Using the MAESTRA model to simulate light interactions and photosynthesis from plant to plot in coffee agroforestry systems

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1. *Introduction*

The geography of coffee production will likely be affected in Central America due to climate changes. Coffee is known to be sensitive to high temperatures, affecting negatively flowering and fruit quality (DaMatta et al., 2008). Moreover, coffee is mainly cultivated by smallholders who are usually economically vulnerable and who have limited capacities of adaptation. Agroforestry (AF) is a practice that could enhance system resilience to climate change at reduced costs. Numerous studies have shown that shade trees in AF systems significantly affect the microclimate by reducing light transmission to the crop. Those studies have measured effects of shade trees on air and leaf temperature, air humidity, plant transpiration, photosynthesis, production, and even fruit quality…

However experimentation alone cannot be directly used to design resilient AFS because of the complexity of the biophysical interactions: combinations of sites, elevations, species involved, planting densities, leaf area index.... Consequently, being able to model the light absorption, energy balance, temperature, photosynthesis or water balance is one of the most important stakes in agroforestry in order to help predicting productivity, quality and profitability for the future.

We present an application of the process-based model MAESTRA (Wang and Jarvis, 1990), one of the few model that can deal with intra-plot vertical and horizontal heterogeneity of AFS, taking into account explicitly the planting design, the size of each individual plant, the seasonal variations of leaf area index etc., in order to describe the internal fluxes and state variables. Our approach was based first on a verification of the model predictions by field measurements in the Coffee-Flux observatory of Costa Rica. MAESTRA was then used to simulate the effect of increasing shade tree density on coffee light absorption and photosynthesis, as an example of the wide possibilities of the model.

2. *Materials and Methods:* The MAESTRA model and its parameterization

Input:

Inventories :
- Positions of plants
- Crown height, diameter, shape
- Leaf area and its dynamics

Parameters:
-Leaf angle and area distribution
- Leaf reflectance and transmittance
-Photosynthesis (Farquhar et al.) and Stomatal conductance (Ball et al.) parameters : LI-6400

Climate/nutrients:
Air temperature, RH, net radiation.
No water or nutrient limitations.

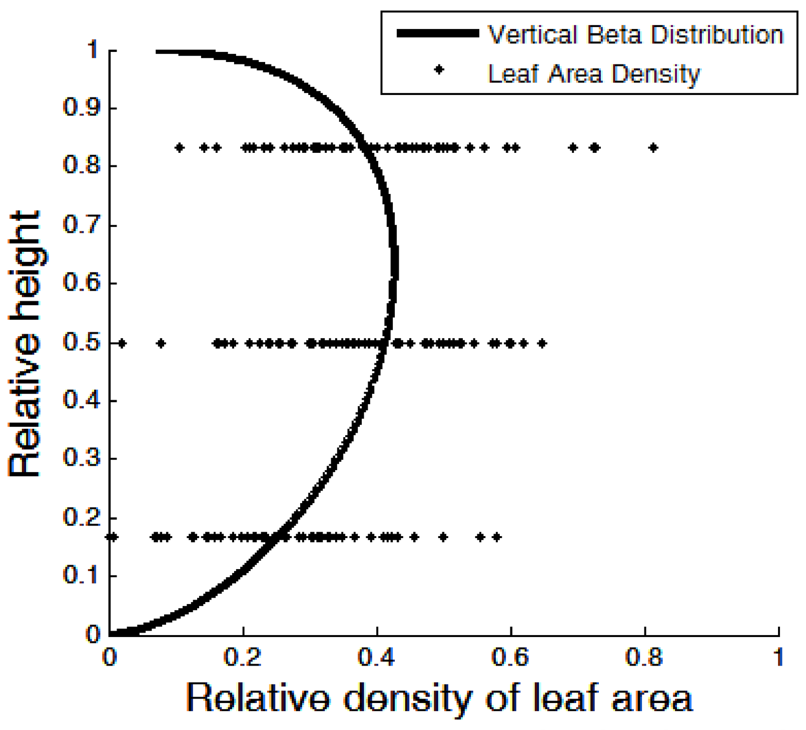


Figure 1: *In MAESTRA, the leaf area is distributed vertically and horizontally in the coffee plant following a field-calibrated beta distribution*

