CASCA

Contract ICA4-2001-10071

GENERAL REPORT

Fourth project year

(1 November 2004 - 31 December 2005)

Title: Sustainability of Coffee Agroforestry Systems in Central America; coffee quality and environmental impacts

Dr. Philippe Vaast (CIRAD), Coordinator

INCO : International Scientific Cooperation Projects (1998-2002)

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TITLE : Sustainability of Coffee Agroforestry Systems in Central America; coffee quality and environmental impacts (CASCA)

SUMMARY (year 4)
Dr. Philippe Vaast (CIRAD), Coordinator

The objective of this **summary report** is to give an overview of the main technical activities and results of the CASCA project during **the fourth and final year** (November 2004 - December 2004).

The E.U. granted to CASCA a two-month extension until the end of December 2005 to permit the recollection and exploitation of field data undertaken during this fourth and final year of the project.

One technical meeting was held in May 2005 at the headquarters of CIRAD, Montpellier, France on progress towards biophysical modeling. The final consortium meeting was held (November 19-23 of 2005) in Costa Rica at the headquarters of CATIE to assess the data collection performed during the fourth year of CASCA and to plan reporting and dissemination activities during the last months of this fourth and final year. This meeting was attended by a total of **16 persons** representing all partner institutions and with researchers from all the work-packages. 22 presentations were done during these four days.

General progress

As exposed in details in the WP reports and activity reports of CASCA partners, a large amount of fieldwork has been undertaken and exploited during this fourth and final year. Following the establishment of experimental sites in 2002, data collecting was continued for all four biophysical Work Packages (WP's 2, 3, 4 & 5) in Costa Rica and Nicaragua in 2005.

For the socio-economic Work Packages (WP's 1, 7 & 8), activities were also continued intensively during this fourth year. Surveys have been undertaken from January to August 2005 in two coffee producing regions of Costa Rica. A 6-month economical survey of the wood sector and stakeholders was also undertaken in one the main coffee producing regions of Guatemala.

Overall, **the project has achieved a significant amount of field works during this fourth year to complete the gathering of the last socio-economic and biophysical data in the 3 target countries. Therefore, good progress** has been performed to meet project schedule in terms of deliverables, despite the late disbursement of funds by the E.U during this last year of project.

- Data collected in 2005 have been added to the database on farmers AF knowledge and main characteristics of coffee AF in the Central American region; hence, the final database comprised information from ten major coffee regions of the three target

countries. A synthesis of these surveys has been completed (see activity report of WP1).

- The models of light partitioning within the coffee tree as well as between coffee and associated trees have been completed (see activity report of WP2).
- A first version of the water model has been completed following additional data gathered in 2005 on water consumption of coffee and associated trees in optimal conditions for coffee cultivation (see activity report of WP2).
- The model on coffee photosynthesis and carbohydrate production at different scales (leaf, coffee tree and plot scales) has been completed (see activity report of WP3).
- Three articles have been submitted to international scientific journals regarding processes regulating coffee physiology (see activity report of WP3).
- Three articles have been published in international proceedings regarding the mechanisms responsible for coffee quality (see activity report of WP3).
- The nitrogen model has been completed after collection of additional data on nitrogen cycling, N_2 and N_2O emissions in target coffee AF systems (see activity report of WP4).
- Additional data have been collected on carbon accumulation in coffee and associated trees as well as organic matter dynamics in soil of coffee AF systems (see activity report of WP5).
- The leader of WP6 has completed and fully tested the integrated plot model (see activity report of WP6).
- The economical model has been completed and tested with data collected from surveys in Guatemala and Costa Rica (see activity reports of WP7).
- Significant progress has been done on regional up-scaling and policies to be included in the final report in mid-April 2006 (see activity report of WP8).
- Recommendations have been elaborated from research results, model outputs and dialogues with stakeholders of the coffee and wood sectors of the 3 target countries and will be included in the final report in mid-April 2006.

With the large amount of biophysical and socio-economical data collected during four years in the 3 target countries, biophysical and socio-economical models have been developed. Regional up-scaling for the watershed of Turrialba, Costa Rica, is under way and results of this exercise will be included in the final report in mid-April 2006.

Through **scientific publications**, partners of CASCA have contributed to the exploitation and dissemination of results. **Six articles** have been published in 2005 and three accepted for publication. **7 theses (2 Ph.D. and 5 Msc)** have also been defended and published in 2005. **One oral presentation** of CASCA main results has been performed during the **Latino American Coffee Congress** (San Salvador, June 2005).

Several presentations in local and national workshops were held by partners in Costa Rica, Nicaragua and Guatemala in front of around **500 coffee farmers** on the main results of CASCA regarding the effects of **agroforestry management on coffee quality and sustainability**.

A **website** (www.casca-project.com) presenting the project and results in English and Spanish, is on the web **since June 2003**.

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TITLE : Sustainability of Coffee Agroforestry Systems in Central America; coffee quality and environmental impacts (CASCA)

Management Annual report (year 4)
Dr. Philippe Vaast (CIRAD), Coordinator

The E.U. granted to CASCA a two-month extension until the end of December 2005 to permit the recollection and exploitation of field data undertaken during this fourth and final year of project.

During this fourth year, three technical meetings took place: one in Nicaragua in February 2005 and one in Guatemala in March 2005 to organize field data collection with national partners (UNA and IICA-PROMECAFE, respectively) and the last one in June 2005 in Montpellier, France, between leaders of WPs 2, 3, 4, 5, 6 and 8 to finalize the parameterization of the biophysical model.

The last consortium meeting was held (November 19-23 of 2005) in Costa Rica at the headquarters of CATIE to assess the data collection performed during this final year, present the main biophysical and economic results, and plan report, dissemination and publishing activities. The first half of this meeting focused on biophysical work-packages, particularly on the coffee physiology model and the integrated biophysical model at plot scale. The second half of this meeting focused on socio-economical work-packages and particularly on the economical importance of tree products and labeling schemes on coffee farmers' revenues. A one-day field trip was organized by CICAFE to visit the experimental station of Barva de Heredia. This final meeting was attended by a total of **16 persons** representing all partner institutions and with researchers from all the work-packages; 22 presentations were done during these four days.

Months of activities

Without exception, all project partners have had an important input in terms of months spent on activities dedicated to the project.

Compared to **168.15 months initially planned** for the fourth year, **211.69 months have been dedicated** to CASCA activities in 2005 (see details of months of CASCA activities per partner in annexes of this document). Through research works of permanent researchers and graduate students, activities were maintained at a very high level despite the late disbursement by E.U. for this final year (8 months after the beginning of Year 4 *i.e.* July 2005)

Financial aspects

A disbursement of **117 66.24 Euros** was granted by the E.U for the fourth year of CASCA that arrived very late, more than half way into this final year despite the on-time submission of reports and cost statements of Year 3.
A total of **201 987.92 Euros is being justified** in the cost statements of this fourth project year by the CASCA partners following the repartition below.

Acronyms *Contractors*	*Advance for Year 4*	*Funds justified* *End of Year 4*	*Balance* *For Year 4*
CIRAD	52 933.76	67 533.62	- 14 599.86
CEH	23 418.51	55 701.47	- 32 282.96
CATIE	14 864.20	56 915.33	- 42 051.13
IICA	19 319.59	13 346.42	5 973.17
UNA	7 130.18	8 491.08	1 360.90
Total	117 666.24	201 987.92	- 84 321.68

Due to the E.U. contract rules reserving 15% of the total budget after acceptance of the final report and also due to the late E.U. disbursement for Year 4, all the partners pre-financed a large part of CASCA activities during this fourth year according to their financial, institutional capacities. **This situation was particularly handicapping for Central American partners** that do not have the financial means to pre-finance a full year of activities and wait for up to 6 months after the end of project to recuperate their advances. In particular, UNA and IICA-PROMECAFE had to decrease their amount of field work and financial support to graduate students due to a lack of funds.

Educational aspects

As already emphasized during the previous years, an important achievement of CASCA is the opportunity given to **graduate students** to undertake their research activities with technical and financial support of the project. **Five Masters and two Ph.D. students** received financial support by the project to do their fieldwork during 2005.

Exploitation and Dissemination

Six articles have been published in 2005 and 8 submitted in 2005 (see annexes of scientific report). **Five Masters theses and two doctoral theses** have been defended and published in 2005. Another two Ph.D. theses will be defended in 2006.

One presentation was done in 2005 at the Latino American Coffee Congress (San Salvador, June 2005). Four presentations on benefits of agroforestry management on coffee quality, farmers' economic sustainability and environmental services have been submitted for the 21st International Coffee Research Conference in Montpellier, France, in September 2006.

Several presentations of CASCA main results regarding **shade management, coffee quality and environmental impacts of coffee agroforestry systems** were held by partners in Costa Rica, Nicaragua and Guatemala for around **500 coffee farmers**.

A website (www.casca-project.com) presenting, in English and Spanish, the project and results is on the web **since June 2003.** It will be updated with the latest results and

publications in March 2006 after completion of the fourth and final annual scientific and WP reports.

Actual Partitioning of months /WP/PARTNER/for the Fourth YEAR

	WP1	WP2	WP3	WP4	WP5	WP6	WP7	WP8	WP9	Done in Year 4	Planned for Year 4
CIRAD											
Total Permanent staff	0.5	3.7	4.65	3	3	0	3.87	0	3.13	21.85	20.25
Students	4	2	4	0	0	0	0	0	0	10	0
Total CIRAD	**4.5**	**5.7**	**8.65**	**3**	**3**	**0**	**3.87**	**0**	**3.13**	**31.85**	**20.25**
Total CEH				**1.18**		**4.68**		**2.43**		**8.29**	**2.9**
CATIE											
Total Permanent Staff	1	0.5	3.5	4.25	5		0.25	0.25	3.75	18.5	27
Total Hired Staff	7	20	20.93	5	8.06		23	6		90	44
Total CATIE	**8**	**20.5**	**24.43**	**9.25**	**13.06**	**0**	**23.25**	**6.25**	**3.75**	**108.5**	**71**
IICA-PROMECAFE											
Total Permanent staff	2	1	2.5	2.5	2.5	0	1.5	1.5	1	14.5	18
Hired staff		5.5	5.5	6.5	5					22.5	26
Total IICA	**2**	**6.5**	**8**	**9**	**7.5**	**0**	**1.5**	**1.5**	**1**	**37**	**44**
UNA											
Total Permanent staff	0.4		6.32		6.32		0.2	0.15	2	15.39	14
Total Hired Staff			5.33		5.33					10.66	16
Total UNA	**0.4**	**0**	**11.65**	**0**	**11.65**	**0**	**0.2**	**0.15**	**2**	**26.05**	**30**
Grand TOTAL	**14.9**	**32.7**	**52.73**	**22.43**	**35.21**	**4.68**	**28.82**	**10.33**	**9.88**	**211.69**	**168.15**

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Scientific annual report (year 4)
Dr. Philippe Vaast (CIRAD), Coordinator

The objective of this **scientific annual report** is to give an overview of the main technical activities undertaken by all the partners of the CASCA project during **the fourth and final year (November 2004 - December 2005)** and the difficulties encountered.

Months of activities

Despite the late disbursement of funds by the E.U., all the partners have had an important input in terms of activities dedicated to the project. Compared to **158.15 months initially planned** for the fourth year, **207.5 months have been dedicated** to CASCA activities in 2005 (see details of months of activities per partner at the end of management report). Research activities were maintained at a very high level due in large part to field work by graduate students of CATIE, CIRAD and UNA. Progress has been made in publishing major results of CASCA in regional and international journals.

This report of scientific activities is presented by Work-packages. Details of the main results in 2005 are presented in the WP reports with graphs and tables. Details of the activities undertaken by partners are presented in the partner annual reports.

Work-Package 1: (Central American coffee agroforestry knowledge)

The main objective of this WP1 was to collect and analyze data **on farmers' agroforestry knowledge**, over the first 36 months of the project, in major coffee-growing ecological zones of the 3 countries (Costa Rica, Nicaragua & Guatemala) considered in the project.

As a leader of this WP1, **CATIE** (Eduardo Somarriba) has helped to coordinate a last series of field surveys and in the supervision of students (two Ms students of UNA and two Ms students from CIRAD in Costa Rica) that have undertaken their fieldwork in 2005.

Dr. Somarriba also updated the database on current coffee Agroforestry (AF) practices and presented, in the final workshop, a synthesis of the surveys performed during previous years (see WP1 report).

0ne Ph.D. student of CIRAD has defended her thesis in December 2005 following two years of surveys on farmers' agroforestry knowledge and strategies in front of the coffee

price crisis in two contrasting regions in Nicaragua and Costa Rica in collaboration with UNA and CATIE.

With a total of 40 months of field works, **10 major coffee producing regions of Central America** (5 in Costa Rica, 3 in Nicaragua and two in Guatemala) have been surveyed during the CASCA project. This results in a total of more than **250 farms surveyed in Costa Rica, 100 in Guatemala and 200 in Nicaragua**.

Deliverables

At the end of this fourth year of project, the **Deliverable D10/D1.1 "Database of current coffee AF practices" is completed** with studies performed during the four years of project in Costa Rica, Guatemala and in Nicaragua.

Several scientific publications describing existing AF typologies and their management have been published in 2003-2004 as well as a chapter "Biodiversity Conservation in Neotropical coffee (*Coffea Arabica*) plantations" in the book entitled "Agroforestry and Biodiversity Conservation in Tropical landscapes" and a Ph.D. thesis in 2005. These documents constitute the second deliverable of WP1 (Deliverable D13/D1.3 "Scientific report describing existing AF typologies and management"- Month 30).

Work-Package 2: (light and water partitioning at plot scale)

The main objective of this WP2 is assessing **light and water partitioning** between coffee and associate tree in a few target coffee AF systems of regions with distinct agro-ecological conditions.

Following data collection in 2002-2004, CIRAD (Jean Dauzat, leader of WP2) refined the methodology (described in WP2 report of 2004) to **quantify and model light interception by five timber tree species,** based on digitalized photos (photos of tree silhouette and photos fish-eye below the canopy).

In 2005, a **model simulating light partitioning within the coffee canopy** was developed following a graduate student work in 2004 (Stéphane Bagnis, University of Toulouse) on 3-D digitalization of coffee plants under 3 shade treatments (75% and 50% shade and the full sun) with varying fruit loads (100%, 50% and "very light load") as detailed in the activity report of WP2.

CIRAD (Philippe Vaast) CATIE (Pablo Siles & Jonathan Ramos) and IICA-PROMECAFE (Luis D. Garcia) were also strongly involved in collecting data on **transpiration and stem flow of coffee and tree strata, rain interception** by their canopies, **soil water content** and **runoff** in one coffee agroforestry trial and one coffee plot in full sun. CIRAD (Jean Dauzat) has also developed a model simulating coffee transpiration that can be compared to actual field measurements (see WP2 report for details).

One article, submitted in 2005, has been accepted for publication on coffee and tree transpiration and two are in preparation on light interception will be submitted in 2006.

Deliverables

The Deliverables D11/D2.1 "Comprehensive model of light partitioning in coffee AF systems" (Month 24) and D22/D2.3 "Report on light and water partitioning between coffee and tree strata in target AF systems" (Month 42) can be considered completed via the two models already developed (model of light interception by shade tree species and model simulating light partitioning within the coffee canopy) and articles published in 2005 and two prepared for submission in 2006 (see Report of WP2).

The water model in two target systems is completed and constitutes the Deliverable D15/D2.2 "Water balance model at plot scale"; one article presenting this model is ready for submission. Nonetheless, additional refinement on its parameterization is needed with data on coffee and timber rainfall interception and stem flow collected in 2005. This will be achieved in 2006 for the defense of a Ph.D. thesis planned for September 2006.

Work-Package 3: (coffee ecophysiology and quality)

The main objectives of this WP3 are studying **physiological responses of coffee leaves** to micro-environmental field conditions, **developing a model of carbon production and allocation** in coffee plants as well as investigating the mechanisms responsible for **coffee quality**.

CIRAD (Philippe Vaast, Jean Dauzat & Nicolas Franck), UNA (Victor Aguilar & graduate students) CATIE (Pablo Siles & Jonathan Ramos) and IICA-PROMECAFE (Victor Chaves & Luis Dionisio Garcia) have been involved in **quantifying carbon allocation between fruit, shoot and root** on two experimental sites (1 in Costa Rica: experimental station of CICAFE in Barva and one AF trial in the pacific zone of Nicaragua). They also continued field data collection in 2005 to assess leaf and fruit photosynthesis in relationships with micro-climatic conditions at the leaf level and according to periods of the day in order to complement data collected the previous years. Measurements have been also performed on coffee leaf water potential along the day during the dry and rainy seasons 2005.

In 2005, work has been mainly concentrating in analyzing data, developing models and publishing results via scientific articles on **leaf assimilation responses to PPFD, VPD, CO_2 concentration, leaf content (starch and soluble sugars), and photo-inhibition**. **One Ph.D student,** Nicolas Franck, defended his **doctoral thesis** in October 2005 on the **modeling of physiological responses of coffee and carbon allocation** (see details in WP3). **Two articles on coffee ecophysiology were published in 2005** and two have been submitted (see Report of WP3).

CIRAD (Philippe Vaast), CATIE (Léonel Lara) and IICA-PROMECAFE (Victor Chaves) were also involved in **quantifying the effects of shade, agricultural management, nitrogen fertilization and productivity on coffee quality** in terms of bean size, bean biochemical composition and cup quality in Nicaragua and Costa Rica. Around 100 analyses were performed in 2005; with those of 2002 to 2004, this amounts to a total of more than **350 cupping analyses** performed by a panel of 8-10 tasters in the laboratory of CIRAD (Bernard Guyot and Jean-Jacques. Perriot) in Montpellier, France. The same amount of biochemical analyses of coffee beans (Fabrice Davrieux) was also undertaken

during the 4 years. **Three articles on coffee quality have been published in 2005 and three have been submitted** (see Report of WP3).

Two presentations are being prepared for the next International Scientific Coffee Congress to be held in Montpellier, France, in September 2006.

Deliverables

The Deliverable D8/D3.1 "Scientific report on physiological responses of coffee to microclimatic conditions" (Month 20) as well as the Deliverable D9/D3.2 "Report of rules of carbon allocation" (Month 20) are completed through publication or submission of **5 scientific articles** and the defense of one Ph.D. thesis (see Report of WP3).

The Deliverable D14/D6.2 "Carbon allocation model of fruit growth in a single bush" was finalized in October 2005 with parameterization and testing of the models on carbon allocation at different scales (leaf, tree and plot scale).

The Deliverable D23/D3.3 "Reports on indicators of coffee quality" can be considered completed through publication or submission of **6 scientific articles** (see list of publications below).

Work-Package 4: (Nitrogen cycling, leaching, uptake and emissions)

The main objectives of this WP4 are to **measure nitrogen (N) fluxes** in a few target coffee management systems, **to model N cycling** in order to **predict the N losses and accumulation**, and to link N measurements to **environmental evaluation** at catchment's scale.

In 2005, CIRAD (Jean-Michel Harmand, Patrice Cannavo, Philippe Vaast), INRA (Etienne Dambrine), UNA (Victor Aguilar, Marta Guttierez, Rodolfo Mungia) IICA-Promecafe (Victor Chavez & Luis Garcia of CICAFE), CATIE (Kristell Hergoualc'h & Jonathan Ramos) and CEH (Ute Skiba) have been strongly involved in collecting and analyzing field data to quantify N cycling in 3 agroforestry systems in Costa Rica and Nicaragua.

In particular, data have been collected on **N inputs, N-fixation, N mineralization, N accumulation in coffee plants, N removal by coffee beans** as well as **N losses via leaching and nitrous oxide emissions** depending on intensities of N fertilization, root distribution and tree pruning in 4 coffee AF sites (see WP4 report for more details). Measurements of key components of the N cycle were also performed using **^{15}N labelled fertilisers** in order to evaluate: (1) uptake of N by coffee and trees, (2) microbial immobilisation of N in the soil, (3) soil nitrate retention and (4) nitrate leaching. The ^{15}N natural abundance (δ^{15}N) of the different components of coffee and tree was also analysed in order to evaluate **N_2 fixation by the shade legume trees** and N_2O emissions were evaluated using the static chamber method three times along the year.

Deliverables

The Deliverable D17/D4.2 "Scientific report on N flux measurements for target coffee systems" (Month 36) can considered completed via articles published in 2003-04, submitted in 2005 and in preparation (see WP4 report).

The Deliverable D18/D4.3 "N flux model at plot scale" (Month 38) can also be considered completed via publications submitted and in preparation (see WP4 report).

Work-Package 5: (carbon sequestration)

The main objectives of this WP5 are to **measure carbon sequestration** in biomass and soil of a few target coffee AF systems, to **create a database** of C sequestration in coffee AF systems in Central America, and to **develop a model** predicting C sequestration at the plot scale and regional scale.

In 2005, CIRAD (Jean-Michel Harmand & Patrice Cannavo), UNA (Victor Aguilar, Rodolfo Mungia & graduate students) IICA-Promecafe (Victor Chaves & Luis Garcia of CICAFE), CATIE (Pablo Siles, Kristell Hergoualc'h & Jonathan Ramos) have continued gathering data from selected coffee systems in Costa Rica and Nicaragua (with and without shade trees). The quantification of plant biomass (above and belowground) and soil organic C was undertaken to evaluate change in C stocks of different systems. In existing long term experiments where greenhouse gas (GHG) emissions were measured such as N_2O and CH_4 emissions, these fluxes were used to establish C budgets of coffee systems (see details in WP5 report).

Deliverables

The deliverable D5/D5.1 "Database on carbon sequestration in coffee agroforestry studies" (Month 18) was completed in 2003.

The Deliverable D19/D5.4 "Model of C sequestration in coffee systems at plot scale" (Month 38) can be considered completed through published and submitted articles (see list of publications in WP5 report).

Work-Package 6: (integrated plot modeling)

The WP Leader, Marcel van Oijen (**CEH**) has **refined the version of the integrated plot model** for coffee growth with and without associated trees. The major developments in year 4 were: (1) The cooling effect of shade trees on the soil and coffee plants was incorporated as being proportional to the fraction of radiation intercepted by the trees, (2) The algorithm for the onset of flowering was simplified, flowering now being triggered by the first major rains after the dry period, (3) The duration of the annual period of coffee reproductive growth is now calculated dynamically as a function of thermal time passed since the onset of flowering, leading to different harvest dates for shaded and unshaded coffee plants; (4) The competition between vegetative and generative parts of the coffee plants has been strengthened through stimulation of leaf senescence by strong reproductive growth and by stimulation of reproductive growth with high leaf area and radiation, (5) Water run-off has been made proportional to the sine of the slope of the

field, and the loss of soil carbon and nitrogen in erosion has been made proportional to the run-off and the concentration of carbon and nitrogen in the upper soil layers (see WP6 report for more details). **The results of model application are presented in details in the WP6 reports.**

Two databases were also developed: (1) A literature database in EndNote format containing 412 references, mostly with abstracts, to the scientific literature concerning the biophysical aspects of coffee agroforestry systems and (2) A biophysical parameter database, in the form of a collection of Microsoft Word tables, with values for model parameters (see WP6 report for more details).
Draft versions of three scientific publications on the WP6 work have been undertaken in 2005 to be submitted in 2006.

Deliverables
The last Deliverable D21/D6.3 "Competition model for light, water and nitrogen at patch scale" (Month 40) can be considered completed through the production and testing of the **integrated plot model** and the production of a biophysical parameter database.

Work-Package 7: (economic modeling at farm scale)

CIRAD (Philippe Bonnal as leader of this WP, Philippe Vaast & one doctoral student: Anne Zanfini), UNA (Prof. Glenda Bonilla) IICA-Promecafe (Bayron Medina of ANACAFE and Mainor Rojas of CICAFE), CATIE (Eduardo Somarriba, Guillermo Navarro and 2 graduate students: Monica Salazar and Mario Martinez) and CEH (Gerry Lawson) have been involved in **household surveys, economic modeling and financial analyses of various scenarios**.

In 2005, an economical study was undertaken in the region of Ococito, Guatemala, in collaboration with IICA-Promecafé (ANACAFE), on the products derived from timber tree species in AF coffee systems and their financial importance for various stakeholders (from coffee farmers to local end users).
A second economical study was undertaken in two regions of Costa Rica on the costs/benefits of converting conventional coffee farms to the environmental and social requirements of the "Coffee –Practices" of the North American coffee firm Starbucks in order to commercialize coffee at a premium price.
0ne Ph.D. student of CIRAD has defended her thesis in December 2005 following two years of surveys on farmers' strategies in front of the coffee price crisis in two contrasting regions in Nicaragua and Costa Rica in collaboration with UNA and CATIE.

Deliverables
The deliverable D12/D7.1 "Synthesis of household surveys" (Month 28) was already completed in year 3 and presented in the consortium meeting of November 2004. Data from the surveys undertaken in 2005 will have to be incorporated after the end of the project.

The economic model was developed in 2004 (Deliverable D20/D7.2 – Month 40) to evaluate management scenarios taking into account economical risks (price of coffee),

climatic factors and other agricultural revenues in order to be validated by the end of the project (Deliverable D27/D7.3 - Month 47). Some of these evaluations (coffee price with and without premium for quality, premium for environmental benefits, intensity of management, timber and fuel wood revenues) were undertaken in 2005 and presented during the final consortium meeting in November 2005.

Work-Package 8: (regional up scaling and policies)

The objectives of this WP8 deal with up-scaling results from the biophysical plot model and from the socioeconomic model to gain an understanding of the validity of conclusions in a wider geographical area, and assessing the market opportunities for coffee-agroforestry systems in world and European markets: Specifically:

1. To determine the requirements to achieve 'sustainable'; 'fair-trade' or 'eco-friendly' labels on the European markets as well as the long-term potential of marketing this coffee in European countries
2. To extrapolate farm-scale socio-economic survey data and model predictions from WP7 to a regional scale using population and agricultural census information
3. To extrapolate biophysical predictions of yields and environmental impact from the plot scale biophysical model (WP6) to larger areas and regions using databases of soil and climate information.
4. To examine the regional implications for coffee production and farm livelihoods of changing climate, economic incentives and widespread uptake of 'eco-friendly' cultivation systems.

Gerry Lawson, as WP leader (**CEH**), has participated in the technical meeting in June 2005 at the headquarters of CIRAD in Montpellier, France.

The market survey for different coffee labels has been updated (see report of WP8).
An email survey of 'shade-friendly' or 'eco-friendly' labels on the European markets as well as the long-term potential of marketing this coffee in European countries, has been sent to about coffee firms dealing with specialty coffee markets (see report of WP8).
A literature review has also been updated on the environmental impacts of coffee plantations (see report of WP8).

The biophysical up-scaling on the catchment of Turrialba, Costa Rica, where sufficient available digitised information on soils, slopes and vegetation cover is under way after gathering geographic and socio-economic information of the Turrialba area with the collaboration of IICA-PROMECAFE (ICAFE) and CATIE.

<u>Deliverables in 2005</u>
Four deliverables were planned for this last project year:

1. Report on prospective markets for eco-friendly coffee in Europe (D8.1, original Month 45-Revised Month 48)
2. Report on extrapolation from socio-economic farm model to level of administrative region (D8.2 Month 46)

3. Report on extrapolation of plot-scale biophysical model results to predict regional yield and environmental impacts (D8.3 Month 46)
4. Delivery of management and policy guidelines taking into account different climate, soil, market price and incentive scenarios (D8.4 Month 48).

As this WP is the final one in the CASCA Project and hence relies on data of other WPs, it has experienced some delay, particularly on up-scaling and delivery of management and policy guidelines. Nevertheless, **these deliverables will be produced in mid-April 2006 and included in the Final Report.**

Work-Package 9: (project management, dissemination, and exploitation)

As leader of this WP9, **CIRAD** (Philippe Vaast) has been co-organizing with **CATIE** the **fourth consortium meeting,** marking the end of the third year, held in Guatemala in late-November 2004 and the **final consortium meeting,** marking the end of the project, held in Costa Rica in late-November 2005.

With the collaboration of all partners and WP leaders, CIRAD (Philippe Vaast) has produced the **present management and scientific reports and the consolidated annual financial report** (Patrick Guezo).

Through **scientific publications** (see annexes), partners of CASCA have contributed to the exploitation and dissemination of results. **Six articles** have been published and 8 have been submitted in 2005 (see annexes below). **Five Masters theses** have been defended and published in 2005. **Two doctoral theses** have been defended and published in 2005 (see annexes below). For the 4 years of project, this amounts to a total of **21 articles, 2 chapters, 30 Masters theses and 3 Ph.D. theses**.

One presentation of the CASCA project was done in 2005 at the Latino American Coffee Congress (San Salvador, June 2005). **Four presentations** of the CASCA results on **agroforestry management on coffee quality and environmental impacts** have been submitted for the coming **21st International Coffee Research Conference** (Montpellier, France, September 2006).

Several presentations of the CASCA research activities and results on the effects of **agroforestry management on coffee quality and sustainability** were held by partners in Costa Rica, Nicaragua and Guatemala for around **600 coffee farmers**.

A website (www.casca-project.com) presenting, in English and Spanish, the project and results is on the web **since June 2003.** It will be updated with the latest results and publications in March 2006 after completion of the fourth and final annual scientific report.

ANNEXES

Masters theses in 2005

CATIE

Monica Salazar (2005). Análisis de rentabilidad financiera del programa C.A.F.E Practices de Starbucks en diferentes tipologías de productores cafeteros de altura en Costa Rica. Tesis Mag Sc. CATIE, Turrialba, CR., 138p.

Mario Martínez. (2005). Contribución económica del componente forestal en diferentes tipos de fincas cafetaleras en la bocacosta pacifica de Guatemala. Tesis Mag. Sci. CATIE, Turrialba, Costa Rica. 123 p.

Leonel Lara Estrada. (2005). Efectos de la Altitud, Sombra, Producción y Fertilización sobre la Calidad del Café (*Coffea Arabica* L. var. Caturra) Producido en Sistemas Agroforestales de la Zona Cafetalera Norcentral de Nicaragua. Tesis Mag. Sc. Turrialba, C.R. CATIE. 106 p.

UNA

Balladares, D.; Calero, M. 2005. Efecto de la Sombra y Fertilizacion sobre el Crecimineto, Estructura Productiva, Rendimiento y Calidad del Café (*Coffea arabica* L.) var Costa Rica 95. Tesis Ing Agrónomo, UNA, Managua, Nicaragua.

Pilati, A. 2005. Evaluacion de tres Diferentes Tipologias de Manejo Agronomico sobre LA Estructura de Crecimiento, Productividad y Calidad del Café (*Coffea arabica* L) en la Zona del Pacifico Sur De Nicaragua. Tesis Lic., Torino Italia / UNA, Managua, Nicaragua.

Doctoral Theses in 2005

CIRAD

Anne Zanfini. 2005. Arbres d'ombrage et café au Costa Rica et Nicaragua: dynamique des strategies paysannes en situation de crise économique. Doctoral thesis, University of Toulouse-Le Mirail. 255p.

Nicolas Franck. 2005. Effet de la charge en fruits et de l'ombrage sur l'assimilation carbonée, la croissance et la production du caféier (*Coffea arabica* L.). Doctoral thesis. ENSA Montpellier. 175p.

International articles published in 2005

Vaast P, Angrand J, Franck N, Dauzat J, Génard M. 2005. Fruit load and branch ring-barking affect carbon allocation and photosynthesis of leaf and fruit of *Coffea arabica* in field conditions. Tree Physiology. 25, 753-760.

Franck N, Vaast P, Génard M, Dauzat J. 2005. Soluble sugars mediate sink feedback down–regulation of leaf photosynthesis of *Coffea arabica* in the field. Tree Physiology. 26, 517-525.

Vaast P, Bertrand B, Guyot B, Génard M. (2005). Fruit thinning and shade influence bean characteristics and beverage quality of coffee (*Coffea arabica* L.) under optimal conditions. Journal of Science of Food and Agriculture. 86, 197-204.

Vaast P, Cilas C, Perriot JJ, Davrieux J, Guyot B, Bolaños M. 2005. Mapping of Coffee Quality in Nicaragua According to Regions. Ecological Conditions and Farm Management. *In* Proceedings of the 20th International Congress on Coffee Research (ASIC) Bangalore, India. p 842-850.

Vaast P, Van Kanten R, Siles P, Dzib B, Frank N, Harmand JM, Génard M. 2005. Shade: A Key Factor for Coffee Sustainability and Quality. Proceedings of the 20th International Congress on Coffee Research (ASIC) Bangalore, India. p 887-896.

Bertrand B, Etienne H, Guyot B, Vaast P. 2005. Year of production and canopy region influence bean characteristics and beverage quality of arabica coffee. Proceedings of the 20th International Congress on Coffee Research (ASIC) Bangalore, India, October 2004; p 878-886.

Articles submitted in 2005

van Kanten RF, Vaast P. Coffee and shade tree transpiration in suboptimal, low-altitude conditions of Costa Rica. Agroforestry Systems. (in press).

Vaast P, van Kanten R, Siles P, Angrand J, Aguilar A. Biophysical interactions between timber trees and coffee in sub-optimal conditions of Central America. Advances in Agroforestry Systems (in press).

Bertrand B, Vaast P, Alpizar E, Etienne H, Charmetant P. Comparison of bean biochemical composition and beverage quality of Arabica hybrids involving Sudanese-Ethiopian origins at various elevations in Central America. Tree Physiology (Accepted)

Harmand JM, Ávila H, Dambrine E, Skiba U, Renderos RV, Oliver R, Jiménez F; Beer J. Nitrogen dynamics, soil nitrate retention and nitrate water contamination in a *Coffea arabica - Eucalyptus deglupta* agroforestry system in Southern Costa Rica. Journal of Environmental Quality (submitted).

Hergoualc'h K, Skiba U, Harmand JM and Oliver R. Nitrification: the major source of nitrous oxide emission from an Andosol of a coffee agroforestry plantation in Costa Rica. Soil Biology and Fertility (submitted).

Vaast P and Bertrand B. Date of harvest and altitude influence bean characteristics and beverage quality of Coffea arabica in intensive management conditions. Field Crop Research (submitted).

Franck N, Vaast P, Dauzat J. Relationships between *Coffea arabica* L. photosynthetic performance and leaf structure as affected by acclimation to growth irradiance: a modelling analysis that includes limitations by stomatal conductance and photoinhibition. Journal of Experimental Botany (submitted).

Franck N, Vaast P, Clément-Vidal A, Dauzat J. Reduction of photosynthesis by low sink demand and photoinhibition in *Coffea arabica* L. leaves in relation to carbohydrate accumulation. Journal of Experimental Botany (submitted).

DATA SHEET FOR ANNUAL REPORT

Contract number: ICA4-2001-10071

Fourth Year
(November 1st 2004 to December 31st 2005)
Data sheet
for annual report of CASCA

1. Dissemination activities (cumulative)	Totals
Number of communications in conferences (published)	3
Number of communications in other media (internet, video, poster)	0
Number of publications in refereed journals (published)	3
Number of articles/books (published)	1
Number of other publications (PhD and Msc theses)	7
2. Training	
Number of PhDs	4
Number of MScs	5
Number of visiting scientists	1
Number of exchanges of scientists (stays longer than 3 months)	0
3. Achieved results	
Number of patent applications	0
Number of patents granted	0
Number of companies created	0
Number of new prototypes/products developed	0
Number of new tests/methods developed	0
Number of new norms/standards developed	0
Number of new softwares/codes developed	2
Number of production processes	0
4. Industrial aspects	
Industrial contacts	no
Financial contribution by industry	no
Industrial partners : - Large	no
- SME [1]	no

S. Comments

Other achievements

A **website** (www.casca-project.com) presenting the project and main results in English and Spanish, is on the web since June 2003.

[1] Less than 500 employees

CENTRE de COOPERATION en RECHERCHE AGRONOMIQUE pour le DEVELOPPEMENT

CIRAD

ANNUAL REPORT of ACTIVITIES for the INCO PROJECT

CASCA

4th YEAR (NOV. 2004 – DEC. 2005)

Dr. Philippe Vaast

February 2006

INTRODUCTION

The project "Coffee Agroforestry Systems in Central America" with acronym **CASCA**, financed by the European Union, officially started on November 1st of 2001 with duration of four years. The objective of the present report is to highlight the main activities undertaken by **CIRAD**, as **coordinator of the project**, during the **fourth year** (November 2004 - December 2005).

A total of **10 permanent CIRAD researchers** were involved in the project for a total of **21.85 months** with 3.13 months dedicated to technical and administrative coordination. **Two students** were involved in CASCA via their doctoral dissertation theses for a total of **10 months**. This results in a CIRAD input of **31.85 months** of work compared to the 20.25 months planned for this fourth year (see annex).

This report of activities is presented by Work-packages.

Work-Package 1: (Central American coffee agroforestry knowledge)

The main objective of this WP1 is collecting and analyzing data on farmers' agroforestry knowledge, over the first 50 months of the project, in major coffee-growing ecological zones of the 3 countries (Costa Rica, Nicaragua & Guatemala) considered in the project.

In 2005, one Ph.D. student of CIRAD (Anne Zanfini, University of Toulouse, France) defended her thesis entitled "Shade trees and coffee in Costa Rica et Nicaragua: dynamics of the farmers' strategies in situation of economical crisis" after conducting surveys in two regions of Nicaragua in 2004 and two regions of Costa Rica in 2003.

Work-Package 2: (light and water partitioning at plot scale)

The main objective of this WP2 is assessing light and water partitioning between coffee and associate tree in a few target coffee AF systems of regions with distinct agro-ecological conditions.

Following data collection in 2002 & 2003, CIRAD (Jean Dauzat, leader of WP2) refined the methodology, developed in 2004, to **quantify and model light interception by five timber tree species,** based on digitalized photos (photos of tree silhouette and photos fish-eye below the canopy). In 2005, a **model simulating light partitioning within the coffee canopy** was developed following a graduate student work in 2004 (Stéphane Bagnis, University of Toulouse) on 3-D digitalization of coffee plants under 3 shade treatments (75% and 50% shade and the full sun) with varying fruit loads (100%, 50% and "very light load") as detailed in the activity report of WP2.

CIRAD (Philippe Vaast) was also strongly involved in collecting data on **transpiration of both coffee and tree strata using sap flow** measurements **in 2 target coffee AF systems** and tutoring **one Ph.D student of CATIE**. CIRAD was also involved in collecting data on **rain interception** by the canopies of coffee and associated trees, **trunk flow** and **runoff in** one coffee agroforestry trial and one coffee plot n full sun (see WP2 report for details).

One article, submitted in 2005, has been accepted for publication on coffee and tree transpiration (see annexes) and two are in preparation on light interception will be submitted in 2006.

Work-Package 3: (coffee ecophysiology and quality)

The main objectives of this WP3 are studying **physiological responses of coffee leaves** to micro-environmental field conditions, **developing a model of carbon production and allocation** in coffee plants as well as investigating the mechanisms responsible for **coffee quality**.

In collaboration with CICAFE and CATIE, CIRAD has continued field data collection in 2005 to assess leaf and fruit photosynthesis in relationships with micro-climatic conditions at the leaf level and according to periods of the day in order to complement data collected the previous years. Measurements were also performed on coffee leaf water potential along the day during the dry and rainy seasons 2005. Work in 2005 has been mainly concentrating in analyzing data, developing models and publishing results via scientific articles on **leaf assimilation responses to PPFD, VPD, CO_2 concentration, leaf content (starch and soluble sugars), and photo-inhibition**. **One Ph.D student,** Nicolas Franck, defended his **doctoral thesis** in October 2005 on the **modeling of physiological responses of coffee and carbon allocation** (see details in WP3). **Two articles on coffee ecophysiology have been published in 2005** and two have been submitted (see annexes).

CIRAD was also involved in **quantifying the effects of shade, agricultural management and fruit load on coffee quality** in terms of bean size, bean biochemical composition and cup quality via the tutoring of one Masters student of CATIE investigating farming management and coffee quality in Nicaragua. Around 100 analyses were performed in 2005; with those of 2002 to 2004, this amounts to a total of more than **350 cupping analyses** performed by a panel of 8-10 tasters in the laboratory of CIRAD (Bernard Guyot and Jean-Jacques. Perriot) in Montpellier, France. The same amount of biochemical analyses of coffee beans (Fabrice Davrieux) was also undertaken during the 4 years. **Four articles on coffee quality have been published in 2005 and three have been submitted** (see annexes).

Some of the preliminary results have been presented in two international congresses in 2004 (First World Agroforestry and International Scientific Coffee Congresses) and **2 presentations are being prepared** for the next International Scientific Coffee Congress to be held in Montpellier, France, in September 2006.

Work-Package 4: (Nitrogen cycling, leaching, uptake and emissions)

The main objectives of this WP4 are to **measure nitrogen (N) fluxes** in a few target coffee management systems, **to model N cycling** in order to **predict the N losses and accumulation**, and to carry out environmental evaluation at catchment's scale.

As leader of this WP4, CIRAD (Jean-Michel Harmand, WP leader, and Patrice Cannavo) has been strongly involved in **collecting field data to quantify N fluxes (N mineralization, losses via denitrification, leaching and nitrous oxide emissions) and N accumulation** in three coffee systems in Costa Rica. They have also tutored one Ph.D. student (Kristell Hergoual'ch) from the University of Montpellier, France, on these topics.

CIRAD (Robert Oliver) has analyzed more than 100 water samples for nitrate and ammonium in its laboratory of Montpellier, France. Numerous gas samples have been sent to CEH for analyses of N_2O.

Etienne Dambrine of INRA, Nancy (subcontractor of CIRAD), was also strongly involved in analyzing N^{15} samples in Nancy, France, and in writing scientific articles from results of an N^{15} study on the experimental station of CICAFE, Costa Rica (see WP4 report for more details).

Two international articles have been submitted in 2005 and two others are in preparation (see annexes). The main results of this WP on nitrogen cycling will be presented at the next international scientific coffee conference (ASIC) in Montpellier, France, in September 2006.

Work-Package 5: (carbon sequestration)

The main objectives of this WP5 are to **measure carbon sequestration** in biomass and soil in a few target coffee AF systems, to **create a database** of C sequestration in coffee AF systems in Central America, and to **develop a model** predicting C sequestration at the site scale and regional scale.

CIRAD (Jean-Michel Harmand) is assuming since 2003 the coordination of this WP5.

In 2005, CIRAD (Jean-Michel Harmand, Patrice Cannavo, Philippe Vaast) have been supervising **measurements of biomass of coffee and shade trees (above and belowground)** and **soil organic carbon to evaluate change in C stocks in** various coffee AF systems in Costa Rica (see WP5 report for details). In existing long term experiments where greenhouse gazes emissions were measured such as N_2O and CH_4 emissions, these fluxes were also used to establish C-CO_2 budgets of coffee systems (see WP5 report for more details).

Work-Package 6: (integrated plot modeling)

Like other partners, CIRAD has contributed indirectly to this WP by discussions during the annual CASCA workshop (November 2004 and November 2005) and the technical workshop in Montpellier (June 2005) and through collation of numerous biophysical data that are been used in the model developed by the WP leader, Marcel van Oijen (see report of WP6).

Work-Package 7: (economic modeling at farm scale)

As leader of this WP7, CIRAD (Philippe Bonnal) has supervised in Montpellier one student involved in the development and testing of the economic model to estimate farmers' revenues according to farm size and management (see report of WP7). CIRAD (Philippe Vaast) has also contributed to this WP through tutoring of two Masters students of CATIE gathering economic data on farms in two regions of Costa Rica and one of Guatemala.

Work-Package 8: (regional up scaling and policies)

CIRAD has contributed to this WP through discussions with its leader (Gerry Lawson of CEH) during consortium and technical meetings. Furthermore, CIRAD (Philippe Vaast) has been tutoring two students of CATIE; one undertaking an economical analysis of timber and fuel-wood derived from coffee AF systems and their importance for farmers' revenues and

other stakeholders in Guatemala, and the second one studying the costs/benefits of converting conventional coffee farms to the environmental and social requirements of the schemes "Coffee – Practices" of Starbucks in order to commercialize coffee at a premium price (see WP5 report for more details).

Work-Package 9: (project management, dissemination, and exploitation)

As leader of this WP9, CIRAD (Philippe Vaast) has been co-organizing with ANACAFE the **fourth consortium meeting,** marking the end of the third year, held in Guatemala in mid-November 2004 and with CATIE the **fifth consortium meeting,** held in Costa Rica in mid-November 2005, marking the end of the fourth and final year of the CASCA project.

With the collaboration of all partners, CIRAD (Philippe Vaast) has produced the **present activities, management and scientific reports as well as the consolidated annual financial report** (Patrick Guezo).

Through **6 scientific articles published** and **8 submitted** with CIRAD staff and/or students as the main or associate authors, CIRAD has greatly contributed to the exploitation and dissemination of results in 2005 (see annexes). Three Masters students and two doctoral students, tutored by CIRAD staff, have defended their theses during this fourth year of project.

CIRAD (Philippe Vaast) has maintained the project **website (www.casca-project.com)** presenting, in English and Spanish, the project and its main results. An update will take place in March 2006 once the reports of the final year of project are completed.

Sub-contracting

The sub-contractor INRA (Institut National de la Recherche Agronomique) has been involved during the project through three visits to Costa Rica of Dr. Etienne Dambrine (INRA, Nancy). In 2005, this researcher and colleagues have been strongly involved in undertaking analyses of N^{15} in Nancy, France, and in participating in the redaction of several scientific articles on N cycling in coffee AF systems.

ANNEXES

Publication of CIRAD
Doctoral Thesis published in 2005

Anne Zanfini. 2005. Arbres d'ombrage et café au Costa Rica et Nicaragua: dynamique des strategies paysannes en situation de crise économique. Doctoral thesis, University of Toulouse-Le Mirail. 255p.

Nicolas Franck. 2005. Effet de la charge en fruits et de l'ombrage sur l'assimilation carbonée, la croissance et la production du caféier (*Coffea arabica* L.). Doctoral thesis. ENSA Montpellier. 175p.

Articles published in 2005

Coffee ecophysiology:

Vaast P., Angrand J., Franck N., Dauzat J., Génard M. 2005. Fruit load and branch ring-barking affect carbon allocation and photosynthesis of leaf and fruit of *Coffea arabica* in field conditions. Tree Physiology. 25, 753-760.

N Franck, P. Vaast, M. Génard, J. Dauzat. 2005. Soluble sugars mediate sink feedback down–regulation of leaf photosynthesis of *Coffea arabica* in the field. Tree Physiology. 26, 517-525.

Coffee quality:

Vaast P., Bertrand B., Guyot B., Génard M. (2005). Fruit thinning and shade influence bean characteristics and beverage quality of coffee (*Coffea arabica* L.) under optimal conditions. Journal of Science of Food and Agriculture. 86, 197-204.

Vaast, P. Cilas, C. Perriot, J; Davrieux, J; Guyot, B; Bolaños, M. 2005. Mapping of Coffee Quality in Nicaragua According to Regions. Ecological Conditions and Farm Management. *In* Proceedings of the 20th International Congress on Coffee Research (ASIC) Bangalore, India. p 842-850.

Vaast, P; Van Kanten, R; Siles, P; Dzib, B; Frank, N; Harmand, J; Genard, M. 2005. Shade: A Key Factor for Coffee Sustainability and Quality. Proceedings of the 20th International Congress on Coffee Research (ASIC) Bangalore, India. p 887-896.

Bertrand B., Etienne H., Guyot B., Vaast P. 2005. Year of production and canopy region influence bean characteristics and beverage quality of arabica coffee. Proceedings of the 20th International Congress on Coffee Research (ASIC) Bangalore, India, October 2004; p 878-886.

Articles submitted in 2005

Nitrogen cycling and emission:

Harmand JM, Ávila H, Dambrine E, Skiba U, Renderos RV, Oliver R, Jiménez F; Beer J. Nitrogen dynamics, soil nitrate retention and nitrate water contamination in a *Coffea arabica* - *Eucalyptus deglupta* agroforestry system in Southern Costa Rica. Journal of Environmental Quality (submitted).

Hergoualc'h K., Skiba U., Harmand J.M. and Oliver R. Nitrification: the major source of nitrous oxide emission from an Andosol of a coffee agroforestry plantation in Costa Rica. Soil Biology and Fertility (submitted).

Coffee physiology:

van Kanten R.F., Vaast P. Coffee and shade tree transpiration in suboptimal, low-altitude conditions of Costa Rica. Agroforestry Systems. (in press).

