8 (32/120)	4 (60)
Health management			
Did the cattle receiveInitial vaccination for respiratory disease[c]	691		
Yes		357 (1050/5352)	333 (4995)
No		1 (3/15)	0
Re-vaccination for respiratory disease[c]	691		
Yes		206 (691/3088)	171 (2567)
No		152 (362/2279)	162 (2428)
Initial vaccination for clostridial disease[c]	691		
Yes		294 (881/4407)	267 (4005)
No		64 (172/960)	66 (990)
Re-vaccination for clostridial disease[c]	691		
Yes		115 (391/1724)	83 (1245)
No		243 (662/3643)	250 (3750)
Treatment for external parasites[c]	691		
Yes		355 (1031/5322)	333 (4995)
No		3 (22/45)	0
Treatment for internal parasites[c]	691		
Yes		355 (1050/5322)	326 (4890)
No		3 (3/45)	7 (105)
Implants[c]	691		
Yes		350 (1044/5247)	320 (4800)
No		8 (9/120)	13 (195)

Table 2 (*Continued*)

Variable	Number of observations	#Pens per category and (number samples positive/total number of samples) (categorical variables) or #pens and value for each quartile (continuous variables)	
		Faecal-positive pens[a]	Faecal-negative pens
Second implants[c]	691		
Yes		298 (924/4467)	248 (3717)
No		60 (129/900)	85 (1279)
Metaphylaxis (injectable)[c]	679		
Yes		57 (175/855)	20 (300)
No		294 (867/4407)	308 (4620)
Antibiotics in ration/water at any time during production[c]	689		
Yes		160 (423/2398)	167 (2507)
No		197 (626/2954)	165 (2473)
Ionophores used at any time during production[c]	680		
Yes		346 (1022/5187)	314 (4710)
No		5 (6/75)	15 (225)
Water management			
Source of cattle drinking water[c]	691		
Municipal		3 (3/45)	7 (105)
Well		355 (1050/5322)	326 (4890)
Tank water chlorinated[c]	681		
Yes		18 (41/270)	14 (210)
No		337 (1009/5052)	312 (4680)
Days since water tank cleaned	669	350 (2; 5; 7)	319 (2; 4; 7)
#Water tanks/pen	701	361 (1; 1; 1)	340 (1; 1; 1)
Tank space accessible (linear inches)[c]	700	360 (96, 132, 176)	340 (102; 150; 184)
Volume of water per tank (cubic inches)[c]	701	361 (6756; 11457; 21,600)	340 (7843; 12,274; 21,600)

Height of tank from pen surface (in.)[c]	701	361 (22; 24; 26)	340 (22; 24; 25)
Water temperature 1 in. below surface (°C)[c]	700	360 (16; 19; 20)	340 (17; 19; 21)
Water temperature at tank bottom (°C)[c]	700	360 (16; 19; 20)	340 (17; 19; 21)
pH of water	670	340 (7.1; 7.4; 7.7)	330 (7.0; 7.3; 7.7)
Bottom of tank visible from surface[c]	700		
Yes		333 (932/4992)	335 (5025)
No		27 (123/405)	5 (75)
E. coli O157 in water[c]	700		
Yes		76 (310/1140)	15 (225)
No		284 (745/4257)	325 (4875)
Feed information			
Components in current ration			
Energy			
Corn[c]	691		
Yes		351 (1046/5263)	329 (4935)
No		7 (7/104)	4 (60)
Milo/sorghum[c]	691		
Yes		6 (7/90)	4 (60)
No		352 (1046/5277)	329 (4935)
Other energy concentrate	691		
Yes		30 (63/449)	12 (180)
No		328 (990/4918)	321 (4815)
Protein			
Canola meal[c]	691		
Yes		9 (13/135)	11 (165)
No		349 (1040/5232)	322 (4830)
Cotton seed: whole[c]	691		
Yes		12 (22/180)	8 (120)
No		346 (1031/5187)	325 (4875)
Cotton seed: meal	691		
Yes		53 (147/795)	47 (708)

