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Calculating the Production Loss Avoided by Disease Control

by

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March 1997

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'The overall goal of this project is to develop and evaluate the .necessary tools to provide decision-makers with reliable animal health information which is placed in context and analysed appropriately in both Thailand and Australia. This goal will be achieved by improving laboratory diagnostic procedures; undertaking research to obtain cost-effective population referenced data; integrating data sets using modern information management technology, namely a Geographical Information System (GIS); and providing a framework for the economic evaluation of the impact of animal diseases and their control.

A number of important diseases will be targeted in the project to test the systems being developed. In Thailand, the focus will be on smallholder livestock systems. In Australia, research will be directed at the northern beef industry as animal health information for this sector of livestock production is presently scarce.'

For more information on *Research Papers and Reports Animal Health Economics* write to Professor Clem Tisdell (c.tisdell@economics.uq.edu.au) or Dr Steve Harrison,(s.harrison@uq.edu.au) Department of Economics, University of Queensland, Brisbane, Australia, 4072.

CALCULATING THE PRODUCTION LOSS AVOIDED BY DISEASE CONTROL

ABSTRACT

This paper initially outlines the effects diseases can have on livestock production then describes the development of a method to estimate the production loss avoided due to the control of a disease by vaccination. The method involves estimation of individual production loss due to disease and the number of cases of disease avoided by vaccination. The method developed is then applied to determine the production loss avoided due to vaccination against *B. bovis*.

Keywords: Animal health, *Bovine babesiosis*, vaccination of livestock.

JEL Classification: Q16

CALCULATING THE PRODUCTION LOSS AVOIDED BY DISEASE CONTROL

1. Introduction

The level of production loss due to disease varies with the severity of the disease and the specific physiological effects of the disease. Some diseases have their greatest effects on productivity early in the subclinical stages of infection without any clinical evidence of disease, while in the case of some other diseases their effects on productivity increase as the clinical disease becomes more severe. In the case of disease caused by *B. bovis* the effect of the disease on production increases with the severity of clinical disease.

This paper initially outlines the effects diseases can have on livestock production then describes the development of a method to estimate the production loss avoided due to the control of a disease by vaccination. The method involves estimation of individual production loss due to disease and the number of cases of disease avoided by vaccination. The method developed is then applied to determine the production loss avoided due to vaccination against *B. bovis*.

2. The Effects of Disease on Livestock Production

Disease has a variety of biological effects on animals that are exhibited as production losses. Disease affects an animal's ability to survive, grow and reproduce. In addition to the effects disease has on individual animals, herd effects are also seen, including adverse modification of the herd structure (Matthewman and Perry, 1985).

Close clinical observation, physical measurement and laboratory examination of specimens is often required to determine the effect a disease has on an animal’s productivity (Morris and Meek, 1980). It is difficult to estimate the effects a disease has had or might have on animal production because of the large number of variables that affect it, such as age, breed, production status and condition of the host, pathogenicity of the disease causing organism and environmental factors (James and Ellis, 1978). Because information on the effects of diseases on production is limited, it is usually necessary to make estimates from a combination of published data and expert opinion (Ellis and James, 1979, Mukhebi et al.,

1992).

The effects of parasitic infestation (which can produce a chronic disease) on animal production have been widely reported (Morris and Meek, 1980; Meek, 1977; Hawkins, 1977; Anderson et al., 1976). A system has been developed to outline the information needed to determine the effects of a disease on livestock production (Morris and Meek, 1980). The system uses a combination of experimental studies and expert opinion to determine the effects of a disease on animal production.

In the case of sporadic or exotic diseases there is much less certainty about disease occurrence. To carry out a field experiment or observational study would either involve artificial infection of a group of animals or the use of a large number of sites which would be expensive. In addition the introduction of an exotic disease pathogen would be unacceptable. In addition, the large number of variables which could not be controlled for in an observational study would lead to the need for unacceptably large sample sizes (James and Ellis, 1985). Under these conditions it is best to use a modelling approach to estimate the effect of the disease on production. This is especially so under extensive grazing conditions where it is difficult to measure the effects of disease on individual animals. However, for modelling to be carried out successfully it is essential to understand the effects the disease may have on the productivity of affected animals.

While systems for the assessment of the effects of chronic diseases, in particular internal parasitism, are well documented, techniques to assess the effects of acute infectious diseases on animal production under extensive conditions are not. Extensive rangeland production of livestock differs significantly from intensive production, for example, animals are rarely observed closely so little animal health information is available, inputs are considerably lower per head and feed intake is difficult to measure.

Few studies have been carried out to assess the effect of disease on animal production in extensive areas in Australia. St George (1986) estimated the cost of outbreaks of bovine ephemeral fever using crude estimates of disease incidence and the effect of disease on production. Bartholemew and Callow (1979) estimated the benefits of using an improved vaccine against tick-borne diseases in Australia. McGowan et al. (1992) estimated the costs of bovine pestivirus infection in extensively grazed cattle. However, none of these studies examined in detail the loss in production due to the disease compared with the loss avoided

when the disease was controlled. Field studies comparing the effect of various disease control measures on animal production have not been carried out in extensively grazed areas of Australia.

2.1 Effects of disease on livestock productivity

Morris and Meek (1980) divide the effects of chronic disease on the productive performance of livestock into two categories, namely, apparent alterations in efficiency and real reductions in efficiency. This conceptual framework is expanded by Morris and Marsh (1992), who have defined apparent alterations in efficiency as changes in production caused by animals eating less food. In some cases appetite suppression may be due to a direct and specific effect on appetite while in others the effect may be indirect due to the reluctance of the animal to forage due to pain or discomfort associated with movement or prehension, caused by the disease.