Vaast P., van Kanten R., Siles P., Angrand J., Aguilar A. Biophysical interactions between timber trees and coffee in sub-optimal conditions of Central America. Advances in Agroforestry Systems (in press).

B Bertrand, P Vaast, E Alpizar, H Etienne, P Charmetant. Comparison of bean biochemical composition and beverage quality of Arabica hybrids involving Sudanese-Ethiopian origins at various elevations in Central America. Tree Physiology (Accepted)

Vaast, P. Bertrand, B. Date of harvest and altitude influence bean characteristics and beverage quality of Coffea arabica in intensive management conditions. Field Crop Research (submitted).

N Franck, P. Vaast, J. Dauzat. Relationships between *Coffea arabica* L. photosynthetic performance and leaf structure as affected by acclimation to growth irradiance: a modelling analysis that includes limitations by stomatal conductance and photoinhibition. Journal of Experimental Botany (submitted).

N Franck, P. Vaast, A Clément-Vidal, J. Dauzat. Reduction of photosynthesis by low sink demand and photoinhibition in *Coffea arabica* L. leaves in relation to carbohydrate accumulation. Journal of Experimental Botany (submitted).

Articles in preparation in 2005

Nitrogen cycling:

Cannavo P., Harmand J.M., Dambrine E., Zeller B., Vaast P. Nitrogen-15 recovery in plants and soil in a *Coffea arabica - Inga densiflora* system. Agronomy Journal.

Harmand J.M., Dambrine E. Subsoil retention of nitrate under a coffee-tree plantation in an Acrisol of Southern Costa Rica. Geoderma.

Planned Partitioning of months /WP/PARTNER/for the FOURTH YEAR

Person-months/Year

CIRAD	**WP1**	**WP2**	**WP3**	**WP4**	**WP5**	**WP6**	**WP7**	**WP8**	**WP9**	**YR 4**
Total Permanent staff	0.25	2.5	3	2.25	6	1	3	0.25	2	**20.25**
Students				5						**5**
Total CIRAD Yr4	**0.25**	**2.5**	**3**	**7.25**	**6**	**1**	**3**	**0.25**	**2**	**25.25**

Actual Partitioning of months /WP/PARTNER/for the fourth YEAR

CIRAD	**WP1**	**WP2**	**WP3**	**WP4**	**WP5**	**WP6**	**WP7**	**WP8**	**WP9**	**Yr 4**
Philippe Vaast									1.59	1.59
Patrick Guezo									1.54	1.54
Philippe Vaast	0.5	3.00	3.00				3.00			9.50
Jean Dauzat		0.70	0.75							1.45
Jean-Pierre Bouillet				0.25	0.25					0.50
Philippe Bonnal							0.87			0.87
Jean-Michel Harmand				0.75	0.75					1.50
Patrice Cannavo				2.00	2.00					4.00
Bernard Guyot			0.30							0.30
Fabrice Davrieux			0.30							0.30
Jean-Jacques Perriot			0.30							0.30
Total Permanent staff	0.50	3.70	4.65	3.00	3.00	0	3.87	0	3.13	**21.85**
Students	4.00	2.00	4.0	0	0	0	0	0	0	**10.00**
Total CIRAD Yr 4	**4.50**	**13.55**	**12.65**	**3.00**	**3.00**	**0**	**3.87**	**0**	**3.13**	**31.85**

CASCA Project

Contractor NERC (Centre for Ecology and Hydrology)

Fourth Year Report

1. Participant number, name and address of the participating organisation

✉ **Contractor 3 (NERC – Centre for Ecology & Hydrology)**

Centre for Ecology and Hydrology – Bush Estate Penicuik, Midlothian EH26 OQP

2. Scientific team

Name.	Tel	Fax	E-mail
Mr Gerry Lawson	44 1793 4111925	44 1793 411545	gela@nerc.ac.uk
Dr Marcel van Oijen	44 131 445 8567	44 131 445 3943	mvano@ceh.ac.uk
Dr Ute Skiba	44 131 445 8532	44 131 445 3943	ums@ceh.ac.uk

3. Time spent on the different workpackages

Time (months) spent on the different workpackages during the fourth year

Name	WP1	WP2	WP3	WP4	WP5	WP6	WP7	WP8	Total
Mr Gerry Lawson						.68		2	2.68
Dr Marcel van Oijen						4		.43	4.43
Dr Ute Skiba				1.18					1.18
Total				1.18		4.68		2.43	8.29

Total time spent (8.3 months) is significantly more than in previous years. Some uncharged work will continue after then end of the Contract, particularly in the area of upscaling model predictions.

4. Contribution to workpackages:

4.1. WP1. Central American Coffee Agroforestry Knowledge

4.2. WP2 Light and Water partitioning at plot scale

4.3. WP3 Coffee ecophysiology and quality

(Total allocation 2.1 months, spend in year 4 =0 months)

Marcel van Oijen has incorporated output from this Workpackage in the integrated plot model.

4.4. WP4 Nitrogen cycling, leaching, uptake and emissions

(Total allocation 3.9 months, spend in year 4 =1.2 months)

During the final year Ute Skibe supervised PhD work carried out by Kristell Hergoualc'h. She visited CIRAD Montpellier on 30th August 2005 to discuss progress with Kristell and Jean-Michel Harmand/ Robert Oliver Kristel visited CEH Edinburgh for a month in Spring 05. Details of this cooperation are included in the WP4 report.

4.5. WP5 Carbon sequestration

(Total allocation 0.7 months, spend in year 4 = 0 months)

4.6. WP6 Integrated plot modelling

(Total allocation 7.8 months, spend in year 4 = 4.68 months)

Marcel van Oijen visited Guatemala from 22-27th November 05 for the annual project meeting, Montpellier from 6th to 9th June for a modelling workshop together with the workpackage leaders from workpackages 2,3 4, 5, 7 (briefly) and 8. He also attended and presented at the Final Workshop in CATIE from 21st to 25th November. His work is detailed in the WP6 report.

4.7. WP7 Economic modelling at farm scale

(Total allocation 1.7 months, spend in year 4 = 0 months)

4.8. WP8 Regional upscaling and policies

(Total allocation 2.8 months, spend in year 4 = 2.43 months)

Gerry Lawson participated in the modelling workshop in Montpellier from 6-9th June, and the final workshop in CATIE from 21-25th November 05. Details of progress on regional up-scaling and policies are given in the annual WP8 report.

5. Significant difficulties or delays experienced during the reporting period.

Year 4 saw a significant increase in time spent compared with previous years. Indeed there has been a financial (but not time) over-spend, explained by a) staff promotions since the start of the project, b) wage inflation being greater than assumed when planning the project in 2001, and c) many activities taking place later than anticipated. It is of course understood that only the contracted budget can be reclaimed.

CEH (Ute Skiba) made a significant contribution to the very successful WP4 and all expected targets have been met. The model developed in WP6 (Marcel van Oijen) was evaluated in Guatemala, Montpellier and Turrialba and successive modifications and calibration techniques incorporated. WP8 (Gerry Lawson) has produced intermediate versions of its deliverables but these need to be completed in the final report. This final report will be finalized by mid April 06.

Table 1 WP8 Workplan for Year 4

No.	Milestone/Task	Original month	Revised month
D8.1	Report on prospective marked for eco-friendly coffee in Europe	45	52
D8.2	Report on extrapolation from socio-economic farm model to level of administrative region	46	52
D8.3	Report on extrapolation of plot-scale biophysical model results to predict regional yield and environmental impacts	46	52
D8.4	Delivery of management and policy guidelines taking into account different climate, soil, market price and incentive scenarios.	48	52

CENTRO AGRONOMICO TROPICAL de INVESTIGACION y ENSEÑANZA

CATIE

ANNUAL REPORT of ACTIVITIES for the INCO PROJECT CASCA

4th YEAR (NOV. 2004 – DEC. 2005)

FEBRUARY 2006

INTRODUCTION

The project "Coffee Agroforestry Systems in Central America" with acronym CASCA, financed by the European Union, officially started on November 1st, 2001, with duration of four years. The objective of **the present report is to highlight the main activities undertaken by CATIE**, as partner of the project, during **the fourth year** (November 2004 - December 2004).

A total of **8 permanent researchers** were involved in the project for a total of **18. 5 months**. **Six students** (5 Masters students and one doctoral student), **2 technicians and several field workers, hired temporally**, were involved in field research for a total of **90 months**. This results in a **total input of 108.5 months** of work for this fourth year in comparison to the 61 months planned (see annex).

This report of activities is presented by Work-packages.

Work-Package 1: (Central American coffee agroforestry knowledge)

The main objective of this WP1 is collecting and analyzing data on farmers' agroforestry knowledge, over the first 24 months of the project, in major coffee-growing ecological zones of the 3 countries (Costa Rica, Nicaragua & Guatemala) considered in the project.

As a leader of this WP1, **CATIE** (Eduardo Somarriba) has helped to coordinate field surveys and in the supervision of students (two Ms students of UNA and two Ms students from CIRAD in Costa Rica).

Dr. Somarriba also updated the database on current coffee Agroforestry (AF) practices, completed and presented, in the final workshop, a synthesis of the surveys performed during previous years (see WP1 report).

Several scientific publications describing existing AF typologies in Central American coffee producing countries and their management have been published in 2003-2004 as well as a chapter "Biodiversity Conservation in Neotropical coffee (*Coffea Arabica*) plantations" in the book entitled "Agroforestry and Biodiversity Conservation in Tropical landscapes". These documents constitute the expected deliverables of Work Package 1 (Deliverable D13/D1.3 "Scientific report describing existing AF typologies and management"- Month 30).

Work-Package 2: (light and water partitioning at plot scale)

The main objective of this WP2 is assessing light and water partitioning between coffee and associate tree in a few target coffee AF systems of regions with distinct agro-ecological conditions.

CATIE has been strongly involved in **collecting data on transpiration** of both coffee and associated trees strata **using sap flow measurements.** One Ph.D student (Pablo Siles) has been collecting sap flow data, rain interception and trunk flow in optimal conditions for coffee cultivation all year long during this fourth year.

CATIE via one technician (Jonathan Ramoz), temporally hired by CATIE, has also been strongly involved in taking, 3 times a month, a total of **over 500 soil water measurements (with TDR equipment) in coffee AF systems** along the year in order to refine the water model.

CATIE via one student and one technician, temporally hired by CATIE, has been taking and analyzing over **700 hemispheric photos of shade tree canopies in AF systems** along the year in order to refine the light partitioning model according to seasonal changes in tree phenology.

Work-Package 3: (coffee ecophysiology and quality)

The main objectives of this WP3 are studying the **physiological responses of coffee leaves** to micro-environmental field conditions, **developing a model of carbon-allocation** in coffee plants as well as investigating the mechanisms responsible for **coffee quality**.

CATIE has been involved in measuring **fruit growth and carbon allocation** in a field trial in optimal conditions of the Central valley of Costa Rica. A technician (Jonathan Ramos) and temporary field workers, hired by CATIE, have helped a Ph.D. student from CATIE in measuring coffee leaf areas, fruit load and root weight of coffee plants in shaded and full sun plots.

CATIE has also been strongly involved in **quantifying the effects of shade, agricultural management and fruit load on the quality of coffee** in terms of bean size, bean biochemical composition and cup quality. During 8 months, one Masters student (Léonel Lara) has been investigating these effects on coffee quality via farmers surveys in Nicaragua with the tutoring of two researchers of CATIE (Elias de Melo and Jeremy Haggar). This student has collected coffee samples at the peak of harvest in over 60 farms for physical, biochemical and organoleptic analyzes (see WP2 report for details)

Work-Package 4: (Nitrogen cycling, leaching, uptake and emissions)

The main objectives of this WP4 are to **measure nitrogen (N) fluxes** in a few target coffee management systems, **to model N cycling** in order to **predict the N losses and accumulation**, and to carry out environmental evaluation at catchment's scale.

CATIE has contributed to this WP through the field work by one technician (Jonathan Ramoz) collecting soil and water samples in four coffee systems (see WP4 report for details). CATIE has analyzed more than 200 water samples for nitrate and ammonium in its laboratory with the N analyzer financed by the project.

Work-Package 5: (carbon sequestration)

The main objectives of this WP5 are to **measure carbon sequestration** in biomass and soil of a a few target coffee AF systems, to **create a database** of C sequestration in coffee AF systems in Central America, and to **develop a model** predicting C sequestration at the site scale and regional scale.

CATIE has contributed to this WP through the update (3 studies undertaken by the project) of the Carbon database in Access recapitulating studies undertaken over the last 25 years on C flux and accumulation in coffee AF systems in Central America and other coffee-producing countries. Furthermore, one technician has undertaken **measurements of tree biomass** in a coffee agroforestry trial in the central valley of Costa Rica.

Work-Package 6: (integrated plot modeling)

Like other partners, CATIE has contributed indirectly to this WP by collecting field data that will be used to finalize the parameterization of the biophysical model developed by the WP leader, Dr. Marcel van Oijen (see report of WP6).

Work-Package 7: (economic modeling at farm scale)

CATIE has contributed to this WP by helping supervising students in the field in Costa Rica and Guatemalan (see report of WP1) and providing an updated database of economic surveys undertaken in 2002-2004.

Work-Package 8: (regional up scaling and policies)

CATIE has contributed to this WP through discussions with the WP leader during consortium and technical meetings of CASCA.

Work-Package 9: (project management, dissemination, and exploitation)

CATIE has contributed to this WP by hosting a final consortium meeting in mid-November 2005.

Through **scientific publications**, CATIE has contributed to the exploitation and dissemination of results. **Six articles,** with CATIE staff or students as the main authors, have been published in 2002-2003 and **5** have been published in 2004 (see annexes below). **Six Masters theses and one Ph.D. thesis** have been presented in 2003 and **3 Masters theses** have been defended in 2004 and **3 Masters theses** in 2005 (see annexes below).

ANNEXES

Publications of CATIE

Articles

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Gutierrez Castillo Martha (2003). Disponibilidad y dinámica de nitrógeno en el suelo bajo especies maderables y leguminosas usadas como sombra en sistemas de café, en la subcuenca del Río Grande del General. Tesis Mag Sc. CATIE, Turrialba, CR., 62p.

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Leonel Lara Estrada. (2005). Efectos de la Altitud, Sombra, Producción y Fertilización sobre la Calidad del Café (*Coffea Arabica* L. var. Caturra) Producido en Sistemas Agroforestales de la Zona Cafetalera Norcentral de Nicaragua. Tesis Mag. Sc. Turrialba, C.R. CATIE. 106 p.

Planned Partitioning of months /WP/PARTNER/for the FOURTH YEAR

CATIE	WP1	WP2	WP3	WP4	WP5	WP6	WP7	WP8	WP9	Total Yr 4
Permanent staff	3	3	3	2	2.5		1.5	1	1	17
Hired staff	7	7	7	7	7		7.5	1.5		44
TOTAL	**12.0**	**12.0**	**12.0**	**11.0**	**9.5**	**0.0**	**9.0**	**2.5**	**1.0**	**69.0**

Actual Partitioning of months /WP/PARTNER/for the FOURTH YEAR

CATIE	WP1	WP2	WP3	WP4	WP5	WP6	WP7	WP8	WP9	Total Yr 4
E. Somarriba	1						0.25		0.25	1.50
J. Beer					0.50				0.25	0.75
J Haggar			1.50						0.25	1.75
E de Melo			1.50							1.50
M. Alvarado									1.50	1.50
L Jimenez									1.50	1.50
M. Cervantes		0.50	0.50	0.50	0.50					2.00
K. Hergoualch				4	4					8.00
Total Permanent Staff	**1.00**	**0.50**	**3.50**	**4.25**	**5.00**		**0.25**	**0.25**	**3.75**	**18.50**
Pablo Siles		8	6							14.00
Leonel Lara			8.93							8.93
Monica Salazar							8	6		14.00
Mario Ramirez		6					8			14.00
Meivis Ortiz	7						7			14.00
Jonathan Ramos		4	4	3	3					14.00
John Zuluaga					1.25					1.25
Victoria Osorio					1.25					1.25
Field assistants		2	2	2	2.56					8.56
Total Hired Staff	**7.00**	**20.00**	**20.93**	**5.00**	**8.06**		**23.00**	**6.00**		**90.00**
Total CATIE Yr 4	**8.00**	**20.50**	**24.43**	**9.25**	**13.06**	**0.00**	**23.25**	**6.25**	**3.75**	**108.50**

IICA-PROMECAFE

ANNUAL REPORT of ACTIVITIES for the INCO PROJECT

CASCA

4th YEAR (NOV. 2004 – DEC. 2005)

Carlos Foncesa and Luis D. García.

FEBRUARY 2006

REPORTE DE ACTIVIDADES DEL PROYECTO CASCA

AÑO 4 (Noviembre 2004 – Deciembre 2005)

IICA - PROMECAFE

Ing. Carlos Fonseca.
Coordinador administrativo.
Ing. Luis D. García.
Coordinador técnico.

Durante este último año del proyecto CASCA, se ha trabajado intensamente en la finca experimental del ICAFE, llamada CICAFE, la cual se ubica en el cantón de Barva, en la provincia de Heredia, Costa Rica.

El personal del ICAFE, en Costa Rica, que ha apoyado los trabajos desarrollados en el proyecto CASCA son: el Ing. Luís D. García y el Ing. Jorge Ramírez (WP 2, 4 y 5), el Ing. Víctor Chávez (WP3, 4 y 5) y el Ing. Carlos Fonseca como el coordinador administrativo por parte del IICA – PROMECAFE. Adicionalmente, el Ing. Mainor Rojas, de la sede Regional del ICAFE en Pérez Zeledón, ha participado durante el taller final de CASCA a la presentación del trabajo de encuestas a productores hecha en esta zona en 2004.

Con respecto al personal de ANACAFE, en Guatemala, el Ing. Byron Medina ha contribuido a los WP 7 y 8. Además, el Ing. Byron Medina ha apoyado la organización del taller del fin de tercer año en noviembre 2004 en la sede de ANACAFE y también participado al taller final de CASCA en Noviembre 2005 en la sede del CATIE en Turrialba, Costa Rica.

Este año se ha trabajo en la continuación de recolección de datos en los diferentes paquetes de trabajo que se están desarrollando en el CICAFE. Además se ha implementado pruebas adicionales a las que ya se llevan a cabo; según como se tenía previsto en los objetivos a realizar en el cuarto año.

El trabajo desarrollado por parte del Ing. Chávez en el paquete de trabajo WP 4, ha consistido en la continuación de la medición de biomasa y cosecha en la variedad de café CR-95, una síntesis de resultados en el ensayo de dosis y fraccionamiento de nitrógeno (ver anexos) y un estudio sobre la calidad del café.

El Ing. Ramírez ha colaborado con la continuación de la asistencia en las parcelas de investigación de Café con sombra de *Inga densiflora* y café expuesto a pleno sol, para medir entre otros parámetros la producción, la contaminación de aguas, emisión de gases de invernadero, fertilidad de suelos y secuestro de carbono. Durante este año, el Ing. Ramírez ha proporcionado también asistencia en parcelas adicionales, café con un manejo orgánico con sombra de *Erythrina poeppigiana* y café a pleno sol en las cuales se hicieron mediciones de biomasa y nitrógeno (ver detalles en reportes WP4 & WP5).

El tiempo empleado por el personal permanente de IICA – PROMECAFE fue de 14. 5 meses. El personal temporal representó 22.5 meses, en esté grupo se incluye al Ing. García y trabajadores de campo (ver Anexos).

Paquetes de trabajo (WP) desarrollados en la Finca del CICAFE.

- **WP 2: Partición de la luz y del agua a nivel de parcela (Ligth and water partioning at plot scale).**

Con respecto a este paquete de trabajo, en la finca del CICAFE se esta tomando datos para el desarrollo de un modelo hídrico, comparando café con sombra de Inga sp. y café expuesto a pleno sol. Adicionalmente se han tomado fotos periféricas (con la cámara de ojo de pez) para determinar la intercepción de luz por parte del follaje de los árboles de Inga.

Dentro de los parámetros que se están midiendo están: el flujo de savia en plantas de café y árboles de *Inga* sp. Se hicieron calicatas en los sistemas agroforestales de Café + Inga sp. y café a pleno sol para determinar la distribución de raíces. Con una estación meteorológica se registro temperatura y humedad del aire, precipitación, radiación solar y viento. también se registraron datos diarios de pluviómetros manuales baja cafetos y árboles para medir la intercepción de parte del follaje. Se midió la escorrentía en sistema de café pleno sol y en sistema agroforestal. Se utilizó un TDR para determinar cada diez días la humedad del suelo durante todo el año 2005.

- **WP 3: Calidad del café.**

Se realizo mediciones del efecto de la fertilización nitrogenada sobre la calidad organoléptica de la bebida con muestras de la cosecha 2004-2005 (ver detalles en anexos).

- **WP 4: Ciclo del nitrógeno, lixiviados y emisión (Nitrogen cycling, leaching and emissions).**

Se realizo mediciones de lixiviados tres veces por mes durante todo el año 2005 en cuatros sistemas agroforestales: el sistema de Café + Inga sp. y café a pleno sol (manejo convencional) con lisímetros a 4 profundidades (30 cm, 60 cm, 120 cm a 200 cm de profundidad) y en dos sistemas de manejo orgánico (60 y 120 cm de profundidad).

Después de la aplicación del isótopo marcado ^{15}N en Mayo del 2004, se recogió muestras para determinar la distribución del ^{15}N dentro de las plantas de café y los árboles de *Inga* y perdidas del N en forma gaseosa. Se proporciono apoyo con mano de obra para recoger gases a Kristell Herguoalc'h cuantificando la pérdida de N como N_2O en los sistemas de Café + Inga sp. y café a pleno sol con un manejo convencional (ver detalles en el reporte WP 4).

- **WP 5: Secuestro del carbono (Carbon sequestration).**

Se está estudiando la dinámica de la biomasa de las plantas de café, *Inga* sp. y *Erythrina* sp. y de la materia orgánica del suelo. Durante este cuarto año del proyecto CASCA, se realizó un estudio de biomasa de 10 ramas principales de árboles de *Inga densiflora* por medio de análisis destructivos de biomasa.

ANEXOS

Evaluación de la fertilización nitrogenada en el cultivo de café

Víctor Chaves Arias, ICAFE

A) Producción

Con el propósito de evaluar en el cultivo de café la fertilización nitrogenada en relación a dosis (150, 250 y 350 Kg/ha/a), fuentes (Nitrato de Amonio y UAN -fertilizante líquido producto de la mezcla de Nitrato de Amonio- y Urea) y fraccionamiento (3 y 6 aplicaciones), se estableció un ensayo en Barva de Heredia a 1180 msnm con el cultivar CR 95 manejado a plena exposición solar. Los cafetos fueron sembrados a plena exposición solar en Agosto de 1997 a una distancia de siembra de 1,70 por 0.90 m y a dos plantas por punto de siembra. Se empleó un diseño de bloques completos al azar con parcela dividida; clocándose el fraccionamiento en las parcelas grandes y fuentes y dosis en las pequeñas.

En 1998 se inició la aplicación diferencial de las fuentes y su fraccionamiento, empleándose en todas las parcelas una dosis uniforme de 150 Kg/ha/año; la que a partir de 1999 fue variada de acuerdo a los tratamientos.
Luego de 4 años de aplicación de los tratamientos y 3 cosechas evaluadas (Cuadro 1), no se encontró diferencia significativa para el fraccionamiento de la fertilización, pero sí para las fuentes, en donde en dos de los tres años y en el promedio de ellos el nitrato de amonio superó significativamente al UAN (Cuadro 1).

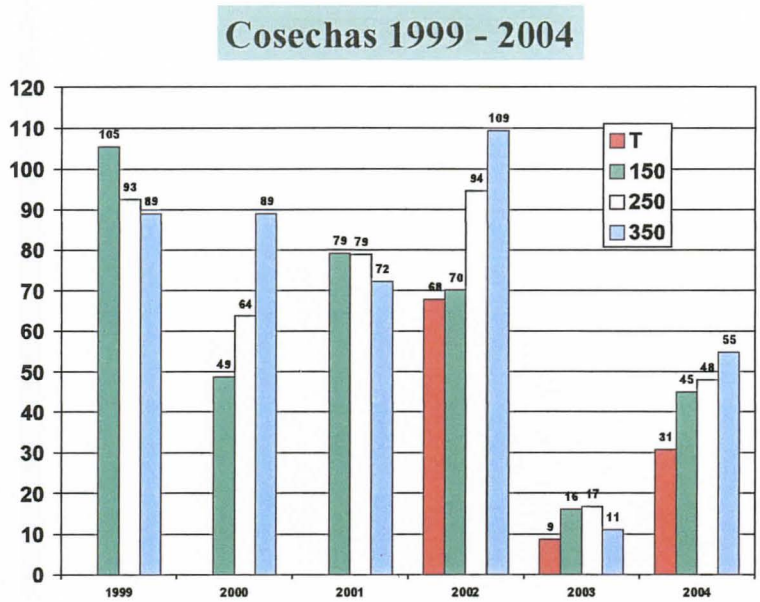
Cuadro 1. Cosechas evaluadas en Fa/ha.

	99/00	00/01	01/02	Promedio
Fuentes				
Nitrato de Amonio	100,5 a	64,4 a	78,2 ns	80,7 a
UAN	89,1 b	47,9 b	76,5	70,8 b
Fraccionamiento				
3 Aplicaciones	92,8 ns	57,9 ns	77,0 ns	75,6 ns
6 Aplicaciones	96,8	54,4	77,6	75,9
Dosis (Kg N/ha/a)				
150	96,4 ns	40,4 b	81,9 ns	72,6 b
250	90,0	58,1 b	73,5	73,5 b
350	98,1	69,8 a	76,6	81,2 a

Los tratamientos en los que se empleó Nitrato de Amonio fraccionado en 3 aplicaciones se continuaron por 3 evaluaciones más, completándose un total de 6 cosechas y además a partir del año 2002 se incluyó un testigo sin nitrógeno.

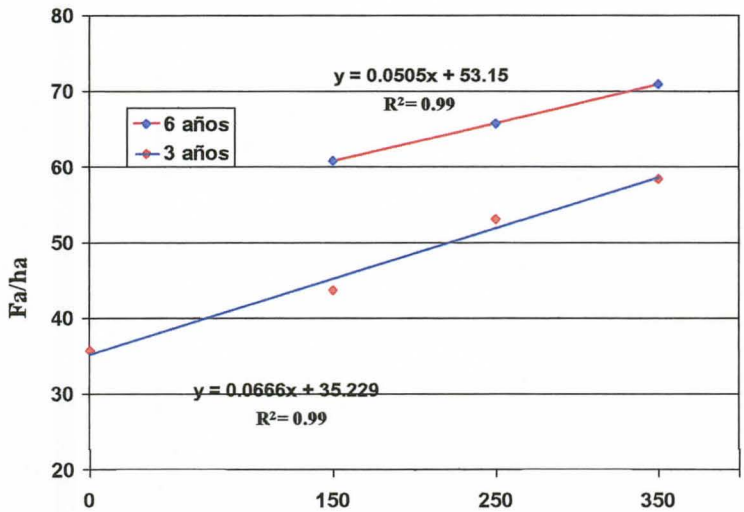
Como se puede observar en la figura 1 a partir de la segunda cosecha se estableció un comportamiento bianual en el que cada dos años (2000, 2002 y 2004) se presentó un efecto lineal al aumentar las dosis y en el intermedio se ubicaron años sin diferencias estadísticas en la producción. Después de la cosecha 2001, se podó anualmente una hilera de las cuatro útiles, por lo que la baja cosecha del 2003 es producto de la combinación de las podas y sobre todo del fuerte agotamiento de los cafetos luego de las elevadas cosechas precedentes.

Figura 1 Producción anual (Fa/ha) de los tratamientos con nitrato de amonio fraccionado en 3 aplicaciones.



Al analizar los promedios (6 años sin incluir el testigo y 3 años incluyéndolo) se confirma un efecto lineal al aumentar la dosis de nitrógeno.

Figura 2 Promedio de producción (Fa/ha) en tratamientos de nitrato de amonio fracionado en 3 aplicaciones, con (3 años) y sin inclusión (6 años) del testigo.

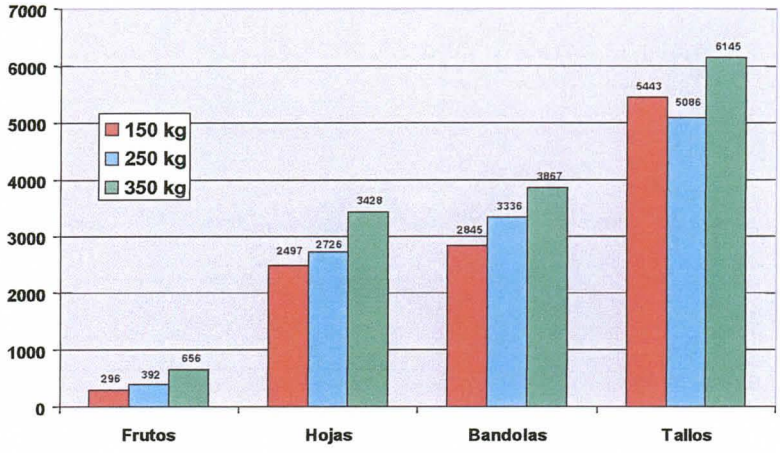


B) Contenido de nitrógeno en la planta

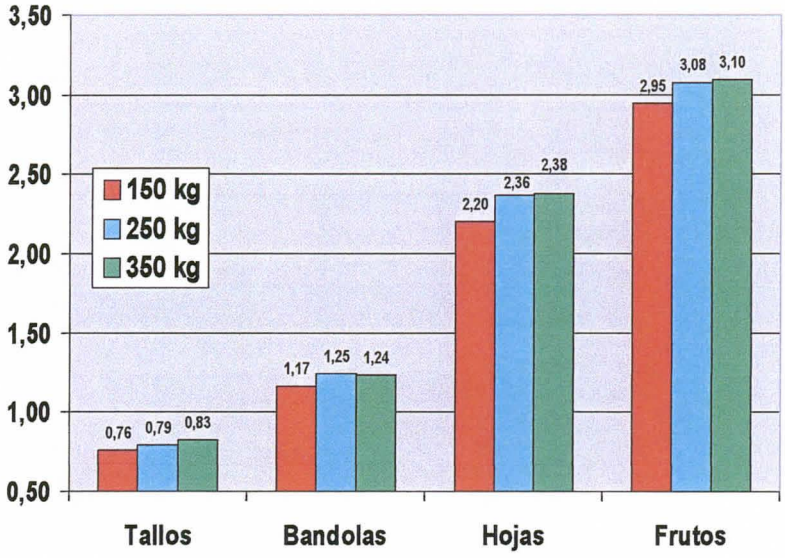
Aprovechando la poda de los cafetos en mayo 02 se cuantificó el contenido de nitrógeno por órgano de la parte aérea. Encontrándose en general que en cada uno de los compar-

Figura 3 Biomasa en kg/P.S. (A), concentración (%) de nitrógeno (B) y contenido (kg/ha) toal de nitrógeno en la parte aérea. Mayo 2002

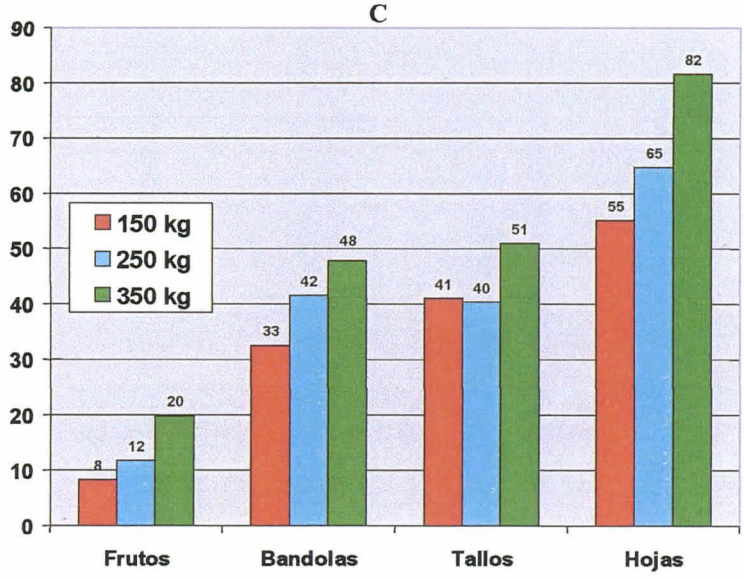
A



B

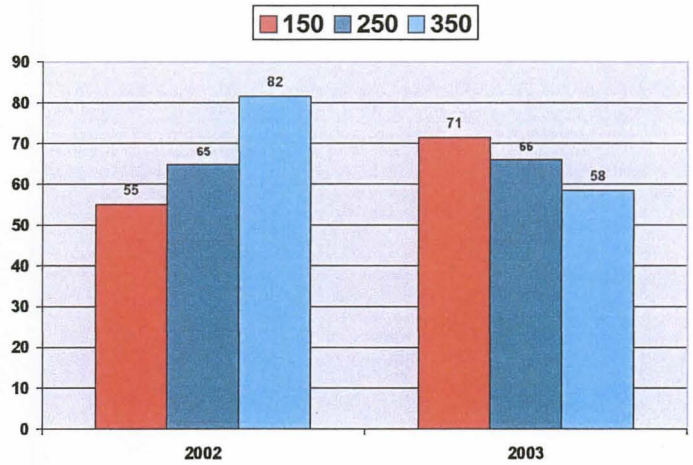


C



timentos evaluados (frutos, hojas, bandolas y tallos) se presentó un aumento en biomasa, concentración y contenido de nitrógeno total al aumentar la dosis del elemento (Fig. 3). No obstante debe indicarse que en posteriores análisis las concentraciones de nitrógeno en las hojas tuvieron un comportamiento errático, que podría explicarse por la carga diferencial de frutos que poseía cada tratamiento. Es por ello que al evaluar el contenido de nitrógeno en el follaje en la poda de mayo 03, se encontró un comportamiento inverso al del año anterior (Fig. 3) y que parece indicar una correlación negativa con la cosecha recién transcurrida.

Figura 4 Contenido de N (kg/ha) en el follaje de plantas podadas en Mayo 2002 y Mayo 2003.



En las cosechas 2003 y 2004 se evaluó la concentración de N en los frutos maduros, siendo el testigo el que claramente presentó los tenores más bajos (1,34 y 1,36% respectivamente). No obstante en el resto de los tratamientos -sobre todo en el segundo año-, la concentración de nitrógeno en los frutos pareció correlacionarse (negativamente) más con la magnitud de la cosecha que con la dosis de nitrógeno empleada (Cuadro 2). En todo caso cabe destacar el elevado contenido de los frutos en el tratamiento de 350 kg N/ha durante el primera cosecha evaluada que sería, producto de la combinación de una dosis alta y una muy baja cosecha.

Cuadro 2 Concentración de N, en frutos maduros. Cosechas 2003 y 2004.

Tratamiento	Cosecha	
Kg N/ha	2003	2004
0	1,34 %	1,36 %
150	1,58 %	1,51 %
250	1,53 %	1,43 %
350	1,89 %	1,40 %

C) Efecto de la fertilización nitrogenada sobre la acidez y contenido de bases en el suelo

Durante el transcurso del ensayo se efectuaron 2 análisis se suelo, tomándose las muestras de cada una de las parcelas sobre la banda de fertilización. En ambos análisis se observó claramente un aumento de la acidez del suelo (Disminución del pH y aumento de la acidez intercambiable) al incrementar la dosis del fertilizante nitrogenado, mientras que el nivel de las bases tendió a disminuir. Ambos efectos concuerdan plenamente con lo reportado en la literatura.

El encalado y la fertilización potásica justificarían que en la segunda medición para cada tratamiento se presentó una menor acidez y mayor contenido de K.

Cuadro 3 Resultados de los análisis de suelos efectuados en febrero 2001 y abril 2004.

D)

Fecha de Muestreo	Dosis N Kg/ha		cmol(+)/L			
		pH	Acidez	K	Ca	Mg
Febrero 2001	150	4,79	1,93	0,59	2,66	1,32
	250	4,50	2,80	0,44	1,60	0,79
	350	4,37	3,17	0,41	1,43	0,68
Abril 2004	0	5,50	0,42	1,16	4,53	1,03
	150	5,23	0,65	0,97	5,09	0,94
	250	5,03	1,87	0,74	2,29	0,50
	350	4,98	2,14	0,59	1,88	0,51

Efecto de la fertilización nitrogenada la calidad organoléptica de la bebida.

A diferencia de otros ensayos reportados en la literatura no se observó un efecto negativo de la fertilización nitrogenada sobre las características organolépticas de la bebida ya que en la prueba de catación solo se presentó diferencia significativa para el aroma, en donde los tratamientos que recibieron nitrógeno no difirieron entre sí, pero todos superaron al testigo (Cuadro 4).

Cuadro 4 Resultados de la catación efectuada en la cosecha 2004-2005.

Dosis N (kg/ha)	Aroma	Cuerpo	Acidez	Taza
0	3,33 b	3,00 a	2,83 a	2,50 a
150	3,88 a	3,13 a	2,25 a	2,38 a
250	4,13 a	3,00 a	2,75 a	2,38 a
350	3,83 a	3,33 a	2,50 a	2,33 a

Variación estacional de la extracción de Nitrógeno

Víctor Chaves (CICAFE, Costa Rica)

En Poas de Alajuela, Costa Rica; a 1300 msnm se montó un ensayo con el propósito de cuantificar la variación estacional de la biomasa y extracción de nitrógeno en el cultivo de café durante un ciclo anual de alta producción. Se escogió una parcela de gran uniformidad fenotípica del cultivar Catuaí, que al inicio del ensayo contaba con dos años de edad y se preparaba para su primera cosecha fuerte; los cafetos fueron establecidos a plena exposición solar y una densidad de 10.176 pts/ha, utilizándose solamente una planta por punto de siembra.

A partir de mayo 2003 y hasta setiembre 2004 se realizaron 7 muestreos, en cada una de los cuales se arrancaron 9 plantas en las que se determinó por órgano (hojas, frutos, bandolas, tallo y raíz) la biomasa (peso seco) y sus contenidos de nitrógeno, potasio, calcio y magnesio; calculándose por diferencia entre muestreos la ganancia en biomasa y la extracción de nutrientes.

El ensayo se inicio en mayo 2003 con una biomasa total de 14 Tm/ha (figura 1), de las cuales un 42 % (figura 2) correspondió a las hojas. En la medición de diciembre 2003 se alcanzó el pico de la biomasa total con 24 Tm/ha, en las que los frutos representaron un 42 % y las hojas tan solo un 22%.

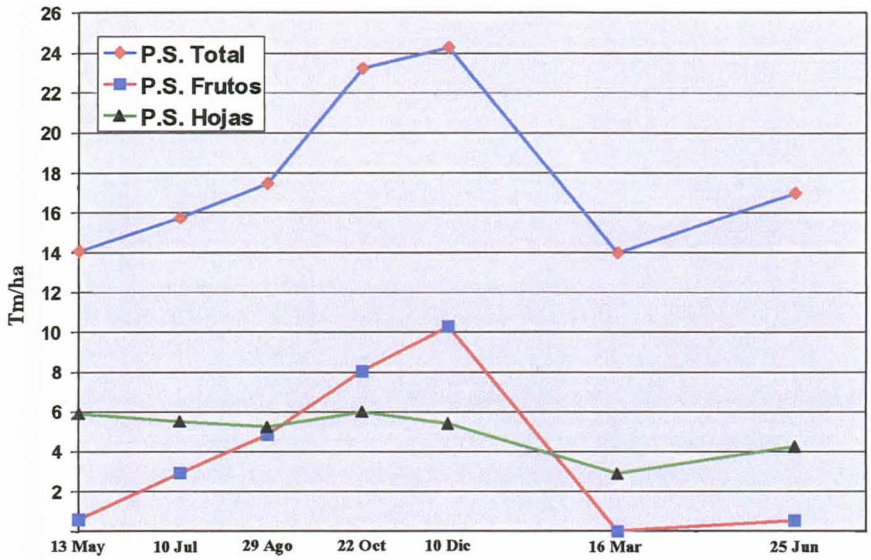


Figura 1 Variación estacional en peso seco (Tm/ha) de la biomasa total, biomasa de hojas y biomasa de frutos. Poas, mayo 2003 – Junio 2004.

Como consecuencia de la cosecha de frutos y una fuerte caída de hojas, en la evaluación de marzo 2004 se alcanzó el menor valor en la biomasa total durante el período de estudio y el sistema tallo-raíz fue su principal componente (52 %).

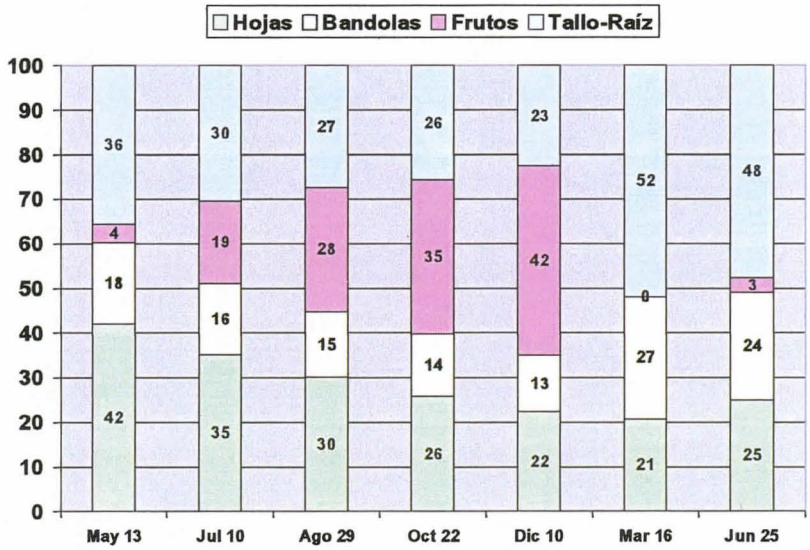


Figura 2 Variación estacional de la contribución porcentual de los órganos en la biomasa total. Poas, mayo 2003 – Junio, 2004.

En mayo 2003 los cafetos tenían en su biomasa el equivalente de 255 kg N/ha (Cuadro 1) de los cuales el 60 % se encontraba en las hojas. En diciembre 2003 el contenido de nitrógeno alcanzó su valor máximo con 415 kg/ha siendo los frutos con un 47 % (figura 3) el principal reservorio del elemento en la planta. A continuación, la cosecha -estimada en 140 Fa/ha-, unida a la defoliación -propia del período seco-, causó una fuerte pérdida de nitrógeno en la plantación, de forma que los 172 kg N/ha encontrados en la evaluación de marzo 04 fue el valor más bajo que de este elemento se registró durante el transcurso del ensayo.

Cuadro 1 Contenido total de nutrientes en los cafetos (kg/ha) en cada una de las evaluaciones realizadas. Poas 2003 – 2004.

	Kg/ha			
Fecha	N	K	Ca	Mg
13 Mayo 03	255	173	123	35
10 Julio 03	275	228	102	36
29 Agosto 03	307	298	120	38
22 Octubre 03	364	410	155	43
10 Diciembre 03	415	440	143	40
16 Marzo 04	172	106	50	23
25 Junio 04	256	199	90	27

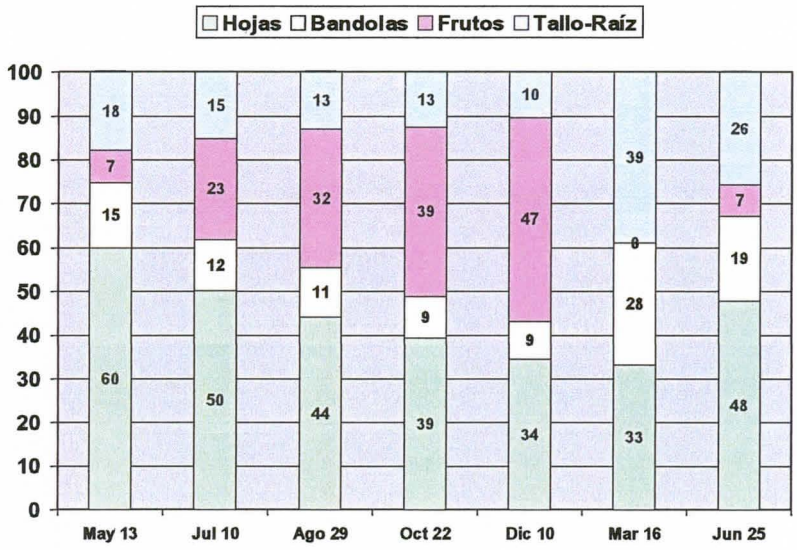


Figura 3 Variación estacional de la contribución porcentual de los órganos en el contenido de N en la planta. Poas, mayo 2003 – Junio, 2004.

Con base en el incremento de la biomasa en pie, más el follaje caído y la cosecha de frutos, se estimó la producción anual de biomasa en 21125 kg/ha y la extracción de nitrógeno en 340 kg/ha, siendo los frutos con 192 kg/ha el órgano de mayor demanda seguido de las hojas con 110 kg/ha (Cuadro 2).

Cuadro 2. Producción de biomasa y extracción de nitrógeno. Poas 2003-2004.

Órgano	kg/ha/año	
	Producción de biomasa	Extracción de nitrógeno
Hojas	5491	110
Bandolas	1403	15
Fruto	11563	192
Tallo-Raíz	2668	23
Total	**21125**	**340**

Para uniformar los períodos de evaluación se calculó por período, la extracción promedio semanal (Figura 4); encontrándose que del inicio del ensayo –al comienzo de la estación lluviosa-, hasta la evaluación de octubre-diciembre, se presentó un comportamiento lineal que se inició con 5,1 kg N/ha/semana y alcanzó su pico con 9,4 kg N/ha/semana. En la evaluación siguiente, que comprende el período de maduración y cosecha, se registró la extracción menor (4,8 kg N/ha/semana).

Los datos del presente ensayo sugieren que en años de elevada cosecha la demanda de nitrógeno por la planta se incrementa junto al desarrollo de los frutos, alcanzando sus máximos valores en la etapa final del llenado del grano, previo a la maduración del mismo.

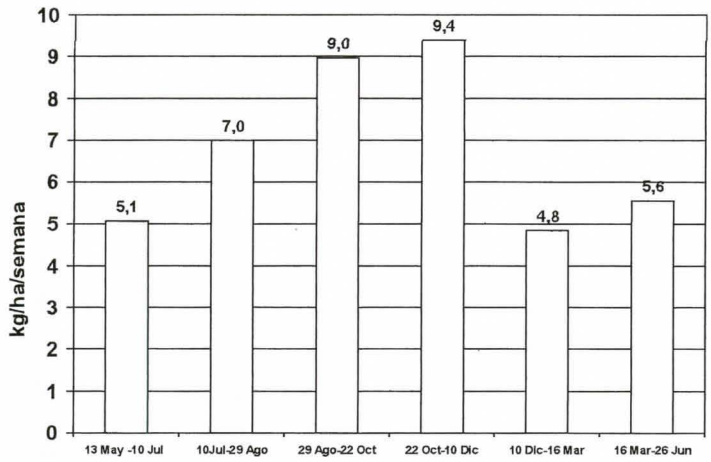


Figura 4. Extracción semanal de nitrógeno. Poas 2003-2004.

Otro ensayo similar al anterior se condujo en CICAFE, finca experimental del Instituto del Café de Costa Rica, situada en San Pedro de Barva Heredia, y en el se contempló el estudio de la evolución de la biomasa y la extracción de nitrógeno en períodos seguidos de alta y baja producción. Este estudio se llevó acabo en un lote de gran uniformidad fenotípica de la variedad Costa Rica 95, el cual se preparaba para su primera cosecha luego de haber sido sometido a una poda baja en el 2001. En este ensayo se consideró únicamente la biomasa de los hijos de poda sin tomar en cuenta el sistema radical ni el tallo original.

A partir de finales de abril de 2003, con una periodicidad de aproximadamente dos meses, se arrancaron los hijos de poda de 12 plantas (4 bloques x 3 plantas), midiéndose en cada una de ellas el peso de hojas, frutos, tallos y bandolas.

Para efectos de discusión el período de estudio de este ensayo se dividirá en 2 ciclos productivos; el primero de ellos abarca del 24 de abril 2003–poco después de las floraciones principales- al 9 de marzo 2004 para un total de 314 días y, el segundo que se inicia en la última fecha señalada y finaliza 414 días después (14 de abril 2005).

