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.

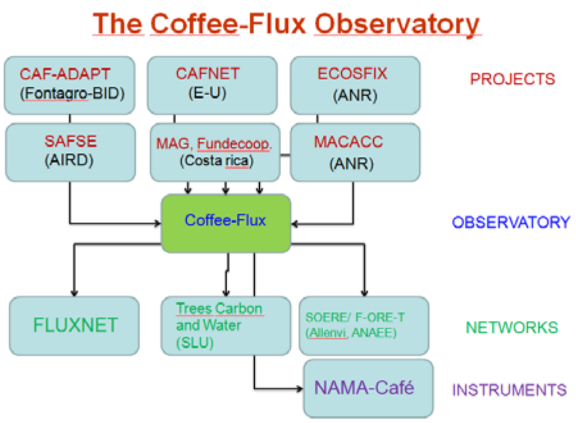
Aims and Philosophy of the CoffeeFlux[1] Collaborative Platform

The aim of Coffee-Flux is to assess carbon, nutrients, 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.



Site and infrastructure description

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 ™" 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

[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

watershed is instrumented with automatic flumes, pluviometers, soil moisture probes, piezometers, turbidimeters, sapflow and eddy-covariance tower (for H_2O and CO_2 gas fluxes).

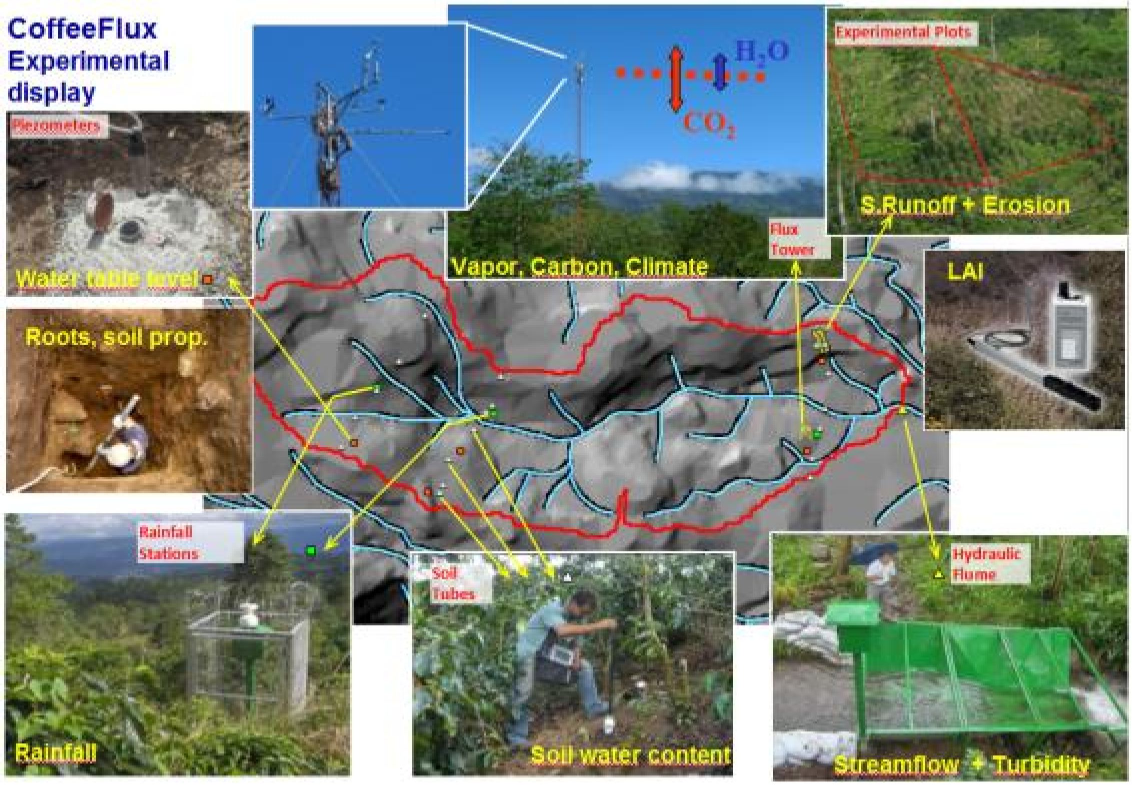


Photo. 2: The Coffee-Flux experimental display.

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 $\delta^{18}O/\delta D$ 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 2015)

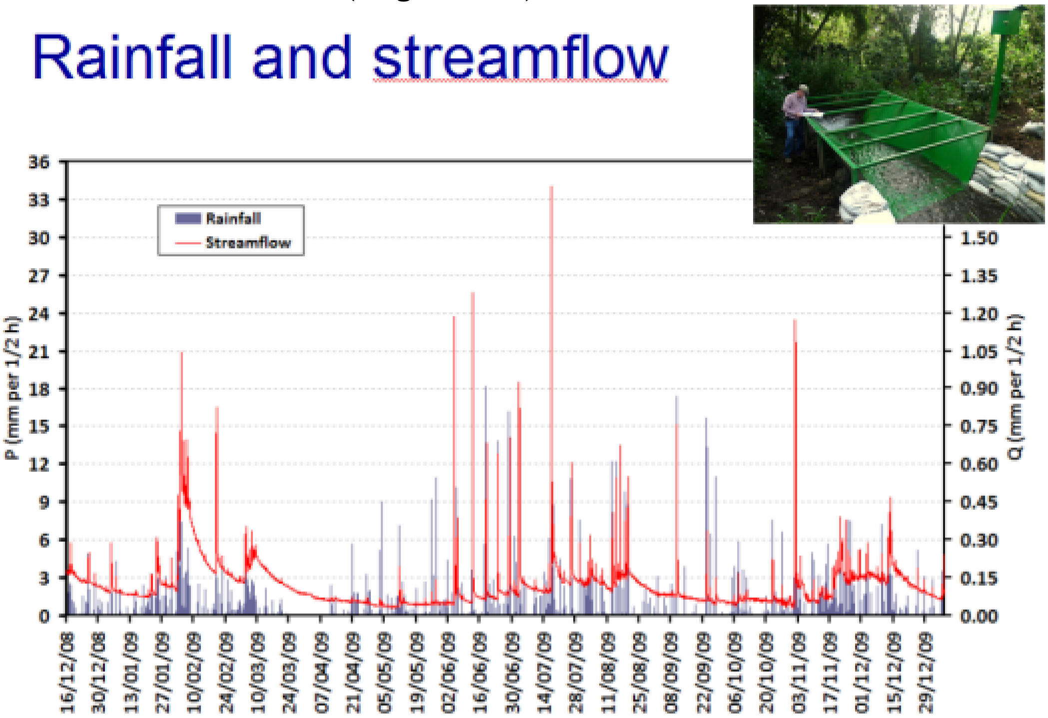


Fig. 1: The red line is the time-course of streamflow at the outlet of the Coffee-Flux watershed (automatic flume), showing a large contribution of the baseline (aquifer responding in terms of discharge and recharge) + episodic and rather low contribution of superficial runoff (peaks after rainfall events). This behaviour is typical of watersheds with large infiltration capacity, low superficial runoff and probably low laminar sediment transport.

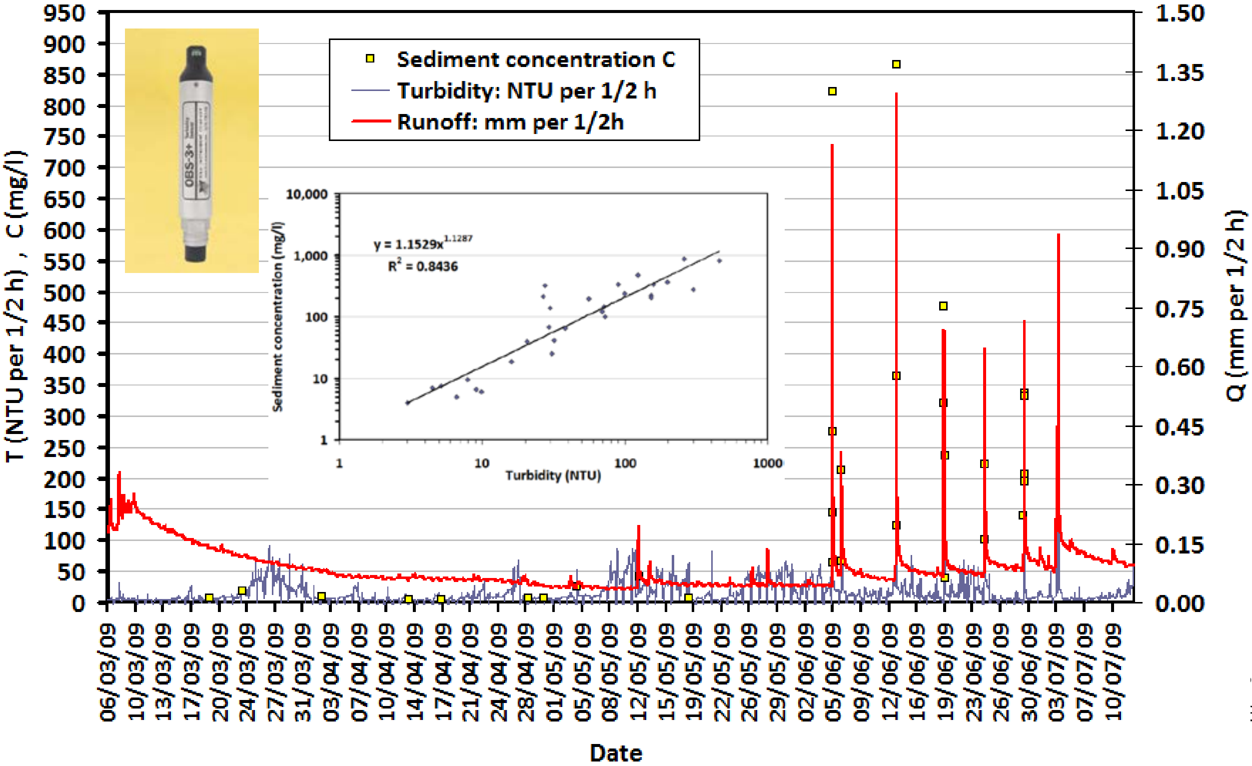


Fig. 2: Time-course of the sediment transport assessed by automatic turbidimeter (OBS-3, see photo) and bottle collection at the outlet of the Coffee-Flux watershed. The rating curve of turbidity in terms of sediment load is also given.

