The "Coffee-Flux Collaborative Observatory": measuring and modeling carbon, nutrients, water and sediment Ecosystem Services in a coffee agroforestry watershed (Costa Rica).

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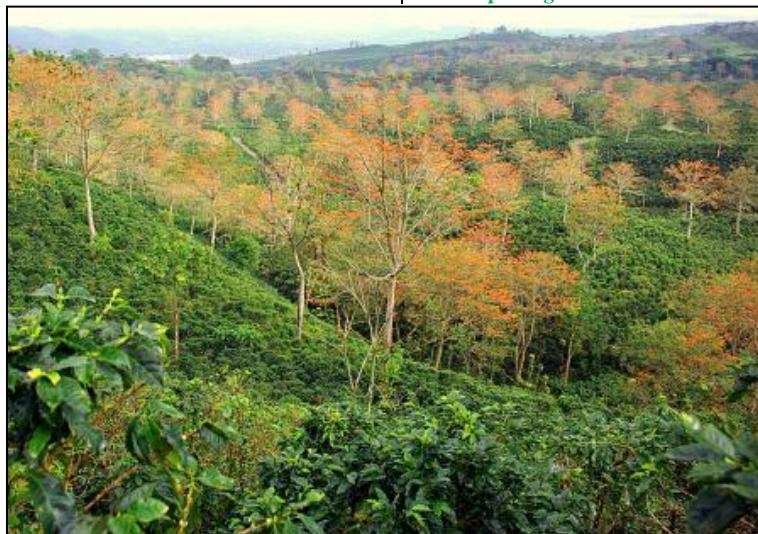
Photo 1: Coffee-Flux experimental watershed: arabica coffee agroforestry watershed in the Aquiares farm (Costa Rica), with *Erythrina poeppigiana* shade tree. *Photo Nils Roar*.

Coffee is one of the world's largest agricultural export by value (FAO, 2011, Pendergrast, 2009). Costa Rica declared its ambition to become the first C-Neutral country in 2021 and will lead the development of NAMA-Café and C-Neutral coffee certification. The Coffee-Flux experimental site is unique to study simultaneously carbon, water, sediment and nutrient ecosystem services.

Aims and Philosophy of the CoffeeFlux[1] Collaborative Platform

The aim of Coffee-Flux is to assess carbon, nutrients, N2O, water and sediment Ecosystem Services (ES) at the scale of a coffee agroforestry watershed. Observation, experimentation, modelling and remote-sensing are combined, collecting data and calibrating models locally, then upscaling to larger regions. The project has been running continuously since 2009, in order to encompass seasonal and inter-annual fluctuations of coffee productivity and ecosystem services.

Coffee-flux is a platform where collaborative research on coffee agroforestry is promoted: data are being shared between collaborators and positive interactions are enhanced. The philosophy is to concentrate several investigations on one specific site and for several years, to share a useful common experimental database, to develop modelling and to publish results in highly-ranked scientific journals. Applied research is also highly encouraged (e.g. C-Neutral certification, NAMA, Agronomy, etc.). Coffee-Flux benefits from infrastructure, easy access from CATIE[2] and very good security, ready to welcome complementary scientific investigations and collaborations. The project is wide open to complementary projects, scientists and of course to students. The core data base is for sharing.

Sponsors-Networks- Flowchart

Coffee-flux was launched in December 2009 in Costa Rica by Cirad[3], CATIE, PCP[4] and the Aquiares far[5]. First, it was a sub-project of CAFNET[6] (EuropAid/121998/C/G): "Connecting, enhancing and sustaining environmental services and market values of coffee agroforestry in Central America, East Africa and India". Coffee-Flux is a contributor of FLUXNET[7] and became an **Observatory** within the European and french SOERE F-ORE-T[8] network in early 2011. It is fueled by projects and delivers products to Networks and Instruments.

The Coffee-Flux Observatory
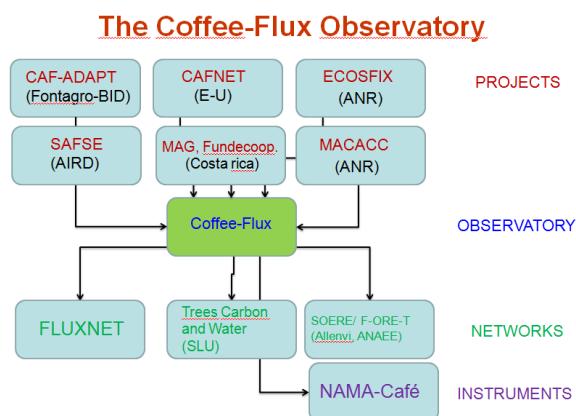
Site and infrastructure description

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[1] CoffeeFlux: http://www6.montpellier.inra.fr/ecosols/Recherche/Les-projets/CoffeeFlux

[2] CATIE : Centro Agronómico Tropical de Investigación y Enseñanza: http://www.catie.ac.cr/

[3] CIRAD : http://www.cirad.fr/

[4] PCP «Agroforesterie à base de cultures pérennes en Amérique Centrale» : http://www.pcp-agroforestry.org/

[5] Hacienda Aquiares : http://auction.stoneworks.com/includes/crq2004/aquiares_brochure.html

[6] CAFNET : http://www.catie.ac.cr/BancoMedios/Documentos%20PDF/cafnet_carbon_sequestration_mela.pdf

[7] FLUXNET (Global Network of Micrometeorological Tower Sites) : http://daac.ornl.gov/FLUXNET/

[8] Observatoire SOERE/F-ORE-T : http://www.allenvi.fr/?page_id=768

A 1 km^2 coffee watershed, homogeneously shaded with tall *Erythrina poeppigiana* was selected in Aquiares, one of the largest coffee farms of the country, "Rainforest Alliance ^{TM}" certified, located on the slopes of the Turrialba volcano, ranging in elevation from 1,020 up to 1,280 m.a.s.l., strongly influenced by the climatic conditions of the Caribbean hillside, and without strong dry spell. The watershed is instrumented with automatic flumes, pluviometers, soil moisture probes, piezometers, turbidimeters, sapflow and eddy-covariance tower (for H$_2$O and CO$_2$ gas fluxes).

Photo. 2: The Coffee-Flux experimental display.

Monitoring Ecosystem Services

Hydrological service: Coffee-Flux is monitoring and modelling the water balance partitioning (rainfall, interception, superficial runoff, infiltration, sapflow, soil water balance, evapo-transpiration, aquifer fluctuations and total streamflow), and the sediment yield from plot to watershed. One model was developed (Hydro-SVAT: Gómez-Delgado et al., 2011). Also δ^{18}O/δD isotopic tracing experiments are underway (collaboration with UNA, Ricardo Sánchez-Murillo et al., 2015). 1 PhD thesis is achieved (Gómez-Delgado F., 2010), two are in progress (Benegas L.; Welsch K.) and 2 postgraduate fellowships achieved (Kinoshita, 2009; Deffner A.).

Carbon service: Coffee-Flux is monitoring the leaf area index (LAI) using field and remote sensing techniques (High Resolution Multispectral Images; MODIS), the Net Primary Productivity (NPP: tree + coffee growth and mortality) above and below-ground (minirhizotrons, rhizotrons), the Gross Primary Productivity or (GPP = ecosystem photoynthesis), the ecosystem + soil respiration, the whole plant gas exchanges, the leaf gas exchanges and the Net Ecosystem Exchange (NEE) which is the ecosystem C balance, using combined eddy covariance, growth+litter monitoring and various plant chambers. The SOC, nitrogen, active C, non-crystalline clay minerals such as allophane, imogolite, ferrihydrite as well as metal-humus complexes have been surveyed, SOC and N were estimated by VISNIR and mapped (kriging) for the whole watershed (Kinoshita et al., 2015). 1 PhD is completed (Charbonnier F.), two PhD in progress (Perez Molina J.P., Vezy, R.), 6 MSc achieved (Taugourdeau S.;

Audebert L.; Defrenet E.; Nespoulous, J., Khac E., Soma M.) and 2 post-graduate fellowships (Jarri, L., Cambou A., Guidat, F., Rançon, F.). One radiation absorption + photosynthesis + transpiration model is being used (MAESPA: Charbonnier et al., 2013).

Nutrient balance: Coffee-Flux is monitoring nutrient inputs, assimilation and leaching, according to distance to shade trees and within an experimental display controlling fertilization (K. Van Den Meersche). Nitrates and P are also being monitored in aquifers and streamflow (PhD of K. Welsch).
Other GHGs emissions: a N_2O & CO2 soil flux automatic monitoring experiment was settled in February 2016 in a fertilization trial, in collaboration with U. Copenhagen; Master of Carolin Mages.

