Johne's disease:

An economic evaluation of control options for the Victorian dairy industry[1]

Elizabeth Brett, Gary Stoneham and Joe Johnston
Department of Agriculture, Victoria
PO Box 500
East Melbourne 3002

Contributed Paper presented to the 39th Annual Conference of the Australian Agricultural Economics Society, University of Western Australia, Perth, 14-16 February 1995

[1]The views expressed are those of the authors and do not necessarily represent the official policy of the Victorian Department of Agriculture.

The authors gratefully acknowledge the assistance of a number of colleagues at the Department of Agriculture, particularly Mike Harrison, Ian Holmes, Ann Hope and Sally Ridge. The research carried out for this report was supported by funding from the Dairy Research and Development Corporation.

1 Introduction

Background

Johne's disease in dairy cattle has been observed worldwide for over 160 years, and its presence was first documented in Australia in the 1930's. The disease occurs in most Australian states and has become quite serious in Victoria where around 17 per cent of herds are known to be infected. The disease can cause significant losses, but in many herds it remains either undetected, or is deliberately concealed because of potential problems with selling a property or its livestock.

Johne's disease is contagious and difficult to control or eradicate. A number of measures are in place to minimise spread of the disease, but the costs and benefits of this approach have not been established. A cost-effective strategy for controlling the disease is necessary because of the importance of the dairy industry to the Victorian economy. Over 60 per cent of the nation's milk was produced in Victoria in 1992-93, and approximately $700 million worth of dairy products were exported.

Aims of this study

This paper reports the findings of an economic analysis of Johne's disease in Victoria. There are three key objectives of the paper:

i) to estimate the economic impact of Johne's disease on Victorian herds;
ii) to identify the conditions under which it is wise to control the disease in herds; and,
iii) to identify industry and government activities required to facilitate effective management of Johne's disease.

This paper is drawn from a more detailed paper published by the Department of Agriculture, Victoria (1994) entitled "Johne's disease: An economic evaluation of control options for the Victorian dairy industry". A number of economic models are used in this analysis to estimate costs and benefits of reducing the level of Johne's disease. Space does not permit the details of these models to be described in this conference paper but detailed analysis can be found in DAV (1994).

2 Johne's disease in Australia

Nature of the disease

Johne's disease is a bacterial disease which inhibits an animal's ability to absorb nutrients through the intestinal wall. Cattle contract Johne's disease by ingesting an infective dose of the bacterium *Mycobacterium paratuberculosis*, usually as calves, in feed or water. The bacteria establishes in the intestine of the infected animal where it damages and causes a thickening of the intestinal wall.

Johne's disease can have a long incubation period and usually progresses through several stages. Visible signs of illness rarely appear in animals less than three years of age. By the third or fourth lactation, the animal may experience some sub-clinical[1] effects of the disease such as lower milk production and an increase in the animal's susceptibility to other infectious diseases (eg. mastitis). Individuals vary in their response to bacterium, however, and may experience all or none of these symptoms.

Only some animals will progress to the clinical[2] stage of the disease, which can be induced by stress, such as when cows are moved to a different herd. Clinical cases suffer significant loss of condition and severe, non-treatable diarrhoea. Certain death follows as there is no treatment available.

Infected animals shed bacterium in the faeces and the disease will spread in a herd if there is faecal contamination of feed and water. Young calves are commonly infected from mothers and bacterium can also be transferred from infected mothers to offspring *in utero*.

Human health

The causative agent of Johne's disease, *M. paratuberculosis*, has been found in Crohn's disease tissue but its role in chronic enteritis in humans remains uncertain (Hermon-Taylor, 1991). Crohn's disease is an intestinal disease in humans, but at this stage, the presence of the disease in cattle is not considered to be a human health issue.

Prevalence, diagnosis and control

Johne's disease is more prevalent in areas with cold climates, dense dairy cattle populations and irrigation or an abundance of rainfall. It is a notifiable disease in all Australian states except for Western Australia, where it is regarded as an exotic disease subject to quarantine and slaughter requirements.