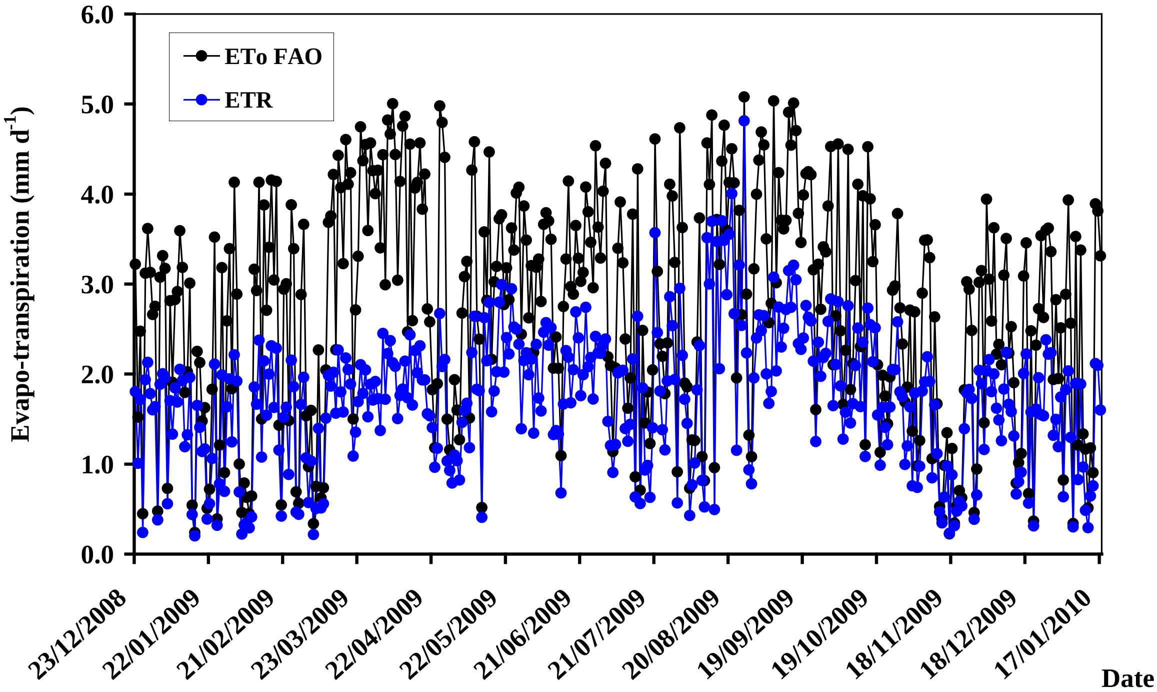


Fig. 3: Time-course of daily potential (ET_0-Penman Monteith, FAO) and real evapo-transpiration (ETR, by eddy covariance) in the Coffee-Flux Watershed. ETR/ET_0 varies from 0.4 to 0.7, according to LAI fluctuations mainly.

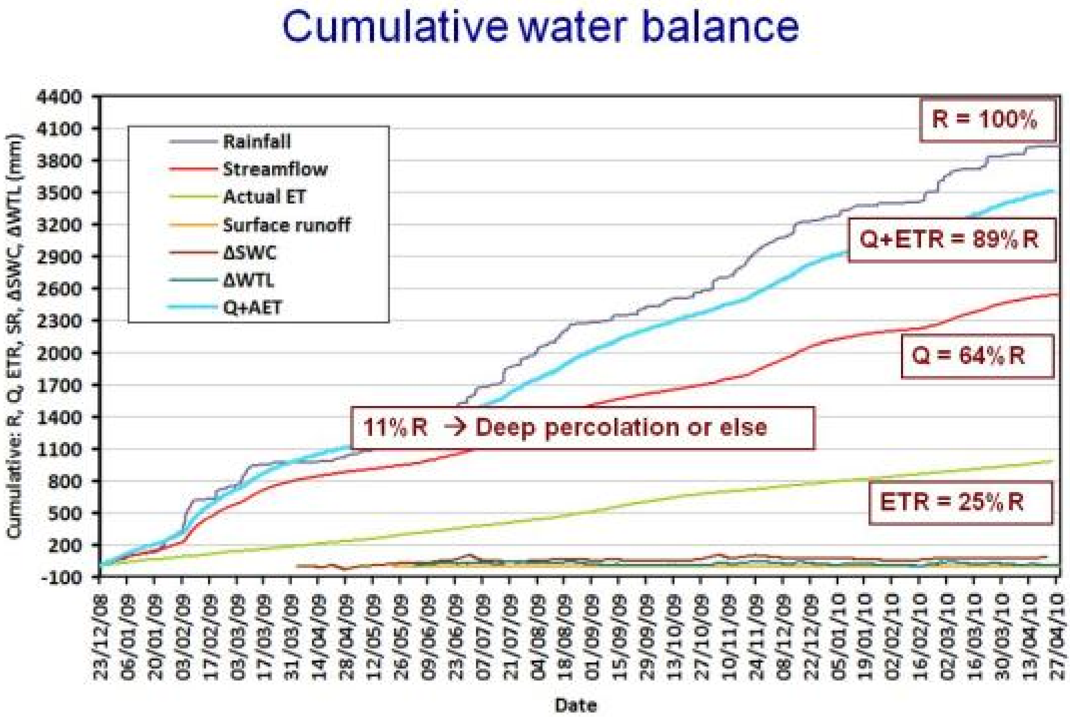


Fig. 4: Cumulative water balance of the CoffeeFlux watershed, as measured by independent methods (ETR by eddy covariance ; Q by flume).

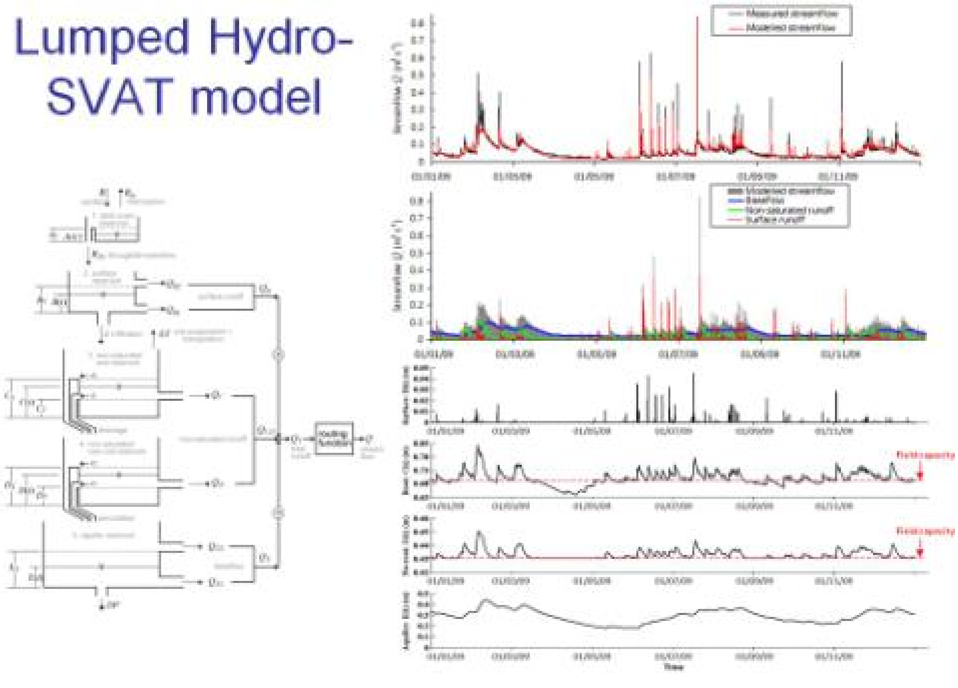


Fig. 6: Structure and simulations of the lumped Hydro-SVAT model for the water-balance partitioning of the Coffee-Flux watershed (Gómez-Delgado et al, HESS, 2011)

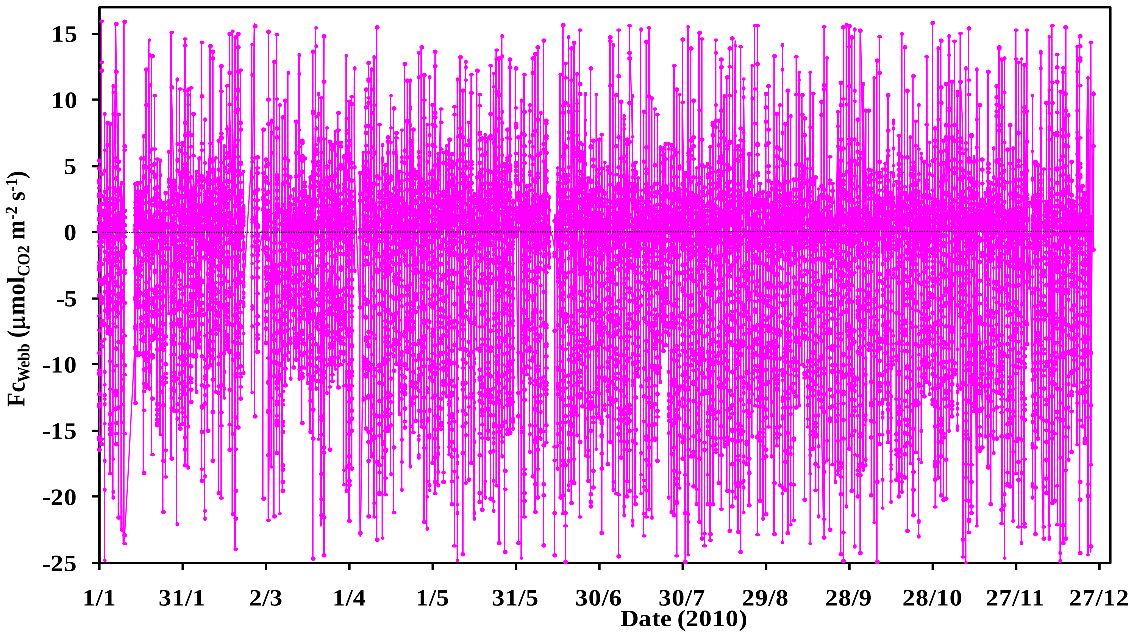


Fig. 7: Time-course of carbon net ecosystem exchange (F_c), and its partitioning into ecosystem respiration (positive values, mainly at night) and C uptake (photosynthesis + respiration, negative values). One cycle is one day, data from year 2010