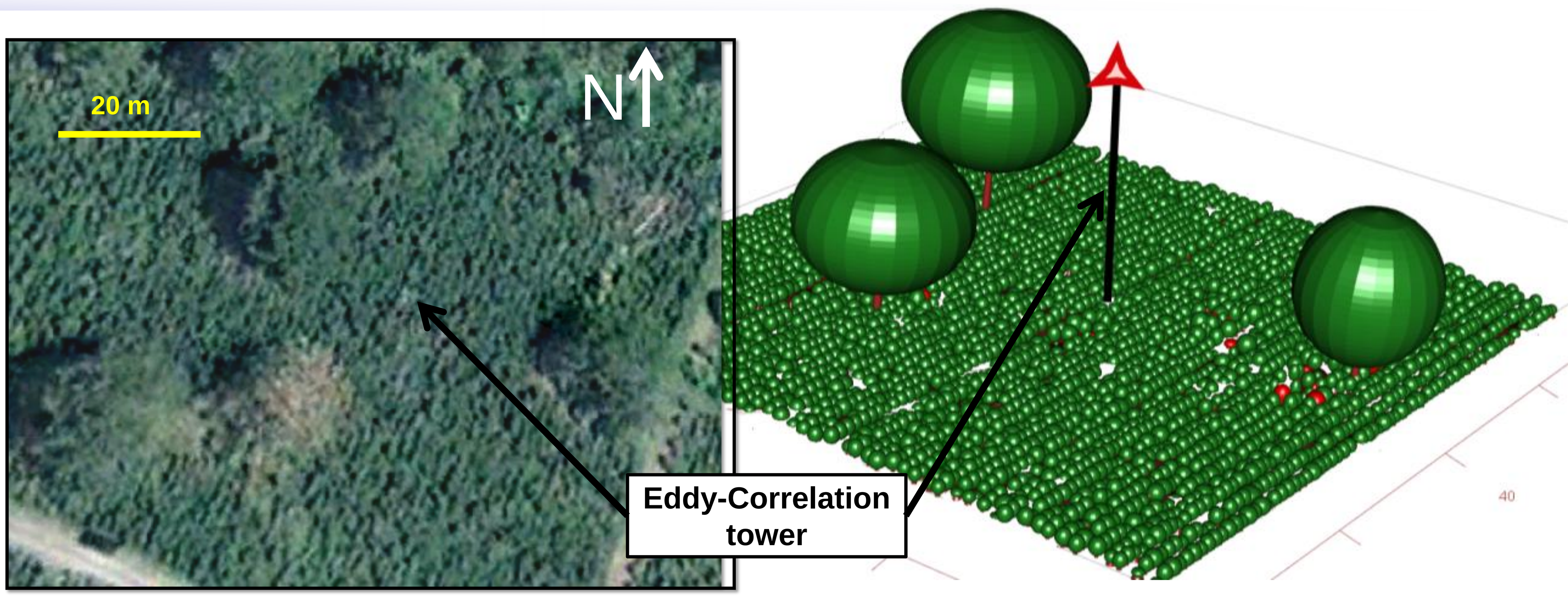


Figure 2: *A virtual scene is planted according to inventories. Each plant (shade tree and coffee) is described by its position, a simplified geometrical shape (i.e semi-elliptical) and a size (I.e crown height and diameter, trunk height). A flux-tower is measuring ecosystem photosynthesis and evapo-transpiration.*

Photosynthesis and transpiration were measured with a dynamic transient-state whole-plant chamber ***on 18 coffees*** *growing under* ***tree shade and full sun*** *and compared with MAESTRA simulations*