Protection against erosion: Coffee-Flux is monitoring erosion at plot scale (with trees and without trees) and sediment yield at the watershed scale (using automatic turbidimeter). Also in the PhD of Gómez-Delgado F. (2010).

Coffee pests and diseases regulation: Incidence and severity of coffee pests and diseases (including coffee leaf rust) are being monitored under shaded and full sun conditions, and compared with or without treatment (C. Allinne). Incidence is also measured in function of the fertilization level.

Effect of Shade on coffee microclimate: The CATIE Agroforestry trial (Elias de Melo) has been equipped to monitor coffee canopy temperature and microclimate according to Shade types (MSc. of Maxime Soma, PhD of Rémi Vezy).

**Selected results and models (August 2016)**
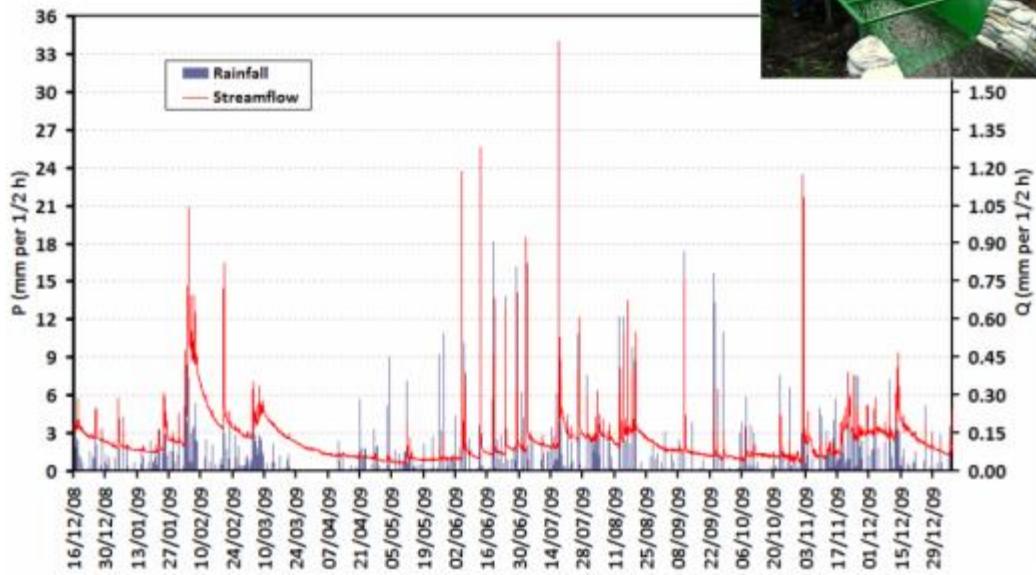
Fig. 1: The red line is the time-course of streamflow at the outlet of the Coffee-Flux watershed (automatic flume), showing a large contribution of the baseline (aquifer responding in terms of discharge and recharge) + episodic and rather low contribution of superficial runoff (peaks after rainfall events). This behaviour is typical of watersheds with large infiltration capacity, low superficial runoff and probably low laminar sediment transport.
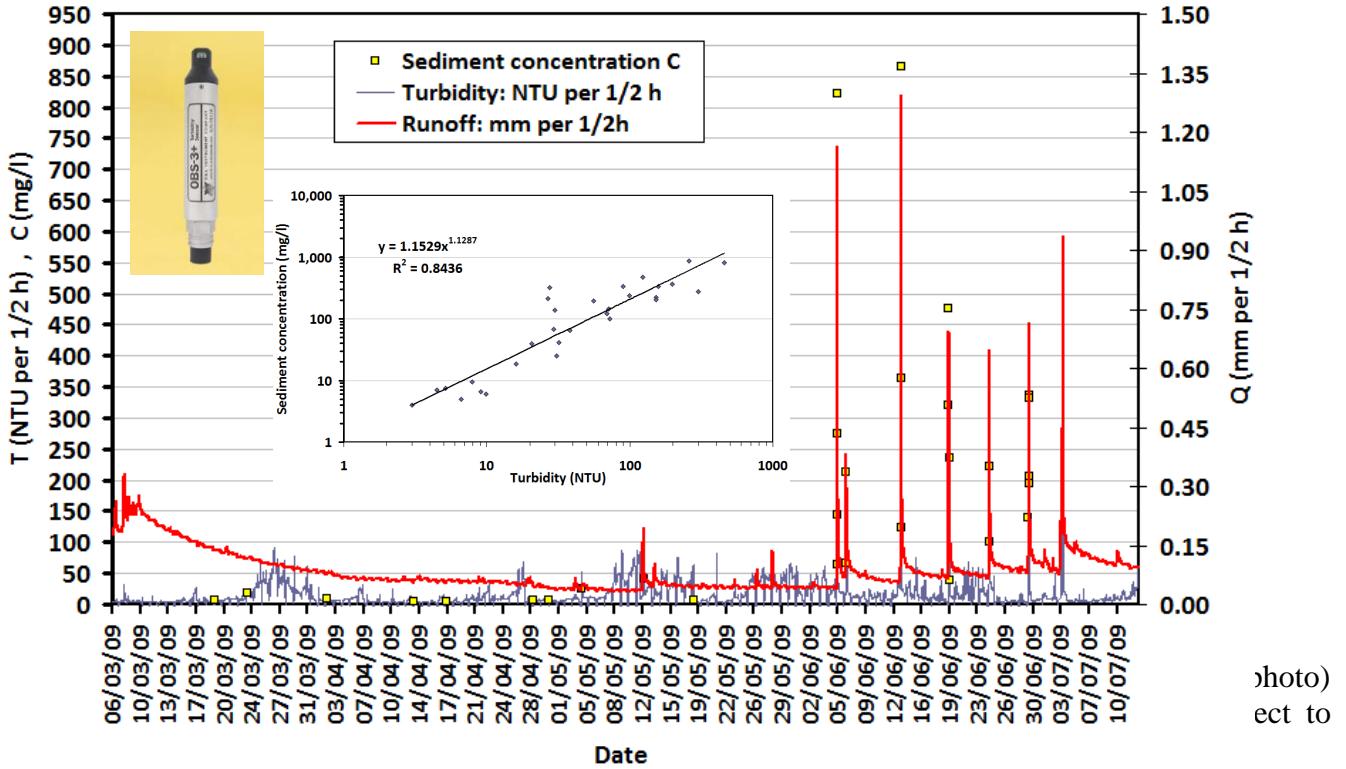
Fig. 2: Time-course of the sediment transport assessed by automatic turbidimeter (OBS-3, see photo) and bottle collection at the outlet of the Coffee-Flux watershed. The rating curve of turbidity in terms of sediment load is also given.
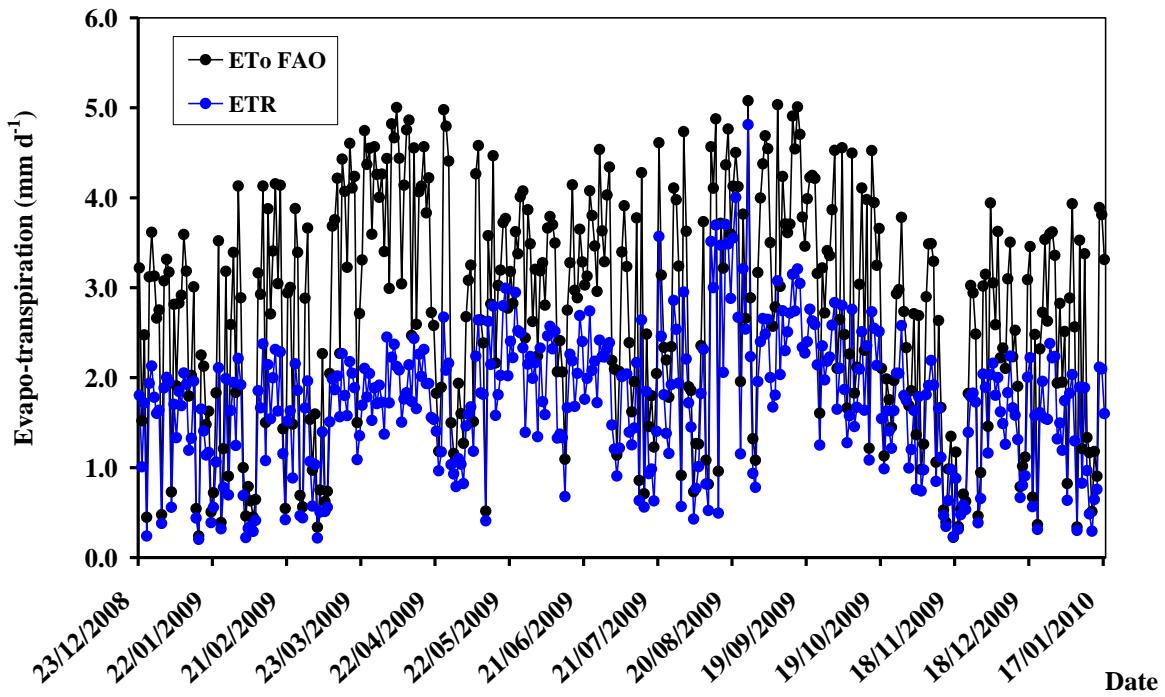

Fig. 3: Time-course of daily potential (ET_0-Penman Monteith, FAO) and real evapo-transpiration (ETR, by eddy covariance) in the Coffee-Flux Watershed. ETR/ET_0 varies from 0.4 to 0.7, according to LAI fluctuations mainly.

