The mango tree – blossom gall midge system: *in-silico* assessment of its functioning and management

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1 Introduction: context and issues

- **Mango (*Mangifera indica*) is an important fruit crop**
  - High economic and nutritional values
  - Produced in tropical and subtropical regions
  - Ranked 5th in the world (~ 50 M t / year)

- **Mango is facing several production constraints, including yield losses due to pest and disease damages**
  - Examples of damages on fruits and inflorescences :

Fruit flies

Stem and rot

Blossom gall midge

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❑ Growers are challenged to produce “more” and “better”

Which management practices, alternative to synthetic pesticides, can contribute to crop protection and reduce yield losses ?

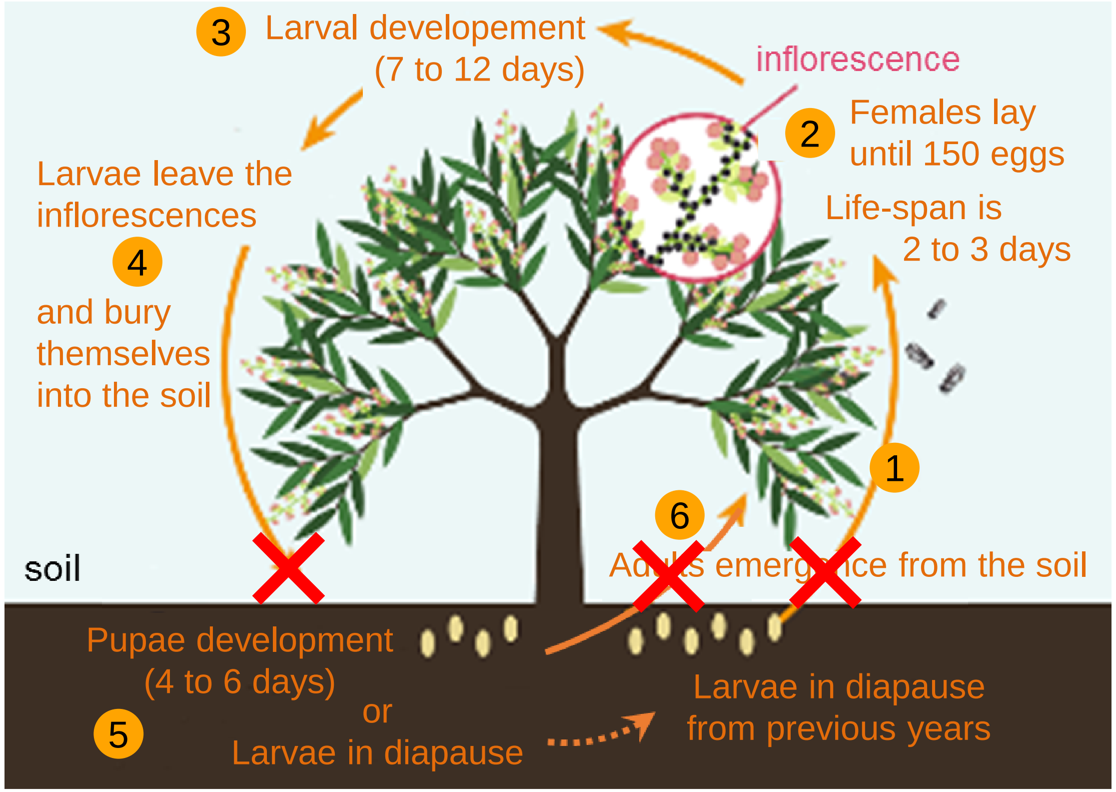
Our case study & objective

➢ A major pest damaging mango inflorescences : the **Blossom Gall Midge** (*Procontarinia mangiferae*)

➢ Develop a process-based modeling approach to **improve our understanding of the crop-pest system functioning and its management using cultural practices**

1 The mango blossom gall midge (BGM)

- BGM life-cycle on mango, its unique host-plant :



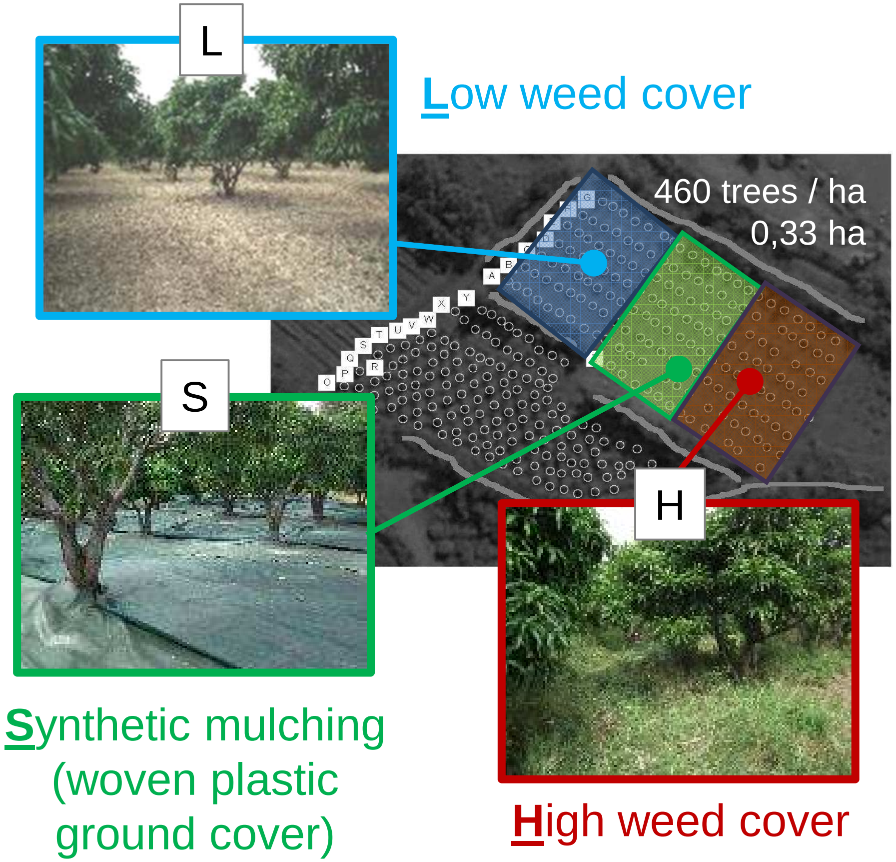
(Amouroux, 2014)

- Two management levers are investigated for pest control :
  1. **Soil mulching** used as physical barrier to break BGM life-cycle
  2. **Manipulation of mango phenology** to synchronize flowering and shorter the period of mango susceptibility

