Evaluation of brown rot (*Ralstonia solanacearum*) control strategies: development of an epidemiological model

A Breukers
Wageningen University, dept. of Business Economics, Hollandseweg 1, 6706 KN
Wageningen, Netherlands
Email: Annemarie.Breukers@wur.nl

D L Kettenis
Wageningen University, Information Technology Group, Dreijenplein 2, 6703 HB
Wageningen, Netherlands

ABSTRACT

An epidemiological model was developed to simulate brown rot prevalence and dispersal in the Dutch potato production chain. The aim of the model was to obtain insight into the contribution of certain risk factors to brown rot prevalence. Model simulations show an irregular pattern of yearly number of infections that is also characteristic for brown rot in reality. They also show the importance of contaminated surface water in brown rot prevalence. The model has many other application possibilities and will be used to evaluate the effect of control strategies on brown rot prevalence.

INTRODUCTION

Potato brown rot, caused by the bacterium *Ralstonia solanacearum* race 3, biovar 2, comprises a major threat to the potato production world wide. Particularly in warm growing areas such as the Mediterranean region, brown rot infections can be very destructive and cause considerable yield losses (Elphinstone, 2001). Incidental outbreaks have been reported in many European countries, and within the EU brown rot has a quarantine status (Elphinstone, 2002). In the Netherlands, where potatoes are the main cash crop (CBS, 2002), brown rot has been found occasionally since 1995. Its prevalence in the Dutch potato production chain has serious economic consequences because of the need for extensive preventive and sanitation measures (Elphinstone, 1996; Janse et al., 1998). Moreover, the risk of establishment of brown rot in the Netherlands threatens the Dutch export of seed potatoes (Vaals and Rijkse, 2001).

As a result of an extensive monitoring and control policy, the number of brown rot cases in the Netherlands has been reduced with approximately 75% over the past decade (Janse and Wenneker, 2002). However, the intended complete eradication has still not been achieved, and knowledge about the importance of several risk factors on brown rot prevalence is still poor. A better insight into the relative importance of these risk factors would facilitate the design of an optimal control strategy. Therefore, an epidemiological model was developed, which simulates brown rot prevalence in the potato production chain over time and space.

THE MODELLED SYSTEM

The potato production chain

The production cycle of potatoes covers one year and can be separated in an on-field and off-field period. The on-field period comprises the growing season of potatoes, which lasts from planting to harvest. During the off-field period, depending on the category and final destination, potato lots are stored, exported, sold to consumers, or industrially processed. Seed potatoes that are not exported are replanted after the storage period. All ware and starch potatoes leave the potato production chain before or after storage. During the first weeks after harvest, all seed lots and a percentage of all ware and starch lots are tested for the presence of brown rot. Positive tested lots are defined "detected" and are destructed. Besides, lots that had a negative test result but are highly suspected of being infected are defined "probably infected"; such lots are downgraded to ware (or starch) potatoes and marketed under restrictions.

Brown rot infection pathways

There are three different pathways through which a potato lot can become infected with brown rot. Firstly, infections may be caused by irrigation or spraying of potatoes with contaminated surface water, in which brown rot bacteria can occur because of the presence of the host weed bittersweet (*Solanum dulcamara*), which is common along many Dutch waterways. Infection through contaminated surface water is called primary infection, because the source of infection is outside the potato production chain. In a disease-free production chain, this is the only way through which an infection can arise. In the Netherlands, the Dutch Plant Protection Service has designated regions in which surface water was found to be contaminated with brown rot as "prohibition areas", in which the use of surface water is prohibited.

Once brown rot has entered the potato production chain, the pathogen can disperse through the chain by horizontal and vertical transmission mechanisms. Horizontal transmission means infection of a healthy potato lot where the source is another infected lot, and can – for instance – be caused by the use of contaminated machinery or equipment. Vertical transmission, also referred to as infection through clonal relationships, indicates transmission of the disease from parent to offspring. This results in an increase in the number of infected lots when an infected but yet undetected seed lot is split into daughter lots, which are subsequently replanted.