Real reductions in efficiency are defined by Morris and Meek (1980) as being due to depression of feed digestibility or of feed conversion efficiency. This is complicated by interactions between the two factors because the level of feed intake can affect the efficiency with which feed is used.

Morris and Meek (1980) also state that it is important to differentiate between a reduction in feed intake and a true reduction in productive efficiency because if a reduction in feed intake is the factor causing the lost production an increase in stocking rate will increase production as an alternative to controlling the disease. Often the dividing line between apparent and real effects is not clear, and if feed intake cannot be measured, as occurs in extensively-run cattle, it is not possible to differentiate between the two effects (Morris and Marsh, 1992).

The effects of acute disease contrast with those of chronic disease because acute disease is short-lived and affected animals usually either recover rapidly or die. In addition, animals that have recovered from acute infectious diseases are often not susceptible to a second attack of that disease, whereas in the case of diseases such as mastitis and internal parasitism recurrent infections or infestations occur.

3. Categories of Livestock Production Affected by Disease

While the effects that a disease has on animals are extremely variable it is essential that a

simplified approach is taken to make it possible to examine these effects. The production loss in beef cattle in Australia due to diseases can be divided into the following categories:

- death
- weight loss
- reproductive loss, and
- lactation effects.

A description of each of these factors is now given.

3.1 Production loss due to death

The death of animals due to disease can have several effects on herd production. Deaths result in a reduced number of animals available for sale and a modification in the herd structure. In extensively grazed animals, production loss due to death is difficult to assess.

3.2 Production loss due to weight loss

The final effect of weight loss, due to disease, on an animal's production will depend on several factors, the most important of which are:

- the amount of weight lost due to the disease
- the composition of that weight loss, that is body fluid, gut content, muscle and fat, and
- the rate at which the weight is recovered, which is affected by compensatory growth, the level of nutrition and the type of weight that has been lost

Considerable information is available on the effects of the restriction of nutrition on the subsequent growth and development of cattle (O'Donovan, 1984). Much of this information is contradictory but there is general agreement that several factors are important in determining if compensatory growth occurs and if it does how much compensatory growth occurs. These are:

- breed,
- age, liveweight, and maturity,
- stage of growth and condition (ratio of fat:lean:bone),
- severity and duration of restriction,
- type of feed, and
- level of nutrients in the feed. (O'Donovan, 1984).

While clinical disease does cause weight loss, little work has been done to measure the amount and variation in the amount of weight lost, the type of weight lost and the ability of animals under various conditions to recover the weight lost.

3.3 Production loss due to effects on lactation

Disease can vary both the quantity and the quality of the milk produced. The effects on quantity can vary from a mild temporary reduction to a total cessation of production. The effects on lactation vary with the stage of lactation at which the disease occurs and the severity of the disease. In beef cattle the main effect of a reduction in lactation is on the growth and survival of calves.

3.4 Production loss due to reproductive loss

Diseases can have several effects on reproduction. The effects on reproduction are firstly examined for females and then for males in this section.

The effects of disease on female reproduction vary with the time in an individual's reproductive cycle that the disease occurs. The system of management, either controlled seasonal breeding or continuous breeding, will influence the proportion of females at each stage of their reproductive cycle at different times of year and therefore the effect that a disease has on reproduction in the herd.

Diseases can affect reproductive efficiency by having the following effects:

- silent oestrus periods,
- prevention of fertilisation,
- early embryonic loss,
- loss in mid gestation,
- abortion in the last trimester of pregnancy,
- birth of dead, weak, or deformed calves which die soon postpartum, and
- delays in heifers breeding due to body weight and condition being below optimal.

The effects of diseases on reproductive efficiency of female cattle in Australia have not been examined in detail for most transmissible diseases, with the exception of those that mainly affect reproduction, such as bovine pestivirus infection (McGowan et al., 1992).

The effects on male reproduction are more restricted and relate to the males' ability to seek, mate with and fertilise receptive females. The effects of a disease in males can be summarised as:

- reduced mobility so that affected animals are not able to seek and mate with receptive females
- reduced libido
- temporary or permanent infertility due to direct effects of a disease on spermatogenesis, and
- temporary infertility due to effects on spermatogenesis and sperm survival due to pyrexia associated with a disease.

Temporary effects are especially important if a disease outbreak occurs during or just before the breeding season.

4. Estimating the Production Loss Avoided

In this section a method to estimate the production loss avoided due to vaccination as part of the development of a model, with links to the disease prediction/vaccination model, to determine the production loss avoided due to vaccination for *B. bovis*.

In its simplest form, the production loss avoided due to vaccination equals the reduction in the number of cases of disease due to vaccination multiplied by the production loss per case. However, the production loss avoided will vary with the age and sex class of the animals and the severity of the disease. The calculation can be made more accurate if the production loss avoided is the sum of the production loss of each age and sex class of the animals in the herd and is weighted according to the different severities of disease.

Production loss due to disease can be divided into several categories. Because of the small amount of published data on the effects of disease caused by *B. bovis* on livestock production, production loss is divided into three categories. These are production loss due to death, weight loss and reproductive loss. Therefore, the formula to calculate the total production loss avoided (TPLA) is calculated as the sum of the production loss avoided for each age and sex class for each area of production as follows:

$$TPLA = PLA(females) + PLA(males)$$

PLA(females) is the production loss avoided for females and is calculated as:

$$PLA(females) = \sum(Df_a + Wf_a + Rf_a)$$

where Df_a is the production loss avoided due to deaths avoided in females aged *a* years

Wf_a is the production loss avoided due to weight loss avoided in females aged *a* years

Rf_a is the production loss avoided due to reproductive loss avoided in females aged *a* years

PLA(males) is the production loss avoided for males and is calculated as:

$$PLA\ (males) = \sum(Dm_a + Wm_a)$$

where Dm_a is the production loss avoided due to deaths avoided in males aged *a* years

Wm_a is the production loss avoided due to weight loss avoided in males aged *a* years.