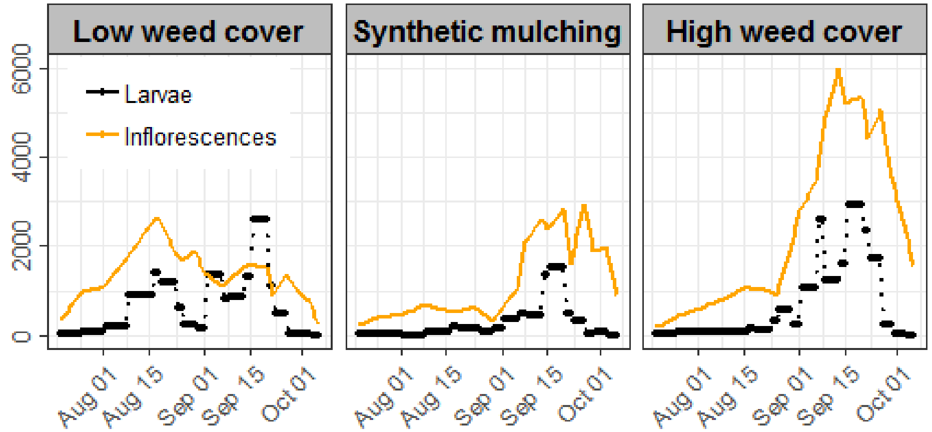
2 Materiel and methods

❑ Experimental data

- Collected in a mango orchard located in Reunion Island in 2017
- Orchard split into three plots according to soil mulching treatments applied during the flowering period



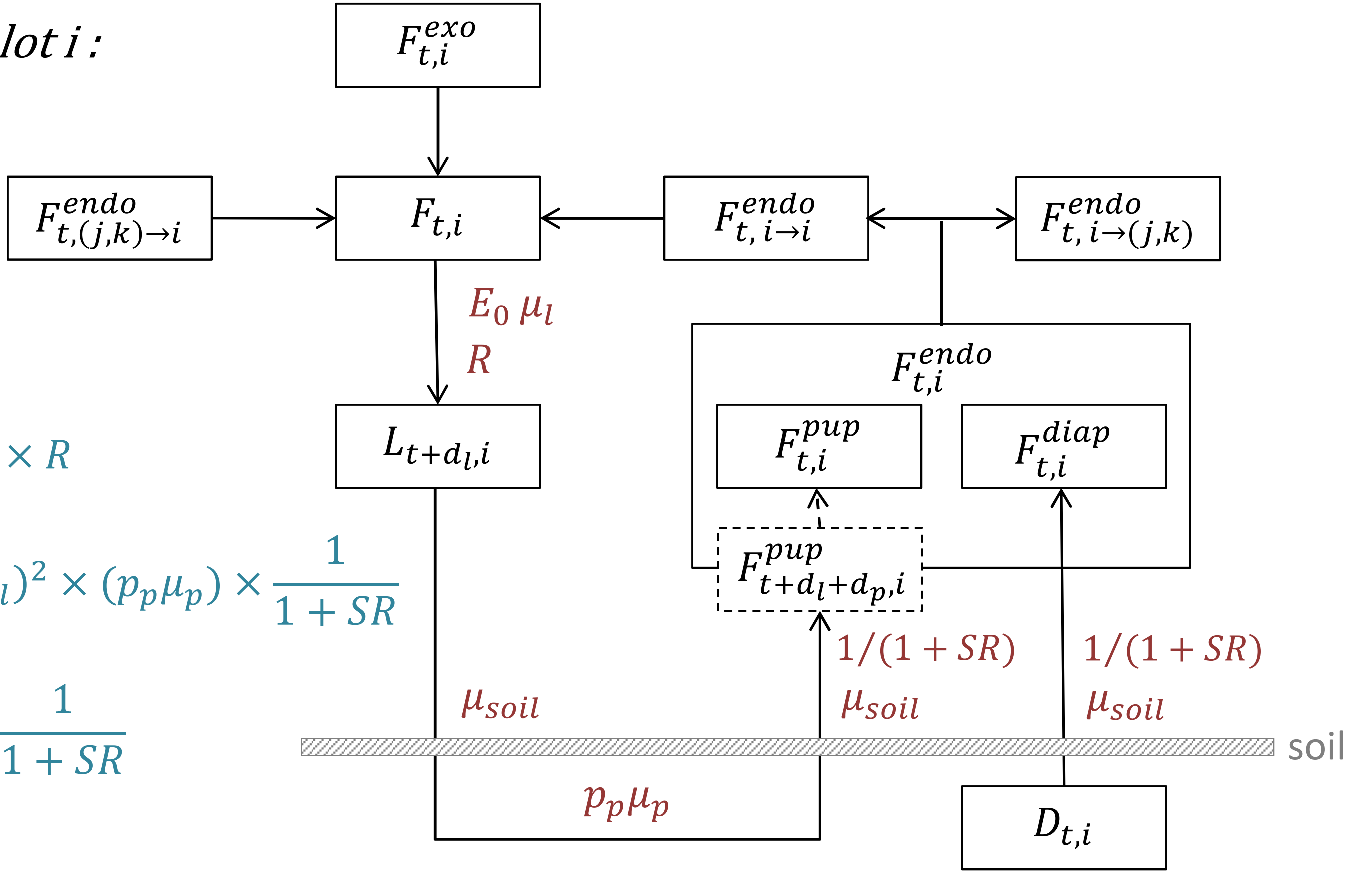
- Dynamics of inflorescences and larvae (assessed by trapping) in each of the three plots



2 Modeling framework

- Describes pest population dynamics in each plot, at a daily time-step during flowering, with inflorescence dynamics as input ($I_{t,i}$)
- Based on a representation of pest life-cycle :

Dynamics in plot i :



$$L_{t,i} = F_{t-d_l,i} \times (E_0\mu_l) \times R$$

$$F_{t,i}^{pup} = L_{t-d_p,i} \times (\mu_{soil})^2 \times (p_p\mu_p) \times \frac{1}{1+SR}$$

$$F_{t,i}^{diap} = D_{t,i} \times \mu_{soil} \times \frac{1}{1+SR}$$

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Modeling framework : Main assumptions

- H1: female egg-laying lasts only 1 day

- H2: exogenous females are proportional to resource availability

- H3: female reproduction (egg-laying or survival) is limited by resource availability :