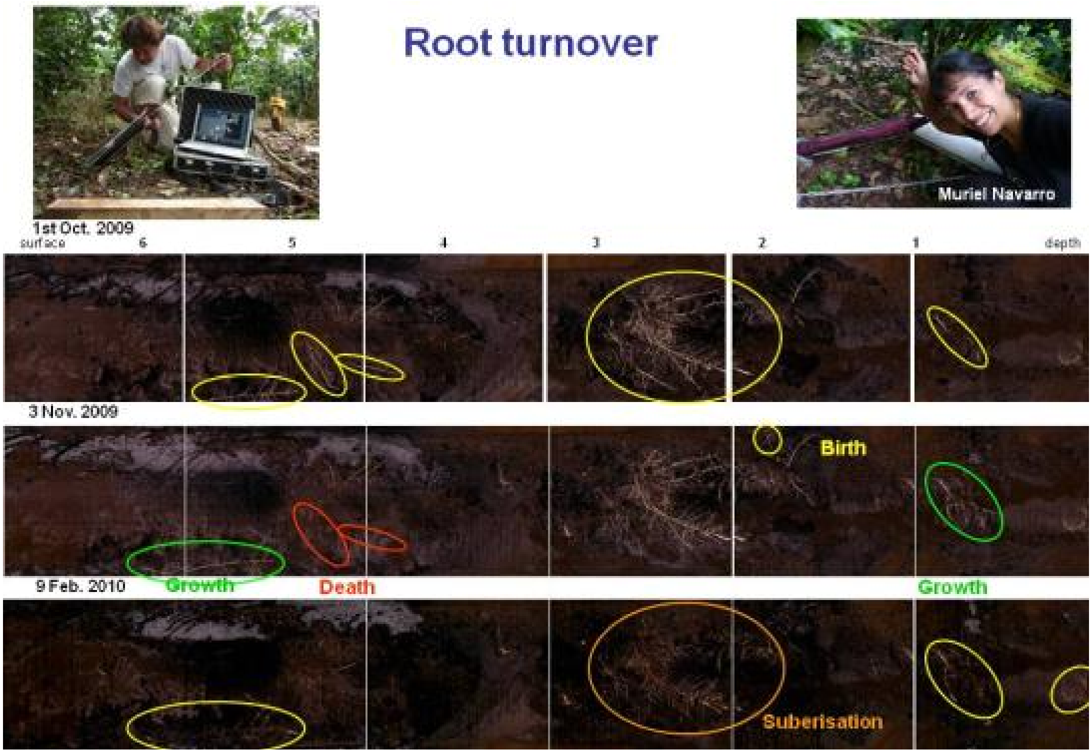


Fig. 8: Root turnover (birth, growth, mortality) assessed by minirhizotrons

Simulating intra-plot light absorption with MAESTRA

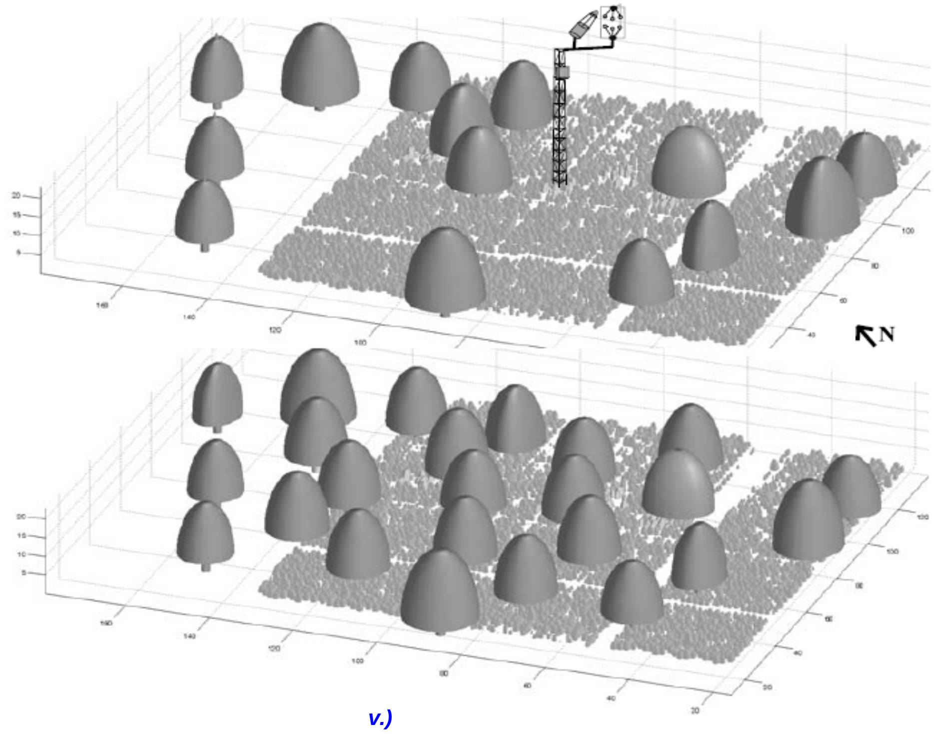


Fig. 9: Scenes for the simulation of light absorbtion, water and CO_2 exchanges by every plant of the plot under actual or double shade-tree density. Charbonnier et al., AFM, 2013

Simulating intra-plot light absorption with MAESTRA

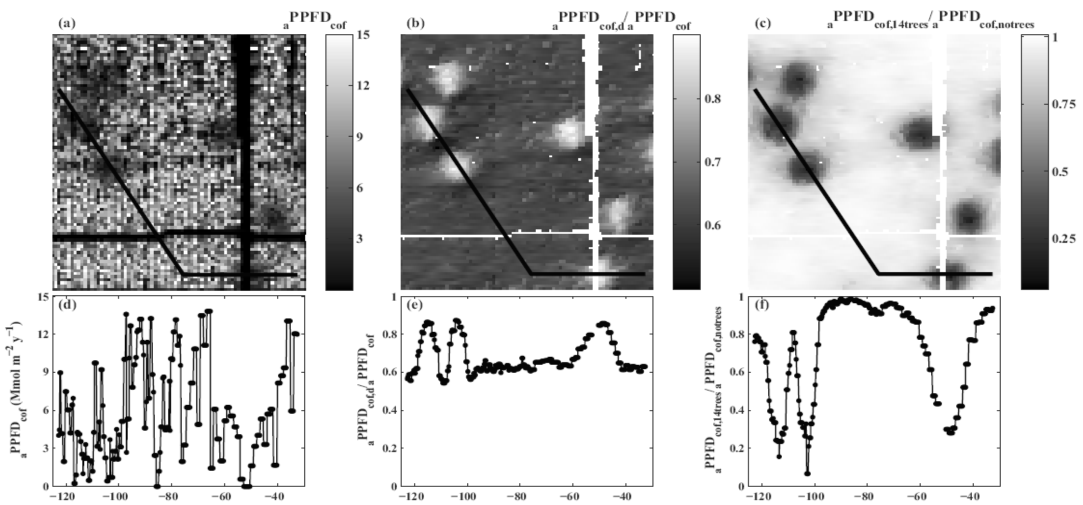


Fig. 10: Intra-plot variability for light absorbtion. Top views and transects for yearly absorbed PPFD by the coffee layer, relative absorbed diffuse PPFD by the coffee layer, relative absorbed by the coffee layer when shade trees are present or not. Charbonnier et al., AFM, 2013.

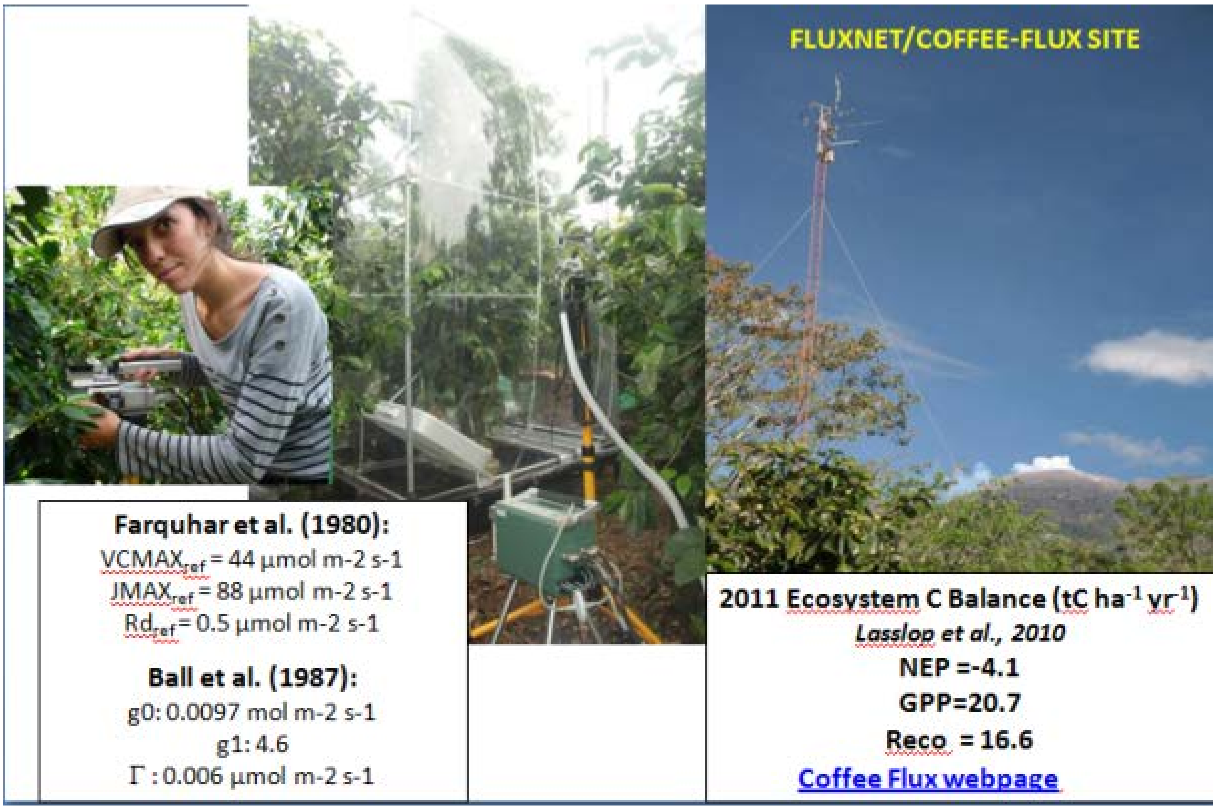


Fig. 11: Measuring photosynthesis at three scales: leaf, whole coffee-plant and ecosystem. Charbonnier et al, 2012.