Cumulative water balance
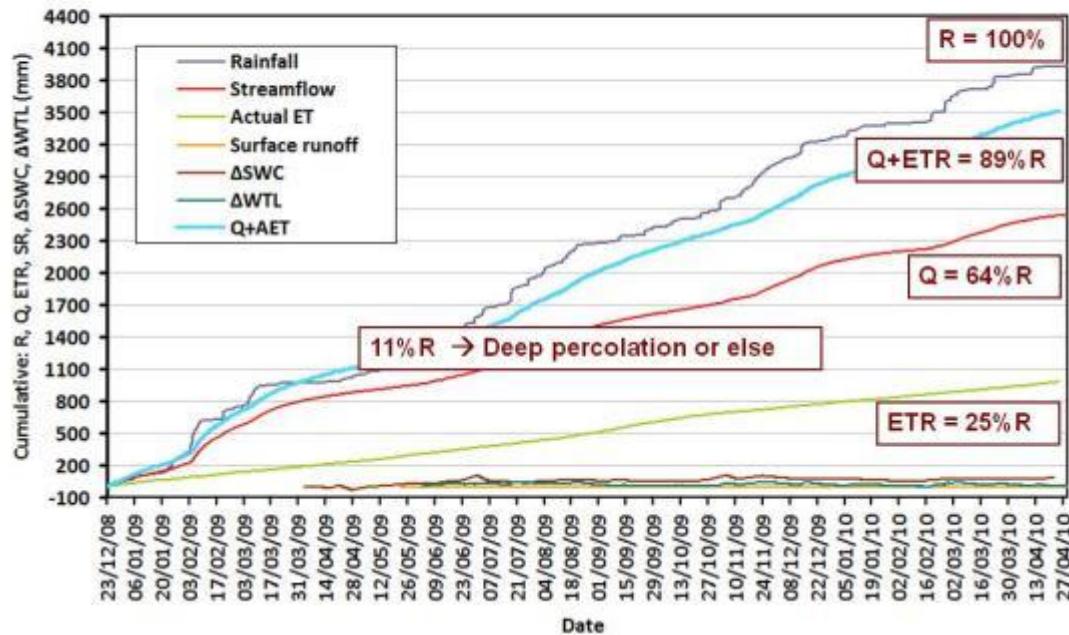
Fig. 4: Cumulative water balance of the CoffeeFlux watershed, as measured by independent methods (ETR by eddy covariance ; Q by flume).


Fig. 6: Structure and simulations of the lumped Hydro-SVAT model for the water-balance partitioning of the Coffee-Flux watershed (Gómez-Delgado et al, HESS, 2011)
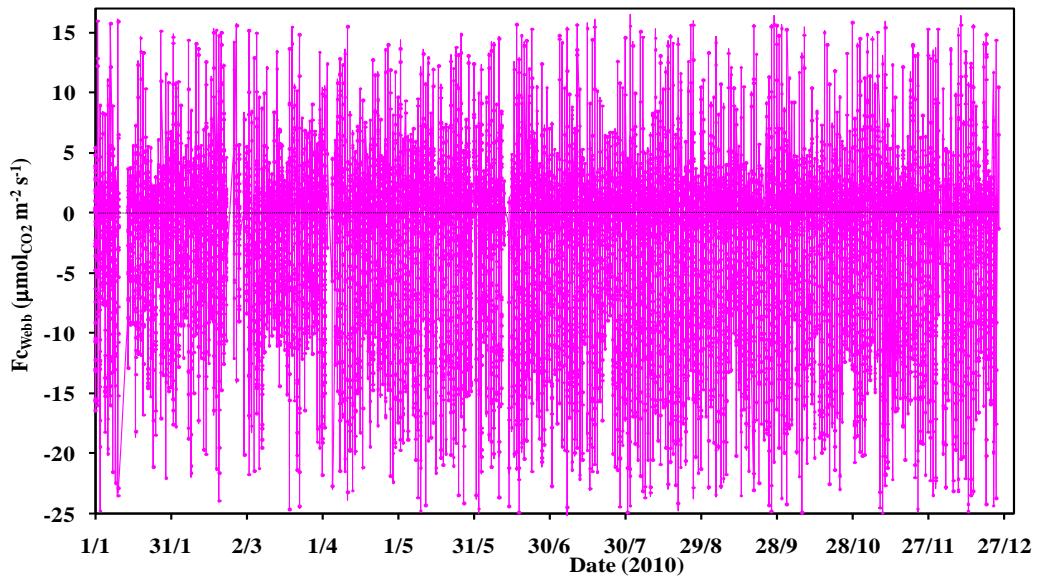
Fig. 7: Time-course of carbon net ecosystem exchange (F_c), and its partitioning into ecosystem respiration (positive values, mainly at night) and C uptake (photosynthesis + respiration, negative values). One cycle is one day, data from year 2010
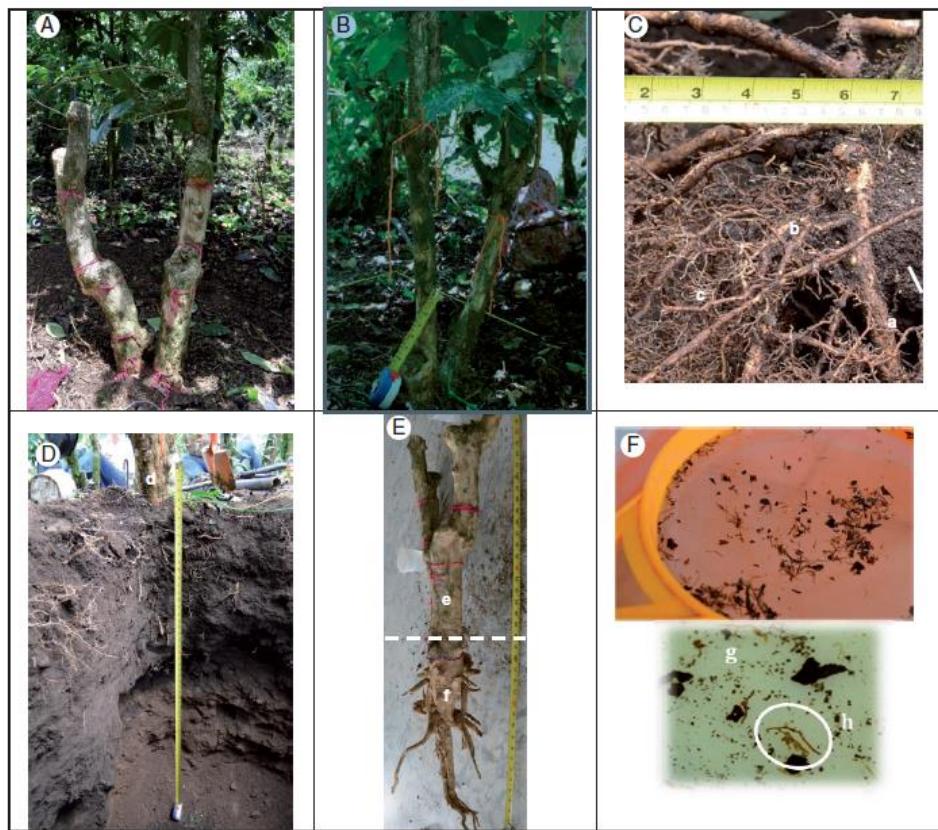

Fig. 8: Accessing the coffee root system and aerial stump (Defrenet et al., 2016)

rev.)