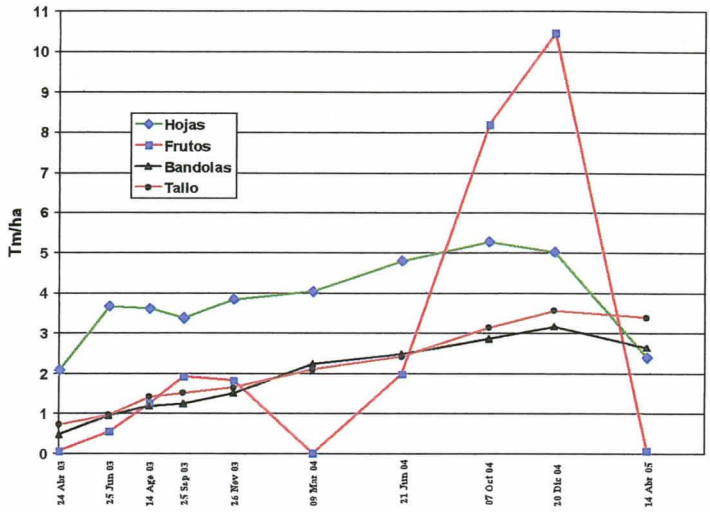


Figura 5. Variación estacional de la biomasa por órgano. CICAFE 2003-2005

En el primer ciclo la producción se estimó en 34,1 Fa/ha, y en el predominó el crecimiento vegetativo sobre el reproducido ya que de una producción de biomasa de 8915 kg/ha el 72,5 % correspondió a los órganos vegetativos (principalmente hojas) contra un 27,5% de los frutos. (Figuras 5 y 6)

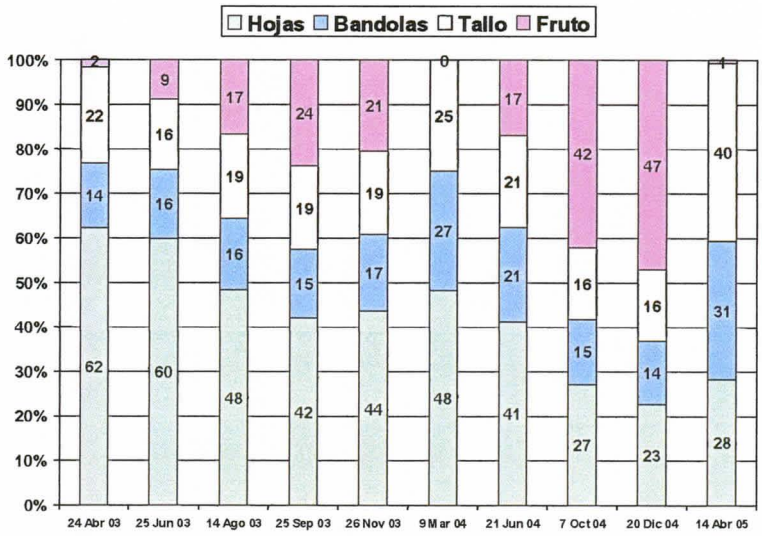


Figura 6. Variación estacional de la distribución de la biomasa por órgano. CICAFE 2003-2005.

El mayor acúmulo de nitrógeno se presentó en la evaluación de noviembre (maduración de frutos) con 178,5 kg N/ha, encontrándose en las hojas el 63% y en los frutos el 18% (Figura 7).

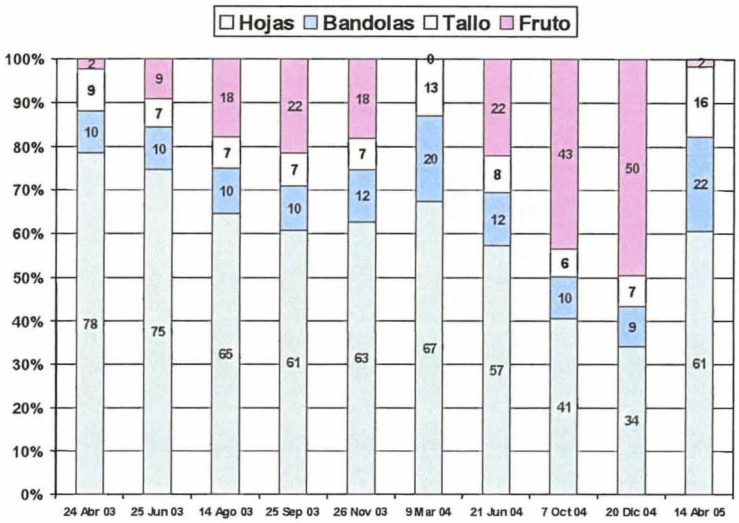


Figura 7. Variación estacional de la distribución de nitrógeno por órgano. CICAFE 2003-2005.

En el segundo ciclo, la producción fue mucho mayor estimándose en 135,7 Fa/ha. El 20 de diciembre 2004 la biomasa alcanzó los 22220 kg/ha, correspondiendo a los frutos el 47 %. El mayor acúmulo de nitrógeno en este período se registró el 7 de octubre 2004 con 361 kg N/ha del que un 43 % se encontraba en la s frutas y un 41 % en la s hojas.

La extracción anual (365 dias) de nitrógeno, se estimó en 185 y 170 kg/ha para el primer y segundo período respectivamente (Cuadro 3).

Cuadro 3. Producción de biomasa y extracción de nitrógeno en el primer y segundo año de evaluación.

Órgano	Kg/ha		
	Biomasa	N	
Hojas	3872	96	Primer año
Bandolas	2043	29	
Fruto	2852	45	
Tallo	1597	16	
Total	10.364	185	
Hojas	2379	37	Segundo año
Bandolas	359	-9	
Fruto	9891	147	
Tallo	1141	-5	
Total	13.771	170	

Durante el primer ciclo la extracción semanal de nitrógeno alcanzó su mayor expresión entre abril y junio 2003, período en el que se presentó un fuerte crecimiento foliar; mientras que en el segundo ciclo ocurrió entre las evaluaciones del 21 de junio y el 7 de octubre 2004, coincidiendo con el llenado de los frutos (Figura 8).

Planned Partitioning of months /WP/PARTNER/for the FOURTH YEAR

IICA-PROMECAFE	WP1	WP2	WP3	WP4	WP5	WP6	WP7	WP8	WP9	Total Yr 4
Permanent staff	3	2	3.5	5.5	1		1	1	1	18
Hired staff	4	4	5	4	4		3	2		26
TOTAL	**7.0**	**6.0**	**8.5**	**9.5**	**5.0**	**0.0**	**4.0**	**3.0**	**1.0**	**44.0**

Actual Partitioning of months /WP/PARTNER/for the FOURTH YEAR

IICA-PROMECAFE	WP1	WP2	WP3	WP4	WP5	WP6	WP7	WP8	WP9	Total Yr 4
C. Fonseca	1								0.75	1.75
V. Chaves			1.5	1.5	1.5					4.5
M. Rojas	1									1
J. Ramirez		1	1	1	1					4
B. Medina							1.50	1.50		3
G. Canet									0.25	0.25
Total Permanent staff	**2.00**	**1**	**2.50**	**2.50**	**2.50**	**0.00**	**1.50**	**1.50**	**1.00**	**14.50**
L.D. Garcia		3	3	3	3					12.00
Field workers		2.50	2.50	3.5	2					10.50
Hired staff		**5.50**	**5.50**	**6.50**	**5.00**					**22.50**
Total Promecafe Yr 4	**2.00**	**6.50**	**8.00**	**9.00**	**7.50**	**0.00**	**1.50**	**1.50**	**1.00**	**37.00**

UNIVERSIDAD NACIONAL AGRARIA

INFORME TÉCNICO ANUAL DEL PROYECTO UNA/CASCA EN NICARAGUA AÑO 4 (Noviembre, 2004 – Diciembre, 2005)

Glenda Bonilla M.Sc.
Víctor Aguilar Ph.D.
Rodolfo Munguía M.Sc.
Martha Gutiérrez M.Sc.

I. INTRODUCCIÓN

El Proyecto CASCA, con financiamiento de la Unión Europea, actualmente está concluyendo el cuarto año de ejecución. El presente informe tiene como objetivo presentar las actividades que la Universidad Nacional Agraria (UNA) ha realizado, como socio del Proyecto, durante el período Noviembre 2004 - Diciembre 2005.

II. EQUIPO DE DOCENTES Y ESTUDIANTES DE LA UNA QUE PARTICIPAN EN LAS ACTIVIDADES DEL PROYECTO

Los docentes-investigadores involucrados en el proyecto CASCA, como parte del equipo de la UNA, son los M.Sc. Glenda Bonilla, Martha Gutiérrez, Rodolfo Murguía y el Dr. Víctor Aguilar. Los estudiantes y egresados de la UNA que participaron durante este mismo período son: Justo Castro, Diana Díaz, Manuel Calero, Dayling Balladares, Enrique López, Carlos Parrales, Yader Calderón Cerros, Wilfredo Fuente Masis, Oswaldo González Rodríguez, Aura Astelia Lazo, Danilo Pérez, Otoniel Soza, y Andrea Pilati.

III. ACTIVIDADES REALIZADAS.

La presentación de los resultados de los trabajo de investigación, se realizará de acuerdo a los paquetes de trabajo que comprende el Proyecto.

Durante el período del cuarto año de actividades del proyecto, el tiempo empleado por el personal permanente de la UNA fue de 15.38 meses, incluyendo en este grupo al equipo de docentes-investigadores, a los conductores y al delegado administrativo. El tiempo empleado por el personal temporal fue de 10.66 meses. En este último grupo se incluyen a los estudiantes, técnicos de campo y trabajadores de campo contratados.

3.1 Avances de las investigaciones, descritos de acuerdo a los paquetes de trabajo.

3.1.1. Aspectos biofísicos: Ecofisiología y Calidad del café (WP3), Reciclaje del Nitrógeno, lixiviación, absorción y emisiones (WP4).

En el marco de los aspectos biofísicos del Proyecto, específicamente en el paquete de Ecofisiología y calidad del café, se ha continuado con el estudio del sistema agroforestal de café con sombra de madero negro (*Gliricidia sepium* (Jacq.) Steud) en la Región Pacífico Sur de Nicaragua. Las actividades desarrolladas desde Junio del 2002 hasta Diciembre del 2005 se detallan a continuación:

Con el inicio del proyecto CASCA, en el mes de Junio del 2002 se establecieron contactos con productores cafetaleros de Masatepe y San Marcos, Carazo. La parcela que presentó las mejores condiciones para este estudio fue localizada en la Empresa Inversiones Generales S. A, conocida como Santa Rosa. El Administrador de esta empresa el Lic. Guillermo Quiñones al exponerle la temática fue muy positivo mostrando interés y apoyo en la investigación. Esta situación la ha demostrado a lo largo del estudio ya que la coordinación entre la UNA y los técnicos de la finca ha sido muy efectiva.

De las tres fincas que conforman la Empresa Inversiones Generales, se seleccionó una parcela de café plantada en el año 2000 con la variedad Costa Rica 95 (T8667) en la finca San Francisco, San Marcos, Carazo. Las plantas de café seleccionadas para la siembra tenían un año de crecimiento en el vivero. La zona presenta temperaturas promedios anuales de 24 grados centígrados, precipitaciones durante los últimos 10 años entre 1200 y 2000 mm, distribuidas entre los meses de mayo y noviembre del año y una humedad relativa de 85%. Los suelos son profundos, francos y de origen volcánico y están a una altitud de 480 metros sobre el nivel del mar.

Los tratamientos seleccionados para el presente estudio quedaron establecidos así:

A. Café con sombra de madero negro con aplicación convencional de fertilizante químico
B. Café a plena exposición solar con aplicación convencional de fertilizante químico.
C. Café con sombra de madero negro sin aplicación de fertilizante.

Cada parcela experimental consta de 24 surcos por 40 metros de largo para un área de 1920 metros cuadrados. La densidad de siembra del café fue de 2 metros entre hileras y 1 metro entre plantas para una densidad poblacional de 5000 plantas por hectárea. El total del área experimental es de 5760 metros cuadrados. Para poder establecer la parcela a plena exposición solar se cortaron todos los árboles de madero negro en junio del 2002, dejando un tocón entre 1.5 a 2 metros de altura tratando de recuperar estos árboles en el futuro.

Manejo agronómico de las parcelas de café

El control de las malezas se realizó a través de aplicaciones de herbicidas como Paraquat (gramoxone) usando dosis de 2 litros por hectárea.y corte de las malezas utilizando como herramienta el machete. En las parcelas existe presencia de diferentes tipos de bejucos o malezas con hábito de crecimiento rastrero y trepador que dificultan el desarrollo normal de las plantas. Estos son retirados de la copa de los árboles de café manualmente. La presencia de estos bejucos es producto del uso continuo de herbicidas a lo largo de los años.

Aunque este año 2005 hubo baja presencia de broca (*Hypotenemus hampei*) en los frutos de café se realizaron aplicaciones del insecticida endosulfan (Thiodan) en dosis de 1.4 litros por hectárea. Se presentó bajos índices de incidencia de chasparria (*Cercospora coffeicola*) por lo que no hubo necesidad de aplicaciones de fungicidas.

La fertilización realizada durante el 2005 fue aplicada en el mes de junio, con 165 kg de Urea 46%, 65 kg de completo 18-46-00 y 32.5 kg de KCl al 60%. En el mes de agosto se aplicaron 259 kg de completo 34.8-18.4-00, 65 kg de completo 18-46-00 y 65 kg de KCl al 60%.

3.1.1.1. Ecofisiología y calidad del café

Antes de iniciar la toma de datos, en julio del 2002, se midió el diámetro y la altura a todas las plantas de café del área experimental para obtener una media de ambas variables. Tomando en cuenta la media de altura y diámetro se procedió a seleccionar 16 plantas por parcela en julio de 2002 y 48 plantas en mayo del 2003. Las plantas de café bajo sombra se seleccionaron entre 2 o 3 metros de los árboles de sombra y las plantas de café a plena exposición solar se seleccionaron a 4 metros o más de cada tocón del árbol de madero negro que fue eliminado.

Las 16 plantas seleccionadas en julio del 2002, fueron evaluadas en Agosto y diciembre del mismo año y las 48 plantas seleccionadas en mayo del 2003 fueron evaluadas en junio, septiembre y diciembre del 2003 y junio, septiembre y diciembre del 2004.

Evaluaciones realizadas

Variables tomadas en Agosto y Diciembre del 2002, Junio, Septiembre y Diciembre del 2003 y 2004

a.- Crecimiento:
1. Altura (cm) de la planta desde la superficie del suelo hasta el último nudo del tallo
2. Diámetro (cm) del tallo a una altura de 10 cm sobre la superficie del suelo
3. Proyección de copa (metros cuadrados)
4. Número de nudos en el tallo principal
5. Número de ramas agotadas en la planta
6. Número de ramas primarias totales de la planta
7. Número de ramas primarias productivas
8. Número ramas secundarias totales de la planta
9. Número de ramas secundarias productivas de la planta
10. Número ramas terciarias totales de las ramas secundarias
11. Número de ramas terciarias productivas

b. Estructura productiva:
Partiendo del ápice de la planta, en las ramas primarias número 7, 11, 15, 19, 23, 27, 31 y 35 se midieron las siguientes variables:

1. Largo del tejido viejo de la rama
2. Largo del tejido nuevo de la rama
3. Número de nudos en el tejido viejo

4. Número de nudos en el tejido nuevo
5. Número de nudos productivos en el tejido viejo
6. Número de nudos productivos en el tejido nuevo
7. Número de hojas en tejido viejo
8. Número de hojas en tejido nuevo
9. Número de frutos totales

c.- Biomasa, absorción y acumulación de nitrógeno en los diferentes componentes de la planta de café se utilizó el método destructivo.

1. Peso fresco, peso seco y contenido de nitrógeno del sistema radicular
2. Peso fresco, peso seco y contenido de nitrógeno del tallo
3. Peso fresco, peso seco y contenido de nitrógeno de las ramas
4. Peso fresco, peso seco y contenido de nitrógeno de las hojas
5. Peso fresco, peso seco y contenido de nitrógeno de los frutos

De cada uno de los componentes de la planta, se tomó una muestra de 200 gramos de peso fresco por planta muestreada y se colocaron en un horno eléctrico de flujo de aire abierto a 60 grados centígrados por 48 horas o hasta peso constante. De esta forma se obtuvo un factor de conversión de peso fresco a peso seco de cada uno de los componentes de la planta de café convirtiendo el peso fresco en peso seco. Las muestras secas se molieron a 1mm de diámetro y se enviaron al laboratorio de la Universidad Nacional Agraria (UNA) para determinar la concentración de nitrógeno. Al laboratorio solo se enviaron muestras en el 2002 y 2003 y por presentar resultados similares de la concentración de nitrógeno en los dos años se decidió tomar el dato promedio de los dos años para obtener los datos de absorción y acumulación de nitrógeno de los datos correspondientes al 2004.De las 8 plantas por parcela, se mezclaron las muestras 1, 2 y 3, la 4, 5 y 6 y la 7 y 8 para un total de 3 muestras por parcela por componente de la planta de café.

d.- Cosecha de café uva

La cosecha de café uva fue realizada en toda la parcela de 1920 metros cuadrados. En el 2002 se realizaron 5 cosechas, en el 2003 y 2004 se realizaron 7 cosechas, y en la cosecha del 2005 se realizaron 4 cosechas. De cada una de las cosechas por año se tomó una muestra por tratamiento y el café oro fue enviado al laboratorio de UNICAFE (CERCAFENIC) para análisis físico y organoléptico. De igual manera se enviaron muestras de café oro al laboratorio del CIRAD Francia para análisis Químico. Los resultados se pueden apreciar en la figura siguiente donde el café bajo sombra sin fertilizante obtuvo el mayor rendimiento acumulado durante los 4 años.

e. Calidad

Para cada año 2002, 2003, 2004 y 2005, se realizaron muestras de café por cosecha y por parcela para análisis físico y organoléptico al laboratorio de CERCAFENIC, UNICAFE, Managua.

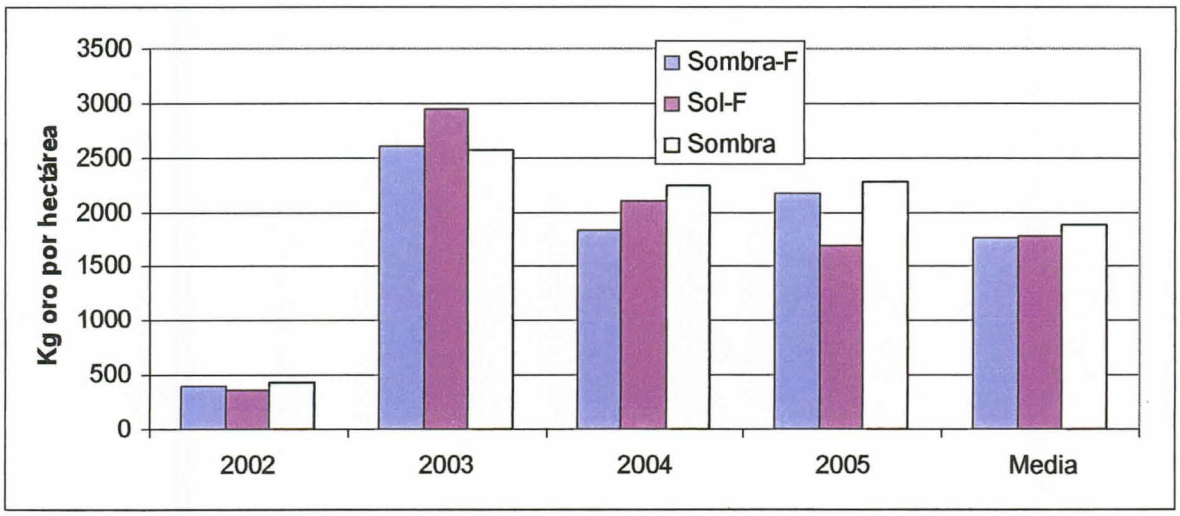


Figura 1. Rendimiento del café oro en café con sombra y fertilización química, café bajo sol con fertilización química y bajo sombra sin aplicación de fertilizante.

f. Biomasa fresca y seca de follaje y ramas de *G. sepium*: En agosto del 2002 y 2003, septiembre del 2004 y agosto del 2005, se midió la biomasa fresca y seca aportada por las hojas y ramas de los árboles de sombra de madero negro al momento de la poda. La poda consistió en elevación y descentralización. Las hojas y las ramas de madero se analizaron para determinar el contenido de nitrógeno obteniéndose 3.7% de nitrógeno en las hojas y 1.04% de nitrógeno en las ramas respectivamente. En total se contabilizaron 156 árboles de madero negro por hectárea.

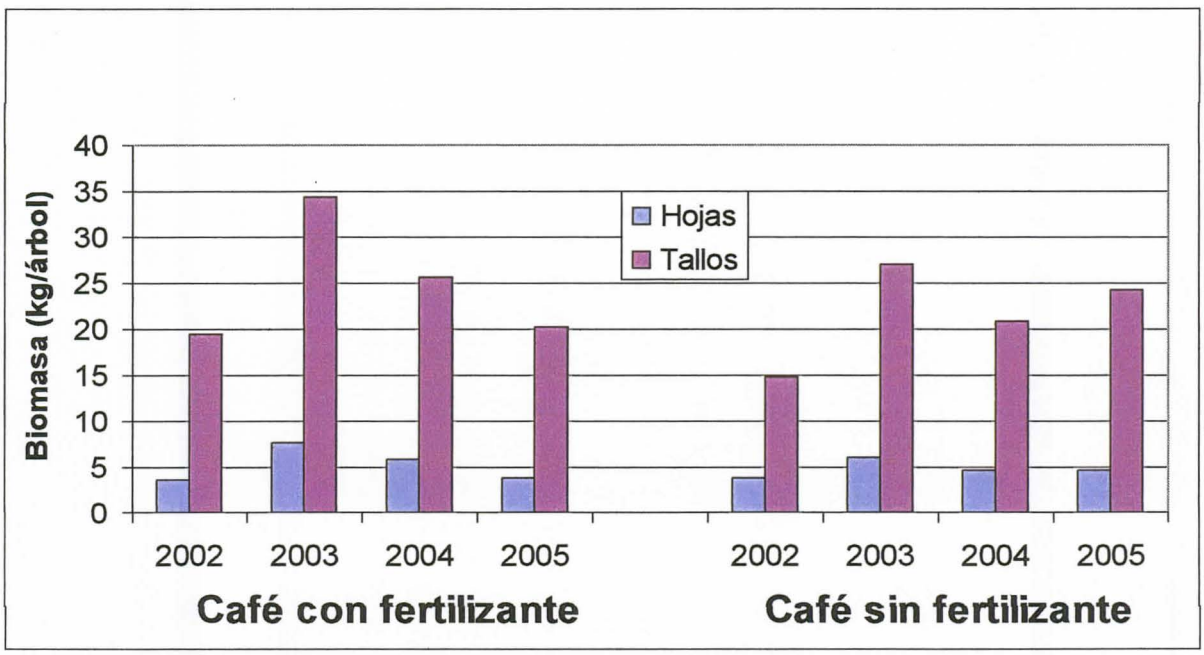


Figura 2. Aporte de biomasa en kg/ha por las hojas y ramas producto de la poda de madero negro en los cuatro años de estudio.

El aporte de nitrógeno al suelo por la poda de las ramas de madero negro se puede ver en la siguiente figura. Las hojas en el sistema con fertilizante aportaron un promedio de 796 kg de biomasa seca por hectárea correspondiente a un promedio de 30.5 kg de nitrógeno por hectárea en los 4 años y los tallos aportaron 3635 kg de biomasa seca por hectárea correspondientes a 40.3 kg de nitrógeno por hectárea. El sistema de sombra sin fertilizante las hojas aportaron un promedio de 27.9 kg de nitrógeno por hectárea y los tallos 35.1 kg de nitrógeno por hectárea.

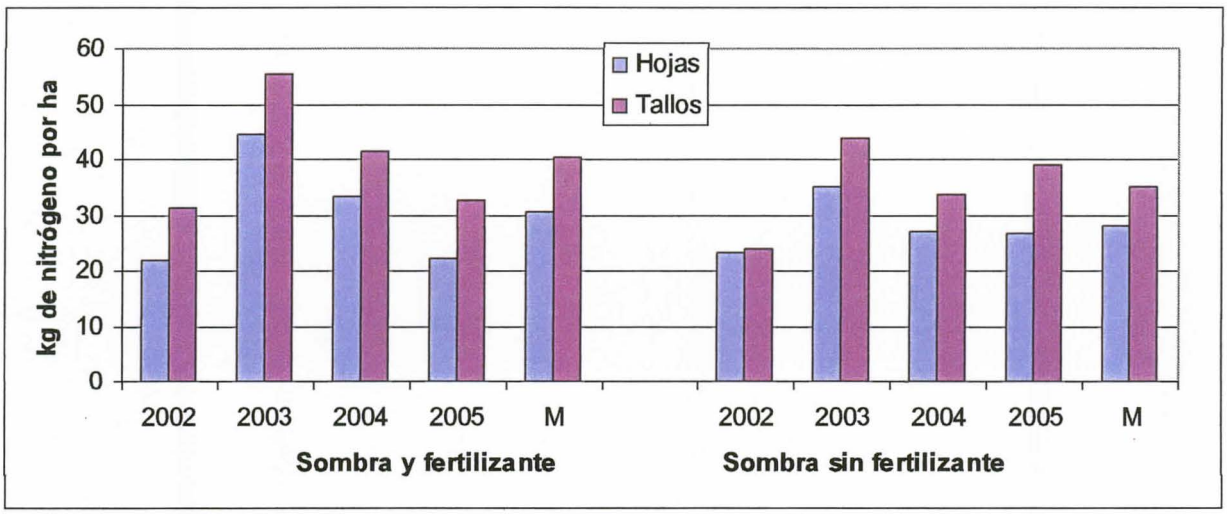


Figura 3. Aporte de nitrógeno por las hojas y los tallos de la planta de madero negro

g. Biomasa de Raíces:

Se midió la biomasa de raíces finas menor de 2 mm a 50 y 100 cm del tallo de la planta de café. Se tomó 6 puntos por parcela de café con sombra y fertilización y a plena exposición foliar y se determinó la biomasa seca de raíces cada 10 cm hasta una profundidad de 70 cm. Se encontró que todavía a 70 cm de profundidad se puede encontrar raíces de café. Se puede notar que en los primeros 30 cm de profundidad se encontró la mayor biomasa de raíces finas de café.

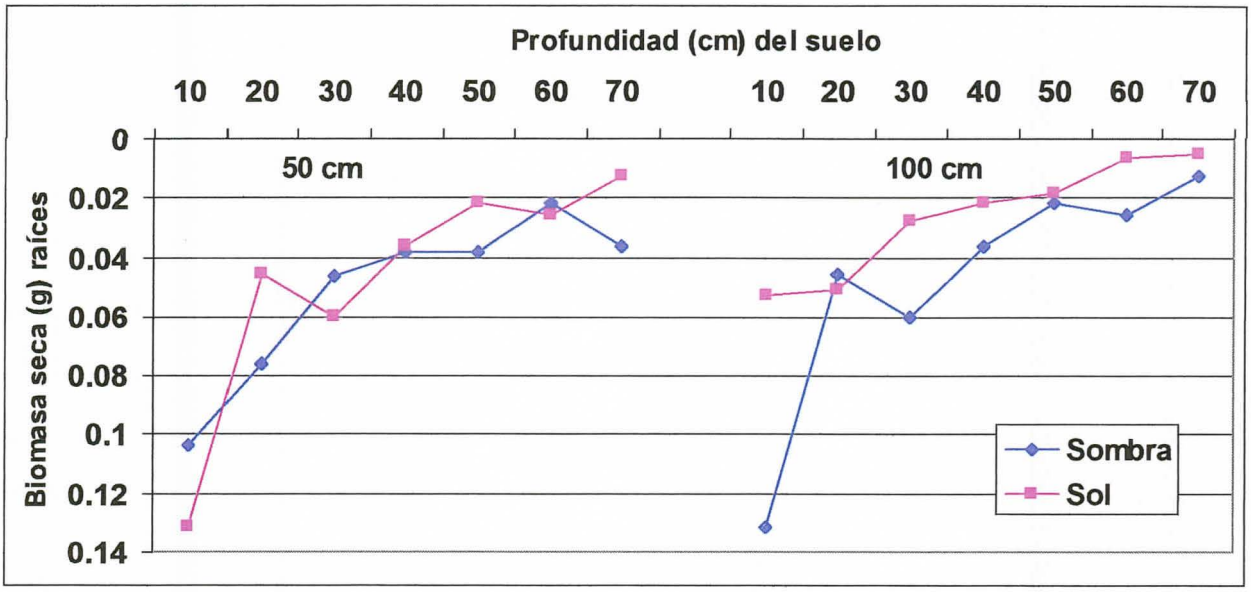


Figura 4. Distribución de la biomasa seca (g) raíces finas a 50 y a 100 cm del tallo de la planta de café y de 0 a 70 cm de profundidad.

h. Altura y diámetro de árboles: El 6 de septiembre del 2002, se midió la altura de los árboles de sombra y el diámetro a la altura del pecho (DAP) del fuste del árbol. En total fueron 30 árboles por parcela.

La altura de los árboles y el diámetro a la altura del pecho (DAP) se volvió a medir en mayo del 2005.

I. Plagas y enfermedades

También se realizo un muestreo de plagas y enfermedades utilizando el muestreo integral al inicio y al final de la etapa lluviosa.

j. Sombra

Otra variable tomada fue el porcentaje de sombra antes y después de la poda de madero negro utilizando tanto el densiómetro óptico como el densiómetro esférico.

3.1.1.2. Estudios sobre Monitoreo de la producción de hojarasca; Descomposición y liberación de nutrientes de la hojarasca.

En la línea de ciclaje de nutrientes durante el período de enero 2004 a Octubre 2005, se realizaron en campo los siguientes trabajos de investigación: a.- Monitoreo y cuantificación de la cantidad de residuos vegetales caídos durante el 2004; b.- Tasas de descomposición de la hojarasca y liberación de N, P y K en 2004 y 2005. Participaron de estos trabajos el Ing. M.Sc. Rodolfo Munguía H. y los estudiantes Br. Danilo Pérez Flores y Br. Otoniel Soza, ambos de la carrera de Ingeniería Forestal de la Facultad de Recursos Naturales y del Ambiente (FARENA / UNA) y los estudiantes Eduardo Enrique Orozco García y Ariel José Rivas Belgara pertenecientes a la carrera de Ingeniería Agronómica Generalista (FAGRO / UNA).

A. Estudio: Monitoreo de la producción de hojarasca

El presente trabajo de investigación dio inicio el 9 de enero del 2004, con el establecimiento en campo de las canastas con malla metálica para la captura de la hojarasca y otros residuos vegetales depositados por el cafeto y los árboles de sombra. El monitoreo se realizó en las tres parcelas establecidas de café con sombra de madero negro y fertilización, café a pleno sol y café con sombra de madero sin fertilización.

Los objetivos propuestos para el monitoreo de la hojarasca en el sistema agroforestal son:

1. Cuantificar la caída anual de la hojarasca y su contenido de nutrientes;
2. Determinar la dinámica de la caída de la hojarasca y la contribución relativa de cada componente al mantillo.

La HIPOTESIS de estudio del presente trabajo es la siguiente:

Las especies *C. arábica* y *G. sepium* muestran una caída fuerte en la época seca y el componente hojarasca de café tiene la mayor contribución porcentual para el ciclaje de nutrientes.

Materiales y métodos empleados

Trampas de malla metálica

Se establecieron en campo 24 trampas de 50 x 50 x 15 cm. y consisten de malla metálica de 4 mm. Los puntos de muestreo se ubicaron a 1.5 m de distancia del tronco de un árbol de sombra. El punto exacto de establecimiento de la primera trampa fue a partir de la base de una planta de cafeto, seguido de una segunda trampa junta por el vértice opuesto de cada una de ellas (Figura 5).

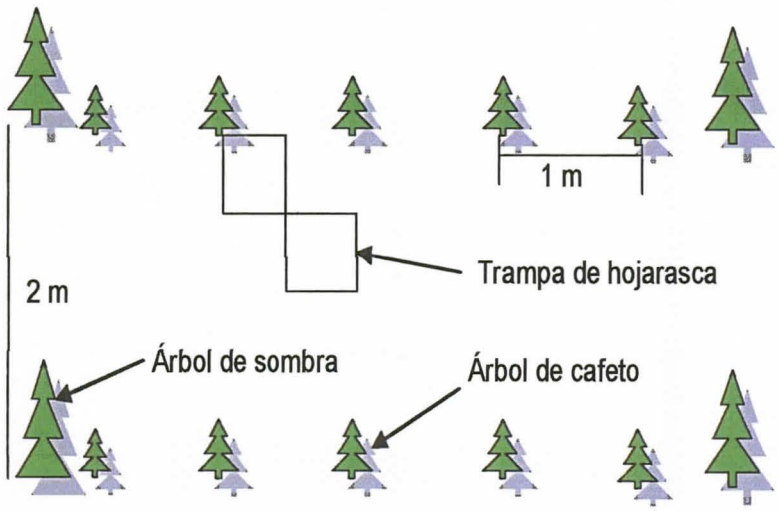


Figura 5. Distribución de trampas recolectoras en el campo.

Tratamientos

1 = Parcela de *C. arábica* a plena exposición al sol
2 = Parcela de *C. arábica* con sombra de *G. sepium* sin fertilización.
3 = Parcela de *C. arábica* con sombra de *G. sepium* con fertilización.

Procedimiento de muestreo

En las parcelas con sombra se seleccionaron aleatoriamente 4 árboles de sombra de *G. sepium*; y para los cafetos a pleno sol se ubicaron al azar 4 puntos con 2 trampas cada uno.

Se recolectó material de cada una de las trampas y se almacenó en bolsas de papel krafts a las que se separaron por componente; de enero a marzo se recolectaron semanal la hojarasca; y en los meses siguientes se realizó cada 15 días y se debió principalmente a la fuerte caída de residuos. Las muestras fueron secadas al horno hasta peso constante a 65°C, posteriormente fueron pesadas para determinar el contenido de materia seca.

Para los análisis de laboratorio fue enviada una muestra compuesta proveniente de 8 submuestras por componente y tratamiento. Se les determinó el contenido de N total por método Micro Kjeldall; el P total por Colorimetría con Metabanadato y el K total por emisión de absorción atómica. El análisis de los datos de captura de residuos y su contenido de N, P y K fue a partir de los promedios por componente y tratamiento respectivos.

Resultados y discusión.

Parcela de café con sombra de *G. sepium* mas fertilización.

En la parcela de café con sombra de *G. sepium* mas fertilización aplicada muestra que los meses de febrero y marzo cae gran cantidad de hojarasca de café debido principalmente a su proceso de senescencia de sus hojas y su renovación que ocurre en el mes de mayo donde se reviste de nuevas hojas. Por ello que la cantidad de hojas de café se reduce en los siguientes meses tal como se muestra en la Figura 6. La hojarasca de café (60.4 %) es que aporta en todos los meses del año la mayor cantidad de residuos que caen sobre el suelo en el sistema productivo, excepto en los meses de octubre y noviembre debido principalmente por una mayor caída de material de la especie de sombra el *G. sepium*. Cabe destacar que los componentes raquiz de *G. sepium* y tanto flores y frutos de ambas especies contribuyen 4.2 y 13.2 % del total de residuos. Mientras el *G. sepium* contribuye en el sistema con 20.1 % y un 2.1 % es aportado por el componente ramas de ambas especies.

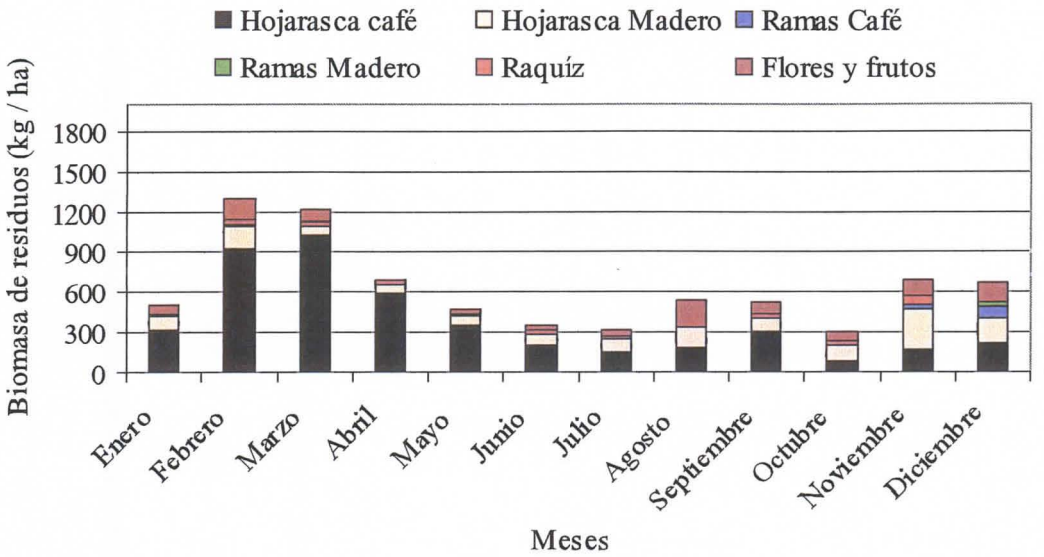


Figura 6.- Dinámica de la caída natural de los residuos vegetales en café con sombra de *G. sepium* y fertilizada, Finca San Francisco, Carazo, Nicaragua, 2004

Parcela de café con sombra de *G. sepium* sin fertilización.

Los resultados en éste tipo de manejo agronómico refleja el mismo comportamiento de la parcela con sombra y fertilización, la diferencia observada en los datos es que la producción fue mucho mayor en los meses desde febrero hasta mayo inclusive. Sin embargo, se puede observar que la caída de madero negro superó al café desde julio hasta noviembre; este comportamiento es natural debido al proceso fisiológico de senescencia que ocurre en este período del año por esta especie (Figura 7).

Las especies de *G. sepium* y *C. arabica* contribuyen en 60.9 y 23.5 % respectivamente, mientras que el componente raquiz de *G. sepium* y flores y frutos contribuyen en un 5.8 y 8.2 % respectivamente del total de la biomasa capturada de los residuos caídos, solamente un 1.6 % es producto de los aportes debido a la caída de ramas de ambas especies. Se debe notar también que en esta parcela durante el mes de diciembre se mostró una caída fuerte de frutos de café afectados probablemente por chasparria.

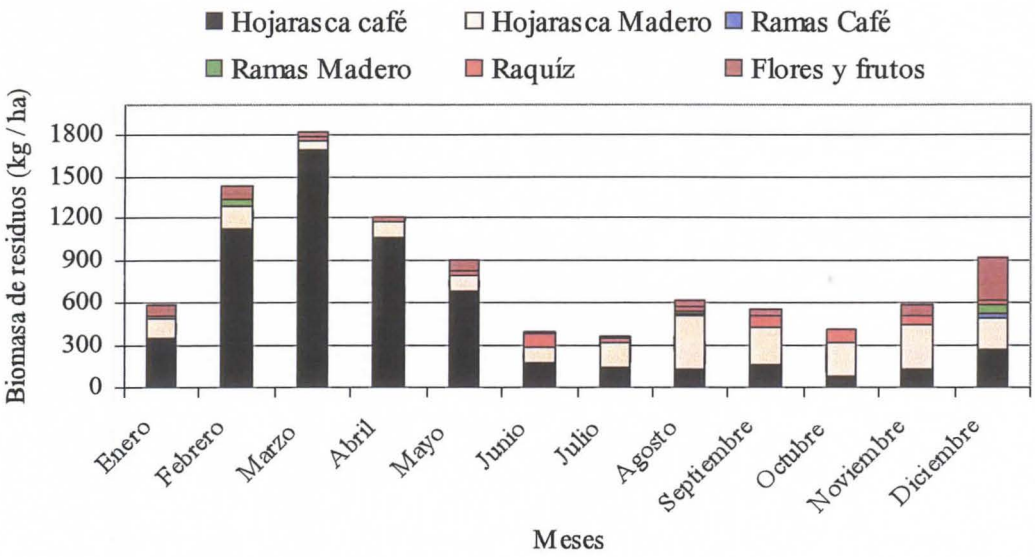


Figura 7.- Dinámica de la caída natural de los residuos vegetales en café con sombra de *G. sepium* y no fertilizada, Finca San Francisco, Carazo, Nicaragua, 2004

Parcela de café a plena exposición solar y fertilización.

En esta parcela se recolectó un total de 7104.2 kg ha^{-1} de residuos vegetales del sistema productivo a plena exposición solar, en donde la mayor caída ocurre en los meses de febrero a abril; mientras que el resto del año se mantiene una caída baja de residuos aunque en el mes de diciembre se incrementó el componente de frutos de café afectados por enfermedad chasparria (Figura 8).

En este sistema de los componentes identificados la hojarasca de café contribuye en un 84.3 % del total de biomasa capturada, el resto es aportado por los componentes ramas, flores y frutos de café.

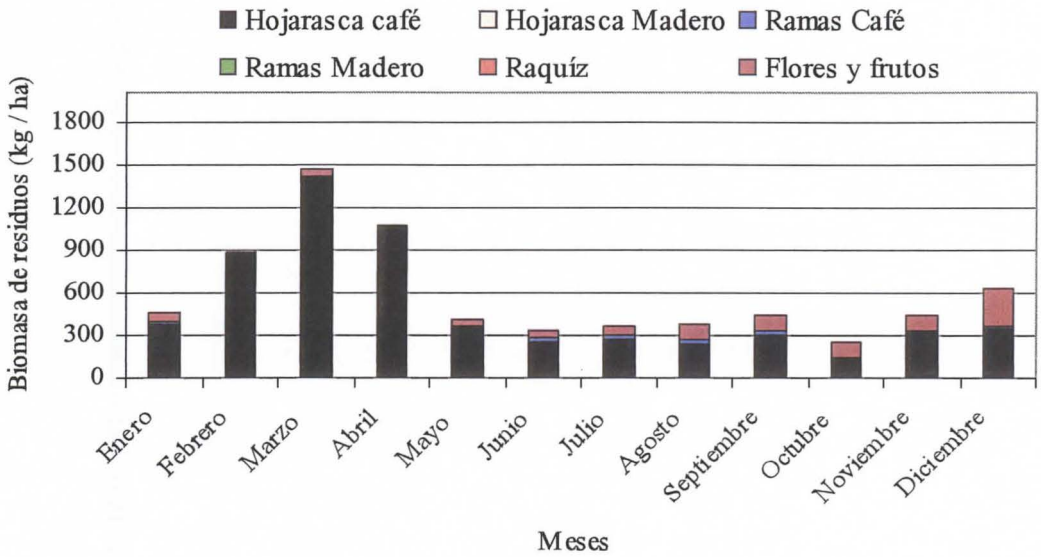


Figura 8.- Dinámica de la caída natural de los residuos vegetales en café a plena exposición solar y fertilizada, Finca San Francisco, Carazo, Nicaragua, 2004

Cantidad de nutrientes en residuos vegetales anuales capturados

De manera general la hojarasca de café tanto en el contenido de Nitrógeno como de Potasio en todos los sistemas de manejo es la que contribuye con el mayor aporte de estos elementos minerales debido a su aporte fuerte de biomasa. Los sistemas con sombra de *G. sepium* tanto fertilizada como no fertilizada aportan mayor cantidad de los dos elementos mencionados en el componente hojarasca de madero. En alguna medida de importancia hace aportes el componente flores y frutos de las dos especies vegetales presentes en los sistemas con sombra e igualmente en pleno sol (Cuadro 1). En resumen, se puede decir que el sistema de manejo sin fertilización y sombra de *G. sepium* mostró el mejor comportamiento en la extracción de K y N los cuales son fijados en los residuos vegetales que posteriormente caen, se descomponen, liberan y mineralizan los nutrientes que se volverán nuevamente disponibles para que el cultivo café y árboles de sombra hagan uso de ellos. Cabe señalar que el sistema a pleno sol con relación al K mostró mejor comportamiento que el sistema con sombra y fertilizada. Caso contrario ocurrió para el caso del N.

Cuadro 1 Contenidos anuales de elementos N y K (kg ha^{-1}) en residuos vegetales capturados durante 2004 en sistemas agroforestales con café. Carazo, Nicaragua.

Mineral	Meses	Hojarasca		Ramas	Raquiz	Flores y frutos	Total
		Café	Madero				
Potasio	Café a pleno sol	143.12	0.00	0.83	0.00	18.81	162.77
	Café con sombra sin fertilización	115.14	39.24	5.41	12.40	19.14	191.33
	Café con sombra mas fertilización	86.85	16.68	5.23	5.51	24.06	138.33
Nitrógeno	Café a pleno sol	137.90	0.00	3.26	0.00	14.12	155.28
	Café con sombra sin fertilización	165.49	57.34	12.43	15.21	18.22	268.68
	Café con sombra mas fertilización	118.05	37.23	1.60	6.82	23.27	186.98

B. Estudio: Descomposición y liberación de nutrientes de la hojarasca en 2004.

Se inició el 3 de septiembre del año 2004, periodo en el cual se logro obtener la cantidad suficiente de material vegetal para el presente estudio. Se puede señalar que el comportamiento de las precipitaciones durante éste año fue irregularidad (Cuadro 2). La lectura de los datos ambientales en la estación meteorológica fue a partir de su instalación el día 26 de marzo del año 2004.

Cuadro 2.- Datas ambientales tomados de la estación meteorológica instalada en el área experimental de la finca San Francisco, San Marcos, Carazo.

Meses	Temperatura °C			Precipitación en mm	Velocidad del viento (m/s)
	Máxima	Mínima	Media		
Marzo	30.1	19.2	23.9	0	1.4
Abril	31.5	19.9	24.5	24.4	1.2
May	29.7	20.5	23.8	200.9	1.2
Junio	28.3	20.6	23.2	110.5	1.1
Julio	28.5	20.0	22.9	91.7	0.8
Agosto	28.6	20.6	23.3	56.9	1.0
Septiembre	28.7	20.0	23.2	28.4**	0.2
Octubre	30.3	17.7	23.2	312.4	0.3
Noviembre	28.2	17.6	22.2	38.6	1.0
Diciembre	28.2	17.2	21.8	1.8	1.6

Fuente: Estación meteorológica instalada por proyecto UNA / CASCA en el área experimental
**: Datos de 23 días por mal funcionamiento de la estación.

OBJETIVOS:

a) Determinar la velocidad (k) de descomposición de las hojas de C. *arábica* sola y en mezcla con *G. sepium.*

b) Obtener las tasas de liberación de N, P y K ocurridas en el proceso de descomposición de la hojarasca.

HIPÓTESIS:

La velocidad de descomposición y liberación de nutrientes es influenciada por los contenidos de lignina, polifenoles y nutrientes de la hojarasca.

METODOLOGÍA

Tratamientos de descomposición.

T1= 50 % hojas de *G. sepium* mas 50 % de C. arabica de parcela sin fertilización

T2= 100 % hojas de *C. arábica*

T3= 50 % hojas de *C. arábica* más 50 % *G. sepium* de parcela con fertilización.

Obtención del material (hojarasca)

Se recolectaron manualmente los hojas de *C. arabica* y *G. sepium* en las parcelas respectivas de acuerdo al sistema de manejo, hasta completar la cantidad de material necesario para el estudio. Dicho material se procedió a secar al horno a una temperatura de 60 °C que permitiera su conservación hasta tener la suficiente cantidad de material.

Bolsas de descomposición
El método utilizado es el conocido "Litterbags" de malla de nylon con 1 - 2 mm de diámetro, lado que estará en contacto con el suelo y de 4 - 5 mm correspondiendo a la capa superior. Las dimensiones de cada bolsa serán de 25* 25 cm y se colocaron de 30 g. de materia seca. Para los tratamientos mezclas los componentes se pusieron en capas una sobre la otra.

