

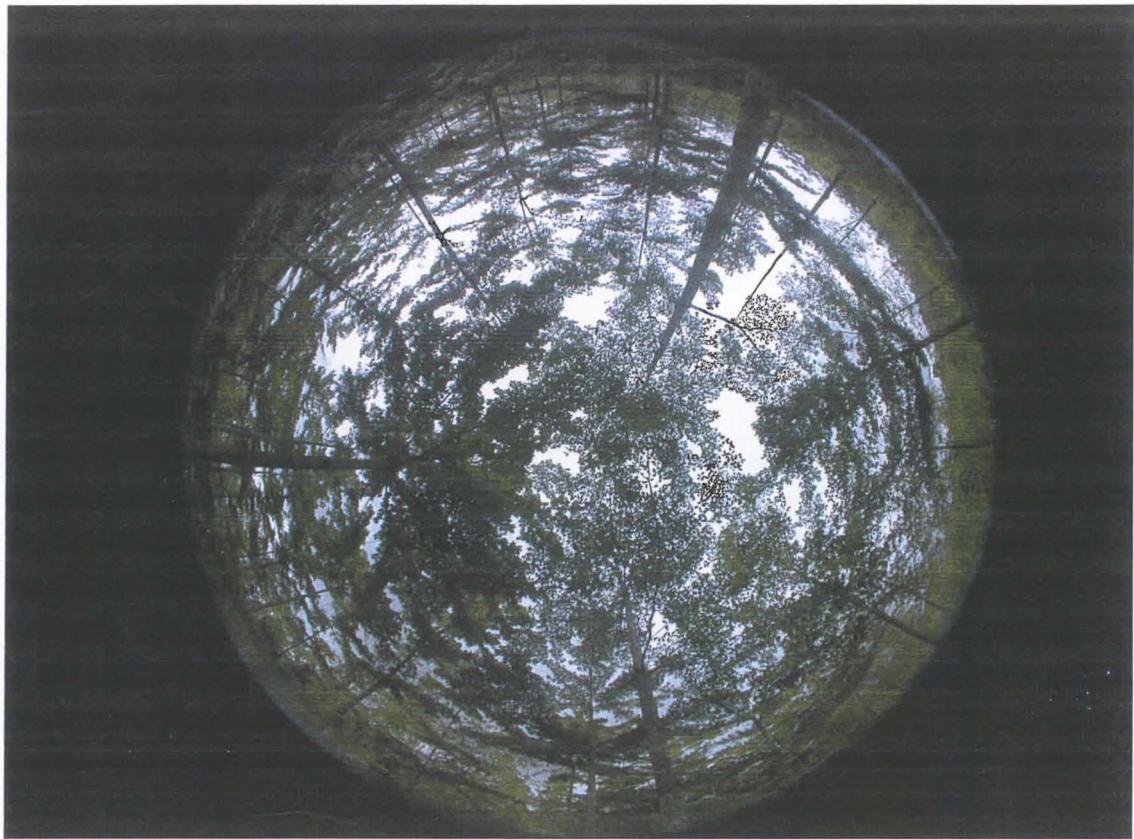
CASCA

Contract ICA4-2001-10071

GENERAL REPORT

Third project year

(1 November 2003 - 31 October 2004)



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)

Contract number: ICA4-2001-10071

THIRD ANNUAL REPORT:

November 1st 2003 to October 31st 2004

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

Project homepage : <http://www.casca-project.com>

Keywords: Agroforestry, Coffee quality, Environmental impacts, Central America

Contract number:
ICA4-2001-10071

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

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ICA4-2001-10071

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| |
|--|
| SUMMARY (year 3) |
| Dr. Philippe Vaast (CIRAD), Coordinator |

The objective of this **summary report** is to give an overview of the main technical activities undertaken by all the partners of the CASCA project during **the third year** (November 2003 - October 2004).

One technical meeting was held in May at the headquarters of CATIE, Turrialba, Costa Rica on progress towards biophysical modeling. One consortium meeting was held (November 22-26 of 2004) in Guatemala at the headquarters of ANACAFE to assess the data collection performed during the third year of CASCA and to plan activities for the fourth and final year. This meeting was attended by a total of **18 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 during this third year. Following the establishment of experimental sites in 2002, data collecting has been continued for all four biophysical Work Packages (WP's 2, 3, 4 & 5) in Costa Rica, Nicaragua and Guatemala.

For the socio-economic Work Packages (WP's 1, 7 & 8), activities were also continued intensively during this third year. Surveys have been undertaken from March to October 2004 in four coffee producing regions of Costa Rica and Nicaragua. An economical survey of the wood sector and stakeholders was also performed in Costa Rica.

Overall, **the project has achieved a significant amount of field works during this third year to gather 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 lack of funding from the E.U during this entire third year.

- An update of the database on farmers AF knowledge and main AF characteristics in nine regions of the three target countries has been undertaken and a synthesis of these surveys has been presented (see activity report of WP1).
- The model of light partitioning between coffee and associated trees has been completed and a simplified field methodology using hemispheric photos has been developed (see activity report of WP2).
- Additional data have been gathered on water consumption of coffee and associated trees in optimal conditions for coffee cultivation and the backbone of the water model has been completed (see activity report of WP2).

- Intensive measurements have been undertaken to refine the model on leaf and fruit photosynthesis and ecological factors controlling carbohydrate production (see activity report of WP3).
- Articles have been submitted to international scientific journals regarding processes regulating coffee quality (see activity report of WP3).
- Additional data have been collected on nitrogen cycling, N₂ and N₂O 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 the refinement of the integrated plot model and performed preliminary simulations (see activity report of WP6).
- The backbone of the economical model has been completed and tested with data collected from surveys in Guatemala, Nicaragua and Costa Rica (see activity reports of WP7).
- The general framework has been refined by WP leader regarding regional up-scaling and policies (see activity report of WP8).

Therefore, large amounts of biophysical and socio-economical data are now available from the 3 target countries and are being used for refining the biophysical and socio-economical models, regional up-scaling and elaboration of recommendations which are the main tasks of the fourth and final year of the CASCA project.

Through **scientific publications**, partners of CASCA have contributed to the exploitation and dissemination of results. **13 articles** and **two chapters** have been accepted and/or published in 2004. **7 theses (Masters)** have also been published in 2004. For the 3 years of project, this amounts to a total of **23 articles, 2 chapters, 22 Masters theses and one Ph.D. thesis**.

Five oral presentations of the CASCA project and preliminaries results of **agroforestry management on coffee quality and environmental impacts** have been performed in the **First World Agroforestry Congress** (Orlando, Florida, June 2004) and the **20th International Coffee Research Conference** (Bangalore, India, October 2004).

One oral presentation of the objectives of CASCA and benefits of coffee agroforestry management has been performed during the **National Coffee Congress in Nicaragua** (RAMACAFE, Managua, September 2004).

One presentation of the CASCA project and preliminaries results of **agroforestry management on coffee quality** was done for around **100 coffee farmers** in Costa Rica (May 2004).

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

Contract number:
ICA4-2001-10071

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

Management Annual report (year 3)
Dr. Philippe Vaast (CIRAD), Coordinator

One consortium meeting was held (November 22-26 of 2004) in Guatemala at the headquarters of ANACAFE to assess the data collection performed during the third year of CASCA and plan activities for the fourth and final year.

The first half of this meeting focused on socio-economical work-packages and particularly on economical importance of tree products on coffee farmers' revenues. A one-day field trip was organized by ANACAFE to visit different coffee farms around Antigua. The second half of this workshop focused on biophysical work-packages, particularly on the integrated biophysical model at plot scale. 22 presentations were done during these four days.

This meeting was attended by a total of **18 persons** representing all partner institutions and with researchers from all the work-packages.

During this third year, technical meetings were held in Nicaragua (August 2004), in Costa Rica (May & August 2004) and Guatemala (November 2004) in order to plan field activities on the experimental sites and to select regions for the last surveys to be performed in 2005.

One technical meeting is planned in May 2005 in Montpellier, France, between leaders of WPs 2 to 8, to finalize the parameterization of the economical and biophysical models.

A consortium meeting, marking the end of the project, is planned for the last week of October 2005 at the headquarters of CATIE in Costa Rica.

Months of activities

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

Compared to **172.8 months initially planned** for the third year, **223.8 months have been dedicated** to CASCA activities in 2004 (see details of months of activities per partner in annexes of this document). Through research works of graduate students, activities were maintained at a very high level despite lack of funds from the E.U. during the entire third year.

Financial aspects

Out of the first **total advance of 258 969 euros** transferred by the E.U. in February 2002 and October 2002, a total of **209 293.72 Euros was justified** in the cost statements at the end of the first project year by the CASCA partners and an amount of **198 255.57 Euros was ultimately declared eligible by the E.U.**

Therefore, a total of **60 713.43 Euros** was left over from the first year to initiate activities at the beginning of the second year and an amount of **116 404.16 Euros** was granted by the E.U for the second year of CASCA that arrived very late, more than half way into the second year.

A total of **155 222.40 Euros was justified** in the cost statements of the second project year by the CASCA partners following the repartition below.

A total of **167 765.06 Euros is being justified** in the cost statements of this third project year by the CASCA partners following the repartition below.

| <i>Acronyms</i> | | <i>Funds</i> | <i>Balance at end of</i> | | <i>Advance</i> | <i>Funds justified</i> | <i>Funds justified</i> | <i>Balance at</i> |
|--------------------|---------------------------|---------------------------|----------------------------|--|--------------------------------|-----------------------------------|-----------------------------------|-----------------------------------|
| <i>Contractors</i> | <i>Advance for Year 1</i> | <i>Eligible in year 1</i> | <i>1st year</i> | | <i>For 2nd year</i> | <i>End of 2nd year</i> | <i>End of 3rd year</i> | <i>End of 3rd year</i> |
| CIRAD | 68 147.00 | 58 333.41 | 9 813.59 | | 38 888.94 | 56 766.28 | 67533.62 | -8 063.75 |
| CEH | 35 400.00 | 29 013.69 | 6 386.31 | | 16 351.87 | 19 796.33 | 27088.83 | -24 146.98 |
| CATIE | 111 422.00 | 90 472.70 | 20 949.30 | | 51 315.13 | 45 311.54 | 44241.15 | -17 288.26 |
| IIICA | 29 227.00 | 11 546.17 | 17 680.83 | | 0 | 24 518.09 | 21676.34 | -28 513.60 |
| UNA | 14 773.00 | 8 889.60 | 5 883.40 | | 9 848.20 | 8 830.16 | 7225.12 | -323.68 |
| Total | 258 969.00 | 198 255.57 | 60 713.43 | | 116 404.14 | 155 222.40 | 167 765.06 | -145869.89 |

No funds were sent by the E.U. during this third year. This has resulted in a deficit of 145 869.89 Euros during this third year. Consequently, all the partners have had to pre-finance most of activities during this third year according to their capacities and this has had some negative impacts on work progress. **This is particularly handicapping for Central American partners** that do not have the financial capacities to pre-finance a full year of activities. In particular, UNA had to decrease its amount of field work due to lack of funds. It is worth mentioning that funds are yet to be received by the CASCA partners at the time of printing this report, *i.e.* beginning of December 04.

Educational aspects

As already emphasized during the two 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.

A total of **30 graduate students** have been involved in the CASCA project since its beginning in 2001. **Eight students from UNA** have done their research works with the help of CASCA in order to obtain their diploma in agricultural engineering in Nicaragua. **Seven European students** (5 French and 2 Spanish) have spent more than five months each doing their fieldwork in Costa Rica and Guatemala for their Masters. **Four doctoral students** (2 French and 2 Latino American) **from CIRAD** have spent a total of 60 months in Costa Rica and Nicaragua doing their field research in 2003 & 2004. **Eleven students (10 Masters and 1 Ph.D.) of CATIE** have done their fieldwork in Costa Rica and Guatemala as part of their degree requirements in 2002 to 2004.

Three Masters students and two Ph.D. students will be financially supported by the project during 2005.

Exploitation and Dissemination

13 articles and two chapters have been accepted and/or published in 2004. **7 theses (Masters)** have been published in 2004. For the 3 years of project, this amounts to a total of **23 articles, 2 chapters, 22 Masters theses and one Ph.D. thesis** (see annexes of scientific report).

In 2004, five oral presentations of the CASCA project and preliminaries results of **agroforestry management on coffee quality and environmental impacts** have been performed in the **First World Agroforestry Congress** (Orlando, Florida, June 2004) and the **20th International Coffee Research Conference** (Bangalore, India, October 2004).

One oral presentation of the objectives of CASCA and benefits of coffee agroforestry management has been performed during the **National Coffee Congress in Nicaragua** (RAMACAFE, Managua, September 2004).

One presentation of the CASCA project and preliminaries results of **agroforestry management on coffee quality** was done for around **100 coffee farmers** in Costa Rica (May 2004).

A website (www.casca-project.com) presenting, in English and Spanish, the project and results of the first and second years, is on the web **since June 2003**. It will be updated with new results and publications in January 2005 after completion of the third annual scientific report.

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

| | WP1 | WP2 | WP3 | WP4 | WP5 | WP6 | WP7 | WP8 | WP9 | Done in Year 3 | Planned for Year 3 |
|-----------------------|-------------|--------------|--------------|--------------|--------------|-------------|--------------|-------------|-------------|-------------------|-----------------------|
| CIRAD | | | | | | | | | | | |
| Total Permanent staff | 1.3 | 9.85 | 5.05 | 7.25 | 7.35 | | 1.5 | | 2.09 | 34.40 | 20.25 |
| Students | 1.0 | 6.7 | | | 2 | | 7.93 | | | 17.63 | 5 |
| Total CIRAD | 2.3 | 16.55 | 5.05 | 7.25 | 9.35 | 0 | 9.43 | 0 | 2.09 | 52.03 | 25.25 |
| Total CEH | | | | 1.6 | | 1.50 | | 0.75 | 0.25 | 4.1 | 4.60 |
| CATIE | | | | | | | | | | | |
| Total Permanent Staff | 2.00 | 1.50 | 2.50 | 4.50 | 5.00 | | 0.50 | 0.25 | 2.00 | 18.25 | 25 |
| Total Hired Staff | 2.00 | 13.43 | 10.95 | 19.00 | 17.88 | | | | | 63.26 | 44 |
| Total CATIE | 4.00 | 14.93 | 13.45 | 23.50 | 22.88 | 0.00 | 0.50 | 0.25 | 2.00 | 81.51 | 69 |
| IICA-PROMECAFE | | | | | | | | | | | |
| Total Permanent staff | 3.00 | 0.75 | 1.00 | 2.75 | 3.75 | | 1.00 | 2.00 | 1.00 | 15.25 | 18 |
| Hired staff | | 9.50 | 9.50 | 9.50 | 10.84 | | | | | 39.34 | 26 |
| Total IICA | 3.00 | 10.25 | 10.50 | 12.25 | 14.59 | 0.00 | 1.00 | 2.00 | 1.00 | 54.59 | 44 |
| UNA | | | | | | | | | | | |
| Total Permanent staff | 0.1 | | 7 | | 7 | - | 0.1 | 0.1 | 2 | 16.3 | 14 |
| Total Hired Staff | | | 7.64 | | 7.64 | | | | | 15.28 | 16 |
| Total UNA | 0.1 | | 14.64 | | 14.64 | | 0.1 | 0.1 | 2 | 31.58 | 30 |
| Grand TOTAL | 9.4 | 41.73 | 43.64 | 44.6 | 61.46 | 1.5 | 11.03 | 3.06 | 7.34 | 223.80 | 172.85 |

Contract number:
ICA4-2001-10071

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

Scientific annual report (year 3)
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 third year (November 2003 - October 2004)** and the difficulties encountered.

Months of activities

Despite lack of funds from the E.U. during the entire third year, all the partners have had an important input in terms of activities dedicated to the project. Compared to **172.8 months initially planned** for the third year, **223.8 months have been dedicated** to CASCA activities in 2004 (see details of months of activities per partner at the end of management report). Research activities were maintained at a very high level due to field work by graduate students of CATIE, CIRAD and UNA.

This report of scientific activities is presented by Work-packages. Details of the major results 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 WP leader, CATIE (Eduardo Somarriba) has coordinated with partners the field surveys undertaken in Costa Rica, Guatemala and Nicaragua (see WP1 report).

Following the design of socioeconomic questionnaires in 2002, four Ms students of UNA undertook in 2002-2003 surveys in one region of Nicaragua, three Ms student from CIRAD in one region of Guatemala and one of Costa Rica, one Ph.D student from CIRAD in two regions of Costa Rica.

In 2004, two last studies were undertaken documenting AF practices in Nicaragua and Costa Rica; one by the Ph.D. student of CIRAD in collaboration with UNA in two contrasting regions in Nicaragua and a second one by IICA-PROMECAFE in collaboration with CATIE in the southern part of Costa Rica.

With a total of 30 months of field works, **7 major coffee producing regions of Central America** (4 in Costa Rica, 3 in Nicaragua and one in Guatemala) have been surveyed during the first 36 months of the CASCA project. This results in a total of more than **150 farms surveyed in Costa Rica, 40 in Guatemala and 120 in Nicaragua.**

Deliverables and Planned activities in 2005

At the end of this third year of project, the Deliverable D10/D1.1 “Database of current coffee AF practices” is completed with studies performed during the first and second years in Costa Rica, Guatemala and in Nicaragua. A synthesis of these surveys has been presented by Dr. E. Somarriba during the consortium meeting marking the end of the second year.

The database has been actualized with 7 studies undertaken in 2003 in Guatemala, Nicaragua and Costa Rica. 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”. These documents constitute the expected deliverables of Work Package 1 (Deliverable D13/D1.3 “Scientific report describing existing AF typologies and management”- Month 30).

In 2005, Dr. E. Somarriba will be updating the database on coffee Agroforestry (AF) practices with the last studies undertaken in 2004.

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) has developed a methodology to **quantify and model light interception by five timber tree species**. This methodology is based on digitalized photos (photos of tree silhouette and photos fish-eye below the canopy). A **model simulating light partitioning** between the associate tree and the coffee stratum has also been completed (see WP2 report for more details).

In 2004, a graduate student (Stéphane Bagnis, CIRAD) has digitized completely 16 plants under 3 shade treatments (75% and 50% shade and the full sun) with varying fruit loads (100%, 50% and “very light load”). These data have been used to refine 3D representations of the coffee plants useful to simulate microclimate at the leaf level.

In March 2004, a Masters student of CATIE defended his thesis on canopy cover and light interception by timber trees (*Terminalia amazonia*, *Eucalyptus deglupta*, and *Cordia alliodora*) in more than 60 coffee farms of 3 regions of Costa Rica.

In 2004, CIRAD (Philippe Vaast) CATIE (Pablo Siles) and IICA-PROMECAFE (Luis D. Garcia) have collected data on **transpiration of both coffee and tree strata** (*Inga* spp.)

using sap flow measurements in 2 target coffee systems in the central region of Costa Rica.

Following the thesis defense by a Ph.D. student of CATIE in March 2003, two articles (Agroforesteria en Las Americas and an international journal: Agroforestry Systems) have been submitted in 2004 on water consumption of coffee and associated trees (either *Terminalia ivorensis*, or *Eucalyptus deglupta*, or *Erythrina poeppigii*). These measurements demonstrate that the combined daily water uptake per hectare by coffee and shade trees in all the three associations is higher than that of coffee plants grown alone in full sun (see WP2 report for details).

CIRAD, CATIE and IICA-PROMECAFE have also been involved in collecting data on **rain interception** by the canopies of coffee and associated trees and on **runoff** (see WP2 report for details).

In 2004, several series of digitalized photos (mostly hemispheric photos below the canopy) of 4 tree species have been taken in AF systems along the year in order to refine the light partitioning model according to seasonal changes in tree phenology.

Deliverables

The Deliverable D11/D2.1 “Comprehensive model of light partitioning in coffee AF systems” due at the end of year 2 (Month 24) is completed (see Report of WP2) and two international publications are in preparation.

The backbone of a water model in two few target systems is completed as planned and according to Deliverables List (D15/D2.2 “Water balance model at plot scale”- Month 36). Nonetheless, additional data are needed to improve the parameterization on timber species consumption.

Planned activities in 2005

In 2005, it is planned to take additional digitalized photos to document more precisely seasonal changes in tree phenology and hence light interception.

A Ph.D. student from CATIE/CIRAD will continue measuring soil water content, plant water status and water consumption of coffee and trees in two target coffee AF systems to refine the model of water balance.

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 & Nicolas Franck), UNA (Victor Aguilar & graduate students) CATIE (Pablo Siles & Walter Ramirez) and IICA-PROMECAFE (Victor Chaves & Luis Dionisio Garcia) have been involved in **quantifying carbon allocation between fruit and shoot** on four experimental sites (3 in Costa Rica: experimental station of CICAFE in

Barva, hybrid trial on a commercial farm in Poas, and shade trial on a commercial farm in Orosi, as well as one AF trial in the pacific zone of Nicaragua).

With a CO₂ analyzer bought with CASCA equipment funds, CIRAD and CATIE have continued undertaking measurements of **leaf and fruit photosynthesis, stomatal conductance and photo-inhibition** in optimal ecological conditions for coffee growth and production on the two experimental sites (Central valley and Orosi Valley, Costa Rica). More than 100 samples of different components of coffee trees (leaves, twigs & fruits) have been harvested during the 2003-04 production cycles and analyzed for nitrogen, starch and soluble sugars.

These results show that **photosynthesis of fruits** could contribute up to 10-15% to their own carbohydrate demand and that this photosynthetic contribution decreased with increasing fruit age and biomass. Results also confirmed a **negative feedback effect of leaf reserves**, especially soluble sugars, on leaf photosynthesis. Results indicate that there is a strong relationship between the degree of **photo-inhibition (Fv/Fm)** and the **light exposition (PPFD)** received by the leaves during hours prior to the measurements (see WP3 report for details).

All these measurements are being analyzed to refine the parameterization of a carbon production and allocation model at the coffee plant level. One Ph.D. student from CIRAD is expected to defend his thesis on the modeling of coffee photosynthesis and carbon allocation by June 2005.

CIRAD, CATIE, UNA IICA-PROMECAFE (CICAFE of Costa Rica) have continued **quantifying the effects of shade and fruit load, date of harvest on the quality of coffee** in terms of bean size, biochemical and cup quality. From 2002 to 2004, more than 250 analyses (biochemical and cupping) have been performed by CIRAD (B. Guyot, F Davrieux and J.J. Perriot) in its laboratory in Montpellier.

All the data, gathered from these five experiments during the last 3 years, confirmed that fruit load and shade significantly affected coffee quality. **Shade** lengthened the berry flesh maturation process and resulted in larger bean size, enhanced bean filling, improved biochemical composition and hence resulted in **higher quality** of coffee beverage in both sub-optimal and optimal conditions. Under optimal conditions, **lower fruit load** decreased competition among fruits for carbohydrate and hence enhanced bean size, composition and cup quality.

These results have been presented in two international congresses (First World Agroforestry Congress in Orlando, Florida, June 2004, and International Coffee Congress, Bangalore, India, October 2004) and a national coffee congress (RAMACAFE, Managua, Nicaragua, September 2004).

Three articles in international journals and 4 articles in proceedings of International congresses (all submitted in 2004) are documenting the physiological responses of coffee to microclimatic conditions and the beneficial effects of shade trees on coffee physiology and quality.

Deliverables

The Deliverable D8/D3.1 “Scientific report on physiological responses of coffee to microclimatic conditions” was due in year 2 (Month 20) as well as the Deliverable D9/D3.2 “Report of rules of carbon allocation” (Month 20). They are completed through publications in regional and international journals (see Report of WP3).

Planned activities in 2005

Three trials (two in Costa Rica and one in Guatemala) are currently being harvested starting October 2004.

A survey of 90 farms is in progress in Nicaragua since October 2004. This research work, undertaken by a graduate student of CATIE, is evaluating the effects of farm management (particularly shade level) and plantation productivity along an altitudinal range (700 to 1400 m) on coffee quality.

Cup tasting and bean biochemical content from these experiments will be assessed during the first semester of 2005.

Parameterization and testing of the model on carbon allocation will be finalized by mid 2005 (Deliverable D14/D6.2 “Carbon allocation model of fruit growth in a single bush” due in year 3; Month 30).

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.

CIRAD (Jean-Michel Harmand, Kristell Hergoualc'h & Patrice Cannavo), INRA (Etienne Dambrine), UNA (Victor Aguilar, Marta Gutierrez, Rodolfo Mungia) IIICA-Promecafe (Victor Chavez & Luis Garcia of CICAFE), CATIE (Victoria Osorio, Tamara Benjamin & Adolfo Martinez) and CEH (Ute Skiba) have been strongly involved in collecting field data to quantify N fluxes in 4 agroforestry systems in Costa Rica and Nicaragua.

Data have been collected on **N inputs, N-fixation, N mineralization, N accumulation in coffee plants and soil profile as well as 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).

CIRAD (Robert Oliver) and CATIE have analyzed more than 200 water samples for N (ammonium and nitrate) in their laboratories. CEH (Ute Skiba) has analyzed gas samples to quantify N₂O emissions. Etienne Dambrine of INRA, Nancy (subcontractor of CIRAD), was also strongly involved in installing an N¹⁵ study on the experimental station of CICAFE and analyzing samples in Nancy, France (see WP4 report for more details).

Two Masters theses were presented in 2004. Three articles have been submitted. One oral presentation was presented at the First World Agroforestry Congress in Orlando, Florida, in June 2004.

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 be considered partly completed via publications submitted and in preparation.

Planned activities in 2005

More measurements, involving one Ph.D. student (in Costa Rica) will be undertaken in 2005, especially on denitrification and N₂O emissions, to parameterize the model of N flux at plot scale due at the beginning of year 4 (Deliverable D18/D4.3 “N flux model at plot scale” – Month 38).

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.

CIRAD (Jean-Michel Harmand & Philippe Vaast), UNA (Victor Aguilar, Rodolfo Mungia & graduate students) IICA-Promecafe (Victor Chaves & Luis Garcia of CICAFE), CATIE (Benito Dzib, John Zuluaga & Adolfo Martinez) have continued undertaking measurements of biomass of coffee and tree characteristics (height, crown projection, diameter at breast height) and soil carbon accumulation in soil of various coffee AF systems in Costa Rica and Nicaragua.