Fig. 9: Scenes for the simulation of light absorbtion, water and CO_2 exchanges by every plant of the plot under actual or double shade-tree density. Charbonnier et al., AFM, 2013

Simulating intra-plot light absorption with MAESTRA

rev.)
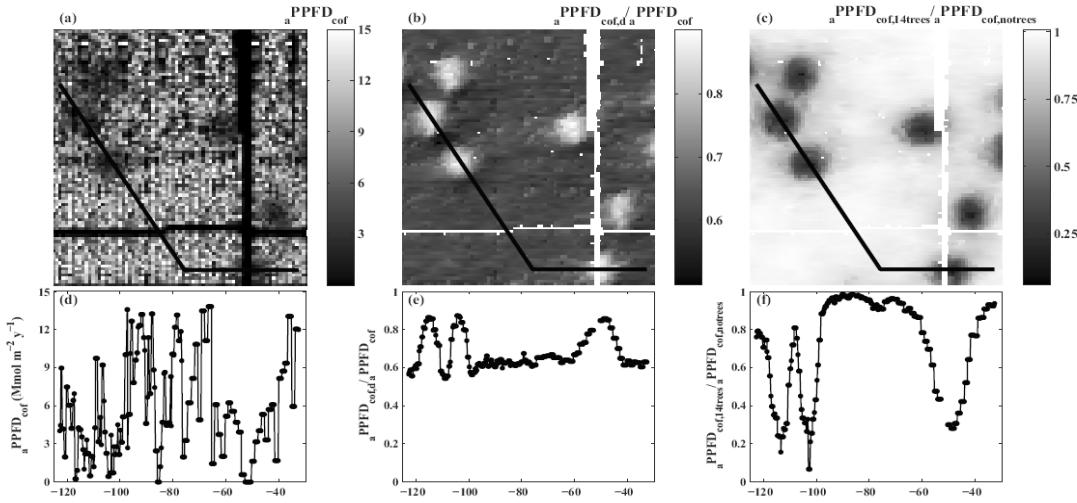
Fig. 10: Intra-plot variability for light absorbtion. Top views and transects for yearly absorbed PPFD by the coffee layer, relative absorbed diffuse PPFD by the coffee layer, relative absorbed by the coffee layer when shade trees are present or not. Charbonnier et al., AFM, 2013.
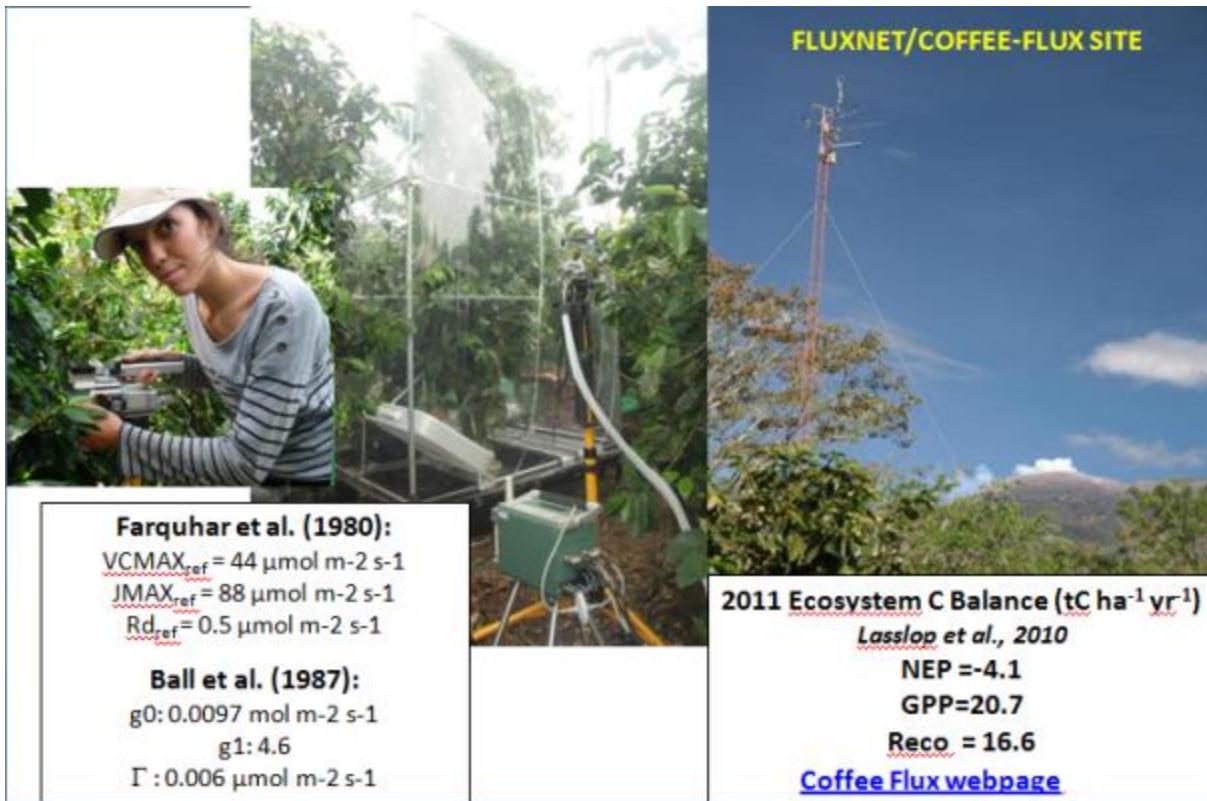
Fig. 11: Measuring photosynthesis at three scales: leaf, whole coffee-plant and ecosystem. Charbonnier et al, 2012.
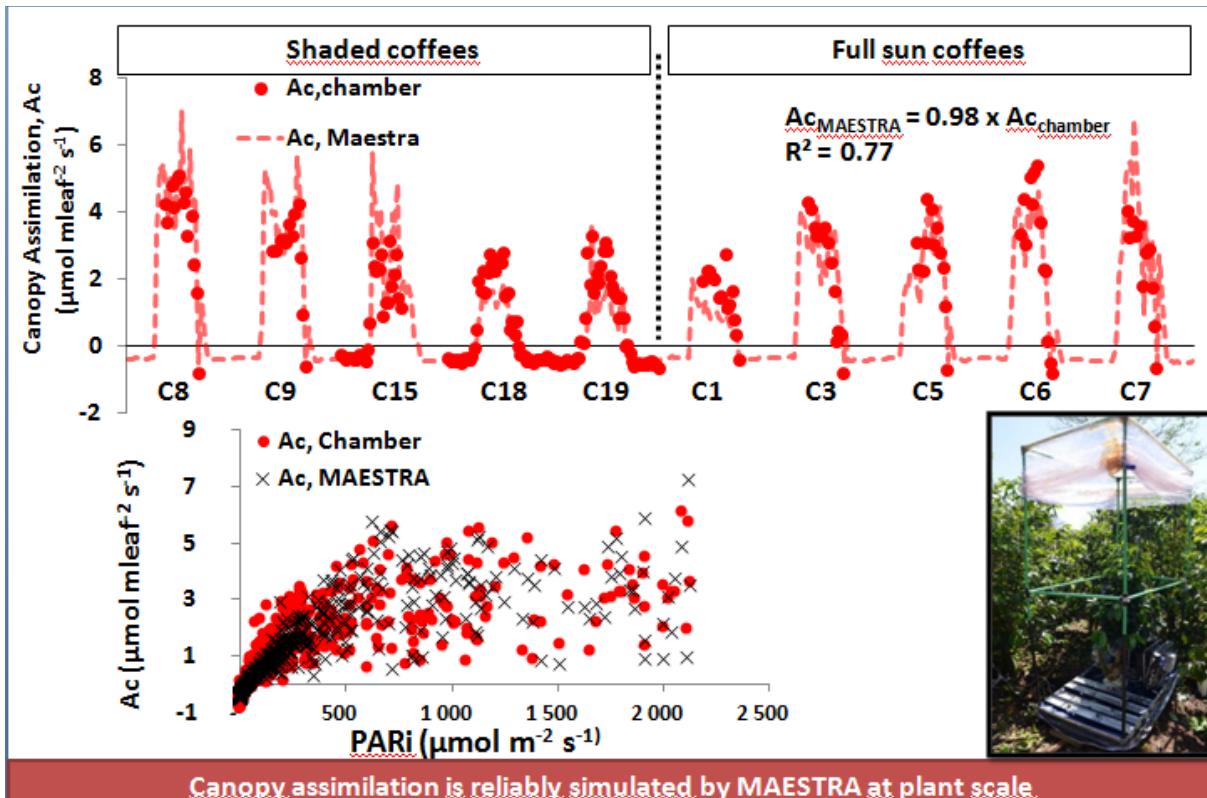
Fig. 12: Verifying photosynthesis simulated by the MAESTRA model at the whole plant –scale. Charbonnier et al, 2012.