It is difficult to eradicate Johne's disease because of the difficulty in detecting the infection in the early stages of the disease. Animals with sub-clinical disease can therefore remain in the herd and continue to spread the disease. Current strategies for controlling Johne's disease have the objective of minimising the spread of the disease through the use of test and cull programs; vaccination programs; and movement controls. Herd owners with diagnosed clinical and sub-clinical cases are paid compensation for the slaughter of infected animals.

[1] Sub-clinical disease refers to the period when the cow is infected with the bacterium but does not display the visible signs of infection.

[2] Clinical disease refers to the period when the cow shows the visible signs of disease, ie. scouring, weight loss.

3 The total cost of Johne's disease in Victoria

The main costs of Johne's disease arise as a result of lower farm productivity and reduced industry efficiency due to livestock movement restrictions. Farm productivity falls because Johne's disease disrupts normal rearing policies for replacement animals. When a milking cow dies suddenly from a disease mid-way through a season, the number of milking cows falls and usually cannot be increased until the end of the season. Costs are incurred through lower milk production, and the loss of cull animals.

The cost of reduced farm productivity due to Johne's disease in Victoria has been calculated by estimating the relationship between clinical cases and cost, and then aggregating this to the State level. The effect on dairy and beef herd productivity has been examined using a whole farm herd model which was developed to mimic the year-to-year workings of commercial dairy and beef herds. The objective of the model was to capture the on-going processes of dairy and beef herd management to include milk or beef production, revenue earned, enterprise costs, herd deaths, replacements and culling. The model runs for a 15 year period to take into consideration the impact of sub-clinical and clinical Johne's disease cases. A detailed description of the model is contained in DAV (1994). Using this model, it has been estimated that the impact of one clinical case of Johne's disease per year on farm productivity is $1,803 for dairy herds and $800 per year for beef herds.

Stud livestock industries are also adversely affected by Johne's disease because stock from an infected herd should not be sold as stud animals and are usually sent for slaughter. To estimate the economic impact of Johne's disease in stud herds, a partial equilibrium model of the stud and slaughter industries has been developed. In this model, the supply of stud animals is diminished because of Johne's disease and these animals are then added to the supply of slaughter animals. The economic impact of each additional animal diverted from the stud to the slaughter market is estimated to be $1,675 per year (DAV, 1994).

Aggregate cost of productivity and marketing losses to Victoria

These estimates of the productivity cost per animal per year have been aggregated to the State level using a database containing individual farm records for all herds with recorded clinical cases of Johne's disease in Victoria. The database was developed from regional veterinary records of herds with Johne's disease dating back to 1955.

The database contains information such as: the history of clinical cases in each herd; the number of years each herd has been infected; the number of breeders in each herd and whether the infected herds are beef or dairy; commercial or stud enterprises. The variables for each herd in the database were manipulated to generate standardised data on the average number of clinical cases likely to appear each year, the cost of reduced productivity on a per breeder basis and the prevalence of the disease across the state.

The information derived from the database is summarised in table 1. The database consists of 1,378 records of infected herds in Victoria, from which an average of 1,832 animals per year were slaughtered following the detection of clinical symptoms of Johne's disease.

Dairy sector

In Victoria, most Johne's disease is detected in dairy herds where 1,116 herds (81 per cent of all infected herds) have recorded some history of disease. Around 77 per cent (1,404 cases) of all reported clinical cases of Johne's disease originate from commercial dairy farms with only 4 per cent (70 cases) being presented from stud dairy farms.

The total cost of reduced farm productivity in the dairy industry as a result of Johne's disease has been estimated at $4.33m per year. Fifty-eight per cent of these costs ($2.53 million) arise from commercial dairy farms where the average productivity cost is estimated at $2,368 per infected commercial dairy farm. In the stud industry, the cost is estimated to be $1.8m per year or $39,000 per infected farm. The losses per stud farm are high because once infected, the impact flows to the entire stud animal component of the farm's turnoff, which no longer attracts premium prices.

