A CROP SIMULATION MODEL TO PREDICT FRUIT YIELD AND QUALITY ON MANGO TREE

Recent progress and future steps…

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1. General context and issues

Mango production in Reunion Island

- **Several production constraints** (in Reunion Island but not only...)
  - Irregular bearing (“on” vs “off” years)
  - Fruit heterogeneity at harvest in size, gustatory quality, postharvest behavior
  - Phenological asynchronisms

- **In few data...**
  - 3,000 tons/year
  - 330 ha
  - 80 farms

Production zones
(In: Vincenot et al. 2009)

- Mango varieties
  - Cogshall
  - José

- ~70 km

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How managing mango trees to reduce these production constraints and improve fruit yield and quality?

- **Acquire knowledge** on the processes involved in fruit yield and quality development, and biotic and abiotic factors that affect them
  
  - **Mango growth and quality traits** are affected by pre-harvest factors such as light, temperature and carbon and water availability (*Léchaudel and Joas 2007*)
  
  - **Phenological asynchronisms** depend on the interplays between structural and temporal components of mango architectural development (*Dambreville et al. 2013*)
  
  - Ripe and fully ripe fruits are generally preferred for fruit flies oviposition (*Diatta et al. 2013*)
  
  - Arrival and movement of blossom gall midge within the orchard depend on inflorescences distribution and availability (*Amouroux 2013*)
How managing mango trees to reduce these production constraints and improve fruit yield and quality?

- **Acquire knowledge** on the processes involved in fruit yield and quality development, and biotic and abiotic factors that affect them

- **Develop a crop simulation model** that predicts fruit yield and quality on mango tree
  - To **integrate** our knowledge and understanding of system functioning
  - To **evaluate** the impacts of different weather or management scenarios on production or **design** management solutions *in silico* (Grechi et al. 2012)

**BUT such models are few on perennial fruit crops**
They mainly concern temperate species (e.g., apple or peach: Costes et al. 2008 Lopez et al. 2010; Lescourret et al. 2011) **but not tropical species**
2. The modeling framework

- Developed for cv. ‘Cogshall’ in Reunion Island

(1) Functional sub-model
(2) Structural sub-model

(3) Crop-pest interactions

Fruit fly

Blossom gall midge

Cultural practices

weather

L-Py

(Boudon et al 2012)
(1) Functional sub-model
Growth, fruit maturation and quality development

Branch level

- Leaves
- Stem
- Growth Units (GUs)
- Fruits

(C-related ecophysiological processes)
- Leaf photosynthesis
- Reserve mobilization / storage
- Respiration
- C allocation
- Growth in dry mass

Fruit level

- Biosynthetic pathway
- Dilution
- Diffusion

Empirical accumulation of biochemical and mineral compounds

Water-related biophysical processes
- Transpiration
- Water inflows from stem
- Growth in fresh mass

L:F ratio (Fruit thinning)

(Fruit dry mass and fresh mass)
- Starch, Glucose, Fructose, Sucrose
- Malic, Citric, Pyruvic, Oxalic Acids
- K⁺, Mg²⁺, Ca²⁺, NH⁴⁺, Na⁺
- Ethylene

(Léchaudel et al. 2005, 2007)

(Nordey 2014)
(1) Functional sub-model
Growth, fruit maturation and quality development

The model simulates well fruit growth and quality & L:F effect

Fruit dry mass (g)

Fruit fresh mass (g)

Gustatory quality

**Flesh sweetness**
Sucrose (g/100g FM)

**Flesh sourness**
Citric acid (g/100g FM)

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(1) Functional sub-model
Tree growth, fruit maturation and quality development

The model is currently scaled-up at the **tree level**

→ Adaptation of the QualiTree peach crop model *(Lescourret et al. 2011)* to mango

- C-related processes are considered for **the 3 other tree compartments** (i.e., the wood, coarse roots and fine roots)