a) 14 Farm transects

b) High Resolution Worldview2 NDVI_HR

c) Farm LAI map (2m resolution)

d) MODIS pixel NDVI-LAI calibration

e) Pixel and farm LAI_MOD

f) Pixel and farm LAI_MOD,coffee

Retrieving pixel and farm LAI_proxy,tree
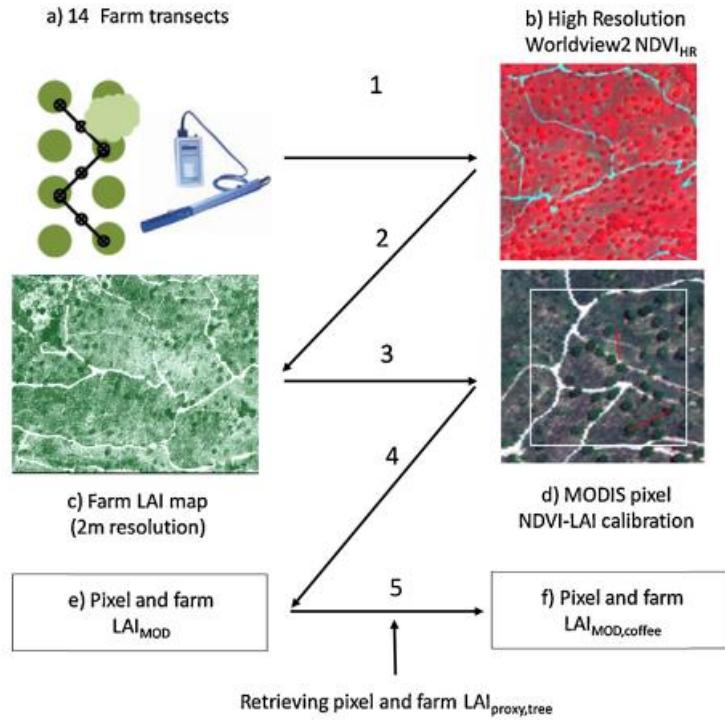
Fig. 3. Scheme for the methods used when upscaling LAI from transects to MODIS pixels and to farm: (a) 14 farm transects (see Fig. 2); (b) High resolution Worldview2 NDVI_HR image, calibrated using the 14 transects (step 1); (c) Farm LAI map at 2 m resolution computed from step 2; (d)MODIS pixel position (white frame) used to compute the LAIHR average and to calibrate the MODIS LAI–NDVI relationship at 250 m resolution from step 3; (e) computing pixel and farm LAI_MOD from step 4; (f) computing pixel and farm LAI_MOD,coffee after retrieving pixel and farm LAI_proxy,tree, from step 5.

Fig. 13: Methods used in Leaf Area Index asssessment from plant to plot to farm. Taugourdeau et al., 2014.

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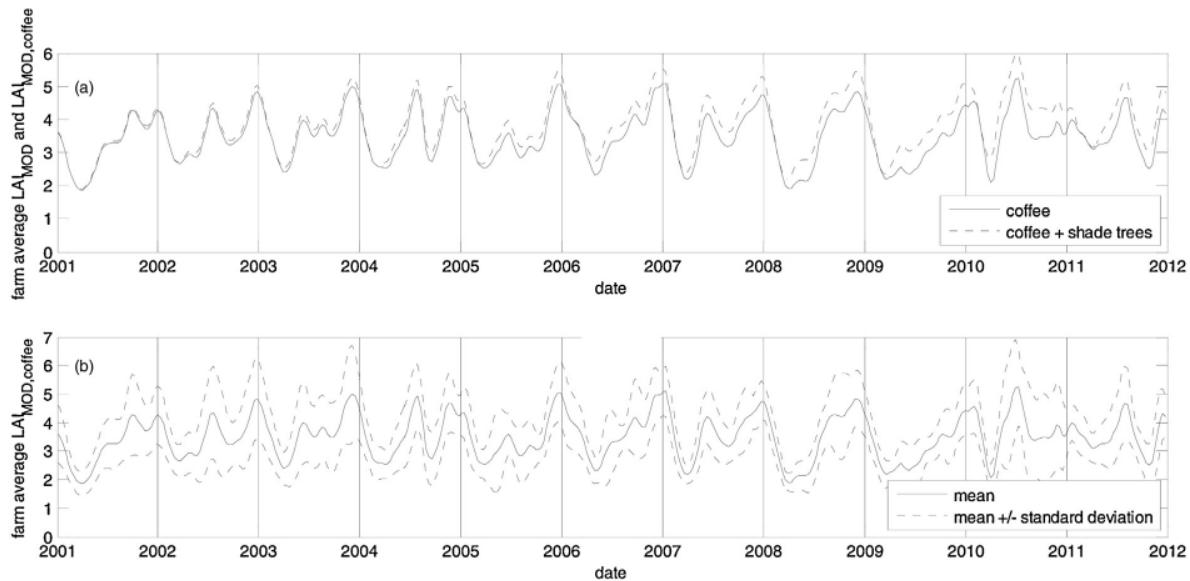
Fig. 14: Monitoring Leaf Area Index at farm scale using MODIS 2001-2012. Taugourdeau et al.AGEE, 2014.