One Ms student of CATIE has surveyed around 60 coffee farms in 3 regions of Costa Rica to investigate how farmers' management was affecting the growth of shade trees (*Terminalia amazonia*, *Eucalyptus deglupta*, and *Cordia alliodora*). This student has defended his thesis in early 2004. A second Ms student of CATIE has investigated carbon accumulation in the long-term coffee AF trial on CATIE campus and defended his thesis in early December 2004 (see WP5 report for more details).

Deliverables

One deliverable was due and completed in 2003, the deliverable D6/D1.2 “Database on coffee agroforestry studies” (Month 18).

Planned activities in 2005

More field measurements will be undertaken in 2005 to parameterize the model of C sequestration at plot scale due at the beginning of year 4 (Deliverable D19/D5.4 “Model of C sequestration in coffee systems at plot scale” – Month 38).

Work-Package 6: (integrated plot modeling)

Marcel van Oijen (CEH) has refined the version of the integrated plot model for coffee growth with and without accompanying trees. The major developments in year 3 were (i) the finalising of the structure of the IP-model, which now includes full biogeochemical cycling of water and nitrogen in the coffee-tree system, (ii) the implementation and testing on the model of a Bayesian calibration method, and (iii) a the execution of a series of preliminary tests for assessing model applicability (see WP6 report for more details). The main challenge for the final year will be to use new and more detailed data from CASCA-observations and experiments for improved model calibration, the application of the model, and the transfer of model results to WP7 and WP8.

Deliverables

No deliverable was due in 2004.

Planned activities in 2005

Following a parameterization meeting planned for June 2005 in Montpellier, France, it is anticipated that application of the model will provide results for WP7 and up-scaling simulations for WP8 during the second half of 2005.

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

CIRAD (Philippe Bonnal as leader of this WP, Damien Jourdain & three graduate students: Anne Zanfini, Adnane Mouzaoui and Axel Boulay), UNA (Prof. Glenda Bonilla and 2 graduate students) IICA-Promecafe (Mainor Rojas of CICAFE), CATIE (Eduardo Somarriba) and CEH (Gerry Lawson) have been involved in **household surveys and economic modeling**.

A last series of socioeconomic farm surveys was undertaken in 2004 in two regions of Nicaragua by Ph.D. student of CIRAD in collaboration with UNA. Valuable information on the diversity of the coffee production systems, farm incomes, costs of inputs and labor is now available from 7 regions of Costa Rica, Guatemala and Nicaragua. A synthesis of these household surveys and typologies, and the framework of an economic model have been completed in 2004 (see WP7 report for more details).

A Masters student (Axelle Boulay) of CIRAD has undertaken in 2004 an economical study in Costa Rica on the products derived from timber tree species in AF coffee systems and their financial importance for the various stakeholders (from coffee farmers to local end users). She has also compared the financial benefit of various timber species (*Eucalyptus deglupta*, *Cordia alliodora*, *Cedrela odorata*). These data on diversification of coffee farmers' revenues will be used in economic simulations.

Deliverables

The deliverable due in year 3 has been completed (D12/D7.1 "Synthesis of household surveys" – Month 28). Data from the surveys undertaken in 2004 will be incorporated in this synthesis in 2005.

Planned activities in 2005

Two studies will be undertaken by graduate students from CATIE and UNA in Guatemala and Nicaragua on commercialization of timber and fuel-wood derived from coffee AF systems and their importance for farmers' revenues and other stakeholders.

An economical study will be undertaken by a 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.

The economic model will be refined (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).

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

The objectives of this Workpackage deal with upscaling 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 mid May 2004 in the headquarters in Costa Rica. The survey of the market for different coffee labels has been updated (see report of WP8). For regional economic upscaling, the availability of information has been checked with Coffee Growers Organisations (ICAFE, ANACAFE and PROMECAFE). A literature review has also been updated on the environmental impacts of coffee plantations. This Workpackage is the final one of the CASCA Project. Most of its reporting is due in year 4, although two milestones due for the end of year 3 have been missed. WP8 has awaited completion of farm surveys and socio-economic survey in WP7 before commencing on upscaling. A revised timetable of Deliverables and Milestones is provided in WP8 report. At the 30-month workshop in CATIE, it was decided to focus biophysical upscaling on the Turrialba catchment where sufficient information on soils, slopes and vegetation cover was available. Consequently,

contact has been made with ICAFE and preliminary results obtained on their surveys of producers in the Turrialba Area.

Deliverables & Planned activities in 2005

There two deliverables planned in the third year could not be completed, but are expected to be completed during the last 12 months of project:

1. Extrapolation of outputs from the socio-economic farm model (WP7) to predict impacts of different management scenarios on farmers at the level of administrative region (Month 36, reprogrammed for Month 42)
2. Extrapolation of plot-scale biophysical model results to predict regional yield and environmental impact on a GIS grid, for at least one country (Month 36, reprogrammed for Month 42)

Four important additional deliverables are planned for the last project year:

3. Report on prospective markets for eco-friendly coffee in Europe (D8.1, original Month 45-Revised Month 48)
4. Report on extrapolation from socio-economic farm model to level of administrative region (D8.2 Month 46)
5. Report on extrapolation of plot-scale biophysical model results to predict regional yield and environmental impacts (D8.3 Month 46)
6. Delivery of management and policy guidelines taking into account different climate, soil, market price and incentive scenarios (D8.4 Month 48)

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 and held in Guatemala in late-November 2004.

With the collaboration of all partners, CIRAD (Philippe Vaast) has produced the **6-month report** of activities as well as this **present management and scientific reports and the consolidated annual financial report** (Patrick Guezo & Farida Sissaoui).

Through **scientific publications** (see annexes), partners of CASCA have contributed to the exploitation and dissemination of results. **13 articles and two chapters** have been accepted and/or published in 2004 (see annexes below). **7 theses (Msc)** have been published in 2004. For the 3 years of project, this amounts to a total of **23 articles, 2 chapters, 22 Masters theses and one Ph.D. thesis** (see annexes below).

Five oral presentations of the CASCA project and preliminaries results of **agroforestry management on coffee quality and environmental impacts** have been performed in the **First World Agroforestry Congress** (Orlando, Florida, June 2004) and the **20th International Coffee Research Conference** (Bangalore, India, October 2004).

One oral presentation of the objectives of CASCA and benefits of coffee agroforestry management has been performed during the **National Coffee Congress in Nicaragua** (RAMACAFE, Managua, September 2004).

One presentation of the CASCA project and preliminaries results of **agroforestry management on coffee quality** was done for **100 coffee farmers** in Costa Rica (May 2004).

A website (www.casca-project.com) presenting, in English and Spanish, the project and results of the first year, is on the web **since June 2003**. It will be updated with results of the third year at the beginning of 2005.

ANNEXES

Publications of the CASCA project

WP1

Articles

Somarriba E. (2002) ¿Cómo estimar visualmente la sombra en cacaotales y cafetales? *Agroforestería en las Américas* 9(35/36): 86-94.

López, A.; Orozco, L.; Somarriba, E.; Bonilla, G. (2003). Tipologías y manejo de fincas cafetaleras en los municipios de San Ramón y Matagalpa, Nicaragua. *Agroforestería de las Américas*. Vol 10(37-38). 74-79.

Chapter

Somarriba, E, Harvey CA, Samper M, Anthony F, Gonzalez J, Staver C, Rice RA. (2004). Biodiversity Conservation in Neotropical Coffee (*Coffea arabica*) Plantations. In “Agroforestry and Biodiversity Conservation in Tropical Landscapes”, eds Schroth G, da Fonseca GAB, Harvey CA, Gascon C, Vasconcelos HL and Izac AMN, Island Press. pp198-226.

Masters theses

Castillo R. y Ortíz P. (2003). Tipologías y manejo de fincas cafetaleras en los Municipios de El Tuma – La Dalia y Rancho Grande, Matagalpa, Nicaragua. Tesis, Universidad Nacional Agraria, Managua, Nicaragua. 70 p.

López A. y Orozco L. (2003). Tipologías y manejo de fincas cafetaleras en los Municipios de San Ramón y Matagalpa, Nicaragua. Tesis, Universidad Nacional Agraria, Managua, Nicaragua. 87 p.

WP2

Articles

van Kanten R.F., Vaast P. (2004). Coffee and shade tree transpiration in suboptimal, low-altitude conditions of Costa Rica. (submitted to Agroforestry Systems, October 04).

Doctoral thesis

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

WP3

Articles

Siles P. and Vaast P. (2002). Comportamiento fisiológico del café asociado con *Eucalyptus deglupta*, *Terminalia ivorensis* y sin sombra. *Agroforestería en las Américas*. 9(35/36): 44-49.

Vaast P., Génard M., Dauzat J. (2002). Modeling the effects of fruit load, shade and plant water status on coffee berry growth and carbon partitioning at the branch level. *Acta Horticulturae*. 584:57-62.

Angrand J., Vaast P. Beer J. Benjamin T. (2003). Comportamiento vegetativo y reproductivo de *Coffea arabica* en tres sistemas agroforestales comparado con pleno sol en Pérez Zeledón, Costa Rica. *Agroforestería en las Américas*. (in press).

Rosenqvist, E., Ottosen, CO., Vaast P. (2003). Effects of shade and fruit load on gas exchange characteristics of coffee (*Coffea arabica* L.) cv ‘Costa Rica 95’ in field conditions. *Tree Physiology* (submitted Oct. 2003 to be revised in 2005).

- Castro J., Díaz D., Aguilar V. (2003).** Evaluación de 3 sistemas de manejo de café (*Coffea arabica*) sobre el crecimiento y la estructura productiva de la variedad CR-95. *Memoria Jornada Universitaria de Desarrollo Científico*. Mesa Agronomía (in press).
- van Kanten R.F., Beer J., Schroth G., Vaast P. (2004).** Interacciones biológicas entre *Coffea arabica* y árboles maderables de rápido crecimiento en el Sur de Costa Rica. Agroforestería en las Américas (in press).
- Vaast P., Angrand J., Franck N., Dauzat J., Génard M. (2004).** Fruit load and branch ring-barking affect carbon allocation and photosynthesis of leaf and fruit of *Coffea arabica* in field conditions. *Tree Physiology* (accepted August 04)
- Vaast P., Bertrand B., Guyot B., Génard M. (2004).** 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* (in press).
- Vaast P., van Kanten R., Siles P., Angrand J., Aguilar A. (2004).** Biophysical interactions between timber trees and coffee in sub-optimal conditions of Central America. *Agroforestry Systems* (submitted July 2004).

Communications in congresses

- Vaast P., van Kanten R., Siles P., Angrand J., Aguilar A. (2004).** Biophysical interactions between timber trees and coffee in sub-optimal conditions of Central America. First World Agroforestry Congress, Orlando, Florida, June 2004.
- Bertrand B., Etienne H., Guyot B., Vaast P. (2004).** 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 (in press).
- Vaast P., van Kanten R., Siles P., Dzib B., Franck N., Harmand JM., Génard M. (2004).** Shade: a key factor for coffee sustainability and quality. Proceedings of the 20th International Congress on Coffee Research (ASIC) Bangalore, India, October 2004 (in press).
- Vaast P., Cilas C., Perriot JJ., Davrieux F., Guyot B., Bolano M. (2004).** Mapping of coffee quality in Nicaragua according to regions, ecological conditions and farm management. Proceedings of the 20th International Congress on Coffee Research (ASIC) Bangalore, India, October 2004 (in press).

Masters theses

- Pablo Siles. (2002).** Comportamiento fisiológico del café asociado con *Eucalyptus deglupta* o *Terminalia ivorensis* y sin sombra. Tesis M.Sc., CATIE, Turrialba, Costa Rica.

- Jobert Angrand. (2003).** Floración, desarrollo vegetativo y fotosíntesis de *Coffea arabica* en diferentes sistemas de cultivos en Pérez Zeledón y Heredia, Costa Rica. Tesis Mag. Sc. CATIE, Turrialba, Costa Rica.

- Castro B., J.; Díaz V., D. (2004).** 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.

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

WP4

Articles

- Payán F., Beer J., Jones D., Harmand J.M., Muschler R.** (2002). Concentraciones de carbono y nitrógeno en el suelo abajo de *Erythrina poeppigiana* en plantaciones orgánicas y convencionales de café. Agroforestería en las Américas. 9(35/36): 10-15.
- Reina Vanessa Renderos Durán, Jean-Michel Harmand, Francisco Jiménez, Donald Kass** (2002). Contaminación del agua con nitratos en microcuencas con sistemas agroforestales de *Coffea arabica* con *Eucalyptus deglupta*) en la Zona Sur de Costa Rica. Agroforestería en las Américas. 9(35/36): 81-85.
- Avila H., Harmand J.M., Dambrine E., Jiménez F., Beer J., Oliver R.** (2004). Dinámica del nitrógeno en el sistema agroforestal *Coffea arabica* con *Eucalyptus deglupta*, en la zona sur de Costa Rica. Agroforestería en las Américas. 10(37/38). (in press).
- Gutiérrez Castillo M., Harmand J.M., Dambrine E.** (2004). Disponibilidad de nitrógeno en el suelo bajo especies maderables y leguminosas usadas como sombra en sistemas de *Coffea arabica*. Agroforestería en las Américas. 10(37/38). (in press).
- Munguía, R., Beer, J., Harmand, J.M., Haggard, 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. 10(37/38). (in press).

Masters Theses

Arana Meza Víctor Hugo. (2003). Dinámica del nitrógeno en un sistema de manejo orgánico de café (*Coffea arabica* L.) asociado con poró (*Erythrina poeppigiana* (Walpers) O.F. Cook). Tesis Mag Sc. CATIE, Turrialba, CR. 100p

Avila Reyes Hector Emilio. (2003). Dinámica del nitrógeno en el sistema agroforestal *Coffea arabica* con *Eucalyptus deglupta* en la zona sur de Costa Rica. Tesis Mag Sc. CATIE, Turrialba, CR. 90p.

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.

Rodolfo Munguía (2003). Tasas de descomposición y liberación de nutrientes de la hojarasca de *Eucalyptus deglupta*, *Coffea arabica* y *Erythrina poeppigiana* solas y en mezclas. Tesis Mag Sc. CATIE, Turrialba, Costa Rica.

Crouzet Gary (2003). Dynamique de l'azote et distribution de racines fines dans un système agroforestier caféier sous *Inga densiflora* en comparaison avec un système caféier cultivé en plein soleil. CNEARC / ENGREF Montpellier, CIRAD, CATIE.

Kristell Hergoualc'h. (2004). Formation d'oxyde nitreux par nitrification et dénitrification en fonction de l'humidité du sol. Étude d'un sol volcanique sous différents systèmes caféiers au Costa Rica. ENSAIA. Nancy, INPL, France: 29.

Victoria Eugenia Osorio Moreno. (2004). Descomposición y liberación de nitrógeno de material foliar y radicular de siete especies de sombra en un sistema agroforestal con café. Tesis M.Sc., CATIE, Turrialba, Costa Rica. 75p.

Communication in congress:

Jean-Michel Harmand, Hector Avila, Etienne Dambrine, Francisco Jiménez, John Beer.
(2004). Nitrogen dynamics and nitrate water contamination in a *Coffea arabica* - *Eucalyptus deglupta* agroforestry system in Southern Costa Rica. First World Agroforestry Congress, Orlando, Florida, June 2004.

WP5

Articles

- De Miguel Magaña S., Harmand J.M., Hergoualc'h K. (2003).** Cuantificación del carbono almacenado en la biomasa aérea y el mantillo en sistemas agroforestales de café en el Sur Oeste de Costa Rica. Agroforestería en las Américas.
- 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. Agroforestería en las Américas.

Chapter

Snoeck D., Vaast P. (2004). Importance of Organic Matter and Biological Fertility in Coffee Soils. J.N. Wintgens (Ed.) In: *Coffee - Growing & Processing*. Wiley VCH, Allemagne.

Masters theses

Sergio De Miguel. (2002). Dynamique de la biomasse de différents systèmes agroforestiers caféiers dans la zone Sud du Costa Rica. ENGREF, Montpellier, France.

John Jairo Zuluaga Peláez. (2004). Dinámica de la materia orgánica del suelo en sistemas agroforestales de café con *Erythrina poeppigiana* (Walpers) O.F. Cook en Costa Rica. Magíster Scientiae, CATIE, Costa Rica, 120p.

Benito Bernardo Dzib Castillo. (2004). Crecimiento de tres especies forestales establecidas dentro de plantaciones de café en tres regiones de Costa Rica. Magíster Scientiae, CATIE, Costa Rica, 45p.

WP7

Masters Theses

Nougadère A., Guezennec S. (2002).. Diagnostic agro-économique de trois zones caféières dans la région de Najanro, Costa Rica. CNEARC-CIRAD, Montpellier, France. 106 p.

Urruela J (2003). Diagnóstico agrario de una región cafetalera de altitud, cuenca alta del río Achiguate, Antigua Guatemala, Guatemala. CNEARC-CIRAD, Montpellier, France. 156 p.

Axelle Boulay. (2004). Production de bois d'œuvre issu des systèmes agroforestiers caféiers au Costa Rica. Mémoire de fin d'études. ENGREF/CIRAD.

WP8

Articles

- Vaast P., Harmand J.M. (2002).** Importance des systèmes agroforestiers dans la production de café en Amérique Centrale et au Mexique. Plantations, Rech., Dév. Mai 02: 35-43.

Masters Thesis

Bayron Medina Fernández (2003). Externalidades hídricas del sistema agroforestal café con sombra en la subcuenca Rio Guacalate, Guatemala. Tesis Mag Sc. CATIE, Turrialba, CR., 86p.

DATA SHEET FOR ANNUAL REPORT

Contract number: ICA4-2001-10071

**Third Year
(November 1st 2003 to October 31st 2004)
Data sheet
for annual report of CASCA**

| <i>1. Dissemination activities</i> (cumulative) | Totals |
|--|--------|
| Number of communications in conferences (published) | 4 |
| Number of communications in other media (internet, video, poster) | 0 |
| Number of publications in refereed journals (published) | 2 |
| Number of articles/books (published) | 2 |
| Number of other publications (PhD and Msc theses) | 7 |
| | |
| <i>2. Training</i> | |
| Number of PhDs | 4 |
| Number of MScs | 7 |
| Number of visiting scientists | 2 |
| Number of exchanges of scientists (stays longer than 3 months) | 0 |
| | |
| <i>3. Achieved results</i> | |
| 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 |
| | |
| <i>4. Industrial aspects</i> | |
| 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, in English and Spanish, the project and results of the first year, 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

3rd YEAR (NOV. 2003 – OCT. 2004)

Dr. Philippe Vaast

DECEMBER 2004

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 **third year** (November 2003 - October 2004).

A total of **9 permanent CIRAD researchers** were involved in the project for a total of **34.4 months** with 2.1 months dedicated to technical and administrative coordination. **Three students**, hired temporally, were involved in field research and economical modeling for a total of **17.6 months**. This results in a CIRAD input of **52 months** of work compared to the 25.25 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 36 months of the project, in major coffee-growing ecological zones of the 3 countries (Costa Rica, Nicaragua & Guatemala) considered in the project.

In 2004, one Ph.D. student of CIRAD (Anne Zanfini, University of Toulouse, France) collected data in two regions of Nicaragua with assistance of UNA.

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) has developed a methodology to **quantify and model light interception by five timber tree species**. This methodology is based on digitalized photos (photos of tree silhouette and photos fish-eye below the canopy). A **model simulating light partitioning** between the associate tree and the coffee stratum has also been completed (see WP2 report for more details).

In 2004, a graduate student (Stéphane Bagnis, University of Toulouse) has digitized completely 16 plants under 3 shade treatments (75% and 50% shade and the full sun) with varying fruit loads (100%, 50% and "very light load"). These data have been used to refine 3D representations of the coffee plants useful to simulate microclimate at the leaf level.

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**. He was also involved in tutoring one Ms student of CATIE that defended his thesis in March 2004 on light interception by shade trees (*Terminalia amazonia*, *Eucalyptus deglupta*, and *Cordia alliodora*) in coffee farms of 3 contrasting regions of Costa Rica (see WP2 report for more details).

CIRAD has also been involved in collecting data on **rain interception** by the canopies of coffee and associated trees and on **runoff** (see WP2 report for details).

Two articles have been submitted to publication on coffee and tree transpiration (see annexes) and two are in preparation on light interception.

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**.

As leader of this WP3, CIRAD (Philippe Vaast) and with one Ph.D. student (Nicolas Franck) have measured intensively **leaf and fruit photosynthesis, carbon production and allocation between fruit and shoot, and photo-inhibition** in two trials in Costa Rica under optimal ecological conditions for coffee growth and production. All the data collected over the last 36 months are being used to parameterize a carbon model at the tree level (see WP2 report for more details). One article on fruit photosynthesis has been accepted in 2004 (see annexes).

CIRAD has also been involved in **quantifying the effects of shade and fruit load on the quality of coffee** in terms of bean size, bean biochemical composition and cup quality. More than 250 analyses were performed from 2002 to 2004 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 last 3 production cycles. Two articles have been accepted in 2004 (see annexes).

The main results have been presented in two international congresses (First World Agroforestry Congress in Orlando, Florida, June 2004, and International Coffee Congress, Bangalore, India, October 2004) and a national coffee congress (RAMACAFE, Managua, Nicaragua, September 2004).

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, 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 four agroforestry systems in Costa Rica. They have also tutored one Masters student (Kristell Hergoual'ch) from the University of Nancy, 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 implementing an N¹⁵ study on the experimental station of CICAFE, Costa Rica, as well as analyzing N¹⁵ samples in Nancy, France (see WP4 report for more details).

One Masters student (Kristell Hergoual'ch, University of Nancy) has defended her thesis in September 2004 on N₂O emissions by nitrification and denitrification on a volcanic coffee soil of Costa Rica.

Preliminary results have been presented in the First World Agroforestry Congress in Orlando, Florida, June 2004.

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.

CIRAD (Jean-Michel Harmand, Patrice Cannavo, Philippe Vaast) have been supervising students of CATIE and undertaking **measurements of biomass of coffee and tree characteristics** (height, crown projection, diameter at breast high) and **carbon accumulation in the soil** of various coffee AF systems and farms in Costa Rica (see WP5 report for details).

Work-Package 6: (integrated plot modeling)

Like other partners, CIRAD has contributed indirectly to this WP by collecting numerous biophysical data that will be 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 & Damien Jourdain) 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). One European Ph.D. student (Anne Zanfini from University of Toulouse) has conducted surveys during a total of 6 months in two regions of Nicaragua. This Ph.D. student will defend her thesis in June 2005.

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, Jean-Michel Harmand has been involved in tutoring one Masters student from ENGREF, France undertaking an economical analysis of the wood products derived from timber trees in coffee AF systems of 2 regions of Costa Rica. Philippe Vaast has been tutoring two students of CATIE; in 2005, one will undertake an economical analysis of timber and fuel-wood derived from coffee AF systems and their importance for farmers' revenues and other stakeholders in Guatemala, the second will study 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.

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 and held in Guatemala in late-November 2004.

With the collaboration of all partners, CIRAD (Philippe Vaast) has produced the **6-month report** of activities as well as the **management and scientific reports and the consolidated annual financial report** (Patrick Guezo & Farida Sissaoui).

Through **5 scientific publications** in 2002, **10 submitted** in 2003-2004, and **5 oral presentations in International congresses**, with CIRAD staff and/or students as the main or associate authors, CIRAD has greatly contributed to the exploitation and dissemination of results (see annexes). Three students, tutored by CIRAD, have defended their theses during this third year of project.

CIRAD (Philippe Vaast) has updated the project website (www.casca-project.com) presenting, in English and Spanish, the project and results of the first two years.

Sub-contracting

The sub-contractor INRA (Institut National de la Recherche Agronomique) has been involved in the project through a visit to Costa Rica (May 2003) of Dr. Etienne Dambrine (INRA, Nancy). This researcher and colleagues have been strongly involved in implementing a nitrogen field study in Costa Rica and undertaking analyses of N¹⁵ in Nancy, France

ANNEXES

Publication of CIRAD

Scientific articles published in 2002-2003

- Payán F., Beer J., Jones D., Harmand J.M., Muschler R.** (2002). Concentraciones de carbono y nitrógeno en el suelo abajo de *Erythrina poeppigiana* en plantaciones orgánicas y convencionales de café. Agroforestería en las Américas. 9(35/36): 10-15.
- Reina Vanessa Renderos Durán, Harmand J.M., Jiménez F., Kass D.** (2002). Contaminación del agua con nitratos en microcuenca con sistemas agroforestales de *Coffea arabica* con (*Eucalyptus deglupta*) en la Zona Sur de Costa Rica. Agroforestería en las Américas. 9(35/36): 81-85.
- Siles P. and Vaast P.** (2002). Comportamiento fisiológico del café asociado con *Eucalyptus deglupta*, *Terminalia ivorensis* y sin sombra. Agroforestería en las Américas. 9(35/36): 44-49.
- Vaast P., Harmand J.M.** (2002). Importance des systèmes agroforestiers dans la production de café en Amérique Centrale et au Mexique. Plantations, recherche, développement. Mai 02 : 35-43.
- Vaast P., Génard M., Dauzat J.** (2002). Modeling the effects of fruit load, shade and plant water status on coffee berry growth and carbon partitioning at the branch level. Acta Horticulturae. 584:57-62.