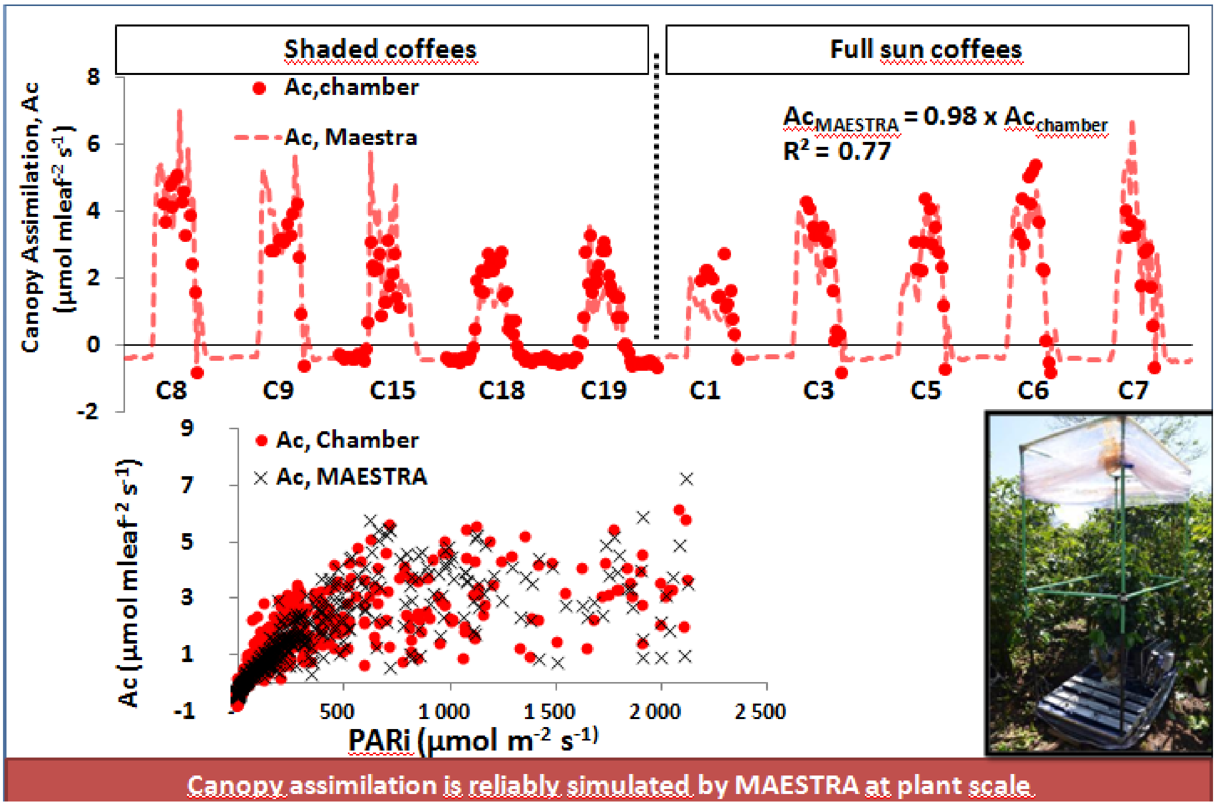


Fig. 12: Verifying photosynthesis simulated by the MAESTRA model at the whole plant –scale. Charbonnier et al, 2012.

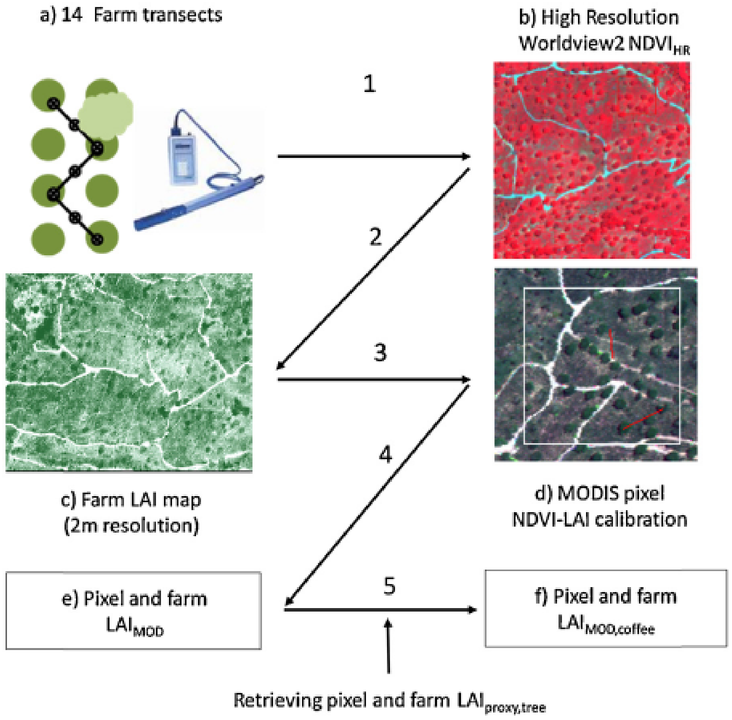


Fig. 3. Scheme for the methods used when upscaling LAI from transects to MODIS pixels and to farm: (a) 14 farm transects (see Fig. 2); (b) High resolution Worldview2 NDVI$_{HR}$ image, calibrated using the 14 transects (step 1); (c) Farm LAI map at 2 m resolution computed from step 2; (d)MODIS pixel 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.

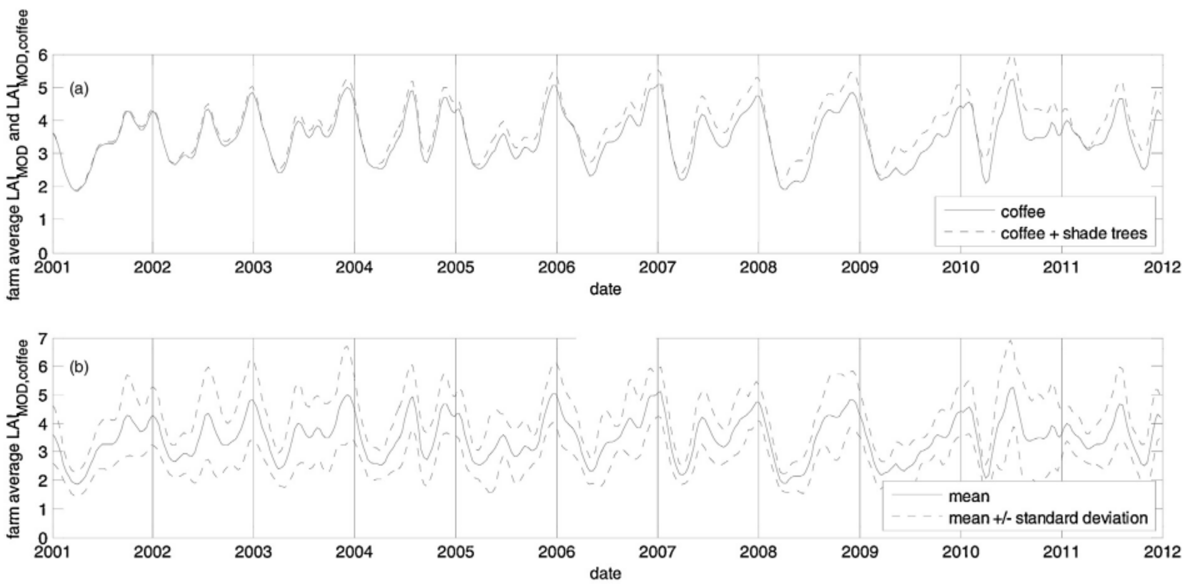


Fig. 14: Monitoring Leaf Area Index at farm scale using MODIS 2001-2012. Taugourdeau et al.AGEE, 2014.

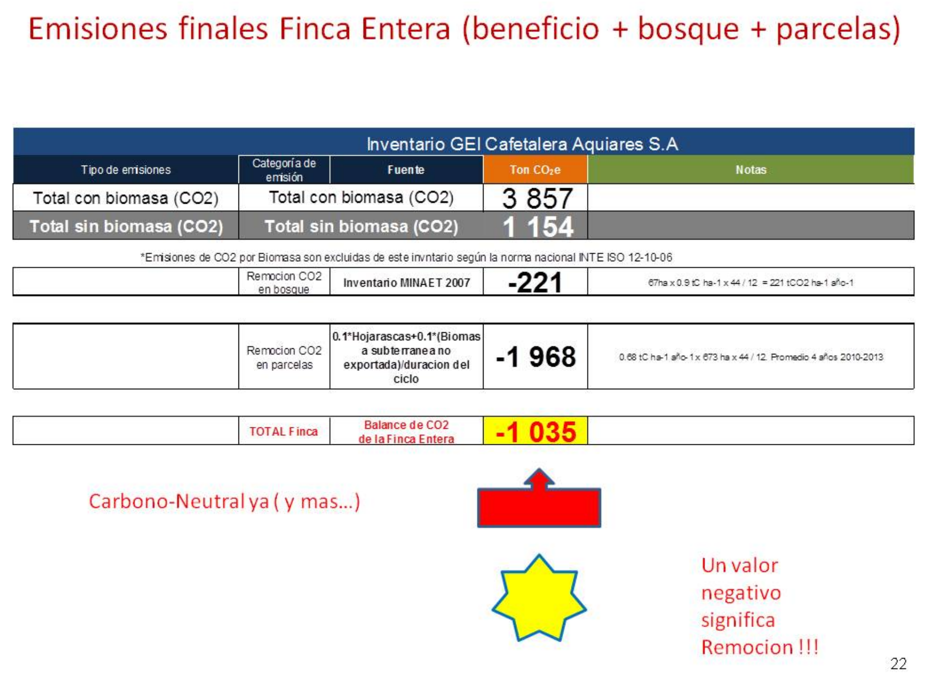


Fig. 15: Estimating the GHG balance of the Aquiares Farm, application to C-Neutral certification. O. Roupsard dec 2014, presentation to Junta Nacional del Carbono/Costa Rica.