Table 2 (*Continued*)

Variable	Number of observations	#Pens per category and (number samples positive/total number of samples) (categorical variables) or #pens and value for each quartile (continuous variables)	
		Faecal-positive pens[a]	Faecal-negative pens
No		305 (906/4572)	286 (4287)
Urea[c]	691		
Yes		124 (286/1858)	136 (2041)
No		234 (767/3509)	197 (2954)
Soybean meal[c]	691		
Yes		115 (279/1723)	95 (1426)
No		243 (774/3644)	238 (3569)
Liquid protein[c]	691		
Yes		175 (608/2624)	147 (2204)
No		183 (445/2743)	186 (2791)
Other protein source[c]	691		
Yes		73 (272/1093)	48 (720)
No		285 (781/4274)	285 (4275)
Roughage			
Alfalfa/sorghum hay[c]	691		
Yes		336 (1008/5037)	290 (4350)
No		22 (45/330)	43 (645)
Alfalfa/sorghum silage[c]	691		
Yes		21 (43/315)	39 (584)
No		337 (1010/5052)	294 (4411)
Corn silage[c]	691		
Yes		184 (615/2758)	127 (1904)
No		174 (438/2609)	206 (3091)
Cotton seed hulls	691		
Yes		35 (96/524)	31 (465)

No		323 (957/4843)	302 (4530)
Other roughage	691		
Yes		36 (101/540)	24 (360)
No		322 (952/4827)	309 (4635)
Byproducts			
Beet pulp	691		
Yes		0	1 (15)
No		358 (1053/5367)	332 (4980)
Corn gluten	691		
Yes		41 (114/614)	39 (585)
No		317 (939/4753)	294 (4410)
Potato waste[c]	691		
Yes		3 (4/45)	8 (120)
No		355 (1049/5322)	325 (4875)
Tallow/grease[c]	691		
Yes		223 (627/3342)	226 (3390)
No		135 (426/2025)	107 (1605)
Wheat fines/midds	691		
Yes		44 (109/660)	26 (390)
No		314 (944/4707)	307 (4605)
Brewer's grain/malt/Distillers[c]	691		
Yes		87 (234/1303)	83 (1248)
No		271 (819/4064)	250 (3747)
Other byproducts	691		
Yes		81 (214/1214)	59 (884)
No		277 (839/4153)	274 (4111)
Hours since last feeding[c]	449	228 (1.2; 3; 4.3)	221 (1.5; 2.5; 3.9)
Dry matter% of current ration[c]	682	355 (73; 76; 80)	327 (75; 77; 80)
Probiotics currently used	691		
Yes		134 (389/2008)	123 (1847)
No		224 (664/3359)	210 (3148)

Table 2 (*Continued*)

Variable	Number of observations	#Pens per category and (number samples positive/total number of samples) (categorical variables) or #pens and value for each quartile (continuous variables)	
		Faecal-positive pens[a]	Faecal-negative pens
Days since ration change	448	230 (55; 108; 143)	218 (55; 91; 133)
Bunk space (square feet per head)	639	300 (0.39; 0.48; 0.57)	339 (0.40; 0.49; 0.64)
Height of bunk from pen surface (inches)[c]	701	361 (18; 20; 21)	340 (17; 20; 21)
Feed temperature 1 in. below surface (°C)[c]	681	352 (16; 28; 33)	329 (19; 29; 35)
Eating surface of bunk[c]	701		
Concrete (rough)		353 (1035/5292)	338 (5070)
Concrete (sealed)		0	0
Plastic/rubber		0	0
Other		8 (22/120)	2 (30)
Pen and cattle characteristics			
Cattle density (ft^2/head)[c]	646	340 (192; 253; 332)	306 (189; 243; 313)
Number of cattle in pen[c]	647	341 (70; 103; 149)	306 (77; 119; 181)
Primary breed[c]	701		
British/Brit. cross		149 (446/2234)	137 (2054)
Continental/Cont. cross		193 (554/2893)	188 (2821)
Brahman cross (low%)		4 (8/60)	11 (165)
Brahman cross (high%)		2 (12/30)	2 (30)
Dairy		12 (36/180)	2 (30)
Other		1 (1/15)	0
Wetness of pen[c]	701		
Cattle dry		257 (663/3852)	292 (4381)
Mud/manure below		103 (395/1545)	45 (674)
Fetlock of cattle			