Muestreo de la descomposición
Se establecieron 4 bolsas por tratamiento y fecha de recolecta, ubicadas correspondientemente en cada una de las áreas de los sistemas de manejo en evaluación; las bolsas se colocoran sobre área de proyección de la hilera del cafeto, de tal manera que las plantas cubrieran las bolsas conteniendo el material a descomponer. Se recolectaron las bolsas a los 6, 12, 24, 48, 96 días por tratamiento. Previo a la colocación de las bolsas en el suelo, se limpio el área para que la superficie de la malla quedara en contacto con el suelo.
Recolectadas las bolsas se colocaron en bolsas de tela de algodón (25 x 25 cm) para evitar pérdida del material en el trayecto del campo al laboratorio. En laboratorio se procedió a limpiar la hojarasca de residuos extraños como piedras, otros residuos vegetales y animales; seguidamente se separaron por componente y especie. Se secaron a 65°C en horno hasta peso constante para obtener materia seca de cada muestra. Se obtuvo una muestra compuesta de las 4 bolsas por tratamiento, utilizada en el laboratorio para determinar la concentración N, P y K.
Se procedió a el análisis de los datos de pérdida de masa aplicando el modelo de regresión doble exponencial negativa debida al comportamiento de los materiales vegetales que inicialmente se descomponen todos aquellos compuestas fácilmente degradables quedando en descomponerse los compuestas recalcitrantes o difíciles al ataque de los microorganismos.
A continuación se expresa el modelo de regresión doble exponencial negativo para obtener un mejor ajusto estadístico para los datos.

$$W_f = W_i e^{-b_1 t} + (100 - W_i) e^{-b_2 t}$$

Donde: Wf = Peso remanente de los residuos vegetales.
Wi = Peso inicial de los residuos vegetales.
B1 y B2 = tasas de descomposición diaria.

T = tiempo de descomposición.

Tasas de descomposición de hojarasca.

El modelo de regresión doble exponencial negativa, explica el comportamiento diferencial de la velocidad de descomposición de la hojarasca de *C. arabica* y *G. sepium* en mezclas para los sistemas de manejo con sombra, así mismo para el sistema de café a plena exposición solar.

En el gráfico 9, se muestra que cuando está presente la hojarasca de *G. sepium* combinada en la hoja de *C. arabica*, el proceso se ve acelerado inicialmente, por ello muestra una dinámica de mayor pérdida de peso inicial (30 g por bolsa) de ambas especies. La hojarasca del sistema de sombra y fertilización finaliza con un peso remanente del 47.4 %, mientras que en el sistema a pleno sol con solo hojarasca de café finalizó un peno remanente del 59.9 %, mostrando con ello que la leguminosa contribuye mayormente a la descomposición de la hojarasca del café, la cual

muy probablemente se deba al tipo de composición nutricional y de compuestos orgánicos los cuales son fácilmente atacados en un primer momento donde las pérdidas son fuertes, quedando el material que es menos atacado por los microorganismos.

A pesar que coincide con la época mas fuerte de precipitaciones en la zona, el 2004 mostró una caída y distribución pobre (Cuadro 2) lo cual afectó desfavorablemente al proceso de descomposición de la hojarasca de café y de madero negro haciéndolo mas lento.

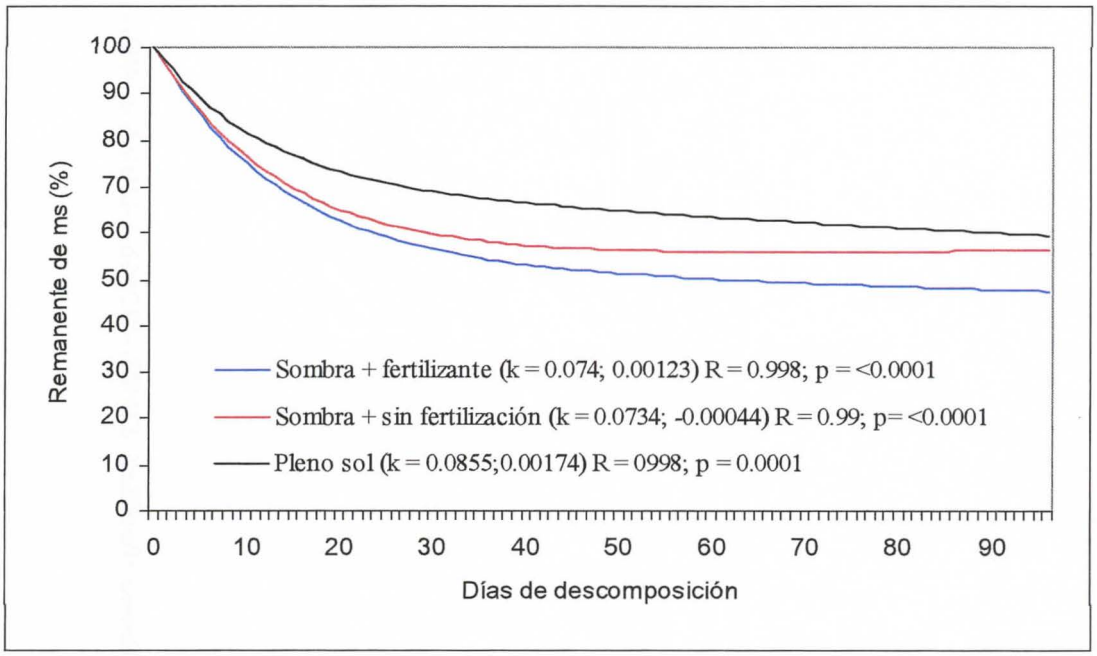


Figura 9.- Tasas de descomposición de la hojarasca de *C. arabica* y *G. sepium* en diferentes sistemas de manejo.

Liberación de nutrientes.

De los elementos N, P y K determinados en laboratorio, solo el K mostró un mejor comportamiento a partir de la aplicación del modelo doble exponencial negativo, debido a que el K se tiende a perder con facilidad de los residuos vegetales y a reducir sus contenidos en el material vegetal de ahí su comportamiento observado (Figura 10), mientras que los elementos N y P tuvieron en el proceso de liberación un comportamiento mas variable. Sin embargo, el P manifestó un comportamiento en una reducción de sus contenidos o sea se liberó por efectos de descomposición de la hojarasca y de alguna manera se ha incorporado a la solución del suelo para su proceso de mineralización, ésta liberación ocurre en los primeros 24 días de exposición a la descomposición en todos los tratamientos (Figura 11). Después de los 48 días se manifiesta muy probablemente una fijación de fósforo incrementándose su concentración en los residuos debido procesos de movilización de este elemento del suelo al material o por efecto de actividad biológica.

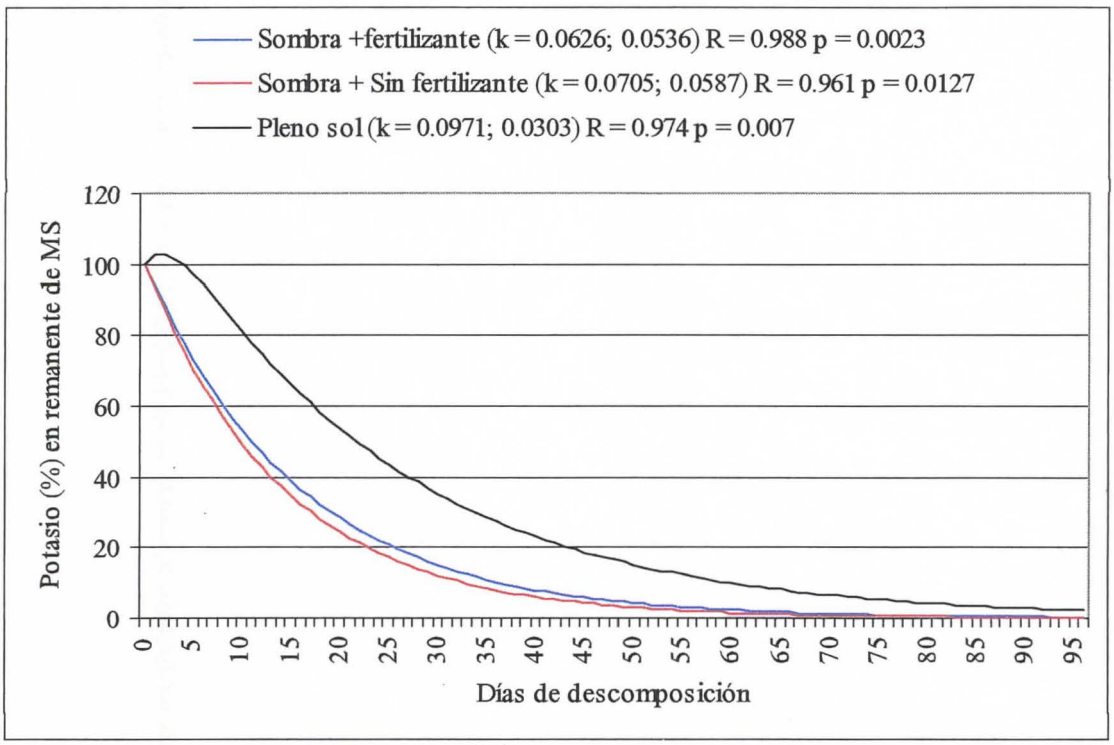


Figura 10.- Tasas de liberación del Potasio ($k^{-diaria}$) en la descomposición de hojarasca bajo diferentes sistemas de manejo en café.

Cuadro 3.- Contenido del peso remanente y liberación de Potasio (%) de la hojarasca para los diferentes sistemas de manejo.

Días de exposición en campo	Sombra *G. sepium* + fertilización		Café a pleno sol		Sombra G. sepium + sin fertilización	
	Peso remanente (%)	Liberación de Potasio (%)	Peso remanente (%)	Liberación de Potasio (%)	Peso remanente (%)	Liberación de Potasio (%)
0	100	100	100	100	100	100
6	85.8	74.12	91.65	93.33	86.62	79.61
12	72.47	40.51	78.30	79.67	72.47	23.66
24	54.95	20.43	66.62	39.25	59.95	16.19
48	54.95	2.61	69.12	14.81	85.30	5.23
96	46.62	11.78	58.30	23.33	55.80	9.58

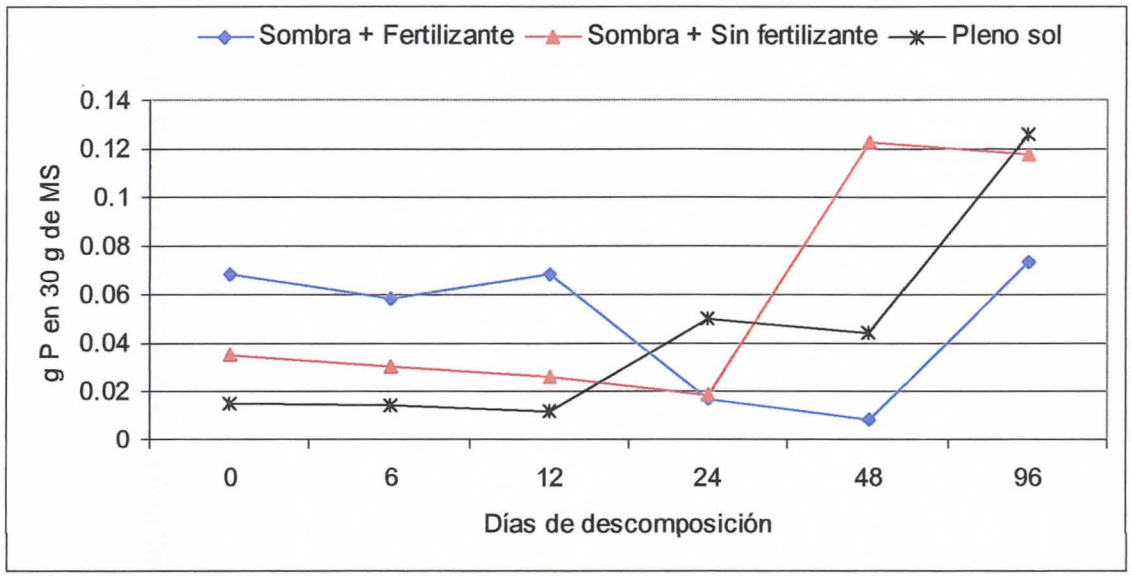


Figura 11.- Comportamiento de la liberación del Fósforo en la descomposición de la hojarasca bajo diferentes sistemas de manejo.

De acuerdo a la figura 12, el comportamiento del N parece tener una tendencia a liberarse mayormente en los primeros días de exposición a la descomposición de la hojarasca tanto de café como de madero negro. Tanto en la parcela de Pleno sol como de la parcela de Sombra con *G. sepium* mas fertilización indica un incremento del contenido de N a partir de los 24 días de exposición a la descomposición debido que hubo contaminación por fertilizantes aplicados por el productor en estas parcelas.

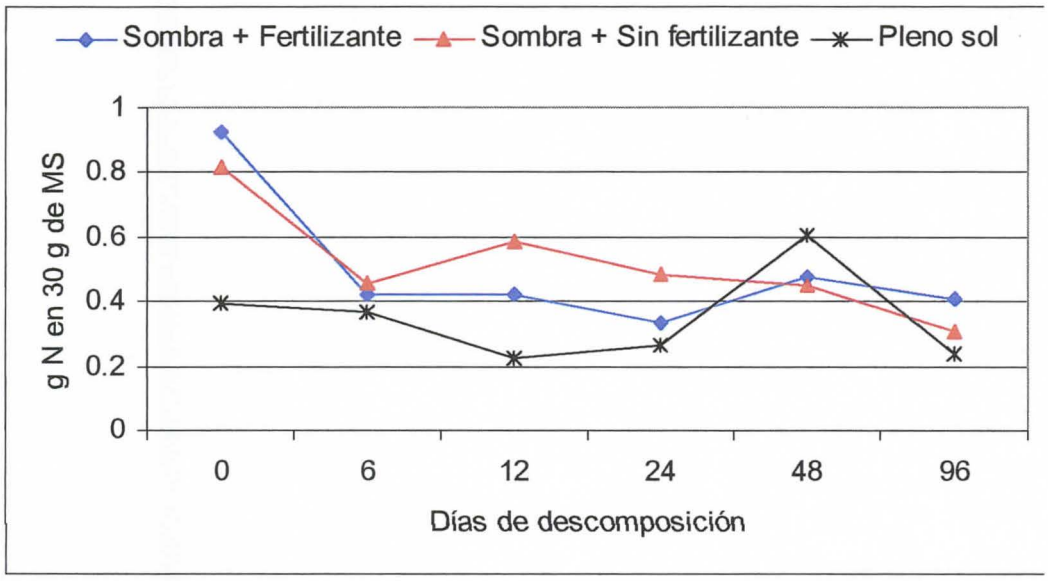


Figura 12.- Comportamiento de la liberación del Nitrógeno en la descomposición de la hojarasca bajo diferentes sistemas de manejo.

3.1.1.3. Avance de actividades de los estudios: Dinámica de N mineral del suelo, pérdidas de N por lixiviación y reservas de Carbono y Nitrógeno del suelo en el sistema de café con sombra de *Gliricidia sepium* y café a pleno sol en la zona de Carazo, Nicaragua.

A.- Estudio de la Dinámica de N mineral del suelo

El documento borrador de la tesis de grado sobre el estudio de la dinámica de N mineral del suelo, está en la fase de revisión. Los estudiantes tesistas son Oswaldo González Rodríguez y Wilfredo Fuentes Masis quienes continúan documentando y trabajando sobre el escrito definitivo.

B.- Estudio de pérdidas de N por lixiviación

La tesis sobre el estudio de pérdidas de N por lixiviación está en el mismo proceso de elaboración el documento borrador del trabajo de los tesistas, Aura Astelia Lazo y Yader Adolfo Calderón Cerros.

C.- Estudio de reservas de Carbono y Nitrógeno del suelo

De la evaluación realizada en la estación lluviosa de agosto del 2003, no se han recibido los resultados del Laboratorio del CATIE, Costa Rica.

Por la situación climática particular para el año 2005 en Nicaragua, los propietarios de la plantación decidieron adelantar el calendario de fertilización en la finca y sin previo conocimiento sobre esto (falta de información) no fue posible realizar la evaluación de reservas de C y N para esta época.

Por otro lado la incertidumbre sobre el pago de los análisis de lixiviación de la época del 2004 significó asumir el costo de estos análisis en el Laboratorio de suelos y agua de la Universidad Nacional Agraria. Por ello, se tomó la decisión de no realizar una segunda evaluación dado los costos que representaba.

Simultáneamente, es necesario que envíen los resultados de los análisis pendientes del Laboratorio de suelo del CATIE, C.R. los cuales son de gran utilidad para completar la solidez de los resultados del ensayo de Carazo, estos son:

- Contenido de Carbono y Nitrógeno del suelo de 72 muestras (Reservas del C y N del suelo)
- Caracterización de los suelos, de 90 muestras de suelo (Mes Dic. 2003)
- Determinación del contenido de nitrógeno en 270 extractos correspondiente a tres muestreos de suelo realizado en la época de verano del año 2004, en los meses de Febrero, Mayo y Junio (antes de la fertilización).

3.1.2. Aspectos Socioeconómicos: Caracterización (WP1), Economía (WP7), Regionalización (WP8)

Actividades realizadas

Actualización de bases de datos de fincas cafetaleras en donde se realizó el estudio sobre tipologías y manejo de fincas cafetaleras en el departamento de Matagalpa. En la Revista Agroforestería de las Américas se publicó el artículo: Tipologías y manejo de fincas cafetaleras en los municipios de San Ramón y Matagalpa, Nicaragua, en el Volúmen 10, número 37-38, páginas 74-79.

3.2 Publicaciones realizadas

Balladares, D.; Calero, M. 2005. Evaluación de tres sistemas de manejo el crecimiento, estructura productiva y calidad del café (*Coffea arabica* L.) vr. Costa Rica 95. Tesis Ing Agrónomo, UNA, Managua, Nicaragua. 80p.

Pilati, A. 2005. Evaluación de tres diferentes tipologías de manejo agronómico sobre la estructura de crecimiento, productividad y calidad del café (*Coffea arabica* L.), en la zona del Pacífico Sur de Nicaragua. Tesis Lic., Torino Italia / UNA, Managua, Nicaragua.

ANEXOS

Anexo 1. Actual Partitioning of months / WP / PARTNER / for the FOURTH YEAR

Socio: UNA	**WP1**	**WP2**	**WP3**	**WP4**	**WP5**	**WP6**	**WP7**	**WP8**	**WP9**	**Yr4**
Víctor Aguilar			2.25		2.25					4.5
Glenda Bonilla	0.30		1.0		1.0		0.10	0.10	1.0	3.5
Rodolfo Munguía			1.425		1.425					2.85
Martha Gutiérrez			0.725		0.725					1.45
Leonardo García			0.665		0.665					1.33
Cristóbal Medina			0.25		0.25					0.50
Emilio Pérez	0.10						0.10	0.05		0.25
Héctor Ortiz									1.0	1.0
Drivers			0.32		0.32					0.64
Total Permanent Staff	**0.40**		**6.315**		**6.315**		**0.20**	**0.15**	**2.00**	**15.38**
Aura Astenia Lazo			0.02		0.02					0.04
Carlos Parrales			0.015		0.015					0.03
Danilo Pérez			0.30		0.30					0.60
Dayling Balladares			0.135		0.135					0.27
Enrique José López			0.02		0.02					0.04
Ernesto López Aguirre			0.08		0.08					0.16
Justo E. Castro			0.31		0.31					0.62
Otoniel Soza			0.205		0.205					0.41
Sergio Ruiz			0.145		0.145					0.29
Tomás Gutiérrez			0.06		0.06					0.12
Yader Calderón			0.02		0.02					0.04
Other Technicians			0.975		0.975					1.95
Field technicians			3.045		3.045					6.09
Total Hired Staff			**5.33**		**5.33**					**10.66**
Total UNA	**0.40**		**11.645**		**11.645**		**0.20**	**0.15**	**2.00**	**26.04**

Anexo 2. Resumen de tesis de grado.

BALLADARES, D.; CALERO, M. 2005. EFECTO DE LA SOMBRA Y FERTILIZACIÓN SOBRE EL CRECIMIENTO, ESTRUCTURA PRODUCTIVA, RENDIMIENTO Y CALIDAD DEL CAFÉ (*Coffea arabica* L.) Vr. COSTA RICA 95. Tesis Ing Agrónomo, UNA, Managua, Nicaragua.

El ensayo se realizó en la Finca San Francisco, propiedad de Inversiones Generales S.A., ubicada en el Km.39.5 de la carretera San Marcos, Carazo, desde agosto del 2002 hasta junio del 2004. Un estudio cuyo objetivo general fue evaluar tres sistemas de manejo del café sobre el crecimiento, estructura productiva, acumulación de biomasa y nitrógeno en la planta; producción y calidad del grano de café. El ensayo se estableció en tres franjas cuyos tratamientos correspondieron a: a) Café bajo sombra de madero negro (*Gliricidia sepium* Jacquin Kunth ex walpers) y fertilización química; b) Café a plena exposición solar y fertilización química y c) Café bajo sombra sin fertilización. En cada parcela se seleccionaron 48 plantas de las cuales se tomaron 8 plantas en cada una de las 6 fechas para realizar las mediciones correspondientes. Una muestra de café oro por tratamiento de cada una de las cosechas de cada año fue tomada y enviada a laboratorio de CERCAFENIC de UNICAFE en Managua, para determinar los aspectos físicos y organolépticos. Empleando el método destructivo se midió la biomasa y cantidad de Nitrógeno acumulado en la raíz, tallo, ramas, hojas y frutos de cada una de las 8 plantas seleccionadas por fecha. Las variables de crecimiento y rendimiento se presentan a través de figuras y la acumulación de biomasa en los diferentes componentes de la planta de café se explica de acuerdo a resultados de la prueba de t-Student. Para los meses junio 2003, septiembre 2003, diciembre 2003, y junio 2004, el sistema café sombra con fertilizante obtuvo la mayor altura con 166, 170.25, 179.87 y 204 cm respectivamente, mientras este mismo tratamiento en el mes de diciembre 2003 obtuvo el mayor diámetro con 4.87 cm; en septiembre y diciembre 2003 obtuvo una mayor proyección de copa con 2.63 y 2.46 cm. El mayor número de nudos totales lo obtuvo en diciembre 2003, con 42.50; el mayor número de ramas primarias totales se encontraron en Diciembre 2003 con 74.87 y las terciarias totales en diciembre 2002 con 11.50; el mayor número de ramas terciarias productivas se encontraron en junio 2003 con 6, estas en el sistema café a pleno sol. En agosto del 2002 las plantas del sistema café sombra sin fertilizante presentaron la mayor biomasa de raíces con 21.75%; el mayor contenido de nitrógeno en raíces con 19.73%; en hojas con 52.02% y en tallos con 8.71%. El sistema café a pleno sol obtuvo la mayor biomasa de raíces con 20.49%, en cambio para junio 2004, el mayor contenido de biomasa fue para el tallo en el sistema café sombra sin fertilizante con 27.63% y la mayor cantidad total de nitrógeno fue para las hojas en el sistema café sombra con fertilizante con 38.41%. El sistema de café sombra sin fertilizante obtuvo el mayor rendimiento en el 2002 con 438 kg oro ha^{-1} y el sistema a pleno sol obtuvo el mayor rendimiento en 2003 con 2952 kg oro ha^{-1} . La calidad 2003 fue buena en los tres sistemas pero la cosecha seis para los tres tratamientos presentó una taza OK, tipo SHG y calidad como café lavado Matagalpa / Jinotega o estrictamente de altura.

Anexo 3. Resumen de tesis de grado.

PILATI, A. 2005. EVALUACIÓN DE TRES DIFERENTES TIPOLOGÍAS DE MANEJO AGRONÓMICO SOBRE LA ESTRUCTURA DE CRECIMIENTO, PRODUCTIVIDAD Y CALIDAD DEL CAFÉ (*Coffea arabica* L), EN LA ZONA DEL PACÍFICO SUR DE NICARAGUA.
Tesis Lic., Torino Italia / UNA, Managua, Nicaragua.

El café (*Coffea arabica* L.) es un componente importante del paisaje y de la economía nacional. El manejo agronómico influye en la ecofisiología y calidad del café, por tal razón son de suma importancia, estudios e investigaciones para evaluar los efectos de diferentes sistemas del cafeto asociados o no con árboles de sombra.
El presente estudio se realizó principalmente en la Finca San Francisco, de Inversiones Generales S.A., ubicada en el Km.39.5 de la carretera San Marcos – Las Esquinas, en el Departamento de Carazo, en un período comprendido entre junio 2002 y diciembre 2004.
El objetivo general del estudio fue evaluar el comportamiento de las estructuras de crecimiento, productiva, rendimiento, contenido de biomasa seca, acumulación de nitrógeno y calidad física y organoléptica del café (*Coffea arabica* L. vr. Costa Rica 95), bajo tres diferentes tipologías de manejo agronómico: a) café con sombra y fertilización (CSF); b) café a pleno sol con fertilización (CSolF) y c) café bajo sombra sin fertilización química (CS). En cada parcela se seleccionaron 8 plantas a las cuales se les tomaron los datos de altura, diámetro, proyección de coopa, nudos totales en tallo principal, número de ramas primarias, secundarias y tericiarias tanto totales como productivas de la planta y rendimiento de café oro por parcela. Una muestra por tratamiento de café oro en las cosechas fue tomada y enviada a CERCAFENIC de UNICAFE, en Managua, para determinar los aspectos físicos y organolépticos de los granos. Empleando el método destructivo se midió la biomasa y cantidad de nitrógeno acumulado en la raíz, tallo, ramas, hojas y frutos.
Para mejorar y fortalecer el trabajo de investigación se hizo una comparación de calidad, del último ciclo cafetalero, con otros sistemas de manejo, usados sobre todo en dos Departamento del Norte del país, Matagalpa y Jinotega. En el caso de Matagalpa se evaluaron los datos físicos del grano y los dictámenes de taza de tres sistemas (*Coffea arabica* L. vr. Catimor y Caturra), a) café orgánico; b) café convencional; c) café de bajo insumo, aplicados en la "Cooperativa la Solidaridad", ubicada en la Cuenca del Aranjuez. Asimismo para Jinotega se sacaron las mismas variables del cafeto de bajo insumo de la "Cooperativa Santa María de Fantasma". Se estructuró un primer análisis de los costos de mantenimiento de los sistemas evaluados, obteniendo como resultado los costos y la ganancia por hectárea y el costo por kilogramo de café oro producido.
El café con sombra y fertilizante presentó el mayor crecimiento en altura, proyección de copa, número de ramas primarias y secundarias totales y productivas. El café a pleno sol obtuvo el mayor diámetro, el número de ramas terciarias, pero también la mayor cantidad de ramas agotadas o muertas. A las variables de biomasa y nitrógeno se aplicó un test "t de Student" por el programa estadístico SAS; solamente en los últimos meses de muestreo (junio, septiembre y diciembre 2004) se encontraron diferencias significativas entre los dos tratamientos abonados y el sistema bajo sombra sin fertilizante. Los rendimientos fueron por dos veces mayores en el caso del sistema a puro sol. Las calidades sea físicas u organolépticas, mejoraron en el curso del estudio, logrando en el último ciclo cafetalero, la

misma clasificación de los café de Matagalpa y Jinotega, taza OK, café lavado Matagalpa/Jinotega. Los café orgánico y de bajo insumo tuvieron resultados más satisfactorio.

El café orgánico presentó los precios más altos y homogéneos, en el curso de los tres años analizados, por eso, conjunto con el manejo convencional de la Finca San Francisco, es la que obtuvo menores oscilaciones. Entre las tres parcelas experimentales, los sistemas a pleno sol con fertilización (CSolF) y el de sombra sin aporte de fertilizantes químicos (CS) son los que obtuvieron las mayores ganancias, saliendo de un primer año con resultados negativos o de poco más de 50 dólares por hectárea.

Anexo 4.- Biomasa de residuos vegetales capturados (kg / ha) en Parcela de café con sombra y fertilizada.

	Hojarasca		Ramas				
Meses	Café	Madero	Café	Madero	Raquíz	Flor y frutos	Totales
Enero	314	105.2	5.2	2.6	7.2	65.6	499.8
Febrero	926	169.6	3.6	2	40	149.2	1290.4
Marzo	1030.4	68	0	0	30.8	77.2	1206.4
Abril	593.2	58	0	0	30.4	0.64	682.24
Mayo	354.4	64.4	0	0	21.6	24	464.4
Junio	201.2	89.2	0	0	34	20.4	344.8
Julio	150.4	110	0	0	7.6	46.8	314.8
Agosto	184.8	144.8	0	4.8	10	187.2	531.6
Septiembre	310	94.8	4.8	0	30	80	519.6
Octubre	84.8	114.8	0	0	30	80	309.6
Noviembre	166.4	311.6	20	0	76.4	106.4	680.8
Diciembre	224.8	184.8	81.6	28	0	156.4	675.6
Totales	4540.4	1515.2	115.2	37.4	318	993.84	7520.04

Anexo 5.- Biomasa de residuos vegetales capturas (kg / ha) en Parcela de café con sombra y no fertilizada

	Horasca		Ramas				
Meses	Café	Madero	Café	Madero	Raquíz	Flor y fruto	Totales
Enero	347.2	137.2	2.4	0	17.2	77.6	581.6
Febrero	1119.2	168	1.2	38	1.6	98.4	1426.4
Marzo	1675.2	72.8	4.4	0	28	36.4	1816.8
Abril	1071.2	104	0	0	36.8	0	1212
Mayo	688	101.6	0	0	42.8	76.8	909.2
Junio	173.6	111.2	0	0	96	13.6	394.4
Julio	137.2	182.8	0	0	31.2	16.8	368
Agosto	122.4	380	27.2	4.8	37.2	51.6	623.2
Septiembre	160	264.8	0	0	84.8	40	549.6
Octubre	80	244.8	0	0	80	10	414.8
Noviembre	124.8	314.8	0	0	70	84.8	594.4
Diciembre	274.8	220	34.8	50	40	294.8	914.4
Totales	5973.6	2302	70	92.8	565.6	800.8	9804.8

Anexo 6.- Biomasa de hojarasca (kg / ha) en Parcela de café a plena exposición solar.

	Hojarasca		Ramas				
Mes	Café	Madero	Café	Madero	Raquíz	Flor o frutos	Totales
Enero	385.2	0	3.2	0	0	71.2	459.6
Febrero	880	0	0	0	0	4	884
Marzo	1418	0	0	0	0	40	1458
Abril	1066	0	0	0	0	0	1071
Mayo	361.2	0	0	0	0	40.4	401.6
Junio	256.8	0	27.6	0	0	39.6	324
Julio	266.4	0	26	0	0	66.4	358.8
Agosto	238	0	24	0	0	113.2	375.2
Septiembre	293.2	0	40	0	0	104.8	438
Octubre	144.8	0	4.8	0	0	110	259.6
Noviembre	326.4	0	0	0	0	113.2	439.6
Diciembre	350	0	14.8	0	0	270	634.8
Totales	5986	0	140.4	0	0	972.8	7104.2

Sustainability of Coffee Agroforestry Systems in Central America; coffee quality and environmental impacts

Contract ICA4-2001-10071

Fourth Annual Report WORK PACKAGE 1
1 November 2004 - 31 December 2005

WP1 – CASCA – Central America coffee agroforestry knowledge (year 4)

Eduardo Somarriba, líder del WP1

Avances en 2005

- Se defendió en diciembre 2005 una tesis de PhD comparativo entre las estrategias de vida y manejo de cafetales de dos regiones contrastantes de Costa Rica (Pérez Zeledón y Tarrazú) y Nicaragua (Carazo y Matagalpa).
- Se realizó un estudio sobre cómo los productores manejan árboles maderables de sombra de sus cafetales en la zona Pacifica de Ococito en Guatemala.
- Se caracterizó fincas cafetaleras en dos zonas altas (San marcos y Grecia) de Costa Rica.
- Se estudio la cadena agroproductiva de cafetales con maderables y otras plantas útiles en Carazo y Matagalpa, Nicaragua y cuenca de Ococito, Guatemala.
- Se actualizó la base de datos de fincas cafetaleras de Nicaragua, Costa Rica y Guatemala.
- Se analizó la base de datos sobre cómo los productores diseñan el dosel de sombra de sus cafetales ante diferentes condiciones de precios y tamaños del cafetal.
- Se sintetizó la información sobre el conocimiento de los productores sobre la relaciones entre precios, niveles de fertilización, sombra y rendimientos y sobre la asociación entre la composición botánica del dosel de sombra y la presencia de plagas y enfermedades.
- Se preparo un manuscrito "Doseles de los cafetales centroamericanos" que resume la información sobre composición botánica, densidades, usos y tipologías de doseles contenida en la totalidad de la base de datos.
- Se sumitió a publicación artículos sobre "Gerencia de cafetales" y "Diseño y manejo del dosel de sombra de cafetales"

Deliverables

Al fin del cuarto año del proyecto, el **Deliverable D10/D1.1 "Database of current coffee AF practices" puede ser considerado completo con la base de datos actualizado de 10 regiones cafetaleras** (5 en Costa Rica, 3 en Nicaragua y 2 en Guatemala). Eso representa más de **250 fincas cafetaleras encuestadas en Costa Rica, 100 en Guatemala y 200 en Nicaragua.**

También, los artículos publicados en 2002-04, el capitulo "Biodiversity Conservation in Neotropical coffee (*Coffea Arabica*) plantations" del libro "Agroforestry and Biodiversity Conservation in Tropical landscapes" y la tesis de doctorado defendida en diciembre 2005 constituyen el segundo deliverable del WP1 (Deliverable D13/D1.3 "Scientific report describing existing AF typologies and management"- Month 30).

Estudiantes 2005

- Zanfini, Anne, CIRAD, estudiante de doctorado, Universidad de Tolosa, Francia
- Salazar, Mónica, CATIE, estudiante de Maestría en agroforesteria, Costa Rica
- Martínez, Mario, CATIE, estudiante de Maestría en agroforesteria, Costa Rica

Publicaciones en 2005

Anne Zanfini. 2005. Arbres d'ombrage et café au Costa Rica et Nicaragua: dynamique des strategies paysannes en situation de crise économique. Doctoral thesis, University of Toulouse-Le Mirail. 255p.

Monica Salazar (2005). Análisis de rentabilidad financiera del programa C.A.F.E Practices de Starbucks en diferentes tipologías de productores cafeteros de altura en Costa Rica. Tesis Mag Sc. CATIE, Turrialba, CR., 138p.

Mario Martínez. (2005). Contribución económica del componente forestal en diferentes tipos de fincas cafetaleras en la bocacosta pacifica de Guatemala. Tesis Mag. Sci. CATIE, Turrialba, Costa Rica. 123 p.

Sustainability of Coffee Agroforestry Systems in Central America; coffee quality and environmental impacts

Contract ICA4-2001-10071

Fourth Annual Report WORK PACKAGE 2

1 November 2004 - 31 December 2005

Jean Dauzat (CIRAD), leader of WP2
Philippe Vaast & Nicolas Franck (CIRAD)
Pablo Siles (CATIE)
Victor Chaves, & Jonathan Ramos (IICA-PROMECAFE)

WP 2: LIGHT and WATER PARTITIONING at PLOT SCALE (Year 4)

The main objective of this WP2 is assessing and modeling **light and water partitioning** between coffee and associate trees in a few target coffee AF systems of regions with distinct agro-ecological conditions.

Following data collection in 2002-2004, CIRAD (Jean Dauzat, leader of WP2) refined the methodology to **quantify and model light interception by five timber tree species,** based on digitalized photos (photos of tree silhouette and photos fish-eye below the canopy).

In 2005, a **model simulating light partitioning within the coffee canopy** was developed following a graduate student work in 2004 (Stéphane Bagnis, University of Toulouse) on 3-D digitalization of coffee plants under 3 shade treatments (75% and 50% shade and the full sun) with varying fruit loads (100%, 50% and "very light load").

CIRAD (Philippe Vaast) CATIE (Pablo Siles & Jonathan Ramos) and IICA-PROMECAFE (Luis D. Garcia & Jonathan Ramos) were also strongly involved in collecting data on **transpiration and stem flow of coffee and tree strata, rain interception** by their canopies, **soil water content** and **runoff** in one coffee agroforestry trial and one coffee plot in full sun to finalize the plot water model.

One article, submitted in 2005, has been accepted for publication on coffee and tree transpiration and two are in preparation on light interception will be submitted in 2006.

Deliverables

The Deliverables D11/D2.1 "Comprehensive model of light partitioning in coffee AF systems" (Month 24) and D22/D2.3 "Report on light and water partitioning between coffee and tree strata in target AF systems" (Month 42) can be considered completed via the development of two models (model of light interception by shade tree species and model simulating light partitioning within the coffee canopy) and articles published in 2005 and two prepared for submission in 2006 (see annexes).

The water model in two target systems is completed and constitutes the Deliverable D15/D2.2 "Water balance model at plot scale"; one article presenting this model is ready for publication. Nonetheless, additional refinement on its parameterization is needed with data on coffee and timber rainfall interception and stem flow collected in 2005. This will be achieved in 2006 for the defense of a Ph.D. thesis planned for September 2006.

Main results of 2005

Modelling light interception of coffee canopy for assessing carbon assimilation and transpiration

1. Rationale

Due to the wide diversity of coffee agroforestry systems in terms of tree species, age, pattern and density, generic simulation tools are needed for evaluating light and water partitioning between coffee and associated shade trees.

The modelling approach for evaluating the shade cast by timber trees on coffee plants was presented in details in the previous WP2 report (2004). According to this approach, individual shade trees were represented by simple geometric shapes and used for simulating the shade cast on coffee plants along the day for any geographic coordinates and radiative conditions. As illustrated for *Eucalyptus deglupta* stands, simulations experiments can further be used to derive simple analytical functions expressing light transmission *vs.* the size of trees and their crown porosity.

As a complement of this work, the present report presents the interception by coffee stands of the light transmitted trough the above tree crowns. This analysis was carried out during 2005 on 3D architectural representations of coffee plants. From these representations, detailed information can be inferred about irradiance of the leaves according to their position within the coffee canopy.

Specific additions were made in the Archimed platform for coupling leaf irradiance to an assimilation-transpiration model at leaf scale (see WP3 for details about this model). Owing to these implementations, carbon assimilation and transpiration could properly be integrated from leaf scale to coffee stand scale.

The assimilation-conductance model at leaf scale was developed by a Ph.D. student of Cirad, Nicolas Franck (see model description in WP3) who conducted experiments in a commercial coffee orchard inthe Orosi valley of Costa Rica (9.79 N, 83.82 W; 1108m above sea level). The model was calibrated for open and shaded coffee canopies. The "upscaling" model is illustrated below for 2 growth irradiance (GI) regimes in this orchard: 45% and 100% of full irradiance (referred as GI_{50} and GI_{100} respectively). Fruit load sub-treatments were applied within each GI treatment.

The description of the modelling tools for simulating the light interception by coffee stands, their carbon assimilation and their transpiration are presented in this WP2 report whereas the assimilation-transpiration model at leaf scale and results of its integration at canopy scale are presented in the WP3 report.

2. Three dimensional representations of coffee stands

With the aim of describing coffee stands as accurately as possible, coffee plants were digitized with an electromagnetic 3D positioning system (Fastrack[1] digitizer equipped with a long ranger emitter and a "stylus" sensor).

Given the 3D coordinates of particular plant nodes and a field description of the plant topology, the whole plant skeleton was reconstructed by interpolation. Leaves were then individually positioned on each plant axis.

The stem and branch internodes were represented as cylinders with a tapering coefficient for a proper restitution of actual diameters. The leaves were represented with a special primitive (fig. 1) with a scaling factor depending on their position on the stem-branch. Axes order and nodes position were associated to each plant element (fig. 2).

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[1] Polhemus, Inc., Winooski; http://www.polhemus.com

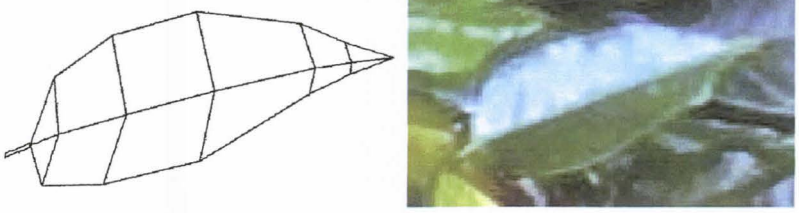


Fig. 1: *Leaf primitive used for simulations and its field model*

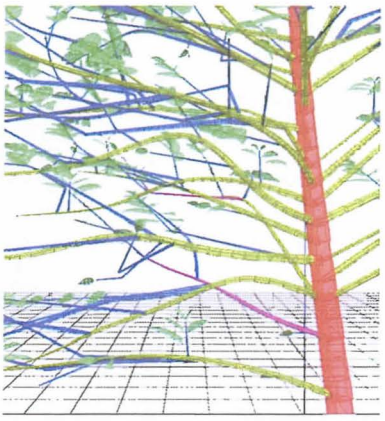
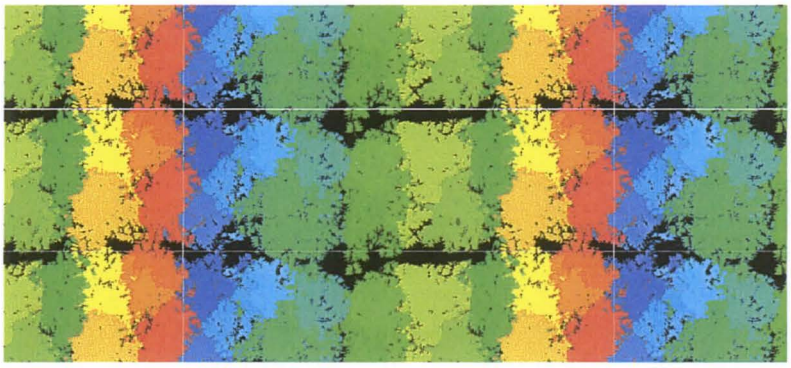


Fig. 2: *Zoom on a reconstructed plant showing leaves and internodes entities.*

Six adjacent coffee plant groups[2] were digitized -*i.e.* a six meter long portion of coffee row, for each growth irradiance treatment. Reconstructed plants were replaced in their actual position to account for the 3D deformation of crowns resulting from their mutual interactions. For the calculation of light interception, a toricity option was used such that the reconstructed portion of row is virtually replicated to simulate an infinite canopy for each GI treatment (fig. below).

Fig. 3:

Top view of the simulated GI50 canopy constituted of a 6m long coffee-tree row virtually replicated to simulate an infinite canopy.



3. Biometric analysis of coffee stands

The leaf and stem area indices (LAI and SAI, respectively) were calculated from computerized GI_{50} and GI_{100} stands (fig. 4). For SAI calculation, the internodes area was divided by π in order to get the area of their projection which is more related to light interception than their total area.

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[2] Coffee plants are planted by groups of two to three plants per planting hole. Groups are planted at 1m apart, along the row and rows are 2m apart.

Fig. 4: *Views of reconstructed coffee-tree rows used for simulations. Top: GI_{100}; bottom: GI_{50}*

The LAI inferred from virtual canopies was 2.07 for GI_{100} with 1063 leaves/m^2 and reached 5.71 for GI_{50} with 1558 leaves/m^2. The stem area index for the two canopies was respectively 0.404 and 0.490.

Despite the fact that stem area density is comparable for the two canopies, the leaf area density is mostly concentrated in the upper half of GI_{50} canopy while more evenly distributed for GI_{100} (fig. 5). A detailed analysis showed that the number of internodes per branch was higher for the shaded canopy but that the defoliation of internodes is mainly responsible for the drastic difference in LAI between the two canopies.

Large differences in LAI were noticeable between digitized plants within the GI_{100} treatment (Fig.4 Top). These differences are related to fruit load; plant fruit loads increased from the left of the row (5% of natural fruit load) to the right (full load). This result points out the strong competition between fruits and vegetative growth; a high fruit load was detrimental to the vegetative growth and can be responsible to rapid plant defoliation leading to dieback of branches when the leaf to fruit ratio is low.

It must also be noticed that the flower initiation was strongly decreased within the GI_{50} treatment in comparison to the GI_{100} treatment. As discussed in the WP3 report, the subsequent lower fruit load in GI_{50} plants are be partly responsible for their higher vegetative growth than the one of GI_{100} plants.

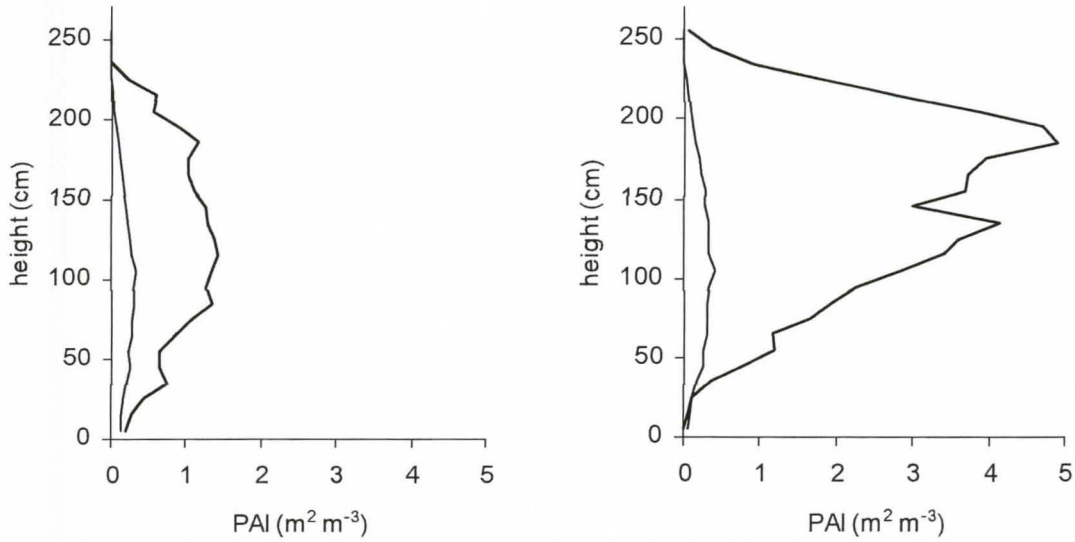


Fig. 5: *Profiles of Plant Area Index for stems and leaves (thin and thick lines respectively). PAI values are given for 10cm thick vegetation layers.*

4. Light interception by coffee stands

Vertical profile of light extinction

The radiation balance within virtual coffee canopies was simulated using Archimed modules (see previous CASCA reports).

The average light interception rate by the coffee canopies during the rainy season was 70.1% for GI_{100} and 93.77 % for GI_{50}. Because the GI_{50} canopy was shaded by a shade house, it therefore intercepted only 45% x 93.77% = 42.2% of the incident radiation.

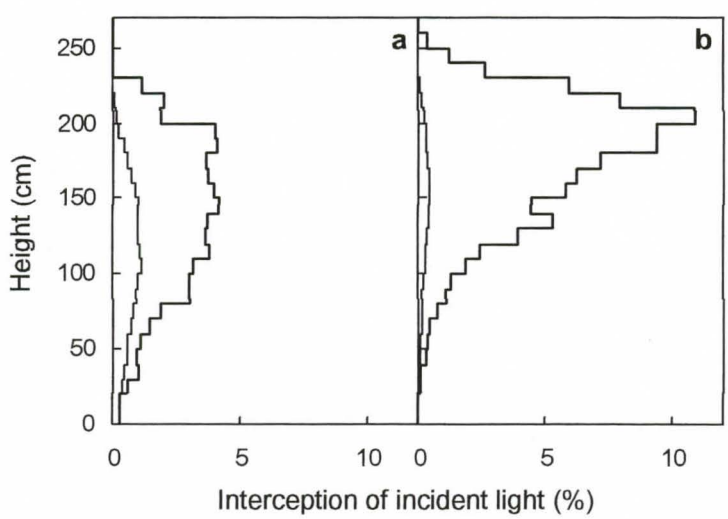


Figure 6: *Vertical profiles of the daily light interception by woody elements (thin lines) and leaves (thick lines) during the rainy season. Results are expressed as percents of light intercepted by 10cm thick vegetation layers.*

Due to the East-West row orientation, the interception of incident light was fairly constant along the day. Woody elements of trunks and branches contributed to 20.6% of the total light interception by the GI_{100} canopy whereas they contributed to only 5.1% for the GI_{50} canopy. Most of the interception was concentrated in the upper part of the GI_{100} canopy whereas the light is more evenly distributed within the GI_{50} canopy (fig. 6).

The analysis of the light profiles *vs.* the LAI cumulated from the top of the canopies showed that the light extinction diverged from the Beer's law prediction. This deviation was particularly important for the GI_{50} canopy. Moreover, if the extinction coefficients are fitted against the total canopy interception, different values for GI_{100} and GI_{50} canopies were obtained (*Kext* = 0.554 and 0.41, respectively). This illustrates the fact that light interception cannot be correctly estimated without considering the actual shape of coffee rows.

