Cost-benefit of implementing a participatory extension model for improving on-farm adoption of Johne's disease control recommendations

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ABSTRACT

The objective of this study was to perform a cost-benefit analysis (CBA) of a participatory extension model, called Ontario Focus Farms (FF), which was designed to facilitate the adoption of on-farm management practices to control Johne's disease (JD) on Ontario (ON) dairy farms. Partial budget models were developed to estimate the annual herd cost of JD on an average 78-cow Ontario dairy herd and the annual herd cost of neonatal calf diarrhea (NCD). With these estimates, a CBA was developed to assess the simulated net benefits of implementing various on-farm management scenarios (i.e., implementing 1, 2, or 3 of the following: calf feeding, maternity pen management, maternity area structure changes), where the benefits represent a reduction in the annual cost of JD and NCD. These models informed the final CBA assessing the net benefits of FF implementation over a 10-yr period. All monetary values are reported in Canadian dollars (Can\$; where 1 Can\$ = 0.823 US\$ at the time of the study). The annual herd cost of JD was estimated to be \$3,242 (\$41.56/cow), and that of NCD was estimated to be \$1,390 (\$36/heifer calf). When farms were expected to have both JD and NCD, all scenarios, when implemented over a 10-yr period, yielded positive net benefits ranging from \$439 to \$2,543 per farm when changes to maternity area structure were combined with calf feeding changes. These effects were sensitive to changes in level of disease (JD and NCD) on the farm, and the costs and effects of making changes. The NPV of making any on-farm change when JD was not present on the farm was negative. Overall, FF implementation yielded positive net benefits of \$426,351 or \$749,808, depending on whether a veterinarian or non-veterinarian served as the facilitator. The NPV was most sensitive to changes in burden of disease, the

cost of implementing changes, and the proportion of FF participants that had JD and NCD on the farm. Benefits of FF implementation are also likely to accrue to veterinarians, as a result of professional facilitator training, and the Ontario dairy industry, as a by-product of improved milk quality and safety; therefore, the true net benefits of FF implementation are likely underestimated. Overall, the FF process should be considered an economically viable program and worthy of investment as part of a JD control strategy, as it demonstrates potential to yield positive net benefits for the Ontario dairy industry.

Key words: Johne's disease, cost-benefit analysis, economics, dairy cattle

INTRODUCTION

Johne's disease (JD) is an important production-limiting disease affecting dairy cattle (Garcia and Shalloo, 2015; McAloon et al., 2016). In addition to decreased milk production and premature culling of subclinical animals, clinically affected animals can develop chronic diarrhea and waste away over time (Tiwari et al., 2006; McAloon et al., 2016). Canadian studies report that 10 to 60% of dairy herds have at least 2 seropositive cows (Tiwari et al., 2009; Corbett et al., 2018). Two partial budgets, monetizing the annual herd costs of JD using Canadian estimates, estimated losses of Can\$2,472 (Chi et al., 2002) and Can\$2,992 (Tiwari et al., 2008). Extrapolating these estimates to all of Canada has resulted in an estimated annual loss of over Can\$15 million for the Canadian dairy industry (McKenna et al., 2006).

With no effective treatment available, the most common approach to addressing JD is through control programs based on periodic testing of cows to identify test-positive cows and implementing management changes to improve farm biosecurity (Sweeney et al., 2012). Beginning in 2010, Ontario implemented a 3-yr rollout of a voluntary JD control program, called the Ontario Johne's Education and Management Assistance Program (OJEMAP) (OJEMAP, 2009). The program

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comprised an education component, a veterinarian-administered on-farm risk assessment, and voluntary whole-herd testing. The education component of OJE-MAP focused on the development of an extension model to improve the adoption of on-farm management practices to control JD. The resulting model, Ontario Focus Farms (**FF**), is a self-directed, learner-centered, participatory model that aims to influence producer behavior by addressing their knowledge, attitudes, perceptions, and opinions. Results of an evaluation of the FF process showed that it was effective in improving participants' knowledge about JD and changing their attitude and behavior with respect to on-farm management; 81% of FF respondents implemented at least one on-farm management change for JD control compared with 38% of control respondents (Roche et al., 2015). Although the pilot implementation and evaluation demonstrated positive on-farm outcomes, further investment in this initiative requires a more in-depth economic evaluation.

Cost-benefit analysis (**CBA**) provides a framework for economically evaluating the efficacy of the FF process for JD control. Cost-benefit analysis allows future costs and benefits to be considered in present day dollars by discounting future costs and benefits to obtain the present value (**PV**). The PV costs and PV benefits are then subtracted to calculate the net present value (**NPV**), or the value of the expected future returns of an investment minus the value of the expected future costs (Boardman et al., 2010). From this perspective, costs of FF implementation mainly represent direct transactions for goods and services (e.g., meeting rooms, facilitation costs). The benefits of FF implementation accrue as a result of FF participants implementing on-farm management changes (i.e., calf feeding changes, changes to maternity pen management, maternity area structure changes), which reduce the cost of JD primarily through the prevention of new *Mycobacterium avium* ssp. *paratuberculosis* (**MAP**) infections and reduce the cost of neonatal calf diarrhea (**NCD**). The objectives of this study were to (1) develop partial budget models to estimate the annual herd cost of JD and NCD on a 78-cow dairy herd in Ontario, and (2) perform a CBA to evaluate the NPV of implementing FF in Ontario over a 10-yr period to facilitate the adoption of on-farm management practices to prevent and control JD.

MATERIALS AND METHODS

General Modeling Approach

A partial budget was first developed to estimate the annual herd cost of JD on an average Ontario dairy

farm. Given that the implementation of management changes for JD control may also have indirect effects on NCD, a second partial budget was created to estimate the annual herd cost of NCD. We then developed a CBA of the implementation of 1, 2, or 3 on-farm management practices (calf feeding changes, changes to maternity pen management, maternity area structural changes) to assess the net benefits of implementing various combinations of on-farm changes to prevent the spread of JD. The final step was to use the previously calculated estimates to inform the creation of a CBA to assess the net benefits of FF implementation in the Ontario dairy industry over a 10-yr period.

For all CBA models, PV costs and PV benefits were calculated using Equations [1] and [2]:

$$\text{PV costs} = C_t/(1+r)^t + \dots C_n/(1+r)^n, \quad [1]$$

$$\text{PV benefits} = B_t/(1+r)^t + \dots B_n/(1+r)^n, \quad [2]$$

where C_t and B_t are the total costs and total benefits for each year (t), respectively, r is the discount rate, and n is the total number of years.

For this study, all discounting was done for a 10-yr time period. Given that a moderate to high level of uncertainty in the realization of future cash flows exists, a discount rate of 8% was used (Pillars et al., 2009). Once all PV costs and PV benefits were estimated, the NPV was calculated using Equation [3]:

$$\text{NPV} = \text{PV benefits} - \text{PV costs}. \quad [3]$$

All partial budgets and CBA models were built in Excel 2019 for Mac (version 16.27; Microsoft Corp., Redmond, WA). All monetized estimates are reported in Canadian dollars (Can\$; where 1 Can\$ = 0.823 US\$ at the time of the study). Model parameters and estimates were obtained from the literature and personal communication with an expert and, where necessary, used to inform our assumptions. The specific parameters, estimates, and calculations used for all analyses are discussed in detail below.

