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MODELLING THE DETECTION DELAY OF A TUBERCULOSIS OUTBREAK BASED ON THE SLAUGHTER INSPECTION COMPARED WITH THE TUBERCULIN TESTING OF THE COWS

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Dans le contexte actuel d'une faible prévalence de la tuberculose bovine en France, les principes de lutte mis en œuvre contre cette maladie dans une période de forte endémie ne sont plus réellement adaptés. C'est la raison pour laquelle l'Union bretonne des groupements de défense sanitaire a mis en place en région Bretagne, depuis 1995 et à titre expérimental, un nouveau système de lutte basé sur une démarche active des éleveurs en matière de prévention et sur la suppression de la détection par tuberculination systématique des cheptels, moyennant un taux de réforme annuel minimal de 10% (pour permettre la détection des foyers à l'abattoir).
Parmi les moyens mis en œuvre pour réaliser une évaluation a priori de ce nouveau système, un modèle de diffusion de la maladie dans le troupeau a été conçu afin de pouvoir comparer le délai de détection des foyers de tuberculose grâce à l'inspection à l'abattoir uniquement, en comparaison avec l'ancien système comprenant à la fois détection à l'abattoir et tuberculination systématique quadriennale. Ce modèle a été ensuite appliqué à deux situations-type plausibles : le troupeau entier infecté en l'espace de 1 an dans un cas, 40% des vaches infectées en l'espace de 4 ans dans l'autre cas.
Dans le cas d'une diffusion rapide de l'infection dans un troupeau de 60 vaches, un taux de réforme de 25% et une bonne sensibilité de la détection à l'abattoir (90%) permettent de détecter le foyer en moins d'un an (p=0.99), et plus rapidement que la tuberculination systématique dans 81% des cas. A l'inverse, il faut 4 ans (p=0.99) pour détecter un foyer en cas de diffusion lente de l'infection et de mauvaise sensibilité du dépistage à l'abattoir (50%) (la tuberculination systématique permettant dans ce cas la détection plus précoce du foyer dans 75 % des cas), voire 8 ans dans un troupeau de 30 vaches avec un taux de réforme de 10%. Ces résultats ont été utilisés pour estimer le risque de transmission de l'infection à d'autres troupeaux.

The control of bovine tuberculosis has been carried out since forty years in France, and the prevalence of the disease in the farms decreased from 25% in 1954 (Bretenet, 1954) to 0.2% in 1994 (DGAI, 1994). The consequence of this evolution is that the control scheme, set up in a high prevalence context, is no more adapted to the actual situation. The control scheme is based on the detection of infected herds, owing to the systematic tuberculin testing of the cows and the slaughter inspection, and on the protection of non-infected herds with the control of introduced animals. In the current situation, there are two major problems with this control scheme. First, the consequence of the low level of tuberculosis prevalence is that the positive predictive value of the tuberculin test and of the routine slaughter inspection decreased. For example, 81% in 1992 (Bénet, 1994) and 78% in 1994 (DGAI, 1994) of the positive animals at the tuberculin testing revealed no lesion at the slaughter inspection. Second, a low level of tuberculosis prevalence still persists and the disease cannot be eradicated with the actual system. Given these facts, the Union of Animal Health Organizations in the Brittany region proposed a new system (Union bretonne des GDS, 1993) whose goal is to be more effective and less expensive. It is based both on active measures taken by the farmer to prevent contamination and on a dispensation for the systematic tuberculin testing (if 10% at least of the cows are culled every year in order to detect tuberculosis at the slaughter inspection). Furthermore, each suspicion at the slaughter inspection is followed by a confirmation study based on pathology, bacterioscopy and bacteriology.

In order to evaluate the new system that has been set up as an experiment from 1995 to 2000, we carried out an a priori analysis of its technical efficacy, and performed a cost-benefit analysis. Given that the detection apparatus is simplified in the new system, one key point of the technical evaluation was to analyze the efficacy of the new system in detecting the tuberculosis outbreaks. The purpose of the paper is to present the study that has been performed in order to evaluate the ability of the new simplified detection system to detect infected farms, compared with the former and more complete system.