Mud/manure above fetlock of cattle		1 (1/15)	3 (45)
Windbreaks provided[c]	700		
Yes		17 (49/255)	6 (90)
No		344 (1008/5157)	333 (4995)
Shade provided[c]	700		
Yes		7 (23/105)	2 (30)
No		354 (1034/5307)	337 (5055)
Sprinklers provided[c]	700		
Yes		40 (118/600)	21 (315)
No		321 (939/4812)	318 (4770)
Mounds provided	698		
Yes		233 (708/3495)	238 (3571)
No		128 (349/1917)	99 (1484)
Wind velocity, feed-bunk area (ft/min)[c]	694	357 (339; 553; 839)	337 (299; 500; 773)

[a] At least one faecal sample positive for *E. coli* O157.
[b] SE USA (Florida, Georgia, Alabama, Mississippi, Arkansas, Louisiana, Kentucy, Tennessee), Midwest USA (Missouri, Iowa, Minnesota, Nebraska, Illinois), SW USA (Texas, Oklahoma, Arizona, New Mexico), Western USA (Montana, Wyoming, Colorado, South Dakota, North Dakota, Idaho), Far West (California, Nevada, Utah, Oregon, Washington).
[c] Significant in univariable statistics at $p < 0.2$, and therefore, offered into final stepwise model.

Table 3
Descriptive statistics for climate factors on 73 feedlots sampled in 4 states in the US between May and August 2001, stratified by feedlot-level *E. coli* O157 status

Variable	#Feedlots	#Feedlots per category and (number samples positive/total number of samples) (categorical variables) or #feedlots and value for each quartile (continuous variables)	
		Faecal-positive feedlots[a]	Faecal-negative feedlots
Temperature at start of sampling (°C)[b]	73	70 (19.8; 24.8; 29.2)	3 (12.6; 20.3; 26.6)
Humidity at start of sampling (%)[b]	73	70 (44; 54; 79)	3 (73; 91; 100)
Heat index at start of sampling (°C)[b]	73	70 (19.1; 26.7; 30.7)	3 (13.5; 23.5; 30.6)
Weather at start of sampling[b]	73		
Sunny		37 (489/5475)	1(75)
Partly cloudy		17 (271/2457)	0
Mostly cloudy		11 (243/1650)	2(300)
Light rain		4 (64/585)	0
Heavy rain		1 (23/120)	0
Amount of rainfall in previous 7 days (in.)[b]	68	65 (0; 0.1; 0.8)	3 (0; 0; 5)
Days since last rainfall[b]	67	64 (2; 5; 10)	3 (1; 11; 13)

[a] At least one faecal sample positive for *E. coli* O157.
[b] Significant in univariable statistics at $p < 0.2$, and therefore, offered into final stepwise model.