MODEL STRUCTURE

To simulate the dynamics of brown rot within the Dutch potato production chain, an individual-based model (IBM) was selected as an appropriate modelling technique (Breukers et al., 2005). An IBM separately keeps track of the dynamics of all entities (called objects) in the simulation, taking into account the individuals' unique properties and their interactions [10, 11]. The model resembles the modelled system to a significant degree of detail, allowing for rare or unexpected events that may cause extreme outputs. Moreover, the brown rot model is spatially explicit in that it assigns a location to each individual, thus including the interactions between an individual and its environment. These characteristic makes the IBM a convenient technique for policy application.

The trading units of the potato production chain are potato lots. Potato lots are grown on fields, which belong to farms. The three nouns in this last sentence comprise the main concepts of the production cycle and logically constitute the individual objects in the model. Within a simulation, changes in the state of these individuals are caused by events. For each process in the production cycle, the model checks which events go together with this process and on which individuals these events have an effect. Examples of occurring events are "primary infection" of a lot as a result of irrigation in a region where surface water is contaminated, or "detection" of a lot, which is related to the process of testing.

Most events that can take place are based on probability distributions, so their occurrence is stochastically determined by the model. This allows for modelling not only the average brown rot prevalence but also the natural variation that can occur as a result of the stochastic nature of these processes (Hardaker et al., 1997). Another reason to include stochastic elements is to represent the uncertainty about many events in the model, which makes it impossible to determine exactly when they take place and which consequences they have. Both variation and uncertainty play an important role in the evaluation of the effectiveness of different control strategies.

Through a geographical information system (GIS), all farms and fields in the model are assigned an x- and y-coordinate by which they can be mapped. Infected potato lots are always linked to the field on which they have been grown, so they can be visualised as well. Consequently, simulation outcomes can easily be spatially represented, allowing for the analysis of possible regional differences in brown rot prevalence. Apart from geographical coordinates, the model output includes other information about infected lots, such as the infection source (e.g. surface water, planting, transport) and the category (seed, ware, or starch).

As a result of the stochastic nature of the model, one should not rely on just one simulation run. Before drawing conclusions, a large number of replications should be done to determine variances between runs. Both the number of replications and the total number of production cycles per simulation are user-defined. The parameters used for the simulations discussed below are provisional estimates of experts and still need to be optimised.

RESULTS AND DISCUSSION

As an example, a simulation was performed over a period of 15 production cycles (i.e. years), and replicated 50 times. The first five production cycles of the simulation period were excluded from the results because the output of these years may be affected by the initial simulation settings. Figure 1 shows the fluctuation of the number of infected lots over time, for one replication and for the average of all replications. The trend line representing the average yearly number of infections remains rather constant, showing between 20 and 25 infections per year. However, the results of one simulation show a strong fluctuation over the years, indicating a large variation in number of infections between years and between replications. This result corresponds with the typical pattern of brown rot dynamics observed in practice.

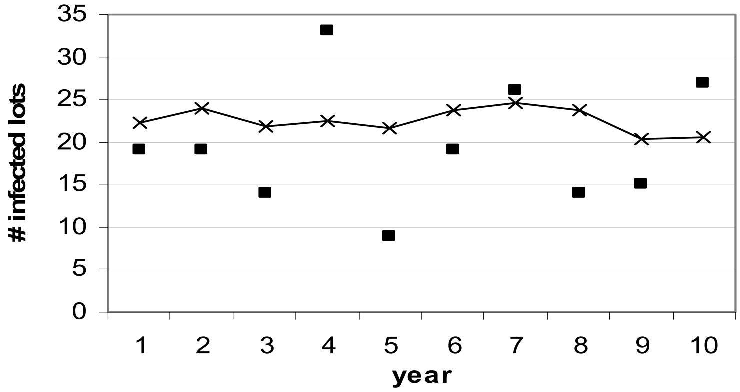

Figure 1. Number of infected lots over time during a period of 10 years, for one arbitrary replication (■) and averaged over 50 replications (continuous line marked with ×).

