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Modelling of the airborne dispersal of a pathogen over a structured vegetal cover.

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Introduction

The spread of a pathogen within a strongly anthropized perennial vegetable cover depends on many factors acting at contrasted spatio-temporal scales. This is of paramount importance for vine and apple trees and their airborne obligated parasites, namely the powdery mildew, and the apple scab respectively, that strongly rely on the susceptibility and status of their hosts. Both crop systems require from 7 to 20 fungicide treatments per year respectively. Sustainable crop management relies on a better understanding of the dynamics of these epidemics at various spatio-temporal scales. We aim at developing a methodology to model plant-pathogen interactions at several spatio-temporal scales.

The vine-powdery mildew model

Our approach is based on the existence of a dynamic discrete model coupling the growth of a vine stock and the development of powdery mildew [2]. The vine stock 3D architecture is described as a structure composed of a trunk, leaves, internodes.

Organs (internodes, leaves, clusters) development depends on accumulated temperature. Both shoot growth and the area of leaf surface satisfy a logistic equation function of temperature. The appearance and growth of secondary shoots is highly dependent on the vigor of the vine, the date of the shoot topping, and the position of the shoot on the primary. The development of secondary shoots is stimulated by shoot topping. Grape clusters are located on primary shoots at a level between the second and fifth primary leaf and appear at the same time as primary leaves.

Concerning the pathogen propagation, the temperature and the leaf age are recognized as the driving force for the development, while wind factors dictate spore dispersal. In our model, the dynamics of the pathogen development on leaves is split into infection, colony growth, and dispersion. At each time step, a quantity of spores is released, depending on wind intensity, colony size, and dispersed within a cone given by wind direction. The spore density decreases, first as an exponential dilution with axial distance to the source, and then linearly according to the radial position within the cone. The quantity of spores caught by a leaf depends upon its distance from the source, and is proportional to its surface area.

Visualization of outputs

Qualitative and 3D graphical outputs of numerical simulations are obtained using the visual programming OpenAlea. This platform offers efficient 3D visualization tools that are easily non-specialist user accessible [5]. The two modules, simulating the vine stock growth and the pathogen propagation, are integrated in OpenAlea (Figure 1).



Fig. 1 : Visualization of vine stock on year 1998, at days 133, 168 and 241 using the PlantGL module from OpenAlea.

Moreover, a friendly user interface has just been devised to facilitate numerical simulations of the model (written in Python-C languages), and to facilitate the investigation of the spatial distribution of the disease (Figure 2).

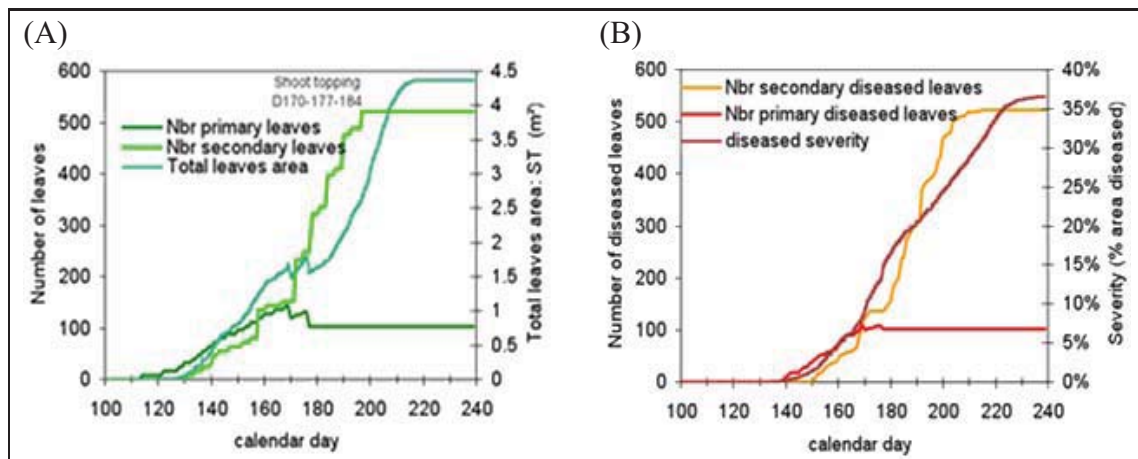


Fig. 2: Temporal evolution of the number of leaves (primary and secondary) and of the leaves area (A). Temporal evolution of the number of diseased leaves (primary and secondary) and severity for one vine stock on year 1998 (B).