Table 4
Associations between factors measured at the feedlot-level and *E. coli* O157 in cattle faeces on 71 feedlots in the US sampled between May and August 2001

Variable	*b*	S.E.	*P*[a]	OR	95% CI OR
Intercept	−1.29	0.48			
Month			0.04		
May	Referent	–		–	–
June	−0.89	0.41		0.41	0.18, 0.92
July	−0.83	0.41		0.43	0.20, 0.97
August	−1.44	0.53		0.24	0.08, 0.66
Frequency of cats in pens/alleys[b]			0.003		
At least daily	Referent	–		–	–
At least weekly	−1.76	0.59		0.17	0.05, 0.55
At least monthly	−2.02	0.63		0.13	0.04, 0.45
Occasionally	−0.60	0.40		0.55	0.25, 1.21
Never	−0.98	0.44		0.38	0.16, 0.89

[a] Type III *F*-statistic. Covariance parameter estimates: feedlot, 0.97; pen (feedlot), 1.36; residual, 0.61. Deviance: 4654 on 10,360 degrees of freedom.
[b] Each category is mutually exclusive of the "preceding" (more-frequent) categories.

Table 5
Associations between factors measured at the pen-level and *E. coli* O157 in cattle faeces in 702 pens on 73 feedlots in the US sampled between May and August 2001

Variable	*b*	S.E.	*P*[a]	OR	95% CI OR
Intercept	−2.44	0.86			
Presence of *E. coli* O157 in water tank			<0.001		
Yes	0.98	0.18		2.7	1.9, 3.8
No	Referent	–		–	–
New cattle added to pen			0.04		
Yes	0.58	0.28		1.8	1.02, 3.1
No	Referent	–		–	–
Treatment for external parasites			0.02		
Yes	−1.75	0.77		0.17	0.04, 0.80
No	Referent	–		–	–
Use of injectable mass medication			0.002		
Yes	0.67	0.21		2.0	1.3, 3.0
No	Referent	–		–	–
Cattle condition (wetness)			0.005		
Dry	Referent	–		–	–
Mud/manure below fetlocks	0.71	0.25		2.0	1.3, 3.3
Mud/manure above fetlocks	−1.13	1.06		0.3	0.9, 2.6
Number of cattle in pen (per 10)	−0.03	0.01	0.002	0.97	0.95, 0.99
Wind velocity (per 100 ft/min)	0.05	0.02	0.03	1.05	1.01, 1.1
Feed-bunk height (per inch)	0.05	0.02	0.007	1.05	1.01, 1.1

[a] Type-III *F*-statistic. Covariance parameter estimates: feedlot, 0.87; pen (feedlot), 1.27; residual, 0.60. Deviance: 4363 on 9889 degrees of freedom.

Table 6
Associations between climate and management factors *E. coli* O157 in cattle faeces in 702 pens on 73 feedlots in the US sampled between May and August 2001

Variable	*b*	S.E.	*P*[a]	OR	95% CI OR
Intercept	−2.84	0.51			
Frequency of cats in pens/alleys			<0.001		
At least daily	Referent	–		–	–
At least weekly	−2.01	0.51		0.13	0.05, 0,37
At least monthly	−1.86	0.51		0.16	0.06, 0.43
Occasionally	−0.79	0.36		0.46	0.22, 0.92
Never	−1.01	0.37		0.36	0.28, 0.75
Presence of *E. coli* O157 in water tank			<0.001		
Yes	0.99	0.17		2.69	1.92, 3.78
No	Referent	–		–	–
Use of injectable mass medication			<0.001		
Yes	0.760	0.21		2.14	1.41, 3.23
No	Referent	–		–	–
Use of antibiotics in ration or water			0.006		
Yes	−0.60	0.22		0.55	0.36, 0.85
No	Referent	–		–	–
Cattle condition (wetness)			0.005		
Dry	Referent	–		–	–
Mud/manure below fetlocks	0.66	0.23		1.94	1.24, 3.05
Mud/manure above fetlocks	−1.16	1.07		0.31	0.04, 2.54
Number of cattle in pen (per 10)	−0.03	0.01	0.002	0.97	0.95, 0.99
Wind velocity (per 100 ft/min)	0.05	0.02	0.04	1.05	1.003, 1.10
Feed-bunk height (per inch)	0.05	0.02	0.009	1.05	1.01, 1.09

[a] Type-III *F*-statistic. Covariance parameter estimates: feedlot, 0.60; pen (feedlot), 1.28; residual, 0.61. Deviance: 4408 on 9292 degrees of freedom.

