LAI dynamics of agroforestry and full sun coffee systems in Costa Rica

Taugourdeau S.[1], le Maire G.[1,2], Roupsard O.[1,5], Avelino J.[3,5], Gómez-Delgado F.[1], Jones J.R.[5], Marsden C.[1], Robelo A.[6], Alpizar E.[7], Barquero A[6], Rapidel B.[4,5], Vaast P.[1], Harmand J.-M.[1]

[1]Cirad-UPR Fonctionnement et pilotage des écosystèmes en plantation; [2] UMR TETIS, [3]Cirad-UPR Bioagresseurs de Pérennes; [4]UMR SYSTEM, [5]CATIE, [6]Aquiares farm, [7]La Hilda-Doka farm.

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1. *Introduction*

Coffee systems show large variability in structure (from monoculture to diversified agroforests), or in management (from organic coffee to very intensive systems). These different systems are not equivalent in terms of profitability and provision of **ecosystem services (ES)** (production, carbon sequestration, erosion control...).

Our hypothesis is to consider that **leaf area index (LAI)** is an integrated indicator of ES: leaf area determines light interception, gas exchange and hence primary productivity, and LAI can be related to **yield**, to the annual input of litter to the soil (**C cycle and soil OM**) and to rain interception (**erosion control**). Most studies of coffee LAI were performed at plot scale. In contrast, we propose to explore the plant, **plot and farm scales, using remote sensing**. Coffee Normalized Difference Vegetation Index (NDVI) has already been studied (Brunsell et al.,2009), but mainly as a vigor indicator and without calibration with true LAI. The aims of our study were (i) to calibrate the relationships between NDVI and LAI for agroforestry coffee systems displaying low shade levels (ii) to assess some relationships between **environmental** or **agricultural** factors and LAI, and (iii) to test the capacity of **remotely-sensed LAI** to be used as an indicator of **yield** and provision of **ecosystem services**.

2. *Materials and Methods*

Study sites: two coffee farms were selected in Costa-Rica. Aquiares had no dry-spell and dispersed shade trees whereas La Hilda (Doka) had dry-spell and no shade at all.

Remotely sensed images: we acquired a **very high spatial resolution** (VHSR-2m) image (worldview 2) for each farm in March 2010. We used also a **moderate resolution satellite** (250 m MODIS) with a high temporal resolution (16 days composite images).

LAI measurement: light transmittance was measured with 2 **LAI 2000** devices on 15 transects across the 2 farms. Effective LAI of coffee and trees was inverted from light transmittance. True LAI of coffee was obtained after measuring the **leaf area of 25 coffee plants** (60 000 leaves) and compared with the effective LAI, their ratio being the clumping factor.

Calibration of LAI-NDVI: first, an experimental relationship between true field **LAI** and VHSR **NDVI** yielded a LAI map at high resolution; second, a relationship was found between the **MODIS NDVI** and the corresponding area of the **LAI map** (Figure 1)

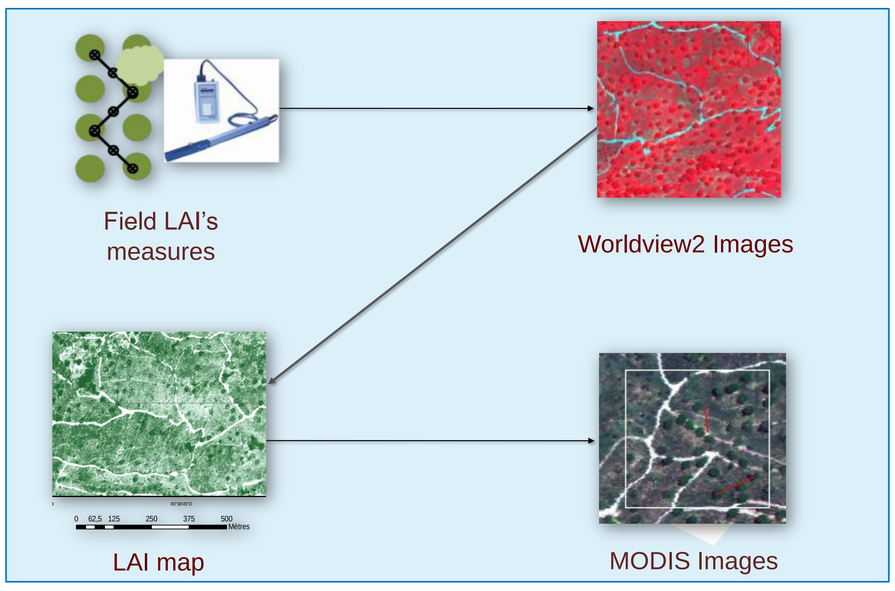

Figure 1: *Protocol for calibrating high and moderate resolution NDVI from ground LAI and for mapping LAI*