Scientific articles submitted or accepted in 2003-2004

- Angrand J., Vaast P., Beer J., Benjamin T.** (2003). Comportamiento vegetativo y reproductivo de *Coffea arabica* en tres sistemas agroforestales comparado con pleno sol en Pérez Zeledón, Costa Rica. Agroforestería en las Américas. (in press).
- De Miguel Magaña S., Harmand J.M., Hergoualc'h K.** (2003). Cuantificación del carbono almacenado en la biomasa aérea y el mantillo en sistemas agroforestales de café en el Sur Oeste de Costa Rica. Agroforestería en las Américas. (accepted Sept. 2003).
- Gutiérrez Castillo M., Harmand J.M., Dambrine E.** (2003). Disponibilidad de nitrógeno en el suelo bajo especies maderables y leguminosas usadas como sombra en sistemas de *Coffea arabica*. Agroforestería en las Américas. (accepted Sept. 2003).
- Munguía, R., Beer, J., Harmand, J.M., Haggard, J.P.** (2003). 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. (accepted Sept. 2003).
- Avila H., Harmand J.M., Dambrine E., Jiménez F., Beer J., Oliver R.** (2004). Dinámica del nitrógeno en el sistema agroforestal *Coffea arabica* con *Eucalyptus deglupta*, en la zona sur de Costa Rica. Agroforestería en las Américas 10(37/38). (in press).
- 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. Agroforestería en las Américas. (accepted Sept. 2004).
- 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. Agroforestería en las Americas (in press).
- Vaast Ph., Angrand J., Franck N., Dauzat J., Génard M.** (2004). Fruit load and branch ring-barking affect carbon allocation and photosynthesis of leaf and fruit of *Coffea arabica* in field conditions. Tree Physiology (revised August 04)
- Vaast Ph., Bertrand B., Guyot B., Génard M.** (2004). 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 (in press).
- Vaast Ph., van Kanten R., Siles P., Angrand J., Aguilar A.** (2004). Biophysical interactions between timber trees and coffee in sub-optimal conditions of Central America. Agroforestry Systems (submitted July 2004).

Communications in congresses in 2004

Vaast Ph., van Kanten R., Siles P., Angrand J., Aguilar A. (2004). Biophysical interactions between timber trees and coffee in sub-optimal conditions of Central America. First World Agroforestry Congress, Orlando, Florida, June 2004.

Jean-Michel Harmand, Hector Avila, Etienne Dambrine, Francisco Jiménez, John Beer. (2004). Nitrogen dynamics and nitrate water contamination in a *Coffea arabica - Eucalyptus deglupta* agroforestry system in Southern Costa Rica. First World Agroforestry Congress, Orlando, Florida, June 2004.

Bertrand B., Etienne H., Guyot B., Vaast Ph. (2004). 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 (in press).

Vaast Ph., van Kanten R., Siles P., Dzib B., Franck N., Harmand JM., Génard M. (2004). Shade: a key factor for coffee sustainability and quality. Proceedings of the 20th International Congress on Coffee Research (ASIC) Bangalore, India, October 2004 (in press).

Vaast Ph., Cilas C., Perriot JJ., Davrieux F., Guyot B., Bolano M. (2004). Mapping of coffee quality in Nicaragua according to regions, ecological conditions and farm management. Proceedings of the 20th International Congress on Coffee Research (ASIC) Bangalore, India, October 2004 (in press).

Chapter

Snoeck D., Vaast Ph. (2004). Importance of Organic Matter and Biological Fertility in Coffee Soils. J.N. Wintgens (Ed.) In: *Coffee - Growing & Processing*. Wiley VCH, Allemagne.

MSc Thesis published in 2002-2003

Nougadère A., Guezennec S. (2002).. Diagnostic agro-économique de trois zones caférières dans la région de Najanro, Costa Rica. CNEARC-CIRAD, Montpellier, France. 106 p.

De Miguel S. (2002). Dynamique de la biomasse de différents systèmes agroforestiers cafiers dans la zone Sud du Costa Rica. ENGREF Montpellier.

Crouzet G. (2003). Dynamique de l'azote et distribution de racines fines dans un système agroforestier caïer sous *Inga densiflora* en comparaison avec un système caïer cultivé en plein soleil. CNEARC / ENGREF Montpellier, CIRAD, CATIE.

Urruela J. (2003) Diagnóstico agrario de una región cafetalera de altitud, cuenca alta del río Achiguate, Antigua Guatemala, Guatemala. CNEARC-CIRAD, Montpellier, France. 156 p.

MSc Thesis published in 2004

Kristell Hergoualc'h. (2004). Formation d'oxyde nitreux par nitrification et dénitrification en fonction de l'humidité du sol. Étude d'un sol volcanique sous différents systèmes caffiers au Costa Rica. ENSAIA. Nancy, INPL, France. 29p.

Axelle Boulay. (2004). Production de bois d'œuvre issu des systèmes agroforestiers caffiers au Costa Rica. Mémoire de fin d'études. ENGREF/CIRAD, Montpellier.

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

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

Person-months/Year

| CIRAD | WP1 | WP2 | WP3 | WP4 | WP5 | WP6 | WP7 | WP8 | WP9 | YR 3 | |
|-----------------------|-------------|------------|----------|-------------|----------|-----|----------|----------|-------------|--------------|--------------|
| Total Permanent staff | 0.25 | 2.5 | 3 | 2.25 | 6 | 1 | 3 | 0.25 | 2 | 20.25 | |
| Students | | | | 5 | | | | | | 5 | |
| Total CIRAD Yr3 | 0.25 | 2.5 | 3 | 7.25 | 6 | | 1 | 3 | 0.25 | 2 | 25.25 |

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

| CIRAD | WP1 | WP2 | WP3 | WP4 | WP5 | WP6 | WP7 | WP8 | WP9 | Yr 3 |
|-----------------------|------------|--------------|-------------|-------------|-------------|-----|-------------|-----|-------------|--------------|
| Philippe Vaast | | | | | | | | | 1.05 | 1.05 |
| Farida Sissaoui | | | | | | | | | 1.05 | 1.05 |
| Philippe Vaast | 0.5 | 3 | 3 | | | | 0.5 | | | 7.00 |
| Jean Dauzat | | 1.85 | | | | | | | | 1.85 |
| Nicolas Franck | | 2 | 4.15 | | | | | | | 6.15 |
| Robert Oliver | | | | 0.25 | | | | | | 0.25 |
| Philippe Bonnal | | | | | | | 0.5 | | | 0.50 |
| Damien Jourdain | | | | | | | 0.5 | | | 0.50 |
| Jean-Michel Harmand | 0.8 | | | 3 | 3 | | | | | 6.80 |
| Patrice Cannavo | | | | 4 | 4.35 | | | | | 8.35 |
| Bernard Guyot | | | 0.3 | | | | | | | 0.30 |
| Fabrice Davrieux | | | 0.3 | | | | | | | 0.30 |
| Jean-Jacques Perriot | | | 0.3 | | | | | | | 0.30 |
| Total Permanent staff | 1.3 | 9.85 | 5.05 | 7.25 | 7.35 | 0 | 1.5 | 0 | 2.09 | 34.40 |
| Students | 1 | 6.7 | 0 | 0 | 2 | 0 | 7.93 | 0 | 0 | 17.63 |
| Total CIRAD Yr 3 | 2.3 | 13.55 | 8.05 | 7.25 | 9.35 | | 9.43 | | 2.09 | 52.03 |

Centre for Ecology and Hydrology

CEH

ANNUAL REPORT of ACTIVITIES for the INCO PROJECT

CASCA

3rd YEAR (NOV. 2003 – OCT. 2004)

Gerry Lawson

November 2004

CASCA Project

Contractor NERC (Centre for Ecology and Hydrology)

Third 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 |
| Prof Melvin Cannell | 44 131 445 8503 | 44 131 445 3949 | mgrc@ceh.ac.uk |

G.J. Lawson BSc MICFor is a systems ecologist and Chartered Forester with European agroforestry experience dating from 1982 and tropical agroforestry experience (mainly Africa) from 1989. He co-ordinated the UK-DFID Agroforestry Modelling Programme, TIGER (a NERC programme on global environmental change), and has developed interaction models for agroforests and mixed tropical forests. He has experience with landscape classification in Europe and socio-economic modelling of household survey data from Ghana and now works for the International Section of the Natural Environment Research Council.

Professor Melvin Cannell DSc. Is a Fellow of the Royal Society of Edinburgh and the Institute of Chartered Foresters. He moved to Kenya in 1966 to do research on coffee, and from there to the Edinburgh Station of the Centre for Ecology and Hydrology, where he is now Head. His research interests are in the physiology and genetics of trees of all kinds - temperate conifers, energy crops, agroforests, plantation crops and tropical rainforests. He has undertaken numerous consultancies since 1974 including: tea research in Kenya and Malawi; forestry research in the USA, including a year spent with the Weyerhaeuser Company; biophysical research at the International Centre for Research in Agroforestry (ICRAF), Kenya; and future research strategies on short-rotation biomass plantations for the EC and agroforestry modelling for DFID

Dr Ute Skiba is a soil microbiologist scientist with 11 years experience in investigating trace gas emissions from soils, principally NO and N₂O emissions, microbial processes and the main variables involved in controlling the fluxes and scaling to regions.

Dr Marcel van Oijen has worked as a modeller of plant and crop processes in Wageningen University and Research Center (The Netherlands) from 1985 to 1999. He developed growth models for the effects on plants of the abiotic environment (light, temperature, CO₂, water- and N- availability, ozone) and weeds, pests and pathogens. In 1999, he moved to the Centre of Ecology and Hydrology in Edinburgh where he focuses on the effects of climate change and N-availability on forest growth.

3. Time spent on the different workpackages

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

| Name | WP1 | WP2 | WP3 | WP4 | WP5 | WP6 | WP7 | WP8 | Total | Total yr2 |
|---------------------|-----|-----|-----|-----|-----|-----|-----|-----|-------|-----------|
| Total Allocation | | 2.1 | 3.9 | 0.7 | | 7.8 | 1.7 | 2.8 | 12.3 | |
| Mr Gerry Lawson | | | | | | | | 1 | | 1 |
| Dr Marcel van Oijen | | | | | | 1.6 | | | | 1.6 |
| Dr Ute Skiba | | | | 1.5 | | | | | | 1.5 |
| Prof Melvin Cannell | | | | | | 0 | | | | 0 |
| Total | | | | | | | | | | 4.1 |

Total time spent (4.1 person months) slightly less than planned for year 3. After movements of days between workpackages, at the beginning of September, 11 days remained for Skibe (WP3), 37 days for Lawson (WP8) and 69 days for van Oijen (WP6).

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 3 = 0 months)

Melvin Cannell has made a modest input on coffee ecophysiological processes to the modelling effort of Marcel van Oijen. He is now retired but remains available to comment on the model.

4.4. WP4 Nitrogen cycling, leaching, uptake and emissions

(Total allocation 3.9 months, spend in year 3 = 1.5 months)

Work undertaken by Ute Skibe in year 3 is described in the WP4 report. She visited Costa Rica for a week in late June to work with Jean Michel Harmand & visited Montpellier for 3 days in August to supervise a PhD collaborator from CIRAD.

4.5. WP5 Carbon sequestration

(Total allocation 0.7 months, spend in year 3 = 0 months)

4.6. WP6 Integrated plot modelling

(Total allocation 7.8 months, spend in year 3 = 1 months)

Marcel van Oijen visited CATIE from 8-15th May 04 for a workshop on modelling, and Guatemala from 22-27th November for the annual project meeting. His work is described in the WP6 report.

4.7. WP7 Economic modelling at farm scale

(Total allocation 1.7 months, spend in year 3 = 0 months)

4.8. WP8 Regional upscaling and policies

(Total allocation 2.8 months, spend in year 3 = 1 month)

Gerry Lawson visited Costa Rica from 8th – 14th May to attend a CASCA project modelling workshop. For further information see the WP8 report.

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

Year three saw slightly less time and travel committed to CASCA by CEH than had been planned. Equipment (mainly WP4) on the other hand is slightly overspent

Work in WP4 is on target. The model developed in WP6 was evaluated in Guatemala, and requires modifications, as planned in the timetable. WP8 is behind schedule having missed two milestone targets in year 3 but a new timetable has been agreed with the project coordinator (Table 1).

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 | 48 |
| D8.2 | Report on extrapolation from socio-economic farm model to level of administrative region | 46 | 46 |
| D8.3 | Report on extrapolation of plot-scale biophysical model results to predict regional yield and environmental impacts | 46 | 46 |
| D8.4 | Delivery of management and policy guidelines taking into account different climate, soil, market price and incentive scenarios. | 48 | 48 |
| M8.1 | Completion of interviews with European traders and estimates of premium prices that European consumers are willing to pay for eco-friendly coffee | 42 | 47 |
| M8.2 | Extrapolation of outputs from the socio-economic farm model (WP7) to predict impacts of different management scenarios on farmers at the level of administrative region (Month 36). | 36 | 42 |
| M8.3 | Extrapolation of plot-scale biophysical model results to predict regional yield and environmental impact on a GIS grid, for at least one country (Month 36). | 36 | 42 |
| M8.4 | Integration of socio-economic-ecological impacts of coffee management systems in the context of broader environmental impacts on stakeholders (Month 40). | 40 | 44 |
| M8.5 | Completion of management and policy guidelines following workshops (Month 48) | 48 | 48 |

**CENTRO AGRONOMICO TROPICAL de INVESTIGACION y
ENSEÑANZA**

CATIE

**ANNUAL REPORT of ACTIVITIES for the INCO PROJECT
CASCA**

3rd YEAR (NOV. 2003 – OCT. 2004)

NOVEMBER 2004

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 third year (November 2003 - October 2004).

A total of **8 permanent researchers** were involved in the project for a total of **18.25 months**. **Five students** (4 as Masters students and one doctoral student), **2 technicians and several field workers, hired temporally**, were involved in field research for a total of **63.25 months**. This results in a **total input of 81.5 months** of work for this second year in comparison to the 69 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 coordinated with partners the field surveys and helped in the supervision of students (two Ms students of UNA in one region of Nicaragua, one Ms student from CIRAD in Costa Rica, one Ph.D student from CIRAD in two regions of Nicaragua, and one study by CICAFE in the southern part of Costa Rica).

Dr. Somarriba also updated the database on current coffee Agroforestry (AF) practices and completed a synthesis of the surveys performed during the two 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.

In 2004, a Masters student of **CATIE** has defended his thesis following 6 months in the field registering canopy cover and light interception by trees in more than 60 coffee farms of 3 regions of Costa Rica where one of the 3 following tree species were predominant (*Terminalia amazonia*, *Eucalyptus deglupta*, and *Cordia alliodora*). The aim of his study was to investigate how farmer management was affecting the growth of shade trees and ultimately the light availability of coffee trees underneath. (see Report of WP2).

CATIE has also 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 following up the collection of sap flow data and soil water content in optimal conditions for coffee cultivation during this third year.

CATIE via and one technician (Adolfo Martinez), temporally hired by CATIE, has also been strongly involved in taking several series of **digitalized photos of 4 tree species 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 **quantifying branch and fruit growth and carbon allocation** in a field trial in optimal conditions of the Orosi valley of Costa Rica. A technician (Walter Ramirez), temporally hired by CATIE, has worked for several months helping a Ph.D student from CIRAD registering branch and fruit growth and dry weight of coffee plant components following their excavation (see annexes 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 carry out environmental evaluation at catchment's scale.

CATIE has contributed to this WP through the field work by one Masters student (Victoria Osorio) and one technician (Adolfo Martinez) by collecting field samples and monitoring **decomposition and N production from leaf and root material** originating from 7 tree species in coffee systems (see WP4 report for more details).

CATIE has analyzed more than 200 water samples for nitrate and ammonium in its laboratory with the N analyzer financed by the project.

One Ms thesis was presented in 2004. Three articles have been accepted in 2004 (see annexes below).

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 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 Ms student of CATIE has defending his thesis in early 2004 on how farmers management was affecting the growth of shade trees (*Terminalia amazonia*, *Eucalyptus deglupta*, and *Cordia alliodora*) in 60 coffee farms in 3 regions of Costa Rica. A second Ms student of CATIE has investigated carbon accumulation in the long-term coffee AF trial on CATIE campus and defended his thesis in early December 2004 (see WP5 report for more details).

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 Nicaragua (see report of WP1) and providing a database of surveys undertaken in 2002-2003.

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

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

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

CATIE has contributed to this WP by hosting a technical meeting in mid-May 2003.

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 7 have been submitted and/or accepted 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 (see annexes below).

ANNEXES

Publications of CATIE

WP1

Articles

Somarriba E. (2002) ¿Cómo estimar visualmente la sombra en cacaotales y cafetales?

Agroforestería en las Américas 9(35/36): 86-94.

López, A.; Orozco, L.; Somarriba, E.; Bonilla, G. (2003). Tipologías y manejo de fincas cafetaleras en los municipios de San Ramón y Matagalpa, Nicaragua. *Agroforesteria de las Américas*. Vol 10(37-38). 74-79.

Chapter

Somarriba, E, Harvey CA, Samper M, Anthony F, Gonzalez J, Staver C, Rice RA. (2004). Biodiversity Conservation in Neotropical Coffee (*Coffea arabica*) Plantations. In “Agroforestry and Biodiversity Conservation in Tropical Landscapes”, eds Schroth G, da Fonseca GAB, Harvey CA, Gascon C, Vasconcelos HL and Izac AMN, Island Press. pp198-226.

WP2

Articles

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 (in press).

Doctoral thesis

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

WP3

Articles

Siles P. and Vaast Ph. (2002). Comportamiento fisiológico del café asociado con *Eucalyptus deglupta*, *Terminalia ivorensis* y sin sombra. Agroforestería en las Américas. 9(35/36): 44-49.

Angrand J., Vaast Ph. Beer J. Benjamin T. (2003). Comportamiento vegetativo y reproductivo de *Coffea arabica* en tres sistemas agroforestales comparado con pleno sol en Pérez Zeledón, Costa Rica. Agroforesteria en las Américas. (in press).

Masters theses

Pablo Siles. (2002). Comportamiento fisiológico del café asociado con *Eucalyptus deglupta* o *Terminalia ivorensis* y sin sombra. Tesis M.Sc., CATIE, Turrialba, Costa Rica.

Jobert Angrand. (2003). Floración, desarrollo vegetativo y fotosíntesis de *Coffea arabica* en diferentes sistemas de cultivos en Pérez Zeledón y Heredia, Costa Rica. Tesis Mag. Sc. CATIE, Turrialba, Costa Rica.

WP4**Articles**

- Payán F., Beer J., Jones D., Harmand J.M., Muschler R.** (2002). Concentraciones de carbono y nitrógeno en el suelo abajo de *Erythrina poeppigiana* en plantaciones orgánicas y convencionales de café. Agroforestería en las Américas. 9(35/36): 10-15.
- Reina Vanessa Renderos Durán, Jean-Michel Harmand, Francisco Jiménez, Donald Kass** (2002). Contaminación del agua con nitratos en microcuencas con sistemas agroforestales de coffeea arabica con *Eucalyptus deglupta*) en la Zona Sur de Costa Rica. Agroforestería en las Américas. 9(35/36): 81-85.
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**Planned Partitioning of months /WP/PARTNER/for the
THIRD YEAR**

| CATIE | WP1 | WP2 | WP3 | WP4 | WP5 | WP6 | WP7 | WP8 | WP9 | Total Yr 3 |
|-----------------|-------------|-------------|-------------|-------------|------------|------------|------------|------------|------------|-------------|
| Permanent staff | 5 | 5 | 5 | 4 | 2.5 | | 1.5 | 1 | 1 | 25 |
| 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
THIRD YEAR**

| CATIE | WP1 | WP2 | WP3 | WP4 | WP5 | WP6 | WP7 | WP8 | WP9 | Total Yr 3 |
|------------------------------|-------------|--------------|--------------|--------------|--------------|-------------|-------------|-------------|-------------|--------------|
| E. Somarriba | 2 | | | | | | 0.5 | 0.25 | | 2.75 |
| J. Beer | | | | | 0.5 | | | | | 0.5 |
| J Haggard | | | 0.5 | | | | | | | 0.5 |
| E de Mielo | | | 0.5 | | | | | | | 0.5 |
| M. Alvarado | | | | | | | | | 1 | 1 |
| L Jimenez | | | | | | | | | 1 | 1 |
| M. Cervantes | | 1.5 | 1.5 | 0.5 | 0.5 | | | | | 4 |
| K. Hergoualch | | | | 4 | 4 | | | | | 8 |
| Total Permanent Staff | 2.00 | 1.50 | 2.50 | 4.50 | 5.00 | | 0.50 | 0.25 | 2.00 | 18.25 |
| Pablo Siles | | 6.43 | | | | | | | | 6.43 |
| Adolfo Martinez | | 2 | | 2 | 2.75 | | | | | 6.75 |
| Walter Ramirez | | | 5.95 | | | | | | | 5.95 |
| Victoria Osorio | | | | 5 | 5 | | | | | 10.00 |
| John Zuluaga | | | | 5 | 5 | | | | | 10.00 |
| Victor H. Arana | | | | 2 | | | | | | 2.00 |
| Benito Dzib | 2 | | | | | | | | | 2.00 |
| Field assistants | | 5 | 5 | 5 | 5.13 | | | | | 20.13 |
| Total Hired Staff | 2.00 | 13.43 | 10.95 | 19.00 | 17.88 | | 0.50 | 0.25 | 2.00 | 63.26 |
| Total CATIE Yr 3 | 4.00 | 14.93 | 13.45 | 23.50 | 22.88 | 0.00 | 0.50 | 0.25 | 2.00 | 81.51 |

IICA-PROMECAFE

ANNUAL REPORT of ACTIVITIES for the INCO PROJECT

CASCA

3rd YEAR (NOV. 2003 – OCT. 2004)

Carlos Foncesa and Luis D. García.

NOVEMBER 2004

REPORTE DE ACTIVIDADES DEL PROYECTO CASCA

AÑO 3 (Noviembre 2003 – Octubre 2004)

IICA - PROMECAFE

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

Durante este último año de trabajo 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. Jorge Ramírez (WP 2,4 y 5), el Ing. Víctor Chaves (WP 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 en un trabajo de encuestas a productores en esta zona (ver informe anexado al final). Con respecto al personal de ANACAFE, en Guatemala, que ha trabajado para el proyecto CASCA se encuentra el Ing. Byron Medina (WP 4 y 8).

Este año se ha trabajado 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 tercer año.

El trabajo desarrollado por parte del Ing. Chaves en el paquete de trabajo WP 4, ha consistido en la continuación de la medición de biomasa en la variedad de café CR-95 y mediciones de lixiviados en el ensayo de dosis y fraccionamiento de nitrógeno.

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. A inicios de este año, se extendieron los estudios a dos sistemas agroforestales más que están a cargo del mismo Sr. Ramírez; dichos ensayos son: café con sombra de *Erythrina poeppigiana* y café a pleno sol, ambos con un manejo orgánico. El fin de implementar dos sistemas más es el de poder comparar los parámetros que se están evaluando en sistemas agroforestales diferentes manejos (convencional y orgánico).

El tiempo empleado por el personal permanente de IICA – PROMECAFE fue de 15.25 meses. El personal temporal representó 39.34 meses, en este 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 el agua a nivel de parcela (Ligth and water partitioning at plot scale).**

Con respecto a este paquete de trabajo, en la finca del CICAFE se está desarrollando 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 intersección 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 factores tales como la conductividad hidráulica, la densidad aparente y la distribución de raíces. Este modelo hidrológico se complementa con la utilización de una estación meteorológica digital que permite medir la temperatura y la precipitación entre otros parámetros; así como el empleo de pluviómetros manuales y la implementación de parcelas de escorrentía. Se utilizó un TDR para determinar la humedad del suelo hasta el mes de Julio, sin embargo no se pudo seguir con esto, ya que este equipo sufrió un desperfecto y todavía no se encuentra disponible.

Las personas que están trabajando en este paquete de trabajo son el Ing. Philippe Vaast, Ph.D. y el Ing. Pablo Siles. M.Sc. El Ing. Siles está desarrollando el modelo hídrico como parte de su trabajo de graduación para optar por el título de doctorado.

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

Actualmente se están realizando mediciones de lixiviados en los cuatro sistemas agroforestales. En el sistema de Café + *Inga* sp. y café a pleno sol (manejo convencional) se tiene instalados lisímetros a 4 profundidades. En total se cuenta con: 4 lisímetros a 30 cm en cada sistema, a 60 y 120 cm se tienen 8 lisímetros / sistema y a 200 cm de profundidad hay 3 lisímetros colocados. En los sistemas de manejo orgánico se instalaron 6 lisímetros a 60 y 120 cm / sistema.

Por otra parte, se están midiendo lixiviados en un ensayo de tres diferentes dosis de N más un testigo absoluto. Dicho ensayo está a cargo del Ing. Víctor Chaves y se están evaluando dos profundidades: 60 y 120 cm. Por cada tratamiento se tiene 4 repeticiones.

En Mayo del 2004 se aplicó el isótopo marcado ^{15}N ; el objetivo de esta prueba es determinar que se hace el nitrógeno aplicado en la fertilización. Se determinará la distribución del ^{15}N dentro de las plantas de café y los árboles de *Inga*, si el N se pierde en forma gaseosa o se pierde por infiltración a capas inferiores en el perfil del suelos.

La estudiante Kristell H'erguoch está cuantificando con la ayuda de la Sra. Ute Skiba (CEH, UK) la pérdida de N como N_2O en los sistemas de Café + *Inga* sp. y café a pleno sol con un manejo convencional. Este trabajo es parte de la tesis de doctorado que está iniciando la Ing. Kristell.

Durante este tercer año del proyecto CASCA, se realizó un estudio de biomasa. Se tomaron 8 plantas de café de los sistemas de *Inga* y pleno sol, así como 10 ramas de 10 árboles de *Inga densiflora* y *Erythrina poeppigiana*. Se cuantificó la cantidad de materia vegetal de cada especie bajo estudio por medio de análisis destructivos de biomasa.

Los ingenieros que se encuentran trabajando en este paquete de trabajo son el Ing. Jean-Michel Harmand; Ph.D., Ing. Patrice Cannavo, Ph.D., y el Ing. Luis Dionisio García.

- **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. En los sistemas de Café + *Inga* sp. y café a pleno sol (manejo convencional) se continua con mediciones semanales de la caída de hojarasca, con los datos que se están colectando se espera determinar su calidad y la cantidad de materia orgánica que se incorpora al suelo.