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.

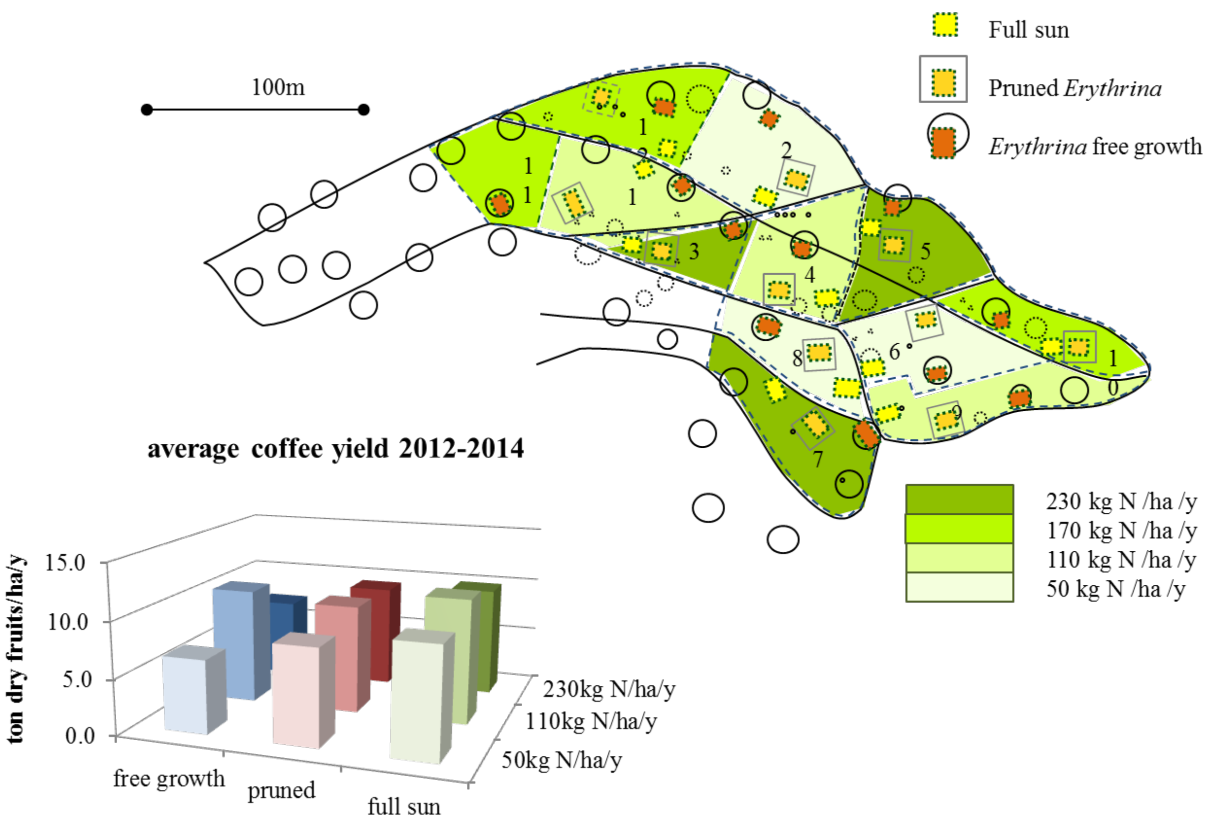


Fig. 17: Schematics and averaged yields in the fertilization/shade experiment (K. Van den Meersche et al.).

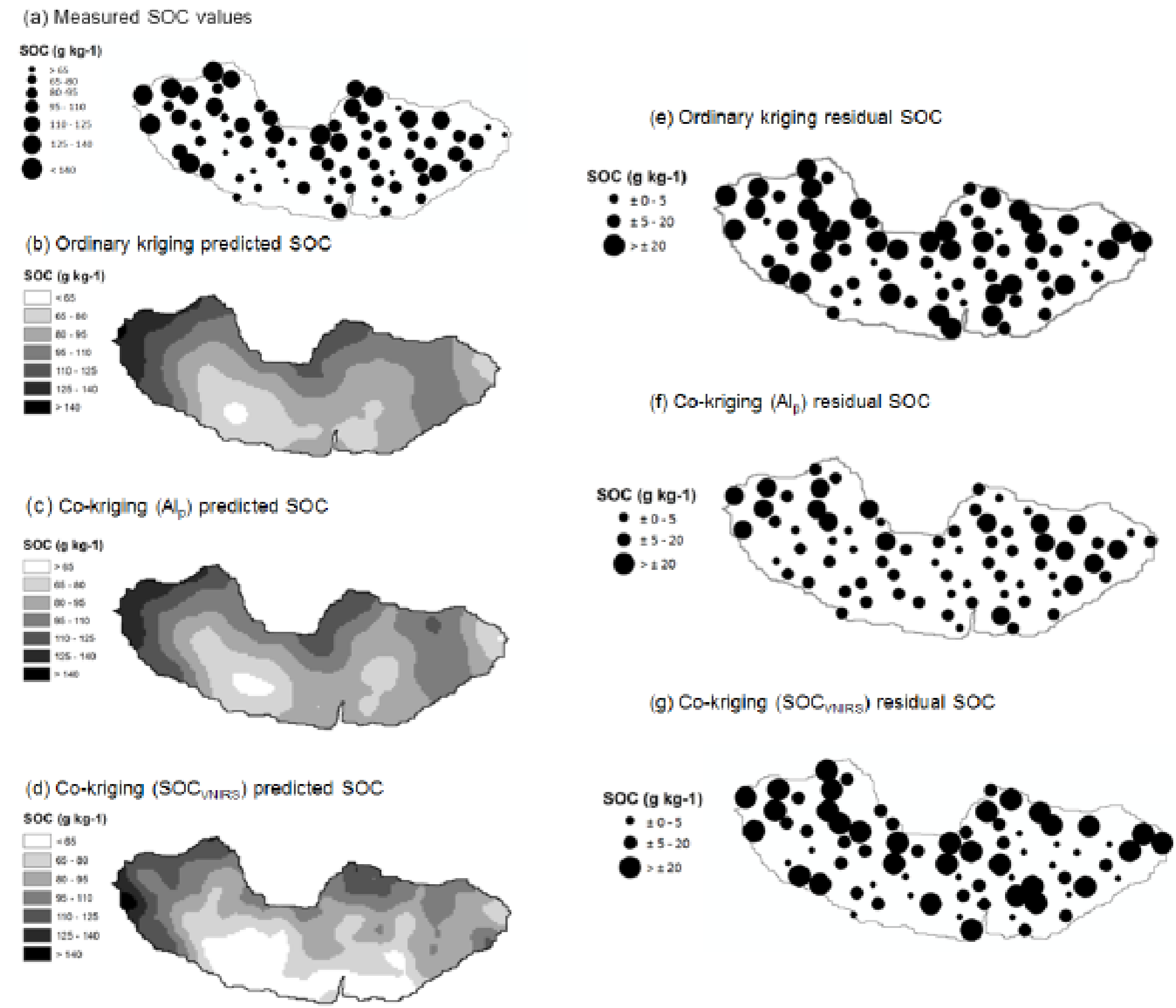


Fig. 18: Maps of a) measured soil organic carbon (SOC) by dry combustion; b) c) and d) predicted soil organic carbon; and e), f) and g) prediction residuals. Figures b) and e) are associated with the ordinary kriging method, c) and f) with co-kriging with aluminum extracted by sodium pyrophosphate (Alp), and d) and g) with co-kriging with visible-near-infrared reflectance spectroscopy (VNIRS) predicted SOC (SOCVNIRS). Kinoshita et al., Geoderma, 2015