To calculate the production loss avoided using the method described above, it is necessary to know:

- the number, and severity, of the cases of disease avoided, as calculated in the previous discussion paper in this series, and
- the production loss which is avoided for each case of disease avoided for each class of animals in each category of production loss. The production loss avoided due to death, weight loss and reproductive failure are calculated in the following sections.

4.1 Calculating the production loss avoided due to deaths avoided

The death of animals affects the number of animals for sale, and the loss avoided due to mortalities avoided can be estimated as the average body weight of animals in the age and sex category not affected by disease. Deaths of pregnant animals also results in calf losses. This is an additional production loss that is considered in the section on reproduction loss. The production loss avoided due to deaths avoided in females (*Df*) is calculated using the following formula:

$$Df = \sum (DAf_a \times Wf_a)$$

where Daf_a is the number of deaths avoided in females aged *a* years

Wf_a is the average body weight of females aged *a* years

Similarly the production loss avoided due to deaths avoided in males (*Dm*) is calculated using the formula:

$$Dm = \sum (DAm_a \times Wm_a)$$

where Dam_a is the number of deaths avoided in males aged *a* years

Wm_a is the average body weight of males aged *a* years

4.2 Calculating the weight loss avoided due to vaccination

To allow for the variation in the time between disease occurrence and sale of animals, a method is developed in this section to estimate the amount of the weight lost and not regained by the time of sale. The two categories of disease severity with recovery are used in this discussion, that is mild disease with recovery and severe disease with recovery. It is assumed that subclinical disease does not cause any weight loss.

Different severities of disease have different effects on the amount of weight lost by animals. The weight loss referred to in this section is empty body weight and does not include loss of fluid or gut fill which are not true production loss and are quickly recovered. The rate at which animals recover lost weight varies with amount of weight lost and quality and quantity of feed available.

The weight loss caused by a disease has been classified by some authors as the estimated weight lost per case of disease during the time the disease occurred (Zessin and Carpenter, 1985; St George, 1986). However, this can be misleading as the animal is not necessarily sold immediately after the disease and associated weight loss. In some cases affected animals will not be sold for several years after recovery from disease.

Two factors that affect the total amount of weight lost and not regained in the herd by the

time of sale are:

- a proportion of animals will die from causes other than the disease being examined between the time at which they have suffer from the disease and the time they are sold. In this case, the owner will not derive any weight benefit if disease is avoided in an animal that subsequently dies due to another cause, and
- animals that have recovered from a disease may show an increased rate of growth and greater efficiency of nutrient use as a result of compensatory growth. In this case, animals will have regained some or all of the lost weight by the time they are marketed. The amount of weight regained will vary with the length of time between the disease occurring and the animal being sold as well as other factors such as the feed conditions.

To calculate the amount of weight loss avoided for a group of animals of the same age, the number of cases of disease avoided in each year is reduced by the mortality due to causes other than the disease being examined, for each subsequent year until the animals are sold. The number derived is then multiplied by the amount of weight lost and not regained by the time of sale. This calculation is performed for each age group and year of life. For example, the weight loss avoided in male animals sold at three years old (Wm_3) is calculated using the formula:

$$Wm_3 = CDA_1(1 - Mm_3) \times WLNR_{1,3} + CDA_2(1 - Mm_3) \times WLNR_{2,3} + CDA_3 \times WLNR_3$$

where CDA_1 is the number of cases of disease avoided in males in the first year of life,

Mm_2 is the mortality rate in males in the second year of life,

Mm_3 is the mortality rate in males in the third year of life,

$WLNR_{1,3}$ is the weight lost and not regained in animals affected by disease in the first year of life by the age of three years, in kilograms,

CDA_2 is the number of cases of disease avoided in males in the second year of life,

$WLNR_{2,3}$ is the weight lost and not regained in animals affected by disease in the second year of life by the age of three years, in kilograms,

CDA_3 is the number of cases of disease avoided in males in the third year of life, and

$WLNR_{2,3}$ is the weight lost and not regained in animals affected by disease in the third year of life by the age of three years, in kilograms.

4.3 Calculating the reproduction loss avoided due to vaccination

Reproduction loss is only calculated for females. The most easily measurable effect of disease on reproduction is the reduction in the number of calves born following a disease occurring. In this case the reproduction loss avoided is the additional calves born as a result of a vaccination program. This loss is divided into two categories, namely loss due to breeding animals affected by the disease not calving and loss due to the death of pregnant animals. To calculate the number of additional calves born, the effect of the disease on the calving rate for each severity of disease for each age group is assessed.

Loss due to reproductive failure is difficult to determine as the interaction between the time of year at which the disease occurs and the breeding pattern of the herd are both important determinants. Because of the great complexity of these interactions seasonality of breeding and disease occurrence are not considered separately but rather assumptions are made to produce a workable model to estimate the reduction in the number of calves born. The assumptions are:

- all calves are born at the end of the year,
- disease caused by *B. bovis* produces reproductive loss in a fixed proportion of affected females,
- losses in reproduction occur only in the year in which the disease occurs and reproductive performance in future years is not affected, and
- subclinical disease does not affect reproductive performance.

The reproduction loss avoided (*Rf*) due to a vaccination program, in terms of calves not born, is calculated using the formula:

$$Rf = RC + RD$$

where *RC* is the reproduction loss avoided due to cases of clinical disease from which animals recover avoided, and *RD* is the reproduction loss avoided due to deaths avoided.