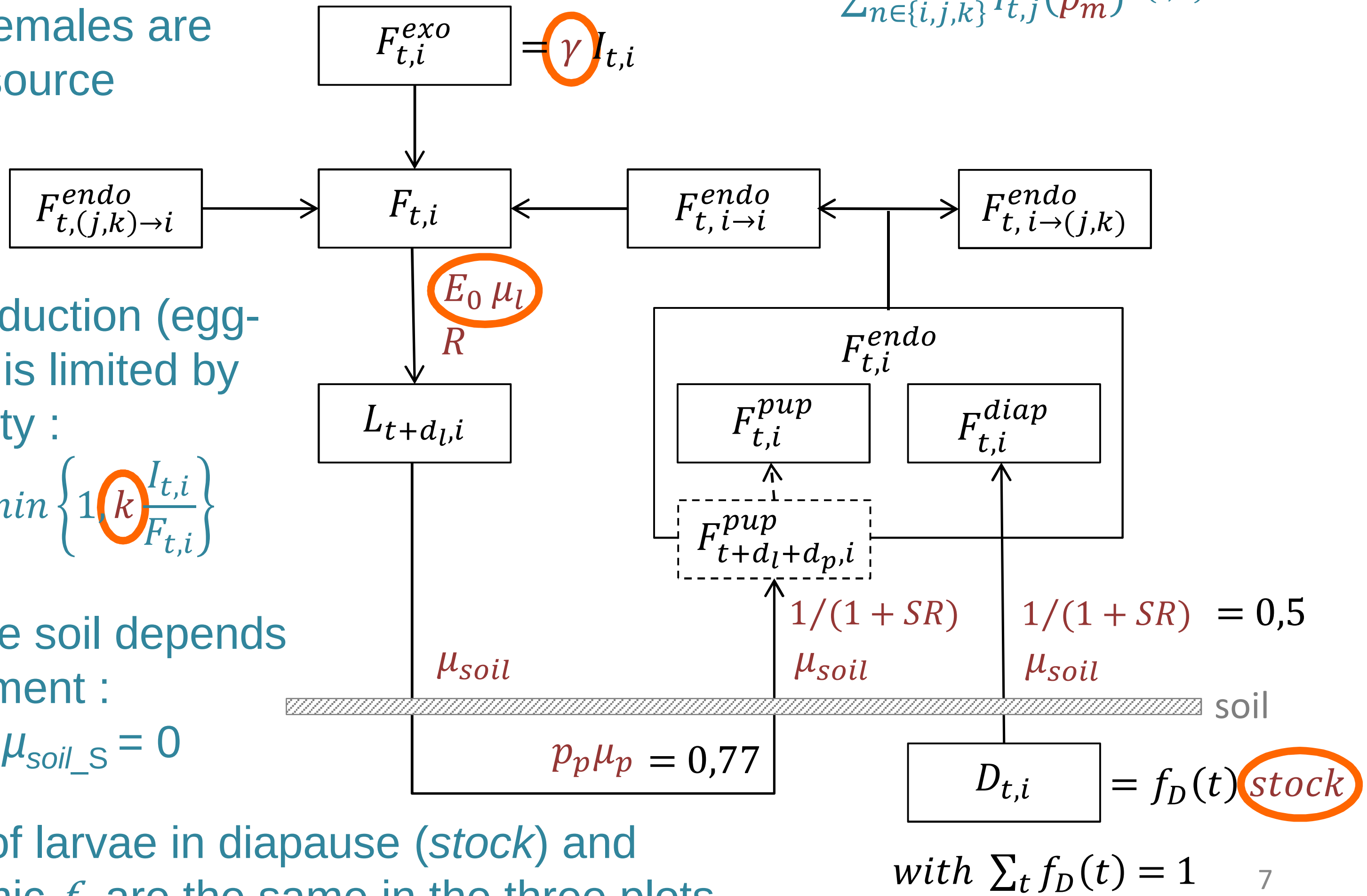
$$R = min\left\{1, k\frac{I_{t,i}}{F_{t,i}}\right\}$$

- H4: survival to the soil depends on mulching treatment : $\mu_{soil\_L} \neq \mu_{soil\_H}$ and $\mu_{soil\_S} = 0$

- H5: the number of larvae in diapause (*stock*) and emergence dynamic f_D are the same in the three plots

- H6: between-plot movements of endogenous females are driven by resource availability and a “distance effect” (δ)

$$F^{endo}_{t,i\rightarrow j} = \frac{I_{t,j}(p_m)^{\delta(i,j)}}{\sum_{n\in\{i,j,k\}} I_{t,j}(p_m)^{\delta(i,n)}} F^{endo}_{t,i}$$



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❑ Model calibration and analysis

- **Calibration method :**
  - **Objective functions** : NRMSE between observed and estimated larvae numbers, assessed in each plot
  - **Optimization algorithm : NSGA-II**, a multi-objective and nondominated sorting genetic algorithm (Deb et al. 2002)

    ↳ subset of solutions converging near the Pareto-optimal front
  - **Hierarchical clustering** to identify groups in the set of nondomintaed solutions

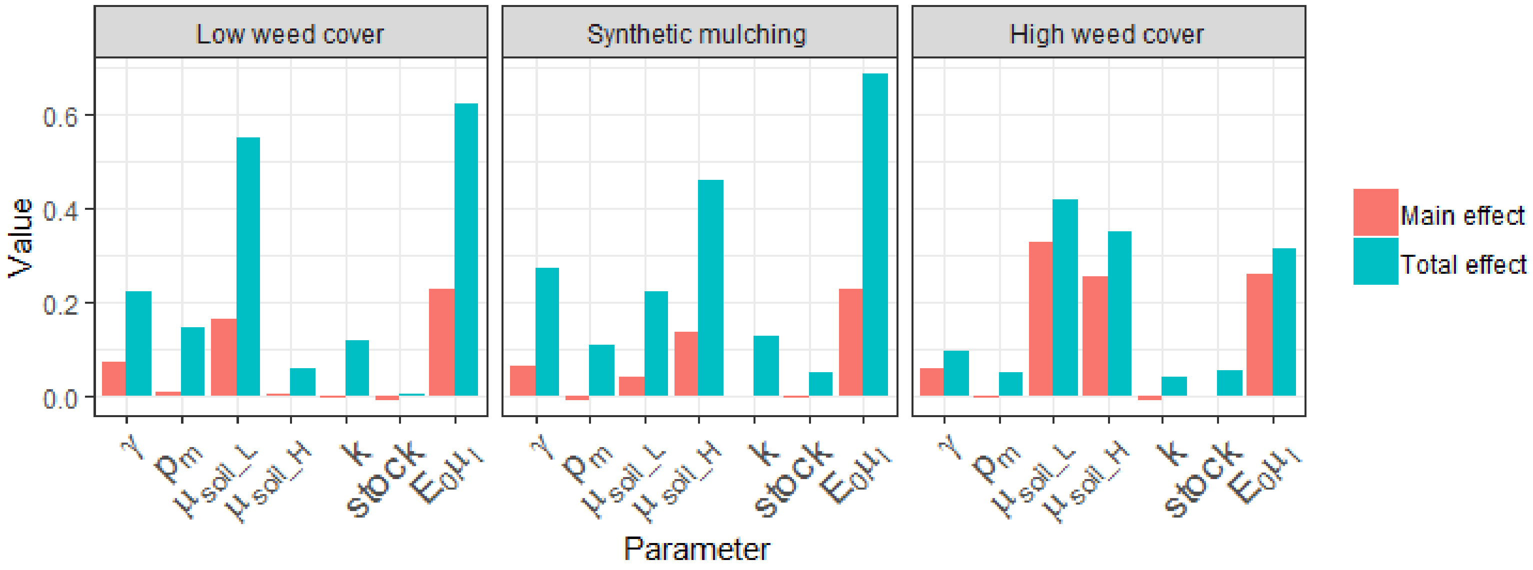
- **Sensitivity analysis** based on a global approach with Sobol method (Saltelli et al 2008)