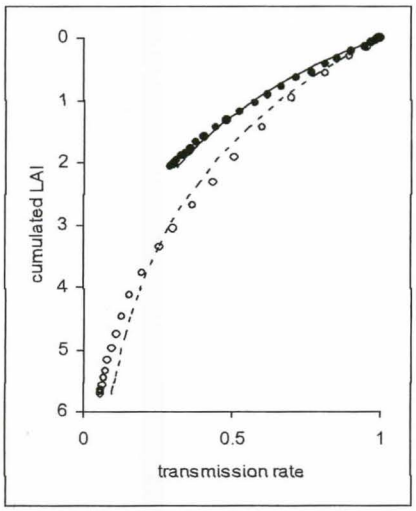


Fig. 7:

Simulated transmission rates of incident radiation for GI_{100} ( ) and GI_{50} ( ) canopies for average radiative conditions during the rainy season.

Fitted exponential profiles vs. cumulated LAI have a Kext of 0.554 (—) and 0.41 (---) respectively.

Leaves irradiance in PAR

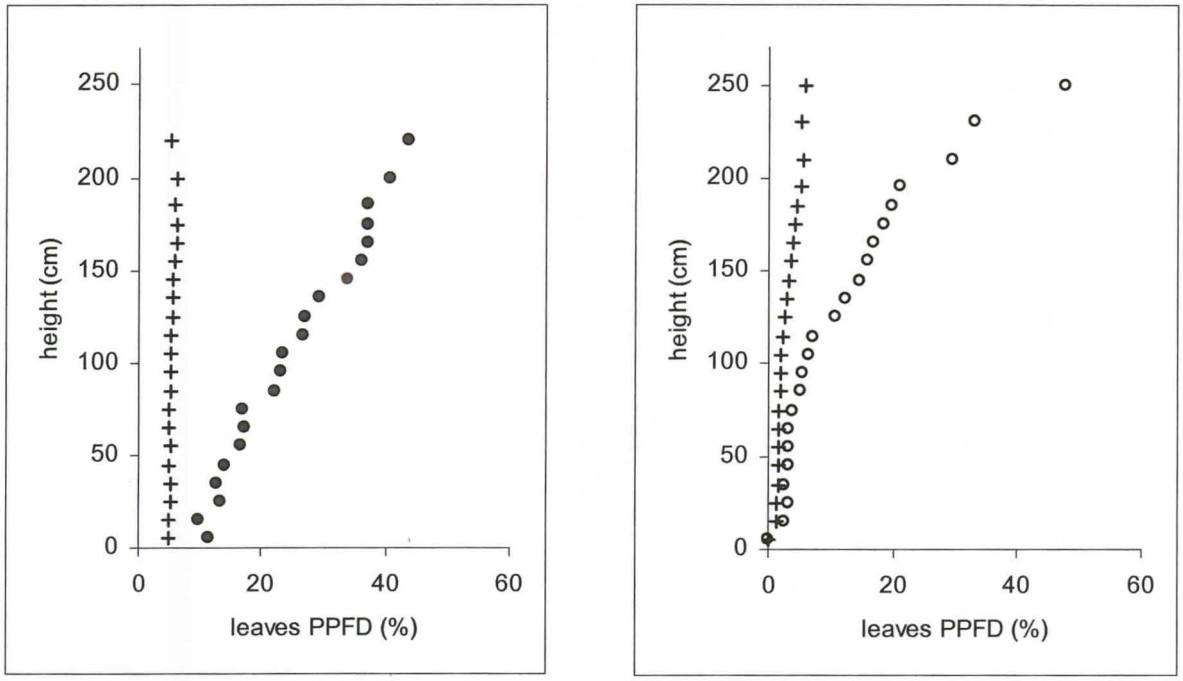
The irradiance of leaves in the PAR (Photosynthetically Active Radiation) is a key variable for the calculation of carbon assimilation. The Archimed modules calculate the irradiance of individual leaves as a sum of two components:

- The (first order) interception of incident radiation.
- The interception of the PAR scattered by the soil and the canopy.

The results in fig. 8 are expressed in terms of relative irradiance, *i.e.* the percentage of the incident PPFD (PAR Photon Flux Density) above the canopy. Therefore, a leaf irradiance of 50% means that the leaf receives half of the irradiance it would have received if positioned horizontally above the canopy.

First order leaves irradiance was on average 27.06 % and 15.56 % of incident PPFD for GI_{100} and GI_{50} respectively. The additional irradiation resulting from scattering within the canopy represents respectively 5.48 % and 3.61 % of incident PAR.

The average irradiance of leaves decreased drastically with the height within the GI_{50} canopy. On average, leaves had a relative irradiance lower than 5% in the lowest part of the stand and their actual irradiance is therefore less than 5% x 45% = 2.25% of the incident PPFD above the canopy.



GI_{100} GI_{50}

Fig 8: *Daily leaf PAR relative irradiance in % of PPFD above the stand during the rainy season vs. their position (height) in the canopy. Circles represent the irradiation resulting from incident PAR interception and crosses represent the additional irradiance resulting from multiple scattering within the canopy. (NB: The GI_{50} stand receives only 45% of incident light and actual irradiances are to be multiplied by a 0.45 factor).*

The actual irradiance of leaves in PAR is maximal under clear sky conditions occurring during the dry season. The figure 9 illustrates the evolution along the day of the average irradiance of leaves versus height for such conditions. Due to the south-north orientation of coffee rows, the irradiance profiles are similar for symmetrical sun positions around zenith and exhibit higher values at noon. If one refers to the figure 5 in the WP3 report, it can be seen that the average irradiance of leaves rarely exceeds their PPFD saturation level for carbon assimilation (around 700 $\mu E\ m^{-2}\ s^{-1}$ for GI100 canopy and 300 $\mu E\ m^{-2} s^{-1}$ for GI50 canopy).

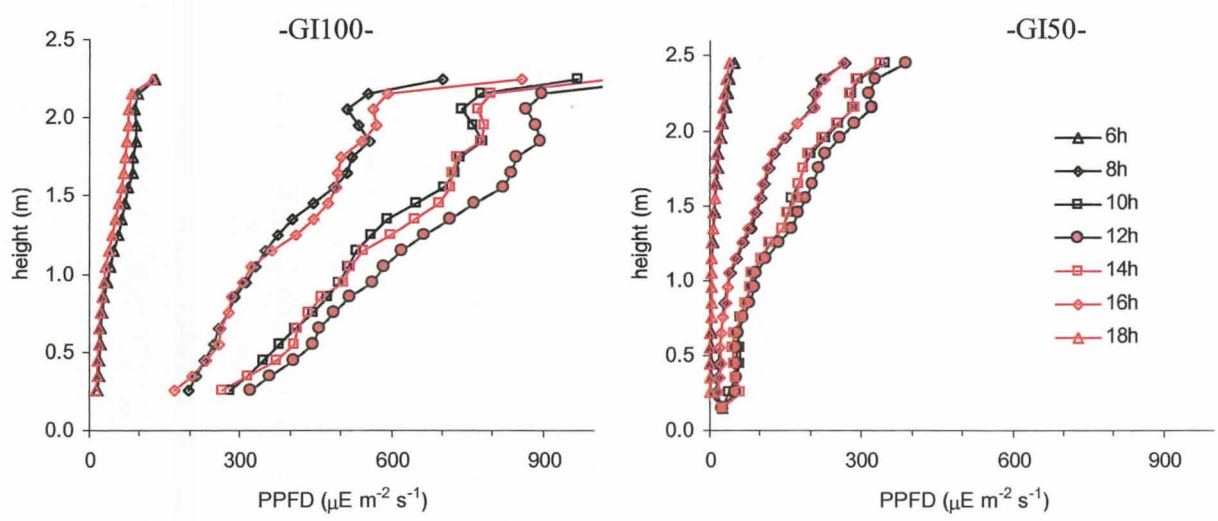


Fig 9: *Average irradiance of leaves vs. height at different times of the day under clear sky conditions. The GI_{100} canopy is exposed to full irradiance whereas the GI_{50} canopy receives only 45% of full irradiance.*

5. Modeling carbon assimilation and transpiration of canopies

The modeling approach consists in calculating the physical and biological processes at the scale of individual leaves. The functional flowchart below indicates the main modules for radiation (in yellow and salmon), turbulent transfers (in blue), energy balance (in pink) and ecophysiological processes (in green) and their connections (Fig. 9).

The ecophysiological model, developed at leaf scale, is described in details in the WP3 report. The starting point is the calculation of leaf irradiance as described previously. The leaf irradiance is calculated separately for the PAR and the NIR (near infrared) wavebands. The PAR irradiance, expressed in $\mu E\ m^{-2}$, is an input for the Farquhar's assimilation model. The PAR and NIR irradiances, expressed in $W\ m^{-2}$, are terms of the leaf net radiation (*Rn*). A third term of *Rn* is the TIR (thermal infrared) balance which depends on the leaf exposure to atmospheric radiation, its own temperature and the canopy temperature.

Leaf energy balance is modulated by the boundary layer conductance and the stomatal conductance. The boundary layer conductance depends mainly on the wind speed within the canopy but is also dependent on the leaf temperature for free convection. The stomatal conductance is related to the leaf carbon assimilation through the Ball-Woodrow-Berry (BWB) model (see details in WP3 report).

The carbon assimilation rate (*An*) is calculated according to the Farquhar's model as a function of the leaf PAR irradiation, modulated by the leaf temperature and the air CO_2 concentration. *An* can be decreased by photo-inhibition which has been related to the integrated PAR irradiance of leaves over 6 hours (see details in WP3 report).

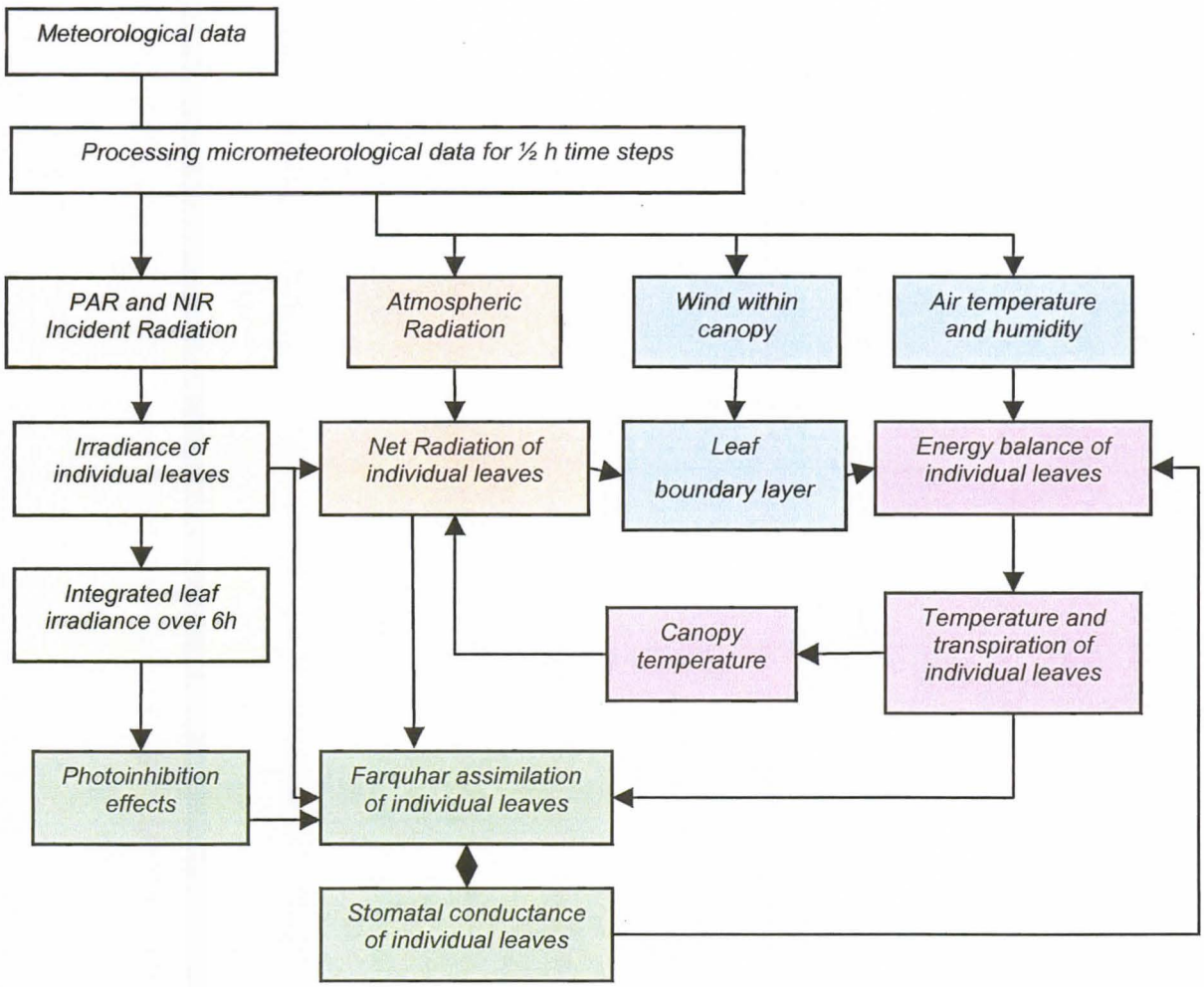


Fig. 10: *Functional flowchart of biophysical modules for calculating light, temperature, carbon assimilation and transpiration of individual leaves within a stand.*

By combining all the mentioned processes, multiple feedbacks between physical and biological processes have to be solved. The analysis of the system behavior showed that an iterative calculation of the different processes within a single loop for temperature was efficient to account for the different feedbacks:

1. In a first step, all leaves are initialized at the air temperature so that the assimilation and conductance models can be run.
2. Given the stomatal conductance output of the BWB model, a new temperature can be calculated for each leaf by solving its radiation and energy balances. Then the canopy temperature is derived from the temperature of individual leaves.
3. The Farquhar and BWB are subsequently run for each leaf according to its new temperature and the step 2 is reiterated.

In order to prevent temperature fluctuations around the solution and to shorten the procedure, a relaxation method was calibrated for controlling the temperature evolution between iterations. This allowed solving of the system with generally less than 5 iterations at each time step.

Part 2: Water partitioning between coffee and associated trees

Philippe Vaast and Jean Dauzat (CIRAD), Pablo Siles and Jonathan Ramos (CATIE) and Luis Dionisio Garcia (IICA-PROMECAFE).

In 2005, **CIRAD, CATIE and IICA-PROMECAFE** have continued a series of field measurements in the optimal coffee cultivation conditions of the Central Valley of Costa Rica on:

- soil water content,
- plant water status,
- water consumption of both coffee and trees,
- rainfall interception by the canopy of shade trees and coffee plants,
- trunk flow of coffee and shade trees,
- and surface runoff,

on coffee systems: coffee associated with shade tree of the genus *Inga* and coffee in full sun conditions.

This latest series of data has permitted to complete the water balance model at plot scale (Expected deliverables, D15/D2.2: water balance model at plot scale) and estimate water drainage and nitrate leaching to the aquifers (see WP4).

From 3-D mockups of coffee plants digitalized in the field in 2004, estimation every 15 min of coffee transpiration rate has been simulated with the coffee plant model and compared to actual measurements of sap flow in the field.

After 2 years (2004-05) of collecting field data with the financial support of CASCA, a Nicaraguan Ph.D. student (Pablo Siles) will be spending 6 months in France in 2006, at INRA (subcontractor of CIRAD) in Nancy, France, and at CIRAD, Montpellier, France, to analyse data and defend his doctoral thesis.

Main results in 2005

Under optimal conditions, coffee vegetative growth was not different in full sun than under shade of leguminous trees of *Inga* spp during the year 2004 with similar leaf area index (LAI) during the dry and wet seasons (Table 1).

Table 1. Main characteristics of coffee and Inga trees under optimal conditions of Heredia during the year **2004**.

System	Density (plants ha^{-1})	Basal Area (m^2 ha^{-1})	LAI Dry season (m^2 m^{-2})	LAI Dry Wet (m^2 m^{-2})
Coffee in full sun				
Coffee	5000	14.23	4.82	4.82
Coffee under shade of Inga				
Coffee	4743	13.58	4.66	4.66
Inga trees	247	6.67	-	1.39

However, differences were noticeable in 2005 with coffee trees under shade loosing more leaves in the dry season than the coffee in full sun and growing a slower pace thereafter (Table 2).

Table 2. Main characteristics of coffee and Inga trees under optimal conditions of Heredia during the year **2005**.

System	Density (plants ha^{-1})	Basal Area (m^2 ha^{-1})	LAI Dry season (m^2 m^{-2})	LAI Transition season (m^2 m^{-2})	LAI Wet season (m^2 m^{-2})
Coffee in full sun					
Coffee	5000	15.16	3.52	4.22	4.97
Coffee under shade of Inga					
Coffee	4743	14.07	2.90	3.48	3.93
Inga trees	247	7.42	-	-	

Following more than two years of sap flow monitoring, results show that transpiration per hectare was lower for coffee under shade than under full sun, either during the dry period (January to March) or the wet period (June to November) during both years (Tables 3 & 4).

Table 3. Calculated evapotranspiration (ETP) and transpiration (T) of coffee and shade trees under optimal coffee cultivation conditions for the **year 2004**.

2004		SAF						Full Sun	
Month	ETP	Coffee		Tree		Coffee+Tree		Coffee	
	mm d^{-1}	mm d^{-1}	T/ETP	mm d^{-1}	T/ETP	mm d^{-1}	T/ETP	Mm d^{-1}	T/ETP
January	4.12	2.26	0.55	1.21	0.29	3.47	0.84	2.75	0.67
February	4.18	2.68	0.64	0.99	0.24	3.67	0.88	3.73	0.89
March	4.21	2.38	0.57	1.24	0.30	3.62	0.86	3.42	0.81
April	4.10	2.11	0.51	1.54	0.37	3.64	0.89	3.07	0.75
May	1.17	0.73	0.62	0.74	0.63	1.46	1.25	1.08	0.93
June	2.52	1.51	0.60	1.56	0.62	3.07	1.22	2.38	0.94
July	2.08	1.40	0.67	1.35	0.65	2.75	1.32	1.90	0.91
August	2.17	1.63	0.75	0.86	0.39	2.49	1.15	1.97	0.91
September	2.14	1.61	0.75	0.98	0.46	2.59	1.21	2.07	0.96
October	2.11	1.59	0.75	1.10	0.52	2.69	1.27	2.16	1.02
November	2.64	1.74	0.66	1.16	0.44	2.90	1.09	2.42	0.91
December	2.94	1.74	0.66	1.16	0.44	2.90	1.09	2.42	0.91

Table 4. Calculated evapotranspiration (ETP) and transpiration (T) of coffee and shade trees under optimal coffee cultivation conditions for the **year 2005.**

2005		SAF						Full Sun	
Month	ETP	Coffee		Tree		Coffee+Tree		Coffee	
	mm d^{-1}	mm d^{-1}	T/ETP	mm d^{-1}	T/ETP	mm d^{-1}	T/ETP	mm d^{-1}	T/ETP
January	3.23	-	-	1.26	0.39	-	-	3.00	0.93
February	3.58	1.71	0.48	1.27	0.35	2.98	0.83	2.77	0.78
March	3.09	1.60	0.52	1.40	0.45	3.00	0.97	2.73	0.88
April	4.44	2.92	0.66	1.72	0.39	4.65	1.05	3.45	0.78
May	2.61	1.85	0.71	1.64	0.63	3.49	1.34	2.12	0.81
June	2.24	1.50	0.67	1.25	0.56	2.76	1.23	1.97	0.88
July	2.56	-	-	1.61	0.63	-	-	-	-
August	2.01	1.27	0.63	1.23	0.61	2.49	1.24	1.91	0.95
September	1.88	1.14	0.61	1.27	0.68	2.41	1.29	1.74	0.93
October	1.34	0.75	0.56	0.86	0.64	1.61	1.20	1.22	0.91
November	2.45	-	-	1.37	0.56	-	-	-	-
December	2.85	-	-	1.62	0.57	-	-	-	-

They also show that the yearly combined water consumption of coffee and shade trees is higher than that of coffee grown in full sun (Table 5).

Table 5. Total yearly rainfall, calculated evapotranspiration (ETP) and transpiration (T) of coffee and shade trees under optimal coffee cultivation conditions.

				SAF			Full Sun
	Year	Rainfall mm yr^{-1}	ETP mm yr^{-1}	Coffee mm yr^{-1}	Tree mm yr^{-1}	Coffee+Tree mm yr^{-1}	Coffee mm yr^{-1}
Total	**2004**	3093	1049	652	424	1076	895
Total	**2005**	2794	985	533	505	1038	773

In 2005, research work was also undertaken on rain interception by shade trees and coffee canopies as well as runoff to parameterize the water model at plot scale.

Results show that runoff under the coffee agroforestry system is lower than under coffee monoculture in full sun, except for the last months of 2005 when the shade trees were severely pruned (Tables 6 & 7).

The amount and % of rainfall intercepted by the coffee and tree canopies was quite large with values up to 164 mm for the rainiest month in the coffee monoculture and 234 mm in the coffee agroforestry in 2004, representing more than 35 and 25% respectively (Table 6). Data, registered in 2005, confirmed these large rainfall interceptions (Table 7).

Table 6. Monthly rainfall of the rainy months (June to November), % of runoff in coffee + Inga system (Coffee AF) and coffee monoculture in full sun (Coffee FS), monthly total and % of rainfall intercepted by combined coffee and tree canopies and coffee canopy in full sun **in 2004**.

	Monthly	**Runoff**		**Interception**		**Interception**	
	Rainfall	Coffee AF	Coffee FS	Coffee AF	Coffee FS	Coffee AF	Coffee FS
2004	**mm m^{-1}**	**%**	**%**	**mm m^{-1}**	**mm m^{-1}**	**%**	**%**
June	177.0	2.6	4.6	69.2	54.2	39.1	30.6
July	279.1	4.3	5.0	107.9	85.9	38.7	30.8
August	239.1	3.5	5.5	99.9	52.4	41.8	21.9
september	633.6	7.9	9.0	219.5	157.5	34.6	24.9
October	657.8	12.8	18.0	234.5	163.8	35.7	24.9
November	361.5	7.6	9.6	136.1	107.6	37.6	29.8

Table 7. Monthly rainfall of the rainy months (June to November), % of runoff in coffee + Inga system (Coffee AF) and coffee monoculture (Coffee PS), monthly total and % of rainfall intercepted by combined coffee and tree canopies and coffee canopy in full sun **in 2005**.

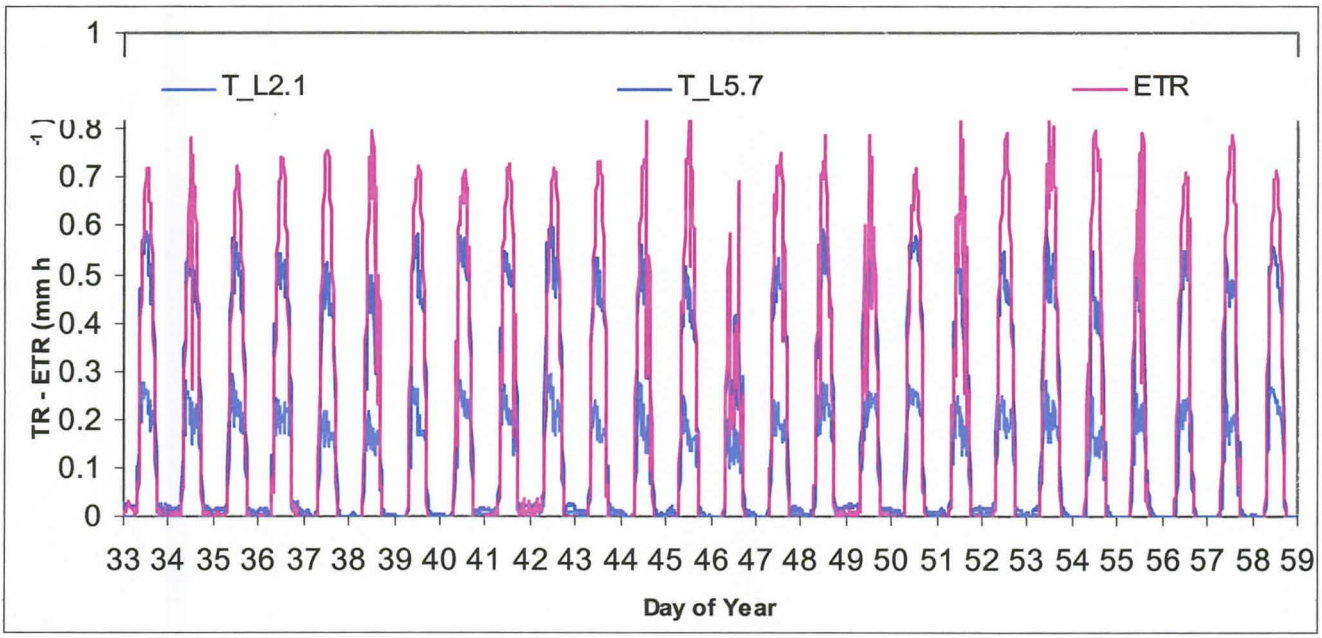
	Monthly	**Runoff**		**Interception**		**Interception**	
	Rainfall	Coffee AF	Coffee FS	Coffee AF	Coffee FS	Coffee AF	Coffee FS
2005	**mm m^{-1}**	**%**	**%**	**mm m^{-1}**	**mm m^{-1}**	**%**	**%**
May	280.1	2.5	2.1	70.5	59.3	25.2	21.2
June	409.0	2.1	3.4	92.8	80.1	22.7	19.6
July	256.8	3.2	5.1	112.0	85.3	43.6	33.2
August	350.4	5.9	10.7	113.3	97.2	32.3	27.7
September	366.6	4.0	1.5	119.7	98.1	32.6	26.8
October	570.8	8.1	7.4	205.5	159.8	36.0	28.0
November	221.4	4.7	4.4	76.0	60.1	34.3	27.2
December	144.3	5.1	4.4	46.7	37.9	32.4	26.3

Part of the rainfall intercepted by the tree and coffee canopies still goes down to the soil via trunk flow. Therefore, trunk flow monitoring was undertaken during 5 months of the rainy season 2005. The results show that trunk flow accounted to 1-2.5% for the Inga trees and 1.3-11.4% for the coffee trees in the agroforestry system while that of coffee in full sun varied from 1% to a maximum of 10.9% (Table 8). Therefore, the net rainfall interception was calculated as the difference between canopy interception and trunk flow. Net interception by the combined coffee and tree canopies ranged from 22.9% to a maximum of 39.6% in the agroforestry system while that of coffee monoculture varied from 17.1% to 31.2% (Table 8).

Table 8. Monthly % of trunk flow of coffee and tree plants and calculated net interception by coffee and tree canopies during the rainy season **2005**.

	Trunk Flow			**Net interception**			
2005	Inga %	Coffee in AF %	Coffee FS %	Inga %	Coffee in AF %	AF system %	Coffee FS %
July	1.14	2.9	2.06	16.3	23.3	39.6	31.2
August	1.19	1.3	0.99	14.4	15.5	29.9	26.8
September	1.41	8.3	6.22	12.4	10.5	22.9	20.5
October	1.15	11.4	10.92	13.7	9.7	23.4	17.1
November	1.23	10.4	8.94	12.3	10.4	22.7	18.2
December	2.42	5.2	4.12	5.1	19.7	24.8	22.1

From 3-D mockups of coffee plants digitalized in the field, estimation every 15 min of coffee transpiration rate can be simulated with the coffee plant model and compared to reference evapo-transpiration (ETR). As an illustration, simulation of transpiration of full sun grown coffee plants with LA1 of 2.1 m m^{-2} and 5.7 m m^{-2} are presented below for the dry season period (February).



Publication of WP2

van Kanten R.F., Beer J., Schroth G., Vaast Ph. (2004). Interacciones biológicas entre *Coffea arabica* y árboles maderables de rápido crecimiento en el Sur de Costa Rica. Agroforesteria en las Americas. 41/42: 5-15.

van Kanten R.F., Vaast Ph. (2006). **:** Coffee and shade tree transpiration in suboptimal, low-altitude conditions of Costa Rica. Agroforestry Systems. (in press).

Doctoral thesis (published in 2003)

Van Kanten RF. (2003). Competitive interactions between *Coffea arabica* L. and fast growing timber shade trees. Doctoral thesis. CATIE, Turrialba, Costa Rica. 141p.

Masters thesis in 2004

Stéphane Bagnis (2004). Développement d'outils informatiques pour la gestion de maquettes 3D de plantes. DESS. Université Paul Sabatier de Toulouse. 31p.

Sustainability of Coffee Agroforestry Systems in Central America; coffee quality and environmental impacts

Contract ICA4-2001-10071

Fourth Annual Report WORK PACKAGE 3

1 November 2004 - 31 December 2005

Philippe Vaast (CIRAD), leader of WP3
Jean Dauzat & Nicolas Franck (CIRAD)
Victor Aguilar (UNA)
Luis Dionisio & Victor Chaves (IICA-PROMECAFE)
Pablo Siles, Leonel Lara & Jonathan Ramos (CATIE)

WP3 - Coffee ecophysiology and quality (Fourth Year)

The main objectives of this WP3 are to study the **physiological responses of coffee leaves** to micro-environmental field conditions, **develop a model of carbon production and allocation** in coffee plants as well as investigate the mechanisms responsible for **coffee quality**.

During the first 3 years of CASCA, field work has been undertaken:

- in two countries (Costa Rica and Nicaragua),
- 5 ecological zones (hot and dry lowland of the southern part of Nicaragua, humid highland of Northern Nicaragua, optimal high-altitude zones of the Orosi valley and central valley of Costa Rica, and hot and humid lowland of the southern part of Costa Rica),
- 5 different systems (coffee in full sun and coffee associated with 4 shade tree species),
- 3 levels of artificial shade (25%, 50% & 75%).

In 2005, one survey on the effects of shade level and intensity of management was undertaken in one coffee region of Nicaragua. Field measurements on eco-physiological responses of coffee leaves to various climatic conditions and on carbon partitioning between aerial and subterranean components of coffee plants were continued during 2005 in Costa Rica and Nicaragua.

Coffee photosynthesis and microclimate effects

In collaboration between CIRAD, CICAFE and CATIE, field data collection has continued in 2005 to assess leaf and fruit photosynthesis in relationships with micro-climatic conditions at the leaf level and according to periods of the day in order to complement data collected the previous years. Measurements were also performed on coffee water potential along the day during the dry and rainy seasons 2005.

Still, most of the work of 2005 concentrated in analyzing data, developing models and publishing results via scientific articles following measurements of previous years on **leaf assimilation responses to PPFD, VPD, CO_2 concentration, leaf content (starch and**

soluble sugars), and photo-inhibition. **One Ph.D student,** Nicolas Franck, defended his **doctoral thesis** in October 2005 on the **modeling of physiological responses of coffee and carbon allocation.**

Modeling of carbohydrate allocation

In 2005, destructive samplings of fruiting branches located on different positions of the plant (high, medium and low) were continued every 3 months to quantify carbohydrate allocation between fruits and vegetative part during the production cycle. These measurements have been done for three consecutive production cycles in one trial in Nicaragua and another one in Costa Rica; two Masters theses were defended by students of UNA on this subject in 2005. These results show that coffee fruits are the most important plant sink for carbohydrates and out-compete other plant organs, especially branch apex in development. These results provide a better understanding on alternate production of coffee trees and die-back of branches in the presence of heavy fruit loads. In both countries, measurements on **root biomass and root depth** were also performed. These are valuable information that complements work on carbon allocation at the whole coffee plant level.

Coffee quality

Harvests of trials, still in progress, were performed from November 2004 to February 2005.
One survey of 67 farms was also undertaken in 2005 in the Northern Central part of Nicaragua on the effects of shade and agricultural management on coffee quality. Coffee samples were taken during the pick of harvest, wet-processed and cupping and biochemical analyses were performed.
With this last series of samples, more than **350 cupping analyses** have been performed from 2002 to 2005 by a panel of 8-10 tasters in the laboratory of CIRAD in Montpellier, France. Around **300 biochemical analyses** on coffee bean composition was also undertaken during these 4 years.

All the data gathered from trials and surveys (one focusing on altitude in Costa Rica and one on shade and agricultural management in Nicaragua) during these fours years, confirmed that fruit load, shade and altitude significantly affected coffee quality. **Altitude** and **shade** permit a better growth and development of coffee berries in a cooler environment which delays the pulp maturation of coffee berries and hence results in larger bean size, enhanced bean filling, better biochemical composition and **higher quality** of coffee beverage. Shade also decreases flowering intensity of coffee trees which results in **lower fruit loads** and decreased competition among berries for carbohydrate and hence enhanced bean size, composition and **cup quality**. In Costa Rica, one trial on fertilization levels show that **increasing nitrogen resulted in higher aroma** of the coffee beverage without affecting significantly the overall cup quality.

Five articles (submitted in 2004) have been **published in 2005** and **six articles submitted in 2005** documenting the physiological responses of coffee to microclimatic conditions and the beneficial effects of shade trees and altitude on coffee physiology and quality. **One Masters thesis** on coffee quality was defended in December 2005, **two theses** on biomass partitioning within coffee plants and **one Doctoral thesis** on coffee eco-physiology and modeling in October 2005.

The Deliverable D8/D3.1 "Scientific report on physiological responses of coffee to microclimatic conditions" and the last Deliverable D9/D3.2 "Report of rules of carbon allocation" can be considered completed through publication or submission of **5 scientific articles** and the defense of one Ph.D. thesis (see list of publications below).

The Deliverable D14/D6.2 "Carbon allocation model of fruit growth in a single bush" was finalized in October 2005 with parameterization and testing of the models on carbon allocation at different scales (leaf, tree and plot scale).

The Deliverable D23/D3.3 "Reports on indicators of coffee quality" can be considered completed through publication or submission of **6 scientific articles** (see list of publications below).

Main results of 2005

Carbon assimilation of open and shaded coffee stands and their potential production

1. Rationale

In coffee agroforestry systems, shade has multiple effects on coffee plants, the most important ones on coffee plant assimilation:

- Lowering the PAR irradiance of leaves potentially decreases their carbon assimilation, nevertheless, coffee leaves acclimation to shaded conditions tends to minimize this effect by enhancing the quantum yield, *i.e.* the assimilation at low irradiances.
- On the other hand, Coffea arabica originated from forest understorey in Ethiopia and is considered as a shade adapted species. As such, it is supposed to be naturally adapted to low irradiances and hence be sensitive to photo-inhibition in full sun.

Besides these effects on carbon assimilation, shade has important effects on plants growth:

- Shade-acclimated leaves are larger and thinner than full sun leaves. As a consequence, for a given carbon investment in the foliage, shaded plants may develop higher leaf area indices.
- Flower initiation is drastically reduced if shade is maintained during the critical period of flowering at the end of dry season. In such case, the reduction of fruit load result in a higher availability of assimilates for the vegetative growth.

In return, these modifications on carbon allocation, through an enhancement of the leaf area index, can increase the carbon fixation at the stand level.

In order to analyze these intertwined effects, a doctoral thesis was undertaken by Nicolas Franck in France and Costa Rica during the last 3 years. A field experiment was designed to address these aspects with treatments combining different shade levels and fruit loads. The observations focused on leaves assimilation in relation to their acclimation as well as the carbon demand and growth of fruits. This work was completed by the development of leaf assimilation model and its integration at the stand scale as described in the WP2 report.

2. Field experiments

The study was carried during years 2003 and 2004 on dwarf cv. 'Caturra' of *Coffea arabica* L. in a commercial orchard of the Orosi valley of Costa Rica. Four growth irradiance treatments were applied: 100%, 75%, 50% and 25% of full sun (fig. 1). Sub-treatments consisted in maintaining 100%, 50%, 25% or 5% of the initial plant fruit load. Micrometeorological were monitored during the whole the rainy season for each treatment.

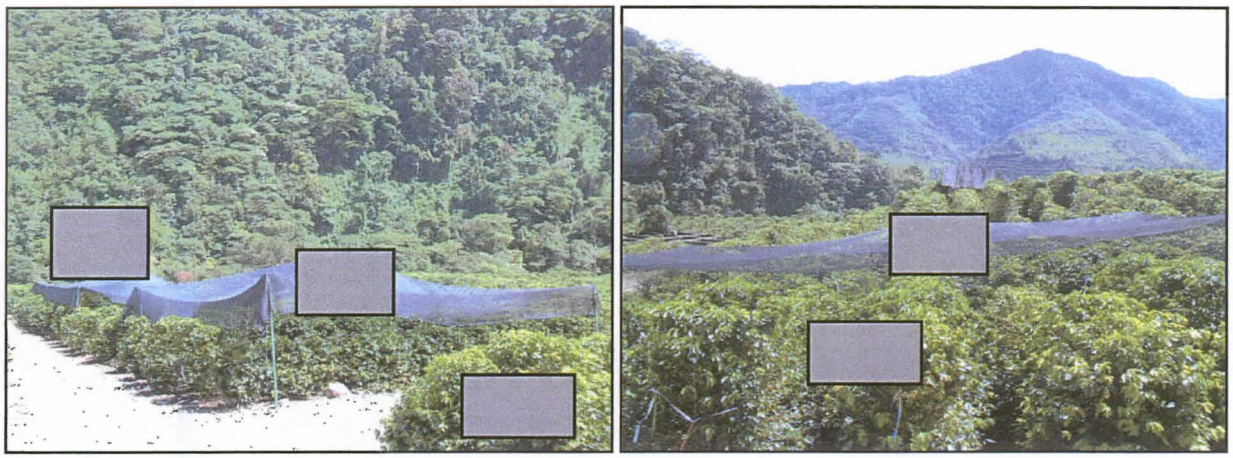


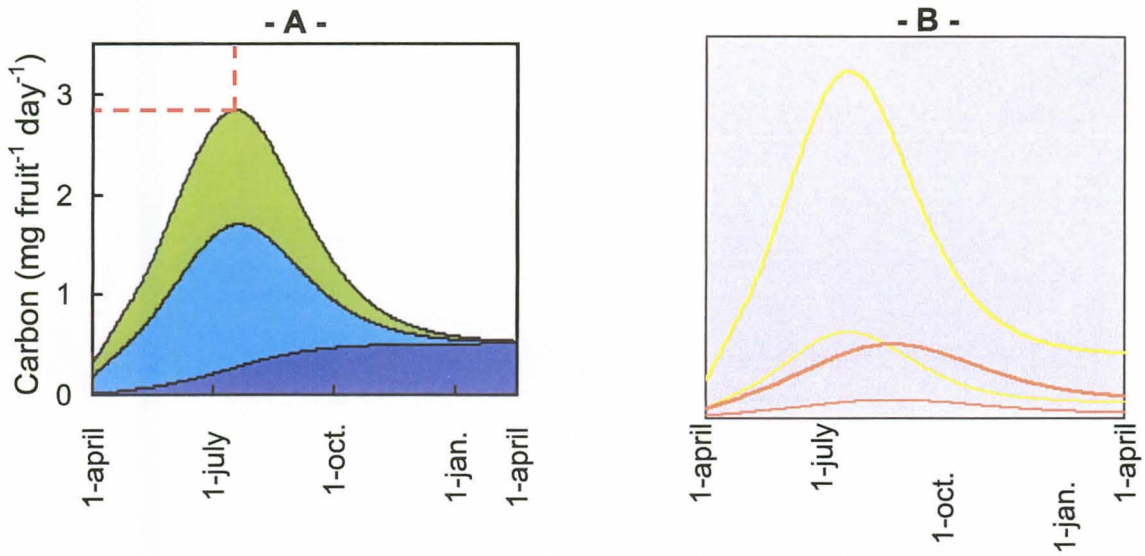
Fig. 1: *Shade houses built to adjust growth irradiances treatments from full sun (GI100) to 25% of sun full (GI25).*

3. Fruit and vegetative growth

The vegetative and fruit growth was followed each month at the top, the middle and the bottom of coffee crowns during the whole fruit growth season. In order to investigate the effect of fruit load on the vegetative growth, a sink-source indicator was built as the ratio of the fruits demand over the cumulated leaves area: *Iss = fruit demand/leaves area.*

Fruits demand for carbohydrates was estimated as the sum of three terms: (i) the carbon fixed in dry fruit mass, (ii) the growth respiration (metabolic cost for fixing carbon estimated at 1.57 Mol of glucose to create 1g of fruit dry matter) and (iii) the maintenance respiration. This demand evolves during the season, exhibiting a peak in July for the GI_{100} stand (fig. 2A) and a delayed peak for shaded stands. Combining the estimated demand per fruit with the actual fruit load gives the actual fruit demand which was later on related to the plant leaf area to get the *Iss* value. The figure 2B illustrates drastic *Iss* differences between treatments resulting not only from the lower fruit load in shaded treatments but also due to their higher LAI. The delayed *Iss* peak under shade can be noticed due to the prolongation of the fruit growing period due to the mitigating effect of shade on temperature experienced by coffee organs.

Fig. 2: *Fruits carbon demand:*
A: *Daily carbon demand per fruit for full load treatment* CF_{100}.
B: *Average fruit carbon demand per square meter of leaves within different growth irradiance and fruit load treatments.*



When analysing the vegetative growth versus the *Iss* indicator, different features were clearly noticeable (fig. 3):

- The natural fruit thinning rate was of the same order of magnitude in all treatments and was not correlated to *Iss*.
- The node initiation severely decreased with *Iss*.
- The branch defoliation drastically increased with *Iss* and could lead to the dieback of heavily loaded branches.

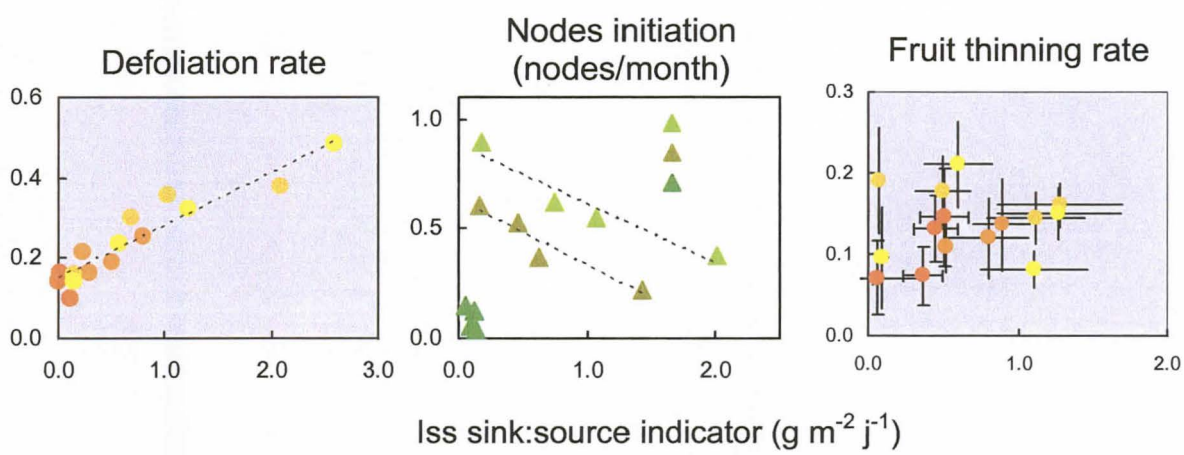


Fig.3: *Sensitivity of defoliation rate (left), nodes initiation at 3 positions within the crown (top, middle & bottom) and fruit drop (right) to the Iss sink:source indicator.*

These results strengthen the hypothesis that the carbon balance plays a determinant role in leaf fall when fruit load surpasses the plant photosynthesis capacity. They also confirm and quantify the effect of fruit load on plant organ genesis. The main consequences of these two features are that an excessive fruit load leads to:

- decreased photosynthetic capacities during the growing season (because of high loss of leaves) and the next season (because of lower leaf renewal on new nodes);

- a decreased potential of production for the following year (because of a decrease in new nodes able to bear fruits).

Both phenomena act jointly to result in biannual cycles alternating between high and low productions. The subsequent question was to determine which production level would conciliate an optimal balance between vegetative and fruit growth. To address this question, modelling the photosynthetic capacity of coffee canopy in relation to its growth irradiance was undertaken.

4. Modelling carbon assimilation at leaf scale

The assimilation rate depends of intrinsic leaf capacity to use solar energy for the synthesis of CO_2 into sugar. Assimilation is reduced if CO_2 transfer into the mesophyll is limited by stomatal conductance. Furthermore, assimilation can be temporarily lowered at high solar irradiances via photoinhibition. Finally, sugar accumulation within a leaf can trigger a negative feedback on its assimilation rate. This study investigated these 4 components of leaf assimilation: (i) leaf photosynthetic capacity, (ii) role of stomatal conductance, (iii) photoinhibition effect and (iv) negative feedback of leaf sugar accumulation.

4.1 Modelling leaf photosynthetic capacities

The reference model for the carbon assimilation is the Farquhar's model which accounts for both the PAR energy requirement for the glucose synthesis and the metabolic limitations. The model parameterisation is based on extensive response curves of assimilation versus PPFD and CO_2 (fig. 4).

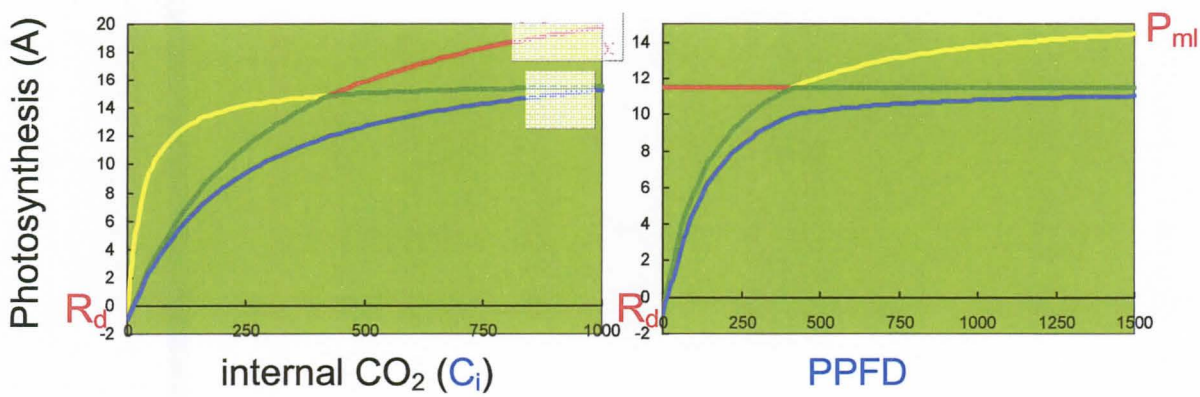


Fig. 4: *Parameterisation of the Farquhar model vs. assimilation response curves to CO_2 and PPPFD irradiance of leaves.*

The model parameterisation was carried out on mature leaves within the four shade treatment. Results highlighted large differences between treatments (fig 5, left). Nevertheless, it was shown that these differences could be simply related to the leaf mass area (*LMA*). As a result, with assimilation rate expressed per unit leaf mass (instead of the more conventional expression per unit leaf area), it appears that the maximum assimilation rate becomes similar for all growth irradiances (fig. 5, right) whereas the parameters α_c, P_{ml}, Vc_{max} and Rd become simple functions of the leaf mass area.

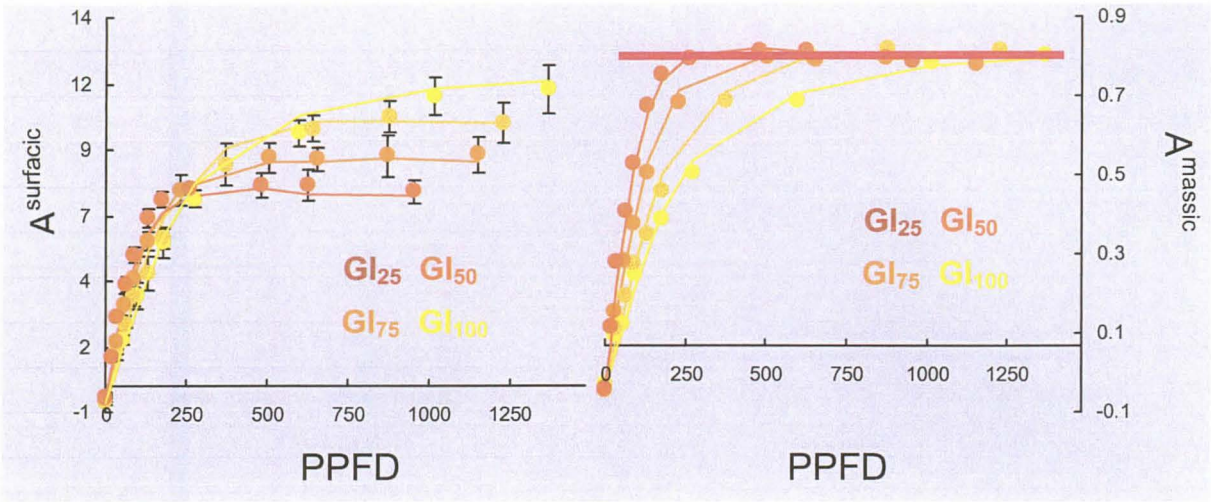


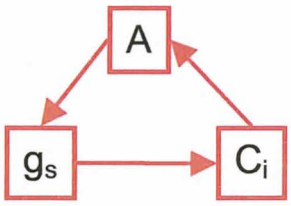
Fig. 5: *Maximal assimilation rate expressed per leaf area unit (left) and expressed per leaf dry mass unit (right).*

4.2 Modelling stomatal conductance

Among the large number of stomatal models, the Ball-Berry model was used for its simplicity as stomatal conductance (gs) is adjusted to maintain a constant internal concentration of CO_2 within the leaf mesophyll (Ci) as illustrated in fig. 6. This model, adapted by Leuning to account for the air VPD effect, fits observations in several species in the absence of limiting factors such as plant stress due to soil water limitation. It was showed that the model behaves satisfactorily for coffee leaves in all treatments during the rainy season.