The reproduction loss avoided due to cases of clinical disease with recovery is calculated using the formula:

where CDA_a is the cases of clinical disease from which animals recover that are avoided in females aged *a* years

Cp_a is the proportion of cows aged a years that are expected to calve

PNC_a is the proportion of cows aged a years affected by clinical disease from which they recover that will not calve due to the disease, and

The additional calves born due to deaths of cows avoided (RD) is estimated as:

$$RD = \sum (NDA_a \times Cp_a)$$

where NDA_a is the number of deaths avoided in cows aged *a* years.

4.4 Incorporation of production loss avoided into a computer spreadsheet

The formulae to calculate the production loss avoided were entered into a computer spreadsheet using the package Microsoft Excel. The spreadsheet has automatically updated links to the disease prediction/control model developed in the previous discussion paper. This enables model simulations to be carried out using outputs from the disease prediction/vaccination model as inputs into the production loss avoided model. The effect of vaccination programs on production loss avoided can therefore be rapidly assessed for various levels of age specific seroprevalence and susceptibility of cattle in the herd to disease.

5. Simulation Results of the Production Loss Avoided Due to Control of *Babesia bovis* by Vaccination

Model predictions of the production loss avoided due to control of *B. bovis* by vaccination are made using the model developed in this chapter. The predictions are examined in Sections 5.1 to 5.3. Simulation results are shown for three levels of incidence risk of infection, low, medium and high, for herds of cattle of three levels of disease susceptibility, resistant, intermediate and susceptible, for each the eight years of the vaccination program. Only the results for the Vaccination program 1 are shown. This is because in all cases the production loss avoided due to Vaccination program 2 was the same as the maximum production loss avoided for Vaccination program 1 for all years of the Vaccination program 2.

Predictions of loss avoided due to deaths avoided are presented in Section 5.1, weight loss

avoided due to cases of clinical disease with recovery avoided in Section 5.2 and additional calves born in Section 5.3.

5.1 Weight loss avoided due to deaths avoided

Large differences are seen in the model predictions for the loss avoided due to deaths avoided between the herd of cattle with different levels of disease susceptibility and between the different levels of incidence risk of infection as illustrated in Figure 1. The larger differences are seen between the herds of cattle of different disease susceptibilities. The greatest loss was avoided in the susceptible cattle with the loss avoided in resistant cattle being considerably less. The loss avoided by vaccination in cattle of intermediate susceptibility was between the other two herds.

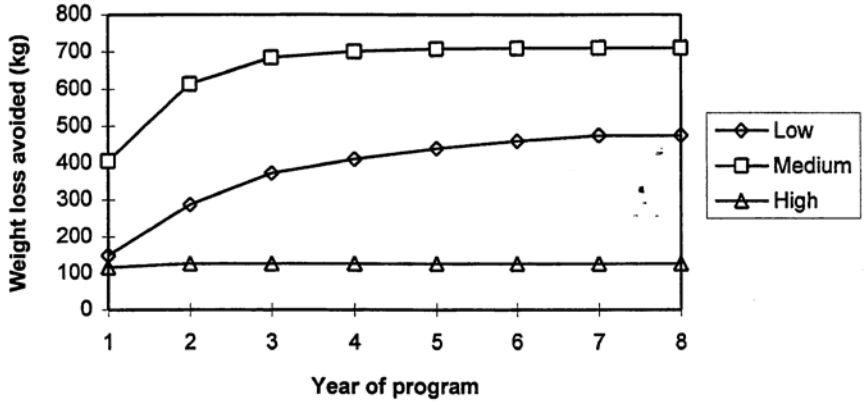
For each type of cattle the greatest loss avoided due to vaccination was at the medium level of incidence risk of infection with the least loss avoided at the high level of incidence risk of infection.

5.2 Weight loss avoided due to the prevention of cases of clinical disease with recovery

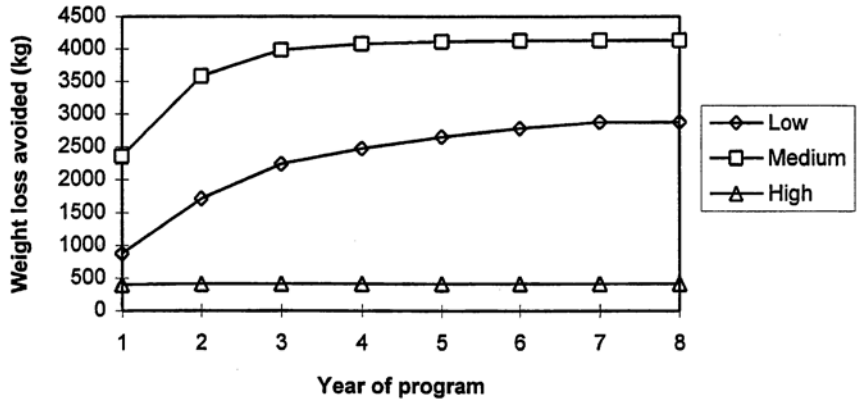
The quantities of weight lost due to disease used in the simulations in this section are derived from the opinions of experts Dr Bob Dalgliesh and Dr Bert de Vos and trials carried out at the Tick Fever Research Centre, Wacol (Bock, 1996a).