Como complemento de este estudio, en un experimento de biomasa del Ing. Chaves, se está evaluando la cantidad de biomasa en la variedad CR-95 en un ensayo ubicado en Poás de Alajuela y otro en la finca del CICAFE. Para poder cumplir con estos objetivos, desde el año 2003, se colocaron trampas para la recolección de hojarasca y se realizan mediciones de biomasa por medio de muestreos destructivos de plantas de café cada 3 meses.

Las personas involucradas en los estudios de este paquete de trabajo son: el Ing. Jean-Michel Harmand; Ph.D., Ing. Patrice Cannavo, Ph.D., y el Ing. Luis Dionisio García y el Ing. Víctor Chaves.

Actividades a realizar durante el cuarto año del proyecto.

Al ser el cuarto año el último de trabajo del proyecto CASCA, se espera terminar con la recolección de datos de campo para de esta manera continuar con el trabajo de elaboración de informes científicos por cada paquete de trabajo.

Depende de cada uno de los investigadores que tienen a cargo los paquetes de trabajo definir si se va desarrollar o complementar alguna otra medición en particular. Por el momento se tiene planeado que el Sr. Siles continúe con las mediciones de flujo de savia durante la estación seca del año 2005 en la finca del CICAFE para complementar los datos de su tesis de doctorado. De igual manera la Sra. Kristell continuará con las mediciones de N₂O en los diferentes sistemas que ella está evaluando.

INFORME TRABAJO CASCA PÉREZ ZELEDÓN 2004

Ing. Mainor Rojas B., M. Sc.

ICAFE, Pérez Zeledón

Entre los meses de diciembre del 2003 y junio del 2004, ICAFE PZ coordinó el estudio de 40 fincas cafetaleras en 24 comunidades de 8 distritos del cantón de Pérez Zeledón, Costa Rica. Esta información es parte del paquete de trabajo WP1.

Para este trabajo fue necesaria la adquisición de un GPS, un clinómetro y un densímetro esférico óptico, materiales comprados con fondos del Proyecto CASCA. De la misma manera, el tiempo del técnico que estuvo a cargo de la aplicación del instrumento fue costeado con fondos del Proyecto.

Se colectaron datos socioeconómicos y biofísicos de las fincas por medio de entrevistas al productor y medición de variables en parcelas temporales de (área cubierta por 10 por al menos árboles maderables). Se tomaron lecturas de pendiente, pedregosidad, porcentaje de sombra bajo los árboles, DAP, condición del cafetal, tipo de poda, ubicación geográfica, entre otras. Las fincas estudiadas debían cumplir con la condición de tener un cafetal con sombra de maderables.

Los análisis de los datos estuvieron a cargo de los estudiantes del Dr. Eduardo Somarriba en CATIE. Se seleccionaron 15 variables cuantitativas (biofísicas y socioeconómicas) para aplicar un análisis de conglomerados utilizando la distancia Euclíadiana entre fincas, y luego se sometieron a un análisis discriminante canónico para identificar las variables que difieren a los tipos de fincas. Se calcularon estadísticas descriptivas de las variables numéricas colectadas.

Con el estudio de tipologías se identificaron tres grupos de fincas cafetaleras, separados por la altitud, número de trabajadores permanentes en la finca, área sembrada de café, producción total de la finca, número de usos del suelo y número de fincas que posee el productor.

bles). Se tomaron lecturas de pendiente, pedregosidad, porcentaje de sombra bajo los árboles, DAP, condición del cafetal, tipo de poda, ubicación geográfica, entre otras. Las fincas estudiadas debían cumplir con la condición de tener un cafetal con sombra de maderables.

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

| IICA-PROMECAFE | WP1 | WP2 | WP3 | WP4 | WP5 | WP6 | WP7 | WP8 | WP9 | Total Yr 3 |
|-----------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|-------------|
| 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 THIRD YEAR

| IICA-PROMECAFE | WP1 | WP2 | WP3 | WP4 | WP5 | WP6 | WP7 | WP8 | WP9 | Total Yr 3 |
|------------------------------|-------------|--------------|--------------|--------------|--------------|-------------|-------------|-------------|-------------|--------------|
| C. Fonseca | 1 | | | | | | | | 0.75 | 1.75 |
| V. Chaves | | | 2 | 2 | | | | | | 4 |
| M. Rojas | 2 | | 1 | | | | | | | 3 |
| J. Ramirez | | 0.25 | | 0.25 | 0.25 | | | | | 0.75 |
| M. Barquero | | 0.5 | | 0.5 | 0.5 | | | | | 1.5 |
| B. Medina | | | | 1 | | | 1 | 2 | | 4 |
| G. Canet | | | | | | | | | 0.25 | 0.25 |
| Total Permanent staff | 3.00 | 0.75 | 1.00 | 2.75 | 3.75 | 0.00 | 1.00 | 2.00 | 1.00 | 15.25 |
| L.D. Garcia | | 2.5 | 2.5 | 2.5 | 3.05 | | | | | 10.55 |
| Field workers | | 7 | 7 | 7 | 7.79 | | | | | 28.79 |
| Hired staff | 9.50 | 9.50 | 9.50 | 10.84 | | | | | | 39.34 |
| Total Promecafe Yr 3 | 3.00 | 10.25 | 10.50 | 12.25 | 14.59 | 0.00 | 1.00 | 2.00 | 1.00 | 54.59 |

**UNIVERSIDAD NACIONAL AGRARIA
UNA**

ANNUAL REPORT of ACTIVITIES for the INCO PROJECT

**CASCA
3rd YEAR (NOV. 2003 – OCT. 2004)**

**Glenda Bonilla
NOVEMBER 2004**

UNIVERSIDAD NACIONAL AGRARIA



INFORME TÉCNICO ANUAL DEL PROYECTO UNA/CASCA EN NICARAGUA AÑO 3 (Noviembre, 2003 – Octubre, 2004)

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

I. INTRODUCCIÓN

El Proyecto CASCA, con financiamiento de la Unión Europea, actualmente está concluyendo el tercer año de ejecución. El presente informe tiene como objetivo presentar las actividades que la Universidad Nacional Agraria ha realizado, como socio del Proyecto, durante el período Noviembre 2003 - Octubre 2004.

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 Munguía y el Dr. Víctor Aguilar.

Los estudiantes y egresados de la UNA que participaron durante este mismo período son: Diana Díaz, Justo Castro, Manuel Calero, Dayling Balladares, Enrique López, Carlos Parrales, Yader Calderón Cerros, Wilfredo Fuente Masis, Oswaldo González Rodríguez, Aura Astelia Lazo, Arlen López, Luis Orozco, Rodolfo Castillo y Pedro Ortiz.

III. ACTIVIDADES REALIZADAS.

Para una mejor distribución del trabajo de investigación, éstas se han dividido en dos grandes paquetes: Aspectos biofísicos y Aspectos Socioeconómicos.

Durante el período del tercer año de actividades del proyecto, el tiempo empleado por el personal permanente de la UNA fue de 14.95 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 13.24 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: Distribución de la Luz y Agua a nivel de campo (WP2), Ecofisiología y Calidad del café (WP3), Reciclaje del Nitrógeno, lixiviación, absorción y emisiones (WP4), Secuestro de Carbono (WP5) y Modelos integrados a nivel de campo (WP6).

En el marco de los aspectos biofísicos del Proyecto 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 Septiembre del 2004 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, esto lo 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, fracos 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 rastretero 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.

Para mantener bajos porcentajes de incidencia 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 fue distribuida en los meses de junio, agosto y octubre del 2002 y 2003. La dosis aplicada fue de 323 kg de la fórmula 12-30-10 y algunos casos de 15-15-15 en junio y agosto y de 257 kg de urea al 46 % de nitrógeno en octubre.

La fertilización realizada en el 2004 fue en Junio de: 1 quintal de urea (46%), 1 quintal de 34.8 – 18.4 (N – P) y 1 quintal de Muriato de K (46%) con una dosis de 5 qq de la mezcla por manzana

En Agosto 2004, 3 quintales de 34.8 – 18.4 (N – P) y 1 quintal de muriato de K (46%) co una dosis de 5 qq de la mezcla por manzana

En Octubre 2004 se aplicó 4 quintales de Urea por manzana.

Total: 450 libras N/mz + 100 libras P/mz + 135 libras K/mz

Total: 291 kg N/ha + 65 kg P/ha + 87 kg K/ha

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 y septiembre del 2004, quedando pendiente la toma de datos de diciembre del 2004.

Evaluaciones realizadas

a.- Crecimiento: Las variables de crecimiento evaluadas en Agosto y Diciembre del 2002, Junio, Septiembre y diciembre del 2003 y junio y septiembre del 2004 se describen a continuación:

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

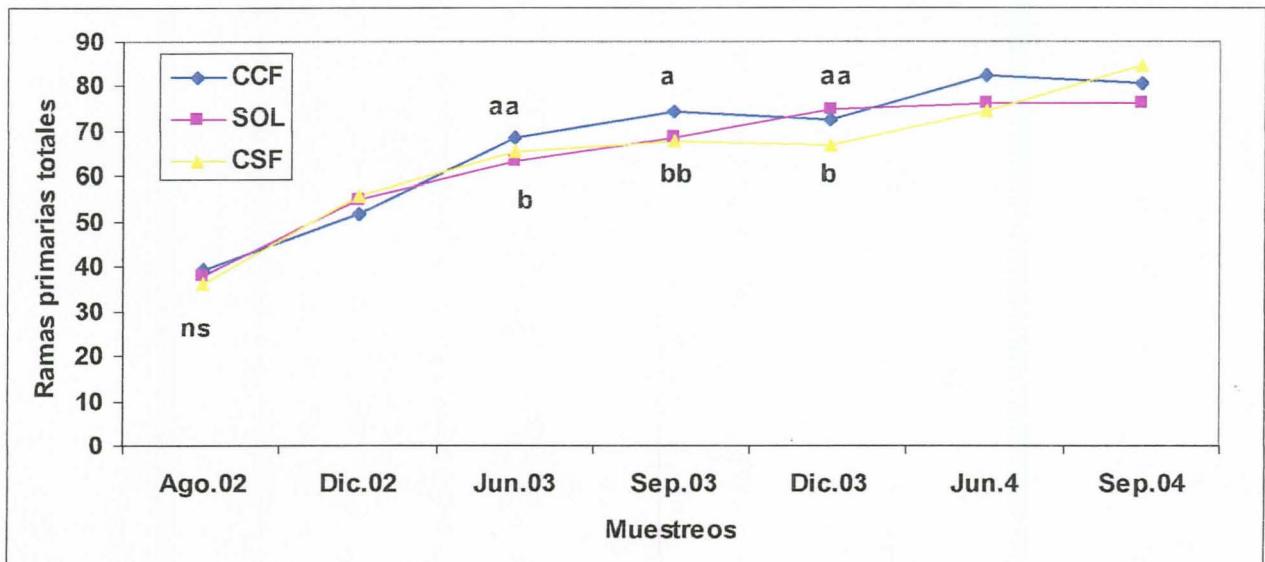


Figura 1. Comportamiento de la altura (cm) de las plantas de café de agosto 2002 a septiembre 2004 como un ejemplo de las variables de crecimiento.

b. Estructura productiva: Las variables de estructura productiva evaluadas en Agosto y Diciembre del 2002, Junio, Septiembre y diciembre del 2003 y junio y septiembre del 2004 se describen a continuación:

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

Se tiene la base de datos completa y falta decidir que tipo de análisis realizar para una mejor interpretación de los resultados.

En agosto y diciembre del 2002, se midió el ancho y largo de una hoja de cada nudo de las ramas primarias, secundarias y terciarias. No se continuaron estas mediciones debido al tiempo que se invertía el cual no permitía que todas las plantas de las tres parcelas se realizaran en el más corto tiempo posible y poder hacer comparaciones estadísticas. A partir de junio del 2003, las variables de número de nudos, número de hojas y número de frutos en

tejido viejo y tejido nuevo se realizaron tomando las 8 ramas primarias con sus ramas secundarias y terciarias como una sola.

c.- Para determinar el **aumento de biomasa, absorción y acumulación de nitrógeno** en los diferentes componentes de la planta de café se utilizó el método destructivo. Las variables tomadas para el incremento de biomasa y acumulación de nitrógeno en las 8 plantas por parcela fueron las siguientes:

1. Peso fresco y peso seco del sistema radicular
2. Peso fresco y peso seco del sistema radicular
3. Peso fresco y peso seco del tallo
4. Peso fresco y peso seco de las ramas
5. Peso fresco y peso seco de las hojas
6. Peso fresco y peso seco 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.

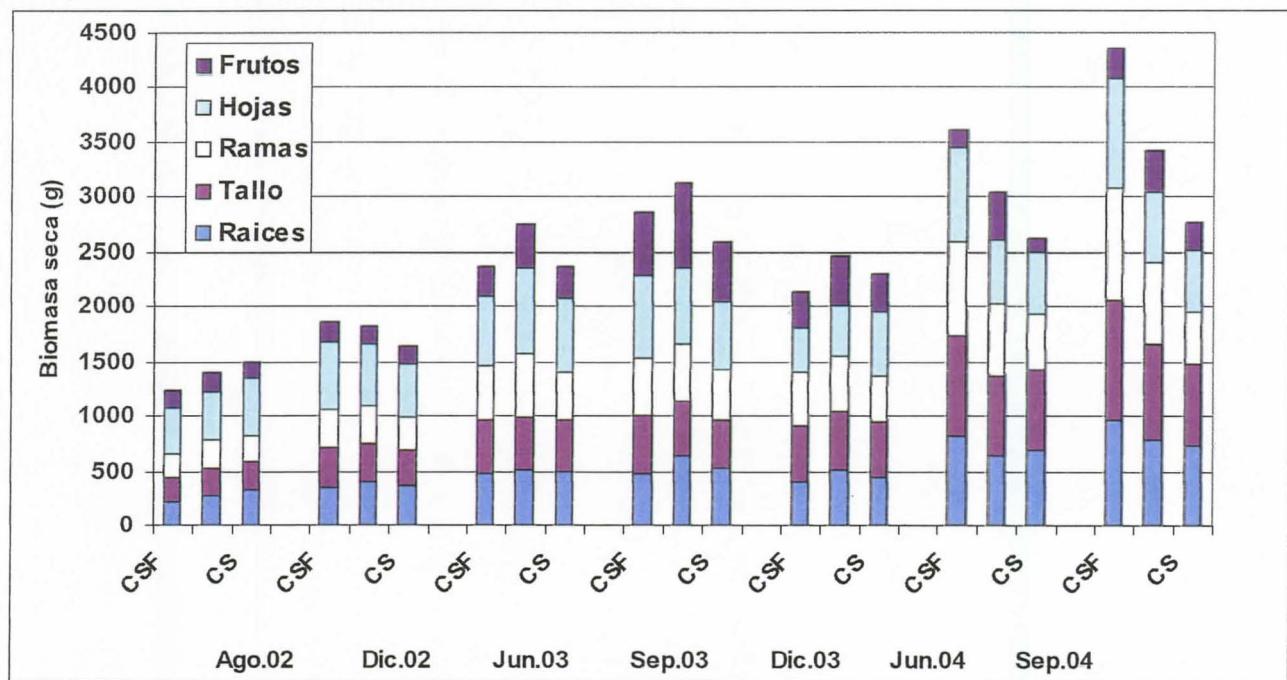


Figura 2. Acumulación de biomasa seca en gramos por árbol en los diferentes componentes de la planta de café desde agosto 2002 a septiembre del 2004.

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. Al laboratorio de la UNA fueron enviadas para análisis de nitrógeno, muestras tomadas en agosto y diciembre del 2002, Junio, septiembre y diciembre del 2003. El total de muestras fueron 3 por parcela por

componente (raíz, tallo, ramas, hojas y frutos) igual a 15 muestras. Como son tres parcelas establecidas da un total de 45 muestras por medición. Tomando en cuenta que se muestreó en agosto y diciembre del 2002, junio, septiembre y diciembre del 2003 dio un total de 225 muestras analizadas.

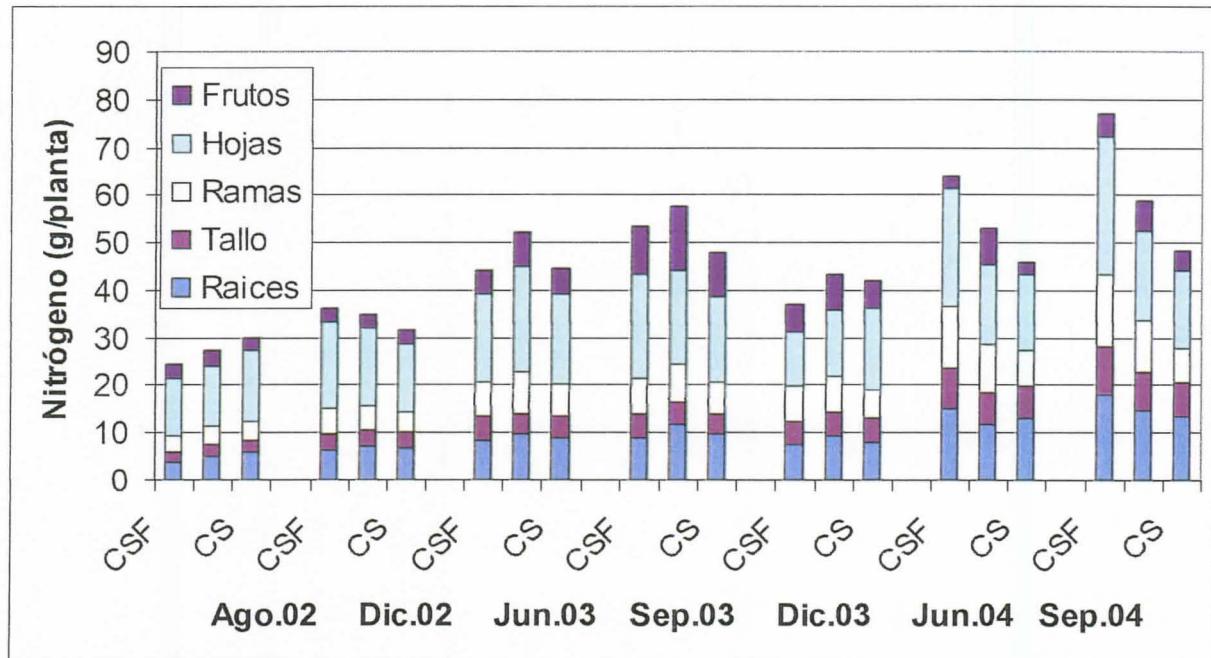


Figura 3. Acumulación de nitrógeno en gramos por árbol en los diferentes componentes de la planta de café desde agosto 2002 a septiembre del 2004.

d.- **La cosecha de café uva** de las plantas de café del ciclo 2002/2003 fue realizada en 5 momentos y se cosecharon todas las plantas que estaban en toda la parcela de 24 surcos por 40 metros de largo (1920 metros cuadrados). La cosecha del ciclo 2003/2004 fue realizada en 7 momentos desde octubre del 2003 a enero del 2004. De la cosecha del 2002/2003 de la cosecha 3, 4 y 5 se tomaron una muestra por tratamiento y el café oro fue enviado al laboratorio de UNICAFE (CERCACAFENIC) para análisis físico y organoléptico. De igual manera de la cosecha 2003/2004 se tomó una muestra por tratamiento de las 7 cosechas y fueron enviadas al laboratorio en junio del 2004.

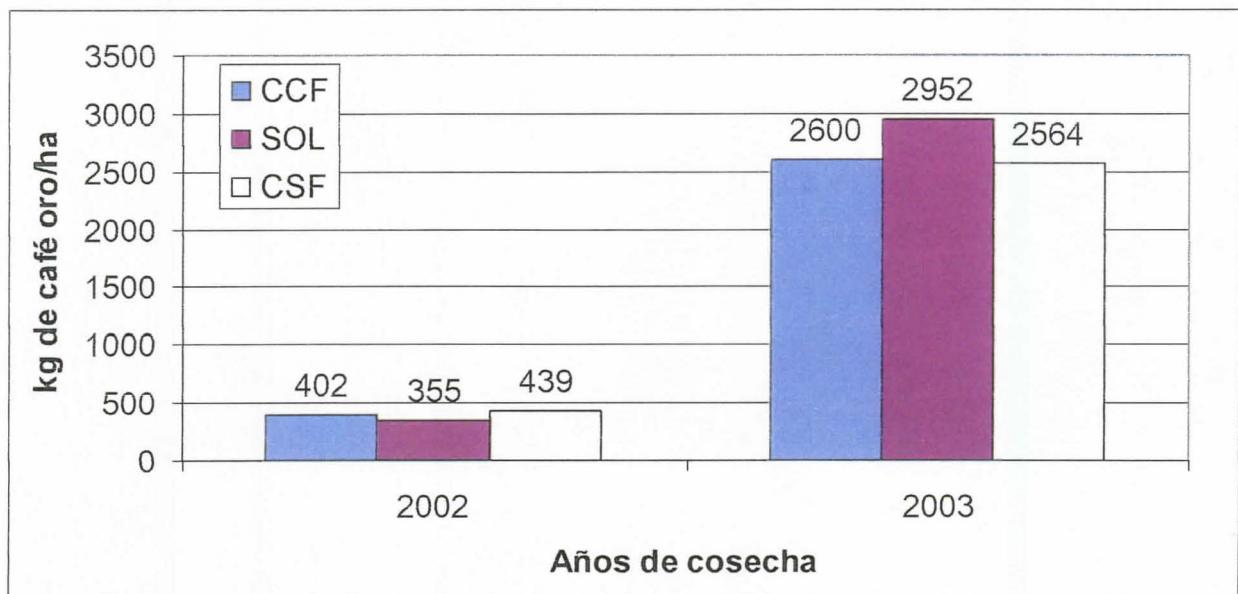


Figura 4. Rendimiento de café oro en kg/ha en café con sombra y fertilizante, café a pleno sol y café con sombra sin fertilizante durante los ciclos 2002/2003 y 2003/2004.

e. **Biomasa fresca y seca de follaje y ramas de *G. sepium*:** En agosto del 2002 y 2003 y septiembre del 2004, 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% y 1.04% respectivamente. La cantidad de biomasa aportada por las hojas de refleja en la figura 5.

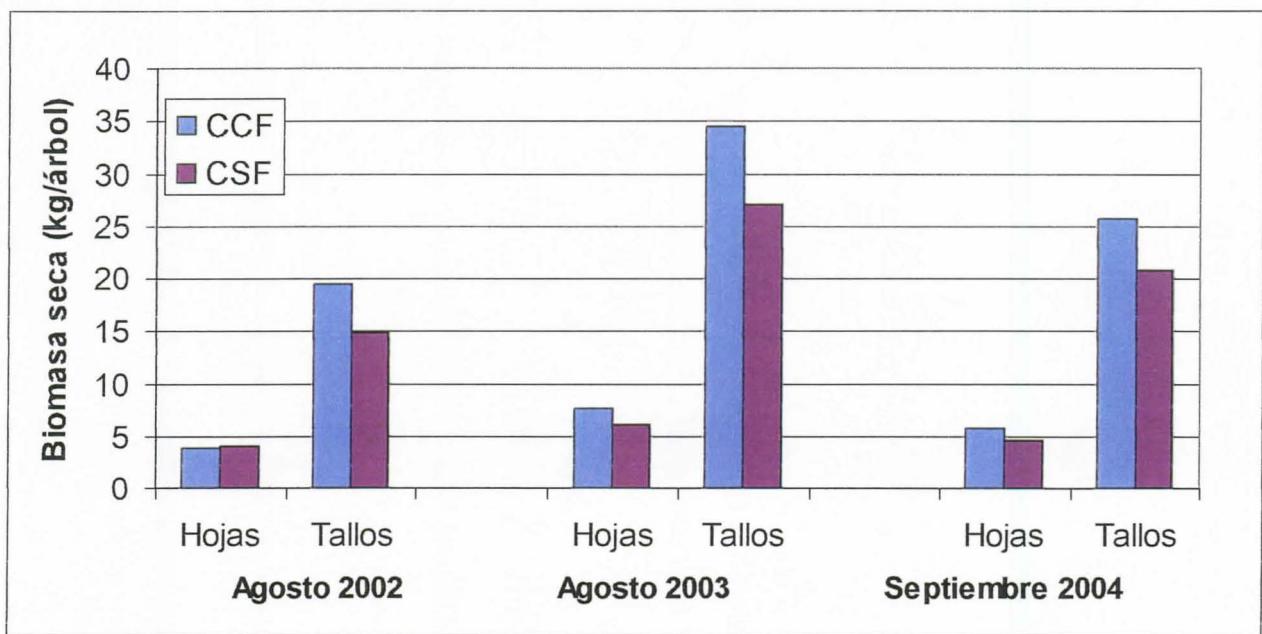


Figura 5. Aporte de biomasa seca en kg por árbol de madero negro desde agosto 2003 a septiembre del 2004.

El aporte de nitrógeno al suelo por la poda de las ramas de madero negro se puede ver en la figura 6.