- **Analysis of mango-BGM system functioning and management** with model-based hypotheses testing and *in silico* experiments

3 Results

❑ Sensitivity analysis

− Main and total effects of the 7 parameters in each plot :



− The model was mainly sensitive to parameters relative to :

- Survival to soil mulching treatment (μ_{soil_L} and μ_{soil_H})
- Reproduction capacity of females ($E_0\ \mu_l$)
- And secondarily, exogenous pest pressure (γ)

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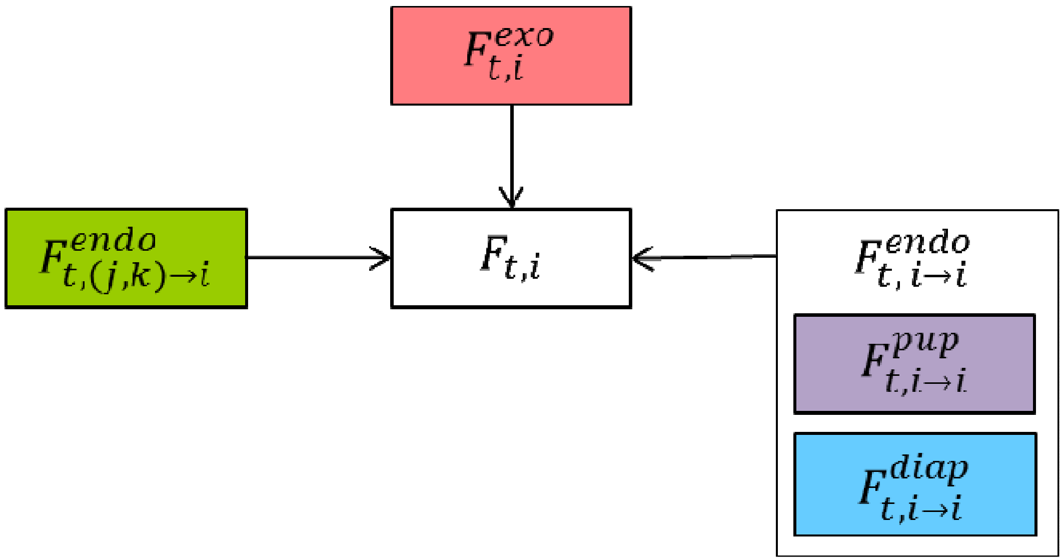
❑ Assessing the contribution of different processes involved in pest population dynamics

Estimated number of larvae were broken down into 4 different origins :

- Exogenous females
- Endogenous females coming from the neighboring plots
- Endogenous females staying in the same plot - emerged from pupae
- Endogenous females staying in the same plot - emerged from larvae in diapause



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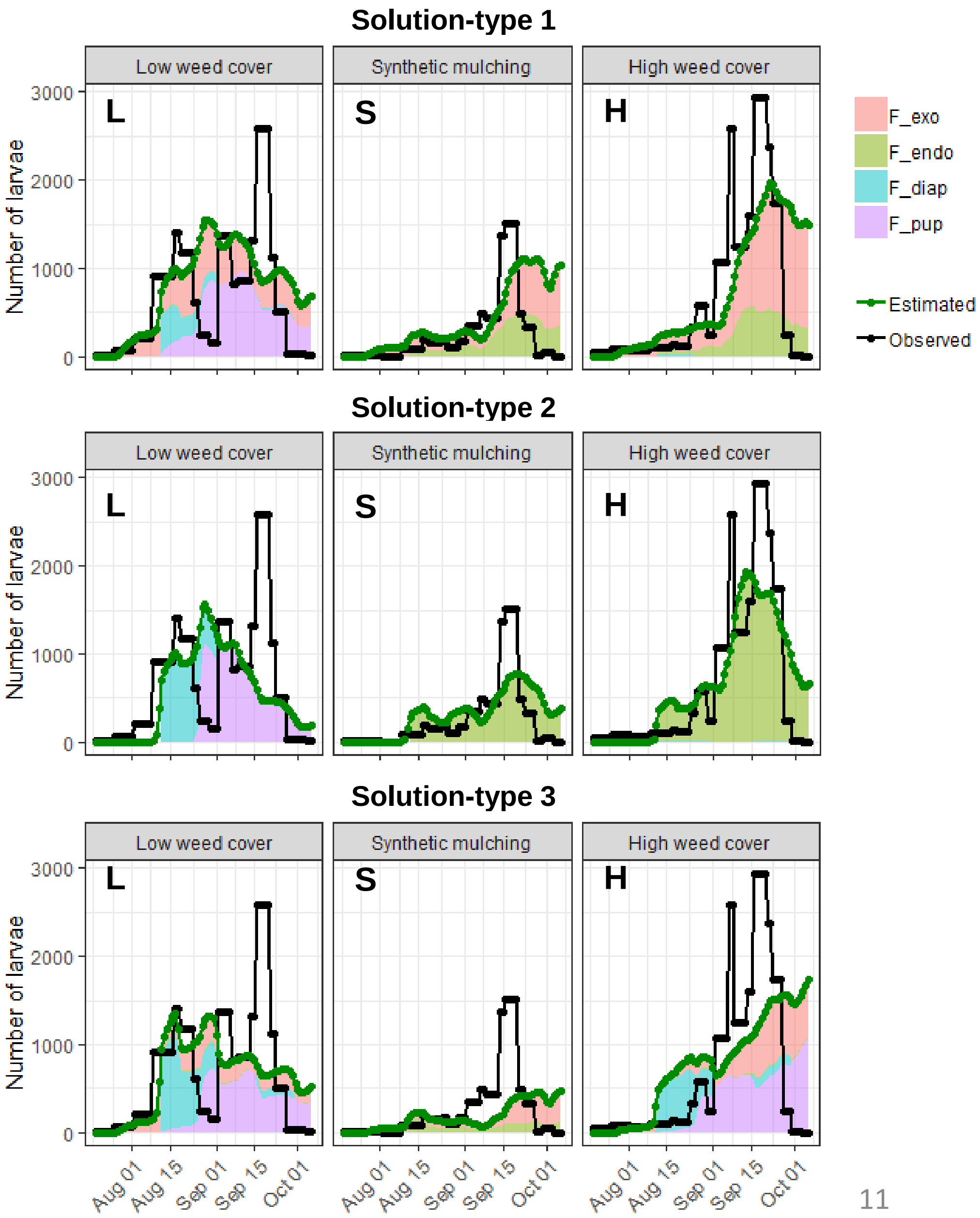
❑ Model solutions