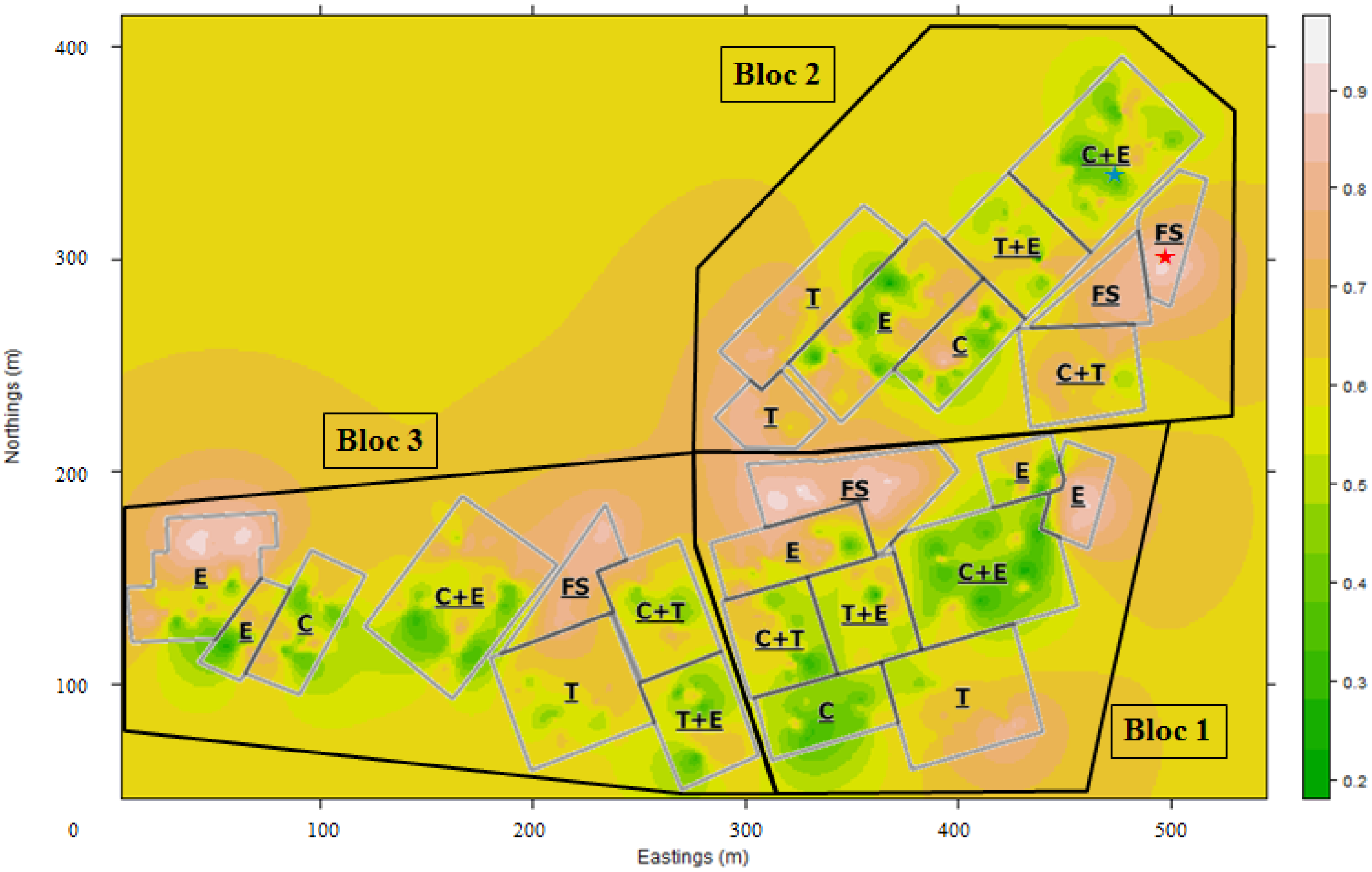


Figure 19 : Kriged map of shade tree canopy openness in the CATIE agroforestry trial. Grey lines represent the edges of the whole-plot treatment (Shade type) and black lines are for the 3 Blocs. *C = Chloroleucon; T = Terminalia; E = Erythrina; ★ = Reference weather stations (blue: shaded in C+E, red: in Full-Sun, FS). N = 570 canopy openness measurements used for kriging.* Source: MSc of Maxime Soma.

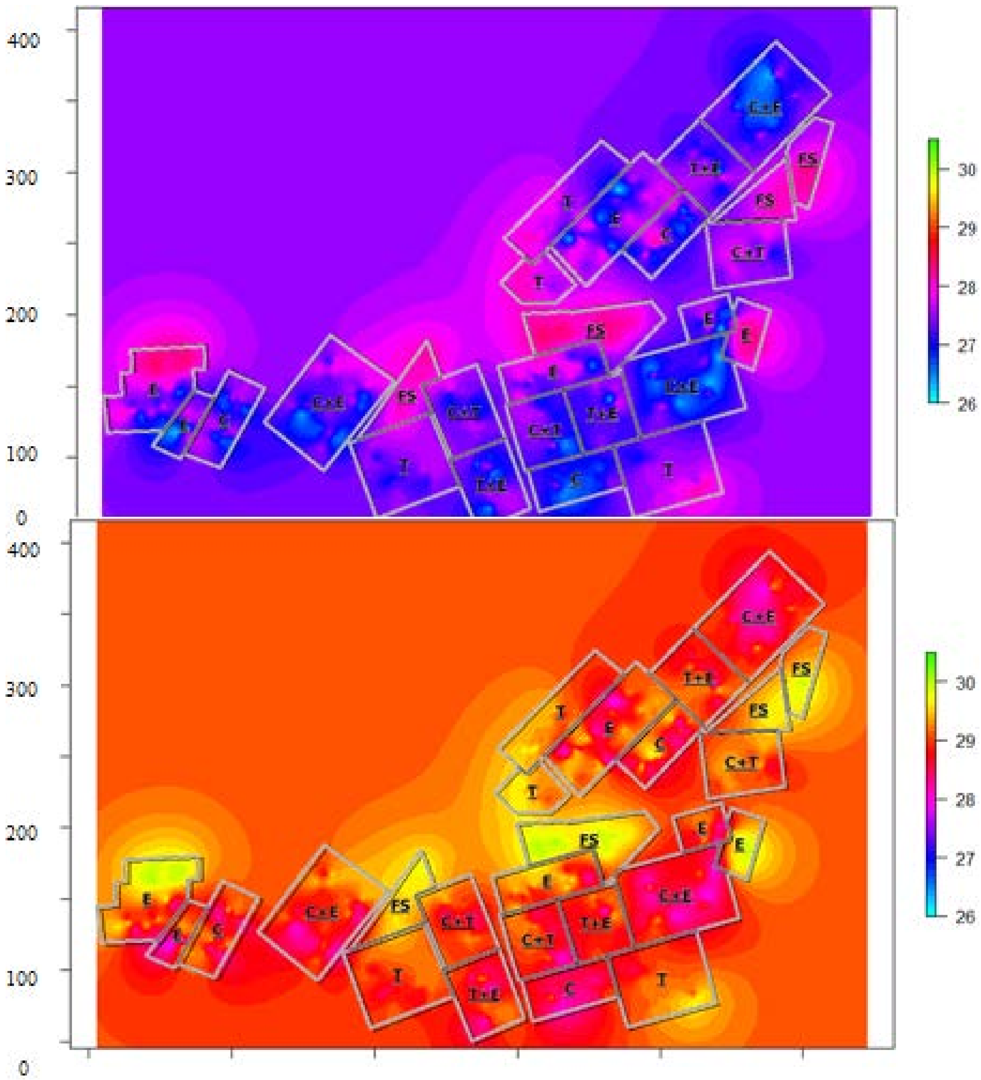


Figure 20 : Kriged map of predicted coffee canopy temperature (Tc) for typical days (top: 08/05/2015 at 02:08 PM; bottom: 01/06/2015 at 12:17 AM), exhibiting contrasted climatic conditions. Top map is typical of cloudy conditions and bottom map is typical of sunny days. Temperatures in °C. N=570 kriged values. Vertical axis in meters. Colour scale in degree Celsius. Source: MSc of Maxime Soma.

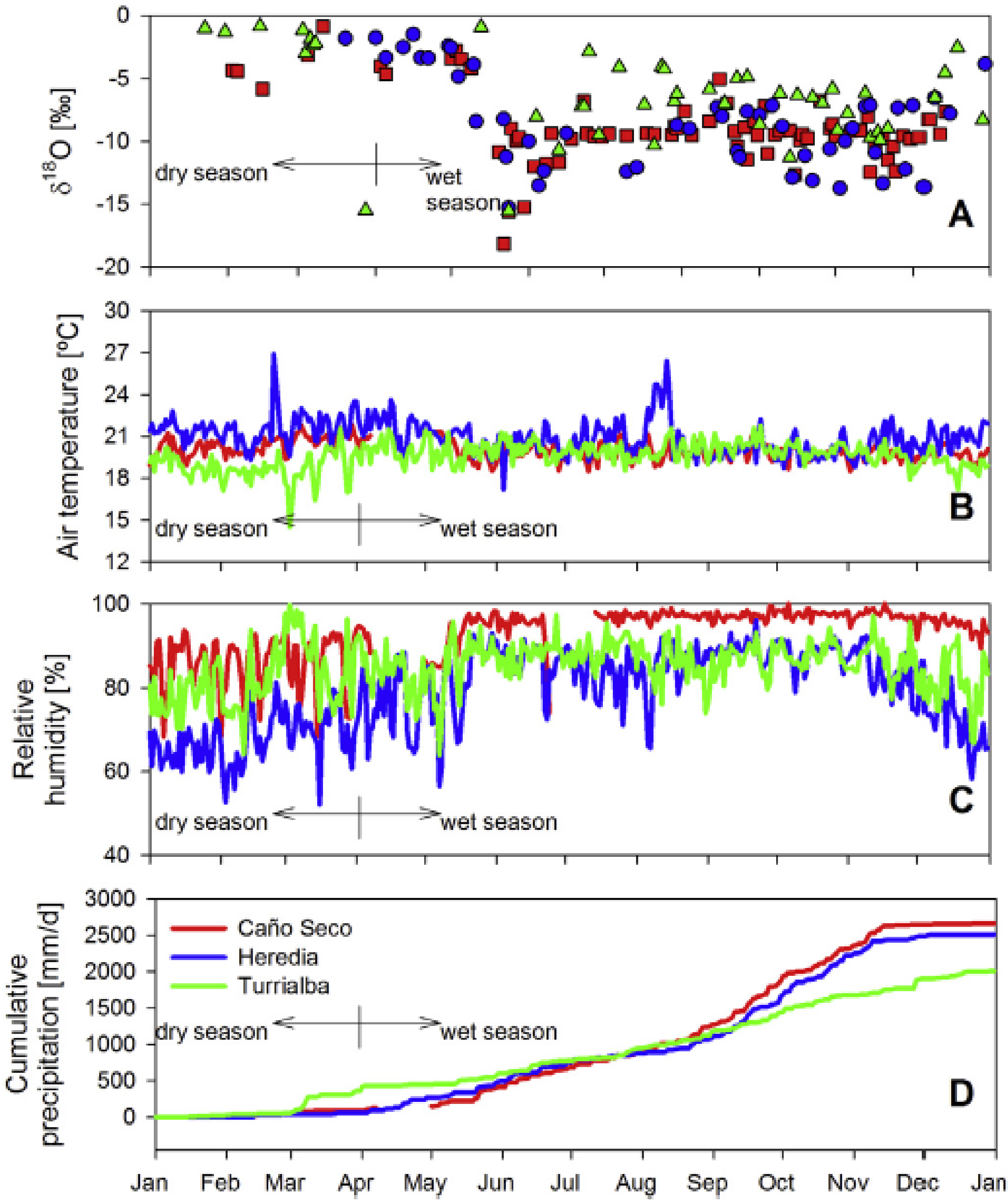


Figure 21 : Time series of (A) precipitation d^{18}O and observed surface meteorological variables, (B) air temperature, (C) relative humidity and (D) cumulative precipitation during 2013 at the three study sites Heredia (blue), Turrialba (green) and Cano Seco (red). Black arrows denote the transition from the dry season (Dec-April) to the wet season (May-Nov). Source: Sanchez-Murillo et al.,Quaternary Science Reviews, 2015