Figure 1: Loss avoided as weight in kilograms by Vaccination 1 due to deaths avoided for resistant, susceptible and intermediate cattle with low, medium and high incidence risk of infection

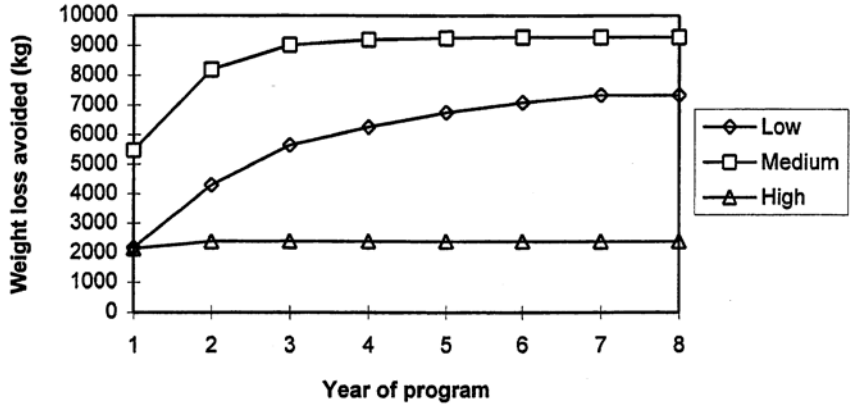
1a Resistant cattle



1b Intermediate cattle



1c Susceptible cattle



Two scenarios are examined in this section. In the first it is assumed that the weight lost is not regained in the year in which the disease occurs but all of the weight lost is regained in the next year. The estimated weight lost and not regained is presented in Table 1. In the second scenario the weight is regained at a slower and decreasing rate, with half of the weight lost being regained in each subsequent year, the estimated weight lost and not regained is presented in Table 2. The first scenario is more likely to occur (Dalgliesh, 1996; de Vos, 1996; Bock, 1996b). -.

Table 1: Weight (in kilograms) lost and not regained before sale for different age groups, for mild and severe clinical disease with recovery, where all weight lost due to disease is regained a year after infection (Scenario 1)

		Weight lost (kg)	
		Years to market	
Mild disease	Age	0	1
	0 years	0	0
	1 year	5	0
	2 years	5	0
	3 years	3	0
	4 years	3	0
	5 years	3	0
	6 years	3	0
	7 years	3	0
		Years to market	
Severe disease	Age	0	1
	0 years	0	0
	1 year	5	0
	2 years	20	0
	3 years	20	0
	4 years	20	0
	5 years	20	0
	6 years	20	0
	7 years	20	0

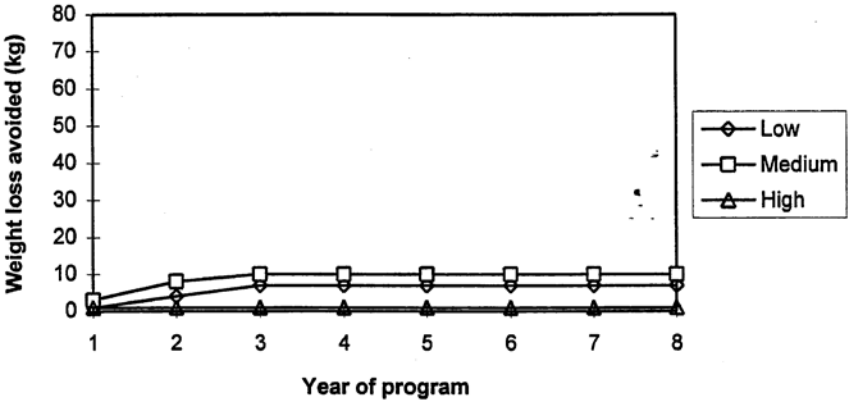
The predicted weight loss avoided by vaccination using Vaccination program 1, and under Scenario 1, is low at all three levels of incidence risk of infection in the resistant cattle, as displayed in Figure 2. The predicted weight loss avoided is higher for the intermediate and susceptible cattle but is still low at less than 40 kilograms for the herd per year of the vaccination program. This is considerably less than the production loss avoided due to deaths avoided by vaccination. In all cases with a high incidence of infection the predicted weight loss avoided is low with less than five kilograms predicted to be avoided in the herd per year.

Table 2: Weight (in kilograms) lost and not regained before sale for different age groups, for mild and severe clinical disease with recovery, where weight lost due to disease is regained over several years (Scenario 2)

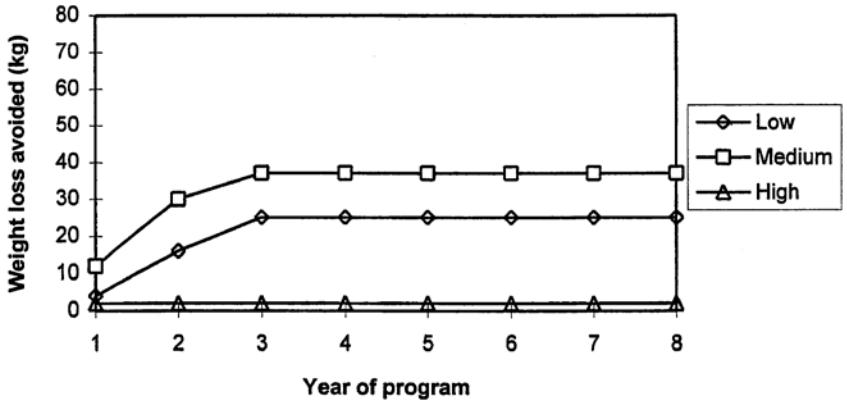
		Weight lost (kg)							
		Years to market							
Mild disease	Age	0	1	2	3	4	5	6	7
	0 years	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1 year	5.00	2.50	1.25	0.63	0.31	0.16	0.08	0.04
	2 years	5.00	2.50	1.25	0.63	0.31	0.16	0.08	0.04
	3 years	3.00	1.50	0.75	0.38	0.19	0.09	0.05	0.02
	4 years	3.00	1.50	0.75	0.38	0.19	0.09	0.05	0.02
	5 years	3.00	1.50	0.75	0.38	0.19	0.09	0.05	0.02
	6 years	3.00	1.50	0.75	0.38	0.19	0.09	0.05	0.02
	7 years	3.00	1.50	0.75	0.38	0.19	0.09	0.05	0.02
Severe disease									
	0 years	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1 year	5.00	2.50	1.25	0.63	0.31	0.16	0.08	0.04
	2 years	20.00	10.00	5.00	2.50	1.25	0.63	0.31	0.16
	3 years	20.00	10.00	5.00	2.50	1.25	0.63	0.31	0.16
	4 years	20.00	10.00	5.00	2.50	1.25	0.63	0.31	0.16
	5 years	20.00	10.00	5.00	2.50	1.25	0.63	0.31	0.16
	6 years	20.00	10.00	5.00	2.50	1.25	0.63	0.31	0.16
	7 years	20.00	10.00	5.00	2.50	1.25	0.63	0.31	0.16