Fig. 15: Estimating the GHG balance of the Aquiares Farm, application to C-Neutral certification. O. Roupsard dec 2014, presentation to Junta Nacional del Carbono/Costa Rica.
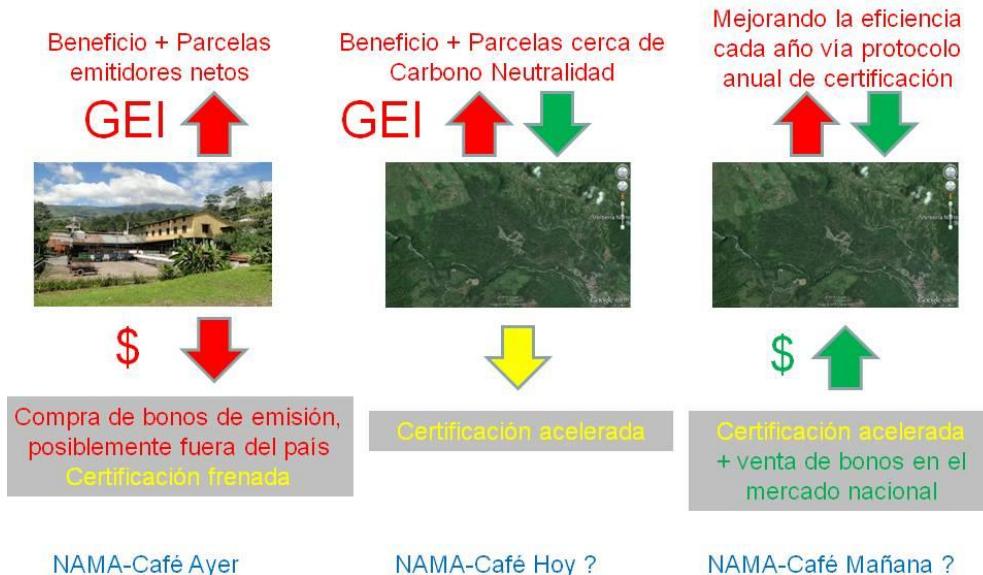
Fig. 16: A proposed strategy to enhance C-Neutral certification in the coffee sector. O. Roupsard dec 2014, presentation to Junta Nacional del Carbono/Costa Rica.
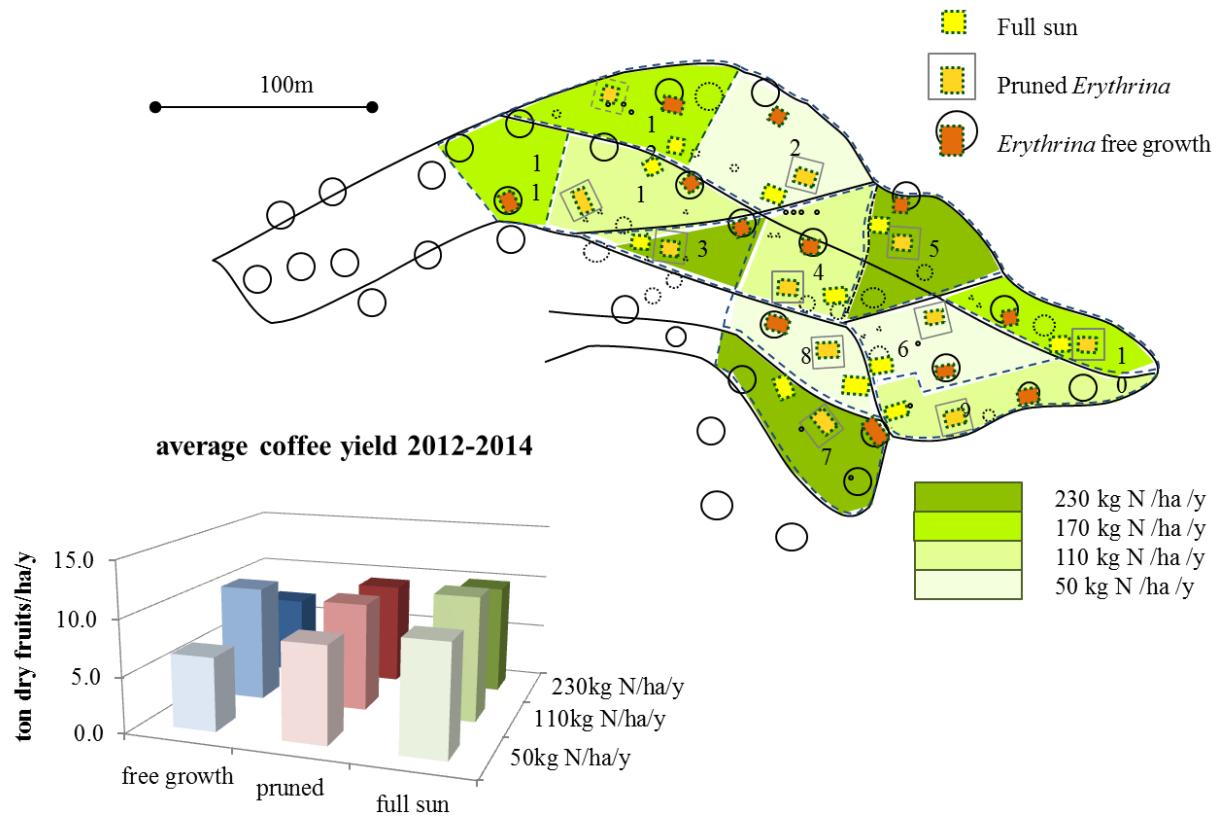
Fig. 17: Schematics and averaged yields in the fertilization/shade experiment (K. Van den Meersche et al.).
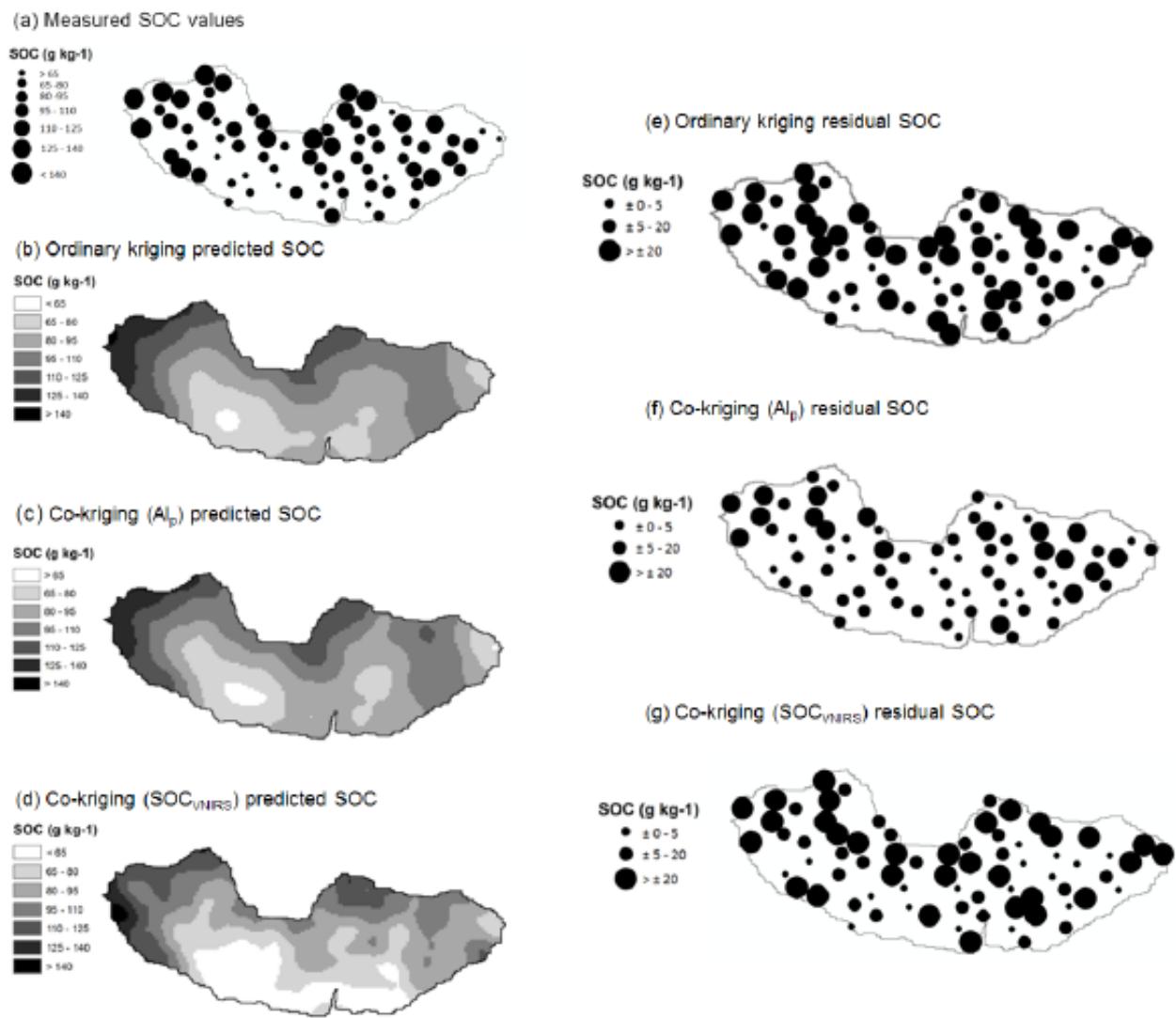
Fig. 18: Maps of a) measured soil organic carbon (SOC) by dry combustion; b) c) and d) predicted soil organic carbon; and e), f) and g) prediction residuals. Figures b) and e) are associated with the ordinary kriging method, c) and f) with co-kriging with aluminum extracted by sodium pyrophosphate (Alp), and d) and g) with co-kriging with visible-near-infrared reflectance spectroscopy (VNIRS) predicted SOC (SOCVNIRS). Kinoshita et al., Geoderma, 2015
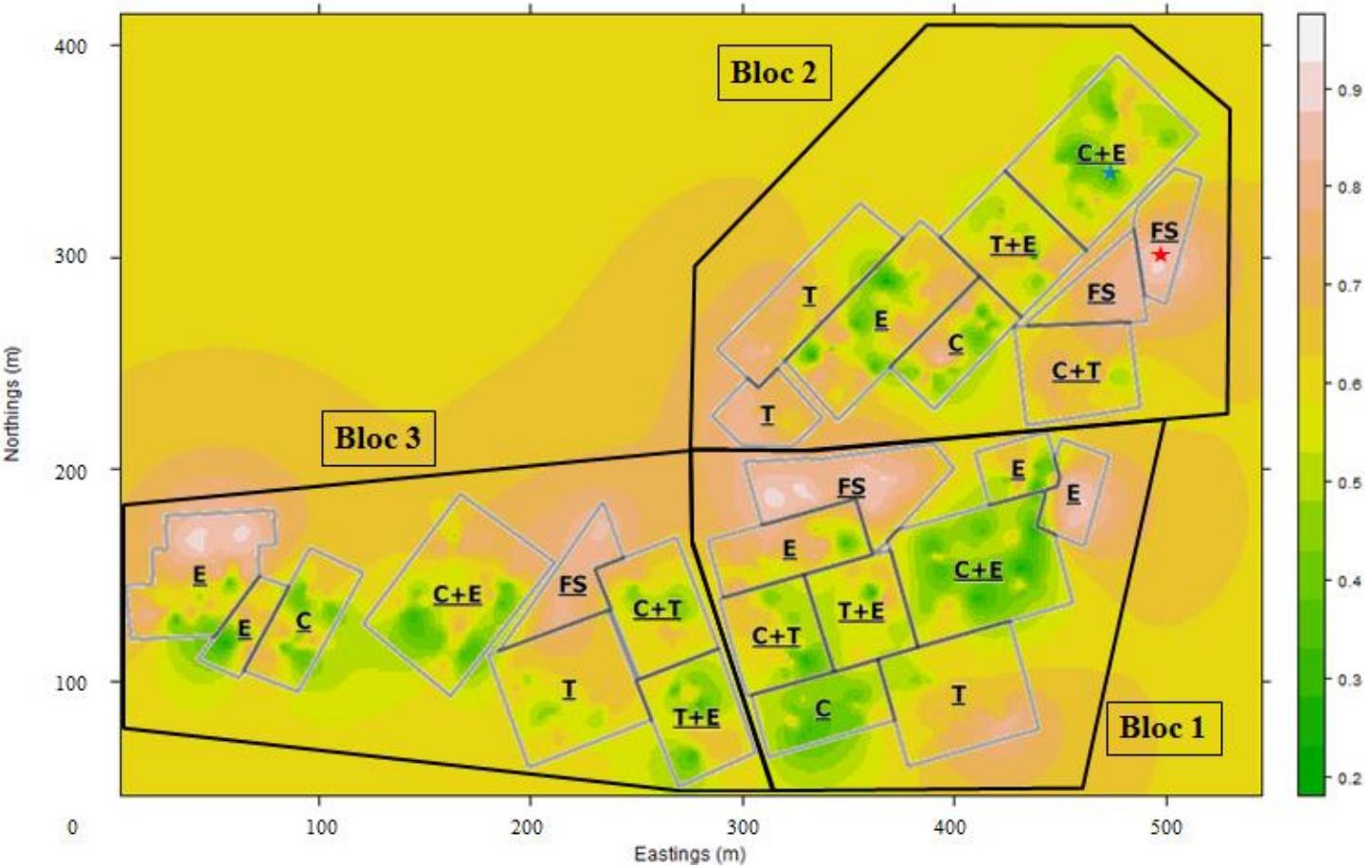
Figure 19 : Kriged map of shade tree canopy openness in the CATIE agroforestry trial. Grey lines represent the edges of the whole-plot treatment (Shade type) and black lines are for the 3 Blocs. *C = Chloroleucon; T = Terminalia; E = Erythrina; ★ = Reference weather stations (blue: shaded in C+E, red: in Full-Sun, FS). N = 570 canopy openness measurements used for kriging.* Source: MSc of Maxime Soma.