3. *Results*

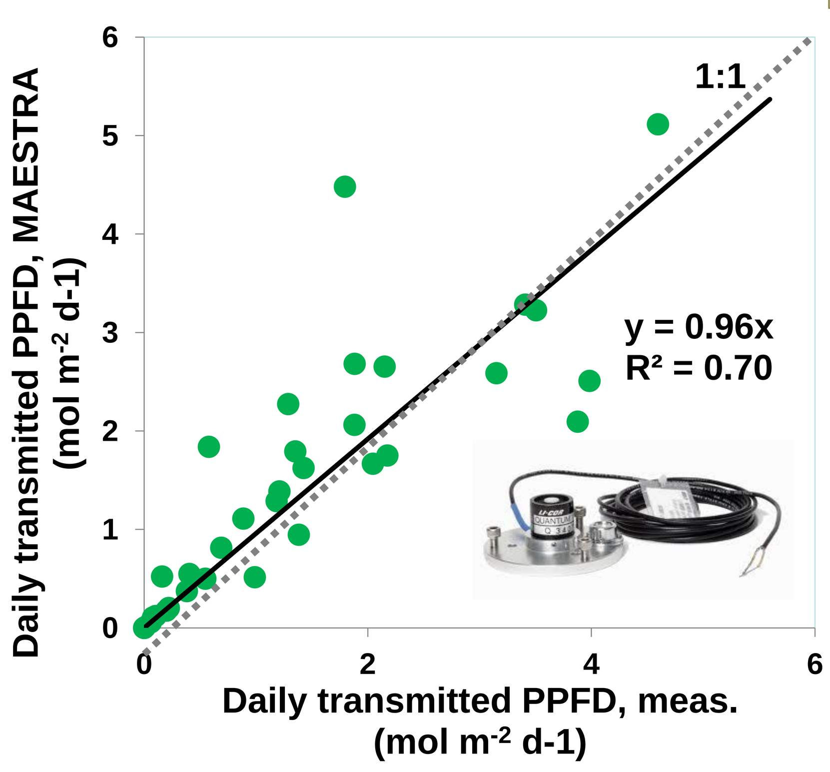


Figure 3: *Transmitted photon flux density (PPFD) below 18 coffees was measured with PAR sensors (Licor LI-190) in the field and compared with MAESTRA outputs on a daily basis.*

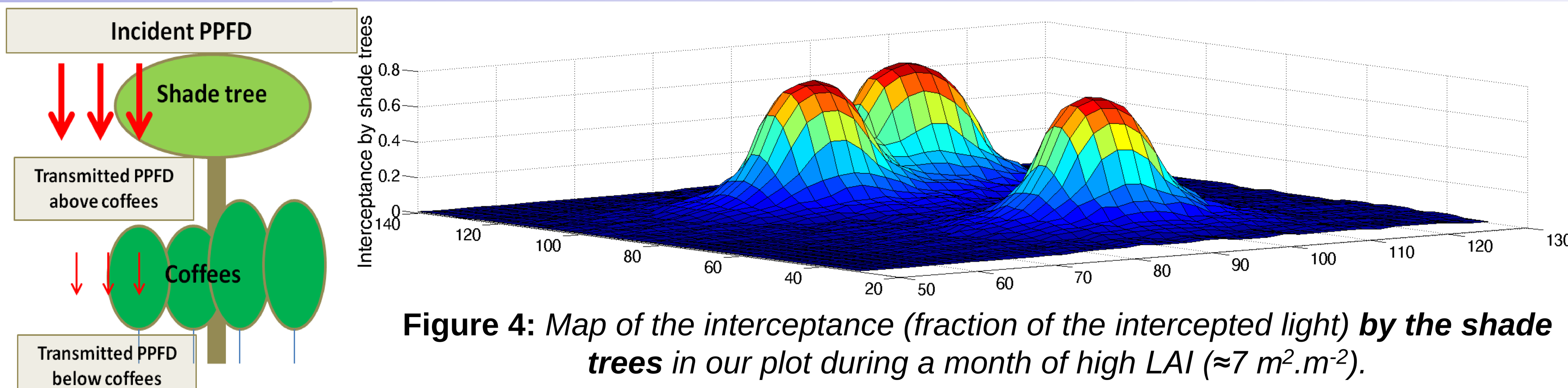


Figure 4: *Map of the interceptance (fraction of the intercepted light)* ***by the shade trees*** *in our plot during a month of high LAI (≈7 m².m⁻²).*