Fig. 6:

Coupling of carbon assimilation (A) and stomatal conductance (gs) in the Ball-Berry model through the internal CO2 concentration within the mesophyll (Ci).

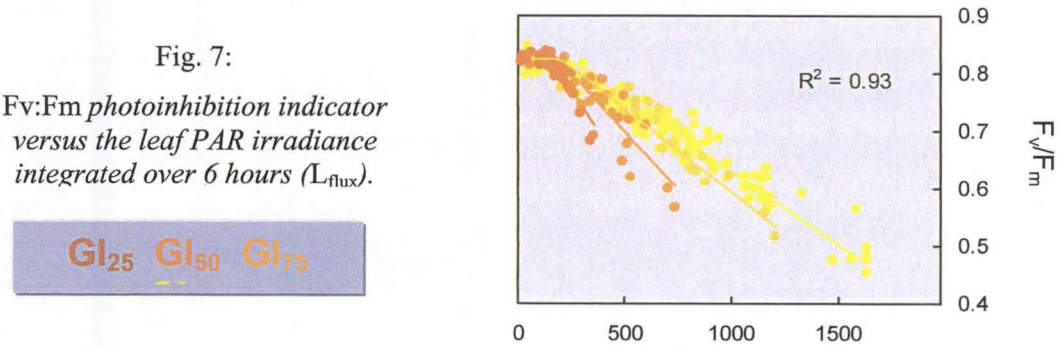


4.3 Modelling photoinhibition

The *Fv:Fm* photoinhibition indicator exhibited a linear decrease with the leaf PPPD irradiance integrated over 6 hours (L_{flux}). The effect of *Fv:Fm* on the Farquhar's model parameters were properly restituted by the Ogren model. Further analyses showed that simple functions with leaf mass area can be used to account for their acclimation to the growth irradiance treatments.

Fig. 7:

Fv:Fm *photoinhibition indicator versus the leaf PAR irradiance integrated over 6 hours* (L_{flux}).



4.4 Modeling leaf sugar negative feedback on assimilation

Previous observations showed a recurrent decrease of assimilation along the day, especially at low fruit load, hence pointing towards a negative feedback effect of sugar accumulation. An experiment was conducted on leaves artificially fed with sucrose. The results led to the following conclusions:

- Sugar accumulation within the leaves reduces their photosynthetic capacities;
- Leaves on branches, bearing a high fruit load, export more assimilates and can therefore express more fully their potential assimilation;
- Alternatively, low sink strength for assimilates (low fruit load) leads to sugar accumulation within the leaves and their assimilation can be strongly reduced by a negative feedback of accumulated sugars.

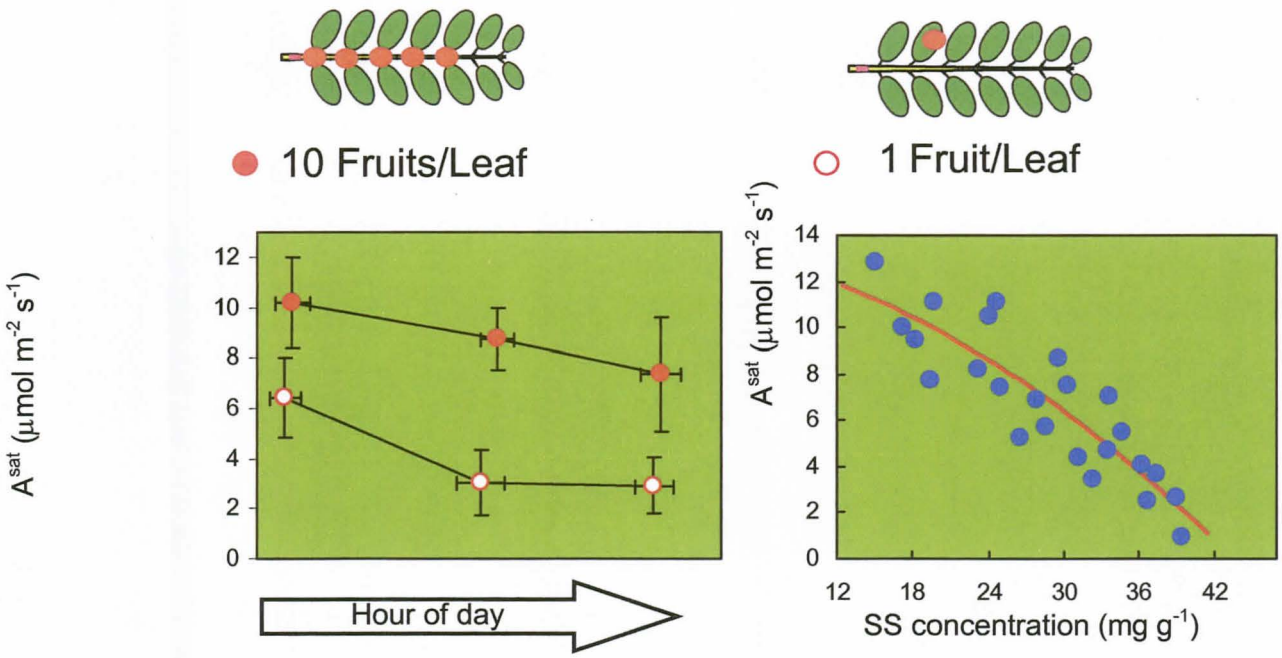


Fig. 8: *Effect of fruit load and soluble sugars concentration within the leaf (SS) on its assimilation at saturating light (A^{sat}).*

Left: defruiting a branch leads to a steeper decrease of A^{sat} with time.

Right a single relationship relates the A^{sat} decrease to SS concentration, whatever the fruit load.

The practical consequence of these mechanisms is that a high fruit load may temporarily optimize the carbon acquisition. On the other hand, a high fruit low may have detrimental effects in the short term (defoliation and die-back) and long term (insufficient vegetative growth for producing and/or sustaining the next year production). To address this complex question, an assessment of sinks and sources at the plant and stand levels has to be undertaken.

5. Carbon assimilation at stand scale

5.1 Upscaling tools

As presented in WP2 report, the up-scaling of the assimilation model from leaf scale to stand scale was achieved by the ARCHIMED simulation platform on 3D architectural representations of coffee plants (derived from measurements in the field undertaken in 2004). As illustrated by fig. 9, calculations were carried out on individual organs.

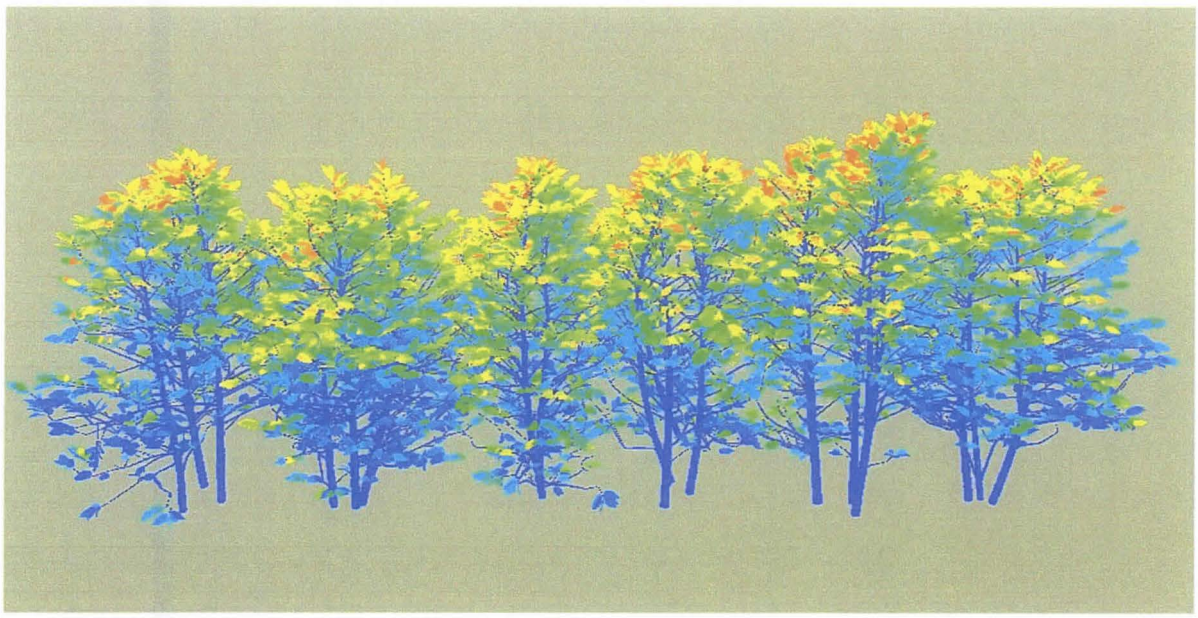


Fig. 9: *Simulation of GI50 canopy photosynthesis at 14:00 under clear sky conditions.*

5.2 Canopy assimilation for shaded and open canopies

The carbon assimilation has been estimated for the GI_{100} and GI_{50} canopies during the whole period of fruit growth (May-November) at a 15mn time step (fig. 10). Surprisingly, it was found that the canopy daily assimilation was very similar for the two canopies despite the fact that the GI_{50} canopy received only 45% of the incident PPFD:

$A^{canopy} = 0.423 \pm 0.068$ mol m^{-2} d^{-1} for GI_{100}

$A^{canopy} = 0.400 \pm 0.102$ mol m^{-2} d^{-1} for GI_{50}.

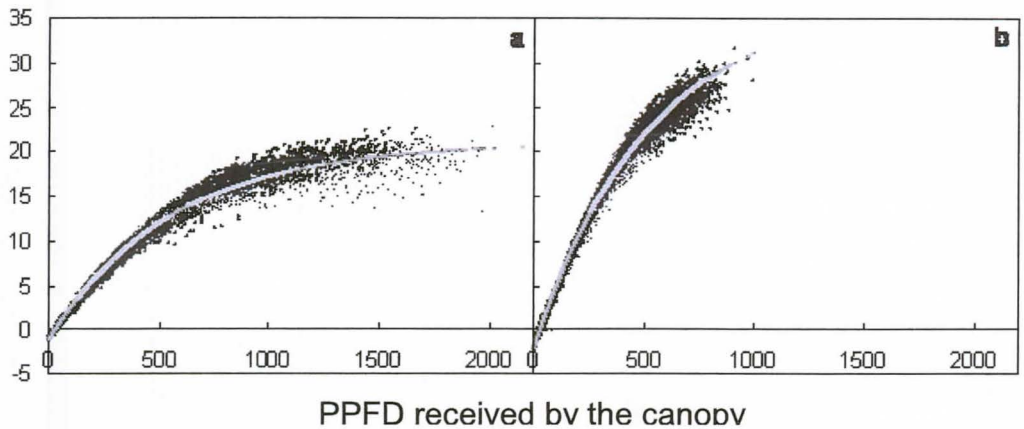


Fig. 10: *Canopy net assimilation per plot square meter vs. incident PPFD during the rainy season. Left: GI100 assimilation in full sun, right: GI50 assimilation under 45% of full sun. Each point represents a 15mn time step for a given day during the rainy season.*

NB: The GI_{50} canopy receives 45% of the incident radiation. The expression of A^{canopy} versus incident PPFD is given in fig. 13.

In order to analyse the canopy adaptations leading to this result, simulations were carried out using the GI_{100} and GI_{50} canopies submitted or not to shade and with leaves acclimated to their growth irradiance (100 and 45% respectively) or the other way around (45 and 100%). The presented simulations were performed with or without accounting for the reducing photoinhibition effect on assimilation (Table 1).

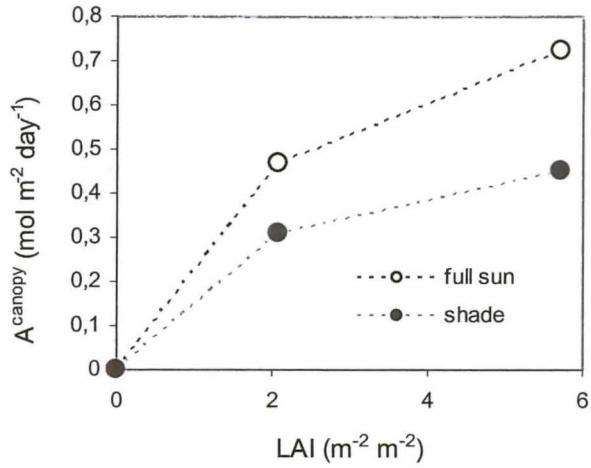
Table 1: *Simulated daily assimilation of GI_{100} and GI_{50} canopies during the rainy season when submitted to full sun or 45% of full sun. Each simulation was repeated with leaves acclimated either to 100% or 45% of natural irradiance. Some simulations were repeated without incorporating the photoinhibition effect.*

Canopy geometry	LAI	Leaves acclimation	% incident PPFD	An canopy assimilation	An without photoinhibition	PI depress. effect on An
GI_{100}	**2.07**	**100%**	**100%**	**0.469**	**0.486**	***-3.50%***
GI_{100}	2.07	45%	100%	0.496	0.525	*-5.52%*
GI_{100}	2.07	100%	45%	0.2245		
GI_{100}	2.07	45%	45%	0.307		
GI_{50}	**5.71**	**45%**	**45%**	**0.450**	**0.454**	***-0.88%***
GI_{50}	5.71	100%	45%	0.225	0.225	*-0.00%*
GI_{50}	5.71	45%	100%	0.882		
GI_{50}	5.71	100%	100%	0.722		

It is particularly interesting to examine the LAI and leaf acclimation effects on the potential canopy assimilation. If GI_{100} canopy had the development of the GI_{50} canopy (*i.e.* with a LAI of 5.71 instead of 2.07), its assimilation in full sun would reach 0.722 mol m^{-2} day^{-1} (instead of 0.469 mol m^{-2} day^{-1}). Alternatively, if GI_{50} had the development of the GI_{100} canopy (*i.e.* with a LAI of 2.07 instead of 5.71), its assimilation under shade would be lowered down to 0.307 mol m^{-2} day^{-1} (instead of 0.450 mol m^{-2} day^{-1}). Clearly, the assimilation of the full sun canopy is hampered by its low LAI and its associated low light interception rate (70.11% of incident light instead of 93.72% for the GI_{50} canopy).

Fig. 11:

Effect of Leaf Area Index and shading (full sun or 45% of full sun) on daily canopy assimilation for average conditions during the rainy season.



On the other hand, it can be observed that the light use efficiency for carbon assimilation is much higher for shaded canopy; reducing the incident radiation by a factor of 55% only reduces the canopy assimilation by a factor of 35% or 38% (for sparse and dense canopies, with LAI of 2.07 and 5.71 respectively). Moreover, it can be seen that leaves acclimation to shade condition has a drastic effect on canopy assimilation; without the shade acclimation features, the GI50 assimilation would be decreased from 0.450 to 0.225 mol m^{-2} day^{-1}.

Photoinhibition has a minor effect on canopy potential assimilation; PI effect is insignificant on GI_{50} canopy under shade and decreases A^{canopy} by only 3.5% for GI_{100} exposed to full sun. This can be explained by the fact that most leaves receive only a fraction of incident PPFD because of their inclination and are shaded during a part of the day. Nevertheless, it can be noticed that if leaves were not acclimated to full sun, the photoinhibition would reduce the GI_{100} A^{canopy} by 5.52%. It must be kept in mind that these results are obtained for average conditions during the rainy season: for a sunny day, the PI reducing effect would reach 9% (and 12% for non-acclimated leaves).

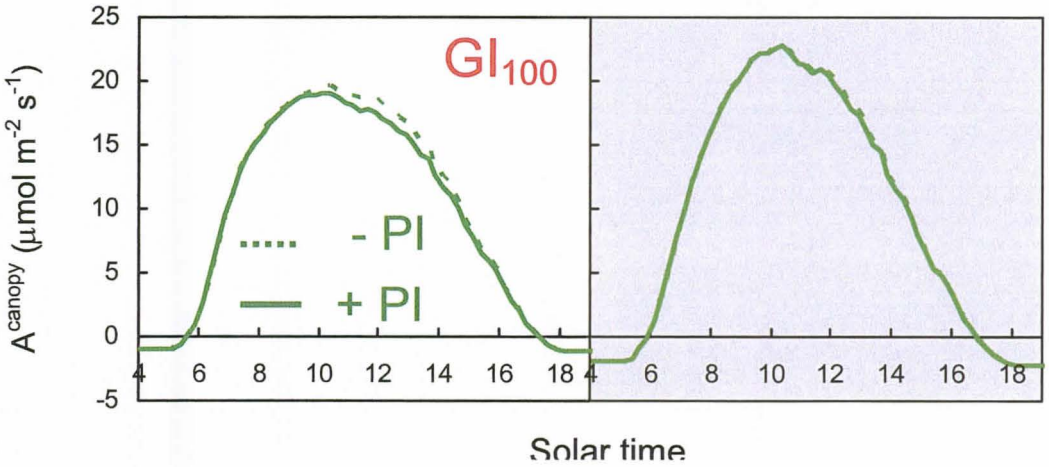


Fig. 12: *Daily evolution of canopy assimilation with (+ PI) or without(+ PI) considering photo-inhibition.*

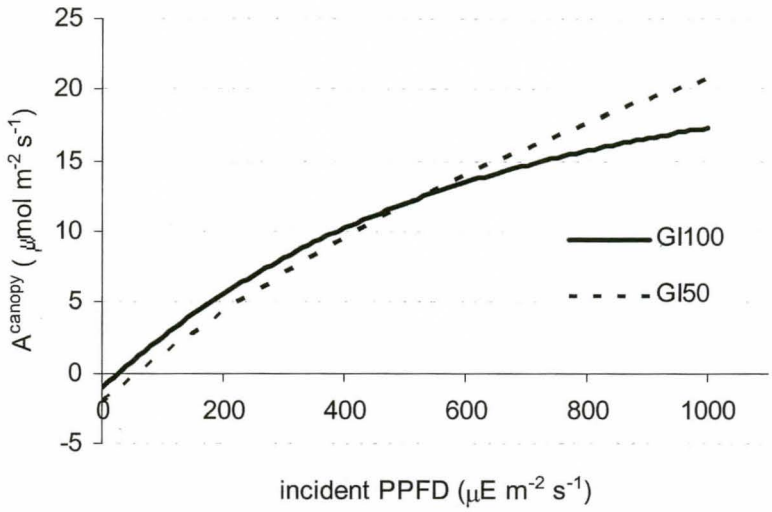
5.3 Temperature and radiation effects on canopies assimilation

As revealed by fig. 10 and 13, the GI_{100} A^{canopy} tends to reach a saturation level for incident PPFD values above 1000µE m^{-2} s^{-1} whereas the shaded GI_{50} A^{canopy} is far from saturation for this level of incident radiation.

Fig. 13 :

Monomolecular fitting of GI_{100} and GI_{50} assimilation rates vs. incident PPFD.

NB: because of shading, the GI50 canopy actually receives only 45% of the incident PPFD.



Consequently, the assimilation of the shade canopy can be considerably increased under clear sky conditions contrary to the one of sun-adapted canopy. This can be verified by comparing the fig. 12 (average conditions during the rainy season) and 14 (green curve; same conditions except clear sky).

All the previous simulations are based on meteorological data at Orosi (altitude: 1108m) and hence optima air temperatures (Tmin~17° and Tmax~25°) during the rainy season for coffee photosynthesis. In order to evaluate the temperature effect at lower locations and/or during the dry season, simulations were performed with temperature scenarios under clear sky conditions[1] (fig. 14). Results confirm that:

- The Orosi air temperature conditions during the rainy season are close to the optimum for canopy assimilation;
- Increasing the temperature by 5° leads to a drastic decrease in assimilation of A^{canopy} from mid-morning to mid-afternoon.
- The depressing effect of high air temperature is lower for the shaded canopy because of lower leaf surface heating due to a lower exposure to solar radiation.

These results confirm the drastic effect of air temperature and may explain the low performance of coffee plantations in lowlands. In this respect, the shade cast by trees in agroforestry systems certainly have several favourable functions such as:

- limiting leaf heating upon lower exposure to solar radiation;
- reducing air and leaf surface temperature.

[1] Simulations with clear sky conditions also take into account the heating of sunlit leaves.

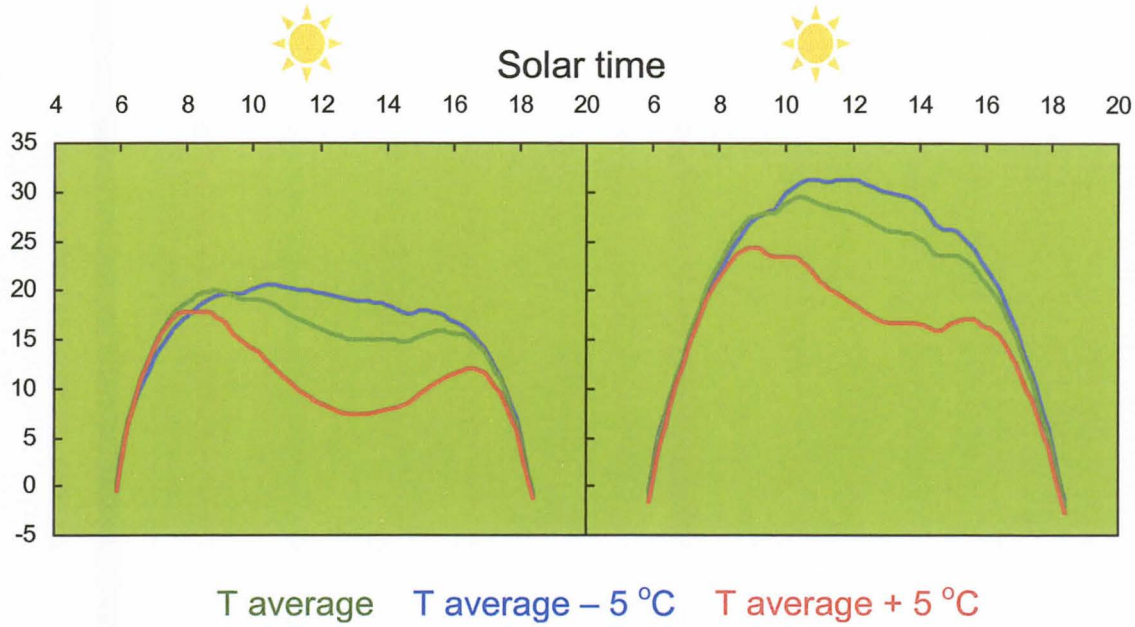


Fig. 14: *Potential GI_{100} and GI_{50} carbon assimilation under clear sky conditions for different air temperature scenarios.*

6. Discussions

Simulations showed that the GI_{100} and GI_{50} canopies have about the same potential assimilation during the rainy season with quite different LAI (2.07 and 5.71, respectively). As shown above, the A^{canopy} performance under shaded conditions is mainly a consequence of its higher LAI. Therefore, it is important investigate how the shaded canopy can develop higher LAI than sun-adapted canopy, especially in terms of the sink-source balance. Sinks cannot be easily assessed for all plant compartments (especially for root systems). Nevertheless, it may be assessed through the carbohydrates potentially available for the vegetative growth as a whole by calculating the difference between the canopy assimilation and the fruits demand. When doing so for the period where the fruit demand is maximal (between July and September), it can be seen (fig. 15) that the fruit demand is about equal to the canopy assimilation for the GI_{100} canopy. Consequently, during this period of maximal fruit demand, no extra carbohydrates are available to ensure a proper vegetative growth. This is consistent with field observations exhibiting a pause/decline in organ genesis and partial plant defoliation. Moreover, it has been shown that plant carbohydrate reserves were decreased during the fruit growth period. On the other hand, the shaded canopy has potentially carbohydrates in excess of its vegetative growth demand due to a lower fruit load and hence a lower carbohydrate sink strength. Therefore, it can be assumed that one of the main reasons for the increased GI_{50} LAI is its low fruit production during the previous season. Another reason is that the average leaf mass area of the shaded plant is about 1.35 times lower than the one of full-sun plants. In other words, for the same foliage biomass, the shaded canopy may develop a 1.35 times larger LAI than the full sun canopy.

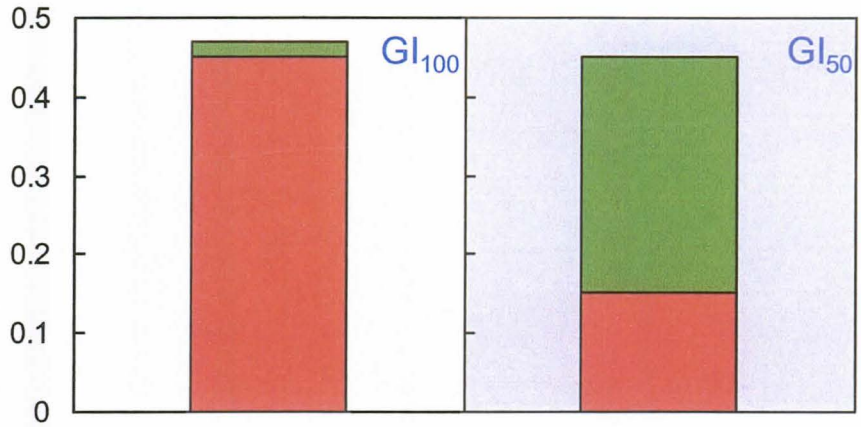


Fig. 15: *Potential carbon assimilation (green) and carbon invested in fruits (red) for GI_{100} and GI_{50} canopies at the period of maximum fruit demand.*

The above results point out towards the key question concerning the optimal fruit load that is needed in order to optimise the canopy assimilation and to prevent biannual production cycles. Obviously, the fruit load in the GI_{100} treatment was above the optimum as it led to a reduction in the potential canopy assimilation via a competitive advantage of fruits over shoots for carbon demand and hence a reduction in vegetative growth (A^{canopy} assimilation would be increased by a factor of 1.88 if its LAI were to increase from 2.07 to 5.71). On the other hand, the GI_{50} canopy can potentially sustain a much higher fruit load. Therefore, agroforestry systems intercepting about 30-50% of solar radiation are highly recommended in lowlands and in all situations where air temperature is above the optimal value for photosynthesis, provided that the negative effect of shade on flower initiation is overcome. As a shade adapted plant species, coffee revealed a good aptitude for leaf acclimation to shade and with a low aptitude to high temperatures. Consequently, the choice and management of shade trees is important to stimulate coffee flowering, but provide buffering effects during the production cycle and furthermore lengthen the maturation of berries resulting in better beverage quality. Selecting shade tree species naturally shedding their leaves by the end of the dry season at the coffee flowering onset and regaining adequate foliage thereafter, appears to be a good strategy. An alternative strategy is to time canopy pruning of the shade tree species as to allow higher coffee exposure to solar radiation when needed around flowering onset.

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Masters thesis summary

Lara E, LD. 2005. Effects of the altitude, shade, production and fertilization on coffee quality (*Coffea arabica* L. var. Caturra) produced in agroforestry systems of the coffee producing zone of Northern Central Nicaragua. Thesis Mag. Sc. Turrialba, C.R. CATIE. 106 p.

Key words: Coffee, Nicaragua, physical quality, organoleptic quality, biochemical composition, near infrared spectrometry reflectance, principal components, geographic discrimination.

With the objective of evaluating the effects of altitude, shade, yield and fertilization on coffee quality, a total of 67 coffee samples of coffee plantations was collected in the Northern Central region of Nicaragua in the departments of Matagalpa, Jinotega, Nueva Segovia and municipality of Waslala. The coffee quality was also discriminated according to its geographic origin.

Altitude influenced the greatest the determination of coffee physical quality (larger, heavier beans and lower % of imperfects beans), organoleptic quality (aroma, body, acidity, flavor and preference) and biochemical compounds (caffeine, trigonelline, sucrose, chlorogenic acids and fat).

Shade influenced significantly the physical quality (larger, heavier beans and lower % of imperfects beans) and biochemical composition (caffeine, chlorogenic acids and sucrose) of coffee beans; in addition, a high correlation was observed between shade and the bitterness of beverage. Shade improved significantly the organoleptic quality (body, acidity, flavor and overall preference) at altitudes in the range of 950 to 1255 m.

Fertilization influenced positively the physical quality (larger, heavier beans and lower % of imperfects beans), biochemical composition (fat and trigonelline content) and organoleptic quality, particularly on aroma, flavor and preference.

Increasing yield affected positively and significantly the physical quality (larger and heavier beans) and biochemical composition of beans (trigonelline, sucrose, chlorogenic acids and fat). However, yield did not affect organoleptic quality.

Coffee quality was discriminated geographically by municipalities in three groups. Group I (Municipalities of Waslala, Wiwili, El Cuá and El Tuma-La Dalia) was characterized by low altitudes < 1000 m, low fertilizer inputs (1 application per year), low yield and high levels of shade (> 60%). Coffees from this group I presented small bean size, large concentrations in trigonelline and sucrose, and low organoleptic quality. Group II (Jinotega, San Rafael del Norte and Dipilto) was characterized by altitudes ranging from 1050 to 1145 m, a greater number of fertilizer applications (>2 applications per year), higher yields than those of the group I. Coffees of this group II presented beans of greater size with greater accumulation of fat and chlorogenic acids content and a better beverage quality (than the produced one by Group I). Group III (Matagalpa y San Fernando) was characterized by altitudes higher than 1290 m and low shade level (< 20 %). Coffees of this group III presented the highest fat and chlorogenic acids content. Coffee from Matagalpa received the highest mark for beverage quality.

The compounds that contributed the most to the geographic discrimination were trigonelline, sucrose, fat and chlorogenic acids. Shade and fertilization can partially compensate the disadvantages of plantations located at low altitude. Biochemical compounds showed a strong relationship with the organoleptic characteristics; these compounds could be used as indicators of coffee quality and thus to eliminate the human error due to the discrepancies that exist between tasters with different experiences.

Sustainability of Coffee Agroforestry Systems in Central America; coffee quality and environmental impacts

Contract ICA4-2001-10071

Fourth Annual Report WORK PACKAGE 4

1 November 2004 - 31 December 2005

Jean-Michel Harmand (CIRAD), leader of WP5
Patrice Cannavo & Philippe Vaast (CIRAD, Costa Rica),
Luis Dionisio (IICA-PROMECAFE)
Kristell Hergoualc'h & Jonathan Ramos (CATIE, Costa Rica),
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Catherine Hénault (INRA-Dijon, France),
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Robert Oliver (CIRAD, France)

WP4 : Nitrogen cycling, leaching, uptake and emissions (Fourth Year)

The four objectives of this WP4 are:

- To improve nitrogen (N) management (N fertilisation, legume tree) by synchronising soil N availability to the needs of coffee and associated trees,
- To measure key components of the N cycle, for 4 target coffee management systems, in field and laboratory conditions,
- To elaborate a model of N cycling which predicts the losses and accumulation of N in different soil types and management systems,
- To link N measurements to environmental evaluation at catchment's scale.

In 2005, key components of the N cycle were measured in Costa Rica in 2 shaded coffee systems in comparison with full sun coffee in field and laboratory conditions. The annual N budget (including N accumulation in biomass and removal in coffee beans) was estimated. Measurements of soil N mineralization were done "in situ". Nitrate leaching was quantified from soil solution data collected from porous cups and lysimeters.
Particular studies were realized in the different systems:
In the high fertilized *Coffea arabica – Inga densiflora* system, measurements of key components of the N cycle were performed using ^{15}N labelled fertilisers in order to evaluate: (1) separate uptake of N by coffee and trees, (2) microbial immobilisation of N in the soil, (3) soil nitrate retention and (4) nitrate leaching. In this system emission of N_2O was measured *in situ* along the year and analysed by gas chromatography. Laboratory experiments were carried out in order to characterize and compare the soils' capacities (full sun and *Inga* systems) to produce N_2O. Acetylene inhibition was used to quantify the contribution of each process (nitrification and denitrification) in the N_2O production and to establish the ratio of N_2O to N_2 production.
In the *Coffea arabica – Erythrina poeppigiana* system which received no mineral N input, ^{15}N natural abundance ($\delta^{15}N$) of the different components of coffee and tree was analysed in order to evaluate N_2 fixation by the shade legume trees and N_2O emissions were evaluated using the static chamber method three times along the year.

Deliverables

The Deliverable D17/D4.2 "Scientific report on N flux measurements for target coffee systems" was due in year 3 (Month 36) and can considered completed via publications submitted and in preparation (see 5. Publications in 2004-2005).
The Deliverable D18/D4.3 "N flux model at plot scale" (Month 38) can also be considered to be completed via publications submitted and in preparation (see 5. Publications in 2004-2005).

1. Nitrogen cycling in a highly fertilized *Coffea arabica - Inga densiflora* system. Use of the ^{15}N isotope tracing technique for the study of the fate of N fertilizer.

Patrice Cannavo (CIRAD/CATIE, Costa Rica), Jean-Michel Harmand (CIRAD, France), Etienne Dambrine (INRA, France), Bernd Zeller (INRA, France), Luis Dionisio (ICAFE, Costa Rica), Philippe Vaast (CIRAD/CATIE, Costa Rica)

1.1. Objective

In order to accurately estimate various N fluxes such as N partitioning between coffee plants and trees, soil microbial immobilisation of N and soil nitrate retention, the use of isotope technique is required. The objective of this present study was to investigate the N balance in a coffee system shaded with *Inga densiflora*, using ^{15}N tracing. The N balance was established from measurements done between May 2004 and April 2005. In this work, we presented N accumulation in soil, coffee plants, shade trees, N leaching and N gas emission. Some N fluxes are also presented for the control full sun coffee system.

1.2. Methodology

The study site was located in the Central Valley of Costa Rica, at Cicafé, Research Center of the Coffee Institute of Costa Rica, at about 1200 m elevation. Mean annual temperature is 20°C and annual precipitation is about 2300 mm with a pronounced dry season from January to April. The soil, derived from the weathering of volcanic ashes, belongs to Andisols and is classified as a Dystric Haplustands.
Two coffee systems (*Coffea Arabica* var. Catuaí), located on nearby plots, were studied: a coffee monoculture (5000 plants ha^{-1}) and a coffee plantation shaded by the N fixing leguminous tree species *Inga densiflora*. In the shaded coffee plot, tree and coffee plant densities were 278 and 4722 plants ha^{-1}, respectively. These plots, installed in June 1997, received mineral N fertilizer at a rate of 250 kg N ha^{-1} yr^{-1}.
The labelled ^{15}N urea was applied only in the shaded coffee plot. We defined a 156 m^2 experimental sub-plot including 6 coffee lines and 4 trees. The complete formula and ^{15}N urea were homogeneously applied in the fertilization zone. On the two first fertilisation dates (24/05/04 and 03/08/04) N was applied as urea, and we added ^{15}N-urea (10% atom excess). At the third and last fertilisation (25/10/04), no ^{15}N-urea was applied, and N fertilisation was NH_4NO_3 form. The ^{15}N natural abundance was determined for soil, soil solution, and plants before the isotope was applied.
In each system, were installed 4 lysimeters (tensionics, SDEC 2200HC, SMS 2500S) at 30 cm depth, 8 at both 60 and 120 cm depth, and 3 at 200 cm depth. Soil solution samples were collected every ten days during the rainy season and analysed for NO_3 and $^{15}NO_3$. The mechanistic PASTIS model was used in order to estimate the water balance and NO_3 leaching in the top 2m depth. In order to quantify organic and inorganic N accumulation in the soil, soil samples were collected in January 2005 in three zones of the ^{15}N application sub-plot: the

fertilization zone (at 30 cm from the coffee plant), the downhill zone (at 30 cm from the coffee plant), and the inter-row zone. The different soil layers until 2 m depth, were collected. For evaluating N accumulation in the coffee biomass, 8 plants were randomly sampled in January 2005 and sorted in the different components (stems, branches, roots and leaves) of which dry matter, N and ^{15}N concentrations were measured. For *Inga densiflora*, allometric relationships were established between stem diameter at breast height and dry weight of the different components (leaves, branches and stems). N and ^{15}N concentration of the different components were measured. Fine root mass was sampling every 10 cm depth using an cylindrical auger (8 cm dia). The amount of litter accumulated on the ground was measured in January 2005. In each plot 8 composite samples of 0.5 m^2 were collected according to a systematic random scheme. N2O emissions were evaluated as described below in the second study presented in this report.

1.3. Results and discussion

Recovery of applied ^{15}N in the Coffee –*Inga densiflora* system

- **^{15}N recovery in vegetation**

  The Figure 1 shows the values of ^{15}N recovery in the different components of vegetation. N uptake by the coffee plants accounted for 13.7% in the recovery of applied N, of which 57.2%, 24.9%, 9.8%, 7.0%, 0.4% and 0.8% were found in the fruits, branches, stems, principal and secondary roots respectively. Compared to the coffee plants, less applied N was taken up by the shade tree (7.1% of the applied N). Tree stems, branches and roots accounted for 65% of this significant uptake. Only 1.3% and 1.5% of the applied N accumulated in the litter layer and fine roots respectively. Thus, only 23.1% of the applied N were recovered in the vegetation.

- **Recovery of applied ^{15}N in soil**

  At the end of the rainy season, only 13.9 % of the applied ^{15}N remained in the soil mainly in organic form, 35% were concentrated in the top 60 cm layer (data not shown), and the rest was homogeneously distributed in the 60-200 cm layer.

- **Recovery of applied ^{15}N in NO_3 leaching**

  According to the variability in spatial distribution of the NO_3 fluxes, 36 to 50 % of the applied N was lost in leaching water as NO_3. In these site conditions (intense rainfall combined with highly permeable soil and low AEC), the main flux is the loss of NO_3 in leaching water.

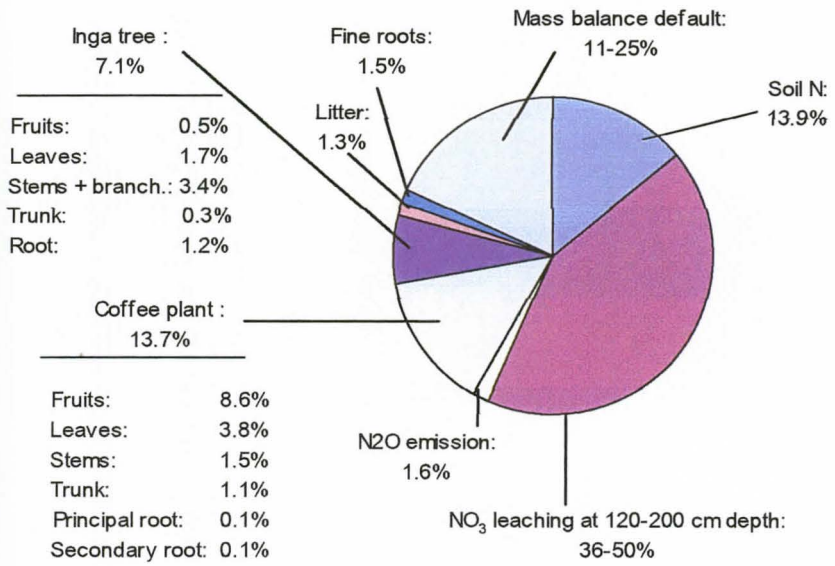


Figure 1: Recovery of applied ^{15}N in the coffee-*Inga* system (% of applied N)

Annual N budget in full sun and shaded coffee (*Inga densiflora*) systems in 2004.
Table 1 shows the different measured N fluxes in full sun coffee and coffee shaded with *Inga densiflora* in 2004. Despite a high N fertilizer input, the N_2 fixation by the legume tree was not negligible. The inclusion of the tree resulted in a significant increase (+ 250%) in N accumulation in biomass (without fruits) and litter. But coffee bean production and N export in bean harvest were high in 2004 and reduced by 33% under shade. This reduction in coffee beans production was associated with a greater amount of NO_3-N leaching under shade than in full sun coffee and NO_3 leaching represent 30 to 46 % of the annual N fertilizer input. In these site conditions with high rates of soil N mineralization-nitrification (data not shown) the contribution of the fertilizer input to the growth of vegetation during this year was rather low.

Table 1: Annual N budget (kg N ha^{-1}) in full sun and shaded coffee (*Inga densiflora*) systems in Costa Rica (Year 2004).

N Flux in 2004	Full sun coffee	Coffee – *Inga*	Recovery of N fertilizer in the Coffee - *Inga* system*
Fertilizer input	250	250	
N_2 fixation		16 to 30	
N accumulation in biomass and litter	46	115	38
Soil N accumulation			38
N losses			
- N export in coffee beans harvest	143	95	22
- N_2O-N emission	5.9	8	*4*
- N loss in runoff	3.2	1.4	*1*
- Nitrate N leaching at 2m depth	74	114	90 -125

* Data deduced from the ^{15}N experiment

Conclusion
These experiments showed a low N fertilizer use efficiency in these coffee plantations. Only 24% of the annual fertilizer input contributed to the vegetation growth and the coffee production mainly depended on the N accumulated in the system during the previous years. In years of high production, the inhibitory effect of shade on coffee production can increase significantly NO_3 leaching. That highlights the need of reducing N fertilizer input in shaded coffee systems intensively managed in order to better match plant needs and reduce NO_3 leaching.

2. Measurements of nitrous oxide emissions from soil in coffee plantations, Costa Rica

Kristell Hergoualc'h (CIRAD, CATIE, Costa Rica), Catherine Hénault (INRA-Dijon, France), Ute Skiba (CEH, UK), Jean-Michel Harmand (CIRAD, France), Robert Oliver (CIRAD, France).

2.1. Site description and objectives
This study was carried out in the highly fertilized coffee systems described above (1.2.). Both plots (full sun coffee and coffee shaded with *Inga densiflora*) received mineral N fertilizer at a

rate of 250 kg N ha^{-1} yr^{-1}. Since fertilizer was applied only at the base of the coffee trees, two zones of the soil have been defined: the fertilized one and the non fertilized one which represent respectively 19.4 and 80.6% in the full sun system; 16.7 and 83.3% in the agroforestry system.

Nitrous oxide (N_2O) is a stable greenhouse gas, 300 times as powerful as CO_2 in term of global warming, which atmospheric concentration increases are largely due to increased use of N fertilizer in agriculture. The objective of this study was to measure and compare annual N_2O emissions from a coffee monoculture and a coffee agroforestry system. The microbial capacities of the soils to emit N_2O were studied in laboratory controlled conditions and "in situ" emissions were measured during one year.

2.2. Laboratory experiments

Objective and methodology

Three experiments were carried out in order to characterize and compare the soils' capacities to produce N_2O in controlled laboratory conditions. Two of them were focused on the denitrification process while the third dealt with N_2O production by nitrification.

The denitrification potentials ($N_2O + N_2$) were measured on undisturbed soil cores incubated during 4 hours in aerobic conditions with 10% C_2H_2 (inhibition of the N_2O reductase). The cores were placed in optimum conditions of denitrification: at 100% of water-filled pore space and saturated of nitrate (450 mg N kg^{-1} dry weight soil). Gas samples were collected every hour in evacuated exetainer tubes sealed with thick wax and N_2O was analysed by TCD gas chromatography, at CIRAD, France.

The soils' capacity to reduce N_2O in N_2 by denitrification was measured in anaerobic conditions (He), by difference between two treatments: with and without 10% C_2H_2. The soils, previously sieved (1 mm) were saturated with water and nitrates (50 ml of KNO_3 solution concentrated at 100 mg N l^{-1} for 50 g of dry soil) and incubated for 9 days. Gas samples were collected at 2, 4, and 7 and 9 days of incubation in evacuated exetainer tubes, sealed with thick wax and analysed by ECD gas chromatography, at CIRAD, France.

The N_2O production by nitrification and the nitrification rate were measured at low soil moisture content (between 15 and 40% of gravimetric soil moisture) and in aerobic conditions. The soils previously sieved (1mm) were incubated during 9 days in non limiting ammonium conditions (400 mg N kg^{-1} dry soil). A control treatment with 10 Pa C_2H_2 (inhibition of nitrification) was established in order to check that denitrification was zero under such experimental conditions. Gas and soil samples were collected at 2, 4, 7 and 9 days of incubation for N_2O dosage and mineral N analysis.

Results

Denitrification potential

The soils featured low denitrification potentials (Table 2), below 1 kg N ha^{-1} d^{-1}.

The full sun coffee system showed higher potentials than the shaded system.

Table 2: Mean denitrification potentials ± standard error (g N ha^{-1} d^{-1}) of a full sun coffee system (FS) and a shaded one (In) for the fertilized zone of the soil (FZ) and the non fertilized one (NFZ).

	FZ	NFZ
FS	418 ± 88	534 ± 125
In	322 ± 60	171 ± 93

Capacity to reduce N_2O to N_2 by denitrification

For both systems N_2O was produced at equal quantities in presence or absence of C_2H_2 meaning that the soils did not reduce N_2O to N_2 during denitrification.

N_2O production by nitrification and nitrification rate as function of soil moisture

The kinetics of nitrification showed a linear relationship with gravimetric soil moisture:

$$N_{\theta_m} = a\theta_m + b$$

Where N_{θ_m} is the nitrification rate (mg N kg^{-1} d.w. h^{-1}) and θ_m (%) is the gravimetric soil moisture.

And N_2O production by nitrification was proportional to the nitrification rate: $N_2O_{NIT} = cN_{\theta_m}$

Where N_2O_{NIT} and N_{θ_m} are respectively the rates of N_2O production by nitrification and the rates of nitrification (mg N kg^{-1} d.w. d^{-1}).

The values of the coefficients a, b, c are indicated in Table 3 as well as the nitrification rates and N_2O production by nitrification at the highest soil moistures studied.

The increase of the nitrification rates with soil moisture and the ratio between N emitted as N_2O and N nitrified were low.

The fertilized zone of the full sun coffee soil showed a higher increase of the nitrification rate with the soil moisture than the one of the agroforestry system soil and the unfertilized zone of the full sun system had a higher ratio between N emitted as N_2O and N nitrified than the one of the agroforestry system.

Table 3: Nitrification rates and N_2O production by nitrification ± standard error at soil moisture of 31, 25, 33 and 36% respectively for FS FZ, FS NFZ, In FZ and In NFZ. Coefficients of the relationships $N_{\theta_m} = a\theta_m + b$ where N_{θ_m} is the nitrification rate (mg N kg^{-1} d.w. h^{-1}) and θ_m (%) is the gravimetric soil moisture; $N_2O_{NIT} = cN_{\theta_m}$ where N_2O_{NIT} and N_{θ_m} are respectively the rates of N_2O production by nitrification and the rates of nitrification (mg N kg^{-1} d.w. d^{-1}). FS: full sun coffee, In: shaded coffee, FZ and NFZ: fertilized and non fertilized zone.

		N (mg N kg^{-1} d^{-1})	N_2O_{NIT} (µg N kg^{-1} d^{-1})	a (‰)	b (‰)	c (‰)
FS	FZ	7.6 ± 0.6	5 ± 0.1	27.1	- 520.3	0.66
	NFZ	2.8 ± 0.5	3.3 ± 0.2	10.7	- 146.5	0.85
In	FZ	5.2 ± 0.5	2.5 ± 0.2	14.6	- 259.6	0.83
	NFZ	4.2 ± 0.7	1.4 ± 0.3	9.6	- 171.9	0.44

Conclusion on laboratory experiments

The soils studied were not able to reduce the N_2O to N_2 produced by denitrification under favourable anaerobic conditions. So the N_2O produced by denitrification "in situ" probably will escape from the soil. However, the data suggest that the potential of denitrification of these soils is small. The capacities of the soils to produce N_2O by nitrification were low, but slightly higher for the full sun coffee system than for the agroforestry system.