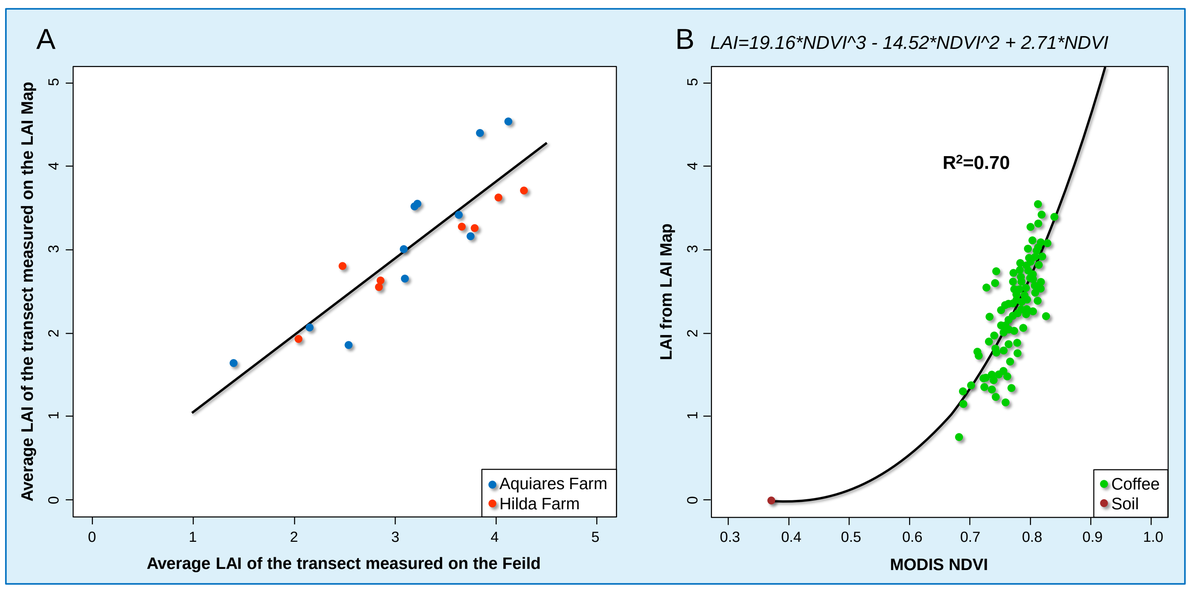

Figure 2: *A) Relationship between Field LAI and LAI derived from the HR LAI Map, after its calibration. B) Relationship between LAI from the HR LAI map and MODIS NDVI. The two farms are presented.*

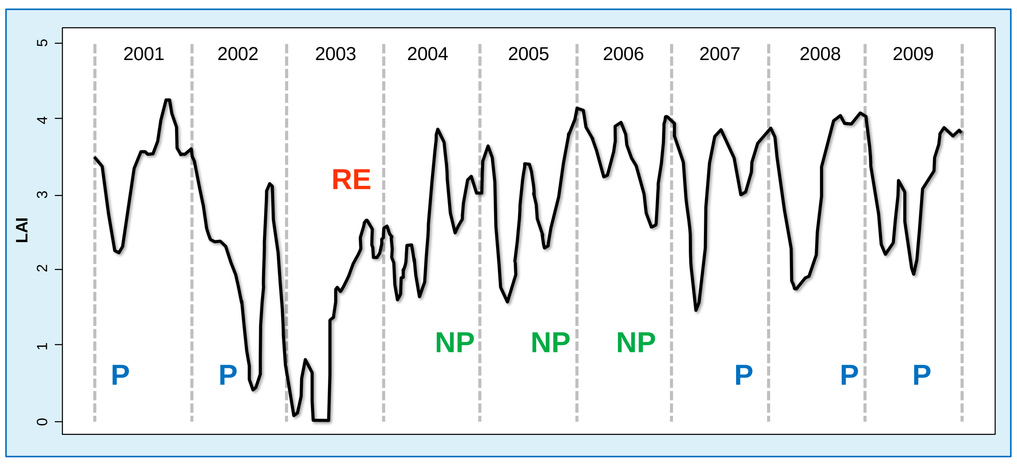

Figure 3: Effect of agricultural practices on *LAI time series detected by MODIS and interpreted from farm questionnaire (P coffee pruning, RE coffee renovation, NP coffee not pruned). One MODIS pixel of Hilda Farm presented as an example.*

3.Results

- Remotely-sensed NDVI has been successfully calibrated at high (HR) and moderate resolution (MR) for coffee systems with little or no shade. We derived HR-LAI maps and MR-LAI dynamics (Figure 2)
- Seasonal dynamics of LAI are influenced by **climate** (rain) and by **agricultural practices** (pruning ,..)(Figure 3 and Figure 4)
- **Coffee prices** during year-N^{-1} explained 78% of the variability of average year-N LAI, which was interpreted as more pruning for renovation and less fertilization when the coffee prices are low.
- **LAI of the driest month** are linked with **yield**. (Figure 5)