Table 7. The frequency with which cats were observed in the pen areas was associated positively with several of the variables related to the frequency of sighting wildlife in the feed-storage areas, with the highest Spearman's correlation observed for the frequency of observing cats in the pen area compared to the feed-storage area (Spearman's correlation = 0.65). In the final model, the direction of the associations between injectable mass medication and *E. coli* O157 and the use of antibiotics in the ration and *E. coli* O157 were opposite. However, the direction of the associations for each variable did not change from the univariable statistics. The use of injectable antibiotics was historical; the pen with the most-recent injectable antibiotic treatment had been treated >90 days prior to sampling. Approximately half of the pens reporting the use of antibiotics in the feed or water were receiving these treatments at the time of sampling. This was almost exclusively due to current use of tylosin. The residual error of this model was substantially <1.0. This indicates underdispersion of the model. The covariance parameter estimates indicate considerable variance at the pen-level (and to a lesser extent, the feedlot-level).

Table 7

Associations between factors included in the final model for feedlot, pen, and climate factors and *E. coli* O157 in faeces and factors that passed initial screening, were significant in univariable associations with the feedlot effect controlled, but were not included in the final model[a]

Factors included in the final model	Stray cats in pens/alley	*E. coli* O157 in water	Metaphylaxis (injectable)	Antibiotics in ration /water at any time during production	Wetness of pen (cattle condition)	Number of cattle in pen	Wind velocity	Height of feedbunk
Month of sampling	Yes	None	Yes	Yes	Yes	Yes	Yes	Yes
State where sampled	Yes	None	None	Yes	Yes	Yes	Yes	Yes
Method of storage of fat supplements	Yes	None	Yes	Yes	Yes	Yes	Yes	Yes
Method of storage of roughage	Yes	None	Yes	Yes	Yes	Yes	Yes	None
Method of water tank cleaning: scrubbed while empty	Yes	None	None	Yes	Yes	None	None	Yes
Insecticide ear tags	Yes	None	None	None	Yes	None	None	Yes
Frequency of vermin seen in pens/alleys								
Stray cats	1	Yes	None	Yes	Yes	Yes	Yes	Yes
Birds	None	None	None	Yes	Yes	None	Yes	None
Frequency of vermin seen in feed-storage areas								
Dogs, foxes, coyotes	None	None	None	Yes	Yes	Yes	Yes	Yes
Stray cats	Positive[b]	None	None	Yes	Yes	Yes	Yes	None
Deer, elk	None	Yes	None	Yes	Yes	Yes	Yes	Yes
Small mammals	Positive	None	Yes	Yes	Yes	Yes	Yes	Yes
Birds	Positive	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Aggressiveness of control measures in feed-storage areas								
Dogs, foxes, coyotes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Deer, elk	Yes	None	Yes	Yes	Yes	Yes	Yes	Yes
Small mammals	Yes	None	None	Yes	Yes	Yes	Yes	Yes
Manure stored on feedlot premises	Yes	None	None	Yes	Yes	Yes	None	None

Table 7 (*Continued*)