Figure 2: Weight loss avoided by Vaccination 1 where all weight lost is regained by the second year after disease occurrence for resistant, susceptible and intermediate cattle herds with low, medium and high incidence risk of infection (Scenario 1)

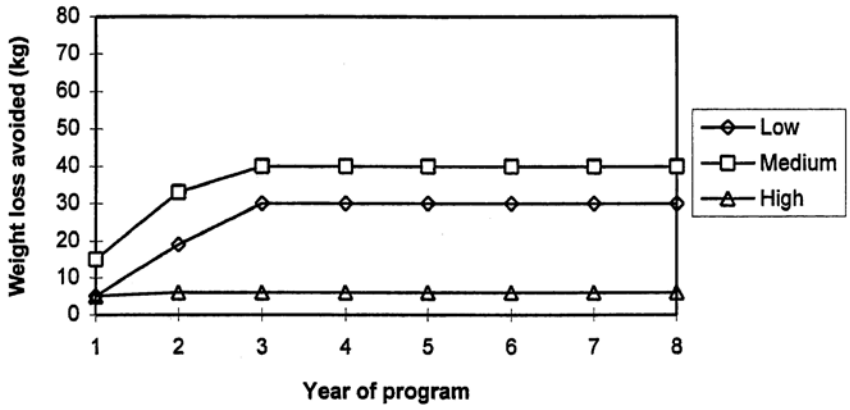
2a Resistant cattle



2b Intermediate cattle



2c Susceptible cattle



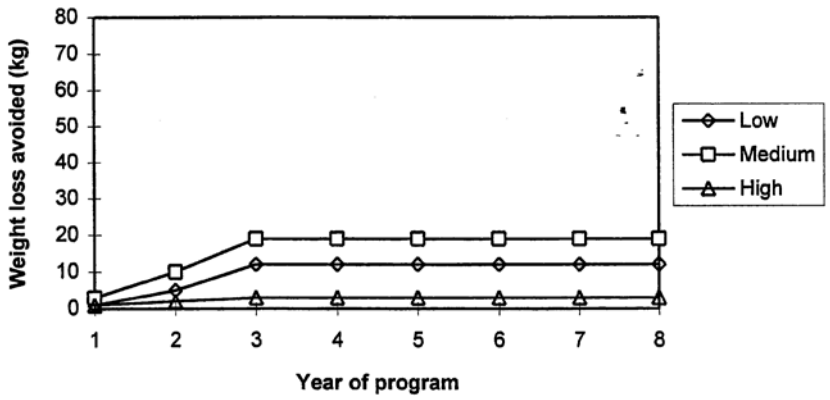
Where weight lost due to disease is regained more slowly as is the case in Scenario 2 the predicted weight loss avoided due to vaccination using the Vaccination 1 program in disease resistant cattle is low (Figure 3). At its maximum level where the incidence of infection is medium the total weight loss avoided is less than 20 kilograms for the herd per year. The predicted weight loss avoided is higher for intermediate and susceptible cattle with a medium incidence risk of infection but is still less than 80 kilograms for the herd per year. Where the incidence risk of infection is low the predicted weight loss avoided is low for cattle of resistant, susceptible and intermediate types.

5.3 The predicted effect of vaccination on the number of calves born in the herd

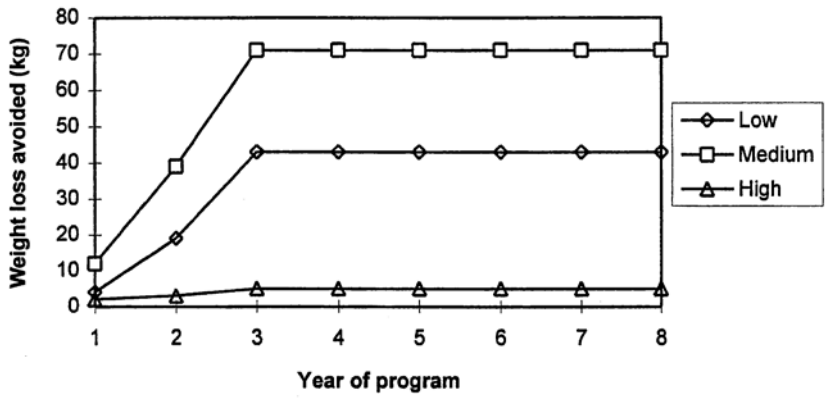
In this section the effect of vaccination on the number of calves born is examined. Two scenarios are examined. In the first it is assumed that half of the breeding females that suffer clinical disease and recover and would normally be expected to calve will not calve in the year in which they are affected. While all breeding females that die from disease caused by *B. bovis* that would have otherwise calved will not calve. In the second scenario all breeding females affected by disease caused by *B. bovis* that would have otherwise been expected to calve will not calve. The second scenario is considered to be an extreme example and not likely to occur in reality. While the first scenario is considered more likely it is also considered to exaggerate the effect of *B. bovis* on female fertility.