In conclusion, the soils studied here do not have a high capacity to produce N_2O by nitrification or by denitrification. The system with the highest capacity to emit N_2O appears to be the coffee monoculture. Variations in emissions depended on environmental variables such as soil moisture (precipitation) and mineral N availability (fertilization).

2.3 Field measurements

Objective and methodology

N_2O fluxes from soil were measured by the static chamber method from October 04 until September 05. Sampling occurred monthly except during the fertilization period when it was daily. Simultaneously, environmental variables of the site were measured: rainfall and air temperature (continuously), soil temperature, moisture and N mineral content (measured at each gas sampling).

Results

N_2O fluxes

N_2O fluxes (Figure 2) were low (0-15 g N ha^{-1} d^{-1}) except during the fertilization period at the beginning of the rainy season (May - August) where fluxes reached values up to 115 g N ha^{-1} d^{-1}. The agroforestry plantation emitted more N_2O than the monoculture, especially during this period of fertilization.

Environmental variables related to N_2O fluxes

Soil temperatures showed little variation over the year: 18-22°C and were higher in the full sun coffee plantation than in the agroforestry system during the dry season.

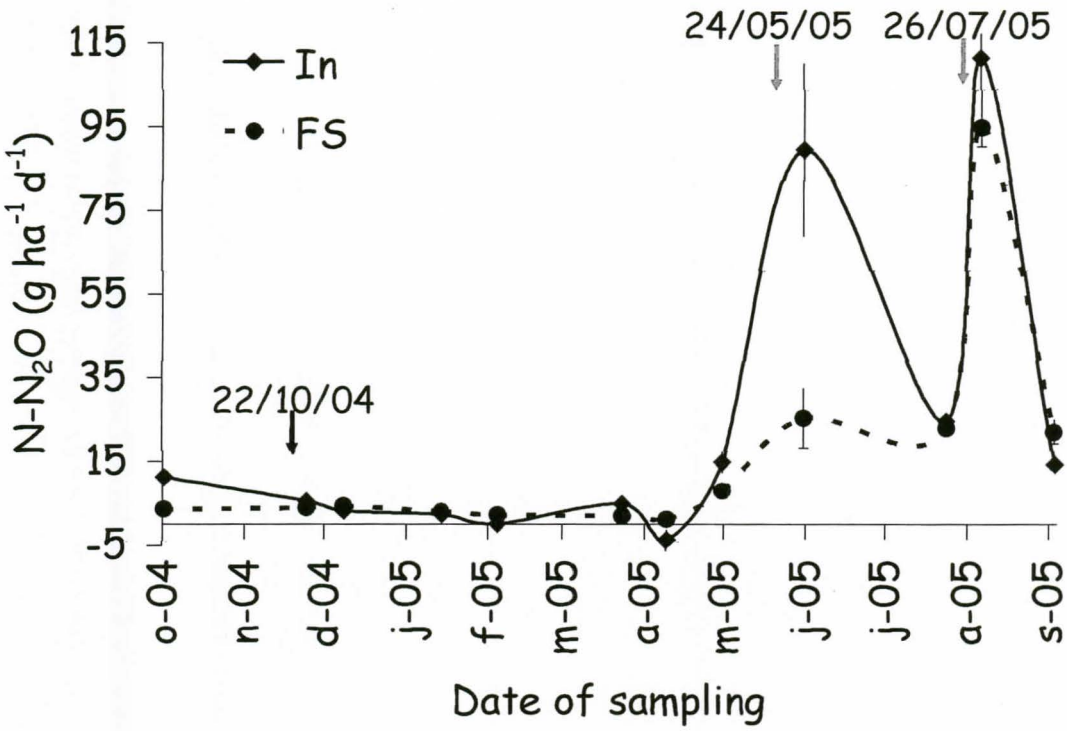


Figure 2: Mean N_2O fluxes (g N ha^{-1} d^{-1}) from soils of a shaded coffee plantation (In) and from a monoculture (FS) of Cicafé, Costa Rica from October 04 until September 05. The arrows indicate the dates of fertilization. Vertical bars represent standard errors.

During the fertilization period ammonium concentrations clearly increased in soils (10-30 mg N kg^{-1} d.w.) but no difference between the 2 coffee systems could be established. Nitrate soil contents fluctuated over the year between 20 and 80 mg N kg^{-1} d.w. with no relation with fertilization or rainfall events. No difference between the studied agricultural systems was

noticed. The only environmental variable that was higher in the agroforestry system than in the full sun plantation throughout the year was the gravimetric soil moisture (average annual soil moisture ± standard errors of 45.3±0.2 and 40.5±0.1 respectively for In and FS).

Conclusion on field studies

In both coffee systems fertilization induced short-lived high pulses of N_2O fluxes. The annual N_2O emissions (±standard error) were higher for the agroforestry system than for the monoculture: 8±0.5 and 5.9±0.2 kg N ha^{-1} yr^{-1} respectively. Differences, however, were only significant shortly after fertilizer application. The only environmental variable measured that can explain the difference in N_2O emissions between the two types of systems is the soil moisture.

2.4. Overall conclusion

The soils of the coffee plantations of Cicafé did not present, in laboratory studies, a high capacity to produce N_2O and indeed during most of the year "in situ" emissions remained low. The high inputs of N fertilizer, however, did induce temporary large N_2O losses.
The laboratory experiments showed higher capacities of the full sun coffee plantation to produce N_2O while "in situ" measurements showed the contrary. This controversy is easily explainable by the higher soil moisture of the agroforestry system which favours N_2O emissions.

3. Nitrogen cycling in an organically managed *Coffea arabica* – *Erythrina poeppigiana* system

Luis Dionisio (ICAFE, Costa Rica), Jean-Michel Harmand (CIRAD, France), Patrice Cannavo (CIRAD/CATIE, Costa Rica), Bernd Zeller (INRA, France), Etienne Dambrine (INRA, France)

31. Introduction

The objective of this study was to evaluate the effect of poro (*Erythrina poeppigiana*), used as a shade leguminous tree in a coffee (*Coffea arabica*) plantation organically managed, on coffee production, N loss from the system through leaching and emissions of N_2O. We examined also a few other key processes of the N cycle: N accumulation in biomass and litter and N_2 fixation by the tree.

32. Methodology

The study site was located in the Central Valley of Costa Rica, at Cicafé, Research Center of the Coffee Institute of Costa Rica, at 350 m from the *Inga* - coffee trial previously presented. Two coffee systems (*Coffea Arabica* var. Catuaí), located on nearby plots, were studied: a coffee monoculture (5000 plants ha^{-1}) and a coffee plantation shaded by the N fixing leguminous tree species *Erythrina poeppigiana*. In the shaded coffee plot, the tree and coffee plant densities were 420 and 4680 per ha, respectively. These plots were installed in June 1999 on a 7 years old fallow plot. From this date onwards, these plots received no mineral N fertilizer but coffee pulp was applied in March-April at a rate of 150 kg N ha^{-1} yr^{-1}.
In each system, 6 lysimeters (tensionics, SDEC 2200HC, SMS 2500S) were installed at both 60 and 120 cm depth. Soil solution samples were collected every ten days during the rainy season and analysed for NO_3.
In February 2005, dry matter and N accumulation in the biomass and litter were estimated. For evaluating N accumulation in the coffee biomass, 8 plants were randomly sampled and sorted in different components (stems, branches, roots and leaves) of which dry matter and N concentration were measured. Five poro trees were pollarded for evaluation of dry weight and

N concentration of leaves and branches. The amount of litter accumulated on the ground was estimated from 8 composite samples of 0.5 m^2 collected in each system. The mean annual increment of dry matter and N accumulation in the biomass and litter was calculated dividing the N content of coffee plants and trees in 2005 per the age of the plantation (6 years). ^{15}N concentration (natural abundance) of the different components of coffee and poro was also measured in February 2005 in order to estimate N_2 fixation by the legume tree. In each coffee plot, coffee beans were harvested from 10 lines of 10 m long at three dates between October 2004 and February 2005. Dry weight and N concentration of coffee beans' samples were measured. N_2O emissions were evaluated using the static chamber method three times along the year.

3.3. Results and discussion

At the beginning of the rainy season, the NO_3-N concentration in leaching water at 1.20 cm depth under the two organically managed coffee systems was relatively high (13 mg L^{-1}) and similar to the values observed in the highly fertilized conventional system (Figure 3). This high value must be due to the mineralization of the organic input applied at the end of the dry season. From the beginning of June onwards, NO_3 concentration was decreasing reaching low values of 2 mg NO_3-N L^{-1} in August. As a consequence of pollarding the poro in August, high restitution of N in pruning residues (260 kg N ha^{-1}) induced an increase of NO_3-N concentration in leaching water under poro up to values of 5 mg L^{-1} in September-October. This nitrate concentration increase was not observed under full sun coffee (Figure 3).

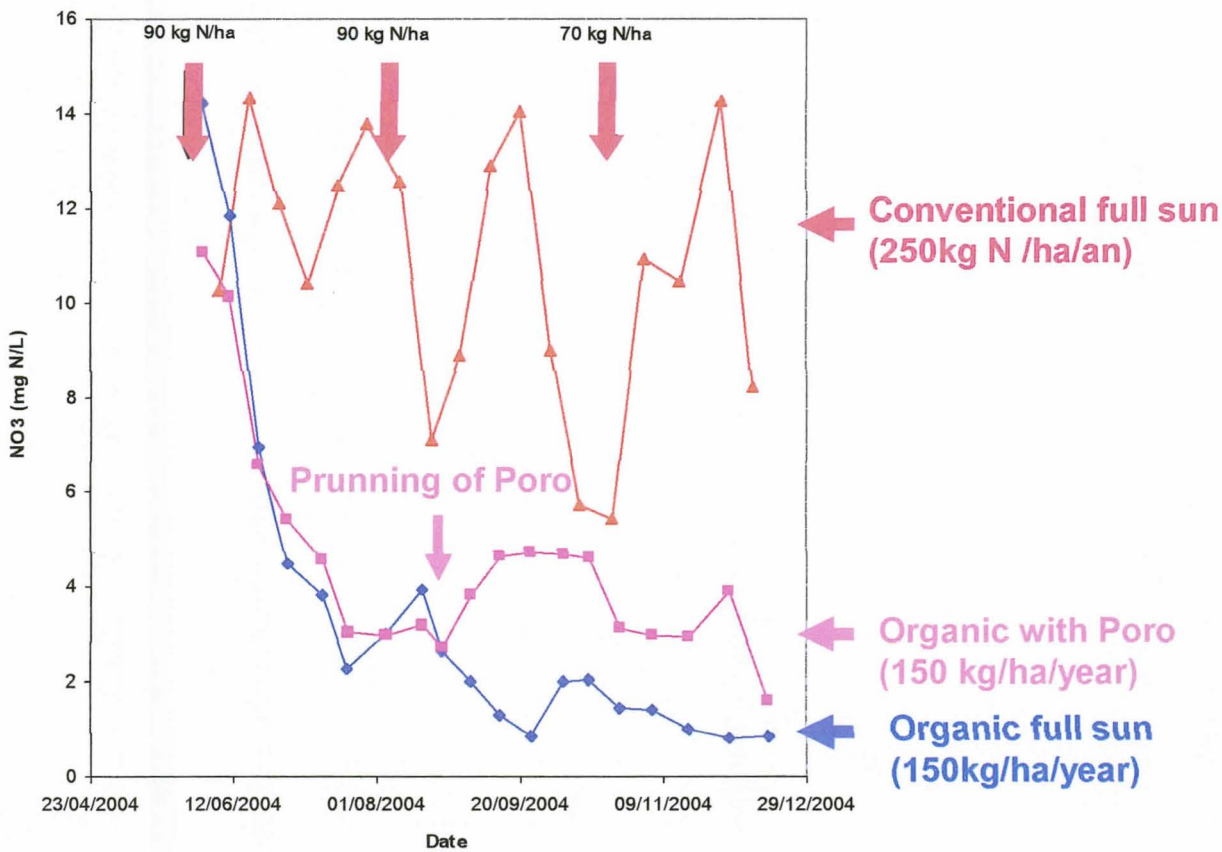


Figure 3: Nitrate-N concentration (mg NO_3-N L^{-1}) in leaching water at 120cm depth in different coffee systems.

The Table 3 shows the different measured N fluxes in full sun coffee and coffee shaded with *Erythrina poeppigiana* in 2004. Symbiotic N_2 fixation by the legume tree was estimated at 93 kg N ha^{-1} (Table 4). Although data of N export in coffee beans' harvest are presented only for 2004, both systems showed rather constant coffee productions during the last three years. Without any chemical N fertilizer input, coffee production was very low in full sun conditions (0.75 t MS ha^{-1} yr^{-1}) while coffee production was acceptable and sustainable (more than 3 t MS ha^{-1} yr^{-1}) under the shade legume tree. Nitrate leaching and N_2O emissions were slightly but significantly increased under shade. Nevertheless, compared to the full sun situation, the coffee production was greatly increased under shade as a result of (1) the shading effect and (2) the higher N availability in the system due to N_2 fixation and high rates of recycling of N in tree pruning residues, roots and litter (more than 350 kg N ha^{-1} yr^{-1}).

Table 4: Annual N budget (kg N ha^{-1}) in full sun and *Erythrina poeppigiana* coffee systems in Costa Rica (Year 2004).

N flux	Full sun coffee	*Coffee - Erythrina poeppigiana*
Organic fertilizer input	150	150
N_2 fixation		93
N accumulation in biomass and litter	23	80
N losses		
- N export in coffee beans harvest	15	62
- N_2O-N emission	1.4	3.1
- N loss in runoff	1	1
- NO_3-N leaching at 1.2 m depth	31	46

5. Publications in 2004 and 2005

Communication in congress:

Harmand J.M., Avila H., Dambrine E., Jiménez F., Beer J., Oliver R., 2004. Nitrogen dynamics and nitrate water contamination in a *Coffea arabica - Eucalyptus deglupta* agroforestry system in Southern Costa Rica. In: Book of Abstracts: 1st World Congress of Agroforestry, 27 June to 2 July 2004, Orlando, Florida, USA, p.182. (Oral Presentation)

Articles in scientific and technical revues:

- Gutierrez M., Harmand J.M., Dambrine E., 2004. Disponibilidad de nitrógeno en el suelo bajo especies maderables o leguminosas usadas como sombra en sistemas de *Coffea arabica*. Agroforestería en las Américas, 41-42
- Avila H., Harmand J.M., Dambrine E., Jiménez F., Beer J., 2004. Dinámica del nitrógeno en el sistema agroforestal *Coffea arabica* con *Eucalyptus deglupta*, en la zona Sudoeste de Costa Rica. Agroforestería en las Américas, 41-42
- Munguía R., Beer J., Harmand J.M., Haggar J.P., 2004. Tasas de descomposición y liberación de nutrientes de la hojarasca de *Eucalyptus deglupta*, *Coffea arabica* y *Erythrina poeppigiana* solas y en mezclas. Agroforestería en las Américas, 41-42
- Harmand JM, Ávila H, Dambrine E, Skiba U, Renderos RV, OliverR, Jiménez F; Beer J. Nitrogen dynamics, soil nitrate retention and nitrate water contamination in a *Coffea arabica* -

Eucalyptus deglupta agroforestry system in Southern Costa Rica. Journal of Environmental Quality. (Submitted 2005)
- Hergoualc'h K., Skiba U., Harmand J.M. and Oliver R. Nitrification: the major source of nitrous oxide emission from an Andosol of a coffee agroforestry plantation in Costa Rica. Soil Biology and Fertility. (Submitted 2006)
- Cannavo P., Harmand J.M., Dambrine E., Zeller B., Vaast P. Nitrogen-15 recovery in plants and soil in a *Coffea arabica - Inga densiflora* system. Agronomy Journal (in preparation)
- Harmand J.M., Dambrine E. Subsoil retention of nitrate under a coffee-tree plantation in an Acrisol of Southern Costa Rica. Geoderma (in preparation)

Sustainability of Coffee Agroforestry Systems in Central America; coffee quality and environmental impacts

Contract ICA4-2001-10071

Fourth Annual Report WORK PACKAGE 5

1 November 2004 - 31 December 2005

Jean-Michel Harmand (CIRAD), leader of WP5
Patrice Cannavo (CIRAD/CATIE, Costa Rica),
Luis Dionisio (IICA-PROMECAFE)
Kristell Hergoualc'h & Jonathan Ramos (CATIE, Costa Rica),

WP5: Carbon sequestration (Fourth Year)

The main objectives of this WP5 are to **measure carbon sequestration** in biomass and soil of a few target coffee AF systems, to **create a database** of C sequestration in coffee AF systems in Central America, and to **develop a model** predicting C sequestration at the plot scale and regional scale.

In 2005, the task of WP5 "Carbon sequestration" focused on gathering data from selected coffee systems in Costa Rica and Nicaragua (with and without shade trees). The quantification of plant biomass (above and belowground) and soil organic C was undertaken to evaluate change in C stocks of different systems. In existing long term experiments where greenhouse gas (GHG) emissions were measured such as N_2O and CH_4 emissions, these fluxes were used to establish C budgets of coffee systems.

One deliverable was due and completed in 2003, the deliverable D5/D5.1 "Database on carbon sequestration in coffee systems" (Month 18).

The last Deliverable D19/D5.4 "Model of C sequestration in coffee systems at plot scale" (Month 38) can be considered completed through articles already published and in preparation (see 3. Publications in 2004 and 2005).

1. Changes in vegetation C stocks and greenhouse gas (N_2O + CH_4) emissions in a highly fertilized coffee agroforestry plantation, Costa Rica.

Kristell Hergoualc'h (CIRAD, CATIE, Costa Rica), Jean-Michel Harmand (CIRAD, France).

11. Site description and objectives

The study site is located in the Central Valley of Costa Rica, at Cicafé, Research Center of the Coffee Institute of Costa Rica, at about 1200 m elevation. Mean annual temperature is 20°C and annual precipitation is about 2300 mm with a pronounced dry season from January to April. The soil, derived from the weathering of volcanic ashes, belongs to Andisols and is classified as a Dystric Haplustands

Two coffee systems (*Coffea Arabica* var. Catuaí), planted on nearby plots in 1997, were studied: a coffee monoculture (5000 plants ha^{-1}) and a coffee plantation shaded by the N

fixing leguminous tree species *Inga densiflora*. In the shaded plot, the density of coffee trees and shade trees were respectively 4722 plants ha^{-1} and 278 trees ha^{-1}. These plots, installed in June 1997, received mineral N fertilizer at a rate of 250 kg N ha^{-1} yr^{-1}.
The objective of this study was to estimate the changes in carbon stocks of both systems during the stand life and to establish C budgets taking into account N_2O and CH_4 emissions measured in these systems in 2004 and 2005.

12. Methodology

Changes in C stocks

In basis of phytomass (biomass and litter) measurements done in 04 by the CASCA project, the mean annual increment in vegetation C was calculated as:

$$\Delta C_{phytomass} = \%C \frac{\sum_i B_i}{age}$$

$\Delta C_{phytomass}$ is the mean annual rate of C accumulation in the phytomass (t C ha^{-1} yr^{-1}); $\%C$ is the C content of the dry matter (0.48); age is the age of the plantation in 2004 (7 years) and Bi (t DM ha^{-1}) is the dry matter of the different components of biomass of coffee and shade trees (leaves, branches, stems, roots) and litter, 7 years after plantation.
Normally, the rate of change in C stocks of the system (ΔC_{System}) is calculated as followed: $\Delta C_{System} = \Delta C_{phytomass} + \Delta C_{Soil}$ but, as changes in soil C will be evaluated only in 2006, comparing the values of soil C content in April 2003 with that of April 2006, ΔC_{Soil} was not taken into account in this study.

Greenhouse gases emissions

"In situ" N_2O emissions by soils were measured as described in WP4 report. "In situ N_2O and CH_4 emissions were measured with the same methodology and the two gases were analysed from the same samples by gas chromatography at CEH.

The rate of greenhouse gases emissions in $C\text{-}CO_{2Equivalent}$ was calculated with the following formula:

$$\Delta GHG = 310 \times \frac{M_C}{2 \times M_N} \Delta(N - N_2O) + 21 \times \Delta(C - CH_4)$$

ΔGHG is the rate of greenhouse gases emissions (t $C\text{-}CO_{2Equivalent}$ ha^{-1} yr^{-1}), M_C (12) and M_N (14) are the masses of the atoms of C and N; $\Delta(N\text{-}N_2O)$ and $\Delta(C\text{-}CH_4)$ are the rates of emissions of N_2O and CH_4 (t N ha^{-1} yr^{-1} and t C ha^{-1} yr^{-1}); 310 and 21 are the global warming potentials (GWP) of N_2O and CH_4 respectively.

CO_2 sequestration

The rate of CO_2 sequestration in the coffee system CO_{2seq} was calculated as: $CO_{2seq} = \Delta C_{System} - \Delta GHG$

13. Results

The agroforestry system showed a higher annual increase in vegetation C than the full sun coffee system (Table 1). N_2O emissions were estimated at 5.9 and 8 kg N ha^{-1} yr^{-1} in full sun and shaded coffee respectively. In the same systems, CH_4 was captured at rates of 0.002 and 1.6 kg C ha^{-1} yr^{-1}. N_2O emissions in our site conditions, expressed as CO_2 equivalent emissions accounted for 36% and 22% of C accumulation in phytomass in full sun and shaded coffee respectively (Table 1). In spite of a higher rate of GHG emissions in the agroforestry

system due to higher N_2O emissions, the rate of CO_2 sequestration was more than two fold higher for the agroforestry system than for the coffee monoculture.
For the moment, change in C soil was not taken into account in this study but if C soil could not increase at minimum rates of 0.79 and 1.03 t C ha^{-1} yr^{-1} in full sun and shaded coffee respectively, soil C budgets would be negative in terms of GHG emission.

Table 1: Mean annual C fluxes and budget in full sun and shaded coffee (*Inga densiflora*) systems expressed in t C-$CO_{2Equivalent}$ ha^{-1} yr^{-1} for a 7 years period.

C fluxes and budget (t C-$CO_{2Equivalent}$ ha^{-1} yr^{-1})	Full sun coffee	Coffee- *Inga densiflora*
$\Delta C_{phytomass}$	+ 2.20	+ 4.73
N_2O emission	- 0.79	-1.06
CH_4 capture	+ 0	+ 0.03
GHG emission	- 0.79	- 1.03
CO_2 sequestration (without C soil)	1.41	3.7

14. Conclusion

The rate of CO_2 sequestration was calculated as the CDM (Clean Development Mechanisms) of the Kyoto's Protocol requires, taking into account greenhouse gases emissions in the C budget of the system. Although change in soil C was not included in the estimation of C budgets, the value of CO_2 sequestration was more than two fold higher for the coffee agroforestry system than for the coffee monoculture, showing the interest of coffee agroforestry management for global warming mitigation.

2. Biomass and litter accumulation in an organically managed *Coffea arabica – Erythrina poeppigiana* system, Costa Rica

Jean-Michel Harmand (CIRAD, France), Luis Dionisio (ICAFE, Costa Rica), Patrice Cannavo (CIRAD/CATIE, Costa Rica), Hergoualc'h Kristell (CIRAD/CATIE, Costa Rica)

21. Introduction

The objective of this study was to estimate the amounts of aboveground biomass and litter in two organically managed coffee systems: (1) a full sun coffee plantation and (2) a coffee plantation shaded by poro (*Erythrina poeppigiana*). Taking into account N_2O emissions, a C budget was also established.

22. Methodology

The study site was located in the Central Valley of Costa Rica, at Cicafé, Research Center of the Coffee Institute of Costa Rica, at 350 m from the *Inga* - coffee trial previously presented. Two coffee systems (*Coffea arabica* var. Catuaí), located on nearby plots, were studied: a coffee monoculture (5000 plants ha^{-1}) and a coffee plantation shaded by poro a N fixing tree species. In the shaded coffee plot, the tree and coffee plant densities were 420 and 4680 per ha, respectively. These plots were installed in June 1999 on a 7 years old fallow plot. From this date onwards, these plots received no mineral N fertilizer but coffee pulp was applied in March-April at a rate of 150 kg N ha^{-1} yr^{-1}. Management of poro trees was practiced as followed: in August of each year the tree was pollarded and the pruning residues were spread

all over the ground; slight partial pruning also occurred in March of each year in order to enhance flowering intensity of the coffee plants.
In February 2005, plant biomass and litter were estimated. For the coffee biomass assessment, 8 plants were randomly sampled and sorted in different components (stems, branches and leaves) of which dry matter was measured. Five poro trees were pollarded for evaluation of dry weight of leaves and branches. Stem volume of each poro tree in the plot was estimated using stem basal diameter, stem diameter below the ramification and stem length which was always lower than 2.2 m. The amount of litter accumulated on the ground was estimated from 8 composite samples of 0.5 m^2 collected in each system.
The mean annual increment of dry matter was calculated dividing the total DM in 2005 per the age of the plantation (6 years).

23. Results

The inclusion of the poro tree in the coffee plantation resulted in significant increases of coffee biomass and litter (Table 2). The improved coffee growth (and production) under shade, in absence of chemical N fertilizer input, could be due to (1) the shading effect and (2) the higher N availability in the system resulting from N_2 fixation and high rates of recycling of N (see WP4 report). Compared to full sun coffee, total aerial phytomass (biomass + litter) was multiplied by 4.1 in the coffee system shaded by poro.

Table 2: Aboveground biomass and litter layer of full sun and shaded (*Erythrina poeppigiana*) coffee systems of 6 years of age.

Component	Sub-component	Full sun coffee Dry matter (kg .ha^{-1})	Coffee – poro Dry matter (kg .ha^{-1})
Coffee	Leaves	1440 (211)	2012 (280)
	Branches	2998 (222)	3415 (410)
	Fruits	124 (47)	132 (25)
	Stem	4843 (371)	6260 (350)
Total Coffee		**9405 (700)**	**11820 (865)**
Poro	Stems		13094
	Branches		2101.59
	Leaves		5284.03
Total poro			**20480**
Litter		**1085 (217)**	**11136 (1250)**
Total Phytomass		**10491**	**43436**

Taking into account N_2O emissions measured in these systems in 2005, tentative C budgets were established. As branches and leaves of the shade tree were annually pruned and recycled, only the tree stems was considered as permanent biomass in this study. N_2O emissions were estimated at 1.4 and 3.1 kg N ha^{-1} yr^{-1} in full sun and shaded coffee respectively (See WP4 report). Expressed as CO2 equivalent emissions, these N_2O emissions accounted for 28% and 17% of C accumulation in aerial phytomass in full sun and shaded coffee respectively (Table 3). In spite of a higher rate of GHG emissions in the agroforestry system due to higher N_2O emissions, the rate of C sequestration was four fold higher for the agroforestry system than for the coffee monoculture.

Table 3: Mean annual C fluxes and budget in full sun and shaded coffee (Erythrina *poeppigiana*) systems expressed in t C-$CO_{2Equivalent}$ ha^{-1} yr^{-1} for a 6 years period.

C fluxes and budget (t C-$CO_{2Equivalent}$ ha^{-1} yr^{-1})	Full sun coffee	Coffee – poro
$\Delta C_{\text{Coffee aerial biomass}}$	0.752	0.946
$\Delta C_{\text{Poro stem biomass}}$	-	1.048
ΔC_{Litter}	0.087	0.891
$\Delta C_{\text{Total aerial phytomass}}$	**0.839**	**2.884**
N2O emission	-0.186	-0.412
C sequestration (without C soil)	**0.653**	**2.472**

24. Conclusion

Without any chemical N fertilizer input, the inclusion of the legume shade tree in the coffee plantation enhanced coffee growth and bean production while increasing C sequestration.

3. Publications in 2004 and 2005

De Miguel Magaña S., Harmand J.M., Hergoualc'h K., 2004. Cuantificación del carbono almacenado en la biomasa aérea y el mantillo en sistemas agroforestales de café en el suroeste de Costa Rica. Agroforestería en las Américas, 41-42: 98-104.

Dzib B., Vaast P., Harmand JM., Llanderal T., 2004. Manejo, almacenamiento de carbono e ingresos económicos obtenidos de árboles maderables en fincas cafetaleras de tres regiones contrastantes de Costa Rica. Agroforesteria en las Américas, 41-42.

Harmand J.M., De Miguel S., Hergoualc'h K., Saint André L. Biomass dynamics in coffee-*Eucalyptus* agroforestry systems in Costa Rica. Forest Ecology and Management (in preparation).

Sustainability of coffee agroforestry systems in Central America; coffee quality and environmental impacts

Contract ICA4-2001-10071

Fourth Annual Report WORK PACKAGE 6
1 November 2004 - 31 December 2005
M. van Oijen, CEH, United Kingdom, leader of WP6

Objectives of Work package 6 (WP6): "Integrated Plot Modelling"

WP6 has developed a physiological model of the vegetative and reproductive growth of coffee plants in response to different levels of light, moisture and nitrogen and integrated this in a plot-scale model of tree and coffee growth which includes competition for light, water and nutrients between shade trees and coffee plants, and management treatments such as spacing, thinning, pruning and fertilizing. WP6 has drawn on the information provided by the other biophysical work packages (WP2, WP3, WP4, WP5), and supplied information on the biophysical aspects of coffee farming to WP7 and WP8.

The model developed in WP6 is referred to here as the "Integrated Plot Model" or "IP-model".

Activities undertaken in WP6 from 1 November 2004 to 31 December 2005

The previous three annual reports described how the IP-model was developed. In the period we report about here, the final changes were made to the model structure. A great part of the activities was directed at collecting data for the completed model, i.e. data on model inputs, parameters and outputs. Additionally, this final project period was used for model application and evaluation as well as for preparing the final project reports and publications. We shall describe these activities in greater detail in the following sections.

1. Model development

The overall modelling approach, i.e. producing a dynamic model for coffee agroforestry systems that takes site-specific input and produces site-specific output remained unchanged, and is depicted in Fig. 1. The list of required inputs for running the model comprises: (1) Weather variables: temperature, radiation, rain, wind, humidity; (2) Atmospheric composition: [CO_2], (3) Soil characteristics: fertility, water retention characteristics, (4) Site characteristics: slope, (5) Coffee management: fertilization, timing and intensity of pruning, (6) Tree species characteristics: N-fixation capacity, wood density, specific leaf area, etc. (7) Tree management: planting density, timing and intensity of thinning & pruning. The model outputs are manifold and include, besides annual coffee bean yield and tree wood volume production, the carbon and nitrogen

content of the various aboveground and belowground organ systems of the coffee and tree plants. Furthermore, the model calculates how soil pools of carbon, nitrogen and water change over time including the rates at which resources are lost from the system in the processes of respiration, drainage and leaching.

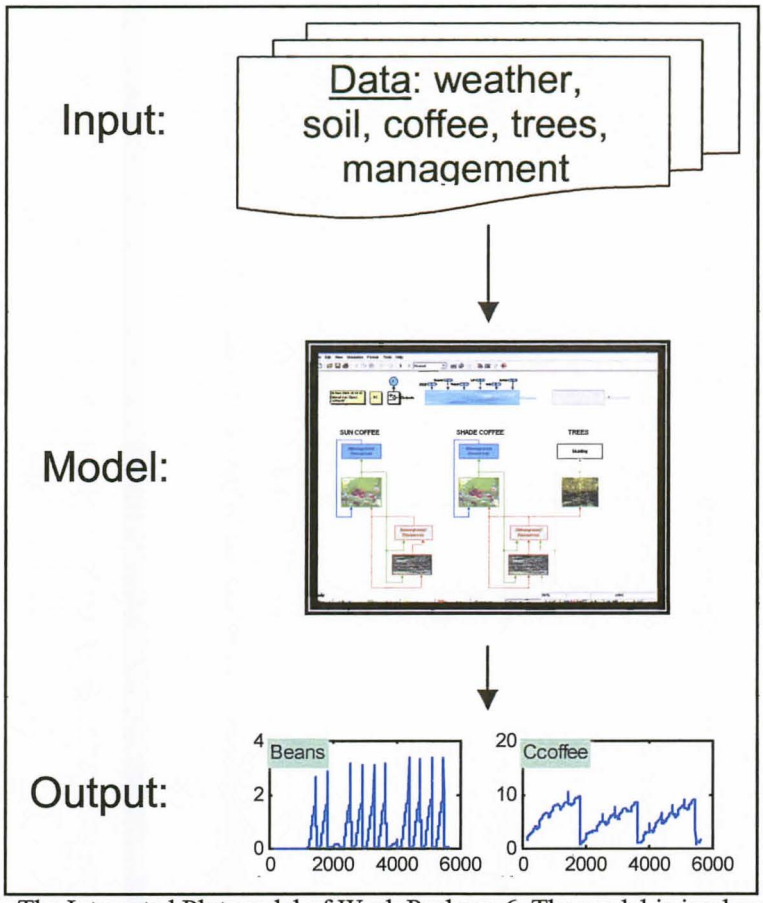


Fig. 1. The Integrated Plot model of Work Package 6. The model is implemented in MATLAB/Simulink. It takes as input datafiles containing site-specific information on weather, soils, coffee cultivar characteristics, tree species characteristics and management activities. As output, the model produces site-specific time-series for the growth and yield of coffee and trees, as well as time-series for changes in the soil and losses of carbon, nitrogen and water from the system.

The following changes were made to the model in this final project period: (1) The cooling effect of shade trees on the soil and coffee plants was incorporated as being proportional to the fraction of radiation intercepted by the trees, (2) The algorithm for the onset of flowering was simplified, flowering now being triggered by the first major rains after the dry period, (3) The duration of the annual period of coffee reproductive growth is now calculated dynamically as a function of thermal time passed since the onset of flowering, leading to different harvest dates for shaded and unshaded coffee plants; (4) The competition between vegetative and generative parts of the coffee plants has been strengthened through stimulation of leaf senescence by strong reproductive growth and by stimulation of reproductive growth with high leaf area and radiation, (5) Water run-off has been made proportional to the sine of the slope of the field, and the loss of soil carbon and nitrogen in erosion has been made proportional to the run-off and the concentration of carbon and nitrogen in the upper soil layers.

2. Model parameterisation

A large part of the work in the reporting period was devoted to collecting quantitative information about coffee agroforestry from the literature. This work led to two databases: (1) A literature database in EndNote format containing 412 references, mostly with abstracts, to the scientific literature concerning the biophysical aspects of coffee agroforestry systems (Fig. 2); (2) A biophysical parameter database, in the form of a collection of Microsoft Word tables, with values for model parameters. The parameter database was built by analysing the data from the literature database. Both databases will be made public through the CATIE website in 2006.

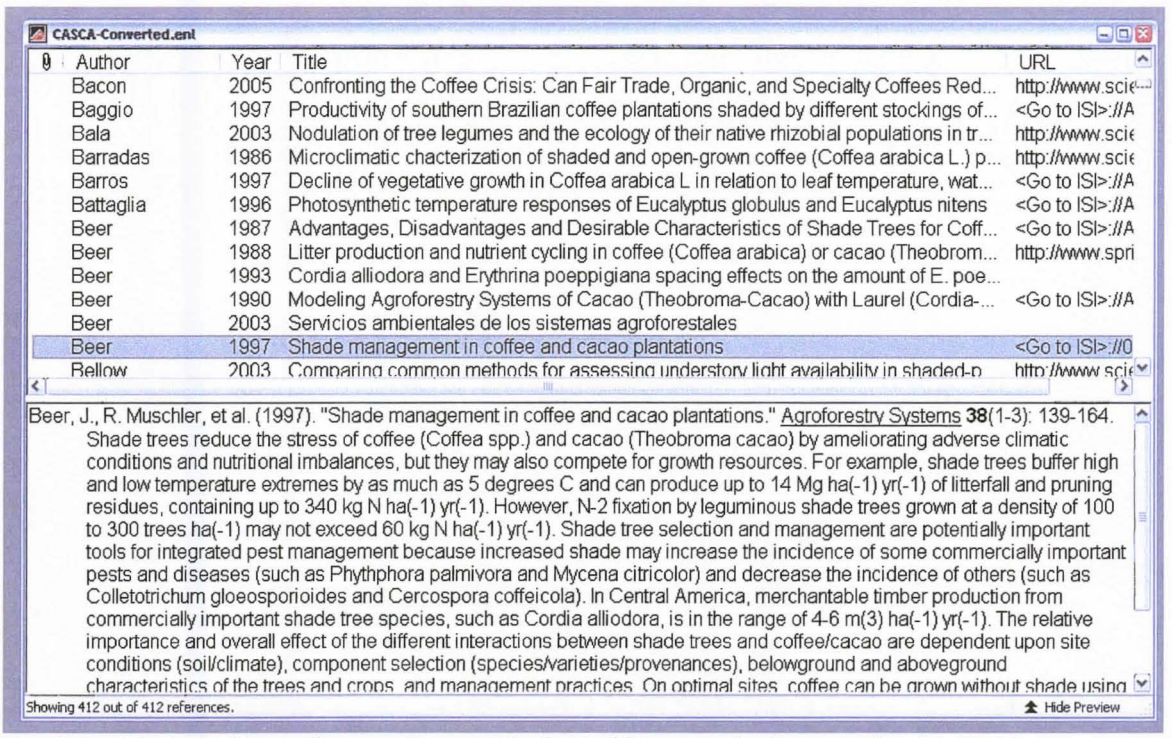


Fig. 2. Partial view of the coffee agroforestry biophysical literature database produced in WP6.

3. Results of model application

The IP-model has been applied to a variety of conditions, in order to identify which choices regarding site, shade-tree species and management led to the best results regarding coffee and tree productivity as well as impact on the environment through C-sequestration, leaching of nitrate to the groundwater, erosive loss of soil and gaseous loss of nitrogen from the soil surface. We shall below present examples of these simulation results, and subsequently list the general conclusions derived from the work.

Figure 3 shows how fertilization above 150 kg N ha^{-1} y^{-1} is unlikely to benefit coffee yield unless atmospheric CO_2 is significantly higher than at present. Tree wood volume production may benefit somewhat longer from increased fertilization. The results

reflect the typically high level of fertility of the soils in the Central American coffee growing regions.

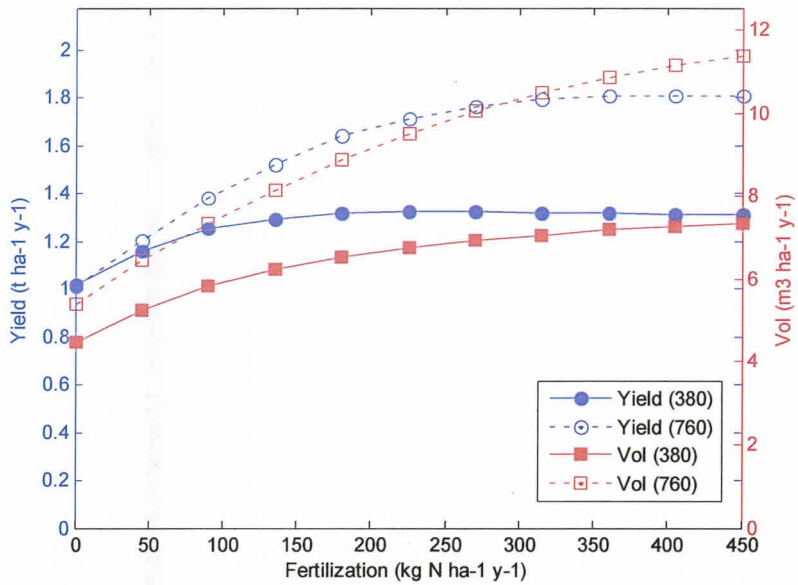


Fig. 3. The interactive effect of N-fertilization (0-450 kg N ha^{-1} y^{-1}) and atmospheric CO_2 concentration (380 or 760 ppm) on dry coffee bean yield (ton ha^{-1} y^{-1}) and wood volume production (m^3 leguminous wood ha^{-1} y^{-1}). Weather and soil conditions as in Turrialba, Costa Rica.

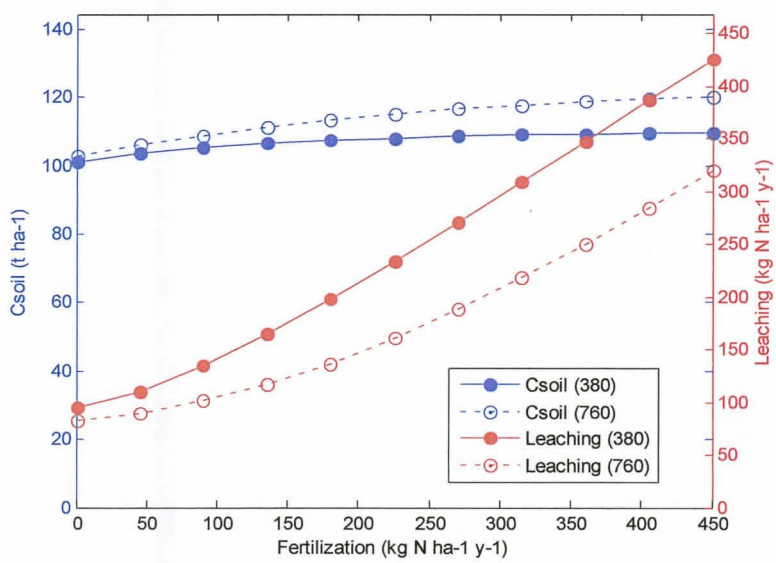


Fig. 4. The interactive effect of N-fertilization (0-450 kg N ha^{-1} y^{-1}) and atmospheric CO_2 concentration (380 or 760 ppm) on soil carbon stocks (ton C ha^{-1}) and nitrate leaching (kg N ha^{-1} y^{-1}). Weather and soil conditions as in Turrialba, Costa Rica.

Figure 4 shows, for the same interaction of fertilization and CO_2, that fertilization only marginally increases C-sequestration whereas it drastically increases the rate of leaching of nitrate to the groundwater. Both environmental impacts would be slightly improved in case of elevated CO_2. Figure 5 shows that fertilization may provide some protection

against loss of soil resources by surface erosion, through the mechanism of increased foliar growth leading to better protection against rain-induced loss of soil.

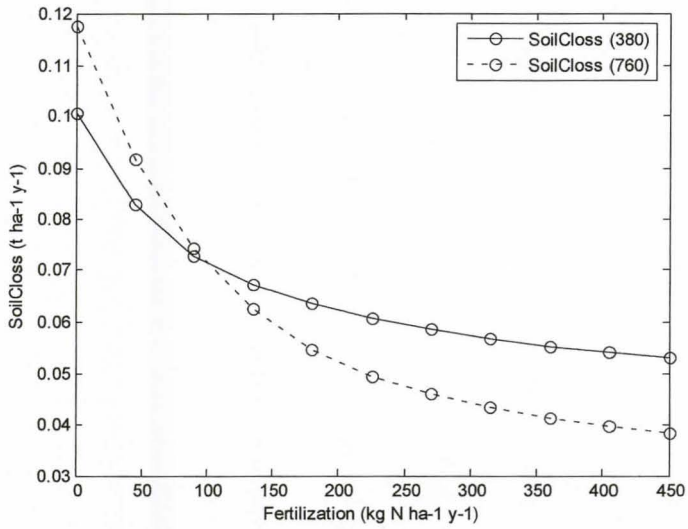


Fig. 5. The interactive effect of N-fertilization (0-450 kg N ha^{-1} y^{-1}) and atmospheric CO_2 concentration (380 or 760 ppm) on soil carbon loss by surface erosion (ton C ha^{-1} y^{-1}). Weather and soil conditions as in Turrialba, Costa Rica.

The simulation results shown in Fig. 6 illustrate the competition between trees and coffee plants, through an analysis of the interactive effect of N-fertilization (0 or 450 kg N ha^{-1} y^{-1}) and shade tree density. Increasing tree density reduces coffee yield, but the position of the optimum trade-off could not be determined by the IP-model alone as this required the economic analysis of WP7.

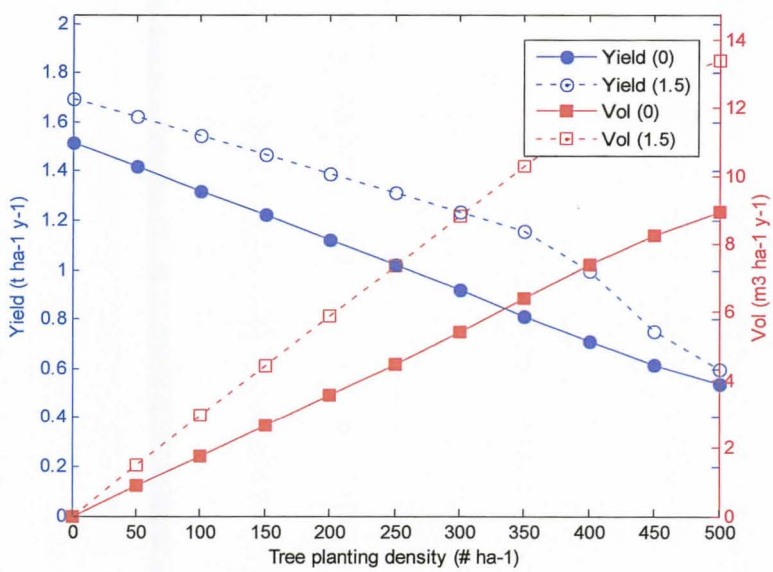


Fig. 6. The interactive effect of N-fertilization (0 or 1.5 times the normal rate of 300 kg N ha^{-1} y^{-1}) and shade tree density (0-500 trees ha^{-1}) on dry coffee bean yield (ton ha^{-1} y^{-1}) and wood volume production (m^3 leguminous wood ha^{-1} y^{-1}). Weather and soil conditions as in Turrialba, Costa Rica.

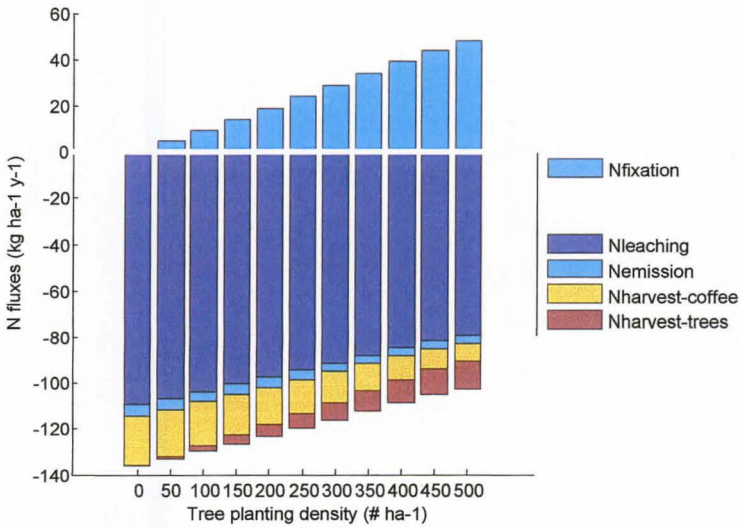


Fig. 7. The effect of shade tree density (0-500 trees ha^{-1}) on the nitrogen balance of the agroforestry system (all fluxes in kg N ha^{-1} y^{-1}). Weather and soil conditions as in Turrialba, Costa Rica, no fertilization applied.

Fig. 7 shows how the presence of leguminous shade trees affects the nitrogen balance of the system. The largest N-flux across the boundaries of the agroforestry system is that caused by N-leaching, irrespective of shade tree density. The loss of nitrogen through harvesting of coffee beans and removal of tree material is much less significant. However, increasing tree density does reduce N-leaching somewhat even though that coincides with higher nitrogen fixation rates.

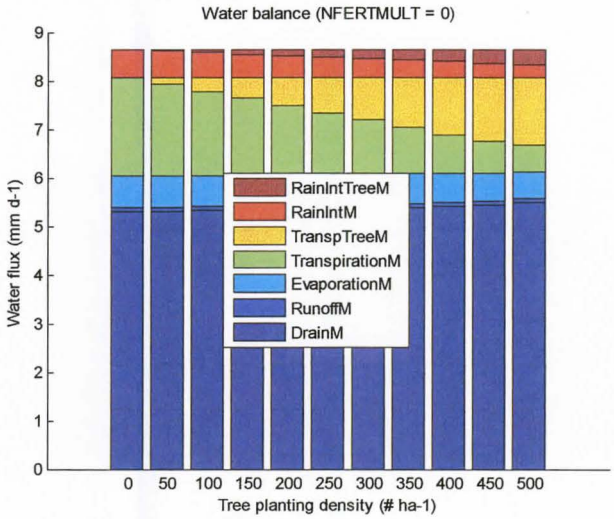


Fig. 8. As Fig. 7, but showing the water balance with the rotation-average fluxes expressed in mm d^{-1}.