- **C allocation is considered:**
  - Between branches
  - Between branches and other tree compartments
Vegetative and reproductive development: decomposed into 3 elementary and stochastic events modeled by GLMs

- Occurrence
- Timing
- Intensity

Successive GLMs

GLMs account for the effect of temporal and structural architectural factors (i.e., the position, fate and date of burst of parent GU)

Fructification: modeled by GLMs
(2) Structural sub-model

Tree phenology and architectural development

- Tree architecture development: simulated by successive applications of development rules (i.e., the GLMs results)
  - Nb, topological position and dates of burst of GUs and inflorescences
  - Nb of fruits per inflorescence

- GU and inflorescence growth and phenology: simulated by thermal time models and empirical relationships

3-D mock-up of simulated mango tree architectural development and phenology
(3) Crop-pest interactions
Inflorescence infestation by Blossom gall midge

• A stochastic and mechanistic model that simulates:
  – Spatio-temporal distribution of adults within the orchard in relation to mango inflorescence abundance and distribution
  – Female egg-laying and larval development

- Observed abundance and distribution of mango inflorescences
- Temporal dynamics of collected larvae within the orchard in traps

(Amouroux 2013. PhD)
(3) Crop-pest interactions
Fruit infestation by fruit fly

- An empirical model that simulates:
  - Probability of a mango (cv. ‘Cogshall’) to be infested by flies (*Bactrocera zonata*) in relation to fruit maturity, assessed by fruit ethylene content.

For more details: see my poster # 11 in this symposium (“Effect of fruit maturity on mango infestation by fruit flies: from experimental analysis to modeling”)
3. Model simulations & results

- **Virtual experiments** to investigate the effect of:
  - C availability → light environment (from 1: shady to 5: sunny)
  - L:F ratio (from 10 to 150 leaves/fruit)
  - **fruit maturity** → harvest date

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**Functional mango sub-model (at the branch level)**

- Fruit growth
  - Fruit dry mass
  - Fruit fresh mass

- Ethylene

- Infestation probability
  - Sugars
  - Organic acids
  - Minerals

Fruit infestation by fruit flies
Simulations of fruit growth and quality of 1000 virtual fruits:
- Virtually harvested at 130 DAB
- 2 subsets of fruits with ≠ conditions of C availability:
  - HIGH C availability
    - (LF ≥ 90 & light env. = 4 or 5)
  - LOW C availability
    - (LF ≤ 70 & light env. = 2 or 3)

- HIGH C: higher fresh mass & higher starch + sucrose content
- LOW C: lower infestation rates
  Explained by a maturity delay of about 11 days
**Harvest date and fruit maturity**

- **Simulations of virtual fruits** (conditions of HIGH C availability)
- **Fruit maturity** :
  - expressed in **days before natural fruit fall (DBFF)**
  - day of fruit fall (DBFF = 0) : day when simulated ethylene content $\geq$ random value sampled in a gamma distribution

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**Maturity gradient**

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- **DBFF=20**
  - Infestation rates: 4%

- **DBFF=15**
  - Infestation rates: 7%

- **DBFF=10**
  - Infestation rates: 11%

- **DBFF=5**
  - Infestation rates: 17%

- **DBFF=0**
  - Infestation rates: 21%

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4. Conclusions and perspectives

• A modeling approach suitable to address production issues and fruit yield and quality management on mango
  – To study fruit yield and quality compromises
  – To design of management solutions

• But further challenging steps to complete the model…
  – To complete and couple the functional and structural sub-models
  – To add a model of light interception (instead of the empirical light environments used as inputs)
  – To add the effect of pruning on tree development
  – To validate the global crop model
  – To couple the global model with models of pest dynamics
Thank you for your attention

Acknowledgment

This work was partially funded by a grant from DAMAGE key action of INRA’s Meta-programme SMaCH, European Community, the Regional Council of Réunion Island and CIRAD.
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