Table 1 *Johne's disease observations and cost: All infected farms in Victoria*

Industry/Sector	Number of herds with Johne's disease	Number of breeders in infected herds (average per farm)	Number of clinical cases per year (average per farm)	Potential benefits $m (average per farm)
Commercial dairy	1,070	156,128 (146)	1,404 (1.31)	2.53 (2,368)
Stud dairy	46	6,453 (140)	70 (1.53)	1.80 (39,152)
Total dairy	1,116	162,581 (145)	1,474 (1.32)	4.33 (3.933)
Commercial beef	123	8,862 (72)	154 (1.26)	0.18 (1211)
Stud beef	21	3,159 (143)	21 (0.97)	0.78 (37,333)
Total beef	144	11,821 (82)	174 (1.21)	0.96 (6,303)
Combined Dairy/Beef	118	34,920 (250)	182 (1.54)	0.47 (3,937)
Total	*1,378*	*209,322 (152)*	*1,832 (1.33)*	*5.76 (4,181)*

Beef sector

There are 144 beef farms with recorded incidence of Johne's disease in Victoria and the total cost to these farms is estimated to be $960,000 per year or $6,303 per farm. Most of these costs stem from stud rather than commercial beef farms.

The potential productivity cost of Johne's disease to all farms was estimated to be $5.76m, or $4,181 per farm. This is a conservative estimate because official records of cases are probably incomplete.

The second category of economic costs arising from Johne's disease are those due to reduced industry efficiency. Livestock movement controls apply to cattle which are traded because of the potential for infected animals to spread Johne's disease and impose costs on other farm businesses. These controls, usually in the form of a test or certificate, affect the commercial decisions of buyers and sellers of cattle and impose costs on the industry. Movement controls are applied to both domestic and international movements of cattle.

The cost of domestic movement controls

To estimate the cost of the movement controls aimed at limiting the spread of Johne's disease within Australia, a partial equilibrium model of interstate trade in cattle has been developed. The method used is explained in detail in DAV (1994). A summary of the impact of the movement controls is provided in table 2. The economic cost to Victoria of the existing movement controls for cattle transported interstate has been estimated to be between $369,000 and $485,000 per year.

Table 2 *Estimated economic cost of movement controls for Victorian cattle*

	Low range	High range
Number of cattle sold into NSW and Q'ld from Vic	60,000	120,000
Cost of restriction	*$82,700*	*$124,330*
Number of cattle agisted into NSW from Vic	270,000	340,000
Cost of restriction	*$286,200*	*$360,400*
Total cost	$368,900	$484,730

The costs of international movement controls

Exporters of live cattle face higher costs because they must comply with regulations set by importing countries to demonstrate that cattle are free from Johne's disease. Export regulations are similar to those for domestic livestock movement. This cost of compliance has been estimated using a trade model, which is explained in detail in DAV (1994).

In 1993-94, approximately 257,000 live cattle were exported, of which 75 per cent required proof of Johne's disease free status. The economic cost of testing and certifying live export cattle for Johne's disease is estimated to be $1.2 million per year.

The total cost of Johne's disease in the Victorian cattle industries is summarised in table 3. The estimated cost of productivity losses in Victoria, as well as losses in economic efficiency from interstate and international movement controls, is $7.5 million per year.

Table 3 *Cost of Johne's disease to Victoria and export markets*

Source	Estimated value ($m)
Reduced productivity/market opportunity	5.76
Interstate movement controls from Vic	0.48
International movement controls	1.21
Total cost of Johne's disease for Victoria and export market	7.45

4 Control strategies for Johne's disease

Dairy producers can reduce the prevalence and cost of Johne's disease using calf-rearing management in conjunction with a test and cull program or a vaccination program. Calf-rearing management involves early separation and rearing of calves in isolation from effluent and cattle, which reduces the exposure of calves to a heavy bacterial load. Being relatively low in cost, calf rearing techniques can be used with either a vaccination or test/slaughter program.