Estimating the Cost of JD and NCD

Input parameters used for the partial budget models included industry- and herd-level characteristics, JD effects on milk production and culling, and NCD effects on treatment costs and inputs lost to calf mortality, each of which are briefly described below. A detailed explanation of the assumptions and estimates used can be found in Roche (2014, page 194) and within

Supplemental File S1 (<https://doi.org/10.3168/jds.2019-16708>). Table 1 presents the arithmetic used to calculate the estimated costs based on the assumptions and estimates discussed below. Briefly, industry- and herd-level characteristics; that is, average milk price (\$0.77/kg), herd size (78 milking cows), annual number of heifer calves born (39), apparent within-herd test positive prevalence of JD (7%), estimated true within-herd prevalence (calculated using equation [4]; 10%), incidence of NCD (23%), case fatality rate of NCD (6%), and severity of NCD cases (85% mild and 15% severe), were used to create a base model.

$$\text{True within-herd prevalence} = \frac{\text{Apparent prevalence} + \text{Test specificity} - 1}{\text{Test specificity} + \text{Test sensitivity} - 1} \quad [4]$$

JD Partial Budget. Estimates of the average milk loss among MAP-infected animals for parity groups 1, 2, and ≥ 3 were calculated to account for milk losses using reported findings from Sorge et al. (2011b) on milk loss among JD milk ELISA-positive cows by parity. To estimate the herd cost of suboptimal culling due to MAP infection, we assumed that MAP-infected cows had a 20% increased risk of being culled prematurely (Chi et al., 2002). Estimates of the cost of having to prematurely cull and replace a MAP-infected cow were determined using the “Cow Value” function found in the dairy herd management computer program DairyComp305 (DC305; Valley Agricultural Software, Tulare, CA). Estimates were separated based on low (≥ 0.1 to < 1.0) and high (≥ 1.0) test-positive results and then averaged.

NCD Partial Budget. The cost of treating mild and severe cases of NCD, including veterinary costs and drugs administered, was assumed to be \$35/d and \$120/d, respectively (K. Leslie, University of Guelph, Guelph, ON, Canada; personal communication). The average number of days calves were treated for NCD was 3 (Waltner-Toews et al., 1986). The average age of mortality of calves due to NCD was estimated to be 15 d (Windeyer, 2013). The marginal feed costs for pre-weaning heifers was assumed to be \$3.00/d (K. Leslie; personal communication). The opportunity cost (sale value) of a heifer calf was assumed to be \$150.

Under these base assumptions and inputs listed above, the PV costs of JD and NCD were calculated over a 10-yr term. Levels of within-herd infection for both JD and NCD were assumed to remain fixed over the 10-yr period, to provide a conservative estimate of the PV costs of disease over this period.

CBA for Implementing On-Farm Management Changes

We assumed that producers would focus on making on-farm management changes to one or more of the following areas: (1) calf feeding, (2) maternity pen management, and (3) maternity area structure. The cost of each on-farm management change is outlined in Table 2; further explanation on these estimates is provided in Supplemental File S1 (<https://doi.org/10.3168/jds.2019-16708>).

NPV of Implementing On-Farm Management Changes

Producers were assumed to implement 1, 2, or all 3 of the management practices considered in this study over a 10-yr period, resulting in 7 potential implementation scenarios. Further, as the incubation period of JD is a minimum of 2 yr (Tiwari et al., 2006), we assumed that benefits did not begin accruing until 2 yr after implementation. Conversely, the effect of changes on the incidence of NCD were expected to be immediate, with annual benefits accruing for 2 yr and then remaining fixed at the yr 2 incidence rate for the remainder of the 10-yr term. Finally, we assumed that as producers observed positive effects of the management practices on the incidence of NCD in the first year of implementation, their persistence to perform the change in the second year would improve. For calf feeding changes, persistence was assumed to increase from 90% to 95% in yr 2, and remain at that level, whereas for maternity pen management changes, persistence was assumed to increase from 75% to 85% in yr 2 and remain at that level. The PV and NPV costs of implementing on-farm management changes, based on these parameters, are provided in Table 3.

CBA for Implementing FF

We estimated that 8 FF groups would be held in Ontario each year. Each FF group was assumed to have 12 dairy producer participants who formally met 4 times in 1 yr, for 6 h each meeting. At the end of each year, it was assumed that a new group of dairy producers would begin the FF process. The implementation costs considered include start-up, recurrent, and opportunity costs. Table 4 provides additional detail on the specific cost estimates used.

The benefits of FF implementation were determined by calculating the number of FF participants adopting each scenario, and considering network effects (non-FF

participants who would adopt a scenario as a result of networking with a FF participant), and the proportion of participating farms that have both JD and NCD (75%). The arithmetic used to calculate the estimated benefits of FF implementation, based on these parameters, is provided in Table 5.

Table 6 provides the PV and NPV benefits of FF implementation, based on all parameters discussed above. Figure 1 presents a network diagram outlining the primary parameters (and their relationships) that formed the basis for calculating NPV of FF implementation.

Sensitivity Analysis

Sensitivity analyses were performed on the annual cost of JD, the annual cost of NCD, the NPV of each management scenario, and the NPV of FF implementation over a 10-yr period, to determine the inputs that had the greatest influence on estimates. Where applicable, the discount rate was varied from 3 to 10%. All other factors were varied based on reasonable biological endpoints. Upon completion of all sensitivity analyses, tornado charts were created to provide a visual representation

of the sensitivity analysis by ranking them from most sensitive to least sensitive and presenting them graphically. A global sensitivity analysis was conducted to calculate "best-case" and "worst-case" scenarios, and to explore the differences in NPV that occurred from a group of changes made to model parameters. The variable groupings that were evaluated related to disease burden (prevalence of JD, incidence of NCD), effect of each management scenario (reduction in JD prevalence and incidence of NCD), and program factors (program costs, number of program participants, network effects). All primary parameters listed in Figure 1 were favorably changed to produce a best-case scenario, and then unfavorably changed to produce a worst-case scenario. All other global sensitivity analyses were conducted by changing one group of parameters favorably, and then unfavorably, and recording the NPV.

RESULTS

Partial Budgets for JD and NCD

The total economic losses attributed to JD, based on a true within-herd JD prevalence of 10% in a 78-cow

Figure 1. Network diagram outlining the primary parameters, and their relationships, contributing to the calculation of net present values (NPV) for making a given management change and for program implementation. JD = Johne's disease; NCD = neonatal calf diarrhea; PV = present value.

Table 1. Input parameters and estimates, sources of parameter estimates, and the mathematical formulas used to calculate the annual financial cost (Can\$; where 1 Can\$ = 0.823 US\$ at the time of the study) of Johne's disease (JD) and neonatal calf diarrhea (NCD) on an average Ontario dairy farm

