Modelling Plant-Insect interactions
Theory and Application in crop protection

A.Lebon[1], L. Mailleret[2,3], F. Grognard[3], and Y. Dumont[1]

[1]CIRAD, Umr AMAP, F-34398 Montpellier,[2]INRA, URIH, F-06903 Sophia-Antipolis,[3]INRIA, Biocore, F-06903 Sophia-Antipolis

Context

Reducing the use of chemicals and thus developping environmentally friendlier methods such as biological control is one of the current important challenges in crop protection. But, even if biological control has developed very rapidly in the past decades, its successes in efficiently controlling insect pests have been mixed. Modelling and simulation tools can help to grasp biological interactions and also improve biological control. At the core of any biological control program lies a tri-trophic food chain linking plants, pests and their natural enemies. However, up to now, biological control modelling has primarily focused on pests-natural enemies interactions considering somehow that crop yield is not affected by the pests. In pratice even if the pests are under control, the crop can be lost. If the main objective of the control is to maintain the crop yield above a critical threshold, then plant growth and plant-insect interactions have to be taken into account. Using a minimal modelling approach, our contribution focuses on plant-insect interactions as a first step towards a full plants-pests-natural enemies model [1].

The biological test-case

Tuta absoluta (Meyrick), the tomato leafminer

- Plant quarantine in France
- Discovered in France in 2008
- Significant dammages : loss of 80 to 100 % of production without control
- No chemical treatment approved in France

Hypothesis

For the plant equation (B) :
- based on the open-ended like logistic growth of John Thornley [2]

For the insect equation (R) :
- chewing insect
- an undifferentiated population

For the interaction between plant and insect :
- insects impact the plant growth rate (r), the plant biomass (B) and the plant potential growth (B_f)

The mathematical model

$$\begin{cases} \dot{B} = \frac{rB}{1+R}\left(1-\frac{B}{B_f}\right) - \phi\frac{B}{B+1}R \\ \dot{B}_f = \frac{-DR}{1+R}(B_f - B) \\ \dot{R} = \alpha R - \left(\mu_1 + \frac{\mu_2}{B+1}\right)R \\ R(nT^+) = (1-e)R(nT) \end{cases}$$

With $B(0) = B_0 \geq 0$
$B_f(0) = B_{f0} \geq 0$
$R(0) = R_0 \geq 0$

Without control

- Existence of a continnum of pest-free equilibria
- The value of the equilibrium toward which the system converges, depends on initial conditions

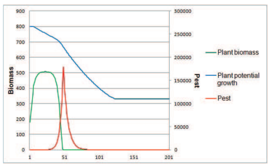
With control

Numerical simulations achieved to compare the effectivness of different treatment methods on different scenarii.

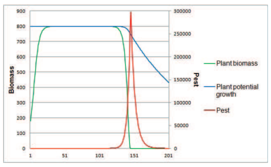
Applications in crop protection

The treatments can be mechanical control or the use of a non-persistent biopesticide. They are done one day after the pest infestation.

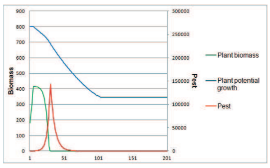
Column 1 : Infestation=2 larvae at days 5



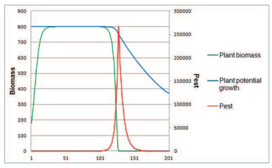
Column 2 : Infestation=2 larvae at day 100



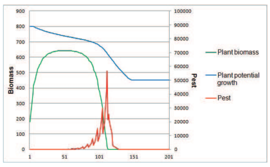
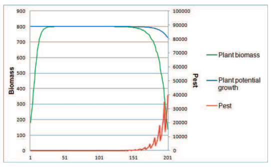
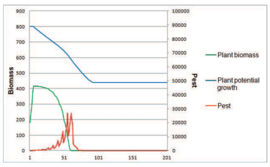
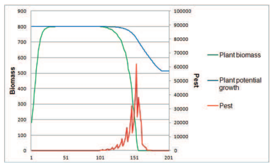
Column 3 : Infestation=200 larvae at days 5



Column 4 : Infestation=200 larvae at days 100

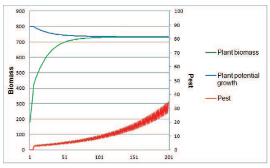
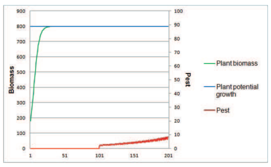


Without control, the plant dies

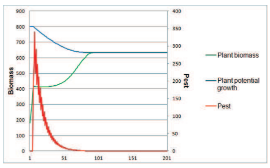
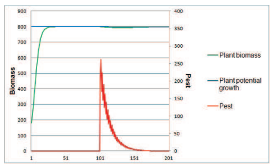





If the treatment periodicity is around 7 days, the efficacy must be high (80 or 90%)
Here the treatment has 70% of efficacy

Infestations with 2 larvae, treatment every 2 days with 40% of efficacy

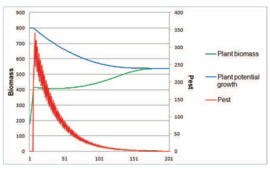



Infestations with 200 larvae, treatment every 2 days with 50% of efficacy

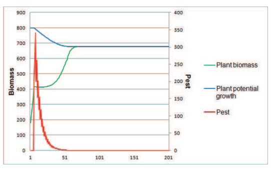



A later and under-control attack has less effect on the plants

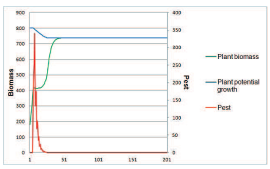
45% of efficacy



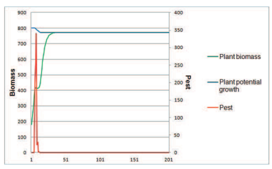
55% of efficacy



70% of efficacy



95% of efficacy



Even if the treatment is successful, different efficacies correspond to different impacts on the plants
Infestation : 200 larvae at day 5, Treatment : every 2 days

Conclusions

We have developed a minimal generic plant-pest model, which allows the conceptualization of some hypotheses and knowledge about plant-insect interactions. It is a first step towards models that may take into account more plant growth processes. Numerical simulations of the test-case Tomato-*Tuta absoluta* show clearly that biological control has to be adapted since it may depend on the level and the date of initial pest infestation, on the efficacy and the periodicity of the control. Further investigations, and in particular experimental data, are needed to validate our approach and to incorporate more biological facts. One aim is to get a complete biological control model, including a control agent equation.

References

[1] Audrey Lebon.
Elaboration d'un modele plante-ravageur dans le cadre de la lutte biologique.
Master's thesis, Enita de Bordeaux, Montpellier Supagro, 2011.

[2] John H.M. Thornley and James France.
An open-ended logistic-based growth function.
Ecological Modelling, (184) :257–261, 2005.