Partial budget analysis of sow *Escherichia coli* vaccination

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Summary: *We evaluated the profitability of vaccinating sows against* Escherichia coli *using a partial budget analysis incorporated into a computer spreadsheet. Herd inputs intended to approximate the average swine operation were used to provide generalizable results. Vaccine efficacy was estimated using previous reports of reduced diarrhea morbidity and mortality in neonatal piglets associated with vaccination. Our results indicate that the average swine producer who does not currently vaccinate sows against* E. coli *could expect to generate $5.51 per sow in additional yearly profits by implementing a vaccination program. Losses attributable to piglet diarrhea would be reduced by nearly $10 per sow per year. Investment in a sow* E. coli *vaccination program is expected to result in a 124% return on investment. Sensitivity analysis found that these results were fairly insensitive to variations in vaccine efficacy, market value of pigs, vaccine cost, liveborn litter size, and diarrhea morbidity and mortality rates without vaccination. Threshold analysis suggests that herds with diarrhea morbidity and mortality rates in 1- to 14-day-old piglets of at least 3.5% and 0.8%, respectively, could expect returns adequate to justify investment. We therefore predict that* E. coli *vaccination of sows would be a cost-effective health management strategy for many United States swine producers.*

Enterotoxigenic *Escherichia coli* infections are commonly associated with diarrhea problems in neonatal piglets.[1-3] Approximately half of all swine producers in the United States vaccinate gestating sows in order to provide passive lacteal immunity against *E. coli* infection to suckling piglets.[4] We recently reported that the risk of diarrhea morbidity and mortality in piglets up to 14 days of age was lower among herds that employed sow *E. coli* vaccination programs.[5,6] That observation, together with experimental work[3] support the biologic efficacy of commercial *E. coli* vaccines in swine herds. However, the cost-effectiveness of swine *E. coli* vaccination programs has not been addressed. When only biologic efficacy is considered, the use of economically impractical management practices may be perpetuated. We therefore used the results of the National Animal Health Monitoring System (NAHMS:USDA:APHIS:VS) National Swine Survey (NSS)[4] and estimates of reduced piglet diarrhea morbidity and mortality associated with the use of maternal *E. coli* vaccination[5,6] to evaluate the profitability of *E. coli* vaccination of sows.

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Methods

The profitability of vaccinating sows against *E. coli* was analyzed using a partial budgeting technique. The partial budget was incorporated into a spreadsheet (Lotus Development Corporation, Cambridge, Massachusetts), closely following a format previously presented by DeGraves and Fetrow.[7] Data were used to approximate the average swine herd that does not currently vaccinate sows against *E. coli.* We considered a 23-kg feeder pig to be the production endpoint for this analysis.

As with any budget, certain input assumptions are required. This analysis assumes that:

- diarrhea morbidity and mortality in piglets greater than 14 days of age is not affected by vaccination of sows against *E. coli*. Most piglet morbidity and mortality, including that attributed to diarrhea, occurs during the first 2 weeks postpartum;[8]
- piglets saved through reduced death loss will not differ from other piglets in costs to raise to market weight and in market value; and
- other than intervention costs, the cost of production per sow (i.e., the cost of raising a litter to weaning) would not change due to reduced diarrhea morbidity and mortality.

Description of the partial budget

The partial budget is divided into seven sections designed to separately present important components of the analysis (see Table 1).

Section I: Herd inputs

Herd inputs used for this analysis were estimated from national averages where possible, except for the number of sows and gilts. A herd size of 500 breeding females, with 20% gilts, was used as an example. The partial budget estimates of intervention effects on per-sow profitability are independent of herd size. Average litters per female per year and piglets born alive per litter were estimated from reported national averages.[8,9] Labor costs and labor required per morbidity and mortality are estimates. Morbidity treatment costs were estimated to be $0.04 per day for a 3-day antibiotic treatment regimen. We assume that when one sick piglet is observed that the entire litter generally receives treatment. However, due to clustering of diarrhea within litters, each recorded morbidity represents approximately two piglets that receive treatment. Thus, we estimate a drug cost of $0.24 per morbidity (i.e., $0.04 per day × 3 days × 2 piglets). The variable costs per piglet weaned are the estimated costs required to raise a piglet from wean-