Figure 3: Weight loss avoided by Vaccination 1 where half of the weight lost is regained in each subsequent year following disease occurrence for resistant, susceptible and intermediate cattle herds with low, medium and high incidence of infection (Scenario 2)

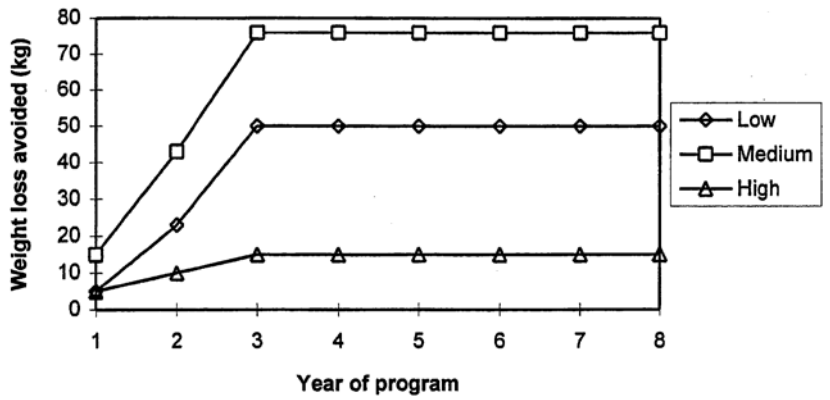
3a Resistant cattle



3b Intermediate cattle



3c Susceptible cattle



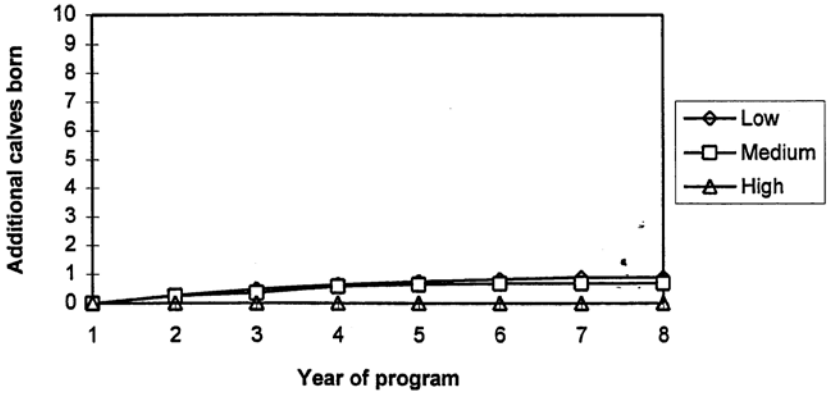
As presented in Figure 4 predictions of the number of additional calves born, where half of the breeding cows that are affected by clinical disease do not calve due to the disease, suggest that disease caused by *B. bovis* does not have a large impact on the level of herd fertility. In the case of the disease resistant cattle less than one additional calf per year is predicted at all levels of incidence of infection. In the case of cattle of intermediate disease susceptibility the number of additional calves born due to vaccination is less than three per year. The prediction of additional calves born is greatest for the disease susceptible herd with a low incidence risk of infection. In this case as cows are infected for the first time each and every year there are still susceptible cows present in the population for each reproductive year. In contrast for all types of cattle where the incidence risk of infection is high there is small effect of vaccination on the number of calves born as most cows have been infected before they reach sexual maturity.

As illustrated in Figure 5 in the scenario where all cows affected by disease do not calve the benefits expected for the use of vaccination are at their greatest. However, in this case there is virtually no change in the predictions of the number of additional calves born for the disease resistant cattle. At all levels of incidence risk of infection, less than one additional calf per year is predicted to be born in the herd. In the case of the herd of cattle with intermediate disease susceptibility the increase in the number of calves born is also small with the maximum increase predicted to be less than four per year.

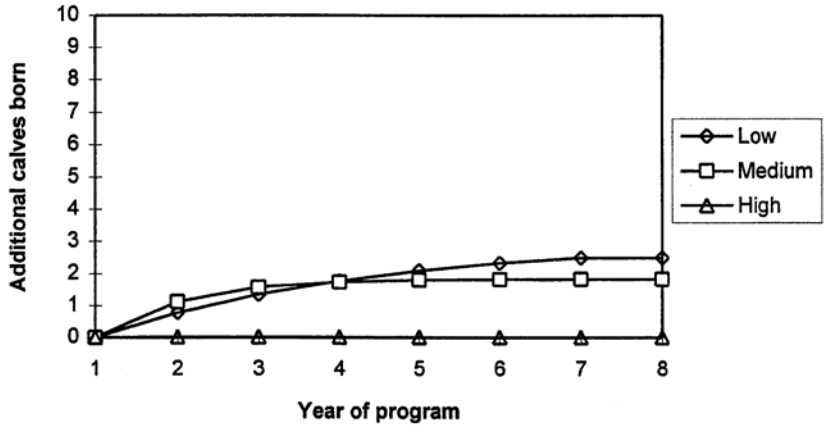
The greatest predicted increase in the number of calves born is in the susceptible cattle where the incidence risk of infection is low, however, even in this case less than seven additional calves are predicted to be born in the herd each year.