Variable ID	Variable name	Formula	Estimate	Reference
1	Milk price (/kg)	—	\$0.77	DFO, 2013
2	Herd size (milking cows)	—	78	DHI, 2013
3	Apparent within-herd prevalence of JD ¹	—	7%	Sorge et al., 2010, 2011a
4	True within-herd prevalence of JD ¹	$(3) + 0.98 - 1/0.52 + 0.98 - 1$	10%	Dohoo et al., 2009; Idexx, 2013
5	Number of <i>Mycobacterium avium</i> ssp. <i>paratuberculosis</i> (MAP)-infected cows	$(4) \times (3)$	7.8	—
JD: Reduced milk production				
6	Average reduction in milk yield per parity group (kg/cow per 305-d lactation) ²	—	(a) Parity 1: 72.00 (b) Parity 2: 211.34 (c) Parity ≥ 3 : 460.78	Sorge et al., 2011b
7	Odds of a MAP-infected cow per parity group	—	(a) Parity 1: 1.00 (b) Parity 2: 3.15 (c) Parity ≥ 3 : 3.87	Nielsen et al., 2002
8	Number of MAP-infected cows per parity group ³	Parity 1: $[(5)/8.02] \times (7a)$ Parity 2: $[(5)/8.02] \times (7b)$ Parity ≥ 3 : $[(5)/8.02] \times (7c)$	(a) Parity 1: 0.97 (b) Parity 2: 3.06 (c) Parity ≥ 3 : 3.76	—
HRMP	Total annual herd cost of reduced milk production	$[(1) \times (10a) \times (13a)] + [(1) \times (10b) \times (13b)] + [(1) \times (10c) \times (13c)]$	\$1,899.26	—
JD: Suboptimal culling				
9	Average cost of culling and replacing a MAP-infected cow ^{2,4}	—	\$860.70	OJEMAP, 2013
10	Increased risk of prematurely culling MAP-infected cows	—	20%	Chi et al., 2002
HSC	Total herd cost of suboptimal culling	$(5) \times (9) \times (10)$	\$1,342.69	—
Total annual herd cost of JD				
HL-JD	Total annual herd losses due to JD	HRMP + HSC	\$3,241.95	—
11	Number of heifer calves (/year)	$(1) \times 0.5$	39	Assumption
12	Incidence of NCD	—	23%	Windeyer, 2013
13	Case fatality rate of NCD	—	6%	Windeyer et al., 2014
14	Number of heifer calves with NCD (/year)	$(11) \times (12)$	8.97	—
15	Proportion of mild NCD cases	—	85%	Assumption
16	Proportion of severe NCD cases	—	15%	Assumption
NCD: Treatment costs				
17	Number of heifer calves treated for mild NCD ⁵	$(14) \times (15)$	7.63	K. Leslie, University of Guelph, Guelph, ON; personal communication Waltner-Toews et al., 1986
18	Number of heifer calves treated for severe NCD ⁵	$(14) \times (16)$	1.36	
19	Cost of treatment for mild NCD (/day)	—	\$35.00	
20	Cost of treatment for severe NCD (/day)	—	\$120.00	
21	Average number of days treated for NCD ⁶	—	3	—
TC	Total annual treatment costs for NCD	$[(17) \times (19) + (18) \times (20)] \times 21$	\$1,284.95	
NCD: Inputs lost to heifer calf mortality				
22	Annual number of heifer calves dying due to NCD	$(11) \times (12) \times (13)$	0.54	—
23	Marginal feed costs of pre-weaned calves (/day)	—	\$3.00	
24	Average age of mortality due to NCD (days)	—	15	

Continued

Table 1 (Continued). Input parameters and estimates, sources of parameter estimates, and the mathematical formulas used to calculate the annual financial cost (Can\$, where 1 Can\$ = 0.823 US\$ at the time of the study) of Johne's disease (JD) and neonatal calf diarrhea (NCD) on an average Ontario dairy farm

Variable ID	Variable name	Formula	Estimate	Reference
25	Total feed costs lost (/heifer calf)	$(23) \times (24)$	\$45.00	—
FCL	Total annual feed costs lost due to NCD mortality	$(22) \times (25)$	\$24.22	—
NCD: Opportunity cost of heifer calf mortality				
26	Potential sale price of lost heifer calf	—	\$150	Assumption
OC	Total opportunity costs of calf mortality	$(22) \times (26)$	\$80.73	—
Total annual herd cost of NCD				
HL-NCD	Herd losses due to NCD (/year)	TC + FCL	\$1,389.90	—

¹Apparent prevalence based on JD testing with Idexx Milk ELISA (sensitivity = 52%; specificity = 98%; Idexx, 2013).

²Losses are weighted based on 11% high-positive cows and 89% low-positive cows (with milk ELISA) in Ontario (OJEMAP, 2013).

³A constant of 8.02 (sum of all odds) is used to proportionately weight the number of cows per parity group by the odds of a MAP-infected cow.

⁴The DairyComp 305 (Valley Agricultural Software, Tulare, CA) module Cow Value provided cost of replacing a JD high and low test-positive animal with an average replacement heifer.

⁵Assumption made that all calves are treated for NCD.

⁶Assumption made that calves are treated for all 3d.

dairy herd, were estimated to be \$3,242 annually (\$42/cow and \$416/MAP-infected cow). Approximately 59% (\$1,899/\$3,242) of the total cost was attributed to reduced milk production, and the remaining 41% (\$1,343/\$3,242) was due to suboptimal culling.

The total economic losses attributed to NCD, based on a 23% incidence and 6% case fatality rate in a 78-cow dairy herd, were estimated to be \$1,390 annually (\$18/cow and \$155/sick heifer calf). Treatment of NCD represented the most significant cost, contributing 93% (\$1,285/\$1,390) of the total cost of NCD. The remaining 6% (\$81/\$1,390) and 2% (\$24/\$1,390) of financial losses were attributed to opportunity costs and feed costs lost to NCD mortality, respectively. Table 1 provides a breakdown of the input parameters and their values.

Of all input parameters, the estimated annual cost of JD was most sensitive to changes in true within-herd prevalence and was least sensitive to milk price and the average decrease in milk production (Figure 2). Overall, a 50% decrease in true within-herd prevalence (from 10% to 5%) changed the annual cost from \$3,242 to \$1,621, whereas a 50% increase increased the annual cost to \$4,863.

The estimated annual cost of NCD was most sensitive to changes in the incidence of NCD and the average number of days treated, whereas cost was least sensitive to the average age of mortality due to NCD (Figure 3). Overall, a decrease in the incidence of NCD (from 23% to 15%) decreased the annual cost of NCD from \$1,390 to \$935, whereas an increase to 31% increased the annual cost of NCD to \$1,845.

CBA for Implementing On-Farm Management Changes

Table 2 presents the costs incurred and the reduction in annual true within-herd prevalence of JD and annual incidence of NCD as a result of implementing on-farm management practices (calf feeding, maternity pen management, and maternity area structure) on an average, 78-cow, dairy farm in Ontario. Overall, changes to calf feeding were considered the easiest and least costly to implement (\$5/cow), followed by maternity pen management changes (\$6/cow) and maternity area structure (\$19/cow). The impact of each practice on reducing the true within-herd prevalence of JD, after considering persistence of each change, was highest for changes to maternity area structure (4%/yr), followed by maternity pen management (3%/yr) and calf feeding changes (1.8%/yr). For the annual reduction in the incidence of NCD, changes to calf feeding (13.5%/yr), followed by maternity area structure (5%/yr) and ma-

Table 2. Cost (Can\$; where 1 Can\$ = 0.823 US\$ at the time of the study) of making management changes for calf feeding, maternity pen management, and maternity pen structure and the effect of each change on Johne's disease (JD) prevalence and neonatal calf diarrhea (NCD) incidence on an average Ontario dairy farm