Factors included in the final model	Stray cats in pens/alley	*E. coli* O157 in water	Metaphylaxis (injectable)	Antibiotics in ration /water at any time during production	Wetness of pen (cattle condition)	Number of cattle in pen	Wind velocity	Height of feedbunk
Use of fencing	Yes	None	None	None	Yes	None	None	None
Month of cattle entry	Yes	None	Yes	Yes	Yes	Yes	Yes	None
New additions during production	Yes	None	Yes	None	None	Yes	None	Yes
Average arrival weight	None	None	Yes	None	Yes	None	Negative[b]	Positive
Were cattle from a single source	Yes	None	Yes	Yes	Yes	None	None	Yes
Source of majority of cattle	Yes	None	Yes	Yes	Yes	Yes	Yes	Yes
Re-vaccination for respiratory disease	Yes	None	Yes	Yes	Yes	Yes	Yes	Yes
Re-vaccination for clostridial disease	Yes	Yes	None	Yes	Yes	Yes	Yes	Yes
Treatment for external parasites	None	Yes	None	None	None	None	Yes	Yes
Implants	Yes	None	None	Yes	Yes	None	Yes	Yes
Second implants	Yes	None	Yes	Yes	Yes	Yes	None	None
Metaphylaxis (injectable)	None	None	1	None	None	None	Yes	None
Antibiotics in ration/ water at any time during production	Yes	None	None	1	Yes	Yes	Yes	Yes
Ionophores used at any time during production	Yes	None	None	None	None	None	None	Yes
Tank space accessible	Yes	None	None	None	None	Positive	None	None
Height of tank from pen surface	Yes	None	None	None	Yes	None	None	None
Water temperature 1 in. below surface	Yes	None	None	Yes	Yes	Negative	None	Negative
Water temperature at tank bottom	Yes	None	None	Yes	Yes	Negative	None	Negative
Bottom of tank visible from surface	Yes	Yes	None	Yes	Yes	None	Yes	None

E. coli O157 in water	Yes	1	None	None	None	None	None	None
Canola meal in current ration	Yes	None	None	Yes	None	None	None	None
Urea in current ration	Yes	None	Yes	Yes	Yes	Yes	Yes	None
Liquid protein in current ration	Yes	None	None	Yes	Yes	Yes	None	Yes
Alfalfa/sorghum hay in current ration	Yes	None	None	None	Yes	None	Yes	None
Alfalfa/sorghum silage in current ration	Yes	None	Yes	Yes	Yes	Yes	Yes	None
Corn silage in current ration	Yes	None	None	Yes	Yes	None	Yes	Yes
Hours since last feeding	Yes	None	None	Yes	None	Positive	None	None
Height of bunk from pen surface	Yes	None	None	Yes	Yes	None	None	1
Feed temperature 1 in. below surface	Yes	None	None	Yes	Yes	Negative	Positive	Negative
Cattle density	Yes	None	None	Yes	None	Negative	None	Positive
Number of cattle in pen	Yes	None	None	Yes	None	1	None	None
Primary breed	Yes	None	Yes	None	None	None	None	None
Wetness of pen	Yes	None	None	Yes	1	None	None	Yes
Wind velocity, feed-bunk area	Yes	None	Yes	Yes	None	None	1	None
Temperature at start of sampling	Yes	Yes	Yes	Yes	Yes	Negative	None	Negative
Humidity at start of sampling	Yes	None	None	Yes	Yes	Positive	Negative	Positive
Heat index at start of sampling	Yes	Yes	None	Yes	Yes	Negative	None	Negative
Days since last rainfall	Yes	Yes	None	Yes	Yes	None	None	Negative

[a] Significance testing at 0.05 (two-sided).

[b] Directionality provided for comparisons between continuous vs. continuous variables and ordinal vs. ordinal variables.

4. Discussion

Many feedlot, pen, and climate factors were tested for associations with *E. coli* O157 in cattle faeces, yet relatively few were significant in the final model. The feedlots participating in this study were not randomly selected; selection was based on geographic location (four states), and willingness to participate. The four states represented in this study produce approximately 70% of the annual beef production in the United States (National Agricultural Statistics Service, 2002). The smallest feedlot in this study had an annual capacity of 7500. Therefore, smaller feedlots were not represented in the present study.

Differences in sampling strategies and laboratory methods make comparisons of prevalence between studies difficult. However, our prevalence was similar to a recent national study of randomly selected herds (National Animal Health Monitoring System, 2001). We used a cross-sectional study design. *E. coli* O157 is shed transiently in cattle. Therefore, our sampling strategy might have underestimated the magnitude of *E. coli* O157 in cattle.