Local team and students

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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
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Journal Articles (published)

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

Charbonnier, F., le Maire, G., Dreyer, E., Casanoves, F., Christina, M., Dauzat, J., Eitel, J.U.H., Vaast, P., Vierling, L.A., Roupsard, O., 2013. Competition for light in heterogeneous canopies: Application of MAESTRA to a coffee (Coffea arabica L.) agroforestry system. Agricultural and Forest Meteorology 181, 152-169. http://dx.doi.org/10.1016/j.agrformet.2013.07.010

Gómez-Delgado, F., Roupsard, O., le Maire, G., Taugourdeau, S., Perez, A., van Oijen, M., Vaast, P., Rapidel, B., Harmand, J.M., Voltz, M., Bonnefond, J.M., Imbach, P., Moussa, R., 2010. Modelling the hydrological behaviour of a coffee agroforestry basin in Costa Rica. Hydrol. Earth Syst. Sci. 15, 369-392. www.hydrol-earth-syst-sci.net/15/369/2011/doi:10.5194/hess-15-369-2011

Kinoshita R, Roupsard O, Chevallier T, Albrecht A, Taugourdeau S, Ahmed Z, van Es HM. 2016. Large topsoil organic carbon variability is controlled by Andisol properties and effectively assessed by VNIR spectroscopy in a coffee agroforestry system of Costa Rica. Geoderma, 262: 254-265. http://dx.doi.org/10.1016/j.geoderma.2015.08.026

Prieto I, Roumet C, Cardinael R, Dupraz C, Jourdan C, Kim JH, Maeght JL, Mao Z, Pierret A, Portillo N, Roupsard O, Thammahacksa C, Stokes A. 2015. Root functional parameters along a land-use gradient: evidence of a community-level economics spectrum. Journal of Ecology, 103: 361-373. DOI : 10.1111/1365-2745.12351

Sánchez-Murillo R, Birkel C, Welsh K, Esquivel-Hernández G, Corrales-Salazar J, Boll J, Brooks E, Roupsard O, Sáenz-Rosales O, Katchan I, Arce-Mesén R, Soulsby C, Araguás-Araguás LJ. 2016. Key drivers controlling stable isotope variations in daily precipitation of Costa Rica: Caribbean Sea versus Eastern Pacific Ocean moisture sources. Quaternary Science Reviews, 131, Part B: 250-261. http://dx.doi.org/10.1016/j.quascirev.2015.08.028

Taugourdeau, S., le Maire, G., Avelino, J., Jones, J.R., Ramirez, L.G., Jara Quesada, M., Charbonnier, F., Gómez-Delgado, F., Harmand, J.-M., Rapidel, B., Vaast, P., Roupsard, O., 2014. Leaf area index as an indicator of ecosystem services and management practices: An application for coffee agroforestry. Agriculture, Ecosystems & Environment 192, 19-37. http://dx.doi.org/10.1016/j.agee.2014.1003.1042.

Journal Articles (submitted)

Defrenet E, Roupsard O, Van den Meersche K, Charbonnier F, Perez Molina JP, Khac E, Prieto I, Stokes A, Roumet C, Rapidel B, De Melo Virginio Filho E, J. VV, Robelo D, Barquero Aguillar A, Jourdan C. 2015. Deep root biomass and net primary productivity in a coffee agroforestry system of Costa Rica. Annals of Botany. Submitted November 2015.

Gómez-Delgado F, Roupsard O, Vaast P, Robelo A, Moussa R. 2014. When runoff and sediments are not coming from plots: a spatio-temporal analysis in a coffee agroforestry system. Agriculture Ecosystems & Environment. Submitted December 2015.

Thesis

Audebert L. 2011. Productivité aérienne du café agroforestier : effets de l'ombrage et de l'âge des rejets. Master II. UHP Nancy I, Nancy, France, p 25 pp + Annexes

Benegas, L., 2010-2013. The role of trees for groundwater recharge: PhD research plan, CATIE/SLU October 2009 – November 2013. Faculty of forest Sciences. Swedish University of Agricultural Sciences (SLU), Umeå/Uppsala/Alnarp.

Cambou, A., 2012. Mesures des sucres lents et rapides d'organes de caféier par double approche VISNIR et Biochimique. Césure ENSAIA, Rennes.

Charbonnier, F., 2013. Measuring and modelling light, water and carbon budgets and net primary productivity in a coffee-based agroforestry system of Costa Rica. PhD. Ecole doctorale RP2E. Université de Nancy I. 19 dec 2013, p. 54 p. + Appendices.

Deffner, A., 2012. Partition du bilan hydrique d'une parcelle de café agroforestier au Costa Rica. Césure. Supagro-ENSAM, Montpellier, p. 31.
Defrenet, E. 2012. Evaluating belowground biomass and net primary productivity (NPP) of coffee in an coffee agroforestry system in of Costa Rica., Master II Productions Végétales option Ingénierie des Agrosystèmes. Agrocampus Ouest Rennes-France. 29 pp + Appendices.
Deswarte, C. 2015. Spatio-temporal distribution of coffee diseases according to shade in agroforestry systems, Master II Productions Végétales option Ingénierie des Agrosystèmes. Agrocampus Ouest Rennes-France. XX pp + Appendices.
Jarri, L., 2012. Adaptation to Climate Change and Genotype x Environment Interactions in leaf water-use efficiency and carbon isotope discrimination (Δ13C) of Coffee F1 hybrids: a field trial experiment under contrasting altitudinal and drought conditions. Césure. Supagro-ENSAM, Montpellier.
Khac, E., 2012. Plasticity and Genotype x Environment Interactions in productivity, biomass partitioning and drought tolerance of Coffee F1 hybrids in Costa Rica. MSc. Aproparistech, Montpellier.
Kinoshita, R., 2009. Experimental display for rainfall interception and steady state infiltrability in a coffee agroforestry system of Costa Rica (E.U. CAFNET/Coffee-Flux project in Aquiares farm). Internship report, April to August 2009. Cirad, CATIE, PCP, Turrialba, p. 31.
Kinoshita, R., 2012. Strategies for soil quality assessment using VNIR hyperspectral spectroscopy. Cornell, USA. , New-York. Master Sc. 89pp.
Gómez-Delgado, F., 2010. PhD Thesis: Hydrological, ecophysiological and sediment processes in a coffee agroforestry basin: combining experimental and modelling methods to assess hydrological environmental services. Centre international d'études supérieures en sciences agronomiques -Montpellier Supagro; Ecole doctorale Systèmes Intégrés en Biologie, Agronomie, Géosciences, Hydrosciences, Environnement (SIBAGHE), Montpellier, p. 254.
Nespoulous J. 2011. Relations entre la stabilité structurale, la résistance au cisaillement et les caractéristiques physicochmiques des sols-Application sur trois sites agroforestiers. Master Sciences et technologies: U. Savoie, Montpellier, p 25 + annexes.
Perez Molina, J.P., 2013. Variabilidad temporal y espacial de la respiración del suelo y su partición en respiración autotrófica y heterotrófica, necromasa y tasas de liberación de nutrientes de la hojarasca, en un sistema agroforestal de café, comparado a bosque de origen. MSc, Dep. Forestal, CATIE. Costa Rica. 29 Nov 2013, p. 82.
Perez Molina JP. 2014-2018. Coffee Acclimation to elevated [CO2]. A field experiment with FACE (Free-Air CO2 Enrichment) in Brazil, PhD project PhD, PhD Project, U. Viçosa, Brazil. Bourses du Sud CIRAD.
Soma M. 2015. On the relationship between structure and canopy temperature in stands: comparing Shaded and Full-Sun situations in a coffee agroforestry trial in Costa Rica, Nancy I. MSc, Master Forêt, agronomie, gestion des écosystèmes, Spécialité Forests and their environment, AgroParisTech Nancy I. Defended 1rst of September 2015. 25pp + Appendices.
Taugourdeau S. 2010. Indice foliaire d'un système agroforestier à base café, mesure, dynamique et relation avec la production. Master FENEC: Université des Sciences et Technologies du Languedoc, Montpellier, p 12 + annexes.
Vezy R. 2014-2017. Simulation of alternative management practices for perennial plantation adaptation to global changes, PhD, Université de Montpellier 2, France.
Welsh, K., 2011-2014. Balance of water and contaminants in various systems of the Reventazon watershed (Costa Rica). PhD project. U. Idaho-CATIE, IGERT, Idaho.

Communications

Charbonnier, F., Roupsard, O., Dreyer, E., Le Maire, G., 2012. Using the MAESTRA model to simulate light interactions and photosynthesis in a heterogeneous agroforestry system under alternative density and pruning practices. Oral Presentation. 30th AMS Conference on Agricultural and Forest Meteorology. American Meteorological Society, Boston, MA ,USA, 29 May -- 1 June 2012.
Charbonnier, F., Le Maire, G., Dreyer, E., Casanoves, F., Christina, M., Dauzat, J., Eitel, J., Vierling, L., Van den Meersche, K., Harmand, J.M., Roupsard, O., 2014. The End of the Sun / Shade dichotomy in AFS: mapping of plant light budgets in multistrata heterogeneous plots. Oral Presentation. World Congress on Agroforestry, Dehli, India, 10-14 February 2014.
Charbonnier, F., Roupsard, O., Casanoves, F., Audebert, L., Defresnet, E., Cambou, A., Alline, C., Rapidel, B., Avelino, J., Van den Meersche, K., Harmand, J.M., Jourdan, C., Vaast, P., Barquero Aguillar, A., Leandro, P., Dreyer, E., 2014. Strong spatial variability of light use efficiency in a coffee AFS, highlighted by 3D light and gas exchange model. Oral Presentation. World Congress on Agroforestry, Dehli, India, 10-14 February 2014.
Dauzat, J., Griffon, S., Roupsard, O., Vaast, P., Rodrigues, G., 2013. Building the foundations of a Coffea arabica FSPM. In: Risto Sievänen, E.N., Christophe Godin, Anna Lintunen, Pekka Nygren (Ed.),

Proceedings of the 7th International Conference on Functional-Structural Plant Models (FSPM2013), Saariselkä, Finland, 9-14 June 2013. Vantaa, : Finnish Society of Forest Science, p. 269-270. International Conference on Functional-Structural Plant Models. 7, 2013-06-09/2013-06-14, Saariselkä, Finland, Saariselkä, Finland.