Variable number	Variable name	Formula	Estimate	Reference
1	Herd size (milking cows)	—	78	Assumption
2	Number of heifer calves (/yr)	$(1) \times 0.5$	39	Assumption
3	Cost of labor (/h)	—	\$17.33	Lang, 2010
4	Cost milk replacer (/heifer calf)	—	\$1.63	Quigley, 2014
5	Cost of colostrum replacer (/heifer calf)	—	\$19.70	K. Leslie, University of Guelph, Guelph, ON; personal communication
Management change 1:				
Calf feeding				
6	Implementation difficulty	—	Low	Assumption
7	Annual JD prevalence reduction	—	2%	Dorshorst et al., 2006; Nielsen et al., 2008; Pithua et al., 2009
8	Annual NCD incidence reduction	—	15%	Wells et al., 1997; Svensson et al., 2003; Gulliksen et al., 2009; K. Leslie; personal communication
9	Persistence	—	90%	Assumption
10	True annual JD prevalence reduction	$(7) \times (9)$	1.8%	—
11	True annual NCD incidence reduction	$(8) \times (9)$	13.5%	—
12	Cost of implementation (/cow) ¹	$\{[(2) \times 0.66] \times [(2)/60] \times 5\} + [(2) \times 0.33] \times (5) + (2) \times (4)] \times (1)$	\$4.54	—
Total annual herd costs of calf feeding changes				
13	Maternity pen management	$[(9) \times (12)] \times (1)$	\$318.71	—
Management change 2:				
Maternity pen management				
14	Implementation difficulty	—	Moderate	Assumption
15	Annual JD prevalence reduction	—	4%	Merkal et al., 1975; Groenendaal et al., 2003; Dorshorst et al., 2006; Ferrouillet et al., 2009
16	Annual NCD incidence reduction	—	5%	Wells et al., 1997; Trotz-Williams et al., 2007; K. Leslie; personal communication
17	Persistence	—	75%	Assumption
18	True annual JD prevalence reduction	$(14) \times (16)$	3%	—
19	True annual NCD incidence reduction	$(15) \times (16)$	3.75%	—
20	Cost of implementation (/cow) ²	$[(2)/60] \times 20$	\$5.78	—
Total annual herd costs of maternity pen management				
21	Maternity area structure	$[(16) \times (19)] \times (1)$	\$338.13	—
Management change 3:				
Maternity area structure				
22	Implementation difficulty	—	High	Assumption
23	Annual JD prevalence reduction	—	4%	Pithua et al., 2013
24	Annual NCD incidence reduction	—	5%	Gulliksen et al., 2009; K. Leslie; personal communication
25	Persistence	—	100%	Assumption
26	True annual JD prevalence reduction	$(21) \times (23)$	4%	—
27	True annual NCD incidence reduction	$(22) \times (23)$	5%	—
28	Cost of implementation (/cow) ³	$[\$1,500/(1)]$	\$19.23	—
Total one-time herd costs of maternity area structure				
29		$[(23) \times (26)] \times (1)$	\$1,500	—

¹Assume 66% of heifer calves receive JD test-negative colostrum from dam (assume 5 min for feeding); 33% of heifer calves receive colostrum replacer; 100% of heifer calves receive milk replacer.²Assume 20 min required to perform action.³Assume that 3 individual maternity pens are made from 1 group maternity area. Gate costs are \$1,000 and smaller structural costs for installment are \$500. The pens are assumed to have a life of 10 yr.

Table 3. Present value (PV) costs (Can\$; where 1 Can\$ = 0.823 US\$ at the time of the study) of Johne's disease (JD) and neonatal calf diarrhea (NCD), discounted at 8% over 10 yr, and the net present value (NPV) of implementing 7 unique management scenarios (i.e., implementing changes to 1, 2, or 3 of calf feeding, maternity pen management, maternity area structure), on an average 78-cow Ontario dairy farm

Variable	Scenario ¹						
	1: Calf feeding changes	2: Maternity pen management changes	3: Maternity area structure changes	4: Calf feeding and maternity pen management changes	5: Calf feeding and maternity area structure changes	6: Maternity pen management and maternity area structure changes	7: Calf feeding, maternity pen management, and maternity area structure changes
Annual cost ²	\$318.71	\$338.13	\$549.90 (only in yr 1)	\$656.84	\$868.61 (yr 1); \$318.72 (yr 2+)	\$888.03 (yr 1); \$338.13 (yr 2+)	\$1,206.74 (yr 1); \$656.84 (yr 2+)
PV cost of implementation	\$2,138.56	\$2,268.88	\$1,500	\$4,407.44	\$3,638.50	\$3,768.82	\$5,907.38
PV costs of JD after implementation	\$20,560.05	\$19,685.00	\$19,350.66	\$18,655.59	\$18,385.17	\$17,752.31	\$16,907.04
PV costs of NCD after implementation	\$6,665.30	\$8,145.44	\$7,985.74	\$6,110.04	\$5,971.45	\$7,376.85	\$5,446.49
PV benefits for JD ³	\$1,193.72	\$2,068.77	\$2,403.11	\$3,098.18	\$3,368.60	\$4,001.45	\$4,846.73
PV benefits for NCD ⁴	\$2,119.35	\$639.21	\$798.91	\$2,674.61	\$2,813.20	\$1,407.80	\$3,338.16
NPV of implementing scenario 1 ⁵ [farms with NCD only (no JD)]	-\$19.21	-\$1,629.67	-\$701.03	-\$1,732.83	-\$825.30	-\$2,361.02	-\$2,569.22
NPV of implementing scenario 1 ⁵ (farms with NCD and JD)	\$1,174.51	\$439.10	\$1,702.08	\$1,365.35	\$2,543.30	\$1,640.43	\$2,277.51

¹Scenarios 1–7 assumed to reduce NCD incidence in yr 1 and 2, with yr 3 to 10 fixed at yr 2 value, and to reduce within-herd prevalence of JD starting in yr 3. Persistence of calf feeding changes is assumed to increase from 90 to 95% in yr 2, while persistence of maternity pen management changes is assumed to increase from 75 to 85% in yr 2. Persistence changes assumed to remain fixed at yr 2 values.

²Sourced from Table 2.

³Benefits for JD realized as a reduction in the 10-yr costs of JD, calculated as PV costs of JD (scenario 0) – PV costs of JD (after implementing a scenario).

⁴Benefits for NCD realized as a reduction in the 10-yr costs of NCD, calculated as PV costs of NCD (scenario 0) – PV costs of JD (after implementing a scenario).

⁵NPV of implementing a scenario, calculated as PV benefits for NCD (or NCD and JD) – PV cost of implementation.

Table 4. Input parameters and estimates, assumptions and sources of parameter estimates, and the mathematical formulas used to calculate the costs (Can\$, where 1 Can\$ = 0.823 US\$ at the time of the study; start-up costs, opportunity costs, and recurrent costs) incurred as a result of implementing Focus Farms (FF) in yr 1, and beyond yr 1, for Ontario dairy producers

Variable ID	Variable name	Formula	Estimate	Assumptions/notes
1	Number of FF meetings (/FF group per year)	—	4	Assumption
2	Number of FF groups (/year)	—	8	Assumption
3	Number of participants (/FF group)	—	12	Assumption
4	Average FF meeting duration (h)	—	6	Assumption
Start-up costs: Training				
5	Average cost of training FF facilitators	—	\$1,271.72	T. Nelson, University of Guelph, Guelph, ON; personal communication
6	Duration of training for FF facilitators (d)	—	2	Assumption
7	Lunch cost (/person per day)	—	\$12.00	Assumption
8	Hotel cost (/person per day)	—	\$125.00	Assumption
9	Training costs per facilitator	$(5) + (6) \times (7) + (8) \times 0.5$	\$1,358.22	Assume 50% require hotel
10	Number of FF facilitators	—	8	1 FF facilitator per FF group
TC	Total training costs	$(9) \times (10)$	\$10,865.76	—
Start-up costs: Administrative support				
11	Hours worked (/FF meeting)	—	60	T. Nelson; personal communication
12	Wage (/h)	—	\$20.00	Assumption
13	Consumables	—	\$200.00	Office space, phone, fax, internet, paper
AC	Total administrative costs	$(11) \times (12) + (13)$	\$1,400.00	—
Total start-up costs (TSC)		TC + AC	\$12,265.76	—
Opportunity cost of FF participants				
14	Marginal opportunity cost (/h)	—	\$17.33	Lang, 2010
15	Opportunity costs (/FF participant per FF meeting)	$(14) \times [(4) + 1]$	\$121.31	Assume 1 h of travel time
OC	Total opportunity costs (/FF group per FF meeting)	$(15) \times (3)$	\$1,455.72	—
Recurrent costs: Meetings				
16	Average meeting room cost (/FF meeting)	—	\$200.00	T. Nelson; personal communication
17	Average cost of meeting materials (/FF meeting)	—	\$5.00	Assumption
MC	Total meeting cost (/FF meeting)	$[(3) + 1] \times (7) + (16) + (17)$	\$361.00	Lunch provided for facilitator each meeting
Recurrent costs: Facilitator				
VFC	Veterinarian facilitator (VF) costs (/facilitator per FF meeting)	—	\$2,000.00	T. Nelson; personal communication
NFC	Non-veterinarian facilitator (NF) costs (/facilitator per meeting)	—	\$1,000.00	Assumption. Costs include meeting preparation and full-day facilitation fee
Recurrent costs: Facilitator assistant				
18	Hours worked (/FF meeting)	$(4) + 2$	8	2-h set-up/wrap-up
19	Wage (/h)	—	\$20.00	Assumption
FA	Facilitator aid costs (/FF meeting)	$(18) \times (19)$	\$160.00	—
Recurrent costs: Guest speaker				
GS	Average guest speaker costs (/FF meeting)	—	\$1,250.00	Assumption
Total recurrent costs: Veterinarian facilitator (TRCV) (/FF meeting)		MC + VFC + FA + GS $\times$ (0.5)	\$3,146.00	Assume guest speaker at 50% of FF meetings
Total recurrent costs: Non-veterinarian facilitator (TRCN) (/FF meeting)		MC + NFC + FA + GS $\times$ (0.5)	\$2,146.00	—
Total yr 1 FF implementation costs (veterinarian facilitator)		TSC + [OC + TRCV $\times$ (1)] $\times$ (2)	\$159,520.80	—
Total yr 1 FF implementation costs (non-veterinarian facilitator)		TSC + [OC + TRCN $\times$ (1)] $\times$ (2)	\$127,520.80	—
Total annual FF implementation costs beyond yr 1 (VF)		[OC + TRCV $\times$ (1)] $\times$ (2)	\$147,255.04	—
Total annual FF implementation costs beyond yr 1 (NF)		[OC + TRCN $\times$ (1)] $\times$ (2)	\$115,255.04	—