Table 1

Partial budget for estimating the cost-effectiveness of sow *Escherichia coli* vaccination

I	**Herd Inputs**		
	Sows	400	
	Gilts	100	
	Litters per female per year	2.2	
	Piglets per litter	9.9	
	Labor $ per hour	$5.00	
	Hours labor per morbidity	0.5	
	Hours labor per mortality	0.05	
	Drug cost per morbidity	$0.24	
	Variable costs per pig weaned	$8.00	
	Piglet value as 23-kg feeder	$40.00	
II	**Observed proportion of population with clinical disease**		
	Diarrhea morbidity 1 to 14 days	8.8%	
	Diarrhea mortality 1 to 14 days	1.9%	
III	**Intervention description**		
	Costs per sow		
	Labor (hour)	0.025	
	Vaccine	$0.99	
	Syringes	$0.10	
	Cases prevented (% of rate without intervention)		
	Diarrhea morbidity 1 to 3 days	0.34	
	Diarrhea morbidity 4 to 14 days	0.76	
	Diarrhea mortality 1 to 3 days	0.38	
	Diarrhea mortality 4 to 14 days	0.58	
IV	**Disease costs**	*Without*	*With*
	Expected cases per year	*intervention*	*intervention*
	Diarrhea morbidity	958	553
	Diarrhea mortality	207	111
	Costs attributable to piglet diarrhea		
	Drugs	$230.00	$132.78
	Labor	$2447.53	$1410.77
	Death loss	$8276.40	$4427.87
	Total loss per year	$10,953.92	$5971.42
	Loss per sow per year	$21.91	$11.95
	Total preventable loss per year	$4982.50	
	Preventable loss per sow per year	$9.97	
V	**Intervention costs**		
	Material costs	$1308.00	
	Labor costs	$150.00	
	Increased variable costs—weaning to 23 kg	$769.71	
	Total program costs per year	$2227.71	
	Total program costs per sow per year	$4.46	
VI	**Profit analysis**		
	Total profit from intervention	$2754.80	
	Profit per sow per year from intervention	$5.51	
VII	**Investment summary**		
	Return on investment	124%	
	Intervention costs per sow per year	$4.46	
	Time required to implement (hours)	30	
	Profit per hour of intervention	$91.83	

ing to 23 kg market weight. The average market value of a piglet is based on the estimated 10-year average value of $40 for a 23-kg feeder pig.

Section II: Observed proportion of population with clinical disease

The observed proportions of clinical disease are the proportions of piglets born alive that are observed with diarrhea morbidity or mortality during the first 14 days of life. Our estimates were obtained from the previously reported risk factor analyses[5,6] of NSS data by calculating the average expected rates of these conditions among herds that did not vaccinate sows against *E. coli*.

Section III: Intervention description

The intervention description section of the partial budget details the direct costs and reduction in disease occurrence associated with an *E. coli* vaccination program. Labor was estimated at 1.5 minutes per dose administered. The local cost of *E. coli* vaccine, $0.99 per dose, was used for this analysis. The expected reduction in diarrhea morbidity and mortality rates are the adjusted odds ratios for vaccinated versus nonvaccinated herds reported from analysis of NSS data.[5,6]

Section IV: Disease costs

Total direct costs attributable to treatment of diarrhea morbidity and death loss, both with and without vaccination, are summarized in the disease costs section. The expected number of cases without vaccination were obtained by calculating the expected number of piglets from information in Section I, and multiplying by the expected rates of diarrhea morbidity and mortality reported in Section II. The expected number of cases with vaccination was calculated by multiplying the expected cases without vaccination by the appropriate odds ratios, weighted for the expected proportion of cases within each appropriate age group.

Sections V, VI, and VII: Intervention costs, profit analysis, investment summary

The remaining sections of the partial budget summarize the intervention costs and expected returns resulting from the intervention. The intervention costs assume that all producers will follow a typical program in which gilts are vaccinated twice prior to farrowing and sows once before each farrowing. Return on investment was calculated as the expected profits resulting from intervention expressed as a percentage of the intervention costs.

