An agent-based model on disease management in potato cultivation in the Netherlands

F.C.A. Pacilly[1], G.J. Hofstede[2], J.C.J. Groot[1], E.T. Lammerts van Bueren[3]

[1] Farming Systems Ecology, Wageningen University, P.O. Box 430, Wageningen, The Netherlands.

[2] Information Technology, Wageningen University, P.O. Box, 8130 6700 EW, Wageningen, The Netherlands

[3]Wageningen UR Plant Breeding, Wageningen University, P.O.Box 386, 6700 AJ Wageningen, The Netherlands

Abstract
In this project the host-pathogen system of potato (*Solanum tuberosum*) - late blight (*Phytophthora infestans*) was analysed as a model system to study management of crop-disease interactions. Resistant cultivars play an important role in sustainable management of the disease. We used an agent-based modelling approach to explore the use of resistant cultivars in late blight control. Important processes in the system are farmers' decision-making and biophysical processes such as potato growth and *Phytophthora* growth and dispersal within a certain landscape configuration. To get input for model development in-depth interviews with farmers were carried out to identify the factors involved in decision-making. In the cultivar selection process we focus on a trade-of between the yield and the risk of infection. The first results showed that the model is able to represent ecological and social processes related to potato late blight and farmers' decision-making and their interactions.
Keywords
Social-ecological systems, agriculture, disease control, farmers' decision-making

1. Introduction

Damage due to pests and diseases is one of the main factors responsible for yield loss [1]. This project will focus on the Netherlands which is a large producer of potato. One of the most important diseases in potato production is potato late blight (*Phytophthora infestans*). This pathogen has a short life cycle and because the spores disperse by wind, a late blight epidemic can spread over large regions in a short time. In this project the host-pathogen system of potato - late blight will be analysed as a model system to study management of crop-disease interactions.

Nowadays the use of fungicides is the most important control method, but this involves high costs and they are harmful for the environment. Schöber [2] described a combination of methods as part of integrated disease management (IDM) to limit the use of fungicides to a minimum. Two important strategies include sanitary precautions and the use of resistant cultivars. Related to the first aspect, the Dutch government implemented sanitary regulations that state that infected potato fields should be destroyed if the infection reaches a certain level (±7%) to prevent spread to neighbouring fields. An inspection was set up that can fine farmers if they do not comply with the rules.

Secondly, resistant cultivars should be used to reduce the risk of infection and the spread of the disease. In the Netherlands the use of resistant cultivars in late blight control is limited. In the past several resistant cultivars were introduced to the market but these do not yet have all the characteristics required for the industry and retail such as yield level or cooking type. Furthermore, because the application of fungicides leads to effective control, there is no strong need for alternative control methods. In organic potato production the use of chemicals is not allowed. Therefore the use of resistant cultivars could play an important role in sustainable management of the disease. However, when these cultivars become more widely used, resistance breakdown can occur as a result of pathogen adaptation, which was also observed in the past [3]. Since breeding for resistant cultivars is a long process and requires large investments, these cultivars should be protected from resistance breakdown that can be considered a scarce and common good.

Since management of potato late blight is influenced by ecological as well as social factors this is an example of social-ecological system. Agent-based modelling (ABM) has been recognized as a suitable tool to analyse human decision-making in a spatial environment is which biophysical processes occur. In this paper we will use an agent-based modelling approach to explore the use of resistant cultivars in late blight control. Important processes in the system are farmers' decision-making and biophysical processes such as potato growth and *Phytophthora* growth and dispersal within a certain landscape configuration. To get input for model development in-depth interviews with farmers were carried out to identify the factors involved in decision-making. Some of the important findings include:

1) *Farmer types*: Conventional and organic farmers differ in their options in late blight control because organic farmers have no means to combat the disease. This influences the importance of alternative control methods and the willingness to adopt these.
2) *Risk perception:* Differences were observed in the way potato late blight was perceived by farmers as a threat to their crop. For example some farmers had a strong fear of getting an infection in their crop while others considered late blight as a controllable problem.
3) *Network*: Farms are located in a landscape and they spend much time on their land so they are well aware how other farmers (successfully) manage their crops. They also communicate about issues related to crop management.
4) *Competition*: Farmers try to optimize their yield because this is directly related to farmers' profit. Therefore they compare their yield to the yield of others, which results in competition.

These factors were used to develop a framework for farmers' decision-making. The epidemiological model of *Phytophthora* was achieved by simplifying an existing model [4]. This previous work analysed *Phytophthora* dispersal in a landscape but did not include social processes and therefore the development of an ABM is of importance.

The ABM will be used to analyse the effect of releasing a new resistant cultivar by a breeding company. We focus on three different aspects: (1) the adoption of resistant cultivars by farmers, (2) the effect of resistant cultivars on the infection with late blight in a landscape and (3) the durability of resistant cultivars. The model framework will be described in the next section and an example of model output is presented in the results.