Table 5. Proportion of Focus Farm (FF) participants, and networked producers, that are assumed to implement each of the 7 management scenarios, and the resulting benefits (Can\$; where 1 Can\$ = 0.823 US\$ at the time of the study) that accrue to producers as a result of FF implementation each year

Variable number	Variable	Formula	Estimate	Assumption/ notes
1	Number of producers participating in FF each year	—	96	Table 2
2	Proportion of participants making an on-farm management change	—	81%	Assumption
3	Number of FF participants making an on-farm management change per year	$(1) \times (2)$	77.76	—
4	Number of producers networked per FF participant per year	—	2	Assumption
5	Total number of producers networked per year	$(3) \times (4)$	155.2	—
6	Proportion of networked producers making an on-farm management change	—	50%	Assumption
7	Total number of networked producers making an on-farm management change per year	$(5) \times (6)$	77.6	—
Scenario 1: Calf feeding changes				
8	Proportion of producers making an on-farm change that implement scenario 1	—	12.5%	Assumption ¹
9	Number of FF producers implementing scenario 1	$(3) \times (8)$	9.72	—
10	Number of networked producers implementing scenario 1	$(7) \times (8)$	9.72	—
11	Net present value (NPV) of scenario 1 (neonatal calf diarrhea, NCD)	—	—\$19.21	Table 3
12	NPV of scenario 1 (Johne's disease, JD, and NCD)	—	\$1,174.51	Table 3
13	Total annual net benefits from scenario 1 implementation ²	$\{[(8) + (9)] \times 0.25\} \times (11)$ $+ \{[(8) + (9)] \times 0.75\} \times (12)$	\$25,546.58	—
Scenario 2: Maternity pen management changes				
14	Proportion of producers making an on-farm change that implement scenario 2	—	10%	Assumption ¹
15	FF producers implementing scenario 2	$(3) \times (14)$	7.78	—
16	Networked producers implementing scenario 2	$(7) \times (14)$	7.78	—
17	NPV of scenario 2 (NCD)	—	—\$1,629.67	Table 3
18	NPV of scenario 2 (JD and NCD)	—	\$439.10	Table 3
19	Total annual net benefits from scenario 2 implementation ²	$\{[(14) + (15)] \times 0.25\} \times (17)$ $+ \{[(14) + (15)] \times 0.75\} \times (18)$	—\$1,821.90	—
Scenario 3: Maternity area structure changes				
20	Proportion of producers making an on-farm change that implement scenario 3	—	2.5%	Assumption ¹
21	FF producers implementing scenario 3	$(3) \times (20)$	1.94	—
22	Networked producers implementing scenario 3	$(7) \times (20)$	1.94	—
23	NPV of scenario 3 (NCD)	—	—\$701.03	Table 3
24	NPV of scenario 3 (JD and NCD)	—	\$1,702.08	Table 3
25	Total annual net benefits from scenario 3 implementation ²	$\{[(20) + (21)] \times 0.25\} \times (23)$ $+ \{[(20) + (21)] \times 0.75\} \times (24)$	\$6,422.79	—
Scenario 4: Calf feeding and maternity pen management changes				
26	Proportion of producers making an on-farm change that implement scenario 4	—	45.5%	Assumption ¹
27	FF producers implementing scenario 4	$(3) \times (26)$	35.38	—
28	Networked producers implementing scenario 4	$(7) \times (26)$	35.38	—
29	NPV of scenario 4 (NCD)	—	—\$1,732.83	Table 3

Continued

Table 5 (Continued). Proportion of Focus Farm (FF) participants, and networked producers, that are assumed to implement each of the 7 management scenarios, and the resulting benefits (Can\$; where 1 Can\$ = 0.823 US\$ at the time of the study) that accrue to producers as a result of FF implementation each year

Variable number	Variable	Formula	Estimate	Assumption/ notes
30	NPV of scenario 4 (JD and NCD)	—	\$1,365.35	Table 3
31	Total annual net benefits from scenario 4 implementation ²	$\{[(26) + (27)] \times 0.25\} \times (29)$ $+ \{[(26) + (27)] \times 0.75\} \times (30)$	\$62,709.38	—
Scenario 5: Calf feeding and maternity area structure changes				
32	Proportion of producers making an on-farm change that implement scenario 5	—	6.5%	Assumption ¹
33	FF producers implementing scenario 5	$(3) \times (32)$	5.05	—
34	Networked producers implementing scenario 5	$(7) \times (32)$	5.05	—
35	NPV of scenario 5 (NCD)	—	—\$825.30	Table 3
36	NPV of scenario 5 (JD and NCD)	—	\$2,543.30	Table 3
37	Total annual net benefits from scenario 5 implementation ²	$\{[(32) + (33)] \times 0.25\} \times (35)$ $+ \{[(32) + (33)] \times 0.75\} \times (36)$	\$25,794.90	—
Scenario 6: Maternity pen management and maternity area structure changes				
38	Proportion of producers making an on-farm change that implement scenario 6	—	13%	Assumption ¹
39	FF producers implementing scenario 6	$(3) \times (38)$	10.11	—
40	Networked producers implementing scenario 6	$(7) \times (38)$	10.11	—
41	NPV of scenario 6 (NCD)	—	—\$2,361.02	Table 3
42	NPV of scenario 6 (JD and NCD)	—	\$1,640.43	Table 3
43	Total annual net benefits from scenario 6 implementation ²	$\{[(38) + (39)] \times 0.25\} \times (41)$ $+ \{[(38) + (39)] \times 0.75\} \times (42)$	\$19,410.99	—
Scenario 7: Calf feeding, maternity pen management, and maternity area structure changes				
44	Proportion of producers making an on-farm change that implement scenario 7	—	10%	Assumption ¹
45	FF producers implementing scenario 7	$(3) \times (44)$	7.78	—
46	Networked producers implementing scenario 7	$(7) \times (44)$	7.78	—
47	NPV of scenario 7 (NCD)	—	—\$2,569.22	Table 3
48	NPV of scenario 7 (JD and NCD)	—	\$2,277.51	Table 3
49	Total annual net benefits from scenario 7 implementation ²	$\{[(44) + (45)] \times 0.25\} \times (47)$ $+ \{[(44) + (45)] \times 0.75\} \times (48)$ $(13) + (19) + (25) + (31)$ $(37) + (43) + (49)$	\$24,863.67	—
Total annual net benefits of Focus Farm implementation			\$192,861.98	—

¹Assumptions based on Roche et al. (2015).²Assume that 75% of those implementing a management scenario have JD and NCD issues and that the remaining 25% have only NCD issues.