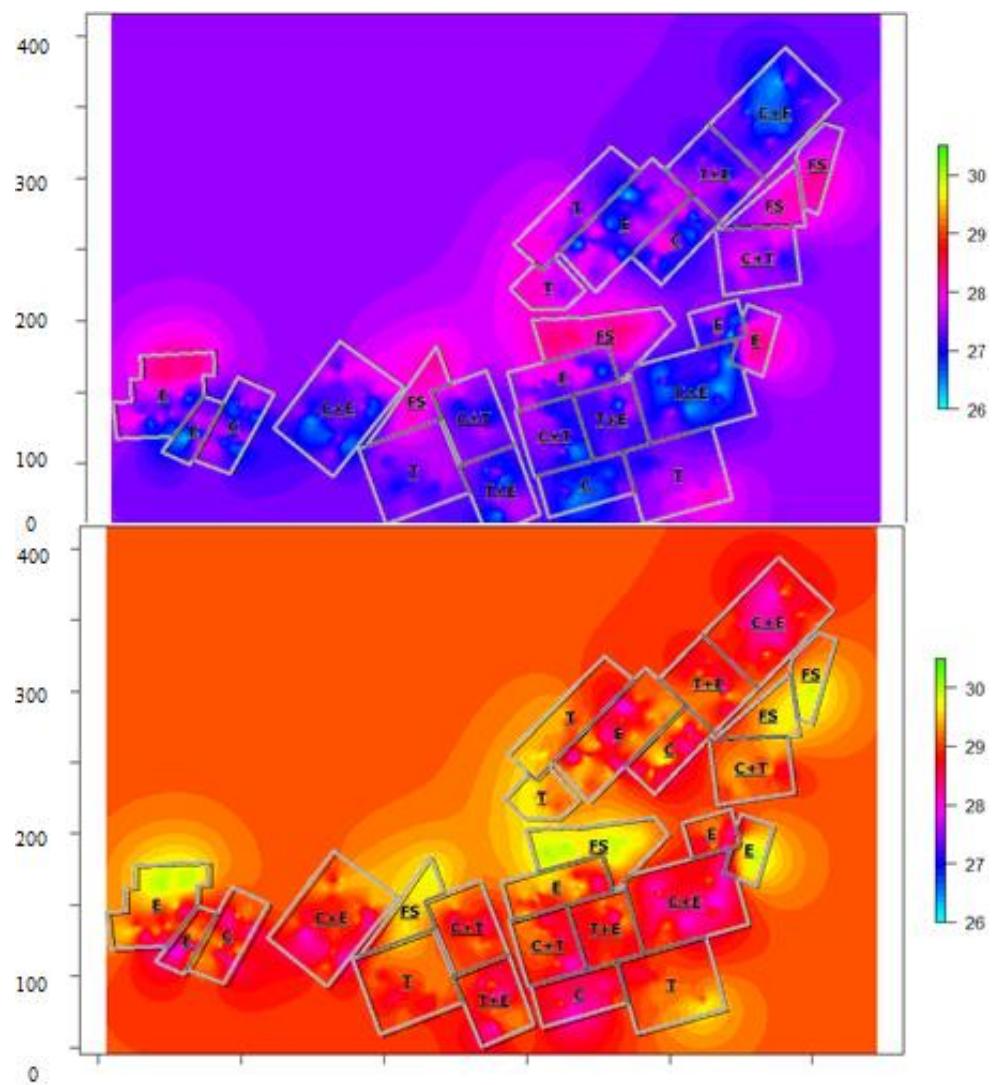
Figure 20 : Kriged map of predicted coffee canopy temperature (Tc) for typical days (top: 08/05/2015 at 02:08 PM; bottom: 01/06/2015 at 12:17 AM), exhibiting contrasted climatic conditions. Top map is typical of cloudy conditions and bottom map is typical of sunny days. Temperatures in °C. N=570 kriged values. Vertical axis in meters. Colour scale in degree Celsius. Source: MSc of Maxime Soma.
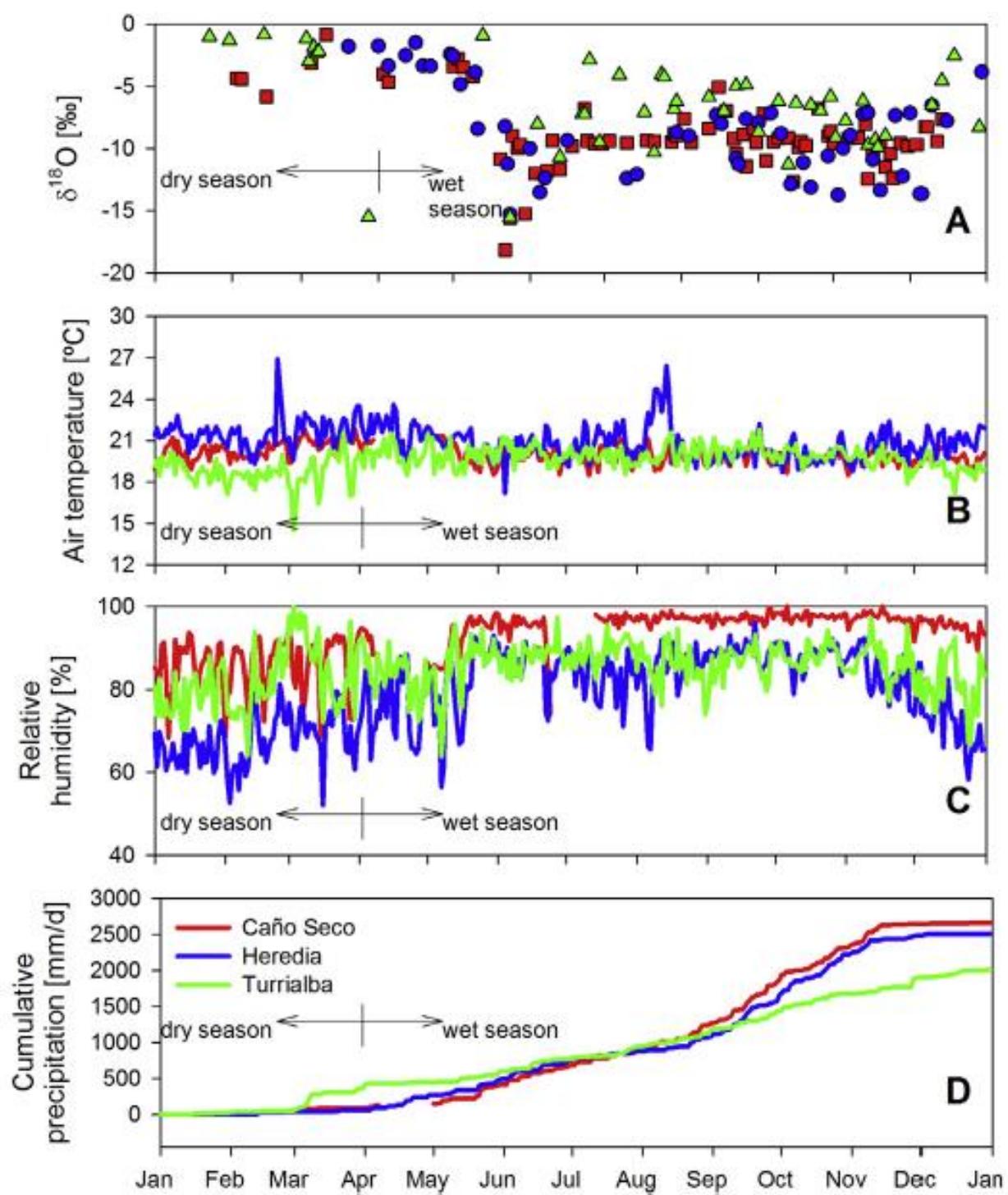
Figure 21 : Time series of (A) precipitation d[18]O and observed surface meteorological variables, (B) air temperature, (C) relative humidity and (D) cumulative precipitation during 2013 at the three study sites Heredia (blue), Turrialba (green) and Cano Seco (red). Black arrows denote the transition from the dry season (Dec-April) to the wet season (May-Nov). Source: Sanchez-Murillo et al.,Quaternary Science Reviews, 2015
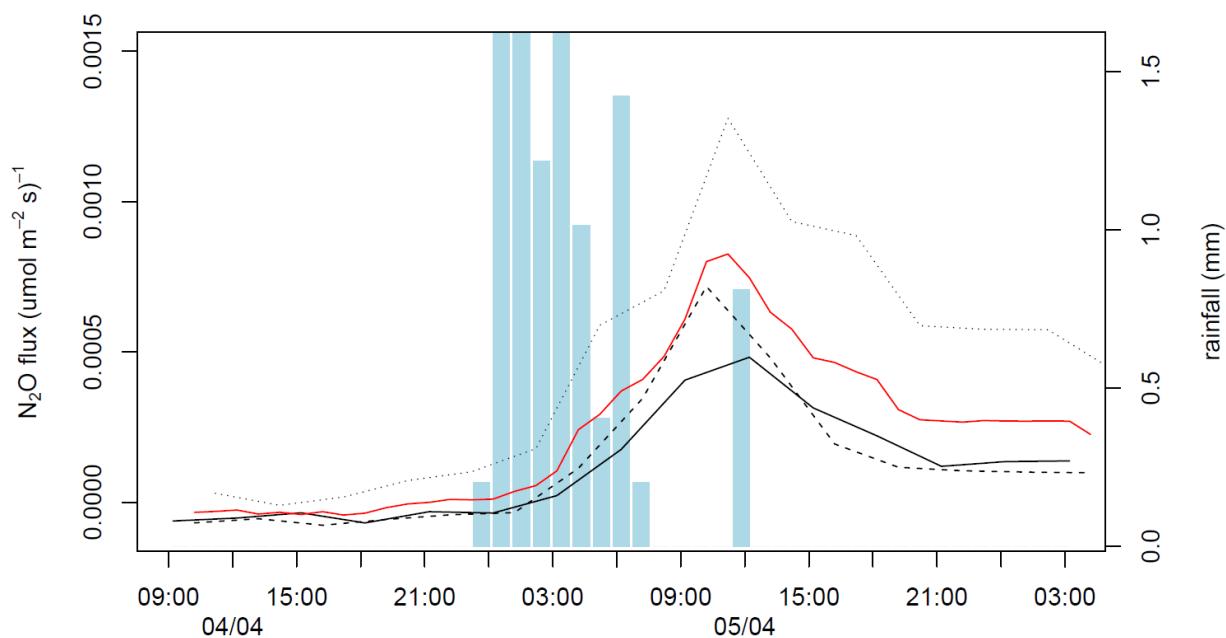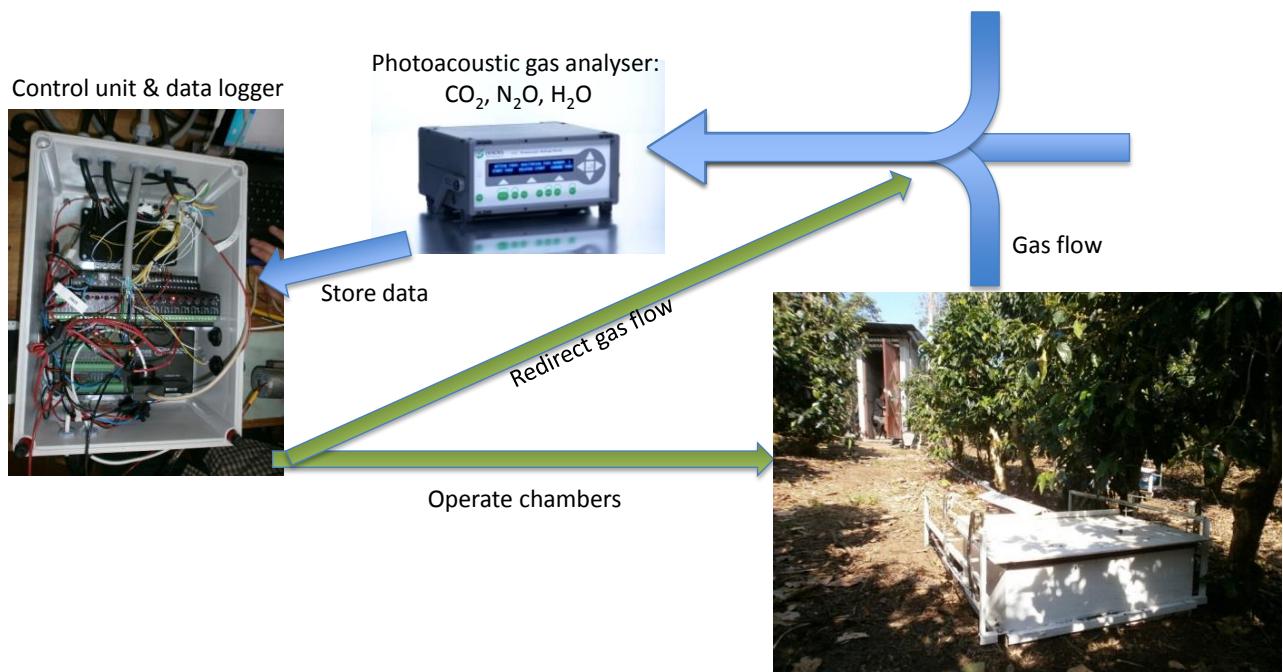
Figure 22 : N2O and CO2 automatic chambers in a fertilization experimental display. N2O soil efflux after a rain event, as measured in 3 chambers (and average in red)