Fig. 8 shows the water balance of the same series of tree densities depicted in Fig. 6. The total transpiration rate of coffee plants plus trees is almost constant as is the rate of the major water flux, i.e. drainage to the ground water.

4. General conclusions from the modelling work of WP6 carried out in year 4

Section 3 showed figures with results for only a small fraction of the simulations carried out using the IP-model. In this section we list the major conclusions from the modelling work:

- Coffee yield tends to decrease with tree density, even if the trees are N-fixers. Tree pruning tends to benefit coffee productivity but with some decrease in tree productivity.
- In a comparison of six tree species, the N-fixers *Erythrina poeppigiana*, *Gliricidia sepium* and *Inga densiflora*, and the non-N fixers *Cordia alliodora, Eucalyptus deglupta* and *Terminalia ivorensis*, the simulations identified *E. poeppigiana* and *T. ivorensis* as the species producing most wood (that of *E. poeppigiana* considered to be of little economic value), with only *T. ivorensis* significantly hampering the growth of the coffee plants.
- Global warming, as calculated using the HadCM3 Global Climate Model, is expected to increase temperatures in Central America by 3.3-4.4 °C in this century. This level of warming is expected to decrease coffee yields significantly.
- Coffee is overfertilized at present.
- The expected future increase in atmospheric CO_2 concentration is likely to make N-fertilization slightly more effective.
- N-fertilization may be more beneficial to tree wood volume production than to coffee yield.
- Global warming is likely to hamper shade tree growth.
- The degree of N-leaching is very high in coffee agroforestry systems and this is difficult to change through any management activity other than reducing N-fertilization.
- Soil loss in Central America is less than in other tropical regions. High fertilization levels are of benefit in this respect as they guarantee large, protective ground cover. Tree pruning decreases ground cover and is likely to increase soil loss rates but not to very high levels.
- Carbon sequestration rates in coffee agroforestry systems are not very high and are relatively insensitive to management choices.
- The contribution of coffee agroforestry systems to greenhouse gas production in the form of gaseous N-emission is low, even at high levels of N-fertilization.
- The rate of N-fixation by leguminous trees is generally only a minor flux in the overall N-budget of the system, but large enough to maintain productivity.
- Drainage of water to the groundwater is very high in the systems, and only marginally smaller at sites with steep slopes – where runoff rates are higher than elsewhere.

5. Conclusions with regard to the methodology developed and applied in WP6

Comparison of the IP-model with reports on the biophysical behaviour of coffee agroforestry systems in the literature seem to indicate that the model works well. However, as for any dynamic agro-ecological model, further development remains

advisable. The model may need improvement in the areas of simulating inter-annual coffee yield variability and it may need changes to allow simulating multiple flowering events per year. Furthermore, even though many data were collected from literature and from the work of CASCA-colleagues, further data-assimilation is required to increase the reliability of the model.

The study of the biophysical literature on coffee agroforestry, together with analysis of the model simulation studies, suggest that the following types of experiments and measurements are most critically needed:

- Trials with many different shade tree species compared at the same site
- Trials with the same coffee-tree association studied on multiple different sites
- Full-rotation experiments (10-15 years), with recording of tree, coffee, soil and (importantly) daily weather data
- Closed-balance studies for carbon, nitrogen and water which allow quantification of the full flux-budgets without the need for guesses regarding missing fluxes.

6. Summary of outputs from WP6 in year 4

In previous years work package 6 had already produced preliminary versions of the IP-model as well as a daily rainfall generator, i.e. a piece of software that allows estimation of time series of daily rainfall from data files with only monthly precipitation data. WP6 also had previously produced software for Bayesian calibration of the model.

The outputs generated by work package 6 in the reporting year were as follows:

(1) The completed process-based coffee agroforestry model (see section 1 of this report),
(2) Literature database on coffee agroforestry (see section 2),
(3) Biophysical parameter database (see section 2),
(4) This report and an overall final report for the whole project duration,
(5) Draft versions of three scientific publications on the WP6 work, to be completed in 2006.

Sustainability of Coffee Agroforestry Systems in Central America; coffee quality and environmental impacts

Contract ICA4-2001-10071

Fourth Annual Report WORK PACKAGE 7

1 November 2004 - 31 December 2005

WP7 – Economic modeling at farm scale (Year 4)

Philippe Bonnal (CIRAD, WP leader)

CIRAD (Philippe Bonnal as leader of this WP, Philippe Vaast & one doctoral student: Anne Zanfini), UNA (Prof. Glenda Bonilla) IICA-Promecafe (Bayron Medina of ANACAFE and Mainor Rojas of CICAFE), CATIE (Eduardo Somarriba, Guillermo Navarro and 2 graduate students: Monica Salazar and Mario Martinez) and CEH (Gerry Lawson) have been involved in **household surveys, economic modeling and financial analyses of various scenarios**.

In 2005, two last series of socioeconomic farm surveys were undertaken in two regions of Costa Rica and one region of Guatemala by two students from CATIE.
In collaboration with IICA-Promecafé (ANACAFE), one Masters student of CATIE (Mario Martinez) has undertaken an economical study in the region of Ococito, Guatemala, on the products derived from timber tree species in AF coffee systems and their financial importance for various stakeholders (from coffee farmers to local end users).
An economical study was undertaken by a second Masters student of CATIE on the costs/benefits of converting conventional coffee farms to the environmental and social requirements of the "Coffee –Practices" of Starbucks in order to commercialize coffee at a premium price.
0ne Ph.D. student of CIRAD has defended her thesis in December 2005 following two years of surveys on farmers' strategies in front of the coffee price crisis in two contrasting regions in Nicaragua and Costa Rica in collaboration with UNA and CATIE.

Deliverables

The deliverable D12/D7.1 "Synthesis of household surveys" (Month 28) was already completed in year 3 and presented in the consortium meeting of November 2004. Data from the surveys undertaken in 2005 will have to be incorporated after the end of the project.

The economic model was developed in 2004 (Deliverable D20/D7.2 – Month 40) to evaluate management scenarios taking into account economical risks (price of coffee), climatic factors and other agricultural revenues in order to be validated by the end of the project (Deliverable D27/D7.3 - Month 47). Some of these evaluations (coffee price with and without premium for quality, premium for environmental benefits, intensity of management, timber and fuel wood revenues) were undertaken in 2005 and presented during the final consortium meeting in November 2005.

Students in 2005
Masters
Mario Martínez. (2005). Contribución económica del componente forestal en diferentes tipos de fincas cafetaleras en la bocacosta pacifica de Guatemala. Tesis Mag. Sci. CATIE, Turrialba, Costa Rica. 123 p.

Monica Salazar (2005). Análisis de rentabilidad financiera del programa C.A.F.E Practices de Starbucks en diferentes tipologías de productores cafeteros de altura en Costa Rica. Tesis Mag Sc. CATIE, Turrialba, CR., 138p.

Ph.D.
Anne Zanfini. 2005. Arbres d'ombrage et café au Costa Rica et Nicaragua: dynamique des strategies paysannes en situation de crise économique. Doctoral thesis, University of Toulouse-Le Mirail. 255p.

Publications prepared in 2005

Salazar M., Vaast P. and Navarro G. Rentabilidad financiera de diferentes tipos de manejo cafetalero de altura en Costa Rica.

Salazar M., Vaast P. and Navarro G. Financial analyses of different farm types of high altitude, participating in the labeling scheme "C.A.F.E - PRACTICES" in Costa Rica.

Martínez M., Vaast P., Navarro G. and de Melo E. Contribución económica del componente forestal en diferentes tipos de fincas cafetaleras en la bocacosta pacifica de Guatemala.

Annexes

Mario Martínez. (2005). Contribución económica del componente forestal en diferentes tipos de fincas cafetaleras en la bocacosta pacifica de Guatemala. Tesis Mag. Sci. CATIE, Turrialba, Costa Rica. 123 p.

Key words: agroforestry, farm typology, land expected value, Ocosito watershed, production costs, shade level, timber and firewood commodity chains.

This investigation was undertaken in different types of coffee agroforestry farms in the Pacific region of Guatemala. The objectives of the study were a) to determine the economic contribution of the forest products derived from different coffee producing systems in the watershed of Ocosito, Guatemala; and b) to study the commodity chains for timber and firewood extracted from these coffee agroforestry farms.

By means of multivariate analyses, farm typologies were determined. The potential revenues derived from timber and firewood in these existing typologies were quantified by assessing the volume and market price of standing timber trees with a diameter superior to 40 cm. The actual economic contribution of timber and firewood was determined for each typology via the quantification of the volume sold during the last three years. Through interviews and informal discussions, the stakeholders of the local commodity chains of timber and firewood were identified and their interactions determined.

A total of 6 typologies were identified (the average farm size and altitude are indicated per typology):1) Traditional small-medium size farms (37 mz) of low land (777 m); 2) semi-intensive, large farms (278 mz) of higher altitude (1178 m); 3) Traditional, large farms (361 mz) of low land (690 m); 4) Semi-intensive, large farms (177 mz) of low altitude (790 m) with diversified crops; 5) Traditional, small-size, organic farms (3,1 mz) of high altitude (1400 m); and 6) traditional, medium-size farms (58 mz) of low land (757 m) with high timber exploitation (0.84 m^3 mz^{-1} $year^{-1}$).

The results show that the present rate of timber extraction in these coffee farms is sustainable as less is extracted (0.2 to 0.8 m^3 mz^{-1}) than the annual timber tree growth rate (up to 2.09 m^3 mz^{-1} $year^{-1}$). However, the recent tendency is to increase this exploitation inasmuch as it becomes necessary to regulate and to plan exploitation of this resource for the benefit of the commodity chain. Only in semi-intensive, large farms, firewood is exploited at a higher rate (9.6 m^3 mz^{-1} $year^{-1}$) than that of growth (7.1 m^3 mz^{-1} $year^{-1}$).

For traditional, low-land farms, the exploitation of timber and firewood generate up to 76.6% of the farm revenues; this includes the valuation of the firewood used for coffee processing and household consumption. Furthermore, there is the potential to exploit more timber and firewood in a sustainable manner as the current rate of extraction is quite lower than the annual average growth increase of timber trees with diameters greater than 40 cm and that of the annual firewood tree biomass production, which would allow to increase farmers' incomes and to better values these traditional systems. The coffee agroforestry systems of low altitude with shade predominantly composed of non-timber species are the least profitable. Furthermore, they are the most sensitive to a decrease in coffee prices which affects greatly their economic performance. Consequently, ANACAFÉ must focus its technical assistance towards this group. Farms located at higher altitude generate the greatest incomes due to higher coffee prices and high yields followed by semi-intensive farms of low altitude due to greater coffee yields.

The timber and firewood commodity chains were found to be disorganized with an absence of agreements and little cooperation among stakeholders, but with potential to improve its organization and development.

The poor farmer knowledge of forestry practices within their coffee agroforestry systems (SAF) does not permit to increase the economic efficiency of these SAFs, hence it is critically important to improve this aspects for the producers' benefit.
There are potentially important local markets, especially for timber species with high value and market acceptance such as *Roseodendron donnel Smith* as well as for firewood produced by tree species from *Inga* genus. Hence, this should contribute greatly to improve the livelihoods of coffee farmers in the Watershed of Ocosito.

Monica Salazar (2005). Análisis de rentabilidad financiera del programa C.A.F.E Practices de Starbucks en diferentes tipologías de productores cafeteros de altura en Costa Rica. Tesis Mag Sc. CATIE, Turrialba, CR., 138p.

Key words: certification, coffee of high altitude, coffee sustainability, financial analyses, land expected value, Starbucks.

The instability of coffee prices, and especially low prices, leads to the crisis of the coffee sector. In order to face this problem, alternatives have sought such as improving quality and looking for new niche markets just as "sustainable" coffee labels. The objective of the study was to analyze the financial profitability of different types of coffee farms of high altitude in participating in the program "C.A.F.E - Practices" (PPP) of Starbucks; this pilot program aims at improving the social, environmental and economic sustainability of the producers and other stakeholders of the coffee commodity chain. Thus, 51 coffee farms were studied from 3 cooperatives in zones of altitude superior to 1300 m of Costa Rica: Tarrazú, Dota and San Luís.

The farms were grouped according to their technical and biophysical characteristics via a multivariate analysis. Four types of farms were defined: 1) small size farms relying exclusively on household labor (P-F: 3.84 mz^{-1}); 2) medium size farms with household and temporary labor (M-TF: 8.04 mz^{-1}); 3) large size farms with temporary labor and, to a lesser extent, permanent and household labor (MG-TPF: 14.14 mz-^{1}); and 4) large size farms depending exclusively on temporary and permanent labor (G-TP: 33.98 mz^{-1}). For each farm type, an economic analysis in the short term was performed "Without PPP" as well as a long term financial analysis "With and Without PPP", using the following indicators: Expected Land Value (ELV) and Costs/benefit.
For the coffee cycle of 2004/05, financial analyses in the short term indicated that the four farm types presented positive net incomes with a relation benefit/costs superior to 1. Under constant conditions of coffee prices and yields, the results indicated that the PPP was financially profitable for the different farm types. Nevertheless, these results need to be taken with "caution" as the incentives of this PPP program are not long term. Hence, this does not motivate the producers to change their agronomical management towards a more sustainable and environmentally friendly coffee production and a higher social responsibility towards their workers.

Sustainability of Coffee Agroforestry Systems in Central America; coffee quality and environmental impacts

Contract ICA4-2001-10071

Fourth Annual Report WORK PACKAGE 8

1 November 2004 - 31 December 2005

Gerry Lawson, WP leader (CEH)

Fourth Annual Report, February 2006

Contents

8.1 Introduction

Work-package 8: Regional Up-scaling and Policy
Phase: Third Year
Start date: 1/11/2001
Completion date: 31/11/2005
Current status: Write Up Phase
WP leader: GJ Lawson (CEH, Edinburgh)

Person months per partner and total:

	CIRAD	CEH	CATIE	PROME-CAFE	UNA	Total
Technical Annex	1	2.8	10	12	8	33.8
First Year		0.5				0.5
Second year	0.125	1.0	0.125	7		8.25
Third Year	0.5	1.0	0.25	1		2.75
Fourth Year	0	2.4	6.25	1.5	0.2	10..35

8.2 Objectives

Objectives of this Workpackage deal with up-scaling results from the Biophysical plot model and from the socioeconomic model to gain an understanding of the validity of conclusions in a wider geographical area, and assessing the market opportunities for coffee-agroforestry systems in world and European markets: Specifically:

1. to determine the requirements to achieve 'sustainable'; 'fair-trade' or 'eco-friendly' labels on the European markets as well as the long-term potential of marketing this coffee in European countries;
2. to extrapolate farm-scale socio-economic survey data and model predictions from WP7 to a regional scale using population and agricultural census information;

3. to extrapolate biophysical predictions of yields and environmental impact from the plot scale biophysical model (WP6) to larger areas and regions using databases of soil and climate information;
4. to examine the regional implications for coffee production and farm livelihoods of changing climate, economic incentives and widespread uptake of 'eco-friendly' cultivation systems.

8.3 Methodology and study materials

During the final year the WP leader made a visit to Montpellier in June 05 to attend a modelling workshop. He also attended the final project workshop in CATIE, Turrialba in November 05, and collected a large amount of literature – mainly MSc Theses. Significant progress has also been made by Byron Medina (ANACAFE Guatemala) in identifying the water quality and quantifying advantages of traditional coffee systems in the Antigua district of Guatemala.

The Tasks identified for WP 8 are as follows:

1. interviews with European traders to identify the requirements to achieve 'sustainable', 'fair-trade' or 'eco-friendly' labels on the European markets, and to forecast the growth of this market niche and the premium that European consumers are willing to pay;
2. use of socio-economic surveys and farm type to extrapolate impact predictions of coffee management from individual farms to predict impacts on the farming community in wider administrative regions;
3. use of information on climate and soil type to extrapolate biophysical predictions for individual plots to predict average yield and economics in wider regions;
4. examine the overall economic-environmental services of coffee agroforestry for different stakeholders.

In year 3, Appendices to the Annual Report were presented dealing with these 4 Tasks. It is the intention within two months to update these Annexes as four Deliverable Reports which will comprise the final report. This Annual Report will therefore not contain as much detail as usual.

8.4 Progress during the fourth year

This Workpackage is the final one in the CASCA Project. Many of the deliverables were due in year 4, and were presented in draft form in Annexes to the year 3 report. They will all be completed in the final report by mid-April. Deliverables are listed in Table 4.

8.4.1 Task 1 (Identification of Markets for Shade Coffee).

This section updates Annex 1 of the 2003 Report. During the past year a number of interesting initiatives have taken place

Markets for Coffee:

A document on '**Action to avoid further coffee price crise**s' was submitted to the G8 summit by the International Coffee Organisation[1]. This stressed the loss in income from the late 80s to the present day (10 to 12 billion dollars annually declining to 5 billion dollars), whilst the value of retail sales of coffee in consuming countries has risen from around 30 billion dollars to over 70 billion dollars during this period. For several countries in Africa, Asia and Latin America that are dependant on coffee for a large percentage of their exports, it has been estimated that losses in earnings from coffee more than nullify total aid inflows in terms of value. In general the crisis had led to increased poverty, social unrest, incentives to plant illicit drugs, rural unemployment, and illegal emigration in many developing countries. Action was requested to a) redress the supply/demand imbalance – particularly by increasing consumption, b) promote diversification through tariff reduction, c) support broad-based rural development – e.g. through producer organisations, and d) institute improved information initiatives.

[1] http://dev.ico.org/documents/g8.pdf

The **International Coffee Organisation has updated information on coffee production**, and Arabica production is shown to be constant over the past 5 years. In the three CASCA countries, however, production has declined: markedly so in Guatemala (

Figure 1). This is likely to be because of the comparatively high costs of production in these countries (*Figure 2*). Yields are comparatively stable from year to year compared with Brazil, which dominates the market (*Figure 3*).

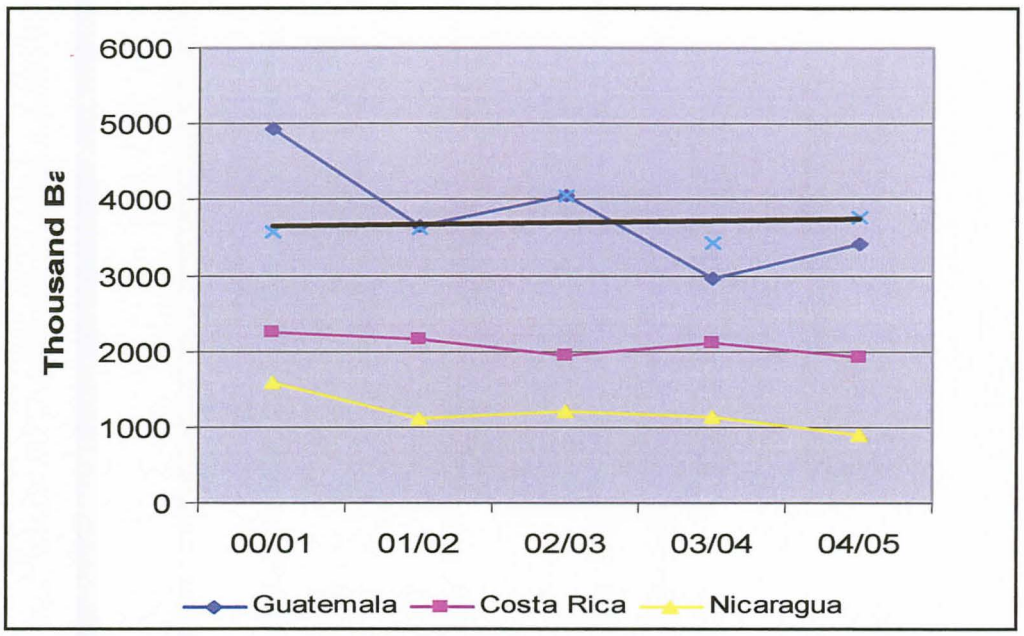


Figure 1: Recent declines in Costa Rican cofffee production (ICAFE). The black line shows world production/20 and is stable over the period.

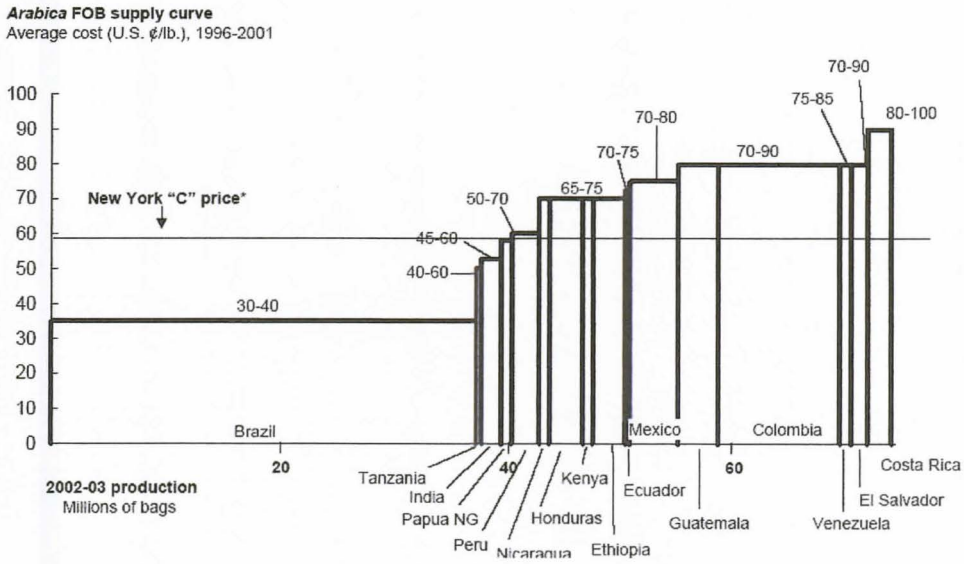


Figure 2: National differences in coffee production costs (Technoserve 1973)[2]

[2] http://www.technoserve.org/TNSCoffeeReport_Master.pdf

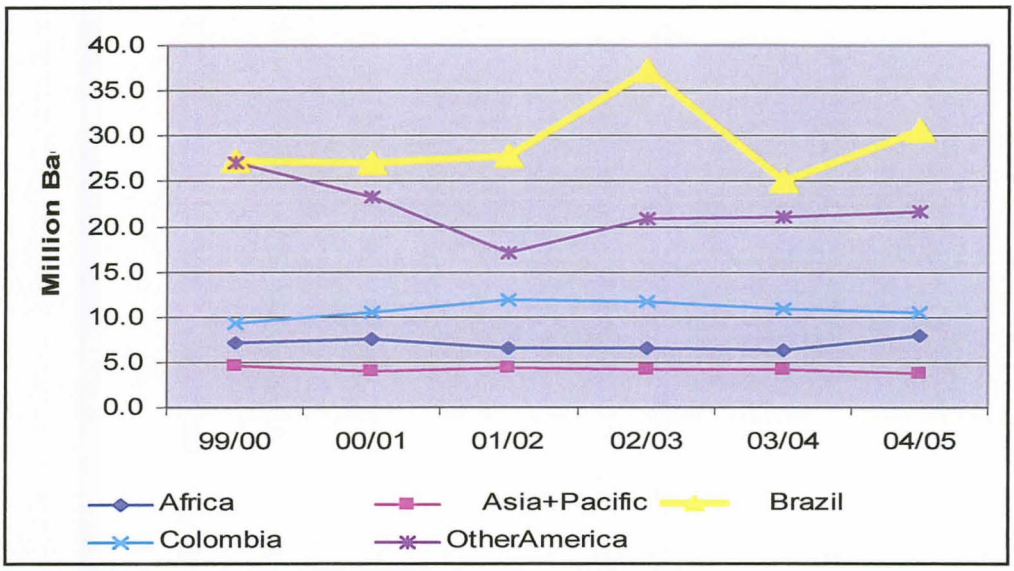


Figure 3 World production of Arabica coffee (ICO), showing the importance of Brazil and the variability of its annual yield. A bag weighs 60kg.

Prices for 04/05 were at a 5-year high but still much lower in the mid-90s (Figure 4).

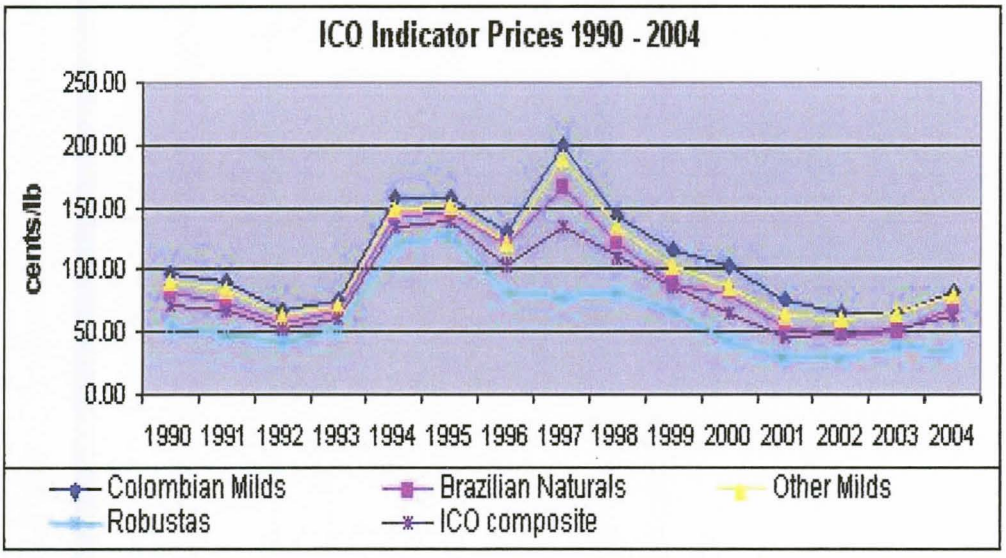


Figure 4: ***Indicator prices collected by the International Coffee Organisation for 5 categories of coffee***[3]

Surveys to Identify Premiums for 'Shade Coffee'

Detailed interviews with European Traders will not take place, but a simple questionnaire has just been sent (2 March 06) to the certifying organisations listed in Table 1, national representatives of the Specialist Coffee Association of Europe[4], and company members of the European Coffee Federation[5].

[3] Sss.thecoffeeguide.org

[4] National coordinators of the Specialist Coffee Association of Europe (http://www.scae.com).

[5] http://www.ecf-coffee.org/

Table 1: Major Certifying Organisations in the Coffee Sector (ICO Coffee Guide 2005)

Company	Country	Website
ACT Organic Agricultural Certification Thailand	Thailand	
AIAB Associazione Italiana per l'Agricoltura Biologica	Italy	www.aiab.it
AIMCOPOP	Costa Rica	
Argencert	Argentina	www.argencert.com.ar
BCS Oko-Garantie GmbH	Germany	www.bcs-oeko.de
Bio.inspecta	Switzerland	www.bio-inspecta.ch
Biolatina	Peru	www.biolatina.org
BioAgriCert	Italy	www.bioagricert.org
Bio-Gro New Zealand	New Zealand	www.biogro.nz
Bolicert	Bolivia	
CCOF California Certified Organic Farmers	United States	www.ccof.org
CCPB Consorzio per il Controllo dei Produtti Biologici	Italy	www.ccpb.it
CERTIMEX	Mexico	
ECOCERT	France	www.ecocert.fr
Ecologica	Costa Rica	
IBD Instituto Biodinamico	Brazil	www.ibd.com.br
ICS International Certification Services Inc. also seen as Farm Verified Organic (FVO)	United States	www.ics-intl.com
ICS Japan	Japan	www.pure-foods.co.jp/index2.html
IMC Instituto Mediterraneo di Certificazione	Italy	www.imcdotcom.com
IMO Institut fur Marktologie	Switzerland	www.imo.ch
IMO Institut fur Marktologie GmbH	Germany	www.imo.ch/imo/imo-frame.html
INAC GmbH	Germany	www.inac-certification.com
JONA Japan Organic & Natural Foods Association	Japan	www.jona-organic.jp
KRAV Ekonomisk Forening	Sweden	www.krav.se
Lacon GmbH	Germany	www.lacon-institut.com
NASAA	Australia	www.nasaa.com.au
Naturland e.V.	Germany	www.naturland.de
OCIA Organic Crop Improvement Association	United States	www.ocia.org
OCIA Japan	Japan	www.ocia.org
OCPRO	Canada	www.ocpro-certcanada.com
OIA Organizacion Internacional Agropecuaria	Argentina	www.oia.com.ar
OFG Organic Farmers & Growers	United Kingdom	www.organicfarmers.uk.com
OMIC overseas Merchandise Inspection Co Ltd	Japan	www.omicnet.com
OTCO Oregon Tilth Certified Organic	United States	www.tilth.org
Qualité-France	France	www.qualite-france.com
QAI Quality Assurance International	United States	www.qua-inc.com
QAI Japan	Japan	www.qua-inc.com
QC&I GmbH	Germany	www.qci.de
SGS Nederland	Netherlands	www.sgs.nl
SKAL	Netherlands	www.skal.com
Soil Association	United Kingdom	www.soilassociation.org

To encourage a response, the questionnaire only has 5 questions:

1. How much coffee (in area or weight or both) does your organisation certify annually?
2. Can you send a copy, or a website reference, to your coffee certification conditions?
3. Is there a shade threshold or criteria in your classification system – if so what.?
4. What premium in coffee sale price does your certificate typically provide to the farmer.
5. What summary trends to you foresee in coffee certification in the next 5 years.

In February 2006 Anacafe (Guatemala), one of the CASCA partners, signed an agreement with USAID & the Rainforest Alliance (together forming the 'Alianza de Productos Certificados Sostenibles') in which all 22 million coffee producers will potentially benefit from the Alliance's environmental mark[6]. Currently some 535 thousand hectares are certified with a production of around US$69 million.

Socio-economic research has been undertaken on the Starbucks Certification Scheme in Costa Rica, and many other certification schemes are listed in Appendix I of the WP8 Year 3 report. This Appendix will be updated by mid-April to provide Deliverable 8.1 of the Final Report.

Developments in Certification

The 2004 Report described a wide range of coffee labels including organic coffee, Fair Trade, Starbucks, Smithsonian 'bird friendly', ECO-OK, country programmes, industry sourcing programmes etc. The most interesting development during 2005 was the launch of the Common Code for the

[6] http://portal.anacafe.org/portal/Home.aspx?tabid=13&lang=1

Coffee Community[7]. The Code's approach to sustainability builds on the Millennium Development Goals of the United Nations, which aim at sustainable livelihoods, and have a social, an environmental and an economic dimension. Coffee production can only be sustainable if it allows for decent working and living conditions for farmers and their families as well as employees. This includes respect for human rights and labour standards as well as achieving a decent standard of living. Protecting the environment such as primary forest and conserving natural resources such as water, soil, biodiversity and energy are core elements of sustainable coffee production and post-harvest processing. Economic viability is the basis for social and environmental sustainability. It includes reasonable earnings for all in the coffee chain, free access to markets and sustainable livelihoods. A number of the 4Cs Criteria relate to environmental factors (Table 2). The role of shade within this scheme will be investigated in the final report.

Table 2: Environmental Criteria within the 4Cs Certification Scheme: Red indicates that the current practice must be distontinues, Yellow that the practice needs to be improved within a transitional period, andGreen indicates a desirable practice.

Environmental Dimension			Criteria			Level of Monitoring
Category	No.	Principle	Green	Yellow	Red	
Biodiversity	1a	Conservation of wildlife and endangered species is facilitated and supported	Conservation of wildlife is practiced and endangered species are protected by demarcation and signage on coffee farms.	No hunting, ensnaring, poisoning and exploitation of endangerred and protected species is practiced and actors along the chain cooperate to develop a communication strategy for the conservation of wildlife.	Hunting, ensnaring, poisoning and exploitation of endangered and protected species is partly practiced.	4C Unit and below
	1b	Native flora is protected and enhanced.	Native flora including watersheds and biodiversity habitats are protected and enhanced.	According to national legislation, no exploitation of native flora or watersheds on the farm is evident and a strategy to protect and enhance native flora is developed.	Irreversible, destructive exploitation of native flora.	4C Unit and below
Agrochemicals	2	Use of pesticides and the effect on human health and on the environment is minimized.	Crop Management (shadow, fertilization, varieties, plant density) for the prevention of phytosanitary problems is in use. Use of natural enemies and the least toxic pesticides is practiced.	Keep to FAO code recommendations regarding WHO I+II and all pesticides of low acute toxicity (see annexed list). System to minimize spraying is in place.	Use of most hazardous pesticides is practiced (see annexed list). There is no system in place to minimize spraying.	4C Unit and below
Soil Fertility	3a	Soil conservation practices are in place.	Full implementation and periodical review of a soil management plan is evident.	Assessment of management options with the preparation of a soil management plan is in line with conservation agriculture. Implementation has started with measures of highest priority.	Observable, continuous, severe, degradation of soil resources by erosion.	4C Unit and below
	3b	Fertilizers are used appropriately	Application of fertilizers is in accordance with the needs of the crop (i.e. based on expected yield) derived from monitoring and soil / plant analyses, encouraging the use of organic material without depleting nutrient stocks in other areas;	A monitoring system for soil / plant analyses is in development. Application of fertilizers is based on standardized prescriptions.	Excessive use of fertilizers polluting water systems, streams and aquifers.	4C Unit and below

Environmental Dimension			Criteria			Level of Monitoring
Category	No.	Principle	Green	Yellow	Red	
	3c	Organic matter management is in place.	Proper use of organic matter as fertilizer to replace mineral fertilizers in a specified time period in accordance with the management plan to enhance biological and physical soil properties.	Organic matter is reused and recycled.	Wasteful and improper disposal of organic matter.	4C Unit and below
Water	4a	Water resources are conserved, this applies to both the quality and quantity aspects.	Water replenishment capacity / quality / water saving technologies are enhanced.	Water conservation practices are implemented.	Withdrawal of water beyond replenishment capacity and pollution of water sources.	4C Unit and below
	4b	Wastewater management is in place.	Discharged load of contaminants is minimized.	Treated wastewater is recycled and reused.	Discharge of untreated wastewater.	4C Unit and below
Waste	5	Safe waste (including packaging waste) management is in place.	Waste generation is minimized, reuse and recycling is maximized. Safe disposal of waste is ensured.	Hazardous waste is recovered, segregated and the safety of farmers, municipality and suppliers is assured.	Unsafe disposal of hazardous waste.	4C Unit and below
Energy	6a	Preferential use of renewable energy.	Maximization of renewable energy sources without surpassing their regeneration capacity is evident.	Management options for use of renewable energy are assessed, and implementation according to priority for the replacement of fossil with renewable energy is started.	Extraction of wood fuel beyond regeneration capacity.	4C Unit
	6b	Saving Energy	Energy use is minimized as evident in regular evaluation.	Use of energy is regularly evaluated and first steps of energy efficiency and alternative options are implemented.	Wasteful use of energy as input for coffee production or processing.	4C Unit and below

[7] www.sustainable-coffee.net

8.4.2 Task 2 (Extrapolation of Socio economic farm surveys to Regional Economic Scale)

WP8 is now concentrating on geographic upscaling. WP7 has conducted socio economic surveys in a number of coffee districts. Economic sampling information and commercial returns are available on the ICAFE website (Sistem de Informacion Cafetelera) which will enable WP7 surveys to be compared against regional averages.

8.4.3 Task 3 (Extrapolation of Biophysical Predictions at Plot Scale to Regional Geographic Scale)

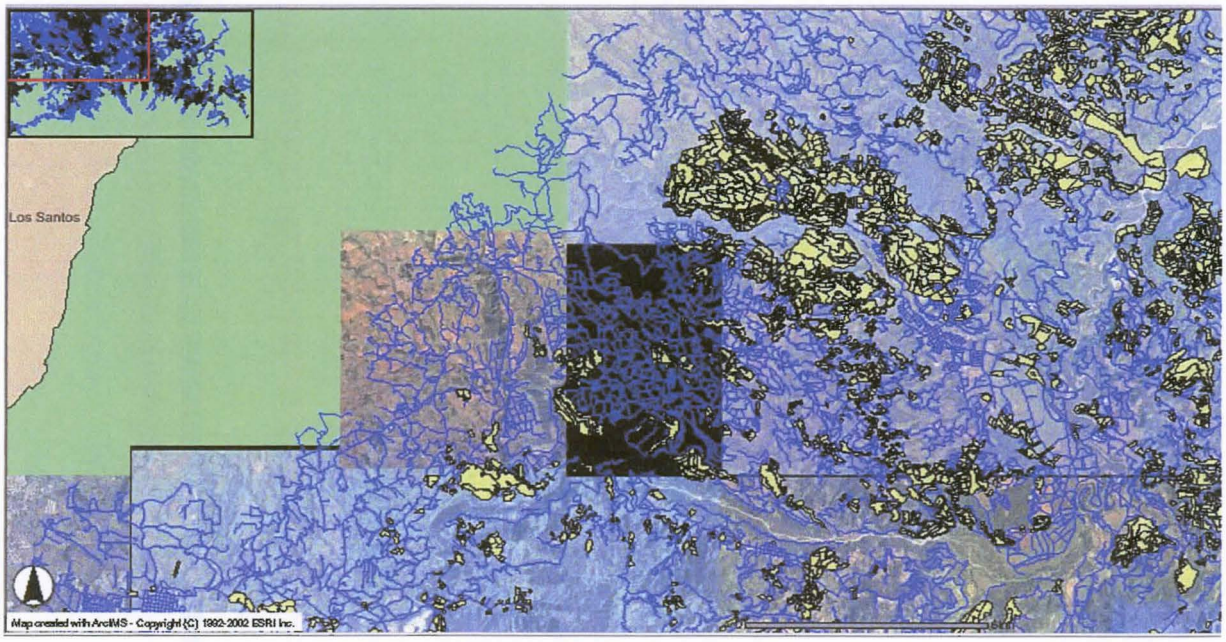
At the 30-month workshop in CATIE, it was decided to focus biophysical up-scaling on a catchment where sufficient information on soils, slopes and vegetation cover was available. Several catchments were considered but the Turrialba catchment was chosen for several reasons:

- Vegetation cover information is available from the 1996 Land Cover study funded by FUNDECOR and MINAE;
- ICAFE has more recent information on distribution of coffee farms from the 2004 survey (Figure 5);
- Some socio-economic socio economic information on coffee farmers was thought to have been collected by ICAFE;
- The ECOMAN project[8] has used soil classifications, limited information on soil-texture, the 96 land-cover map and a digital terrain model to produce a map of potential evaporation rates.

Following acceptance testing of the Plot model at the final workshop in Turrialba in November 05 it is intended in March/April 06 to run the model using a range of (soil/ climate/ slope/ altidude) polygons from the Turrialba catchment (Deliverable 8.3) (Figure 6)

To permit this, ICAFE will make their base map for the Turrialba catchment available to the CASCA Project, and this is gratefully acknowledged.

Figure 5 Coffee distribution and boundaries in portion of the Turrialba district (ICAFE)



[8] http://www.uatla.pt/ecoman/

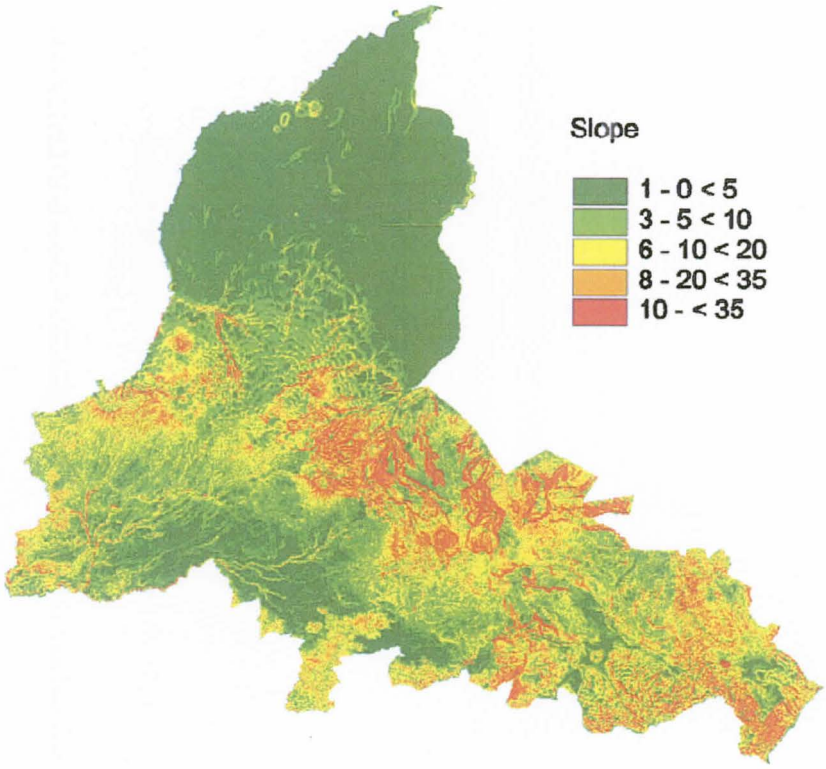


Figure 6: Slope map for Turrialba District

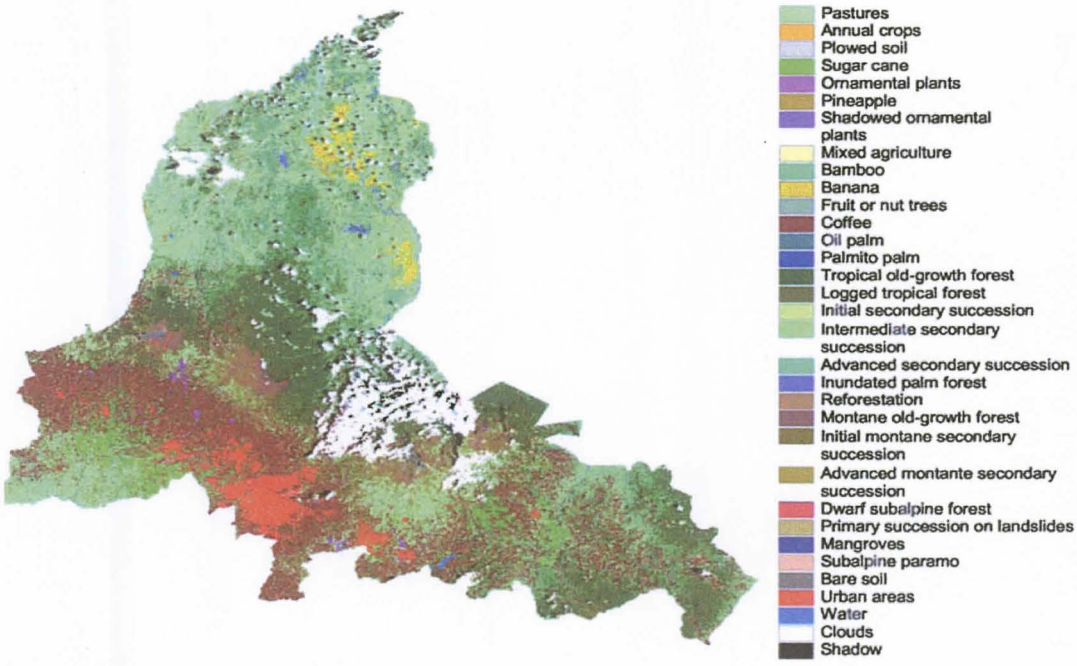


Figure 7: Vegetation types in the Turrialba District

8.4.4 Task 4 (Environmental Services of Shade Coffee)

Whilst in CATIE in November 2005, a large set of MSc Theses and other publications were copied. These will be presented as an annotated bibliography in the final report. Similarly, Appendix 4 of the 2004 report will be updated to produce a final Deliverable 8.4 report on the environmental services of Shade. These will be discussed under the following headings:

- CLIMATE RISK (maintaining stable vegetation covers)
- CLIMATE AMELIORATION (at the meso-scale)
- CARBON CREDITS (using JI/CDM – including all GHGs)

- BIODIVERSITY (biological corridors, species diversity, refuges)
- GENETIC RESOURCES (planting of improved and threatened species)
- WATER QUANTITY and REGULARITY (avoiding floods and low flows- tho this is contentious)
- WATER QUALITY (limiting nitrates and other pollutants)
- EROSION REDUCTION (reducing loss of carbon & nutrients)
- REDUCING SEDIMENT LOAD (avoiding siltation of reservoirs)
- PROTECTING FOREST RESOURCES (timber and firewood elshwhere)
- LANDSCAPE VALUE (Scenic beauty, diversity, tourism & recreation)

Suggested values of these services of shade and sun coffee are summarised in Table 3

Table 3: Market and non-market costs and benefits of forests, shade-coffee and sun coffee to be considered in modelling appoaches.

Process	Process Type	forest	shade-coffee	sun-coffee	Raw units/ha/yr	Energy (MJ/ha/yr)	Money (€/ha/yr)	In model	comment
Labour (cost)	input	low	low	high	md	y	y	N	Planting/pruning/harvesting represented
Herbicide/Pesticide	input	zero	low	high	kg	y	y	N	data from WP7?
non-timber forest products	market	high	medium	low	kg N C	?	y	N	In economic model ??
yield loss due to disease	market (shadow)	n/a	?	?	kg N C	y	(y)	N	Outside scope
biodiversity	non-market	high	medium	low	shannon e n		y	N	Outside scope
risk of fire	non-market	low	low	medium	?	(y)	(y)	N	Outside scope
runoff, erosion & leaching causi	non-market	low	low	high	kg C N	y	(y)	Y	Loss of C and N in surface layers?
erosion causing siltation	non-market	low	low	high	kg soil	?	y	Y	Use RUSLE model and ECOMAN erosion classes
runoff, erosion causing turbidity	non-market	low	low	high	kg C	?	(y)	Y	
runoff, erosion & leaching causi	non-market				Kg N			Y	
N Fertilizer inputs	input	zero	low	high	kg N	y	y	Y	data from WP7?
timber	market	high	medium	zero	kg N C	y	y	Y	allometry to stems, branches, roots
firewood or litter	market	high	medium	low	kg N C	y	y	Y	allometry to stems, branches, roots
catchment flood surges	non-market	low	low	high	peak flow (	?	(y)	Y	Pattern of daily runoff & drainage
catchment total water yield	non-market	low	medium	high	m3	(y)	y	Y	Total runoff & drainage
C sequestration	non-market	high	high	low	kg C N	y	y	Y	Held in aboveground and several litter pools
Sequestered carbon quality	non-market	high	medium	low	C half life	(y)	y	Y	Half-lives of pools known
CO2 emissions	non-market	zero	low	medium	kg C	y	y	Y	Both above and below ground respiration
NOx emissions	non-market	low	low	medium	g N/ forcin	y	y	Y	Proportional to soil water and activity of roots (?)
Prunings	market							Y	
Coffee bean	market							Y	
N fixation	non-market							Y	Depends on soil water contact & growth rate - no feedback YET from soil N content.
soil water holding capacity	non-market	high	high	low	m3/m3	?	(y)	Y-?	Water holding capacity related to SOM?
SOM oxidation	non-market	low	low	high	kg C N	y	y	Y-?	SOM oxidation a function of litter quality, temperature & soil water

8.5 Deliverables

Deliverables are shown in Table 4. All of them were partially completed in Year 4, but significant further work is required before the final report in April. The Deliverable 8.1 report will focus on coffee certification schemes (Year 3 Report Appendix I). The Deliverable 8.2 report will mention economic upscaling but mainly focus on the valuation of environmental services for different stakeholders (Year 3 Report Appendix II) The Deliverable 8.3 report will record results from use of the plot model on trial polygons from the Turrialba catchment with different slopes, soil type and altitude. The final deliverable (8.4) is best met by the project Technology Implementation Plan since it is an output from the whole project team, but an initial version will be produced in WP8 final report.

Table 4 Planning of deliverables

No.	Milestone/Task	Original month	Revised month
D8.1	Report on prospective market for eco-friendly coffee in Europe	45	52
D8.2	Report on extrapolation from socio-economic farm model to level of administrative region	46	52
D8.3	Report on extrapolation of plot-scale biophysical model results to predict regional yield and environmental impacts	46	52
D8.4	Delivery of management and policy guidelines taking into account different climate, soil, market price and incentive scenarios.	48	52