Master internship
- 2024 -

Integrative Model of Carbon Allocation to predict Mango Fruit growth

Location : Montpellier (with work-related mission to Réunion Island)

Study level : Master

Duration and period : 6 months in 2024

Keywords : Spatial modeling, Allocation methods, Sensibility analysis, Data assimilation, FSPM, *Mangifera indica*

Organization and laboratories

CIRAD, the French Agricultural Research Centre for International Development (https://www.cirad.fr/), is a scientific organization specializing in agriculture in tropical and subtropical regions. Its mission is to contribute to agricultural development in developing countries through research, experiments, training and scientific and technical information. The internship will take place in Montpellier, within the HortSys (https://ur-hortsys.cirad.fr/) and AGAP Institute (https://umr-agap.cirad.fr/) research units. A short work-related mission to Réunion Island is envisaged during the internship, depending on the progress of the project.

Context of the study

Mango is a tropical crop characterized by heterogeneity in fruit size at harvest. Fruit size distribution with a reduced fraction of undesirable fruits in lowest (or too highest) size classes is generally expected for marketing. Fruit heterogeneity could partly be explained by water and carbohydrates availability during fruit growth. The effects of source-sink relationships on fruit growth have been reported in many species. The amount of carbohydrates supplied to fruits depends on the balance between sources supply and sinks demand. For example, peach fruit mass depends not only on carbohydrates produced by leaves in the immediate vicinity of the fruit but also on carbohydrates from more distant parts of the tree (Marini and Sowers,1994). On mango, a previous study (Grechi and Normand, 2019) suggested a partial autonomy of the scaffolds and fruit-bearing branches with respect to fruit growth in terms of carbohydrates. Still, Capelli et al. (2021) showed that carbohydrates concentration decreases in fruiting, and even in non-fruiting axes, during fruit growth. Some depletions were also observed in roots and woody part of the tree during fruit growth (Stassen and Janse van Vuuren, 1997) suggesting carbon exchange between different parts of the tree at a global level. While the effects of source-sink relationships on fruit growth have been reported in many species, results on branch and scaffold autonomy for carbohydrates vary depending on studies. This study aims at evaluating how source-sink relationships from a local (branch) to a global (tree) scale affect fruit growth. Given the interplays of the processes occurring at different scales, modelling appears as a powerful integrative methodological approach to address this issue.

Several experiments and measurements have been conducted on mango trees, cultivar Cogshall, in Réunion Island: i) to assess carbon sources and sinks and fruit growth through time, on both girdled and non-girdled branches with different leaf-to-fruit ratios and on trees with different fruit loads; ii) to digitize the 3-D architecture of the aerial part of an adult tree; iii) to acquire a dynamic mapping of biomass and carbon reserves in the different compartments of adult trees during one production cycle. On the other hand, a functional-structural mango tree model (V-Mango; Boudon et al 2020 ; Vaillant et al. 2022) has been developed to simulate tree architectural development and fruit production. Fruit growth modelling is based on carbon exchanges at the branch scale. The current version of the model extends and modularizes the carbon balance model previously proposed by Léchaudel et al. (2005) on fruiting branches. Carbon exchanges from the surrounding GUs to the fruits are formalized explicitly using a simplified version of the distance-based allocation function proposed in previous works (Reyes et al., 2020, Lescourret et al., 2011). It can be easily changed in future versions of the model. In addition, model modularity makes it possible to run simulations based only on carbon-related processes on observed or simulated mango tree architectures, and opens a wide range of model applications.

In this project, a V-Mango-based modelling approach will be developed and used as an integrative framework to analyze jointly data related to different processes and acquired at different scales. This integrative approach will add value to the data, as their joint analysis will make it possible to deeper investigate carbon-related processes from the branch to the tree scale, and quantify the effects of source-

sink relationships, and other structural or environment factors, on fruit size heterogeneity at harvest. From the modelling point of view, the challenge will be to define a multiscale model of plant structure and formalize carbon exchanges at different scales and their interaction. Exchange strength will depend on distances between organs. For this, methods to estimate distances between organs in the tree structure graph will be adapted to take into account the multiscale information. Using such information, a speed-up in the simulation time is expected.

Objectif and tasks of the internship
In this project, the student will investigate the effects of carbohydrates source-sink relationships from a local (branch) to a global (tree) scale on fruit growth using the V-Mango model and available datasets. V-mango, an open-source Python-based functional-structural plant model, is now available on a Virtual Modelling Environment (vmango-lab ; https ://github.com/fredboudon/vmango-lab) that allows working in a distributed and collaborative manner.

More specifically, the student's work will consist of the following tasks:

- Reorganization of the datasets to be easily usable for modelling applications: Experimental results and description of architectural development, stored currently in simple tabular format, need to be converted into structural and temporal indexed database compatible with multiscale representation, using, for instance, multiscale tree graphs (MTG).
- Revision of the carbon-related processes of V-Mango:
  - Extending the distance-based allocation function to take into account multiscale relationships for source-sink carbon allocation.
  - Optimizing the computation of distances between organs using multiscale relationships.
  - Integrating new reserve compartments to represent roots and old wood.
- Recalibration of the model, taking into account that the number of organs, that defined the compartments for the allocation procedure, may vary during the simulation.
- Sensitivity analysis of the behavior of the model using observed and simulated mango tree architectures:
  - Assessing the importance of the different parameters of the model.
  - Quantifying and comparing the exchange of carbon at the different scales
  - Quantifying the effects of carbohydrates source-sink relationships, modified by cultivation practices or pests, on the variability of individual fruit mass at harvest.