Sensitivity analysis, with respect to various crop practices (e.g. shoot topping day, cut height), vine stock architecture (organs length, vigor, distance between shoots), powdery mildew properties (infection day, dispersal coefficients) and climate (year, temperature, wind) indicates the interest of these parameters variability [1, 3]. Among other things, vine vigor and climatic conditions can strongly modify the disease dynamics.

Generic model and application to the apple scab model

Concerning apple trees, a simulation model for the architectural development of trees over years [4] and of organ temperature within digitized trees [6] are available. The coupling with a model for the development and the spread of the apple scab has to be designed. The integration of the vine-powdery mildew in OpenAlea allows creation of modules, and defines common processes about different patho-systems (Figure 3). Our strategy is to extract some generic processes of the vine-powdery mildew system that are usable for the apple scab system. The model of these two patho-systems shares the same abstract structure, with a different source code.

For example:

- the growth of the tree depends on the accumulated temperature on one year span ;
- the colony growth is also a function of the temperature and the leaf age ;
- the propagation of the pathogen takes place on short range and on long range at once;
- The in/out are the same.

On the other hand, specific processes differ for the two patho-systems. For example, the apple scab dispersion strongly depends on the micro-climate.

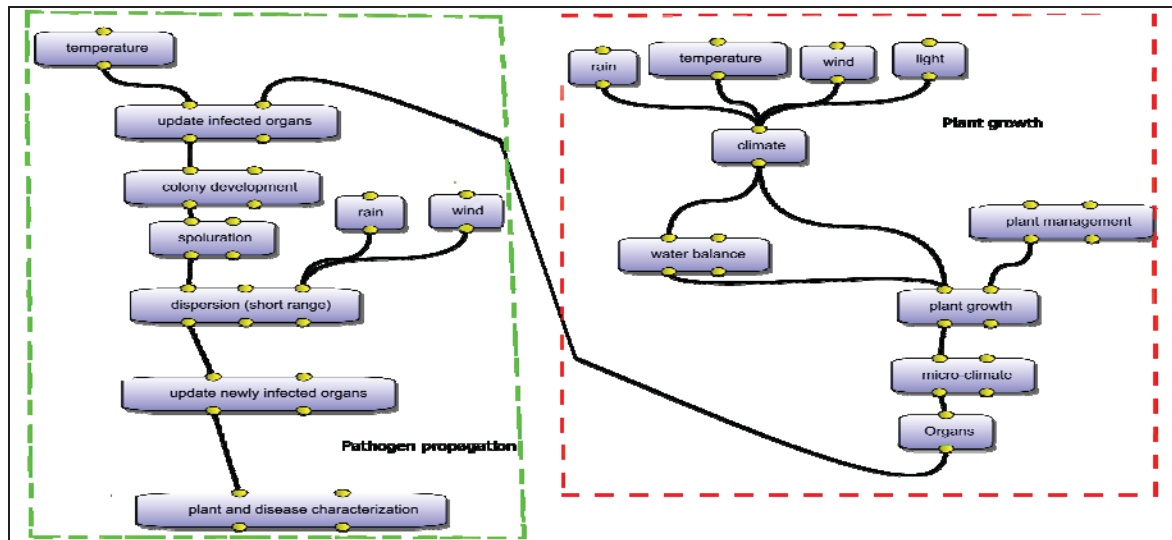


Fig. 3: Generic visual dataflow built using OpenAlea.

Conclusion

Our approach of simulation for the vine crop growth and the powdery mildew propagation seems to be consistent with experimental data. The components being integrated in OpenAlea, we plan to couple different modules describing the plant growth and pathogen propagation to patho-systems other than vine-powdery mildew and apple scab.

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