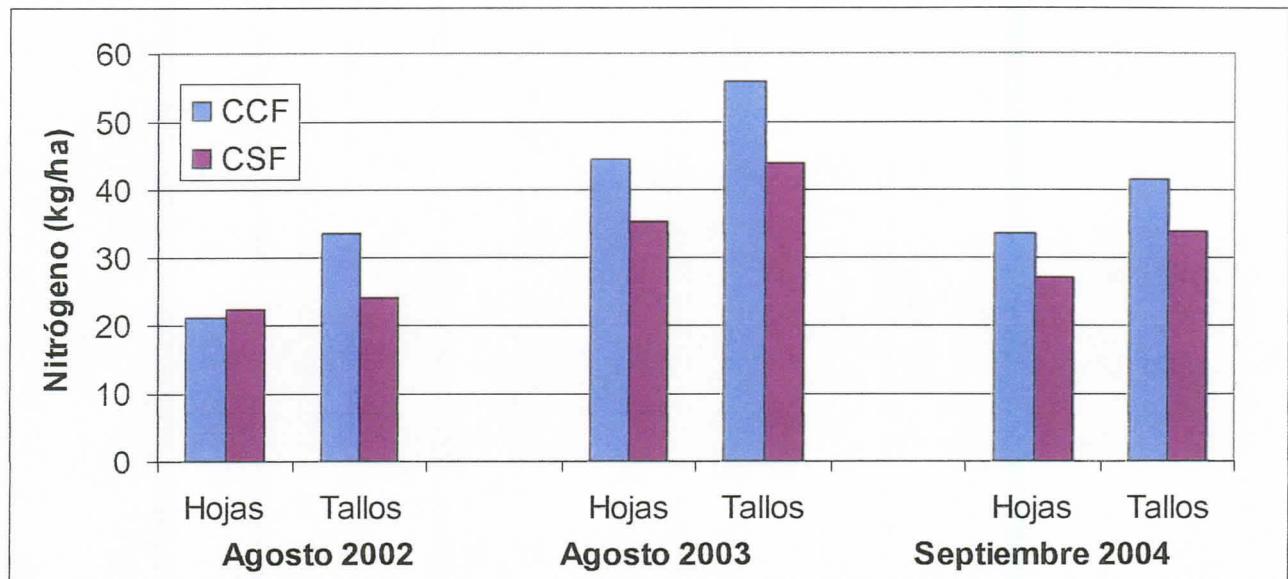


Figura 6. Aporte de nitrógeno en kg/ha por las hojas y ramas producto de la poda de madero negro en los tres años de estudio.

f. 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 de raíces cada 10 cm hasta una profundidad de 70 cm.

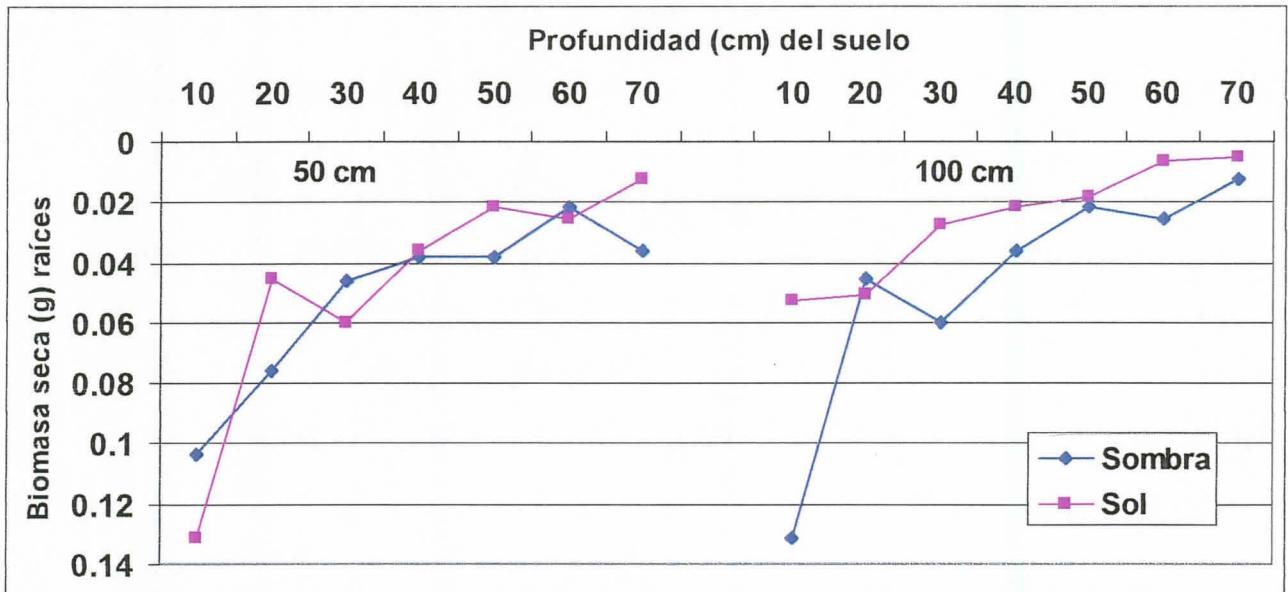


Figura 7. Distribución de la biomasa (g) raíces finas a 50 y a 100 cm del tallo de la planta de café y de 0 a 70 cm de profundidad.

g. 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.

El rendimiento durante el ciclo 2003/2004 fue mayor en café a pleno sol con 2950 kg oro por ha, seguido de café con sombra y fertilización con 2600 kg y con sombra sin fertilización con 2564 kg oro por ha.

No se encontró diferencia en aspectos físicos y organolépticos en el 2002/2003 en los tratamientos. Análisis se hicieron en el 2004 y pudo afectar la calidad. A menor tamaño de grano se encontró mayor porcentaje de defectos.

El tamaño de grano de la cosecha 2002 fue menor (71% 16-20) que la cosecha 2003 (82% 16-20).

La calidad del grano fue mayor en la cosecha 6 y 7 del 2003/2004.

La mayor biomasa seca de raíces finas se encontró de 0 a 20 cm de profundidad en café bajo sombra y a plena exposición solar.

Con la poda de los árboles, las hojas retornaron un promedio de 31 kg/ha por año y los tallos un promedio de 39 kg/ha por año, tomando una población de 156 árboles por hectárea.

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

En los estudios sobre monitoreo de la producción de hojarasca, así como en el de descomposición y liberación de nutrientes de la hojarasca participaron el Ing. M.Sc. Rodolfo Munguía H. y los estudiantes Br. Danilo Pérez Flores y Br. Otoniel Soza, ambos de la carrera

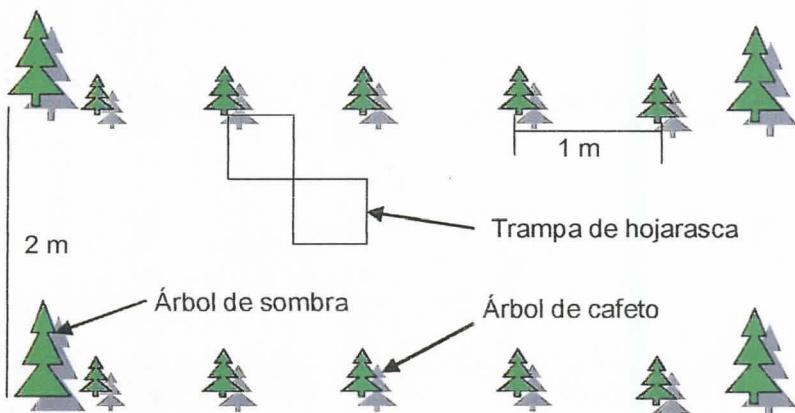
de Ingeniería Forestal de la Facultad de Recursos Naturales y del Ambiente (FARENA / UNA). Ambos estudios se presentan a continuación.

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: Cuantificar la caída anual de la hojarasca y su contenido de nutrientes y determinar el modelo de caída de la hojarasca y la contribución relativa de cada componente al mantillo.

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 (Ver figura 1).



Tratamientos

T1= Parcela de *C. arábica* con sombra de *G. sepium* con fertilización.

T2= Parcela de *C. arábica* a plena exposición al sol

Parcela de *C. arábica* con sombra de *G. sepium* sin 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.

Resultados preliminares.

En la figura 2, se podrá observar que la caída de hojas de café ha sido superior que con respecto a la contribución que hace *G. sepium* (madero negro). En las parcelas donde esta presente la sombra de *G. sepium* se podrá observar que el relativamente menor y bastante similar en cantidad a la variable componente flores y frutos; hay que anotar que la cantidad de frutos ha sido mayor debido a las afectaciones dadas por el ataque de la broca del café.

La figura 3 muestra la tendencia porcentual que contribuye cada uno de los componentes obtenidos de los residuos vegetales por efecto de la senescencia de ellos. Se podrá observar que la hojarasca de *C. arabica* contribuye con un 58.13 % para el caso de la parcela con sombra de *G. sepium* mas fertilización química; mientras que en la parcela con sombra de la misma especie y sin fertilización química aporta en un 64.03 %. La contribución de hojarasca de la especie *G. sepium* es de 14.99 y 17.43 % del total de la biomasa medida para las parcelas con y sin fertilización química respectivamente. La contribución de los otros componentes medidos muestra ser muy baja comparativamente. Sin embargo, el componente flores y frutos medidos de las especies *C. arabica* y *G. sepium* representa un porciento de 19.5 y 11.43 % respectivamente.

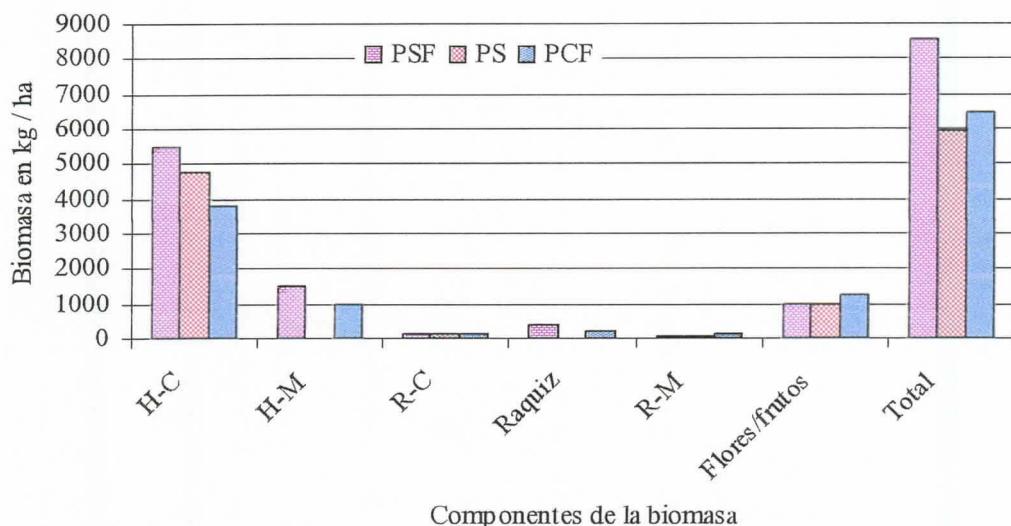


Figura 2.- Comportamiento de la biomasa en diferentes componentes y el total en kg ha⁻¹

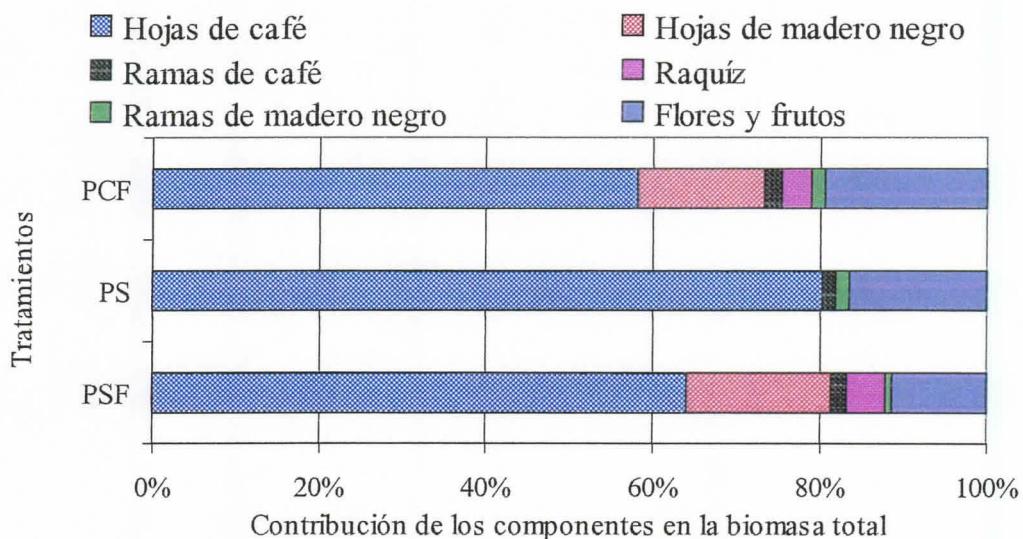


Figura 3. Tendencia porcentual de los componentes sobre la biomasa total.

Cuando observamos la dinámica de la caída de la hojarasca durante los meses de Enero a Octubre del año 2004, se observa la tendencia de una mayor caída de hojarasca en los meses

de Febrero, Marzo y Abril para todas las parcelas debido a que en la época seca se manifiesta una mayor caída de hojarasca de café producto de la senescencia de las mismas. Posterior a estos meses hay una disminución importante, debido al estado de recuperación de la vegetación tanto de *G. sepium* como de *C. arabica* por el establecimiento de la época seca en la zona de estudio. Así como también por la respuesta fisiológica de los cafetos y de los árboles de sombra (Figura 3).

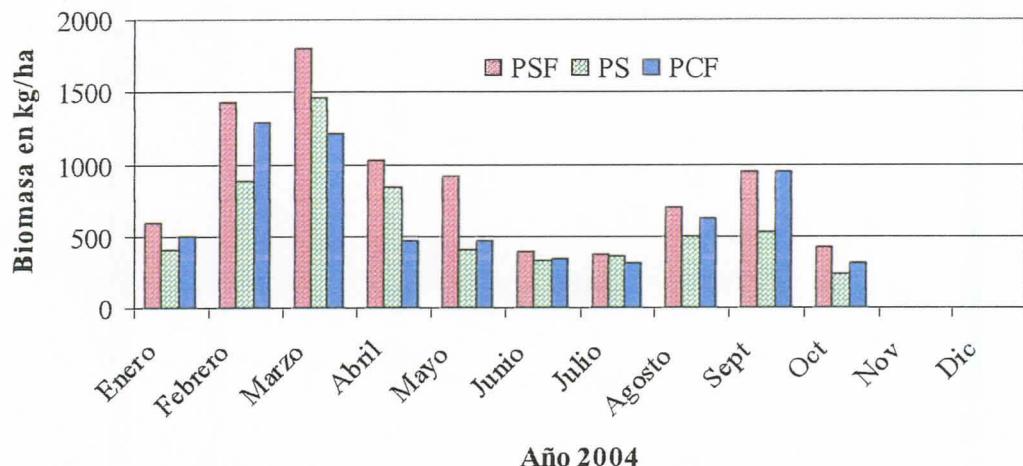


Figura 4. Biomasa seca colectada en los diferentes meses del año.

B. Estudio: Descomposición y liberación de nutrientes N, P y K de la hojarasca.

Este trabajo se inició el 3 de septiembre del año 2004, debido principalmente a la disponibilidad de materiales como una cantidad suficiente de hojarasca de las diferentes especies vegetales en estudio. Así también, se puede señalar por la irregularidad pronunciada de las precipitaciones este año que han sido poca y concentrada en pocos días (Cuadro 1). La lectura de los datos ambientales en la estación meteorológica fue a partir del día 26 de Marzo del año 2004.

Cuadro 1.- 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 |
| Mayo | 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 | 28.1 | 20.4 | 23.1 | 310.4 | 0.3 |

Fuente: Estación meteorológica instalada por proyecto UNA / CASCA en el área experimental

**: Datos incompletos debido a mal funcionamiento de la estación durante este mes por 12 días en esta variable.

METODOLOGÍA

Tratamiento de descomposición.

T1= 50 % hojas de *café* mas 50 % de *C. arabica* de parcela con fertilización

T2= 100 % hojas de *café*

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

Obtención del material (hojarasca)

Se recolectaron hojas en proceso de senescencia separadas de *C. arabica* y *G. sepium* en las parcelas respectivas hasta completar la cantidad de material necesario para el estudio. El método a utilizar es el conocido “Litterbags” de malla de nylon con 1 - 2 mm de diámetro de perforación, la 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 pondrá un peso de 30 g.

Se establecerán 4 bolsas para recolectarse el remanente de la hojarasca a los 0, 6, 12, 24, 48, 96 y 150 días por tratamiento para obtener un total de 84 bolsas, las que serán puestas bajo la copa de los árboles de café y dispuestas aleatoriamente. Previo a la colocación de las bolsas en el suelo, se limpia el área para que la superficie de la malla quede en contacto con el suelo. Recolectadas las bolsas se pondrán en bolsas de tela de algodón (25 x 25 cm) para evitar pérdida del material en el trayecto del campo al laboratorio. Se procederá posteriormente a limpiar el material de hojarasca de suelo agregado producido por termitas, lombriz de tierra, piedras, etc; así como su separación por componente y especie. Se pondrá a secar a 65°C en horno hasta peso constante para obtener materia seca de cada muestra.

A las muestras compuestas se les determinará el contenido o la concentración N, P y K.

A los datos del remanente de la hojarasca se les aplicará una prueba estadística de varianza y el modelo exponencial simple propuesto por Olson (1963), el cual asume que la tasa constante de descomposición (k) es constante en el tiempo.

Resultados preliminares

Los resultados que se pueden mostrar representan 48 días de seguimiento o muestreos de las bolsas de descomposición a través del pesado del peso remanente de la hojarasca. Tal como se podrá observar las parcelas donde se pusieron el 50 % de los componentes de hojas de café y de madero negro en peso en las bolsas de descomposición muestran una mayor pérdidas de peso con relación a la parcela a plena exposición solar con un 100 % del peso (30 g) de hojarasca de café, indicando una menor pérdida por efecto del proceso de descomposición. Para este estudio, hacen falta dos muestreos de las bolsas de descomposición para 96 y 150 días, así como las determinaciones de N, P y K a nivel de laboratorio para determinar el remanente de los nutrientes que no se han liberado.

Los resultados según la figura 5, fueron sometidos a regresiones no lineales simples exponenciales, dobles exponenciales y asimptóticas. La descomposición de la biomasa se ajustaron mejor al modelo doble exponencial.

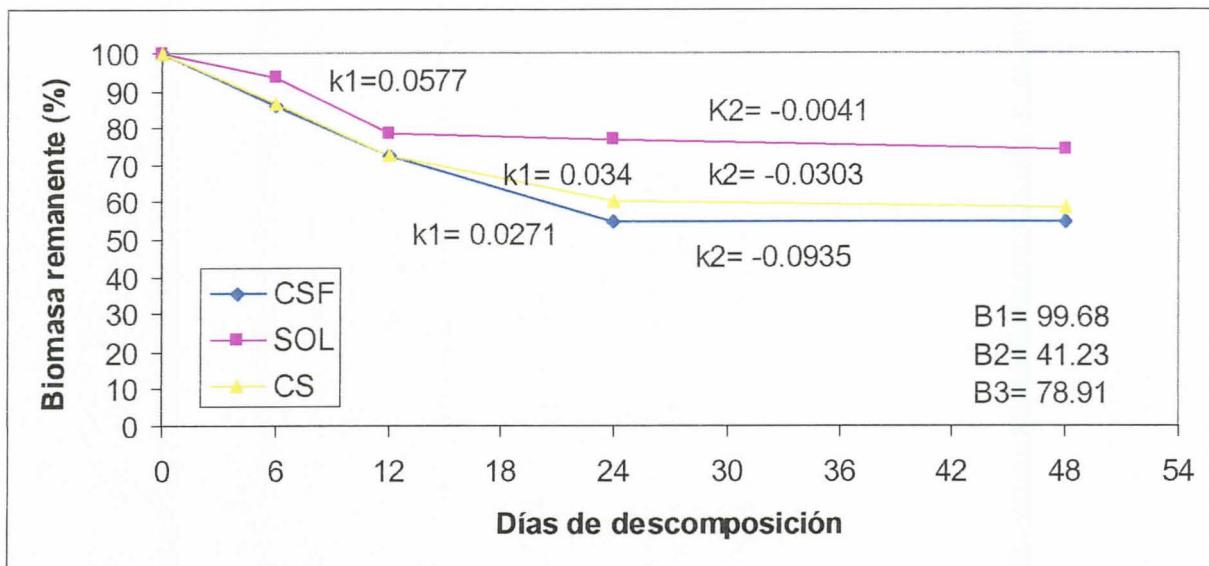


Figura 5. Tasas de descomposición de la hojarasca de café y madero negro según el modelo de regresión no lineal doble exponencial.

3.1.1.3. Estudios sobre Lixiviación de nitratos en el perfil del suelo; Dinámica de Nitrógeno.

El equipo de la UNA que participa en los estudios sobre lixiviación de nitratos en el perfil del suelo, así como en la dinámica de Nitrógeno, son los docentes: Ing. M.Sc. Martha Gutiérrez e Ing. M.Sc. Leonardo García y los estudiantes Yader Adolfo Calderón Cerros, Wilfredo de Jesús Fuente Masis, Oswaldo José González Rodríguez y Aura Astelia Lazo. Los avances de ambos estudios se presentan a continuación.

A. Estudio: Lixiviación de nitratos en el perfil del suelo

Se realizó en la estación seca del año 2003, un muestreo de suelo en el ensayo de Carazo y tres durante la estación seca del presente año 2004, el muestreo de suelo y durante la estación lluviosa cinco muestreos; el primero un día antes de la segunda fertilización: junio y luego cada quince días durante tres meses. Las que se han ejecutado como indica el Cuadro 1.

Cuadro 1. Muestreos realizados en el estudio sobre Lixiviación de nitratos en el perfil del suelo, en San Marcos, Carazo.

| Fecha | Muestreo | Total de muestras |
|-----------------------|---------------------------|-------------------|
| 1 de diciembre 2003 | Primero | 90 |
| 20 de febrero 2004 | Segundo | 90 |
| 7 de mayo 2004 | Tercero | 90 |
| 11 de junio 2004 | Antes de la fertilización | 90 |
| 10 de septiembre 2004 | Primero | 90 |
| 24 de septiembre 2004 | Segundo | 90 |
| 8 de octubre 2004 | Tercero | 90 |
| 22 de octubre 2004 | Cuarto | 90 |
| | 5 | *720 |

En el área de muestreo se tomaron aleatoriamente cinco puntos de muestreos en cada tratamiento del ensayo en la época de verano y en el invierno los puntos fueron seleccionados

al azar y marcados en el campo para el resto de las evaluaciones. En las parcelas con sombra, el muestreo se realizó a 2m del árbol y en el tratamiento sin sombra se ubicaron cinco puntos al azar y fueron tomados aleatoriamente dentro del tratamiento tal y como se describe en el Cuadro 2.

En el laboratorio, la extracción de nitrato (NO_3^-) se realizó con cloruro de potasio (KCl) de 1 M en una relación de 1:10 suelo: solución. Simultáneamente se determinó humedad en 25 gramos suelo, colocándose en el horno a 110°C por 24 horas. Posteriormente, a las mismas muestras de suelo, se le determinó pH en agua y KCl en una relación de 1:2.5 suelo.

Cuadro 2. Descripción de los tratamientos en el estudio sobre Lixiviación de nitratos en el perfil del suelo, en San Marcos, Carazo.

| Tratamientos | Punto de muestreo | Profundidad (cm) | Repeticiones | Total de muestras / trat |
|---|-------------------|--|--------------|--------------------------|
| Sombra de <i>G. sepium</i> con aplicación de fertilizante | Hilera | 0-20; 20-40; 40-60; 60-80; 80-100; 100-120 | 5 | 30 |
| Sombra de <i>G. sepium</i> sin aplicación de fertilizante | Hilera | 0-20; 20-40; 40-60; 60-80; 80-100; 100-120 | 5 | 30 |
| Café a pleno sol con aplicación de fertilizante | hilera | 0-20; 20-40; 40-60; 60-80; 80-100; 100-120 | 5 | 30 |
| TOTAL | | | | 90 |

B. Estudio: Disponibilidad de nitrógeno en el suelo

Para estimar la dinámica de mineralización y nitrificación del nitrógeno que ocurre en diferentes sistemas de manejo de café con o sin sombra a través de la concentración de nitratos en la solución del suelo, se realizó toma de muestras durante la estación lluviosa. Para esto se trasladaron porciones de suelo procedentes del lote de la finca San Francisco en donde están ubicados los tratamientos.

Metodología de muestreo

Para la obtención de muestras de suelo para la incubación aeróbica en el laboratorio, fueron extraídas doce muestras compuestas en el campo durante la estación lluviosa y un día antes de la segunda fertilización (junio 2004) tal y como estaba indicado en el protocolo inicial.

En las parcelas con sombra el muestreo se realizó a 2 m del árbol y en el tratamiento sin sombra se ubicaron 8 puntos al azar y fueron tomados aleatoriamente dentro del tratamiento en la hilera y entre la hilera del café a profundidades 0-10 y 10-20 desde la superficie del suelo en cada punto de muestreo. Las porciones de suelo aproximadas son de 12 kg de suelo por muestras compuesta, de los cuales fueron separados restos vegetales, piedras y luego trasladados el mismo día al laboratorio de la UNA.

Para la incubación aeróbica en el laboratorio cada muestra compuesta fue replicada cuatro veces con proporciones de 3 Kg de suelo, las que fueron colocados en contenedores plásticos después de haberse pasado por un tamiz (4mm) en una distribución como se indica en el cuadro 3.

Cuadro 3. Descripción de tratamientos en el estudio sobre dinámica de nitrógeno en San Marcos, Carazo.

| Tratamientos | Puntos de muestreo | Profundidad (cm) | Repeticiones | Total de muestras / trat. |
|---|--------------------|------------------|--------------|---------------------------|
| Sombra de <i>G. sepium</i> con aplicación de fertilizante | Hilera | 0-10; 10-20 | 4 | 16 |
| | Entre la hilera | 0-10; 10-20 | 4 | |
| Sombra de <i>G. sepium</i> sin aplicación de fertilizante | Hilera | 0-10; 10-20 | 4 | 16 |
| | Entre la hilera | 0-10; 10-20 | 4 | |
| Café a pleno sol con aplicación de fertilizante | Hilera | 0-10; 10-20 | 4 | 16 |
| | Entre la hilera | 0-10; 10-20 | 4 | |
| TOTAL | | | | **48 |

La incubación se efectuó a una temperatura ambiente (30°C) en las instalaciones del laboratorio. El peso de los contenedores plásticos se revisaron en cada semana para mantener la humedad de campo inicial debido a las pérdidas de agua presentadas.

Para el análisis de N mineral (Nmin: nitratos y amonio) se procedió a la extracción por cada tiempo indicado: al inicio, siete, quince y 30 días después de la incubación (T0; T7; T15 y T30) de cada réplica (10 g de la muestra de suelo de cada bandeja).