Test and cull

Evidence shows that the prevalence of Johne's disease in dairy herds can be reduced by testing all adult cows annually, and culling infected animals and their progeny from the herd. This strategy reduces the level of infection in a herd but will not necessarily eradicate the disease because the test (absorbed ELISA[3]), which is currently recommended, will only identify half of the infected animals in a herd.

The ELISA test cost varies between $10 to $20 per cow per test. For this analysis, a test and cull strategy has been simulated using an ELISA test costing $13 per breeder. Veterinary costs are not included in the cost of the test as it should be possible for owners to collect and forward test samples to laboratories.

Vaccination

In a vaccination program, calves are vaccinated within 30 days of birth. Vaccination does not provide complete immunity to the disease (Chiodini *et al*, 1984), but reduces shedding of the infective organism and has been shown to suppress clinical symptoms of the disease. Situations have been documented where on cessation of vaccination there has been no recrudescence of the disease (Wilesmith, 1982; Jorgenson, 1983). By vaccinating young stock to be used as replacement cows, vaccinated herds will generate fewer clinical cases of Johne's

[3] Commonwealth Serum Laboratories, Parkville

disease as the herd becomes fully vaccinated. Various trials have been reported and are reviewed by Holmes in a discussion paper (1992).

A major problem associated with vaccine use is the difficulty of marketing vaccinated animals, their current status being tantamount to that of infected animals. Vaccination has not been generally available as a Johne's disease control strategy in Australia, mainly due to the fact that the presence of vaccinated animals would have confounded official efforts to identify and remove cattle with *Bovine tuberculosis* in the national eradication campaign recently completed. In New Zealand, the low cost of vaccination makes it an economically attractive control procedure even for those dairy herds which have few clinically affected animals.

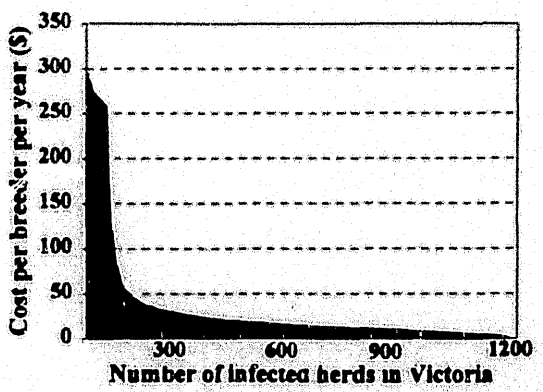
The cost of a vaccine ranges from $2 per dose for replacement cows ($0.47 per breeder) to $15 per dose ($3.56 per breeder), depending on the source and the quantities of vaccine used. The cost in Australia has been some $13 per dose or more, but this may be associated with the small quantities imported as the cost in New Zealand is much less than this. For the purpose of this analysis, a vaccine cost of $5 per dose ($1.20 per breeder) has been adopted because this is closer to the price of the vaccine used in New Zealand.

The effectiveness of each option in controlling the disease varies but no single option will eradicate the disease from an infected herd with certainty.

Costs of control versus losses from Johne's disease

The cost of these control strategies were compared with the cost of the disease to each individual herd, estimated from the database described previously. Figure A illustrates the cost of Johne's disease to each herd, where each point represents the average annual cost of the disease, per breeder. The cost of Johne's disease varies considerably between different herds, ranging from $300 per breeder to only $0.06 per breeder. Herds which display high costs are mostly studs which are precluded from selling breeding animals. The bulk of the profile is made up of commercial dairy and beef farms.

Figure A *Cost of Johne's disease in dairy and beef herds*



Test and cull programs could be economically justified for 57% of recorded herds, while vaccination could be justified for 97% of herds. Farm level modelling documented in DAV (1994) shows that a test and cull program is worthwhile if a farm running 135 milkers has 1 or more clinical cases per year, while vaccination could be a worthwhile investment even if the herd shows up only 1 clinical case every three years.