Candidate profile:
- Master level
- Computer scientist with a taste for biology or eco-physiologist with solid knowledge of computer science
- Modelling and programming skills
- Good knowledge of the Python language and Jupyter notebooks
- Ability to work in a multidisciplinary team (agronomists, computer scientists)

Internship conditions:
Monthly allowance in accordance with current regulations (~620€/month) and luncheon vouchers.
Mission to Réunion Island: plane ticket paid for by CIRAD and financial assistance for accommodation

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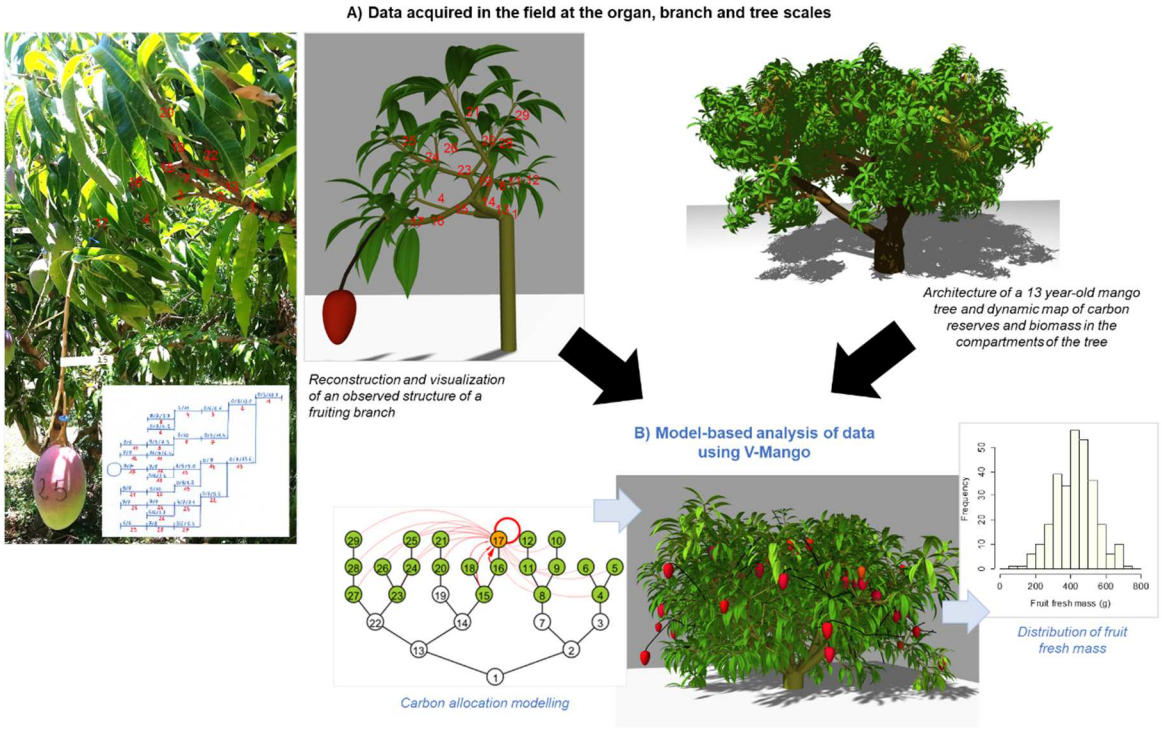
GRAPHICAL ABSTRACT



References:

Boudon F., Persello S., Jestin A., Briand A-S., Grechi I., Fernique P., Guédon Y., Léchaudel M., Lauri P-E., Normand F. (2020). V-Mango: A functional-structural model of mango tree growth, development and fruit production. Ann. Bot. 126: 745-763

Capelli, M., Lauri, P-E., Léchaudel, M., Normand, F. (2021). Hormones and carbohydrates are both involved in the negative effects of reproduction on vegetative bud outgrowth in the mango tree: Consequences for irregular bearing. Tree Physiol. https://doi.org/10.1093/treephys/tpab079

Grechi I., Normand F. (2019). Effect of source-sink relationships from the branch to the tree scale on mango fruit size and quality at harvest. Acta Hort., 1244: 93-100.

Léchaudel, M., Génard, M., Lescourret, F., Urban, L., and Jannoyer, M. (2005). Modeling effects of weather and source-sink relationships on mango fruit growth. Tree Physiol. 25, 583-597.

Lescourret, F., Moitrier, N., Valsesia, P., and Génard, M. (2011). QualiTree, a virtual fruit tree to study the management of fruit quality. I. Model development. Trees-Struct. Funct. 25, 519–530.

Marini, R.P., and Sowers, D.L. (1994). Peach fruit weight is influenced by crop density and fruiting shoot length but not position on the shoot. J. Amer. Soc. Hort. Sci. 119(2), 180–184.

Reyes, F., Pallas, B., Pradal, C., Vaggi, F., Zanotelli, D., Tagliavini, M., Gianelle, D., and Costes, E. (2020). MuSCA: a multi-scale source-sink carbon allocation model to explore carbon allocation in plants. An application to static apple tree structures. Ann. Bot. 126, 571-585.

Stassen, P.J.C., Janse van Vuuren, B.P.H. (1997). Storage, redistribution and utilization of starch in young bearing “Sensation” mango trees. Acta Hortic. 455:151-159.

Vaillant J., Grechi I., Normand F., Boudon F. 2022. Towards virtual modeling environments for functional structural plant models based on Jupyter notebooks: Application to the modeling of mango tree growth and development. in silico Plants, 4(1), 2022, diab040