Table 6. Present value (PV) costs (Can\$; where 1 Can\$ = 0.823 US\$ at the time of the study) start-up, recurrent, and opportunity costs), PV benefits (management scenarios 1 to 7), and net present value (NPV) (PV costs – PV benefits) of implementing Focus Farms (FF), with veterinarian or non-veterinarian facilitators, for 10 yr (discounted at 8% over a 10-yr period)

Variable	Estimate	Reference
Discount rate	8%	—
FF implementation costs		
Total FF start-up costs	\$12,265.76	Table 4
Annual recurrent costs for FF implementation with veterinarian facilitator ¹	\$100,672.00	
Annual recurrent costs for FF implementation with non-veterinarian facilitator ¹	\$68,672.00	
Annual opportunity costs of FF participants ^{1,2}	\$46,583.04	
PV costs for implementing FF for 10 yr ³		
PV start-up costs	\$20,613.63	—
PV recurrent costs (vet facilitator)	\$1,017,596.20	
PV recurrent costs (non-veterinarian facilitator)	\$694,139.05	
PV participants' opportunity cost	\$470,863.04	
PV costs of FF implementation for 10 yr (vet facilitator)	\$1,509,072.87	—
PV costs of FF implementation for 10 yr (non-veterinarian facilitator)	\$1,185,615.72	
Total annual net benefits of FF implementation ⁴		
Scenario 1: Calf feeding	\$25,546.58	Table 5
Scenario 2: Maternity pen management	–\$1,821.90	
Scenario 3: Structural barn changes	\$6,422.79	
Scenario 4: Calf feeding and maternity pen management	\$62,709.38	
Scenario 5: Calf feeding and structural barn changes	\$25,794.90	
Scenario 6: Maternity pen management and structural barn changes	\$19,410.99	
Scenario 7: Calf feeding, maternity pen management, structural barn changes	\$19,410.99	
PV benefits for implementing FF for 10 yr ³		
PV benefits of scenario 1	\$260,118.13	—
PV benefits of scenario 2	–\$18,550.77	
PV benefits of scenario 3	\$65,397.52	
PV benefits of scenario 4	\$638,513.79	
PV benefits of scenario 5	\$262,646.50	
PV benefits of scenario 6	\$197,644.84	
PV benefits of scenario 7	\$253,164.58	
Total PV benefits	\$1,658,934.60	—
NPV of FF implementation for 10 yr ⁵		
NPV for FF implementation with veterinarian facilitators	\$149,861.73	—
NPV for FF implementation with non-veterinarian facilitators	\$473,318.88	—

¹Values calculated assuming 8 new FF groups per year, 12 FF participants per group, 4 FF meetings per group (see Table 2).

²\$121.31 per FF participant per FF meeting (see Table 4).

³Assumptions: 8 new FF groups per year, 12 new FF participants per group, 4 FF meetings per group from yr 1 to 5. In yr 6, 8 new FF facilitators are trained; 16 new FF groups per year, 12 new FF participants per group, 4 FF meetings per group from yr 6 to 10. All PV calculations are discounted at 8% over 10 yr.

⁴Benefits are the NPV of implementing each management scenario over a 10-yr period, discounted at 8%. Calculated as PV benefits of management change – PV costs of implementing the management scenario. Values presented assume 81% of FF participants (77.76/yr) and 50% of networked producers (156/yr) implement 1 of the 7 management scenarios each year, and 75% of those that make on-farm changes have both JD and NCD (proportion of those implementing each scenario provided in Table 5).

⁵NPV of implementing FF over a 10-yr period. Calculated as total PV benefits – PV costs of FF implementation.

ternity pen management (3.75%/year), had the greatest impact.

Table 3 provides the PV costs of JD and NCD, discounted at 8% over 10 yr, and the NPV of implementing 7 unique management scenarios on an average 78-cow dairy farm in Ontario. For farms dealing with both JD and NCD, all 7 implementation scenarios resulted in a positive NPV, ranging from \$439 (scenario 2: maternity pen management changes) to \$2,543 (scenario 5: calf feeding and maternity area structure changes). For farms dealing with just NCD, all 7 implementation scenarios resulted in a negative NPV, ranging from –\$19.21 (scenario 1: calf feeding changes) to –\$2,569

(scenario 7: calf feeding, maternity pen management, and maternity area structure changes).

Figure 4 (a, b, c) presents tornado plots that express the sensitivity of the NPV of each individual management scenario (scenarios 1, 2, and 3) to changes in the discount rate, true within-herd prevalence of JD, incidence of NCD, and the cost, effect, and persistence of each management practice, assuming the farm is dealing with both JD and NCD. The NPV of each management scenario was most sensitive to the true within-herd prevalence of JD, incidence of NCD, and the effect of specific management practices performed in each scenario. Where applicable, the NPV was also sensitive

Figure 2. Tornado plot of the sensitivity of the estimated annual cost of Johne's disease (JD) on an average Ontario dairy herd (Can\$3,241.95; where 1 Can\$ = 0.823 US\$ at the time of the study) to changes in herd size, true within-herd prevalence, average decrease in milk production by parity group, milk price, odds of a *Mycobacterium avium* ssp. *paratuberculosis* (MAP)-infected cow by parity group, overall losses for each culled animal, and increased culling risk due to JD.

to the costs of calf feeding and maternity pen management. The NPV for all scenarios was least sensitive to the persistence of a given change and the discount rate. A reduction in the disease burden (prevalence of JD or incidence of NCD) led to negative NPV for all management scenarios. However, changes for all other management scenarios (regardless of whether they were positive or negative) resulted in positive NPV.

Figure 5 (a, b, c) presents tornado plots that express the sensitivity of the NPV of each individual management scenario (scenarios 1, 2, and 3) to changes in the discount rate, incidence of NCD, and the cost, effect, and persistence of each management practice, assuming the farm is only dealing with NCD. The NPV of each management scenario was most sensitive to changes in the incidence of NCD and the cost and effect of the specific management practices that were being performed in each scenario. Increases in the incidence of NCD (from 23 to 31%) resulted in a positive NPV for all scenarios. Positive NPV were also achieved when parameters were changed for calf feeding (Figure 5a); however, changes for all other management scenarios

(regardless of whether they were positive or negative) resulted in negative NPV.

CBA for FF Implementation

The total implementation costs of FF in yr 1 (8 FF groups, 96 participants, 4 meetings/group) were estimated to be \$159,521 and \$127,521 when using veterinarian and non-veterinarian facilitators, respectively (Table 4). With \$12,266 of start-up costs incurred in yr 1, the total annual implementation costs of FF beyond yr 1, assuming no additional FF facilitators are trained, were estimated to be \$147,255 and \$115,255 when using veterinarian and non-veterinarian facilitators, respectively.

Based on assumptions about the proportion of FF participants, and networked producers, that would implement each of the 7 management scenarios, the total net benefits of FF implementation in yr 1 were estimated to be \$162,926 (Table 5). Overall, 6 of the 7 management scenarios resulted in positive net benefits as a result of FF implementation, with the majority of

Figure 3. Tornado plot of the sensitivity of the estimated annual cost of neonatal calf diarrhea (NCD) on an average Ontario dairy herd (Can\$1,389.90; where 1 Can\$ = 0.823 US\$ at the time of the study) to changes in herd size, incidence, proportion of severe cases, average days treated, cost to treat mild cases, cost to treat severe cases, case fatality rate, marginal feed costs of pre-weaned calves, the average age of mortality, and the opportunity costs of mortality.

producers implementing management scenario 4 (calf feed and maternity pen management changes). However, scenario 2 (maternity pen management changes only) resulted in a loss of only \$1,822.