If the cost of the vaccine rose to $24 per dose ($5.69/breeder), it would still be economic for 87% of recorded herds with Johne's disease. If the cost of the test fell to $8 per test, a test/cull program would be economic for 79% of recorded infected herds.

Farms included in the database have been broken into four categories, comprising commercial dairy herds, commercial beef herds, stud beef and stud dairy herds. The potential benefits from managing the disease vary within these sectors, affecting the extent to which disease control is justifiable. Generally, there is a strong incentive for stud owners to either carry out an expensive control program or not to declare existence of the disease to authorities because trading restrictions cause such high economic losses.

Before vaccinating, producers would need to consider whether they are likely to sell animals to interstate or export buyers, as Johne's disease vaccinated cattle cannot under present arrangements be traded in interstate or export markets. Individual herd owners would need to weigh up the level of loss from the Johne's disease infection with the economic loss of not selling to these markets before embarking on a vaccination program.

5 The role of Government in controlling Johne's disease

Herd managers will invest in disease control only to the point where the costs and benefits of implementing disease control measures balance. When livestock diseases create external costs which are not accounted for by the market, there may be some role for government or industry intervention. The existence of externalities[4] generally suggest that markets will fail to efficiently allocate resources.

In the case of Johne's disease, the only externality which would justify government intervention is the cost caused by the disease spreading from one herd to another when animals are moved between properties. Industry and/or governments may improve the effectiveness of markets by improving the amount and/or quality of market information on which individuals make decisions.

Government intervention is not required to maintain access to export markets because Johne's disease is so widespread in other countries; GATT agreements preclude unreasonable use of disease as a non-tariff barrier; and because of the trade ramifications of such action with the US, where Johne's disease is present and highly unlikely to be eradicated (Chiodini *et al*, 1984). The role of government can therefore be directed towards minimising the spread of Johne's disease from one herd to another.

[4] Externalities are costs which impact on other members of society as a result of the actions of individuals. The costs imposed on the economy by air pollution are externalities.

An economic comparison of alternative livestock movement controls

The rate of transmission of Johne's disease between herds can be interrupted with various disease control measures, such as:

1) Individual animal tests - involving the use of an individual diagnostic test for animals moved from one herd to another;

2) A ban on sales - involving a ban on all animal sales from infected regions or farms to halt the spread of the disease;

3) Herd history reporting scheme - involving a low cost herd reporting system where buyers of livestock have access to information on the number and history of clinical cases of Johne's disease reported;

4) Sale of vaccinated animals - involving the permanent identification of vaccinated animals; and,

5) Development of a market assurance program - involving the development of a method of herd classification as a means of increasing the information on disease status available to buyers of livestock.

Each of these measures have been analysed according to their expected benefits and costs, and details of this analysis are found in DAV (1994). The analysis was conducted by determining the actual and critical probabilities of purchasing an infected animal using each of these measures. A critical probability represents the point at which the expected benefits of the measure are equal to the expected costs. Actual probabilities of purchasing infected animals are influenced by factors such as the number of disease tests performed, and whether the herd has been vaccinated. For instance, if animals are randomly purchased from Victorian herds, one animal in 38.5 is likely to be infected. One movement test would reduce this to 1 in 77 because the ELISA test has a sensitivity of 50 per cent.

By comparing the critical probabilities with the actual probability of purchasing an infected animal, it is possible to identify which disease control actions are appropriate. If the actual probability of purchasing an infected animal is less than the critical probability, then the movement control should not be implemented. If the actual probability of purchasing an infected animal is greater than the critical probability, then the movement control should be implemented.

Estimates of the probability of purchasing infected animals in other circumstances were obtained from Ridge *et al* (1993). The results of this analysis are summarised in table 4. If the probability of purchasing an infected animal is greater than the critical probability, a ✓ tick has been recorded to indicate that the movement control in question is prudent. The values in parentheses represent the ratio between the probability of purchasing an infected animal and the critical probability. The higher the ratio, the more strongly can the movement control be supported.