En el laboratorio se realizó la extracción con cloruro de potasio (KCl) de 1 M en una relación de 1:10 suelo: solución. Para determinar el N-mineral (NH_4^+ y NO_3^-) del extracto filtrado.

* Para estas cantidades de extractos filtrados de muestras de suelo (48 muestras x 4 tiempos =192) que fueron enviadas al Laboratorio del CATIE-Costa Rica.

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

Actividades realizadas

Anne Zanfini, estudiante de doctorado de la Universidad de Toulouse, Francia, realizó la fase de campo en Nicaragua para completar el estudio comparativo sobre los impactos de sistemas agroforestales en la construcción del territorio durante los meses de abril a julio 2004.

Por otro lado, se encuentran completadas las bases de datos de las 74 fincas cafetaleras que se realizó durante los dos primeros años del proyecto en 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

Castro B., J.; Díaz V., D. 2004. 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.

López, A.; Orozco, L.; Somarriba, E.; Bonilla, G. 2003. Tipologías y manejo de fincas cafetaleras en los municipios de San Ramón y Matagalpa, Nicaragua. *Agroforestería de las Américas*. Vol 10(37-38). Pág. 74-79.

Castro J., Díaz D., Aguilar V. (2003). Evaluación de 3 sistemas de manejo de café (*Coffea arabica*) sobre el crecimiento y la estructura productiva de la variedad CR-95. *Memoria Jornada Universitaria de Desarrollo Científico. Mesa Agronomía*. Octubre 2003. En imprenta.

3.3 Limitaciones presentadas durante el tercer año del proyecto.

Una limitación encontrada en el transcurso del tercer año del Proyecto fue el envío de la transacción financiera de los fondos para continuar con las actividades planificadas. El dinero llegó a la cuenta bancaria de la Universidad dos meses antes de concluir el tercer año del proyecto. Esta es una fuerte limitante para el desarrollo de las actividades ya que no se cuenta con otra fuente de financiamiento para desarrollar el cronograma planificado. Aún con esta limitación se ejecutaron las actividades.

3.4 Planificación de actividades para el año 4 del Proyecto.

3.4.1.1 Aspectos biofísicos: Distribución de la Luz y Agua a nivel de campo (WP2), Ecofisiología y Calidad del café (WP3), Reciclaje del Nitrógeno, lixiviación, absorción y emisiones (WP4), Secuestro de Carbono (WP5) y Modelos integrados a nivel de campo (WP6).

A. Ecofisiología y calidad de café.

En Diciembre del 2004 se tiene planificado realizar las mediciones de las 11 variables de crecimiento de las plantas de café, las 9 variables de estructura productiva y las 5 componentes de la planta de café para aumento de biomasa, así como rendimiento de café oro y calidad física y organoléptica se realizarán por última vez en el mismo mes..

Otras mediciones a realizar serán la proyección de copa, altura y diámetro a la altura del pecho de los árboles de madero negro en diciembre 2004 así como la distribución de biomasa y nitrógeno en los diferentes componentes del árbol de madero negro.

B. Monitoreo de la producción de hojarasca; Descomposición y liberación de nutrientes N, P y K de la hojarasca.

Para el estudio de monitoreo de la producción de hojarasca se concluirán las mediciones que han sido descritas para este estudio, hasta el mes de Diciembre del 2004. Asimismo para el estudio de descomposición y liberación de nutrientes N, P y K de la hojarasca se tiene planificado realizarlas las últimas mediciones descritas, a los 96 y 150 a partir del 3 de septiembre del 2004 que fue la primera medición en el campo.

C. Estudios sobre Lixiviación de nitratos en el perfil del suelo; Dinámica de Nitrógeno.
Se analizarán los datos provenientes de las muestras de suelo, las que han estado siendo enviadas al laboratorio de suelos del CATIE. Se tiene planificado realizar el estudio de las reservas de nitrógeno y carbono en el suelo.

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

Se realizará un estudio sobre la cadena maderera y leña en donde se realizó el estudio sobre tipologías cafetaleras en el departamento de Matagalpa. Esto es tentativo porque también pudiese incluir la zona del Pacífico de Nicaragua, la cual fue incluida en el estudio de Anne Zanfini. Esto último dependerá del presupuesto para cada uno de los estudios que se tienen planificados llevar a cabo durante este cuarto y último año del proyecto.

Anexo 1. Resumen de tesis de grado.

CASTRO B., J.; DÍAZ V., D. 2004. 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.

El presente estudio se realizó en la Finca San Francisco de Inversiones Generales S. A., ubicada en el km 39 ½ de la carretera San Marcos, Las Esquinas, en el departamento de Carazo, desde Agosto del 2002 hasta Junio del 2003. El objetivo general del experimento fue evaluar tres sistemas de manejo del café sobre el crecimiento, estructura productiva, acumulación de biomasa y nitrógeno en la raíz, tallo, ramas, hojas y frutos; producción y calidad del café oro de los cafetos. El diseño utilizado fue de bloques completos al azar (BCA), con tres tratamientos que consistieron en: a) Café (*Coffea arabica* L cv. Costa Rica 95) bajo sombra de madero negro (*Gliricidia sepium* (Jacquin) Kunth ex Walpers) y fertilización química, b) Café a plena explosión solar y fertilización química y c) Café bajo sombra sin fertilización. En cada parcela se seleccionaron 8 plantas a las cuales se les tomaron los datos de altura, diámetro, proyección de copa, nudos totales en el tallo principal, numero de ramas primarias, secundarias y terciarias tanto totales como productivas de la planta y rendimiento de café oro por parcela. Una muestra por tratamiento de café oro en cada una de las cuatro cosechas fue tomada y enviada a CERCAFENIC de UNICAFE en Managua para determinar los aspectos físicos y organolépticos de cada una de las muestras de café oro. Empleando el método destructivo se midió la biomasa y cantidad de Nitrógeno acumulado en la raíz, tallo, ramas, hojas y frutos por planta. A cada una de las variables estudiadas se le realizó un análisis de varianza (ANDEVA) y separación de medias por rangos múltiples de Tukey al 5 % de margen de error. En Agosto del 2002 las plantas de café bajo sombra sin fertilizante, presentaron la mayor biomasa de raíces ($Pr = 0.0065$) y el mayor contenido de nitrógeno en raíces ($Pr = 0.0084$), tallo ($Pr = 0.0023$) y hojas ($Pr = 0.0177$); el sistema de café a pleno sol y fertilizante obtuvo la mayor biomasa de tallo ($Pr = 0.0165$), en las variables restantes no se encontró diferencia significativa. Para el mes de Diciembre del 2002 el sistema café a pleno sol y fertilización presentó el mayor número de ramas terciarias totales ($Pr = 0.0166$), en las variables restantes no se encontró diferencia significativa. Los datos del mes de Junio del 2003 presentan al sistema café bajo sombra y fertilizante con la mayor altura ($Pr = 0.0001$) y el mayor número de ramas primarias totales ($Pr = 0.0137$) y el sistema café a pleno sol y fertilizante con el mayor número de ramas terciarias productivas ($Pr = 0.0303$) para las demás variables no se encontró diferencia estadística. El sistema de café bajo sombra sin fertilización obtuvo el mejor rendimiento con $438 \text{ kg oro ha}^{-1}$. La calidad del café fue mejor en el sistema café bajo sombra con fertilizante en la cosecha cuatro y cinco presentando una taza **OK**, tipo **GW** y calidad como café lavado Nicaragua. Por ser el primer año de estudio, al no presentarse diferencia significativa en la mayoría de las variables se pensaría que se inicio con una población altamente homogénea lo cual seria de mucha utilidad para los datos que se tomaran en esta investigación.

Anexo 2. Actual Partitioning of months / WP / PARTNER / for the THIRD YEAR

| Socio: UNA | WP1 | WP2 | WP3 | WP4 | WP5 | WP6 | WP7 | WP8 | WP9 | Yr3 |
|------------------------------|-------------|-----|--------------|-----|--------------|-----|-------------|-------------|-------------|--------------|
| Glenda Bonilla | 0.10 | | 1.0 | | 1.0 | | 0.10 | 0.10 | 1.0 | 3.3 |
| Víctor Aguilar | | | 2.5 | | 2.5 | | | | | 5.0 |
| Rodolfo Munguía | | | 1.85 | | 1.85 | | | | | 3.7 |
| Leonardo García | | | 0.35 | | 0.35 | | | | | 0.7 |
| Martha Gutiérrez | | | 1 | | 1 | | | | | 2.0 |
| Héctor Ortiz | | | | | | | | | 1.0 | 1.0 |
| Drivers | | | 0.3 | | 0.3 | | | | | 0.6 |
| Total Permanent Staff | 0.10 | | 7.00 | | 7.00 | | 0.10 | 0.10 | 2.00 | 16.3 |
| Justo E. Castro | | | 0.5 | | 0.5 | | | | | 1.0 |
| Sergio Ruiz | | | 0.515 | | 0.515 | | | | | 1.03 |
| Manuel Calero | | | 0.08 | | 0.08 | | | | | 0.16 |
| Dayling Balladares | | | 0.16 | | 0.16 | | | | | 0.32 |
| Danilo Pérez | | | 0.03 | | 0.03 | | | | | 0.06 |
| Otoniel Soza | | | 0.03 | | 0.03 | | | | | 0.06 |
| Oswaldo González | | | 0.005 | | 0.005 | | | | | 0.01 |
| Wilfredo Fuentes Masís | | | 0.005 | | 0.005 | | | | | 0.01 |
| Carlos Parrales | | | 0.05 | | 0.05 | | | | | 0.10 |
| Enrique José López | | | 0.06 | | 0.06 | | | | | 0.12 |
| Mauriel Gurdián | | | 0.005 | | 0.005 | | | | | 0.01 |
| Rodolfo Castillo | | | 0.005 | | 0.005 | | | | | 0.01 |
| Pedro Ortiz | | | 0.005 | | 0.005 | | | | | 0.01 |
| Other Technicians | | | 0.52 | | 0.52 | | | | | 1.04 |
| Field technicians | | | 5.67 | | 5.67 | | | | | 11.34 |
| Total Hired Staff | | | 7.64 | | 7.64 | | | | | 15.28 |
| Total UNA | 0.10 | | 14.64 | | 14.64 | | 0.10 | 0.10 | 2.00 | 31.58 |

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

Contract ICA4-2001-10071

**Second Annual Report WORK PACKAGE 1
1 November 2003 - 31 October 2004**

WP#1 – CASCA – Central America coffee agroforestry knowledge

Eduardo Somarriba, líder del WP1

Avances

- Se continuó un estudio de PhD comparativo entre las estrategias de vida y manejo de cafetales de dos regiones contrastantes de Costa Rica (Perez Zeledón y Tarrazú) y Nicaragua (Carazo y Matagalpa).
- Se realizó un estudio sobre cómo los productores manejan arboles maderables de sombra de sus cafetales en la zona Sur de Costa Rica.
- Se actualizó la base de datos de fincas cafetaleras de Nicaragua, Costa Rica y Guatemala.
- Se analizó parcialmente 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 estudió 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.

Publicaciones

- Castillo R y Ortíz P (2003) Tipologías y manejo de fincas cafetaleras en los Municipios de El Tuma – La Dalia – Rancho Grande, Matagalpa, Nicaragua. Tesis, Universidad Nacional Agraria, Managua, Nicaragua. 70 p.
- López A y Orozco L (2003) Tipologías y manejo de fincas cafetaleras en los Municipios de San Ramón y Matagalpa, Nicaragua. Tesis, Universidad Nacional Agraria, Managua, Nicaragua. 87 p.
- López A, Orozco L, Bonilla G y Somarriba E (2003) Tipologías cafetaleras de Matagalpa, Nicaragua. Agroforestería en las Américas 10(37/38). En imprenta.

Estudiantes 2004

- Zanfini, Anne, Univ de Tolosa, Francia
- Castillo, Rodolfo, UNA, Ingeniería Forestal, Nicaragua
- Ortiz, Pedro, UNA, Ingeniería Forestal, Nicaragua

Futuras actividades (2005)

- Analizar y publicar el trabajo de campo del estudio comparativo de Anne Zanfini en Nicaragua y Costa Rica
- Publicar artículos sobre “Gerencia de cafetales” y “Diseño y manejo del dosel de sombra de cafetales”
- Preparar manuscrito “Doseles de los cafetales centroamericanos” que resumirá la información sobre composición botánica, densidades, usos y tipologías de doseles contenida en la totalidad de la base de datos.
- En cooperación con WP#7 seguir elaborando modelos tipológicos y escenarios socioeconómicos de las fincas cafetaleras que interesa modelar para CASCA.
- Estudiar la cadena agroproductiva de cafetales con maderables y otras plantas útiles en Carazo y Matagalpa, Nicaragua y cuenca de Ococito, Guatemala.

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

Contract ICA4-2001-10071

Third Annual Report WORK PACKAGE 2

1 November 2003 - 31 October 2004

Work Package 2: LIGHT and WATER PARTITIONING at PLOT SCALE

Jean Dauzat (CIRAD), leader of WP2

Philippe Vaast and Stéphane Bagnis (CIRAD), Pablo Siles and Adolfo Martinez (CATIE) and Luis D. Garcia (IICA-PROMECAFE)

Light modelling in agroforestry stands

1. Rationale

The work of the previous year was focussed on the characterisation of individual trees of several species commonly associated to coffee tree in Central America: *Cordia alliodora*, *Eucalyptus deglupta*, *Terminalia amazonia* and *Cedrela odorata*. This year was mainly dedicated to the modelling of light transmission under trees stands.

The first step of modelling concerned the geometrical representation of individual trees from their vertical silhouettes. The “topiary” program was extended in order to simulate 3D meshes of the tree crowns.

Given 3D tree representations, one must then associate to them a light interception model. The more commonly used model assimilate the foliage to a turbid medium (TM) within a given volume. Nevertheless, values of the crown porosity from different points of view leaded to propose an alternative “Porous Envelope” model. New modules were includes in the “MIR” program for treating the TM and PE models.

Combining 3D representations of individual trees within a stand and radiative models, one can simulate the light transmission under the trees. Extensive simulations have been performed for eucalyptus stands. Results were then used to fit sets of equations allowing to predict the light transmission rate on a spread sheet according to the crowns size and porosity.

2. Geometrical representation of tree crowns

Modeling

According to the tree description protocol, one get two perpendicular profiles views of the crown. A standardized procedure is then applied to draw simplified contours of the crown silhouette in two vertical planes. The 3D crown reconstruction module interpolates these two silhouettes in intermediate azimuths (figure 1). Note that field data included the measurement of the crown projection on the ground in eight directions. Such data could have been used as additional constraints for the crown reconstruction. However such measurements are considered as inaccurate and it was preferred to keep the “silhouette” method as simple as possible.

The analysis of the crown shapes showed that the average eucalyptus crown can be approximated by an ellipsoid (figure 2). The light interception by ellipsoidal crowns was later on tested against actual crowns.

Programming

The topiary program was formerly restricted to the simulation trees with simple parametric crown shapes (ellipsoids, cylinders, cones or parallelograms). It has been extended in order to simulate non-parametric crown shapes.

The topiary program may outputs two kinds of tree representations:

- (1) With the crown represented by its envelope;
- (2) With the crown represented as a “cloud” of leaves. In that case, leaves are randomly positioned within the envelope. The leaves inclination is determined according to a trigonometric (de Wit), gamma (Goel) or an ellipsoidal (Campbell) LAD function.

Figure 1:

Left: 3D crown envelope reconstructed from 2 vertical profiles

Right: “ellipsoidal” tree.

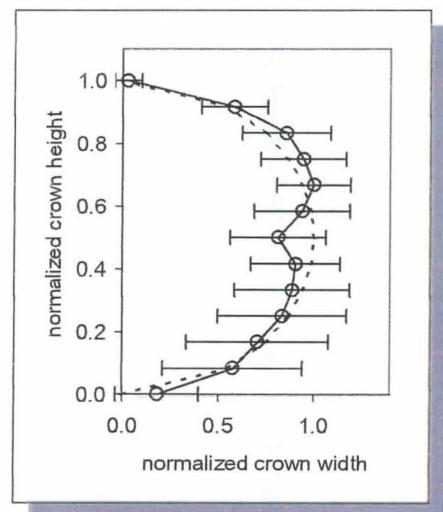
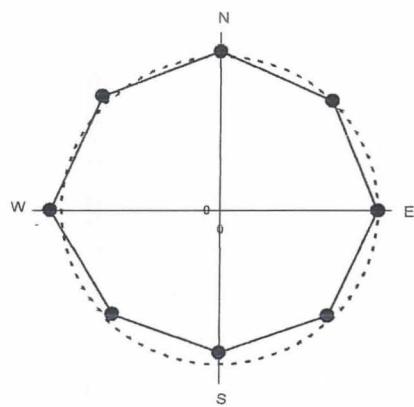
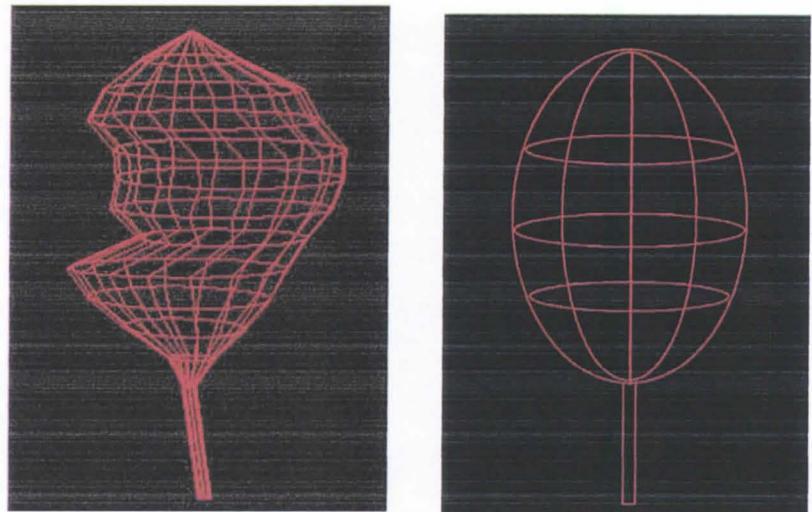


Figure 2: *Analysis of the crown shape. Left: crown projection; Right: vertical crown profile. (solid line: normalized profile; dotted line: ellipse).*

3. Light interception model

Crown porosity

The crown porosity (P_c) was determined on photographs as the ratio of the crown silhouette area over the visible foliage area (fig. 3). The main result was that the P_c value is, on average, independent of the view angle (fig. 4).

Figure 3:

Photographs of crowns are treated to get:

- *The visible foliage area (black pixels)*
- *The area of the crown envelope (red pixels)*

The crown porosity is defined as the area ratio of black pixels over red pixels.

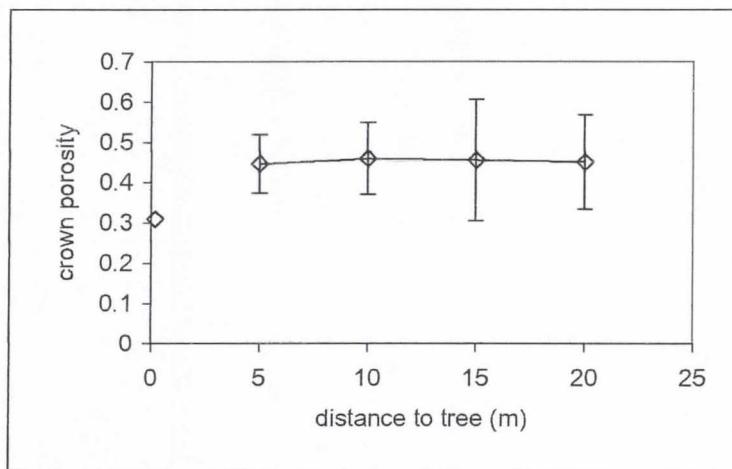
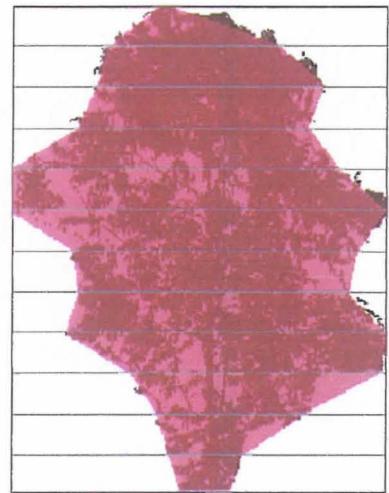


Figure 4:

Average crown porosity vs. the photograph points of view for eucalyptus.

NB: a distance of 0m to the tree corresponds to an elevation of 90° and 20m approximately to 21°.

Modeling

The foliage is classically represented as a turbid medium for the simulating the light interception. The transmission rate of a light ray through a turbid medium is given by:

$$T(\theta) = \exp(-G(\theta) \Omega(\theta) D L(\theta))$$

with : θ , the ray zenith angle;

$G(\theta)$, a projection function of leaves, depending on their inclination;

$\Omega(\theta)$, a clumping factor;

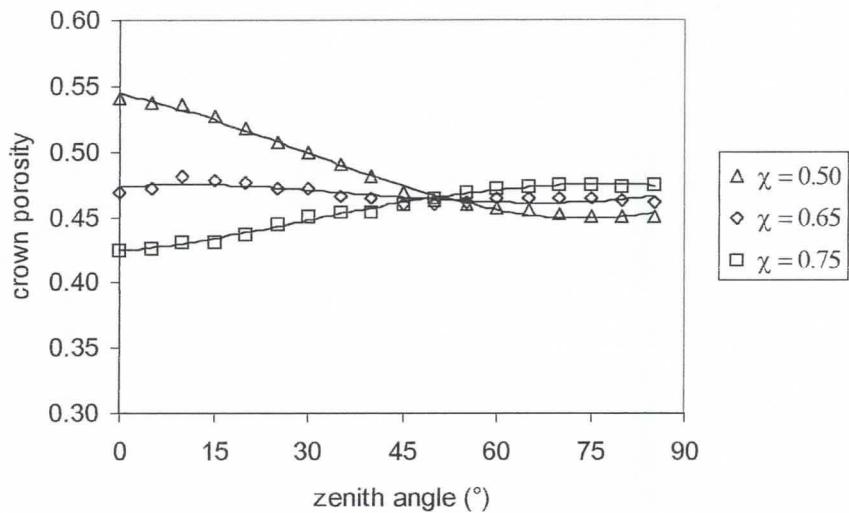
D , the volumic density of foliage area ($m^2 m^{-3}$);

$L(\theta)$, the path-length of the ray through the volume (m).

A turbid medium (TM) model can simulate a crown porosity independent of the light direction with an erectophile foliage (fig.5) and may therefore be used for simulating eucalyptus stands. Nevertheless, the use of this model requires the knowledge of the foliage density. We therefore proposed an alternative model. In this so-called “Porous Envelope” model (PE), the light is intercepted only by the crown envelope (and not inside). The porosity of the envelope (Pe) is set independent on the light direction and such that $\prod_{i=1}^n Pe_i = P_c$, n being the number of intersections between the ray and the envelope.

Figure 5:

Simulated porosity of an ellipsoidal crown filled with a turbid medium. An ellipsoidal LAD with a χ value of 0.65 results in a porosity sensibly independent of the light direction.

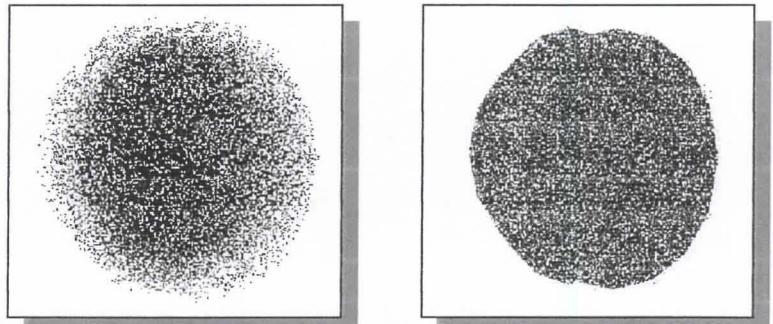


As presented here, the TM model assumes an even foliage distribution within the crown volume whereas the foliage is mostly concentrated in the crown periphery in actual trees. In this respect, the PE model outputs more realistic patterns of light interception (fig. 6).

Figure 6:

Simulated porosity of an eucalyptus crown

- *Left: with a turbid medium model*
- *Right: with a porous envelope model*



The porous envelope model was used later on for simulation of the light transmission under eucalyptus stands because of its simplicity, without reference to the foliage density which is generally unknown.

Programming

The TM and PE models have been implemented in the ARCHIMED software. All the modules can be run on Windows (previously only on Unix) and a package is freely distributed to CASCA participants.

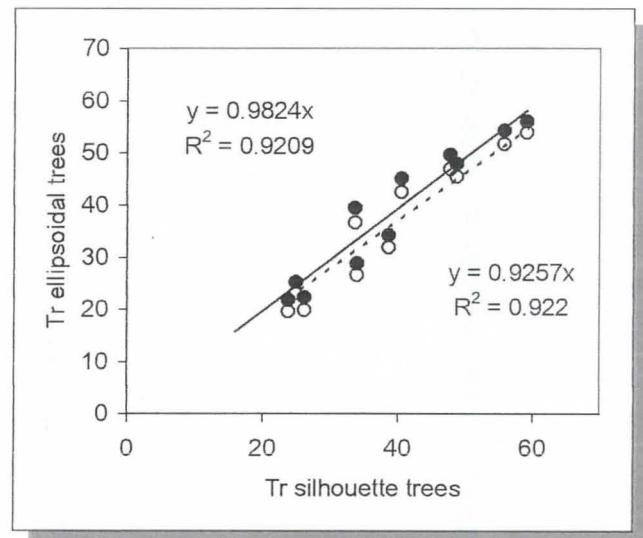
4. Simulation and fitting of light transmission under eucalyptus stands

The first step was to compare the light interception by actual crown shapes and ellipsoidal crowns. It was shown that ellipsoidal crowns can be used with an acceptable accuracy (fig. 7). For the sake of simplicity in data collection, the only parameters used to parameterise the ellipsoids are the crown height and width. Given the observed allometric relationships, one may also get these parameters from DBH or tree height data.