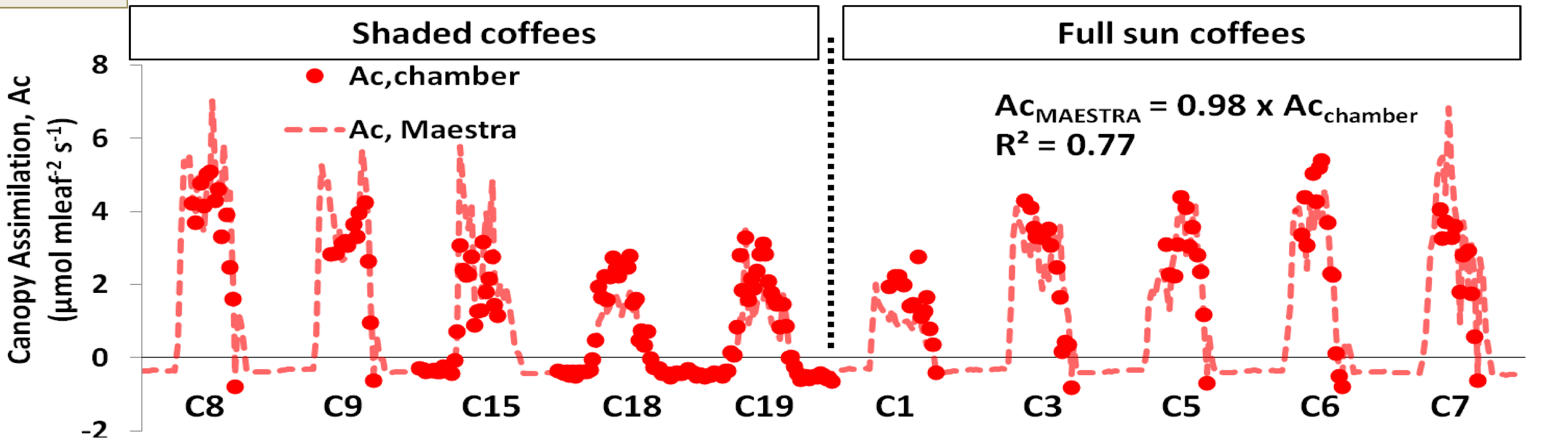
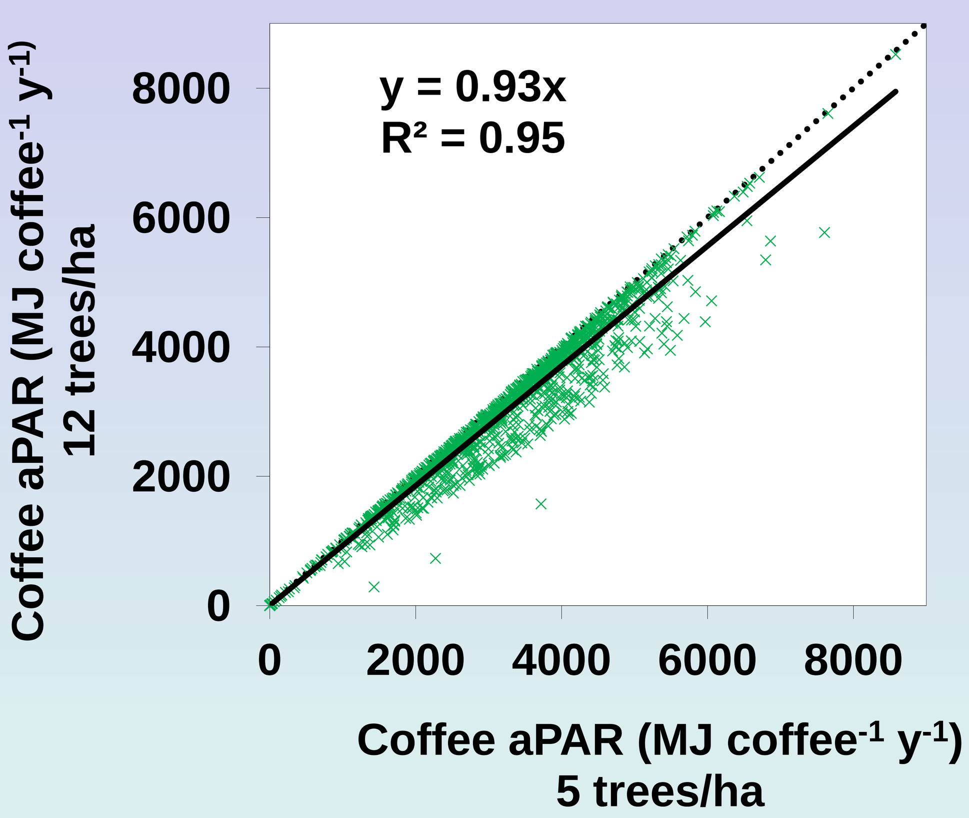
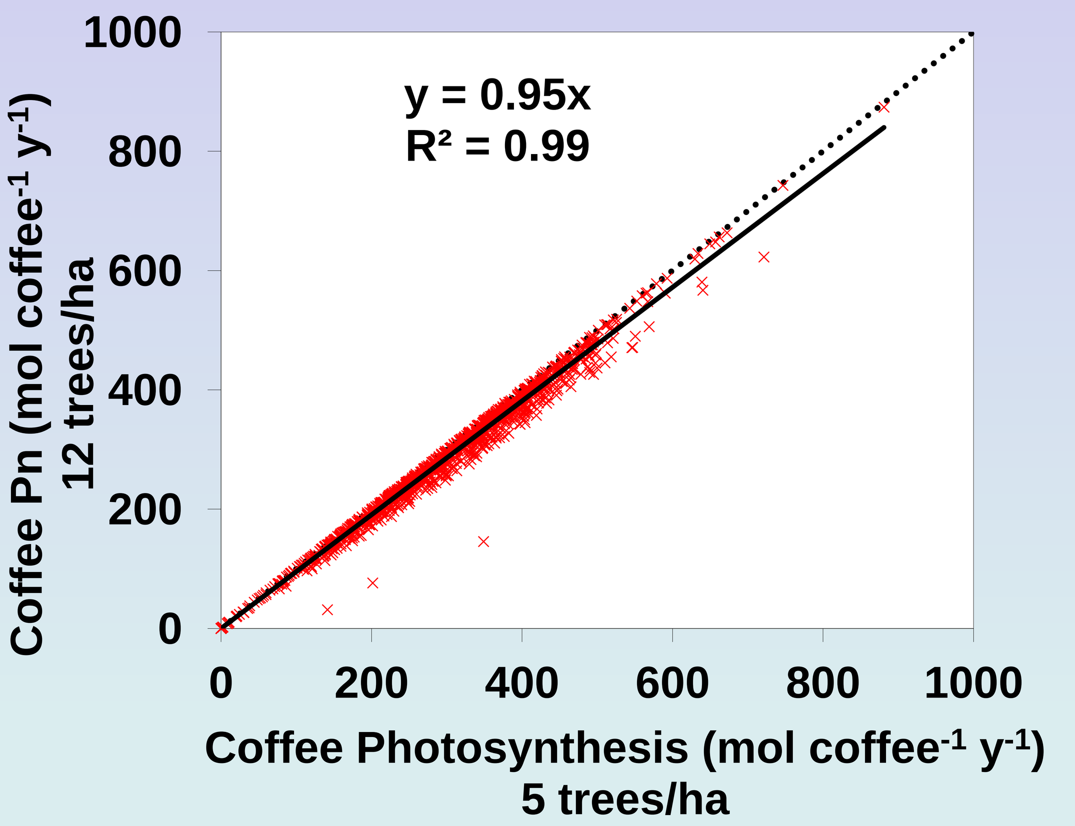