Table 4 *Movement controls required for Johne's disease*

		Destination		
Disease control action		Commercial dairy herd	Commercial beef herd	Slaughter
Movement test		✓ (1.8)	X (.9)	X (.001)
Movement test + herd history:				
Prevalence	0 to 1%	X(.3)	X (.11)	X (.0001)
	1 to 2%	X(.33)	X (.14)	X (.0002)
	2 to 5%	✓ (1.05)	X (.47)	X (.006)
	5 to 10%	✓ (2.8)	✓ (1.24)	X (.015)
	>10%	✓ (5.2)	✓ (2.2)	X (.03)
Herd history:				
Prevalence	0 to 1%	✓ (6.8)	✓ (3)	X (.04)
	1 to 2%	✓ (8.7)	✓ (3.89)	X (.05)
	2 to 5%	✓ (27.9)	✓ (12.4)	X (.13)
	5 to 10%	✓ (74)	✓ (32.8)	X (.27)
	>10%	✓ (136)	✓ (60.7)	X (.39)
Ban on movement		X	X	X
Vaccination ID		✓(2.4)	✓(1.1)	X(.01)

Recommended livestock movement controls

From this analysis, the following conclusions can be made regarding stock movement controls:

i) There are no circumstances under which any disease control action should be taken for animals being moved for slaughter purposes.

ii) When purchasing animals for stud farms, absolute assurance that animals are free of Johne's disease will be required.

iii) Where animals are moved to commercial dairy farms, a movement test should be applied if animals are purchased from herds of unknown Johne's disease prevalence. It is not necessary to test if animals are from herds known to have low Johne's disease prevalence. However, it is prudent to test animals from herds with higher prevalence. This recommendation only applies if vaccination is not widely used.

iv) When moving animals onto commercial beef farms a movement test will not be necessary unless animals are drawn from the general population of farms herds known to have high Johne's disease prevalence.

v) It is always beneficial to investigate the herd history when purchasing animals destined for commercial dairy or beef farms.

vi) If vaccination becomes an established control option, as suggested in chapter 5, the purchase of vaccinated animals could provide the most cost effective method of controlling the spread of Johne's disease.

vii) There are no situations where it is necessary to ban movement of animals.

Development of a market assurance plan

A proposed herd classification scheme (National Johne's Disease Market Assurance Program, or NJDMAP) was also analysed to compare the costs associated with introducing the scheme against the benefits from reducing the spread of Johne's disease. In this scheme, herds would be repeatedly tested and classified according to the number of clean tests achieved. The classes of herds would range from "suspect" on entry to the program, unless "infected" is more appropriate, through to a succession of "tested negative" classes, (TN1) to (TN3). The proposal embraces the concept of "Free Zones" which would be declared as a result of evidence provided by State officials based on the outcome of strategic plans, serological testing, or other monitoring. The system is designed to minimise the risk of introducing Johne's disease into uninfected herds.

A comparison of the benefits and costs arising from the program found that in its current form, the NJDMAP approach is not appropriate for commercial dairy herds because the costs outweigh the benefits. The only situation where the expected benefits exceed the costs of compliance with the NJDMAP is where stud farms purchase animals. However, while the NJDMAP approach is excess to the information needs of commercial dairy and beef producers, it would not provide stud owners with enough assurance of an animal's disease status. This suggests that there may be limited utilisation of this approach even in the stud sector. The NJDMAP should, therefore, remain a strictly voluntary scheme and care should be taken not to link any interstate movement controls to the NJDMAP approach as this will give rise to significant economic costs.

An alternative scheme has been developed which allows for a greater range of information which will be relevant to a broader spectrum of the livestock market. The additional classifications of animals as not relevant (NR), non-assessed (NA), undergoing testing (UT), partially vaccinated (PV) and full herd vaccination (FV) have been added to the tested negative (TN) categories discussed above (table 5). Recommendations for trade in live cattle between classified herds would relate to the risk of spreading disease. Details of these recommendations are in DAV (1994).

