A dynamic model of almond productivity loss due to *Xylella fastidiosa*

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Introduction

The almond tree (*Prunus dulcis*) is a widely cultivated species in the Mediterranean basin and has a significant economic value to the region. Since 2016, the gram negative bacterium *Xylella fastidiosa* (*Xf*) has been spreading and infecting different species crops (almond ,olives, citrus, grapes, etc.) in the Balearic Islands and peninsular Spain. The way in which this infection spreads is through insect vectors of transmission. The primary vectors of *Xf* in the Spanish Mediterranean are the xylem-feeding spittlebugs *Philaenus spumarius* and *Neophilaenus campestris*. Despite the implementation of various management strategies (removal of infected tres plus the surrounding ones, use of insecticide, herbicides and other pesticides, use of biologic control agents, etc.), the situation has reached a critical point in certain areas as they have been drastically affected both in the ecological and economical aspects.

This study addresses the present epidemiological problem through the development of dynamic model in STELLA that considers the entire *Xf* pathosystem, including bacteria, host plants and insect vectors.

The dynamic model

The model is being calibrated using field data from sampling in the province of Alicante in south-eastern Spain, as well as available literature, consultations with specialists in the field and parameter estimates accoding to biological criteria where data were not available.

The dynamic model is composed of three main modules: one for the *Prunus dulcis* population that is being infected by *Xf*, another for the vector insects which carry the bacteria, and a module involving other potentially infectable wild and ornamental plants which could serve as a reservoir of *Xf* in the ecosystem. Complementarily, an economic module connected to different parts of the system, allows us to quantify the potential economic losses to the agricultural sector due to the spread and infection of *Xf*, together with an estimate of costs related to management strategies and crop protection.

The most innovative aspect of this research is the replication of the dynamics of infection and loss of productivity of the almond tree population. This has been achieved through the use of conveyor-type stocks, which comprise a series of conveyors through which the almond trees pass according to the time that has elapsed since they were infected. This has been made possible by adjustments to the transit time on each of the conveyors, accompanied by a specific mortality rate that increases progressively with the length of time that the tree has been infected. This represents an increasingly severe symptomatology caused by the bacteria.

Results and discussion

The model output runs for a total of 600 months (50 years) and reproduces the decreasing population trend of productive trees affected by *Xf*, including the latency between infection and symptom appearance, and allows us to estimate the economic losses resulting from the infection of almond crops by the bacteria.

The infection remains apparently hidden for the first 150 months, which is justified by the fact that up to this point, only minimal symptoms of the infection are found. However, from this month onwards, a more marked reduction in the number of productive almond trees begins, and they begin to die more and more quickly as more severe systemic symptoms appear. This abrupt decline in productivity is reflected in the model when the almond trees exit the non-infected productive almond tree stock and are more likely to die the longer they have been infected as they pass through the different conveyors of infected productive almond trees. The decline lasts approximately 150 months, and stabilises again once the infection wave has subsided, leaving less than 5% of the initial productive almond trees standing.

In relation to the economic output, the benefits of almond production before, after and during Xf infection are quantified. The model predicts that, prior to infection, each hectare of crop generates approximately 6,000 € in profit per year. The increase in symptomatology associated with Xf results in a clear reduction in productivity, leading to a decrease in the size and quantity of almonds produced by the population. Concomitantly with the reduction in the number of productive almond trees, profit per hectare declines. The result of the 50-year simulation is that each hectare generates losses of approximately 1,000 € per year. This is because, in this situation, the benefits of production do not exceed the costs of production.

Finally, it should be noted that this software and type of modelling were chosen due to their flexibility and ease of use in replicating the *Xf* pathosystem. We believe that this approach has the advantages of accurately replicating each life cycle and its adaptability to be applied in other species or places. However, it also has many disadvantages, such as consuming simulation time, a lack of data or samples that provide us with the necessary parameters.

In conclusion, this research establishes an accurate methodology and work framework with significant potential and utility. In future research, it may be possible to conduct simulations of different management and biological interest scenarios, thereby enabling the efficient control of the spread of *Xylella fastidiosa*, with the aim of avoiding any damage to the ecosystem and economy.