3 types of solutions, involving different processes :

1. High number of exogenous females and emergence of females only in the plot L (μ_{soil_L}=0.97 and μ_{soil_H}=0.05)

2. Absence of exogenous females and emergence of females only in the plot L (μ_{soil_L}=1 and μ_{soil_H}=0.03)

3. Intermediate number of exogenous females and emergence of females in plots L and H (μ_{soil_L}=0.56 and μ_{soil_H}=0.65)



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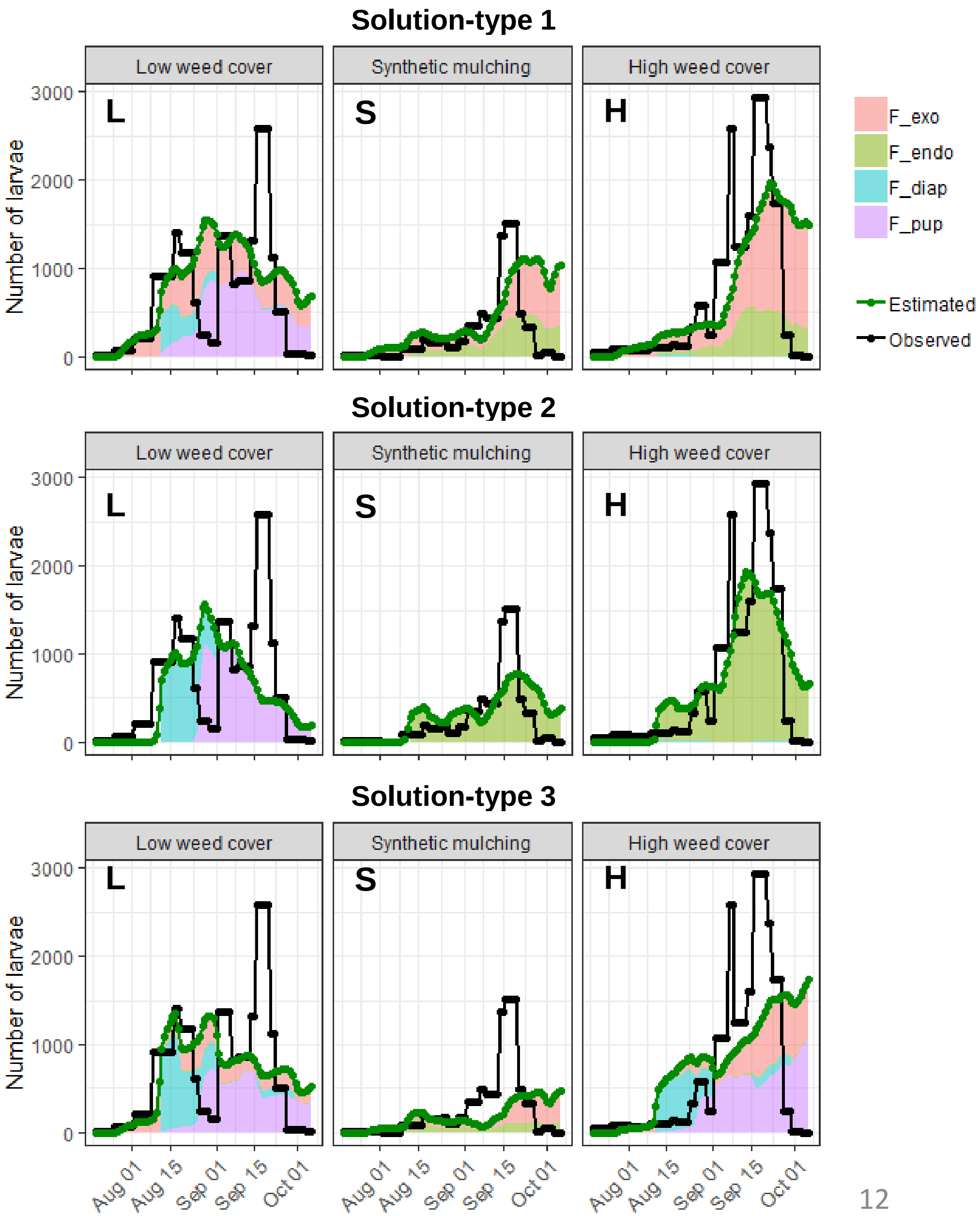
❑ Model solutions

The model captured general trends in population dynamics:

- Higher number of larvae in plots L and H (vs. plot S)
- Later increase in number of larvae in plots S and H (vs. plot L)

But it partly failed to capture others :

- Rapid decrease in number of larvae at the end of the season (for solutions 1 & 3)
- Decrease in number of larvae at the mid-season in plot L



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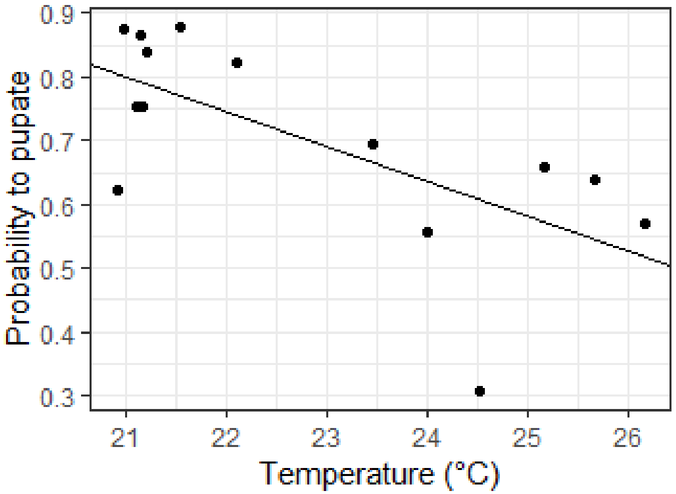
❑ How can the rapid population decrease at the end of the season be explained ?