Table 6 presents the PV costs (start-up, recurrent, and opportunity costs), PV benefits (management scenarios 1 to 7), and NPV (PV costs – PV benefits) of implementing FF, with veterinarian or non-veterinarian facilitators, for 10 yr. Overall, the implementation of FF with veterinarian facilitators yielded an NPV of \$149,862, whereas the implementation of FF with non-veterinarian facilitators yielded a larger NPV of \$473,319.

The estimated NPV of FF implementation, with veterinarian facilitators, was most sensitive to changes in the prevalence of JD, incidence of NCD, and the cost of calf feeding changes; it was least sensitive to the start-up and recurrent costs of FF (Figure 6). Overall, a decrease in the prevalence of JD (10 to 5%) decreased the NPV from \$149,862 to –\$4,077,069, whereas a within-herd prevalence of 15% increased the NPV to \$4,379,069. The estimated NPV of FF implementation with non-veterinarian facilitators was similarly sensi-

tive (data not shown), with a 5% prevalence of JD reducing the NPV to –\$3,562,032, and a prevalence of 15% increasing the NPV to \$5,987,228. Global sensitivity analysis yielded a worst-case scenario (all model parameters fixed at their most unfavorable endpoint) of –\$13,532,531. Conversely, the best-case scenario would yield a NPV of \$35,099,032. Last, the program NPV was more sensitive to changes in burden of disease (–\$11,232,012 to \$12,013,465) than to changes in the impact of each scenario (–\$9,332,059 to \$10,191,893) and program implementation parameters (–\$3,478,934 to \$3,984,431).

Based on the costs and assumptions above, if the total cost of FF implementation were put on the farmer, it would cost \$294/producer per FF meeting (\$1,176/producer per year) and \$211/producer per FF meeting (\$843/producer per year), when using veterinarian and non-veterinarian facilitators, respectively. Assuming a \$50,000 subsidy is obtained for FF implementation, the cost is reduced to \$164/producer per FF meeting (\$656/producer per year) and \$81/producer per FF meeting (\$322/producer per year) for veterinarian and non-veterinarian facilitators, respectively.

Figure 4. Tornado plot of the sensitivity of the net present value (NPV) of (a) calf feeding changes (Can\$1,174.51); (b) maternity pen management changes (Can\$439.09; where 1 Can\$ = 0.823 US\$ at the time of the study); and (c) maternity area structure changes (Can\$1,702.08) to changes in the discount rate, true within-herd prevalence of Johne's disease (JD), incidence of neonatal calf diarrhea (NCD), and the cost, effect, and persistence of each management practice, assuming the farm is dealing with a true within-herd JD prevalence of 10% and an incidence of NCD of 23%.

Figure 4 (Continued). Tornado plot of the sensitivity of the net present value (NPV) of (a) calf feeding changes (Can\$1,174.51); (b) maternity pen management changes (Can\$439.09; where 1 Can\$ = 0.823 US\$ at the time of the study); and (c) maternity area structure changes (Can\$1,702.08) to changes in the discount rate, true within-herd prevalence of Johne's disease (JD), incidence of neonatal calf diarrhea (NCD), and the cost, effect, and persistence of each management practice, assuming the farm is dealing with a true within-herd JD prevalence of 10% and an incidence of NCD of 23%.

DISCUSSION

The partial budget for JD estimated the annual herd cost of JD for a 78-cow dairy farm with a true within-herd prevalence of 10%, to be \$3,242. The estimate for apparent within-herd JD prevalence was obtained from data reported by Sorge et al. (2010, 2011a), which was based on the use of milk ELISA tests. Given the relatively poor sensitivity of this test (52%), estimates of the number of MAP-infected cows and the subsequent losses associated with MAP infection would be underestimated when this estimate is used. Hence, the apparent within-herd prevalence was adjusted to estimate the true within-herd prevalence of JD. However, Tiwari et al. (2006) noted there was little consensus on the appropriate adjustments needed to accurately estimate true prevalence of MAP infection; as such, even estimates obtained using true prevalence should be interpreted with caution and considered when interpreting the results of this study. Sensitivity analysis provides a more robust understanding of the influence of this estimate, with herd costs ranging from \$1,621 (5% prevalence) to \$4,863 (15% prevalence).

Nearly 60% of the estimated annual herd cost (\$1,889) resulted from reduced milk production in MAP-infected cows. It is well accepted that MAP infection is associated with a decrease in milk production (VanLeeuwen et al., 2002; Hendrick et al., 2005; Sorge et al., 2011b; McAloon et al., 2016); however, estimates tend to vary based on the stage of infection (Benedictus et al., 1987), parity (Wilson et al., 1993; McAloon et al., 2016), sampling and testing protocols (Tiwari et al., 2006), and the diagnostic accuracy of tests (Hendrick et al., 2005; McAloon et al., 2016). Two Canadian partial budget models estimating the annual cost of JD (Chi et al., 2002; Tiwari et al., 2008) assumed that milk production among MAP-infected cows did not decrease until the fourth lactation. Thus, lower estimates of the annual herd cost of reduced milk production were found compared with this study. This is primarily due to our consideration of reduced milk production in earlier parity groups. The milk loss estimates provided by Sorge et al. (2011b) showed significant milk losses in earlier lactations, and were considered most appropriate for this model, given they used recent, Canadian-specific data obtained using milk ELISA tests. These data, along

Figure 5. Tornado plot of the sensitivity of the net present value (NPV) of (a) calf feeding changes (–Can\$19.22; where 1 Can\$ = 0.823 US\$ at the time of the study); (b) maternity pen management changes (–Can\$1,629.67); and (c) maternity area structure changes (–Can\$701.03) to changes in the discount rate, incidence of neonatal calf diarrhea (NCD), and the cost, effect, and persistence of each management practice, assuming the farm is dealing with an incidence of NCD of 23% (i.e., no Johne's disease).

Figure 5 (Continued). Tornado plot of the sensitivity of the net present value (NPV) of (a) calf feeding changes (–Can\$19.22; where 1 Can\$ = 0.823 US\$ at the time of the study); (b) maternity pen management changes (–Can\$1,629.67); and (c) maternity area structure changes (–Can\$701.03) to changes in the discount rate, incidence of neonatal calf diarrhea (NCD), and the cost, effect, and persistence of each management practice, assuming the farm is dealing with an incidence of NCD of 23% (i.e., no Johne's disease).

with data provided by Nielsen et al. (2002), allowed for a more realistic estimate of the average reduction in milk production among cows in each parity group.

The total herd cost of JD per cow estimated in this study (\$41.56) was lower than the per-cow costs reported in other Canadian economic assessments. Chi et al. (2002) reported a total cost of \$49.24 per cow for a 50-cow dairy herd with an apparent within-herd prevalence of 7%, while Tiwari et al. (2008) reported a total cost of \$49.05 per cow for a 61-cow dairy herd with an apparent prevalence of 12.7%. Our findings fall within similar ranges to those published from the United States (Can\$21 to Can\$43/cow; Ott et al., 1999; Bhattarai et al., 2013) and the UK (Can\$41.65/cow; Gunn et al., 2004). Some of the primary differences observed relate to other models considering mortality and reproductive losses due to MAP infection, where our model did not. As McKenna et al. (2006) and Garcia and Shalloo (2015) note, research on the effect of JD on fertility, mortality, and predisposition to other diseases, such as mastitis, is inconsistent. Similar to reduced slaughter value, these findings are more likely to be attributed to clinical cases of JD. Given the low expected proportion of clinical cases in the context of Ontario, a decision

was made to not monetize these losses. As a result, our estimate of the total annual herd costs of JD may be considered conservative.