2. Model overview

A model of the social-ecological system of potato late blight management was developed using NetLogo. The model represents a 10km by 10km agricultural region in which each patch represents 1 hectare of arable land. Within the landscape 500 farmers are located each of whom manages one potato field. A potato field consists of a number of patches and has an average size of 5 ha. The landscape is based on a realistic agricultural landscape in the Netherlands with respect to potato density and field size. A network was set up among farmers. Within this network, farmers are connected to a number of other farmers in their surrounding. Two farmer types are distinguished in the model: Sprayers and Non-sprayers. Furthermore farmers are characterized by their field size, the cultivar they grow and personal characteristics.

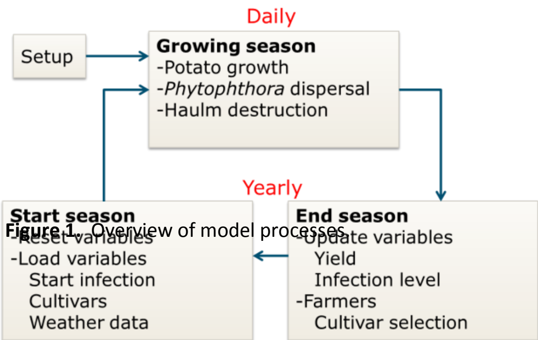


Figure 1. Overview of model processes

The time step in the model represents one day. The model simulates the growing season from April to September and the model can run for many years (Figure 1). Daily processes include crop growth and disease dispersal. Weather data was included in the model which affects spread of the disease. When the infection level in a potato field reaches 7%, the potato haulm is destroyed according to the governmental regulations. This means tuber growth stops directly and the disease can no longer disperse to other fields.

Yearly processes include an update of variables, cultivar selection and resetting and loading of variables. At the end of the season farmers update the variables (mean yield, infection level etc.) and then select a cultivar for the next season. They can choose between a susceptible and resistant cultivar. These cultivars differ with respect to the tuber growth rate and the risk for infection with potato late blight. Changing to another cultivar is triggered by a low yield in the previous season, and influenced by stochastic variables related to farmer characteristics.

2.1 Biophysical processes

Biophysical processes in the model include crop growth and disease dispersal. As a measure for crop growth, the number of m^2 leaf area per hectare (leaf area index, LAI) is calculated using a crop model (Skelsey 2008). The infection level with potato late blight is calculated by using an equation for exponential growth. At the beginning of each season the infection starts in a certain fraction of susceptible cultivars, randomly chosen. Based on the infection level a number of spores is produced that are dispersed by a diffusion process. When the amount of spores in an uninfected patch reaches a threshold this patch becomes infected. As mentioned before, weather is an important factor influencing disease growth and dispersal. Weather data between 1980 and 2010 was analysed to determine the number of days favourable for growth and spread of potato late blight. This data was implemented in the model and the disease can only grow and disperse on these specific days. The amount of yield is calculated based on the LAI, the tuber growth rate and the infection level with late blight.

In this model we want to analyse the durability of resistant cultivars. Therefore we included a mutation fraction which is used to calculate the number of mutated spores as a fraction of the total number of produced spores. These mutated spores are considered to be part of a new virulent population that is able to infect resistant cultivars. The processes for growth and dispersal of the new virulent *Phytophthora* strain are similar to the normal *Phytophtora* type. When a resistant cultivar becomes infected with the virulent *Phytophthora* strain we speak of resistance breakdown.

2.2 Farmers' decision-making

In the model farmers play a key role since they have to make decisions on management of potato late blight. In this model we focus on farmers' decision-making related to the adoption of resistant cultivars. We assume a scenario in which all farmers grow a susceptible cultivar at the start of the simulation. After one year a resistant cultivar is introduced to the market and from now on farmers can chose between these two types. In the cultivar selection process we focus on a trade-of between yield and the risk for infection. In this case, the resistant cultivar has a lower yield but a smaller risk for infection. This is related to the real situation because current resistant cultivars do not yet meet the requirements of the industry and retail, including yield level.

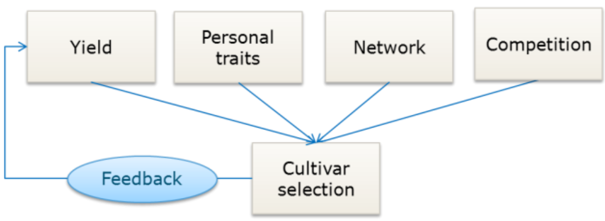
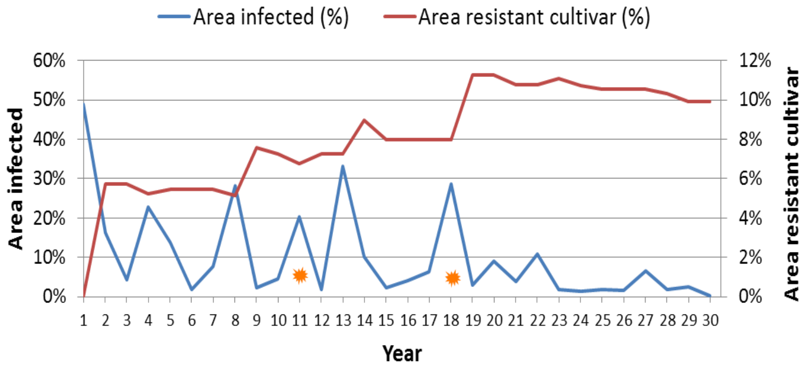