Model-based hypotheses testing :

– H1: effect of **seasonal change in the probability of larvae to pupate** (vs. entering in diapause),

Probability to pupate decreases with temperature increase



– H2: effect of **a shorter period of inflorescence attractiveness,** with only the first phenological stages being attractive

– H3: a **seasonality effect,** that could reduce the number of females laying eggs at the end of the season ($F_{t,i} := \alpha F_{t,i}$ with $\alpha \in [0,1]$)

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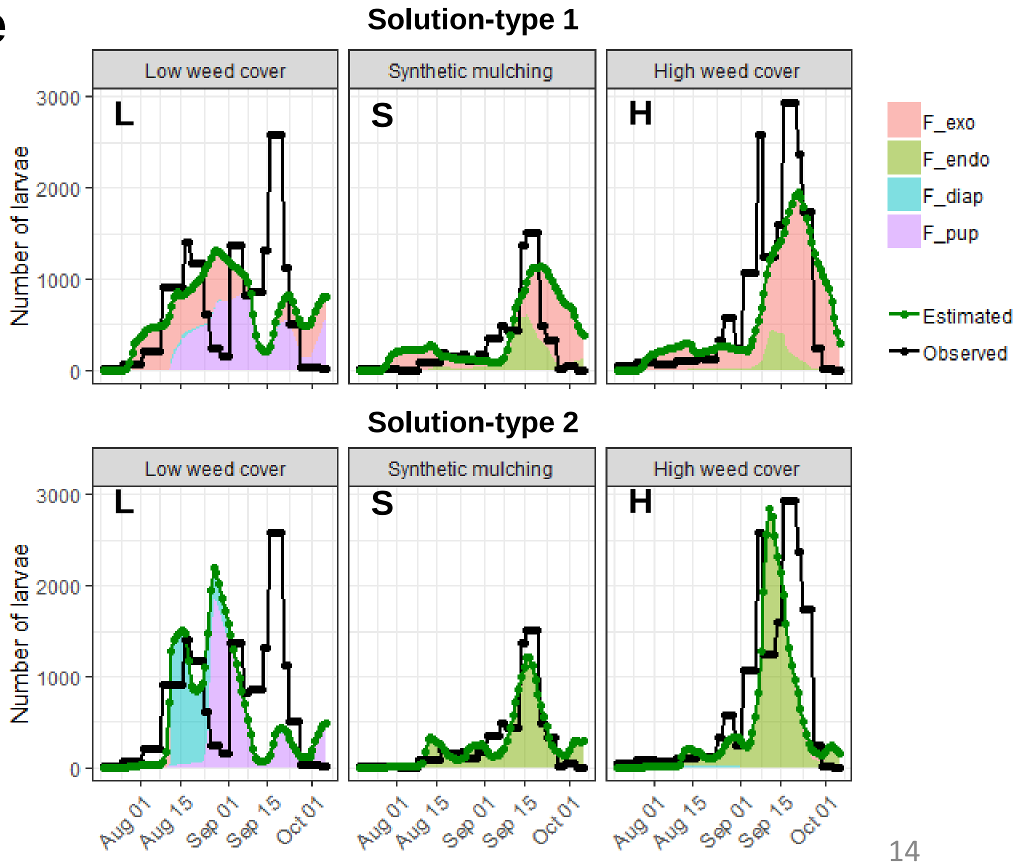
❑ How can the rapid population decrease at the end of the season be explained ?

⇨ **H1/ temperature effect on the probability of larvae to pupate** : Estimated dynamics were not improved

⇨ **H2/ effect of inflorescence attractiveness** :

– Estimated dynamics were improved for solution-types 1 and 2, but only in plots S and H



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❑ How can the rapid population decrease at the end of the season be explained ?

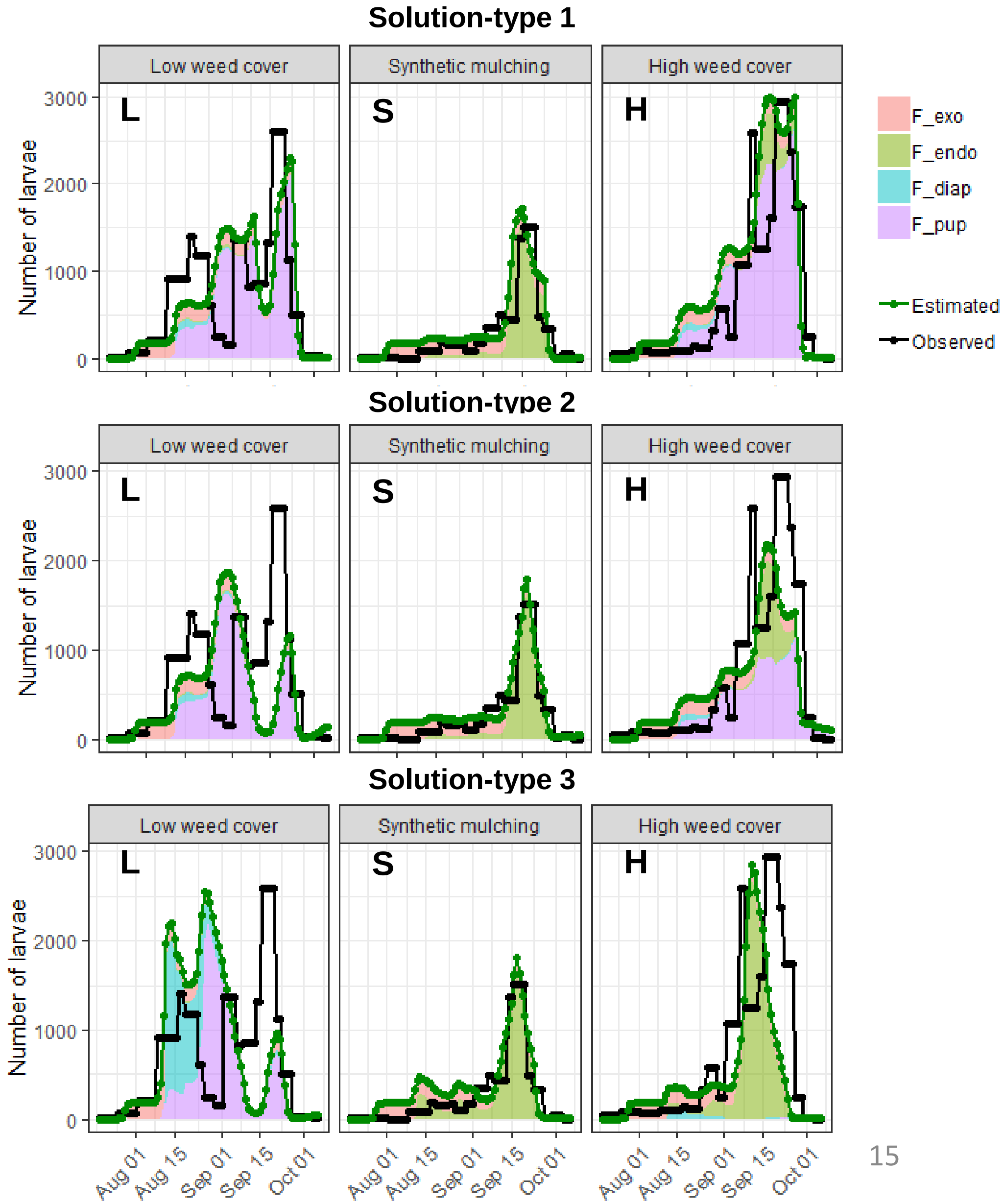
⇨ **H3/ seasonality effect** :