In figure 2, the average relative contribution of each infection source is shown. It is clear that surface water is a very important factor in brown rot prevalence, whereas horizontal transmission plays a minor role. Vertical transmission (i.e. clonal infection) is also a significant factor; however, this source of infection is directly related to all other sources since it represents the multiplication of already existing infections in seed lots that are replanted within the country. The importance of surface water is also reflected in figure 3, which shows a geographic representation of brown rot prevalence in one year of a replication. The grey areas are prohibition areas where the use of surface water for potato cultivation is prohibited. The model run that is presented here assumes there is a small chance that this prohibition is ignored, explaining the infections within these areas. Infections just outside prohibition areas can still be caused by contaminated surface water, because the risk that surface water within one km from a prohibition area contains low densities of brown rot is also taken into account. These areas are especially sensitive as the use of surface water is allowed but may still cause a new infection.

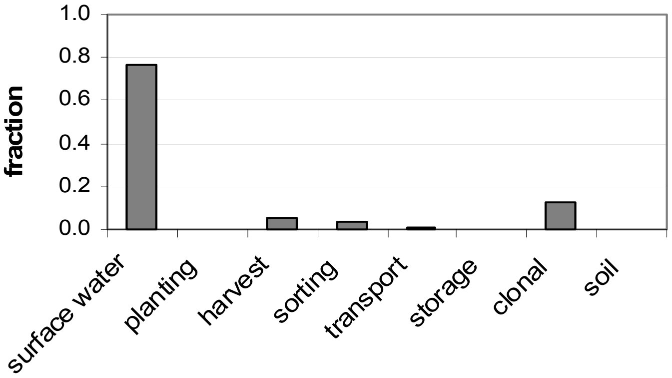

Figure 2: Relative contribution of different infection sources to the total number of brown rot infections.

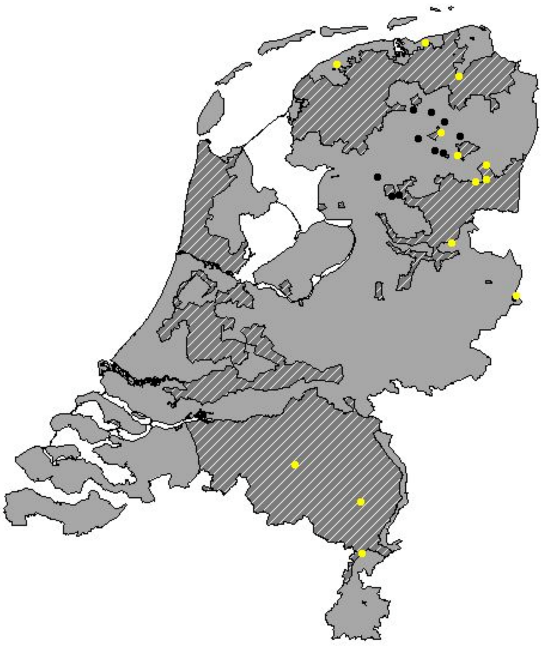

Figure 3. Map of brown rot infections in one year of a simulation run. Shaded areas represent prohibition areas. Infected lots occurring in any of the ten years are indicated by a ●; the light-grey coloured dots represent infections caused by contaminated surface water.

CONCLUSION

The discussed model gives a detailed and realistic representation of brown rot dynamics in the Dutch potato production chain. It is the first model that we know of that applies an individual based modelling approach to plant disease processes at this level of spatial hierarchy. Only a few results have been shown here; the model has many other possibilities for analysis and can be used to analyse for example regional differences in prevalence and effectiveness of detection. In a later stage of the research, an economic module will be developed and combined with the epidemiological model, resulting in a bio-economic model by which control strategies can be evaluated on their cost-effectiveness. This model will then serve as a management tool to optimise brown rot control policy.

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