Threshold and sensitivity analysis

We used a threshold analysis to identify the rates of diarrhea morbidity and mortality in a herd at which investment in an *E. coli* vaccination program would be financially justified. We considered a return on investment of 13% or greater to be adequate to justify investing in the intervention. We also investigated the sensitivity of the partial budget to changes in individual inputs by varying the value of one input while holding the values for all other inputs constant. The sensitivity analysis was used to estimate the effects of variations in herd incidence of diarrhea morbidity and mortality without vaccination, the market value of piglets, vaccine cost, and liveborn litter size. We also examined the sensitivity of the partial budget to vaccine efficacy by simultaneously varying the four odds ratios in Section III by fixed percentages.

Results

Given our initial assumptions and using the described information, we estimate that the average United States swine herd that does not vaccinate sows against *E. coli* could expect to generate additional yearly profits of $5.51 per sow by implementing a vaccination program (Table 1). Losses attributable to piglet diarrhea would be reduced by nearly $10 per sow yearly. Investment in a sow *E. coli* vaccination program would be expected to result in a 124% return on investment. Our threshold analysis suggests that herds with diarrhea morbidity and mortality rates in 1- to 14-day-old piglets of at least 3.5% and 0.8%, respectively, could expect returns adequate to justify investment in the intervention.

The sensitivity analysis indicates that the partial budget is fairly insensitive to variations in the inputs examined over reasonable ranges of operating values. Vaccination would remain profitable with as reduction of up to 73% in vaccine effectiveness at preventing morbidity and mortality (Figure 1). When the market value of piglets is varied, vaccination would remain profitable above a price of $11.37 per piglet (Figure 2). Additional sensitivity analysis found the break-even values for vaccine cost and average liveborn piglets per litter to be $3.28 per dose (Figure 3) and 3.4 pigs per litter, respectively. Vaccination was predicted to remain profitable when the diarrhea mortality rate in piglets up to 14 days of age without vaccination was greater than 0.2% (Figure 4), and across all values of nonvaccinated diarrhea morbidity rates (Figure 5).

Discussion

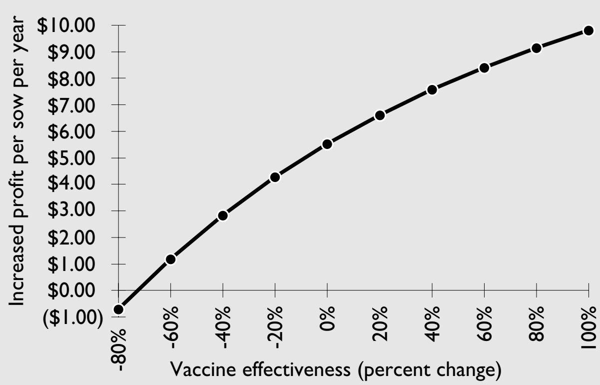
Partial budgeting allows us to estimate the financial consequences of a herd-health intervention program, here *E. coli* vaccination of sows. A partial budget considers only the income and costs that are likely to be influenced by the proposed intervention. Thus, the budgeting process is simplified and more readily applied to the field situation. Veterinarians and producers can use this technique to objectively evaluate the cost-effectiveness of potential management changes when reasonable estimates of production effects are available. This method is appropriate for relatively minor management changes with a limited time horizon, when consideration of the time value of money is not justified.

In this report, data were used to approximate the average swine herd that does not currently vaccinate sows against *E. coli.* Therefore, the primary question addressed is whether the average swine operation that does not vaccinate would be financially justified in beginning a vaccination program. The expected rates of diarrhea morbidity and mortality for herds that do and that do not currently vaccinate are closely related to the odds ratios used to estimate vaccine efficacy. Thus, discontinuing a current vaccination program would be expected to have a similar effect on profitability for the average producer, but in the opposite direction. The spreadsheet is designed so that data from individual herds can be substituted for evaluation. Thus, reasonable herd-specific recommendations can be made.

The partial budget is independent of the number of females in the herd, but because gilts require an extra vaccination, the proportion of gilts in the population is important. An average of 20% gilts was estimated from Dial, et al.[10] Average litters-per-female-per-year and piglets-born-alive-per-litter were estimated from reported national averages.[8-10] We are assuming that averages for herds that do not currently vaccinate sows against *E. coli* are not different from herds that do vaccinate for these values.