Figure 4: Additional calves born where half of cows affected by clinical disease from which they recover do not calve and all cows that die from disease do not calve

4a Resistant cattle



4b Intermediate cattle



4c Susceptible cattle

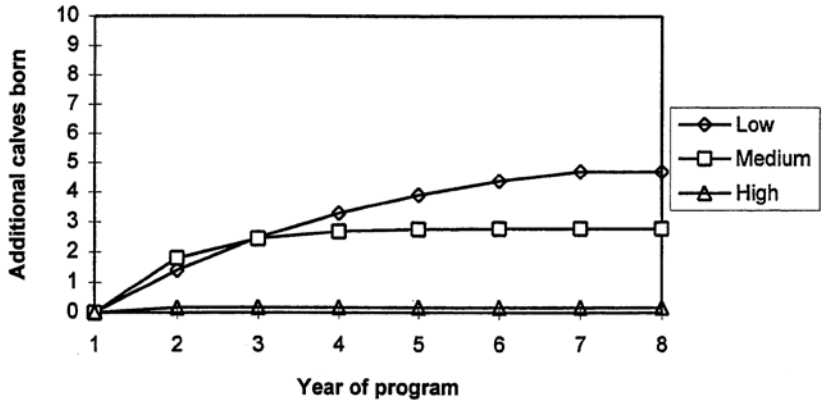
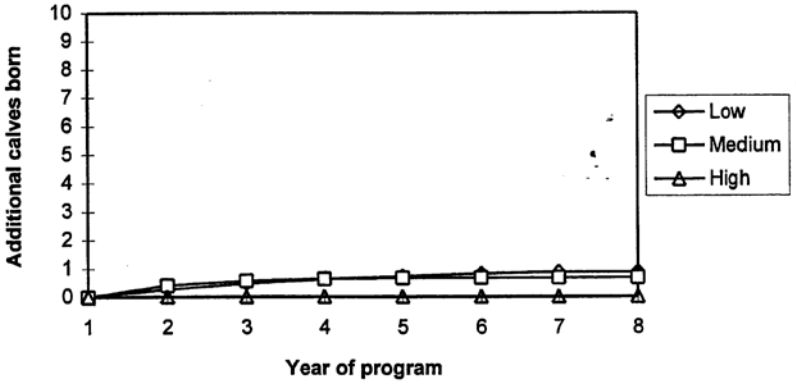
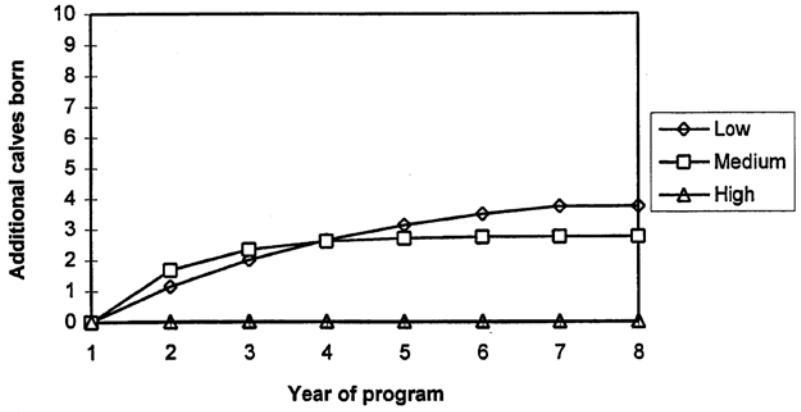


Figure 5: Additional calves born where all cows affected by clinical disease from which they recover do not calve and all cows that die from disease do not calve

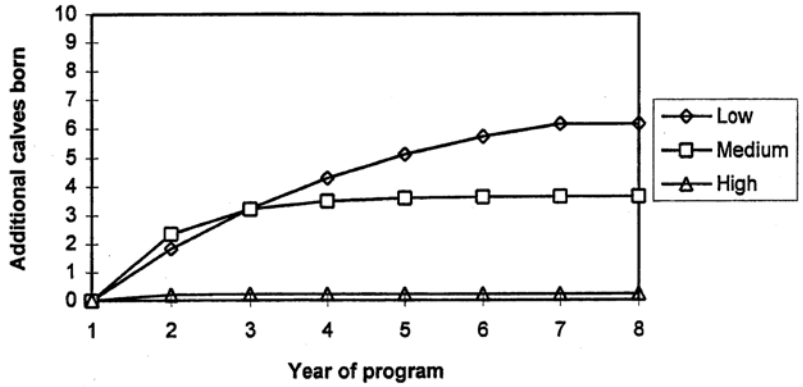
5a Resistant cattle



5b Intermediate cattle



5c Susceptible cattle



6. Summary

The production loss avoided due to a vaccination program to control *B. bovis* is examined in this paper. The production loss is divided into loss due to deaths, weight lost and not regained by the time of sale and reproductive loss. Simulations are carried out to determine the production loss avoided for two vaccination programs, for each of three herds containing cattle that are resistant, susceptible and of intermediate susceptibility to disease following infection with *B. bovis* at high medium and low levels of incidence of infection.

The model developed in this paper provides an effective way of examining the production benefits gained following the institution of a vaccination program. Simulations indicate that the major production benefit from *B. bovis* vaccination is in the area of deaths avoided. Considerably less benefit is predicted to be gained in the form of weight loss avoided due to prevention of clinical disease from which animals recover. The effect of *B. bovis* vaccination on reproductive efficiency is also predicted to be small.

As expected the production benefits of *B. bovis* vaccination are predicted to be greatest in the susceptible cattle and least in disease resistant cattle. The incidence risk of infection also affects the production benefits of *B. bovis* vaccination with the loss avoided being highest where the incidence risk of infection is medium and least where the incidence risk of infection is high.

Model predictions of the production loss avoided due to disease control by vaccination made in this paper are used as inputs in the analysis carried out in the next paper in this series.

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