Le Maire, G., Nouvellon, Y., Roupsard, O., Christina, M., Charbonnier, F., Zhou, J., Ponzoni, F.J., Stape, J.L., Dauzat, J., Couteron, P., Proissy, C., 2012. Very high resolution images for parameterization of tree-scale forest process-based models. Poster. IEEE. Proceedings of 2012 IEEE International Geoscience and Remote Sensing Symposium (IGARSS 2012), Munich, Germany, 22-27 July 2012,. Piscataway : IEEE, p. 6553-6556. IEEE International Geoscience and Remote Sensing Symposium, 2012-07-22/2012-07-27, Munich, Germany.

Le Maire, G., Rançon, F., Charbonnier, F., Roupsard, O., 2014. Characterizing the structure of coffee agroforestry systems in Costa Rica. Poster. Pleiades days. April 1-3 2014, Toulouse, France.

Roupsard, O., Gómez Delgado, F., Rapidel , B., le Maire, G., 2009. Why is agroforestry so challenging for modellers? How to conciliate complexity, interactions, accuracy and upscaling? A proposed strategy for agroforestry modelling. In: Rapidel, B., Roupsard , O., Navarro, M.N. (Eds.), Modelling Agroforestry Systems. Workshop Proceedings. CATIE, Turrialba, Costa Rica, 25-29 February 2008. Technical Series. Technical meetings n°14. ISBN 978-9977-57-479-4, pp. 69-80.

Roupsard, O., Gómez-Delgado, F., Moussa, R., Rapidel, B., Perez, A., Barquero, A., Rivera Wilson, C., Benegas, L., Kinoshita, R., Taugourdeau, S., Navarro, M.N.V., Jourdan, C., Le Maire, G., Harmand, J.-M., Bonnefond, J.M., Vaast, P., 2010. The CAFNET/Coffee-Flux project: evaluating water, sediment and carbon ecosystem services in an agroforestry coffee watershed (Costa Rica). 21st Century Watershed Technology: Improving Water Quality and Environment. American Society of Agronomical and Biological Engineers (ASABE), University La Earth Costa Rica, Poster presentation.

Roupsard, O., Charbonnier, F., Taugourdeau, S., Kinoshita, R., Guidat, F., Rançon, F., Le Maire, G., Van den Meersche, K., Jourdan, C., Harmand, J.M., Vaast, P., De Melo, E., Imbach, A., Albrecht, A., Chevallier, F., Do, F., Rocheteau, A., Chotte, J.L., 2014. Using process models, remote sensing and spectrometry to open scientific locks in agroforestry systems: the example of coffee in Costa Rica. Poster. In: FAO (Ed.), International Symposium on Agroecology for Food and Nutrition Security, FAO, Rome, 18-19 sept. 2014. FAO, Rome.

Roupsard O. 2014. Cafetaleras cerca de la Carbono-Neutralidad. Un método original y sencillo para mostrarloDocumento Powerpoint, 30 diapositivas. Charla a La Junta Nacional del Carbono. 12 de Diciembre 2014. Powerpoint. Centro de Cambio Climatico, San Pedro, San José, Costa Rica.

Roupsard O. 2014. ?Es mi finca cafetalera Carbono-Neutral? Acompanando productores de cafe son su certificacion Carbono Neutral. Documento Powerpoint, 30 diapositivas. Visita de Campo en la finca Aquiares y charla a la GIZ, ICAFE, NAMA-Café, Fundecooperacion, MAG, MINAE. 15 de Mayo 2014. Aquiares, Turrialba Costa Rica.

Roupsard O, Loustau D, Subervie J, Le Maire G, Laclau JP, Nouvellon Y, Domec JC, De Melo E, Imbach P, Rapidel B, Le Coq JF, Augusto L, Avelino J, Van den Meersche K, Duursma RA, Medlyn B, Trichet P, Bosc A, Maris C, Garcia A, E. B, Le Meilleur S, Picart D, Lamour A, Vezy R. 2014. MACACC ANR Project: Modelling to accompany stakeholders towards adaptation of forestry and agroforestry systems to global changes (MACACC). ANR Agrobiosphère 2014-2017 (ANR-13-AGRO-0005). 3 million euros budget. Xylofutur-MACACC: http://xylofutur.fr/macacc/.

Roupsard O. 2015. Accompanying NAMA-Café with the C-Neutral certification : a joint PCP effort to link our activities with socio-economical stakes. In: PCP, ed. PCP Evaluation. CATIE.

Roupsard O. 2015. La utilización de modelos para apoyar la validación de Innovaciones Agroforestales. In: CATIE, ed. Diseño de Piloto de Sistemas Agroforestales en el ámbito de la NAMA-CAFÉ Costa Rica–CATIE-CIRAD-FUNDECOOPERACIÓN-ICAFE-MAG. CATIE: NAMA-Café Costa Rica.

Roupsard O, Soma M. 2015. Visio-chat : Agroforesterie et changement climatique, l'exemple du Costa-Rica. Participants : lycée Franco-Costaricien de San José (Costa Rica) / lycée agricole de Mirecourt, Vosges / collège de Langogne, Lozère / Vigie de l'eau, Vittel. http://www.lavigiedeleau.eu/node/822 . 30th of April 2015. Visio-Chats. Vittel.

Roupsard O, Van den Meersche K, Rapidel B, De Melo Virginio Filho E, Charbonnier F, Alline C, Avelino J, Roumet C, Stokes A, Bonnefond. J-M, Vierling L, Boll J, Dreyer E, Saint-André L, Loustau D, Elberling B, Isaac ME, Malmer A, Sanchez-Murillo R, Vargas V, Fonseca C. 2015. COFFEE-FLUX (Costa Rica): Observatory for monitoring and modeling carbon, nutrients, water and sediment ecosystem services in coffee agroforestry systems; Mitigation and adaptation to climate changes through ecosystem manipulation. ANAEE-France. Toulouse.

Sánchez-Murillo R, Welsh K, Birkel C, Esquivel Hernández G, Corrales-Salazar J, Boll J, E. B, Roupsard O, Sáenz-Rosales O, I. K, Arce-Mesén R, C. S, Araguás-Araguás L. 2015. Key drivers controlling daily stable isotope variations in precipitation of Costa Rica: Caribbean Sea versus eastern Pacific Ocean moisture sources. Paper EGU2015-4277. Oral presentation and Poster, session AS4.8/BG1.11/CL5.11/HS7.10. 2015 IAEA Isotope Hydrology Symposium. Vienna, Austria, 15th April 2015.

Somarriba E, Roupsard O. 2015. Impactos del cambio climatico sobre el café. Entrevista de la radio Columbia 98.7FM. 11 de Setiembre de 2015. 30 minutos.

Soto, M., 2011. Como se sabe cuanto carbono captura un cafetal? , El Periodico La NACION-Costa Rica, 5th of June 2011, San José.

Soto, M. 2012. Cafetales con arboles funcionan como esponjas durante las lluvias, pp. 20 El Periodico La NACION-Costa Rica, 27th of June 2012, San José.

Taugourdeau, S., Le Maire, G., Roupsard , O., Avelino, J., Gómez-Delgado, F., Jones, J.R., Marsden, C., Robelo, A., Alpizar, E., Barquero, A., Rapidel , B., Vaast, P., Harmand, J.M., 2010. LAI dynamics of agroforestry and full sun coffee systems in Costa Rica. Poster. ASIC 2010, Bali, Indonesia, October 3-7 2010. Poster Communication and Proceedings.

Vezy R, Picart D, Christina M, Soma M, Charbonnier F, Loustau D, Le Maire G, Roupsard O. 2016. Effect of shade on temperature mitigation and canopy assimilation of coffee agroforestry systems. EURAF: 3rd European Agroforestry Conference, 23-25 May 2016, Montpellier, France. Poster presentation.

Vezy R, Picart D, Roupsard O, Charbonnier F, Loustau D, Le Maire G. 2016. Coupling a 3D light interception with a growth and yield model to adjust the shade level in coffee agroforestry systems simulated under climate change. 32nd Conference on Agricultural and Forest Meteorology, 20-24 June 2016, Salt Lake City, Utah, USA. Oral presentation.

Welsh K, Boll J, Roupsard O. 2014. Seasonal isotope hydrology of a coffee agroforestry watershed in Costa Rica. Poster. AGU. December 2014. Session "Emerging Issues in Tropical Ecohydrology". San Francisco, USA.

Workshops organized

Roupsard, O., L. Vierling, J. Eitel, G. Le Maire, and J. Dauzat. 2011. PCP Workshop. "From the Leaf to the Landscape: Field and Remote Sensing Approaches for Understanding Vegetation Structure and Dynamics". CATIE, 12-13 May 2011. Website: https://sites.google.com/site/laiworkshoppcp/ [Online].

Roupsard, O., Loustau, D., Braconnier, P., 2014. Modelling to accompany stakeholders towards adaptation of forestry and agroforestry systems to global changes (MACACC). Kickoff meeting Bordeaux-Lacanau, France. 17-24 of March 2014. https://sites.google.com/site/macacclacanau/.

Roupsard O, Loustau D, Subervie J, Le Maire G, De Melo E, Imbach P, Rapidel B, Le Coq JF, Van den Meersche K, Garcia A, Lamour A. 2014. Modelling to accompany stakeholders towards adaptation of forestry and agroforestry systems to global changes (MACACC). Costa Rica meeting Tarrazu & CATIE, October 2014. https://sites.google.com/site/macacccostarica/.

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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Web sites:

CIRAD-Persyst: Agricultural Research for development: http://www.cirad.fr/en UMR ECO&SOLS: http://www.montpellier.inra.fr/ecosols Theme 3 of UMR Eco&Sols: Carbone et changements globaux: http://www5.montpellier.inra.fr/ecosols/Themes-de-recherche/carbone_changements_globaux CATIE (Centro Agronómico Tropical de Investigación y Enseñanza): http://www.catie.ac.cr/

Coffee-Flux platform: http://www6.montpellier.inra.fr/ecosols/Recherche/Les-projets/CoffeeFlux