Figure 2. Overview of factors involved in farmers' decision-making on cultivar selection.

The framework for the cultivar selection process is based on the findings from the interviews. Two different farmer types (Sprayers and Non-sprayers) are included in the model (finding 1). Farmers follow a strategy in which a low yield level from previous year is a trigger to switch cultivars. This low yield level is relative: farmers compare their yield level with the average yield level of the farmers in their network (based on finding 3 and 4). A relative low yield can be the result of an infection with late blight, or because of growing a resistant cultivar in a year with low pressure of the disease. Furthermore, all farmers are characterized by a certain level for risk-behaviour (finding 2). If farmers have a low value for risk-behaviour they have a larger probability to adopt the resistant cultivar while more risk-taking farmers have a larger probability to continue growing the susceptible cultivar. The factors involved in the cultivar selection process are summarized in Figure 2.



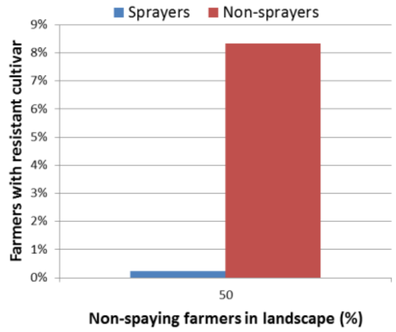


Figure 3. An example of one model run in a landscape with 50% of non-spraying farmers. The blue line represents the area of infected potato (%) and the red line the area of potato with the resistant cultivar (%). The asterisks indicate the occurrence of resistance breakdown.

Figure 4. Percentage of spraying and non-spraying farmers that grow a resistant potato variety after 30 years. An example of one model run in a landscape with 50% of non-spraying farmers.

3. Results

A first version of the model was developed and an example of model output is presented in Figure 3 and 4. As a case study, we run the model in a landscape with 50% of non-spraying farmers. Weather data of thirty years was used to run the simulations which resulted in a large variation in the fraction of infected potato fields over the years. Figure 3 shows that after years with a severe outbreak of the disease, some of the farmers will adopt the resistant cultivar. In years with low pressure of late blight, some of these farmers will switch back to the susceptible cultivar. In this simulation already two cases of resistance breakdown were observed, indicating that in years with high pressure of late blight a risk exist that a new virulent strain emerges, which is able to infect resistant potato cultivars. Figure 4 shows that resistant cultivars are mainly adopted by non-spraying farmers (Figure 4). This indicates that it is only beneficial to grow a resistant cultivar (with a relative lower yield) when no other control methods are used. However, a very small percentage of the spraying farmers adopted the resistant cultivar, probably the ones with a very low level for risk-behaviour.

4. Discussion

The first results of the model showed that the model is able to represent ecological and social processes related to potato late blight and farmers' decision-making and their interactions. Furthermore the model output seems to correspond to our understanding of the system and the findings from the interviews. For example, only non-spraying farmers will benefit from a resistant cultivar with a lower yield since they have no other options in disease control. Therefore, resistant cultivars play currently no important role in management of potato late blight. Breakdown of resistance was observed in years with severe outbreaks of the disease, which has also happened in the past. Next steps in the modelling process include a sensitivity analysis to analyse important drivers of the system. Furthermore several scenarios will be explored, for example for alternative climatic conditions, different percentages of non-spraying farmers in the landscape and different levels of farmers' risk behaviour.

References

1. Lobell, D.B., K.G. Cassman, and C.B. Field, *Crop yield gaps: Their importance, magnitudes, and causes*, in *Annual Review of Environment and Resources*. 2009. p. 179-204.
2. Schöber, B., *Control of late blight, Phytophthora infestans, in integrated crop management.* Netherlands Journal of Plant Pathology, 1992. 98(2 Supplement): p. 251-256.
3. Fry, W., *Phytophthora infestans: The plant (and R gene) destroyer.* Molecular Plant Pathology, 2008. 9(3): p. 385-402.
4. Skelsey, P., *Multi-scale modeling of potato late blight epidemics*, 2008. Wageningen University, PhD Thesis, Wageningen, The Netherlands, 257 p.