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- A. Perez (CATIE, Technician)
- A. Barquero and family (Aquiares farm, Technicians)

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. University of Oslo: Prof. Lars Gottschalk; Dr. Irina Krasovskaia; Prof. Nils Roar
. University of Viçosa, Brazil: Prof. Fabio Da Matta; PhD std. Junior Pastor Perez Molina
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.World Meteorological Organization (WMO, Costa-Rica): Dr. Federico Gómez-Delgado

Journal Articles (only papers using Coffee-Flux)

Benegas, L., Ilstedt, U., Roupsard, O., Jones, J.R., Malmer, A., 2014. Effects of trees on infiltrability and preferential flow in two contrasting agroecosystems in Central America. Agric. Ecos. Envir. , 185-196. http://dx.doi.org/10.1016/j.agee.2013.10.027

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Visitors

Coffee-Flux is also place for organizing visits, training and for demonstrating the PCP, CATIE, Aquiares and Cirad collaboration: we organize one or two visits per month for officials (e.g. coffee sector in Central America, MAG, Fundecooperacion, GIZ, NAMA-Café), politicals (MAE, French Embassy), journalists (Daily Newspaper-La Nación; Et si on changeait le monde-Television, Vigie de l'eau-Visio conference and Web site), University Professors (Norway, Sweden, Denmark, USA, England), groups of students (all levels, e.g. U. Costa Rica), and congress field trips (21st Century Watershed Technology Conference ASABE; ASIC 2012-Costa Rica)

Contacts and links

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