Our culture techniques identified the presence of *E. coli* O157 as a yes–no dichotomy, and due to the use of enrichment and IMS, it was not possible to quantify the level of *E. coli* O157 in individual-samples. Therefore, management practices associated with a decrease in the concentration of *E. coli* O157 in faeces, but not associated with the presence or absence per se, would not have been identified in our study, unless the change in magnitude corresponded to a reduction below the detection limit of our diagnostic test.

Questions pertaining to the observed frequency and level of control of several non-domestic species were included in the survey. The association between the frequency of cats observed in the pen or alley areas and *E. coli* O157 was significant in both the herd and the overall model. We did not sample the faeces of cats present in the feedlots. Therefore, we cannot determine whether the cats themselves were shedding *E. coli* O157 concurrently with the cattle. *E. coli* O157 has been detected in numerous non-bovine species (reviewed in Sargeant and Smith, 2003). The role of cats in the epidemiology of *E. coli* O157 is not clear. *E. coli* O157 were not detected in 33 faecal samples of feral cats in cattle operations (Hancock et al., 1998) and faecal samples from cats on eight dairy farms (Rahn et al., 1997). Verocytotoxigenic *E. coli* (VTEC) have been isolated in cat faeces, although the O157 antigen was not identified in any of the nine VTEC positive samples which were serotyped (Smith et al., 1998). Contact with the faeces of cats that are shedding *E. coli* O157 could serve as a source of these bacteria to cattle. However, there is the potential for numerous non-domestic species to contact the cattle, and to interact with each other in the feedlot environment. Therefore, control of one species may lead to changes in another, with unknown effects on *E. coli* O157 and other enteric pathogens. For instance, control of feral cats in the feedlot environment could lead to increases in the rodent population. Therefore, further research needs to be done to investigate the effect of controlling one or more wildlife species in the feedlot environment before specific recommendations for wildlife control as a means of reducing *E. coli* O157 in cattle environments can be made.

The association between the presence of *E. coli* O157 in water tanks and the faeces of cattle with access to that water is consistent with observations in the literature. Several studies have documented identical genetic strains of *E. coli* O157 in cattle faeces and cattle water sources within farms (VanDonkersgoed et al., 2001; Hancock et al., 1998; Shere et al., 1998). Experimentally, *E. coli* O157 can survive in water tanks and remain infectious to cattle for months (LeJeune et al., 2001). Thus, water might represent a critical control point for reducing transmission of *E. coli* O157 in cattle operations. However, none of the variables related to water-trough hygiene and management in our study showed associations with the presence of *E. coli* O157. For some variables, this might be related to the lack of variability; all of the feedlots reported that they routinely cleaned the water tanks. However, there was no association between the interval from cleaning the water tanks and the presence of *E. coli* O157 in cattle faeces.

The associations between antibiotic use and *E. coli* O157 were somewhat contradictory, with the use of injectable antibiotics at the pen-level appearing to increase the risk and the use of pen-level medication in the feed and water appearing to decrease the risk. In dairy cattle, Shere et al. (1998) observed that *E. coli* O157 was isolated from dairy calves on farms with more-extensive use of antibiotics, but not on farms where antibiotics were not used routinely. However, the study contained only four dairy farms and investigating farm-management associations with *E. coli* O157 was not the primary objective. The use of antibiotics in the current study was historical for all of the pens reporting use of injectable antibiotics and approximately half of the pens reporting the use of antibiotics in the feed or water. We did not collect information on individual-level therapeutic antibiotic use, nor did we identify specific cattle that were shedding *E. coli* O157 in their faeces at the time of sampling. Thus, we were not able to test associations between individual-animal use of antibiotics and *E. coli* O157 shedding. Groups of cattle receiving antibiotics might differ from groups where antibiotic use (particularly injectable antibiotics administered to the entire pen) is not used. It is possible that the observed associations are indirect and related to characteristics of the groups of animals that received the antimicrobials, rather than indicative of antimicrobial use, per se. Further research is needed to clarify the relationship between antibiotic use and *E. coli* O157.

