Building the foundations of a *Coffea arabica* FSPM

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Highlights: Several data sets are being gathered to build a functional-structural model for *Coffea arabica*. The one pitfall in this integration process is the difficulty of calibrating a large number of parameters. A step by step procedure is thus necessary to validate the sub-models. The focus is put here on the backward reconstruction of the plant structure from its description at a given times as a way to decrease the degrees of freedom of the model before addressing the carbon acquisition and allocation.

Keywords: *Coffea Arabica*, plant structure, AMAPstudio, light capture

INTRODUCTION

Coffee is the most valuable product worldwide after oil. A quite large literature is dedicated to the agronomy and physiology of coffee tree (DaMatta et al. 2007) but there have been few attempts to model plant growth and production on functional bases. The most integrative process-based model was recently proposed by Rodriguez et al. (2011). This model combines phenology, shoot and root dynamics, light interception, photosynthesis and carbon allocation. However it works with cohorts of branches and leaves and doesn't explicitly consider the plant geometry and topology. Our purpose is thus to lay the foundations of coffee FSPM using information obtained in different experiments.

FSPMs mostly lie on four cornerstones: plant topology, plant geometry, carbon acquisition and carbon allocation. Putting together these different components leads to complex models with numerous parameters and, as far as many parameters need to be calibrated, there is then no insurance that proper parameter values can be obtained through automatic optimization methods. A step by step procedure is thus necessary for calibrating and validating the components of the integrated model.

Plant topology is the first step to address when aiming to develop a functional growth model with an explicit 3D structure. Basically the plant structure is the result of bud activity (growth, dormancy, death and ramification processes) over time. Unfortunately the functional bases of organogenesis are complex and poorly understood. A way to overcome this problem is to force the plant structure against field observations. This procedure is not straightforward since the plant structure cannot be reasonably measured all along its development and in coffee trees and there is no growth marker that can be used for inferring the age of the elements of a plant structure (Taugourdeau et al. 2012). Dating the elements of a coffee tree therefore needs a precise knowledge of the growth rates of plant sub-structures. Fortunately the growth rates of the main stem and branches are closely related in coffee trees (deReffye, 1990), making possible to retrieve back in time the plant structure in former stages. This procedure is illustrated here for arabica coffee plants at six growth stages from DAP 156 to 797. The experience acquired on modeling the carbon acquisition and the 3D plant structure is also briefly presented.

MATERIAL AND METHODS

Available information comes from several studies on Arabica coffee in Costa Rica –mainly the ICAFE experiment (Vaast et al. 2004) and the Orosi experiment (Franck et al. 2006)- and in Brazil (Rodrigues et al. 2011). The Costa Rica experiments were conducted for plants grown under different natural or artificial shade (Franck and Vaast, 2009). The effect of fruit load and ring braking was studied (Vaast et al. 2002 & 2004). These studies allowed to parameterize Farquhar's model for the different growth irradiances Dauzat et al. 2006). In both experiments 3D digitizing was performed on several plants along a row.

The Brazilian experiment was set up in the Embrapa Cerrado experimental field near Brasilia to compare the response of two cultivars (Iapar, drought tolerant and Rubi, drought sensitive) to temporary water shortage in terms of plant architecture, shoot and root biomass, physiology and gene expression. The experiment was conducted during two years with subplots irrigated or not during the dry season for each cultivar. Three treatments were applied as illustrated in Fig. 1. Three times a year, before, during and after

the dry season, plants were taken from the field to the laboratory for a comprehensive description of plant architecture including the measurement of leaves and internodes length, the stem and branch diameter and the branching angles. The total dry matter of stem and branches was then measured as well as the dry matter of roots. The dry matter of leaves was measured separately for each branch.

Data were coded under the MTG format (Godin & Caraglio, 1998) and loaded as an ArchiTree in the AMAPstudio-Xplo software (Griffon and Coligny, 2012) for performing simple analyses or for exporting data to dedicated statistical software such as R. XPLO was also used for creating 3D plant models under the AMAPstudio "OPF" format. The AMAPstudio-Simeo software (ibid.) was then used to create virtual plots and to run the simulation of light interception. The light model is an adaptation of the MMR model (Dauzat et al. 2008) that calculates the irradiance of individual plant organs.
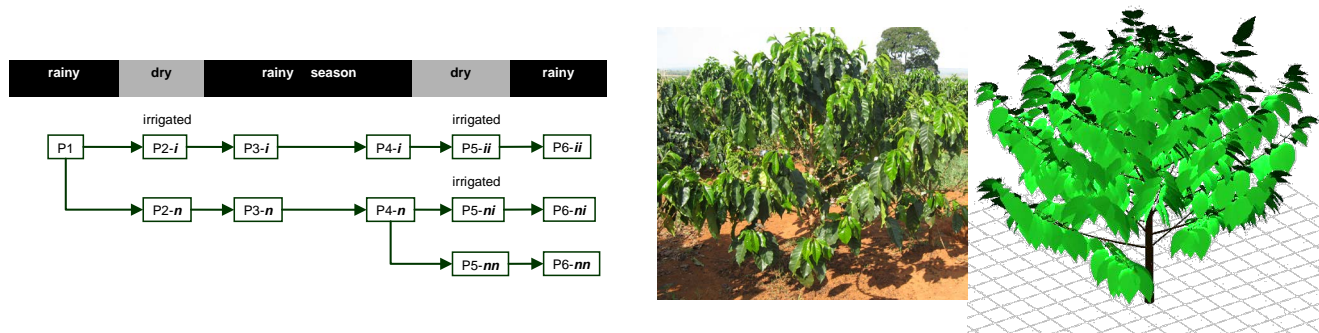

Fig. 1. A: Treatments applied on the different plots P in the Brazilian experiment. The plot were irrigated (i) or non irrigated (n) during the first and the second dry season. B: view of a plant in P5. C: example of simulated plant.