– Estimated dynamics were improved in the three plots

Low number of exogenous females and emergence of females in both L and H plots *(μ_{soil_L}=0.94 and μ_{soil_H}=0.92)*

– Two other solutions with lower *(μ_{soil_H}=0.74)* or almost no *(μ_{soil_H} =0.06)* emergence of females in plot H

But estimated dynamics not as well improved in plot L



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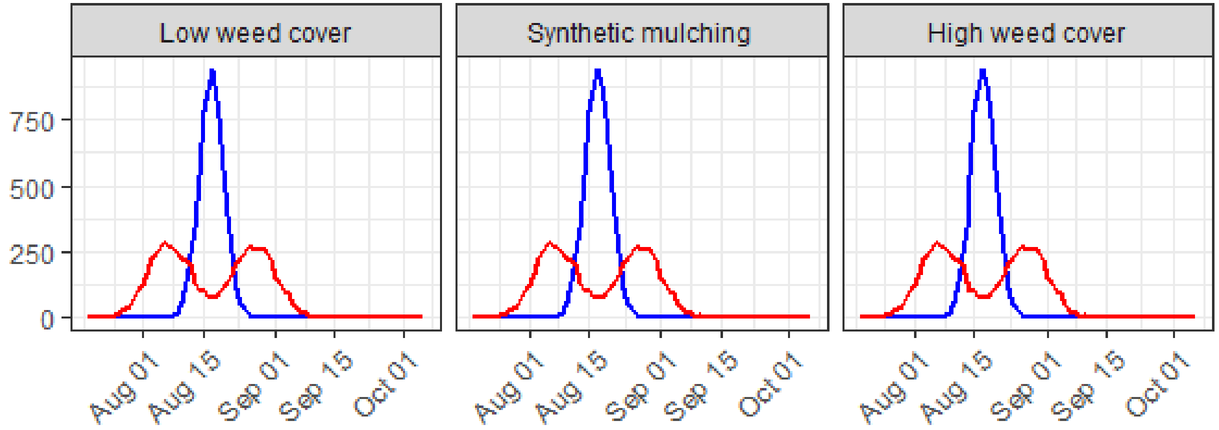
❑ What about the effect of flowering synchronization on pest dynamics ?

- Two flowering dynamics with the same number of inflorescences (N = 7000) but with 1 flush and 2 flushes were simulated



Budburst dynamics of the 7000 inflorescences

- Flowering synchronization could reduce the number of pest :

Model : Initial model +	Low weed cover	Synthetic mulching	High weed cover
+ attractiveness effect (solution-type 1)	-28%	-9%	-2%
+ seasonality effect (solution-type 1)	-39%	-14%	-37%

4 Conclusion and perspectives

- At this point :
  - We identified a potential seasonality effect that can be modelled and quantified, but open questions on the biological processes involved
  - We assessed the effects of management levers on pest dynamics

- To go further in model-based design of management solutions, several developments are now considered :
  - Accounting for pest-induced mortality of inflorescences to predict yield losses
  - Accounting for multi-year effect of soil mulching treatment on the stock of larvae in diapause
  - Coupling with V-Mango (Boudon et al. submitted), a functional-structural plant model predicting mango development and fruit growth

Thank you for your attention !