Our finding that muddy pens were associated with a higher risk of *E. coli* O157 is consistent with the results of a study of cattle in 29 pens in 5 feedlots (Smith et al., 2001). Those authors speculated that wet pen conditions facilitated transmission of the bacteria by cattle movements raising organisms surviving in the soil to the surface of the pen.

Number of cattle within pen was associated negatively with the presence of *E. coli* O157, and there was no association with cattle density, suggesting that high cattle numbers or densities are not necessary for *E. coli* O157 to be present. This is supported by the identification of *E. coli* O157 in cow–calf and weaned cattle operations (which are typically range based, and therefore, have lower cattle density compared to feedlots) (Renter et al., 2003; Sargeant et al., 2000; Laegreid et al., 1999).

The presence of *E. coli* O157 was associated positively with wind velocity. *Esherichia coli* can remain viable in aerosol (Kang and Frank, 1989; Wathes et al., 1986). Therefore, one possible explanation for our finding is that wind disperses the bacteria either directly between animals or via dust contamination of water or feed. There was no significant association between the presence of windbreaks within pens and *E. coli* O157. However, only 23 of 701 pens had windbreaks present.

The measurement of bunk height was included as an independent variable to investigate the biologically plausible hypothesis that lower bunks could have greater potential for contamination with cattle faeces (providing an opportunity for dissemination of *E. coli* O157 via contaminated feed). Feed samples taken from the bunks on a subset of 504 pens from 54 feedlots in the current study were tested for *E. coli* O157 (Dodd et al., 2003). Fifteen percent of the feed samples were positive-although it was not known whether the feeds were contaminated prior to feeding or whether these bacteria were present due to faecal or salivary contamination from the cattle or other species. Our finding of a positive association between bunk height and *E. coli* O157 could represent a spurious association or bunk height could be a proxy for another unidentified factor.

None of the pen-level variables related to the presence or absence of specific feedstuffs was significantly associated with the presence of *E. coli* O157. This is in contrast to studies reporting a decreased prevalence of *E. coli* O157 on dairy farms feeding whole cottonseed (Garber et al., 1995), and an increased *E. coli* O157 prevalence in dairies feeding corn silage (Herriott et al., 1998). Dargatz et al. (1997) reported that pens fed barley were 2.75-times more likely to have one or more faecal samples positive for *E. coli* O157. However, in our study, none of the feedlots reported feeding barley and $<3\%$ of the rations contained whole cottonseed. Therefore, the power to detect significance with these variables was low or zero.

In summary, we investigated the association between *E. coli* O157 in feedlot cattle faeces and a wide range of management and climate factors. The ubiquitous nature of *E. coli* O157 in feedlots illustrates that control of this pathogen is a concern for all feedlot producers. The study design was cross-sectional and observational. Given that the management factors and presence of *E. coli* O157 were measured at a single point in time, it is not possible to determine cause and effect. A large number of variables were tested, leading to considerable potential for some of the identified associations to be false-positive (type-I-error) results. Therefore, this type of study is useful for identifying areas for further investigation, rather than testing specific hypotheses related to the effect of controlling a management factor on the presence of *E. coli* O157. However, this study has identified several areas where targeted research could be performed, including wildlife control, water tank management, and wind control. The relatively low number of management factors identified, and the large amount of unexplained variability suggests that management change alone is unlikely to prevent the presence of *E. coli* O157 in the feedlot. Therefore, control efforts should be targeted at reducing the prevalence in feedlot operations, while realizing that minimizing the potential for human disease will need to target multiple segments of the food industry, from farm to fork.

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