RESULTS AND DISCUSSIONS

Coffea arabica seedlings develop an orthotropic stem bearing systematically two plagiotropic branches on each node with the exception of some very basal nodes. These first order branches are sylleptic, i.e. they start their development with no delay. Branches may themselves develop two plagiotropic ramifications (second order branches) on each node and these ramifications may also develop two third order ramifications and so on. However these ramifications develop with delays and are set up at uneven node positions. Because plants are generally coppiced every 2 or 3 years in order to keep them short and facilitate fruit collection, the plant architecture remains rather simple with branch orders limited to 3 or 4.
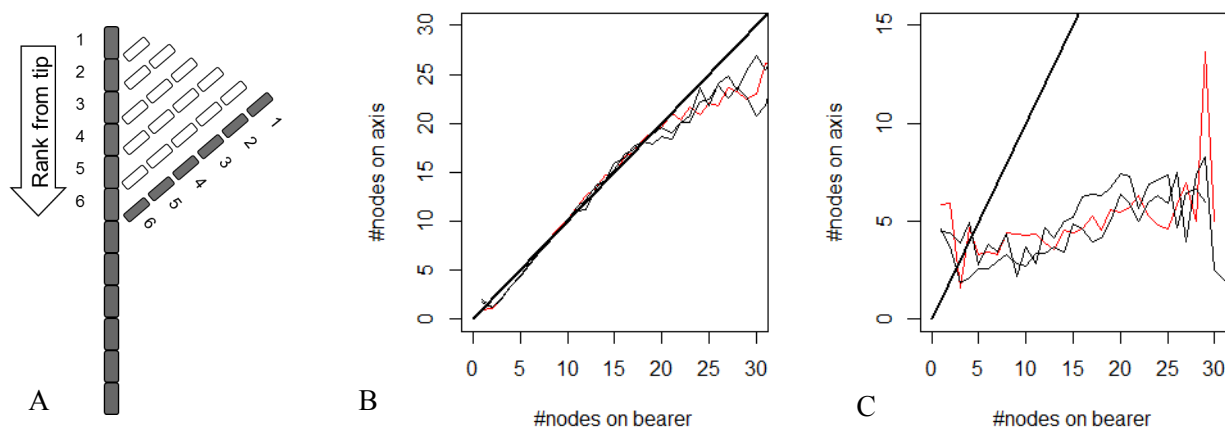

Fig. 2. A: comparison of the number of nodes on branches vs. the number of nodes on their bearing axis. B: results obtained for 1st order branches vs. main stem. C: results obtained for 2nd order branches vs. 1st branches. (Results obtained for the Iapar cultivar). The 3 lines in B and C correspond to the 3 treatment (ii, ni and nn).

The main stem phyllochron was found to be about constant over the two years for irrigated plants but was slightly increased during the dry seasons for non-irrigated plants. In order to analyze the phyllochron of branches we compared their number of metamers to the number of metamers of the distal portion of their bearer axis (Fig. 2A). Results show that the first order branches have the same growth rate as the main stem except for older branches in which the growth rate progressively decreases (Fig. 2B). The same trends are observed for the two cultivars in all treatments. Likewise second or third order branches have a growth rate

similar to their bearer. However their set up is spread out in time, leading to ramifications of about 1/3 the size of the distal portion of their bearer on average (Fig. 2B). Second and third order branches are more or less randomly located on "mature" nodes (nodes of rank >15) whatever the size and position of their bearer.

Different responses to water shortage were found for the two cultivars in terms of biomass acquisition. The main explanation is that the sensitive cultivar has a poor stomatal regulation and therefore rapidly exhausts the soil water reserves. However the analyses revealed no clear response of plant architecture to drought.

Virtual plants were simulated based on the above mentioned organogenetic rules and compared to actual plants in terms of biometric data and light capture. This step was achieved owing to a plant builder in which bud events -i.e. initiation of new metamers- are triggered by a scheduler. By doing so the complete plant structure is automatically updated at any time.

Simulations fairly reproduced the plant structure on average (Fig. 1B & C) but failed to render the inter-plant variability. Given that plants were sampled to cover the spectrum of plant height at the setting of the experiment, it was therefore necessary to initialize the plant development in young stages before running the simulations. This was achieved by applying the organogenetic rules to associate an initiation date to each plant component and finally get the plant state at any date. Likewise the number of leaves was interpolated from field observations for each branch order.

Ongoing steps using previous results from Costa Rica experiments are (i) the evaluation of light capture vs. the geometrical parameters by comparing simulated plants to digitized plants and performing sensitivity analyses of light interception vs. leaves angles, (ii) the integration and re-parameterization of the carbon acquisition model (Dauzat et al. 2006) and (iii) checking the consistency between the simulated carbon acquisition and the biomass accumulation over time. A major question mark for steps ii and iii is the negative feedback from sinks to carbon sources (Franck et al. 2006 & 2009; Vaast et al. 2002 & 2004) suggesting that the growth of coffee trees can be sink driven in case of a low fruit load.

<div align="center">LITERATURE CITED</div>

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