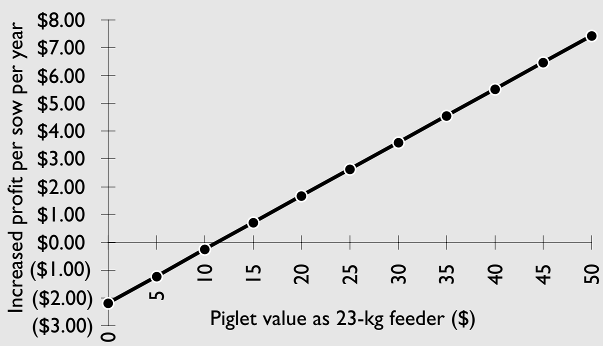
The estimates of diarrhea morbidity and mortality rates used in this analysis were obtained from the risk factor analysis of NSS data[5,6] by calculating the average expected rates among herds that did not vaccinate sows against *E. coli*. That analysis examined daily risk separately for piglets aged 1–3 days and 4–14 days. However, for simplicity, we have designed the partial budget so that producers enter observed diarrhea morbidity and mortality rates for the entire 14-day period. When using this partial budget to make individual herd decisions, producers may be better able to provide accurate estimates of rates for the entire 2-week period. Our estimates were obtained by summing the average daily risk predicted by the risk factor analysis across the 14-day period of interest. We assume that when one sick piglet is ob-

Figure 1



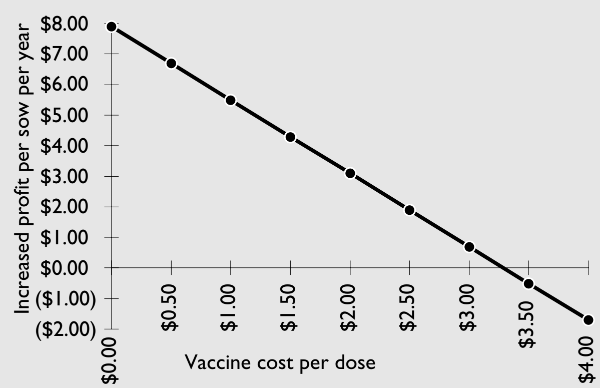
Profit versus vaccine effectiveness for sow *Escherichia coli* vaccination

Figure 2



Profit versus piglet value at weaning for sow *Escherichia coli* vaccination

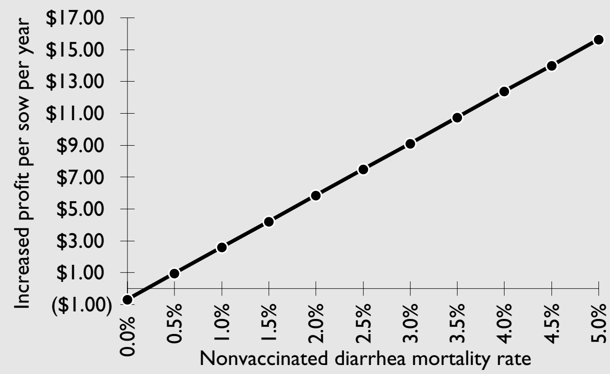
Figure 3



Profit versus vaccine cost for sow *Escherichia coli* vaccination

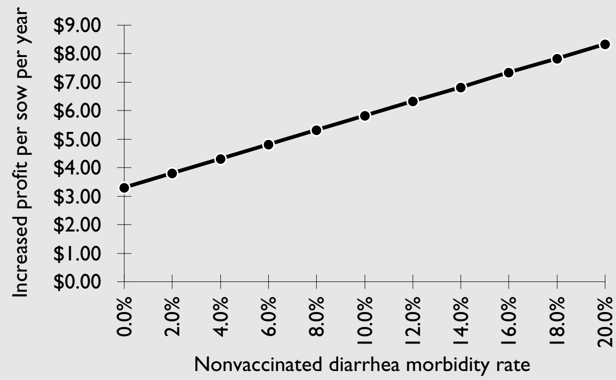
served, the entire litter generally receives treatment. However, due to clustering of disease within litters, each morbidity does not represent one litter that receives antibiotic treatment. Our estimates of within-litter clustering of diarrhea and the observed age distribution of cases from NSS data suggest that each morbidity represents approximately two piglets that will receive treatment. We assume that any piglet reported as a mortality that was not previously reported as a morbidity

Figure 4



Profit versus diarrhea mortality rate without vaccination for sow *Escherichia coli* vaccination

Figure 5



Profit versus diarrhea morbidity rate without vaccination for sow *Escherichia coli* vaccination

did not receive treatment. Thus, labor required for 3 days of antibiotic treatment has been associated only with diarrhea morbidity, so that the expected labor is greater than for diarrhea mortality.