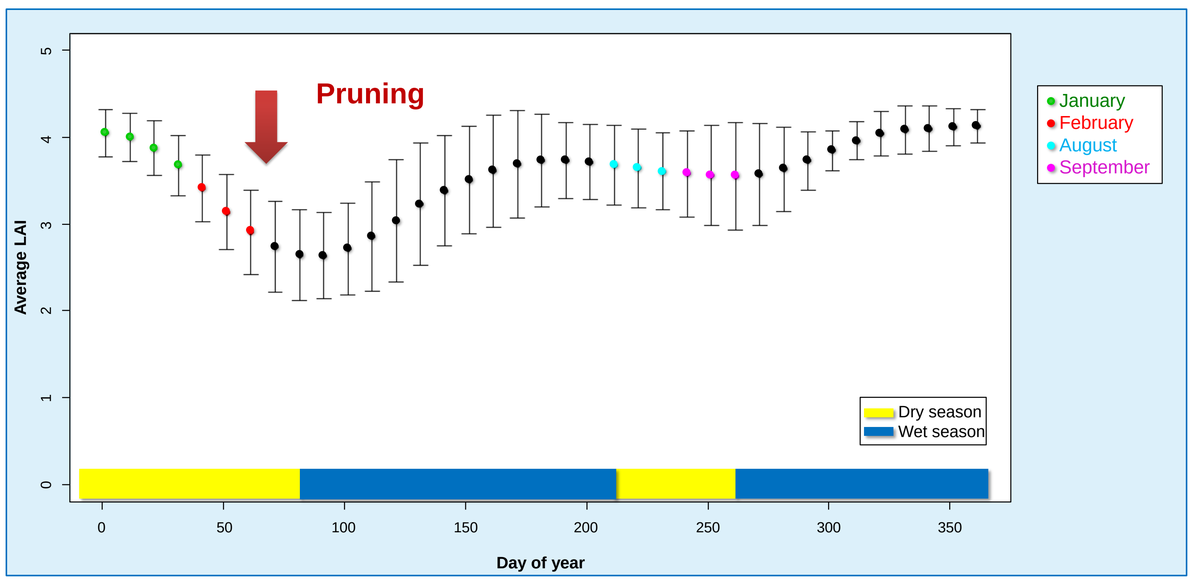

Figure 4: *Example of seasonal variations of LAI of a coffee plantation (tree + coffee) derived from MODIS NDVI time-series for one pixel Error bars represent the variability on the 9 year time-series in one entire farm (Aquiares)*

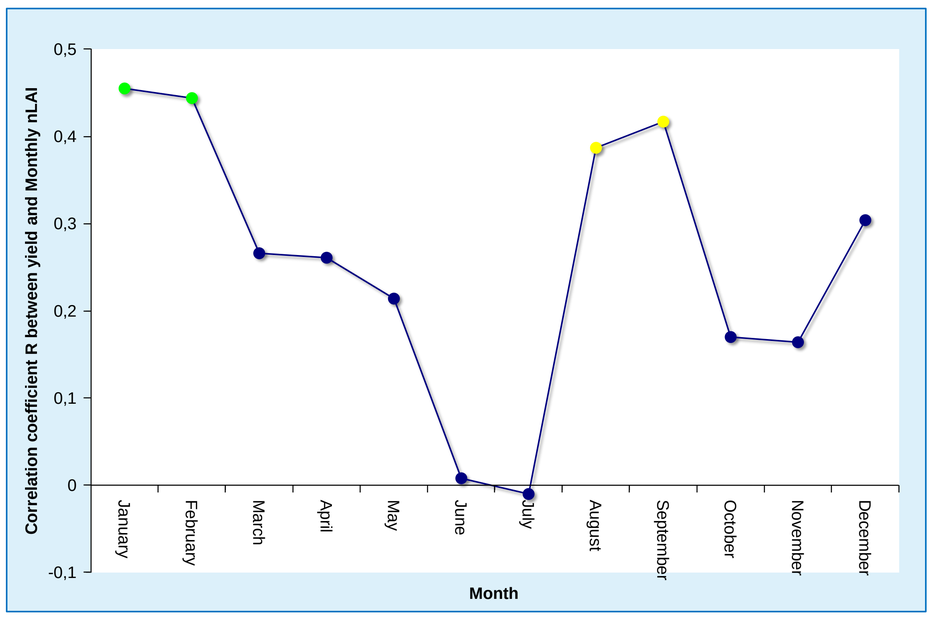

Figure 5: *Yearly Evolution of R correlation coefficient between the yield and the average LAI of the month (green: pvalue <0.01, yellow: pvalue<0.05)*

4.Conclusions

- High (HR) and moderate (MR) resolution NDVI were calibrated using field-truth and we derived **HR-LAI maps** and **MR-LAI dynamics**, for full sun coffee or for little shade agroforestry coffee
- Inter-annual variations of LAI are controlled by renovation cycles and fertilizers, which are influenced by coffee prices. Seasonal variations of coffee LAI are influenced by the **climate** and by the **agricultural practices** such as pruning
- Coffee LAI is a promising factor for modelling **yield.** Another output is to model **environmental services** of entire farms (Gómez-Delgado et al., 2010), according to practices.

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