Figure 5: *Verification of the MAESTRA predictions for diurnal canopy assimilation and noctural respiration and with chamber measurements for 10 shaded and unshaded coffee plants. Each cycle is one day of measurements.*

4. Example of simulation: Let's double shade tree density





-The **absorbed radiation (aPAR)** by the coffee layer **diminished by only 7%**. Many coffees have their **light budget unchanged**.

- The **net photosynthesis** of the plantation **decreased by only 5%** due to the non linearity of the relationship between photosynthesis and absorbed light.

5. *Discussion and conclusions*

MAESTRA was able to simulate reliably the spatial variability induced by shade trees on light absorbed by coffee plants and also their temperature, transpiration and photosynthesis. The model allows to partition between shade tree/coffee layers or to map the spatial and seasonal heterogeneity of state variables + fluxes.

Once verified through a bottom-up approach from leaf to whole plant, MAESTRA was used to run prospective simulations at the plot scale. For instance, we studied the effect of doubling shade tree density on light and carbon budget of the coffee layer.

MAESTRA proved to be a promising tool to study competition for light between shade trees and the main crop. It could help designing virtual AF plots and test their efficiency in terms of light and carbon capture. It can even be used to study the potential resilience of AFS to increasing temperature or atmospheric CO2 concentrations…

MAESTRA could also be used to study interactions within the main crop: effects of planting direction, planting density, pruning practice on light and carbon capture.

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