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Simulation of between-farm transmission of porcine reproductive and respiratory syndrome virus in Ontario, Canada using the North American Animal Disease Spread Model

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ABSTRACT

Porcine reproductive and respiratory syndrome (PRRS), a viral disease of swine, has major economic impacts on the swine industry. The North American Animal Disease Spread Model (NAADSM) is a spatial, stochastic, farm level state-transition modeling framework originally developed to simulate highly contagious and foreign livestock diseases. The objectives of this study were to develop a model to simulate between-farm spread of a homologous strain of PRRS virus in Ontario swine farms via direct (animal movement) and indirect (sharing of trucks between farms) contacts using the NAADSM and to compare the patterns and extent of outbreak under different simulated conditions. A total of 2552 swine farms in Ontario province were allocated to each census division of Ontario and geo-locations of the farms were randomly generated within the agriculture land of each Census Division. Contact rates among different production types were obtained using pig movement information from four regions in Canada. A total of 24 scenarios were developed involving various direct (movement of infected animals) and indirect (pig transportation trucks) contact parameters in combination with alternating the production type of the farm in which the infection was seeded. Outbreaks were simulated for one year with 1000 replications. The median number of farms infected, proportion of farms with multiple outbreaks and time to reach the peak epidemic were used to compare the size, progression and extent of outbreaks. Scenarios involving spread only by direct contact between farms resulted in outbreaks where the median percentage of infected farms ranged from 31.5 to 37% of all farms. In scenarios with both direct and indirect contact, the median percentage of infected farms increased to a range from 41.6 to 48.6%. Furthermore, scenarios with both direct and indirect contact resulted in a 44% increase in median epidemic size when compared to the direct contact scenarios. Incorporation of both animal movements and the sharing of trucks within the model indicated that the effect of direct and indirect contact may be nonlinear on outbreak progression. The increase of 44% in epidemic size when indirect contact, via sharing of trucks, was incorporated into the model highlights the importance of proper biosecurity measures in preventing transmission of the PRRS virus. Simulation of between-farm spread

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of the PRRS virus in swine farms has highlighted the relative importance of direct and indirect contact and provides important insights regarding the possible patterns and extent of spread of the PRRS virus in a completely susceptible population with herd demographics similar to those found in Ontario, Canada.

1. Introduction

Porcine reproductive and respiratory syndrome (PRRS) is an important viral disease of swine and has major economic impacts on the swine industry (Neumann et al., 2005). PRRS affects all production stages and is characterised by late-term abortions, still-births, mummified foetuses and weak piglets in breeding herds; and an increased mortality rate in piglets and respiratory disease, poor growth performance and mortality in growing pigs (Nodelijk, 2002). The causative agent for PRRS is an enveloped, spherical, single stranded, positive-sense RNA virus of the family Arteriviridae (Murtaugh et al., 1995). Genetic studies of the virus indicate significant antigenic and molecular variability, suggesting two distinct genotypes: Type I (European genotype) and Type II (North American genotype). Wide genotypic variation within each genotype is another notable characteristic of this virus (Murtaugh et al., 1998).

The virus is present in serum and excreted in several bodily secretions, which include semen, colostrum, urine, feces and oral fluids of infected animals (Wills et al., 1997b; Bierk et al., 2001). Survival of the PRRS virus in the environment is affected by ambient temperature and pH. The virus can survive for long periods (four months) at temperatures below −20 °C; however, at higher temperatures viability of the virus decreases. It can remain infective for around one month at 4 °C, six days at 21 °C, one day at 37 °C, and for only 20 min at 56 °C (Benfield et al., 1992).

Several mechanisms for transmission of the virus between farms have been outlined; the most important and widely agreed upon mechanisms are via the movement of infected animals between different farms/stages of swine production, and through the introduction of infected semen (Yaeger et al., 1993; Mortensen et al., 2002). Vehicles used for the transportation of pigs and associated fomites (boots, coveralls, bedding materials etc.) can also spread the infection over long geographical distances, as has been demonstrated in a number of transmission experiments using contaminated vehicles and fomites (Dee et al., 2002; Otake et al., 2002b; Dee et al., 2004; Holtkamp et al., 2010). Local transmission by aerosols within 150 metres has also been reported from an experimental study (Otake et al., 2002a).

Simulation models which explore artificially designed experiments have become an important tool for epidemiologists to simulate the spread of a range of infectious diseases of livestock (Kao, 2002; Kobayashi et al., 2007; Evans et al., 2010). Such 'experiments' would not normally be possible in real world conditions, due to cost, time and/or animal welfare considerations. Disease spread models are intended to mimic real world situations and can be useful in explaining the behaviour of complex biological systems; identifying the key factors influencing a system, predicting the effect of interventions on disease outcomes and providing a means to inform policy decisions (Taylor and Gate, 2003). NAADSM (North American Animal Disease Spread Model) is a spatial, stochastic, farm level state-transition modeling framework originally developed to simulate the between-farm spread of highly contagious and foreign livestock diseases (Harvey et al., 2007). It allows for user-established parameters to define model behaviour in terms of disease progression, has flexibility to simulate disease spread by direct contact through the movement of animals, indirect contact via personnel or fomites, airborne dissemination and local spread. In NAADSM the individual population units (farms) are defined by their actual physical location within a geographical region. The disease spread which occurs between individual farms in NAADSM is influenced by rates of direct and indirect contact, relative locations and distances between farms; all of which are driven by stochastic processes based on distributions and relational functions specified by the user. Once a farm has become infected it follows a natural, predictable cycle over time, transiting from one to another disease state (Harvey et al., 2007). One key advantage of this approach is that by including randomness, the chance nature of epidemic spread is accounted for, while by incorporating the contact structure between farms a higher degree of realism can be achieved in the model (Dangerfield et al., 2009).

A single study, so far, has been published which attempt to evaluate the between-farm transmission dynamics of PRRS virus and outline the extent of disease spread in a geographical region. Neumann et al. (2007) evaluated the risk of introduction of the PRRS virus into New Zealand through the importation of raw pig meat and predicted the extent of any subsequent spread of the virus within the swine industry in New Zealand. Additionally, truck sharing between farms for shipment of pigs has been considered to be one of the major pathways for between-farm spread of PRRS virus by Canadian producers (http://www.opic.on.ca/biosecurity-resources/transportation) and experts in the swine industry. Recent studies have demonstrated high levels of truck sharing between farms for the shipment of pigs (Bottoms et al., 2012; Thakur et al., 2014) and have documented that only around one third of such trucks are properly cleaned and disinfected between successive shipments (Lambert et al., 2012). However, the likely impact of truck sharing on the spread of PRRS virus has not been explored in previous studies. So, this study attempted to describe the likely spread of PRRS virus due to movement of pigs between farms and indirect contact associated with such movement. The objectives of this study were to develop a model to simulate the between-farm spread of PRRS virus in Ontario swine farms via direct (animal movement) and indirect (sharing of trucks between farms)