Our results suggest that the average United States swine herd that does not currently vaccinate could realize $5.51 in additional profits per sow yearly by implementing an *E. coli* vaccination program. The average swine producer that currently vaccinates sows is similar to the average producer that does not vaccinate. Thus, we would predict a similar reduction in profits for herds that currently vaccinate if that vaccination program were discontinued. The additional profits expected from implementing a vaccination program are not large on a profit-per-sow basis. On a herd basis, however, they can be significant. Our expected return on investment and profit-per-hour of intervention should be attractive to any producer.

Our threshold analysis found that returns adequate to justify investment in an *E. coli* vaccination program would be realized at relatively low rates of herd diarrhea morbidity and mortality. In addition, our sensitivity analysis found that the results are fairly insensitive to changes in inputs. Thus, we predict that *E. coli* vaccination of sows is a cost-effective health management strategy for many United States swine producers. It is unlikely that the truly "average" herd actually exists. However, herd-specific decisions could easily be supported by substituting information for individual herds into the partial budget.

Our results are dependent upon estimates of *E. coli* vaccine effectiveness which we previously reported as adjusted odds ratios representing the expected reduction in diarrhea morbidity and mortality for vaccinated versus nonvaccinated herds.[5,6] These estimates were based on data from over 700 swine herds selected to represent much of the United States swine population. Hence, we believe they provide valid estimates of differences between vaccinated and nonvaccinated herds. While other unmeasured factors may have resulted in these differences, experimental data support the efficacy of *E. coli* vaccination of sows for reducing piglet diarrhea.[3] We estimate that the observed effectiveness of the vaccine could be reduced by approximately 70% and still remain profitable. A 70% reduction would be outside the 95% confidence intervals reported for each of the odds ratios used in this analysis.[5,6]

Normal cycles in the swine industry result in large fluctuations in the market value of a feeder pig over time. The relatively low break-even market value of approximately $11 indicates that an *E. coli* vaccination program would remain cost-effective even in times of more unfavorable market conditions. Likewise, the break-even cost of the vaccine of over $3 per dose is well above our locally observed maximum cost of $1.36 per dose.

The average liveborn piglets per litter at which a vaccination program is predicted to break even, approximately 3.5 piglets, is likely below the point at which an operation could continue to operate. Average litter size of an operation would not therefore be expected to influence the decision to implement a vaccination program. Vaccination is predicted to be profitable at all possible nonvaccinated rates of diarrhea morbidity, and above a nonvaccinated diarrhea mortality rate of 0.2%. Thus, nearly any level of piglet diarrhea in a herd could potentially be addressed cost-effectively with maternal *E. coli* vaccination.

Our results support the general cost-effectiveness of sow vaccination programs designed to provide passive lacteal immunity to piglets against enterotoxigenic *E. coli*. The spreadsheet format allows for easy substitution of herd-specific information to generate individual herd recommendations. In addition, the spreadsheet could be modified to assess the impact of other possible herd health or management interventions. A copy of the partial budget spreadsheet is available from the authors upon request.

Implications

- The average swine producer who does not currently vaccinate sows against *E. coli* could expect to generate $5.51 per sow in additional yearly profits, or a 124% return on investment by implementing a vaccination program.
- Swine herds with diarrhea morbidity and mortality rates of at least 3.5% and 0.8%, respectively, in 1- to 14-day-old piglets could expect returns adequate to justify investing in an *E. coli* vaccination program.
- Individual herd variations in vaccine effectiveness, market value of pigs, vaccine cost, litter size, and diarrhea morbidity and mortality rates over reasonable operating ranges are not expected to influence the profitability of a vaccination program.

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