Table 5 *A framework to expand the national Johne's disease market assurance program proposal (NJDMAP)*

Category	Description	Management of individual animal	Management of herd
Not relevant (NR)	Regions deemed to be economically unaffected by Johne's disease		
Non-assessed (NA)	No assessment made - could indicate no interest or advantage perceived by the producer in herd history assessment.		
Undergoing testing (UT)		Animal either reacts or does not react to ELISA test	Subject to whole herd testing , as per NJDMAP
Tested negative (TN)	One, two and three successive clean tests	Animal does not react to ELISA test	Whole herd with no reactors to ELISA test
Part herd vaccinated (PV)		A vaccinate has received vaccine with subsequent nodulation at the site.	All replacements being vaccinated, some adults not yet vaccinated
Full herd vaccinated (FV)		A vaccinate has received vaccine with subsequent nodulation at the site.	All replacements vaccinated, all adults now vaccinated

This approach recognises the role of vaccination as both a means of limiting the productivity costs of Johne's disease and in limiting the spread of the disease between herds. It also takes account of the fact that a test and cull strategy will be too expensive for many commercial dairy and beef farms. The concept of herd or area vaccination, even restricted to adoption in closed commercial herds trading only in bobby calves, surplus heifers and aged cows, requires a substantial change in industry and veterinary thinking.

Vaccination as a management tool

Once vaccination is established as a means of preventing cows breaking down to Johne's disease, a trade in surplus vaccinated animals is likely to develop. In New Zealand, vaccinated cattle are said to attract neither a penalty nor a premium when sold. There is no reason why vaccinated herds should be completely barred from trading, as long as such trade does not increase overall industry prevalence.

After familiarisation with vaccination as a management tool, owners of vaccinated herds might be prepared to purchase breeding stock from vaccinated herds specialising in producing stud quality or replacement animals. The factors that will be important in establishing vaccination as a management tool to complement testing are:
. that the selection of whether to control the disease, and by what strategy, remains the decision of the producer.

. that herds using vaccine are recorded on a professional register. Vaccine should be available on prescription by veterinarians, even if the actual vaccination is performed by others.

. that there is adoption of a standardised, permanent marking for vaccinated cattle.

. that any impediments to the sale of vaccinated animals are removed.

Finally, compensation payments, as they are now administered, should be discontinued. It is likely that the availability of compensation payments discourages producers from identifying the extent of disease in the herd and perhaps controlling it by either testing or vaccinating.

References

Chiodini, R.J., van Kruiningen, H.J. and Merkal, R.S. 1984, "Ruminant paratuberculosis (Johne's disease): The current status and future prospects" *Cornell Veterinarian*, vol. 74, pp. 218-262

Department of Agriculture, Victoria 1994, *Johne's disease: An economic evaluation of control options for the Victorian dairy industry*, Department of Agriculture, Victoria.

Hermon-Taylor J. 1991, "Johne's bacillus and human Crohn's disease", in R.J.Chiodini and J.M.Kreeger (eds), Proceedings of the Third International Colloquium on Paratuberculosis, 1991, pp 196-200.

Holmes, I. 1992, *Discussion Paper on the Role of Vaccination in a Johne's Disease Control Program for Victoria*, Second edition, Department of Agriculture, Victoria

Jorgenson J.B. 1983, "The Effect of Vaccination on the Excretion of Mycobacterium paratuberculosis", in B. Jorgenson and O. Aalund, *Paratuberculosis, Diagnostic Methods, their Practical Application and Experience with Vaccination*, Commission of the European Communities, Copenhagen, pp. 131-136.

Ridge, S. 1993, *New Strategies for the Control and Eradication of Bovine Johne's disease*, Victorian Department of Agriculture Report to the Dairy Research and Development Corporation, Melbourne.

Wilesmith, J. W. 1982, "Johne's disease: A retrospective stud of Vaccinated Herds in Great Britain", *British Veterinary Journal* vol. 138, pp. 321-330.