Figure 7:

Simulated transmission rate of eucalyptus crowns vs. equivalent ellipsoidal crowns.

- : ellipse width = crown width
- : ellipse width = 0.95 crown width



Extensive simulations of the stand transmission rate (Tr) were then performed with ellipsoidal crowns of variable size and porosity, the trunk being represented as an opaque vertical cylinder. Simulated results were then fitted (fig. 8) with a single equation:

$$Tr = \exp((\alpha P c^\beta + \chi) S F^{(\delta P c^\beta + \varepsilon)}) \quad \text{with } \alpha, \beta, \chi, \delta \text{ and } \varepsilon, \text{ constant parameters.}$$

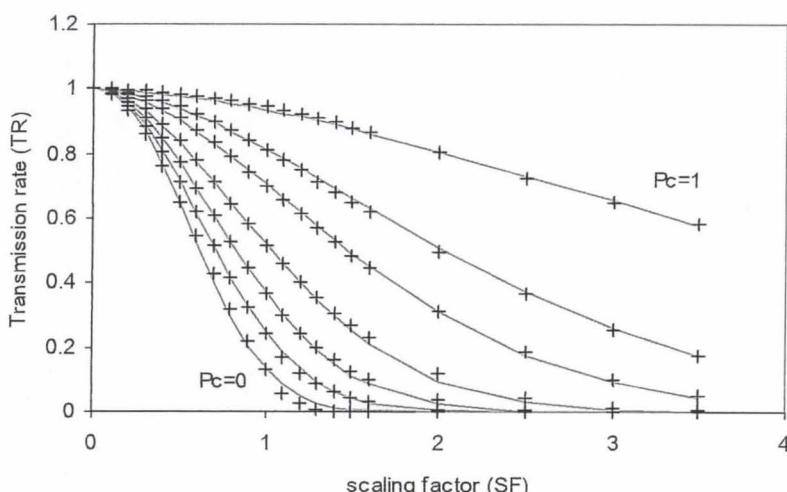
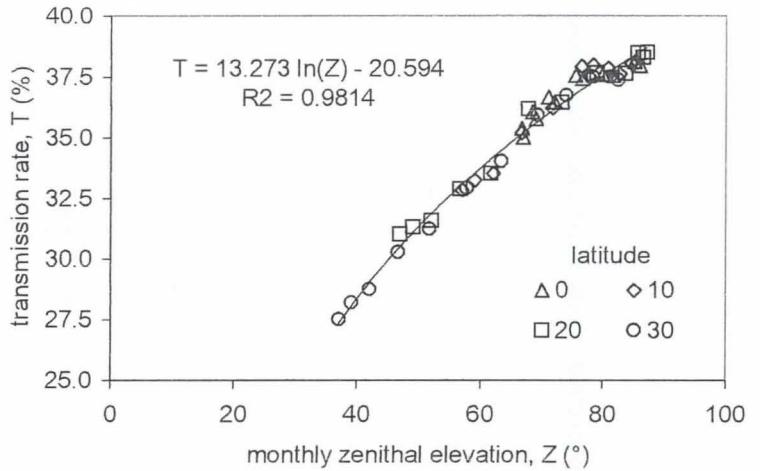


Figure 8: *Simulated stand transmission rate (+) and fitting (---) vs. the tree size and the crown porosity. The scaling factor is applied on an “average” tree, 11.26m high. Crown porosity (P_c) was set from 0 ⇔ opaque crown (lower curve) to 1 ⇔ transparent crown (upper curve).*

Above simulations were done for the whole year at a latitude 0° (equator). Additional simulations showed the effect of the date and the latitude on Tr . Both effects can be modelled as a function of the sun elevation (fig9).

Figure 8:

Transmission rate simulated for different dates and latitudes. Results are fitted by a function of the sun elevation.

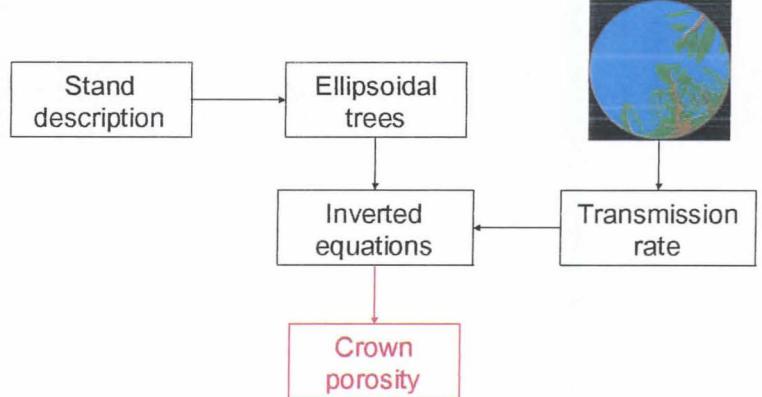


5. Conclusions

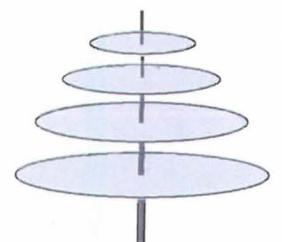
The light transmission through eucalyptus stands can be simulated by a set of equations from simple variables such as the crown height and width, the tree height or the DBH, provided the crown porosity is known. Indeed, the porosity differs among trees and, overall, it can change greatly when the trees defoliate during the dry season. More porosity data are therefore needed. The determination from photographs of individual trees is long and difficult. Therefore, the proposed alternative procedure is its determination at the stand level with hemispherical photographs (fig. 9).

Figure 9:

Determination of the average crown porosity from tree description and hemispherical photographs.



Developed programs and methods are being applied for other species (*Cordia alliodora*, *Terminalia ivorensis* and *amazonica*) with a specific crown representation in the case of *T. Ivorensis*.



Terminalia ivorensis

Water partitioning between coffee and associated trees

Philippe Vaast and Patrice Cannavo (CIRAD), Pablo Siles and Adolfo Martinez (CATIE) and Luis D. Garcia (IICA-PROMECAFE).

CIRAD, CATIE and IICA-PROMECAFE have been involved in collecting data on transpiration of both coffee and associated trees using sap flow measurements, and in quantifying rain interception and runoff.

In the sub-optimal conditions of the southern part of Costa Rica characterized by hot days and a long dry season, measurements initiated in December 2001 were terminated in July 2003. Following the doctoral thesis defended by Rudi van Kanten (CATIE), two articles have been submitted for publication (see annexes below).

In the optimal conditions of the experimental station of CICAFE, central valley of Costa Rica, sap flow measurements were initiated in August 2003 in 2 coffee systems (one with a leguminous service tree, *Inga sp.* and coffee in full sun.) and will continue until the end of the dry season of 2005

In 2004, a Ph.D student (Pablo Siles) spent 1 month at INRA (subcontractor of CIRAD) in Nancy, France, and 1 month at CIRAD, Montpellier, France, analysing the results of data collection during the first 18 months of his research.

Main results

Under sub-optimal conditions of low altitude (< 700 m), the results show that shade creates more favorable microclimatic conditions for coffee cultivation by decreasing leaf temperature of up to 4°C. These results demonstrated that coffee transpired more on a leaf area basis in sun full than under shade trees (*Eucalyptus deglupta* or *Terminalia ivorensis*), especially during the dry season (Table 1) due to exposition of the sun-grown coffee plants to higher solar radiation and air temperature. Under these sub-optimal conditions, the presence of shade trees reduces coffee heat stress, enhances coffee growth and productivity with an adequate shade level in the range of 20-40%. Especially during the sunny days of the dry season, higher leaf senescence and leaf drop were observed on sun-grown plants.

Table 1: Effects of shade management (coffee in full sun or under *Eucalyptus deglupta* or *Terminalia ivorensis* or *Erythrina poeppigiana*) on coffee daily transpiration (1 day⁻¹ m⁻² of foliar area).

| Coffee under | Full sun | Eucalyptus | Terminalia | Erythrina |
|--------------|----------|------------|------------|-----------|
| December | 0.83 a@ | 0.62 b | 0.47 b | 0.58 b |
| January | 0.78 a | 0.80 a | 0.57 b | 0.98 a |
| February | 0.87 ab | 0.39 b | 0.45 b | 1.06 a |
| March | 1.04 a | 0.54 b | 0.56 b | 0.61 b |
| April | 1.59 a | 0.86 b | 0.74 b | 1.74 a |
| May | 0.80 a | 0.57 b | 0.49 b | 0.68 b |
| June | 0.72 a | 0.60 a | 0.38 b | 0.74 a |
| July | 0.79 ab | 0.63 ab | 0.39 b | 1.01 a |

@ values within a line with the same letter(s) do not differ significantly according to the test of Newman-Keuls (P = 0.05).

Although coffee transpired more per unit leaf area in full sun than under shade, daily coffee water consumption per hectare was generally higher under shade of *E. deglupta* than in full sun (Table 2) due higher vegetative growth of the coffee in the shade. On the other end, coffee water consumption per hectare under shade of *T. ivorensis* was not significantly different than that in full sun (Table 2). This is due to the fact that the higher vegetative growth of coffee under this timber tree was counterbalanced by low solar radiation experienced by these coffee plants under the dense shade of this tree species. Coffee transpiration per hectare was particularly high under *E. poeppigiana* during the dry season when this species was shedding most of its leaves and coffee plants were exposed to high solar radiation.

Table 2. Effects of shade management (coffee in full sun or under *Eucalyptus deglupta*, *Terminalia ivorensis* or *Erythrina poeppigiana*) on coffee daily transpiration ($\text{mm ha}^{-1} \text{ day}^{-1}$) during the 8-month period of sap flow monitoring.

| Month | Coffee in Full sun | Coffee under | | |
|----------|-----------------------|--------------------|---------------------|---------------------------|
| | | <i>E. deglupta</i> | <i>T. ivorensis</i> | <i>E. poeppigiana</i> |
| December | 1.54 a [#] | 1.76 b | 1.32 a | 1.35 a |
| January | 1.29 a | 2.43 b | 1.61 a | 2.15 b |
| February | 1.37 a | 1.17 a | 1.27 a | 2.33 b |
| March | 1.52 a | 1.81 b | 1.63 a | 1.39 a |
| April | 2.59 a | 2.68 a | 2.17 a | 4.08 b |
| May | 1.40 a | 1.85 b | 1.47 a | 1.66 b |
| June | 1.24 a | 1.95 b | 1.12 a | 1.80 b |
| July | 1.45 a | 2.07 b | 1.15 a | 2.50 b |

[#] values (n = 4) within a line with the same letter(s) do not differ significantly according to the Newman-Keuls test ($P < 0.05$).

Due to their marked differences in leaf shedding, minimum tree daily water consumption occurred in different months for the timber tree species than for the service tree (Table 3). *Terminalia ivorensis* water use decreased to a minimum in March when its foliage density was at its lowest and then increased during the wet months to its highest values in June and July after regaining its dense foliage.

Table 3. Daily transpiration of associated trees ($\text{mm ha}^{-1} \text{ day}^{-1}$) during the 8-month period of sap flow monitoring.

| Month | <i>E. deglupta</i> | <i>T. ivorensis</i> | Facc ($\text{mm ha}^{-1} \text{ day}^{-1}$) | |
|----------|---------------------|---------------------|---|--------|
| | | | <i>E. poeppigiana</i> | |
| December | 0.35 b [#] | 0.55 a | | 0.15 c |
| January | 0.37 b | 0.69 a | | 0.24 c |
| February | 0.21 b | 0.50 a | | 0.22 b |
| March | 0.14 a | 0.24 b | | 0.27 b |
| April | 0.18 b | 0.39 a | | 0.04 c |
| May | 0.14 b | 0.44 a | | 0.17 b |
| June | 0.17 b | 0.92 a | | 0.20 b |
| July | 0.16 b | 0.81 a | | 0.21 b |

[#] values (n = 4) within a line with the same letter(s) do not differ significantly according to the Newman-Keuls test ($P < 0.05$).

Eucalyptus deglupta water use was at its highest in December and January before the beginning of its simultaneous processes of shedding and renewal of leaves which resulted in a constant daily transpiration during the first months of the wet period (Table 3).

Erythrina poeppigiana water use was quite constant over the months, except during April when its consumption was only $0.04 \text{ mm ha}^{-1} \text{ day}^{-1}$ due to the fact that this tree species had almost completely shed its foliage.

Estimation of the combined daily water uptake per hectare by coffee and shade trees in all the three associations was higher than that of coffee plants grown alone in full sun. Indeed, this combined water consumption was generally 10% to more than 100% higher than that of coffee in full sun (Table 4).

- For the association with *E. deglupta*, this is due to the fact that the more vigorous coffee plants grown under shade transpired more per hectare than that of coffee plants in full sun and that transpiration of *E. deglupta* trees accounted for an extra 7-17%.
- For the association with *T. ivorensis*, coffee water consumption was equivalent to that of sun-grown plants, but transpiration of *E. deglupta* trees accounted for an extra 13-33%.
- For the association with *E. poeppigiana*, slightly higher coffee water consumption was associated with a legume tree consumption accounting for an extra 1-16%. It is important to notice that coffee water uptake accounted for the largest part of the water consumption in all these agroforestry systems.

Table 4. Daily transpiration ($\text{mm ha}^{-1} \text{ day}^{-1}$) of coffee in full sun, daily combined transpiration of coffee and associated trees ($\text{mm ha}^{-1} \text{ day}^{-1}$) and percentage of these combined transpirations with respect to that of coffee in full sun (% FS) during the 8-month period of sap flow monitoring.

| Month | Coffee in full sun $\text{mm ha}^{-1} \text{ day}^{-1}$ | Coffee and | Coffee and | Coffee and |
|----------|---|--------------------|---------------------|-----------------------|
| | | <i>E. deglupta</i> | <i>T. ivorensis</i> | <i>E. poeppigiana</i> |
| December | 15.4 a [#] | 21.1 b (137%) | 18.7 b (122%) | 15.1 a (98%) |
| January | 12.9 a | 27.9 b (217%) | 23.0 b (179%) | 23.9 b (185%) |
| February | 13.7 a | 13.8 a (100%) | 17.7 b (129%) | 25.5 c (186%) |
| March | 15.2 a | 19.5 b (128%) | 18.7 b (123%) | 16.6 a (110%) |
| April | 25.9 a | 28.6 a (110%) | 25.5 a (99%) | 41.2 b (159%) |
| May | 14.0 a | 19.9 b (142%) | 19.2 b (136%) | 18.3 b (130%) |
| June | 12.4 a | 21.2 b (170%) | 15.8 ab (127%) | 19.9 b (160%) |
| July | 14.5 a | 22.3 b (154%) | 17.2 ab (119%) | 27.1 b (188%) |

[#] values (n=4) within a line with the same letter(s) do not differ significantly according to the Newman-Keuls test ($P < 0.05$).

Under optimal conditions, coffee vegetative growth was not different in full sun than under shade of leguminous trees of *Inga* spp (Table 5).

Table 5. Main characteristics of coffee and *Inga* trees under optimal conditions of Heredia.

| System | Density (plants ha ⁻¹) | Basal Area (m ² ha ⁻¹) | LAI (m ² ha ⁻¹) | Mean Leaf area (m ² ha ⁻¹) |
|--|---------------------------------------|--|---|---|
| Coffee in full sun | | | | |
| Coffee | 5000 | 14.23 | 4.82 | 9.64 |
| Coffee under shade of <i>Inga</i> | | | | |
| Coffee | 4743 | 13.58 | 4.66 | 9.82 |
| <i>Inga</i> trees | 247 | 6.67 | 1.39 | - |

Preliminary 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 (Table 6). Shade tree transpiration accounted for less than 25% than that of coffee. Combined water consumption of coffee and shade trees appeared equivalent of that of coffee grown in full sun during the rainy season but of lower magnitude during the dry season.

Table 6. Calculated evapotranspiration (ETP) and transpiration of coffee and shade trees under optimal coffee cultivation conditions.

| Month | ETP | SAF | | | | | | Full Sun | |
|-----------|------|--------------------|--------------------|-------|--------------------|-------------|--------------------|----------|--------------------|
| | | 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 |
| August 03 | 2.39 | 1.76 | 0.74 | 0.32 | 0.14 | 2.08 | 0.87 | 2.13 | 0.89 |
| Jan 04 | 4.12 | 2.26 | 0.55 | 0.42 | 0.10 | 2.68 | 0.65 | 2.75 | 0.67 |
| Feb 04 | 4.18 | 2.68 | 0.64 | 0.34 | 0.08 | 3.02 | 0.72 | 3.73 | 0.89 |
| March 04 | 4.21 | 2.38 | 0.57 | 0.43 | 0.10 | 2.81 | 0.67 | 3.42 | 0.81 |
| April 04 | 4.10 | 2.11 | 0.51 | 0.53 | 0.13 | 2.64 | 0.64 | 3.07 | 0.75 |
| August 04 | 2.17 | 1.63 | 0.75 | 0.30 | 0.14 | 1.93 | 0.89 | 1.97 | 0.91 |

In 2004, research works were also undertaken on rain interception by shade trees and coffee canopies as well as runoff to parameterize the water model.

Preliminary results show that at higher rainfall (> 15 mm day⁻¹) percentage of rain interception was higher than expected with values up to 30% for coffee + shade trees and 15-20% for coffee monoculture (Figure 1). Therefore, monitoring of trunk flow appears necessary to confirm these high rain-interception values.

Preliminary results show that at moderate to higher rainfall (> 10 mm day⁻¹) runoff is strongly reduced by the presence of shade trees (Figure 2).

Figure 1: Percentage of rain intercepted by coffee (monoculture) and coffee + shade trees according to rainfall intensity.

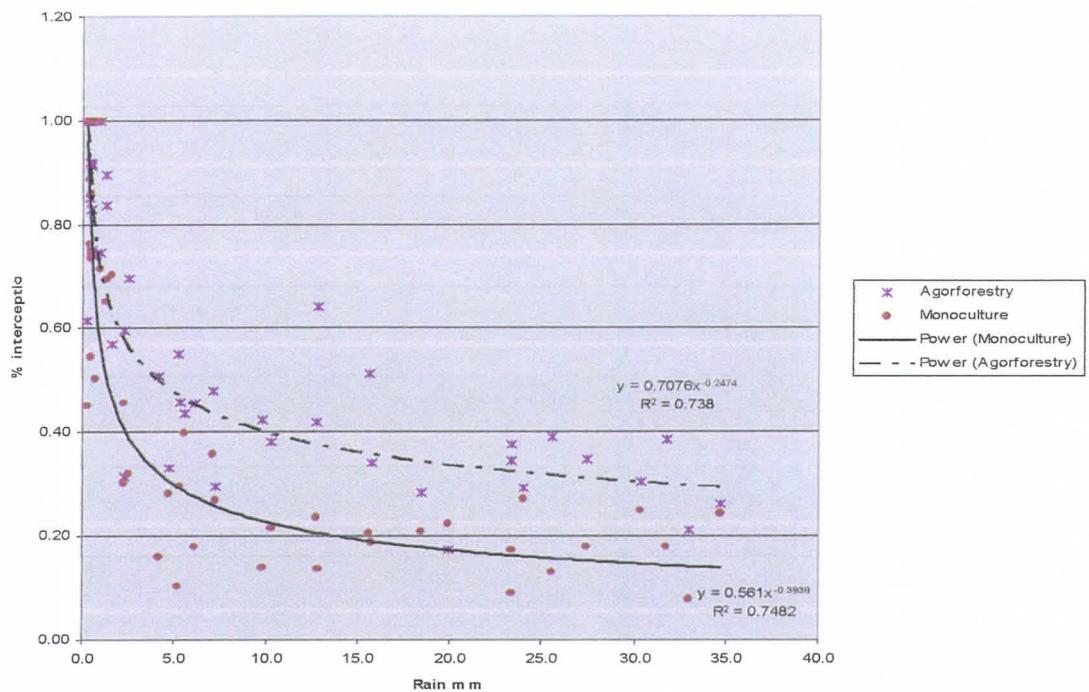
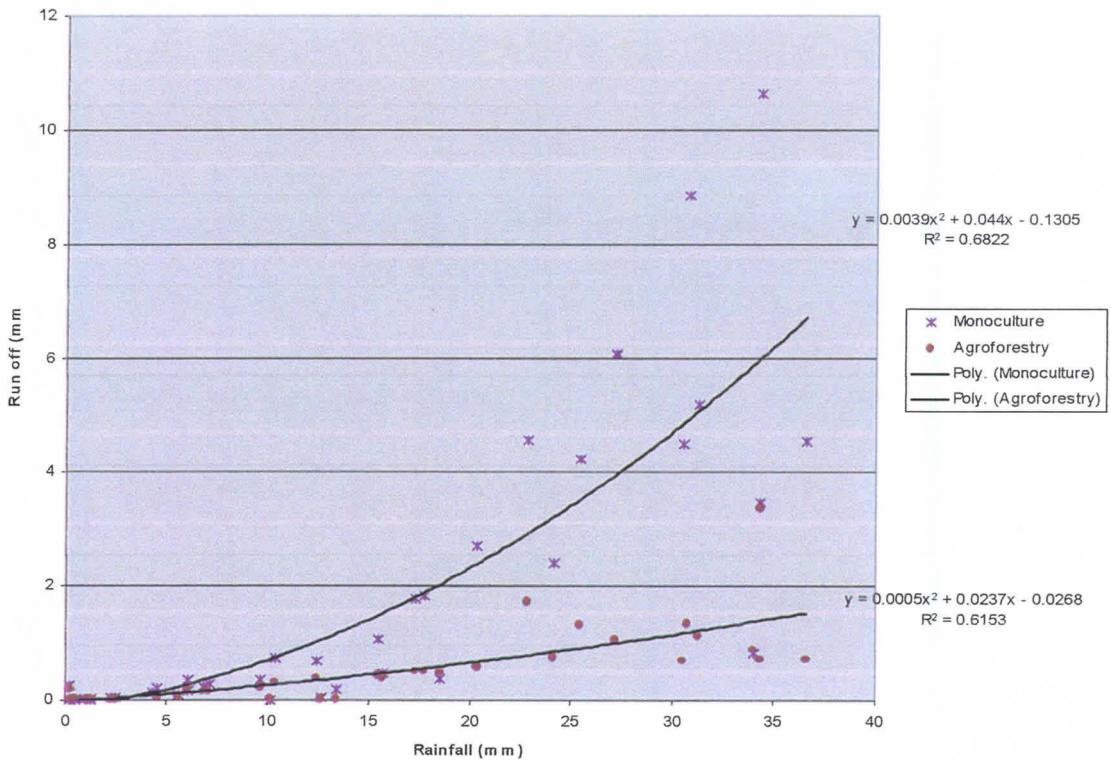


Figure 2. Runoff under coffee in full sun or coffee under shade trees according to rainfall intensity.



Planned activities in 2005

Light modeling

In 2005, hemispheric photos will be taken at different periods along the year to characterize phenological changes of the target shade tree species in order to refine the model of light interception at the plot scale. Two articles in progress will be submitted to international journals.

Water partitioning

In 2005, field measurements of soil water content, plant water status, water consumption of both coffee and trees, rainfall interception, runoff and trunk flow will be continued in optimal conditions in order to finalize the water model that was due at the end of 2004 according to the timetable of expected deliverables (D15/D2.2: water balance model at plot scale).

Publication of WP2 in 2004

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 (in press).

van Kanten R.F., Vaast Ph. (2004). : Coffee and shade tree transpiration in suboptimal, low-altitude conditions of Costa Rica. (submitted to Agroforestry Systems).

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

Third Annual Report WORK PACKAGE 3

1 November 2003 - 31 October 2004

Philippe Vaast (CIRAD), leader of WP3
Nicolas Franck (CIRAD)
Victor Aguilar (UNA)
Victor Chaves (IICA-PROMECAFE)
Stéphane Bagnis (CIRAD)

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**.

Field work has been undertaken:

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

Coffee photosynthesis and microclimate effects

In collaboration between CIRAD, CICAFE and CATIE, field data collection have continued in 2004 to assess **leaf and fruit photosynthesis** (P_n) in relationships with micro-climatic conditions at the leaf level and according to periods of the day. These results confirmed that leaf temperature and leaf to air vapor pressure deficit (VPD) strongly decreased leaf stomatal conductance (g_s) and hence leaf P_n (Figure 1); modeling of these micro-environmental effects on g_s and P_n is in progress by a Ph.D student of CIRAD (Nicolas Franck).

A second series of measurements on fruit photosynthesis has been undertaken in 2004. These results confirmed that **photosynthesis of fruits** could contribute up to 10-15% to their own carbohydrate demand and that this photosynthetic contribution decreased with increasing fruit age and biomass (Figure 2). Therefore, more data need to be collected in 2005 to precisely

evaluate coffee fruit contribution to its own carbohydrate demand over the whole production cycle. An article has been accepted for publication in 2004 (see annexes below).

In 2004, field work on Pn was continued to estimate the **parameters of the Farquhar Photosynthesis model**. Assimilation response curves to PPFD, VPD and intercellular CO₂ concentration were performed with a portable infrared analyzer (ADC-LCPro). Measurements have also been undertaken in 2005 to relate **Pn to leaf nitrogen content and reserves** (starch and soluble sugars). Results confirmed a **negative feedback effect of leaf reserves, especially soluble sugars, on leaf Pn** (Figure 3).

Assessment of **photo-inhibition** of coffee leaves, exposed to high solar radiation, was carried out with a portable fluorometer (miniPAM, Waltz). Results indicate that there is a **strong relationship between the degree of photo-inhibition (Fv/Fm) and the light exposition (PPFD) received by the leaves during hours prior to the measurements** (Figure 4).

Modeling of carbohydrate allocation

In 2004, destructive samplings of fruiting branches **located on different positions of the plant** (high, medium and low) have been performed **every 3 months** to **quantify carbohydrate allocation** between fruits and vegetative part during the production cycle. These measurements have been done for two consecutive production cycles in one trial in Nicaragua and another one in Costa Rica.

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 2004, a graduate student (Stéphane Bagnis, CIRAD) has digitized completely 16 plants under 3 shade treatments (75% and 50% shade and the full sun) with varying fruit loads (100%, 50% and “very light load”). These data were used to refine 3D representations of the coffee plants useful to simulate microclimate at the leaf level.