Given the fecal–oral transmission of MAP, any on-farm management practice implemented to break this transmission cycle is likely to have positive effects on other diseases, most notably NCD (McKenna et al., 2006). The primary costs associated with NCD in dairy calves primarily relate to treatment costs and mortality due to NCD (Gunn, 2003). Although recent Ontario estimates were available for the incidence (Windeyer, 2013) and case fatality rate of NCD (Windeyer et al., 2014), a lack of estimates on the cost of treatment, mortality, feed costs, as well as the severity of NCD cases make accurate assumptions on the treatment costs difficult. With the assumptions provided, the annual herd cost of NCD for an average 78-cow dairy herd was estimated to be \$1,390 (\$36 per heifer calf). Other estimates of the cost of NCD per calf vary (Gunn, 2003; Sischo et al., 1990), likely due to differences in geographic location, herd management, herd recruitment, and sampling procedures. Sensitivity analysis provided a better understanding of the robustness of estimates, with final estimates being most sensitive to incidence of

NCD, average number of days treated, and the proportion of severe cases of NCD.

We assumed that producers considering on-farm changes for JD control would implement 1, 2, or all 3 of the management practices considered, resulting in 7 possible management scenarios. For those dealing with JD and NCD, all 7 strategies resulted in a positive NPV, with the most useful scenario being scenario 5, in which producers implemented changes to maternity area structure combined with calf feeding changes. The primary reason for the success of this scenario was the low cost for implementation, relative to the other management scenarios. Although changes to maternity area structure require a large upfront cost, the permanent nature of the change means no further costs are incurred

and persistence of the change is 100%. By combining these changes with calf feeding changes, which have the lowest recurrent costs, a moderate effect on JD, and a high effect on NCD, producers are able to keep their costs low. Interestingly, sensitivity analysis demonstrated that the costs of implementing nonpermanent changes (calf feed, maternity pen management) tended to be more influential on NPV than their corresponding effects on JD and NCD. However, the inverse was true for structural changes, where the effect was more influential. This further highlights the benefit of structural or permanent changes that correspond to a higher one-time investment, allowing benefits to accrue over time, as opposed to routine practices that require consistent working time to be expended to realize benefits.

Figure 6. Tornado plot of the sensitivity of the net present value (NPV) of Ontario Focus Farm (FF) implementation over a 10-yr period (Can\$149,861.73; where 1 Can\$ = 0.823 US\$ at the time of the study) to changes in the discount rate; proportion of producers with Johne's disease (JD) and neonatal calf diarrhea (NCD); cost, persistence, and effect of each on-farm management change; number of FF participants; number of networked producers; proportion of networked producers making changes; proportion of FF participants making changes; proportion of those making changes implementing 2 changes; start-up, opportunity, and recurrent costs; true within-herd prevalence of JD; and incidence of NCD.

Given that not all participants in FF will be dealing with JD on their farms, the NPV of each management scenario on farms dealing just with NCD was assessed. Interestingly, all 7 management strategies resulted in a negative NPV, suggesting that, although these practices do reduce the burden of NCD, the costs of the change outweigh the benefits. Recommendations for prevention of NCD typically focus on improved hygiene and quantity of colostrum feeding, as well as use of vaccination (Rossini, 2004; NADIS, 2014). Improved calf feeding changes were considered in this study and were expected to have a high impact on the incidence of NCD, which, when solely implemented, resulted in an NPV of $-\$19$. Sensitivity analysis suggested that positive net benefits were attainable if the incidence of NCD increased (i.e., a larger impact of implemented changes on calf health), costs of calf feeding were reduced, or their efficacy or persistence was improved. Therefore, ensuring that producers perform these behaviors consistently over time is a key factor in the realization of benefits. Overall, estimates on the cost-effectiveness of various implementation scenarios suggest that the adoption of multiple management changes proposed here is only beneficial if the farm is dealing with both JD and NCD.

The NPV of FF implementation was most sensitive to burden of disease (JD and NCD). A reduction in JD prevalence below 10%, a reduction in NCD incidence below 23%, or both led to a negative NPV. Conversely, JD and NCD morbidity above those values resulted in considerable gains. Another important and highly sensitive assumption was the proportion of producers that were assumed to be dealing with both JD and NCD on their farms. We assumed that, as the FF process was designed to address JD control specifically, the majority of producers implementing changes would be dealing with both JD and NCD. Importantly, sensitivity analysis revealed that a decrease in this proportion (from 75 to 50% of participants with JD and NCD) would result in $-\$1,661,090$ when veterinarian facilitators were used. The global sensitivity analysis further demonstrated this point, with NPV being significantly more sensitive to changes in disease status than program implementation parameters. Therefore, the success of the program is determined, in part, by the current burden of disease that exists on participants' farms. It would therefore be reasonable to recommend that only producers who are dealing with a high prevalence of JD (or NCD) should be considered for the program.

The most influential program component on program NPV was the network effect of participants. One of the goals of agricultural extension is to educate producers in the hopes that they will not only use that information to improve their own farm situation but relay that

information to other producers throughout their own social networks (Andreata, 2001; Fisher, 2005). Each FF participant was expected to relay information about the change they had made to 2 other producers, 50% of whom were assumed to implement that same change. Sensitivity analysis demonstrated that a positive NPV is dependent upon network effects when there are fewer than 100 participants in a given year. Although a negative NPV would therefore be achieved if no non-participants adopted changes as a result of networking with participating producers, a positive NPV would easily be attained with an increase in participation. For example, an increase in the number of FF participants from 96/yr to 150/yr resulted in a NPV of $\$1,083,012$.

If all FF costs are passed on to the FF participants, then the cost would be nearly $\$300$ /producer per meeting (using veterinarian facilitators). This cost is likely too high to attract much participation among producers. In addition, given that the reduction of prevalence of JD represents a positive not only for producers, but also for veterinarians, and the dairy industry in general, we suggest that an annual subsidy should be provided to implement the FF process. Investments from dairy industry organizations themselves, leveraged by provincial and federal government agencies, would be a reasonable expectation, given the importance of JD from an animal health, food safety, and consumer assurance perspective. The result of a $\$50,000$ annual subsidy for FF implementation would reduce the cost to roughly $\$160$ /producer per meeting if using veterinarian facilitators. Ideally, the cost would be reduced to $\$100$ per producer per meeting (requiring a subsidy of $\$74,500$). Alternatively, non-veterinarian facilitators could be used to reduce this cost, in which case a $\$50,000$ subsidy would result in a cost of roughly $\$80$ /producer per meeting. Although these subsidies would need to be considerably higher to scale this process in Ontario (to reach $\sim 3,500$ dairy producers), previous investments in Canada for JD control have been in the tens of millions (contributing to research, testing, producer support, and education). Given the positive economic case that is made for specific scenarios here, future investment in JD should consider this form of program.

CONCLUSIONS

The total annual herd cost of JD to an average Ontario dairy farm, with a true within-herd prevalence of 10%, was estimated to be $\$3,242$. The total annual herd cost of NCD to an average Ontario dairy farm, with an incidence rate of 23%, was estimated to be $\$1,390$. Implementation of various combinations of calf feeding changes, maternity pen management changes, and maternity area structure changes resulted in vary-

ing net benefits in these simulations, depending on the presence of JD and NCD, the true burden of disease, and the specific management practices implemented. Overall, the implementation of the FF process over a 10-yr period yielded positive net benefits, suggesting that its implementation would be valuable for reducing the burden of JD and NCD on Ontario dairy farms.

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