1. MATERIAL AND METHOD

The former detection system is based both on the slaughter inspection and the tuberculin testing whereas the new system depends solely on the slaughter inspection. The general idea is that the new one may be less efficient so that it can take much more time to detect an infected herd. In order to help reasoning that question, we built a simulation model of the spread of tuberculosis within a herd and of the probability to detect the disease

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at the slaughter inspection. Then we applied the model for two different plausible situations and we analyzed the efficacy of the new system compared with the previous one.

1.1. Modelling principles and technique

. *Spreading of the disease among the cows :* In order to model the reality more simply, the following hypotheses were taken into account : one infected and contagious animal is introduced in the herd, this representing the beginning of the tuberculosis outbreak. The spread of the disease within the herd is assumed to follow a logistic curve (y(t)) :

$$y(t) = \frac{A_c\, e^{kt}}{A_o / y_o - (1 + e^{kt})}$$

where A_c is the maximum percentage of infected animals in the herd (asymptote),
k determines the slope of the curve at the inflection point (maximum speed of transmission),
t is time, in months,
y_o is the ordinate at the origin (1/N, N being the number of cows in the herd).

. *Detection of the disease at the slaughter inspection :* the lesions of tuberculosis are assumed to happen within the same delay for all infected animals, so that the percentage of animals with lesions follows the z(t) formula, « t » been replaced by « t-delay », and « A_o » been replaced by « A (maximum percentage of infected animals with lesions) » in the y(t) formula.

The cullings are considered to be performed regularly along the year, one animal being culled at a time, and being replaced immediately by a non infected animal. So, the culling of an animal can be considered as a sampling with replacement. The sensitivity of the detection based on slaughter inspection (Se) can vary, so the probability to detect an infected animal at the slaughter inspection follows the w(t) formula : w(t) = Se z(t).

. *Probability of no detection of a tuberculosis outbreak :* Given these hypotheses, it is then possible to compute the probability of no detection of the tuberculosis outbreak on the farm at a given time (u(t)), that is the product of the probabilities of no detection at each of the previous cullings :

$$u(t) = \Pi_1^t (1 - w(t))$$

1.2. Applying the model to plausible farm situations

The model has been applied to two opposite but plausible situations in order to compute the delay of the tuberculosis outbreak detection for each case. These cases have been chosen on the basis of field observations and have been discussed with experts. In each case, the herd comprises 60 cows, 25% (15 cows) of them being culled every year.

One of the two cases represents a quick spread of the tuberculosis within the herd, which could correspond to a situation where a very contagious animal is introduced in a loose housed herd. In this case, the speed of contamination is considered to be high (k = 0.5), 100% of the animals are infected on the long run (Ac = 100%), 90% of the infected animals have lesions (A = 90%), and the sensitivity of the slaughter inspection is assumed to be high (Se = 90%), given the hypothesis of large and visible tuberculosis lesions.

The second case represents a slow spread of the tuberculosis within the herd, that can be observed in a tie housed herd. In this case, the speed of contamination is considered to be low (k = 0.1), 50% of the animals are infected on the long run (Ac = 50%), 90% of the infected animals have lesions (A = 90%), and the sensitivity of the slaughter inspection is poor (Se = 50%), given the hypothesis of rare and small tuberculosis lesions. Another simulation has been performed in that case, considering a smaller herd (30 cows) and a 10% annual culling rate.

1.3. Comparison of the detection delay depending on the detection method

Given that the former detection system is more complete than the new one, in that sense that it depends both on the slaughter inspection and the tuberculin testing, the comparison between the two systems consisted in analyzing in which situations the tuberculin testing detects the tuberculosis outbreak earlier than the slaughter inspection. This was performed considering a four-year tuberculin testing of the herds, and assuming that the probability to detect the outbreak with the tuberculin testing is 99% when two animals are infected (Bénet, 1990), i.e. with a prevalence equal to 3.3% in a 60-cow herd.