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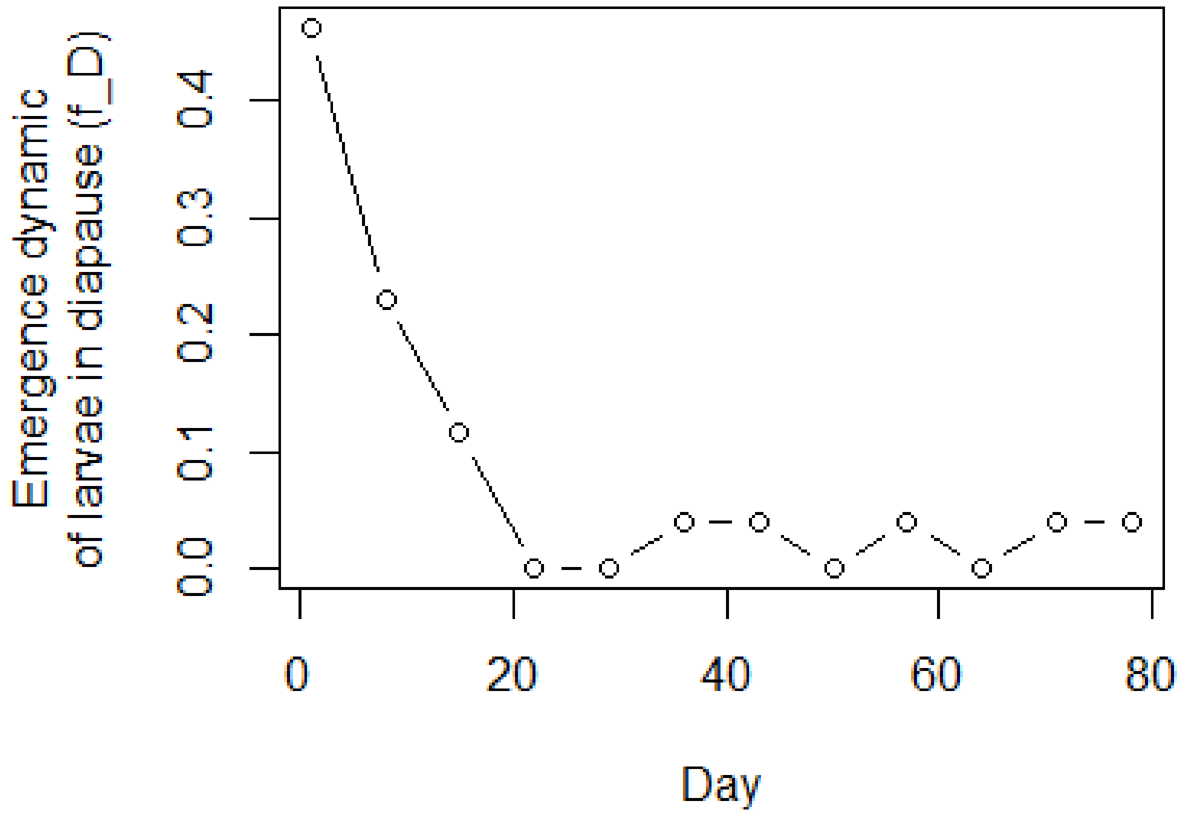
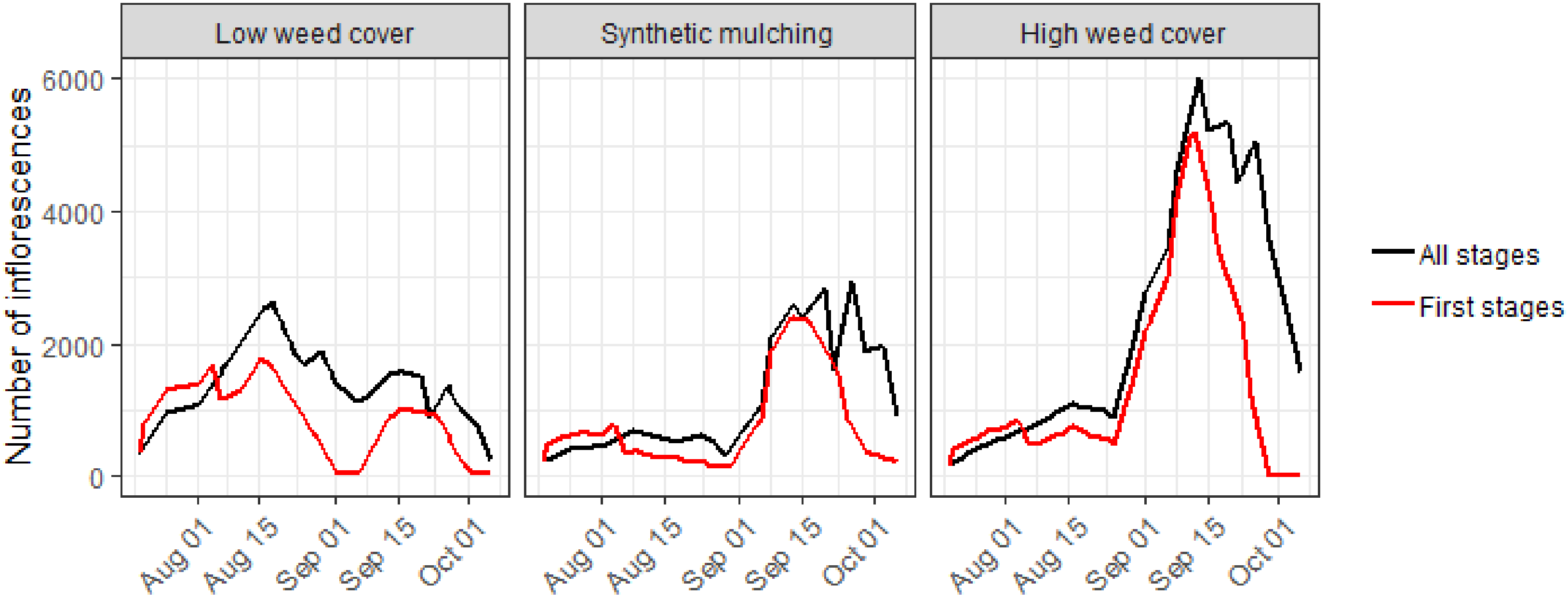
❑ Annex 1: emergence dynamic of larvae in diapause f_D

Number of adults emerging from larvae in diapause :

$$D_{t,i} = f_D(t)\ stock \quad with \ \textstyle\sum_t f_D(t) = 1$$



❑ Annex 2: Inflorescence dynamics for the first vs. all stages

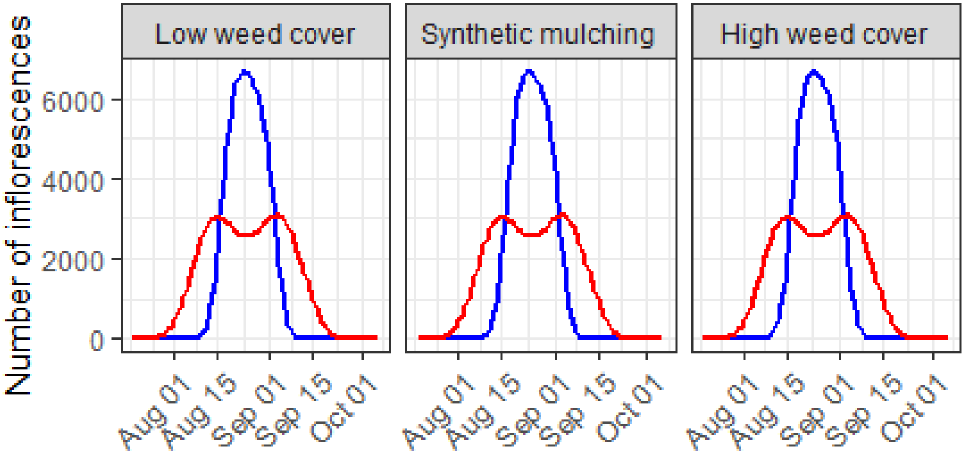


C D E F

All stages: C-D-E-F

First stages: C-D-E

❑ Annex 3: What about the effect of flowering synchronization on pest dynamics ?



Inflorescence dynamics for the first phenological stages (C-D-E) with 1 flush or 2 flushes

Reduction in larvae number with flowering synchronization :

Model : Initial model +	Low weed cover	Synthetic mulching	High weed cover
+ attractiveness effect (solution 1)	-28%	-9%	-2%
+ attractiveness effect (solution 2)	-74%	-71%	-66%
+ seasonality effect (solution 1)	-39%	-14%	-37%
+ seasonality effect (solution 2)	-53%	-22%	-34%

❑ Annex 4: NSGA-II procedure

Population size N = 200
Generation number = 200

NSGA-II procedure
repeated **30 times**
[nsga2; Mersmann 2014]

6000 solutions

Nondominated solutions
[is_dominated; Mersmann 2012]

Generation t

Parent population P_t of size N

Selection
Crossover
Mutation

Offspring population O_t of size N

Population $R_t = P_t \cup O_t$ of size 2N

Nondominated sorting

Ranked nondominated fronts:

- Front F^1 (nondominated solutions)
- Front F^2 (solutions dominated only by F^1)
- Front F^i (solutions dominated only by F^{i-1})

if size $n_1 < N$

if size $n_1+n_2 + \ldots + n_{i-1} < N$

Parent population P_{t+1}
of size N

Generation t+1