2. RESULTS AND DISCUSSION

The results of the simulation models are presented on Figure 1. As expected, the most favorable case for an early detection of the outbreak in the herd is observed in the case of a quick spread of tuberculosis and a good sensitivity of detection at the slaughter inspection (Figure 1a). In this situation, and given the model, there are 50% chance to detect the outbreak after six months, and 99% chance after one year (the probability of no detection falls during the first year of infection in the herd). In the other case, related to a low evolution of the infection in the herd, with a 50% sensitivity of the detection at the slaughter inspection and a 25% annual rate of culling (Figure 1b), it takes 20 months to detect the outbreak with a 50% probability, and 45 months (almost 4 years) with a 99% probability. Cumulating other non favorable circumstances (small herd, and low culling rate)(Figure 1c), the detection delay is very long. There are 50% chance to detect the outbreak after 32 months (2 years and a half), and 99% chance after 96 months (8 years). Very close results were observed in the Netherlands (Frankena, personal communication) using a different method to compute the detection delay with the slaughter inspection : 5 years for a stable prevalence equal to 30-40%, 94% probability to detect the outbreak after 3 years with an annual prevalence increasing from 20 to 50%. It appears that the delay to detect infected farms varies strongly depending on the epidemiological situation of the disease in the herd : from 1 year up to 8

a. quick spread
60-cow herd
25% culling rate
90% sensitivity of detection

b. slow spread
60-cow herd
25% annual culling rate
50% sensitivity of detection

c. slow spread
30-cow herd
10% annual culling rate
50% sensitivity of detection

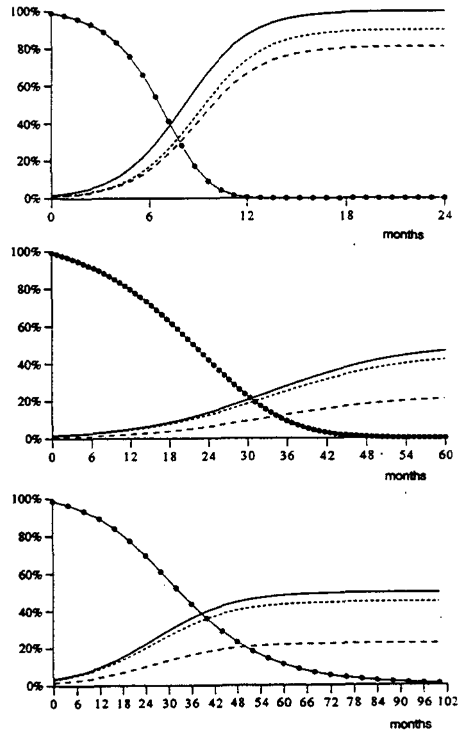

Figure 1. Simulation of the probability to detect the tuberculosis outbreak on the basis of the slaughter inspection depending on the delay since the beginning of the outbreak in the herd.

——— % infected animals

- - - - - % animals detected at the slaughter inspection

.... % animals with lesions

—•—•— probability of no detection of the infected farm

years in order to be sure (p=0.99) to detect the outbreak.

In the case of a quick spread of the tuberculosis outbreak in the herd, with a good sensitivity of detection at the slaughter inspection, the four-year tuberculin testing should permit to detect the outbreak earlier if it was performed between 2 months (when the prevalence becomes higher than 3.3%) and 11 months (when the detection is effective at the slaughter inspection) after the beginning of the outbreak in the herd, that is to say in 19% of the cases (9 months over the 48 months of the 4 year tuberculin testing). In the case of a low spread of the disease, with a poor sensitivity of the detection at the slaughter inspection, the tuberculin testing should permit to detect the outbreak earlier if it was performed between 8 and 44 months after the introduction of the infected animal in the herd, that is to say in 75% of the cases (36/48).

In comparison with the former system, it appears that the outbreaks are likely to be detected later within the new system, especially in the case of slow spreading outbreaks. These data have been used to estimate the risk to contaminate other herds by selling contaminated animals (Ducrot et al., 1996), given that the tuberculin testing of the newly introduced animals was planned to be removed in the new system. This conducted to propose measures to control the increased risk of tuberculosis transmission between herds : to maintain the tuberculin testing of newly introduced animals, and to conduct an epidemiological investigation on farms having exchanged animals with every infected herd.

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