Coffee quality

More than 250 analyses were performed from 2002 to 2004 by a panel of 8-10 tasters in the laboratory of CIRAD in Montpellier, France. The same amount of biochemical analyses of coffee beans was also undertaken during the last 3 production cycles. Harvest of the current trials is still in progress until January 2005. Therefore, a last series of analyses of the 2004-05 production cycle, especially on nitrogen content of coffee beans, will be taking place during the first semester of 2005.

All the data gathered from these five experiments during the last 3 years, confirmed that fruit load and shade significantly affected coffee quality. **Shade** resulted in larger bean size, enhanced bean filling, better biochemical composition and hence **higher quality** of coffee beverage in both sub-optimal (Tables 1 & 2) and optimal conditions (Tables 3 & 4). Under optimal conditions, **lower fruit loads** decreased competition among fruits for carbohydrate and hence enhanced bean size, composition and cup quality (Tables 3 & 4).

These results have been presented in two international congresses (First World Agroforestry Congress in Miami, Florida, in June 2004 and International Coffee Congress, Bangalore, India, October 2004) and a national coffee congress (RAMACAFE, Managua, Nicaragua, September 2004).

Six articles (submitted in 2004) are documenting the physiological responses of coffee to microclimatic conditions and the beneficial effects of shade trees on coffee physiology and quality.

The Deliverable D8/D3.1 "Scientific report on physiological responses of coffee to microclimatic conditions" and the Deliverable D9/D3.2 "Report of rules of carbon allocation" (20 Months) were due in year 2 (20 Months). The Deliverable D23/D3.2 "Reports on indicators of coffee quality" is due in year 4 (42 months).

The deliverables D8/D3.1 and D23/D3.2 can be considered completed through publication or submission of six scientific articles (see list of publications below).

To complete the last Deliverable (D9/D3.2), two articles on the modeling of physiological responses of coffee and carbon allocation will be submitted in 2005 after the completion of the Ph.D. thesis of Nicolas Franck by June 2005.

Planned activities in 2005:

Three trials (two in Costa Rica and one in Guatemala) are currently being harvested since October 2004.

A survey of 90 farms is in progress in Nicaragua since October 2004. This research work of a graduate student of CATIE is evaluating the effects of farm management (particularly shade level) and plantation productivity along an altitudinal range (700 to 1400 m) on coffee quality.

Cup tasting and bean biochemical content from these experiments will be assessed during the first semester of 2005.

Parameterization and testing of the model of carbon allocation will be finalized by mid 2005 (Deliverable D14/D6.2 "Carbon allocation model of fruit growth in a single bush" due in year 3; 30 Months).

Publication of WP3 in 2002 & 2003

Siles P. and Vaast Ph. (2002). Comportamiento fisiológico del café asociado con *Eucalyptus deglupta*, *Terminalia ivorensis* y sin sombra. Agroforestería en las Américas. 9(35/36): 44-49.

Vaast Ph., Génard M., Dauzat J. (2002). Modeling the effects of fruit load, shade and plant water status on coffee berry growth and carbon partitioning at the branch level. Acta Horticulturae. 584:57-62.

Angrand J., Vaast Ph. Beer J. Benjamin T. (2003). Comportamiento vegetativo y reproductivo de *Coffea arabica* en tres sistemas agroforestales comparado con pleno sol en Pérez Zeledón, Costa Rica. Agroforestería en las Américas. (in press).

Rosenqvist, E., Ottosen, CO., Vaast P. (2003). Effects of shade and fruit load on gas exchange characteristics of coffee (*Coffea arabica* L.) cv 'Costa Rica 95' in field conditions. Tree Physiology (submitted Oct. 2003 to be revised in 2005).

Publications submitted or accepted in 2004

Vaast Ph., Angrand J., Franck N., Dauzat J., Génard M. (2004). Fruit load and branch ring-barking affect carbon allocation and photosynthesis of leaf and fruit of *Coffea arabica* in field conditions. Tree Physiology (accepted August 04)

Vaast Ph., Bertrand B., Guyot B., Génard M. (2004). 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 (in press).

Vaast Ph., van Kanten R., Siles P., Angrand J., Aguilar A. (2004). Biophysical interactions between timber trees and coffee in sub-optimal conditions of Central America. Agroforestry Systems (submitted July 2004).

Bertrand B., Etienne H., Guyot B., Vaast Ph. (2004). 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 (in press).

Vaast Ph., van Kanten R., Siles P., Dzib B., Franck N., Harmand JM., Génard M. (2004). Shade: a key factor for coffee sustainability and quality. Proceedings of the 20th International Congress on Coffee Research (ASIC) Bangalore, India, October 2004 (in press).

Vaast Ph., Cilas C., Perriot JJ., Davrieux F., Guyot B., Bolano M. (2004). Mapping of coffee quality in Nicaragua according to regions, ecological conditions and farm management. Proceedings of the 20th International Congress on Coffee Research (ASIC) Bangalore, India, October 2004 (in press).

ANNEXES

Table 1: Effects of shade management (coffee under *Eucalyptus deglupta* or *Terminalia ivorensis* or *Erythrina poeppigiana* or in full sun) and year of production on percentage of beans with larger sizes and bean biochemical composition (in g kg⁻¹ of bean dry weight) under sub-optimal conditions.

| | Large beans (%) | | Caffeine (g kg ⁻¹) | | Fat (g kg ⁻¹) | | Chlorogenic acid (g kg ⁻¹) | | Trigonelline (g kg ⁻¹) | |
|-------------------|-----------------|------|--------------------------------|------|---------------------------|------|--|------|------------------------------------|------|
| | 2001 | 2002 | 2001 | 2002 | 2001 | 2002 | 2001 | 2002 | 2001 | 2002 |
| Eucalyptus | 72 | 67 | 14.8 | 14.1 | 141 | 130 | 76.2 | 82.1 | 9.9 | 9.7 |
| Terminalia | 72 | 67 | 14.8 | 14.1 | 141 | 133 | 76.6 | 82.3 | 10.0 | 9.7 |
| Erythrina | 69 | 62 | 14.5 | 13.7 | 137 | 122 | 77.0 | 82.2 | 10.5 | 9.9 |
| Sun | 67 | 56 | 14.2 | 13.6 | 132 | 125 | 77.1 | 82.6 | 10.7 | 10.1 |
| P | 0.05 | 0.05 | 0.05 | 0.01 | 0.01 | 0.05 | 0.05 | ns@ | 0.01 | 0.05 |

@ not significant (P>0.05).

Table 2: Effects of shade management (coffee under *Eucalyptus deglupta* or *Terminalia ivorensis* or *Erythrina poeppigiana* or in full sun) and year of production on beverage characteristics under sub-optimal conditions.

| | Acidity@ | | Bitterness | | Astringency | | Body | | Preference# | |
|-------------------|----------|------|------------|------|-------------|------|------|------|-------------|------|
| | 2001 | 2002 | 2001 | 2002 | 2001 | 2002 | 2001 | 2002 | 2001 | 2002 |
| Eucalyptus | 2.27 | 2.45 | 1.65 | 1.65 | 0.68 | 0.35 | 2.78 | 2.50 | 2.70 | 2.80 |
| Terminalia | 2.13 | 2.41 | 1.75 | 1.73 | 0.70 | 0.36 | 2.89 | 2.53 | 2.90 | 2.78 |
| Erythrina | 1.91 | 2.27 | 1.86 | 1.75 | 0.79 | 0.34 | 2.72 | 2.66 | 2.32 | 2.36 |
| Sun | 1.67 | 2.21 | 1.95 | 1.88 | 0.86 | 0.51 | 2.91 | 2.67 | 2.19 | 2.28 |
| P | 0.001 | 0.05 | 0.01 | 0.01 | 0.05 | 0.05 | 0.05 | ns& | 0.01 | 0.01 |

@ scores for acidity, bitterness, astringency and body were based on a scale of 0-5, where 0=null and 5=very strong.

overall preference was based on a scale of 0-4, where 0=not good for drinking, 1=bad, 2=regular, 3=good, 4=very good. Each value is the average of scoring by 10 judges during 3 tasting sessions.

& not significant (P>0.05)

Table 3: Effects of PPFD regimes (45% of Shade and Full sun), fruit loads (Full: F, half: $\frac{1}{2}$ and quarter: $\frac{1}{4}$ of fruit loads) and year of production on coffee bean biochemical composition (in g kg $^{-1}$ of bean dry weight) **under optimal conditions.**

| | Caffeine | | Fat | | Sucrose | | Chlorogenic acids | | Trigonelline | |
|---------------|----------|-------|-------|------|---------|------|-------------------|------|--------------|-------|
| | 1999 | 2000 | 1999 | 2000 | 1999 | 2000 | 1999 | 2000 | 1999 | 2000 |
| Shade | 14.8 | 14.1 | 131 | 117 | 82 | 77.3 | 76.2 | 82.1 | 9.9 | 9.7 |
| Sun | 14.2 | 13.6 | 122 | 115 | 84 | 78.4 | 77.1 | 82.6 | 10.7 | 10.1 |
| P | 0.001 | 0.001 | 0.001 | 0.05 | 0.001 | NS | 0.001 | NS | 0.001 | 0.001 |
| F | 14.3 | 14.1 | 127 | 119 | 84 | 76.7 | 76.6 | 82.3 | 10.0 | 9.9 |
| $\frac{1}{2}$ | 14.5 | 14.2 | 127 | 119 | 83 | 76.6 | 76.7 | 82.2 | 10.3 | 9.9 |
| $\frac{1}{4}$ | 14.6 | 14.1 | 125 | 116 | 83 | 77.8 | 76.6 | 82.6 | 10.4 | 10.0 |
| P | 0.001 | NS | NS | NS | NS | NS | NS | NS | 0.01 | NS |
| P inter. | NS* | NS | NS | NS | NS | NS | NS | NS | 0.007 | NS |

*non-significant (P>0.05)

Table 4: Effects of PPFD regimes (45% of Shade and Full sun), fruit loads (Full: F, half: $\frac{1}{2}$ and quarter: $\frac{1}{4}$ of fruit loads) and year of production on beverage characteristics **under optimal conditions.**

| | Acidity* | | Bitterness | | Astringency | | Body | | Preference** | |
|---------------|----------|-------|------------|------|-------------|------|------|------|--------------|------|
| | 1999 | 2000 | 1999 | 2000 | 1999 | 2000 | 1999 | 2000 | 1999 | 2000 |
| Shade | 2.27 | 2.45 | 2.65 | 2.65 | 1.68 | 0.35 | 2.78 | 2.50 | 2.57 | 2.80 |
| Sun | 1.67 | 2.21 | 2.95 | 2.88 | 1.86 | 0.41 | 2.91 | 2.67 | 2.29 | 2.58 |
| P | 0.001 | 0.04 | 0.002 | 0.01 | 0.02 | NS | 0.05 | 0.05 | 0.01 | 0.02 |
| F | 1.91 | 2.47 | 2.86 | 2.83 | 1.82 | 0.46 | 2.92 | 2.66 | 2.42 | 2.76 |
| $\frac{1}{2}$ | 2.02 | 2.41 | 2.75 | 2.73 | 1.80 | 0.36 | 2.89 | 2.53 | 2.64 | 2.70 |
| $\frac{1}{4}$ | 2.13 | 2.27 | 2.75 | 2.75 | 1.79 | 0.34 | 2.72 | 2.66 | 2.73 | 2.74 |
| P | 0.03 | 0.05 | NS | NS | NS | NS | 0.05 | NS | 0.001 | NS |
| P inter. | 0.09 | NS*** | NS | NS | NS | NS | NS | NS | 0.001 | NS |

*The scores for acidity, bitterness, astringency and body were based on a scale of 0-5, where 0=null and 5=very strong.

** Overall preference were based on a scale of 0-4, where 0=not good for drinking, 1=bad, 2=regular, 3=good, 4=very good. Each value is the average of scoring by 10 judges during 3 tasting sessions.

***non-significant (P>0.05)

Figure 1: Effects of VPD on stomatal conductance (gs) of coffee leaves under various levels of shade (Ps: full sun; S25: 25% of shade; S50: 50% of shade; S75: 75% of shade)

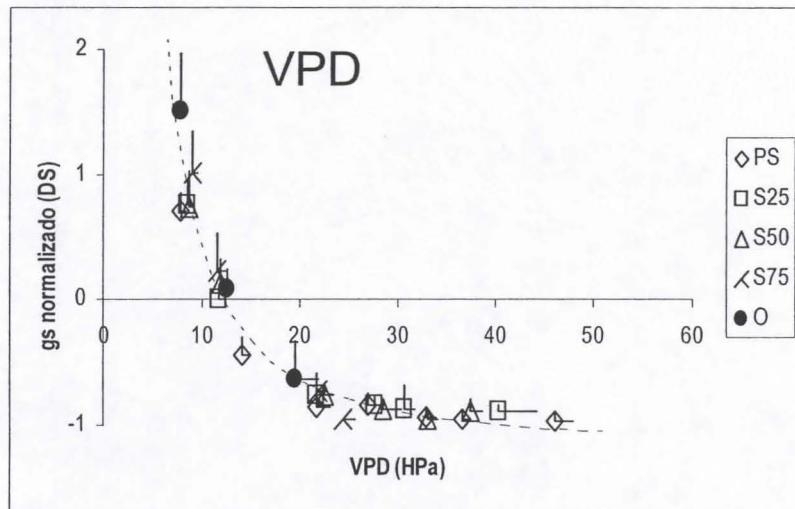


Figure 2. Evolution of calculated berry photosynthetic rates ($\text{nmol CO}_2 \text{ g}^{-1}$ of dry berry weight s^{-1}) of attached green coffee berries as affected by their mean dry weights (low dry weight of 0.120 g (), medium-low dry weight of 0.176 g (), medium-high dry weight of 0.194 g () and high dry weight of 0.222 g (●)) in response to increasing PPFD ($\mu\text{mol quanta m}^{-2} \text{s}^{-1}$).

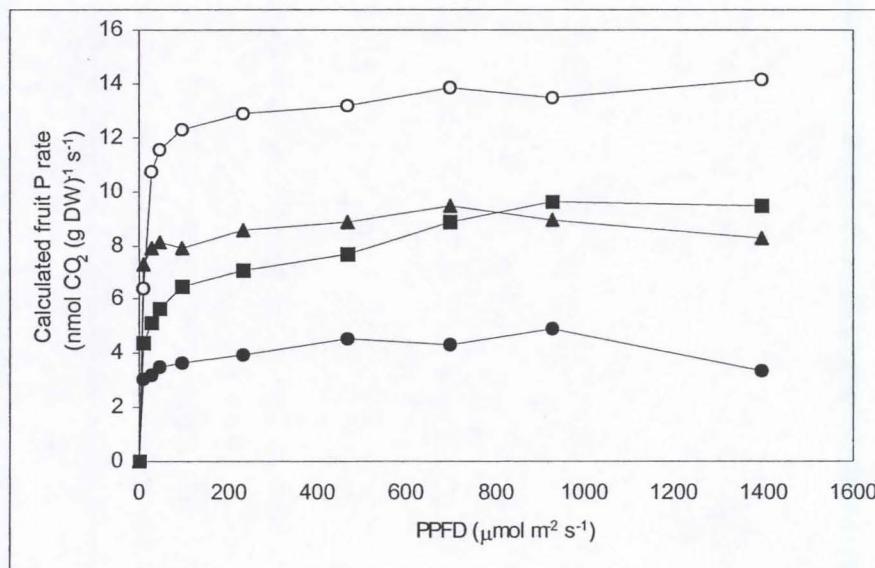


Figure 3. Effect of leaf soluble sugars concentration (SCHC) on saturated leaf photosynthetic rate (A^{sat}).

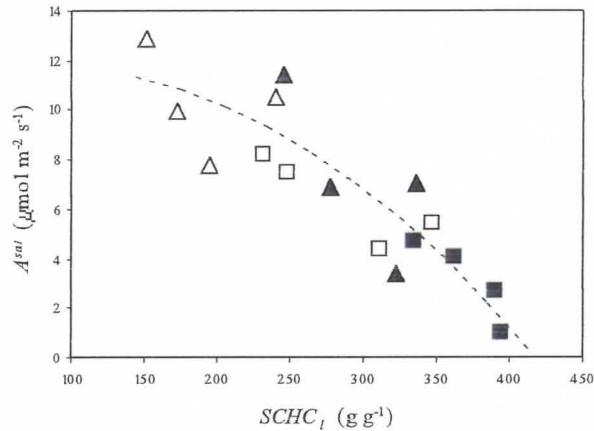
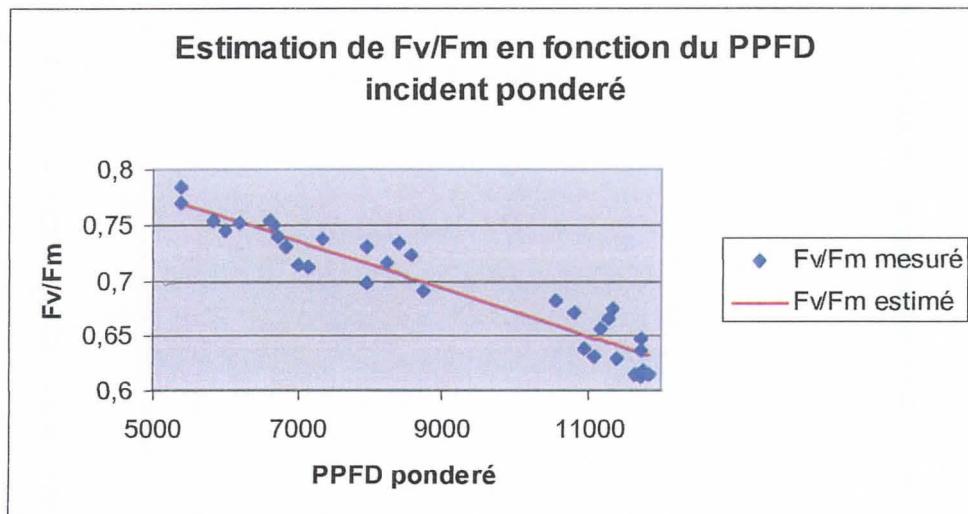


Figure 4: Effects of cumulative light exposition (PPFD) on coffee leaf photo-inhibition (Fv/Fm)



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

Contract ICA4-2001-10071

Third Annual Report WORK PACKAGE 4
1 November 2003 - 31 October 2004

WP4: Nitrogen cycling, leaching, uptake and emissions

Workpackage leader: Jean-Michel Harmand (Cirad, France)

The four objectives of the workpackage “Nitrogen cycling” are:

- To improve nitrogen (N) management (N fertilisation, legume tree) by synchronising soil N availability to the needs of coffee and associated trees,
- To document N accumulation within the various components of coffee plants
- 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 nitrogen in different soil types and management systems,
- To link N measurements to environmental evaluation at catchment scale

Leaf and root contributions from different shade tree species and coffee on N availability and dynamics were studied through lab experiments on N mineralization of vegetal material (roots and litter). The decomposition and N release rates of roots and litter were determined for *Inga densiflora* and *Coffea arabica*.

Key components of the nitrogen cycle were measured in 4 target coffee management systems in field and laboratory conditions. The annual N budget (including N sequestration in biomass and removal in coffee beans) was estimated. Nitrate leaching was quantified from soil solution data collected from porous cups and lysimeters. Monitoring of ^{15}N natural abundance ($\delta^{15}\text{N}$) of legume tree leaves was initiated in order to evaluate N_2 fixation by the shade legume trees. Denitrification, volatilisation of N_2O , and N_2 (gaseous efflux) was measured *in situ* and analysed by gas chromatography. Laboratory experiments were carried out to measure the rate of N oxides emission and to establish the ratio of N_2O to N_2 production for the different treatments. Acetylene inhibition was used to measure denitrification rates and also to assess the contribution of nitrification to the N_2O budget.

Using ^{15}N labelled fertilisers, measurements of key components of the nitrogen cycle in the *C. arabica* – *I. densiflora* were performed in order to evaluate: (1) competition for N uptake between coffee and trees, (2) fertiliser use efficiency along the year, (3) N losses in gases (N_2O , N_2), (4) N immobilisation in the soil, (5) soil nitrate retention and (6) nitrate leaching.

1. Descomposición y liberación de nitrógeno de material foliar y radicular de siete especies de sombra en un sistema agroforestal con café

Victoria Eugenia Osorio Moreno (CATIE, Costa Rica), Tamara Benjamin (CATIE, Costa Rica), Philippe Vaast (CIRAD), Patrice Cannavo (CIRAD)

El estudio esta resumido abajo :

Se realizaron tres ensayos sobre la contribución del material foliar y radicular de siete especies de sombra y el café sobre la disponibilidad y dinámica del N. En el primero, se determinó la mineralización y liberación de N de las hojas verdes de *Erythrina poeppigiana* e *Inga edulis* y la hojarasca y raíces finas de las especies: *Cordia alliodora*, *Erythrina poeppigiana*, *Eucalyptus deglupta*, *Inga densiflora*, *Inga edulis*, *Terminalia amazonia*, *Terminalia ivorensis* y *Coffea arabica*. Se midieron los contenidos de amonio y nitrato de las hojas verdes, hojarasca y raíces finas mezcladas con el suelo durante una incubación de ocho semanas. Las tasas promedio de mineralización de N por semana fueron significativamente mayores en las hojas verdes de *Erythrina* e *Inga* (21.60 y 19.40 mg N kg⁻¹ de suelo) que el testigo (suelo solo), en la hojarasca fue mayor en las especies de *I. edulis* e *I. densiflora* (6.74 y 3.93 mg N kg⁻¹ de suelo) y menor en las especies maderables y el café. En las raíces finas la tasa de mineralización fue mayor en *C. alliodora* (14.22 mg N kg⁻¹ de suelo), seguido de *E. poeppigiana* e *I. edulis* (5.61 y 3.79 kg⁻¹ de suelo) en menor grado en el resto de tratamientos. En el segundo ensayo, se determinó el efecto de la descomposición del material foliar y radicular, de las especies anteriores, en el crecimiento inicial de plantas de maíz. La producción de biomasa y la extracción de N por las plantas de maíz fueron mayores en hojas verdes de *E. poeppigiana*. La liberación de N fue mayor en las especies leguminosas que en las maderables. En el tercer ensayo, se evaluaron las tasas de descomposición y liberación de N y C del material foliar y radicular de las especies *I. densiflora* y *C. arabica*. Después de 18 semanas, las pérdidas de peso y N siguieron un patrón exponencial. La descomposición y liberación de N de los materiales evaluados fue mayor en las raíces que en la hojarasca. En conclusión las hojas verdes de especies leguminosas liberaron más N que las especies de sombra por la acción de una rápida descomposición y mineralización, un proceso que favorece una mayor biomasa para las plantas que crecen en asocio con leguminosas, como el café.

2. Estudio del ciclo del nitrógeno con el uso del ¹⁵N en un sistema agroforestal *Coffea arabica* + *Inga densiflora* en Costa Rica

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

21. Introducción

Para evaluar los varios flujos del nitrógeno como la absorción por los diferentes tipos de plantas, la emisión de N de forma molecular N₂ ó la retención de los nitratos por los suelos, el uso de las técnicas isotópicas es indispensable. Gracias al uso del ¹⁵N en una parcela de *Coffea arabica* + *Inga densiflora*, los objetivos de este estudio fueron :

- Cuantificar las emisiones de gases N₂O et N₂ después de la fertilización,
- Cuantificar la acumulación de N en el suelo y la biomasa vegetal,
- Estimar las pérdidas de N por lixiviación,
- Utilizar un modelo hídrico y predecir los riesgos de contaminación de las capas según varios argumentos en 2 sistemas, con y sin árbol de sombra.

22. Materiales y métodos

Sitio experimental

El sitio experimental se encuentra en la finca experimental del ICAFE, CICAFE; ubicada en San Pedro de Barva, a una altitud de 1180 msnm. La temperatura y lluvia promedios son de 23°C y 2000 mm aproximadamente. Las parcelas estudiadas son cultivadas en *Coffea Arabica* con sombra de *Inga densiflora* (INGA) y sin sombra (PS), sembradas en 1997. Las densidades de plantas de café y de *Inga* son de 4684.ha⁻¹ y 316.ha⁻¹ respectivamente en el sistema INGA. La densidad de planta de café en sistema PS es de 5000.ha⁻¹. El suelo es un Andosol (clasificación FAO).

Aplicación del ¹⁵N en la parcela INGA

En el sistema INGA se delimitó una parcela de 156 m² en donde se aplicó la urea marcada con ¹⁵N a 10%. Esta parcela contiene 6 líneas de matas de café y 4 árboles (**figura 1**). La delimitación de ésta parcela se hizo con láminas hasta 60 cm de profundidad.

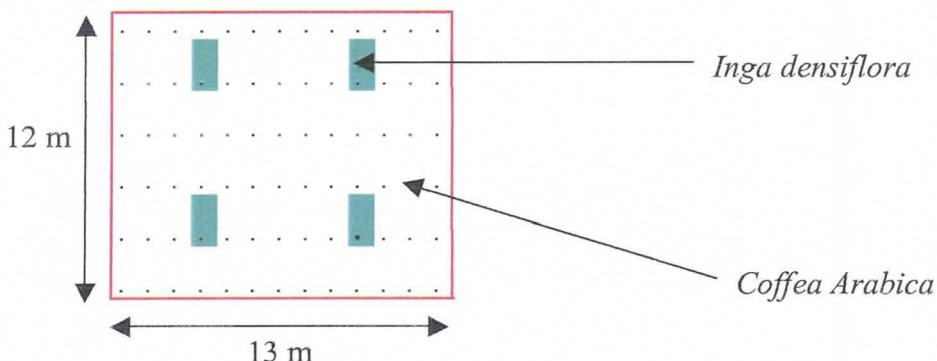


Figura 1 : Parcela de estudio para la aplicación del ¹⁵N

Esta parcela contiene :

- 6 cilindros para medición de gases, 3 en la zona de fertilización y 3 en la calle. El diámetro es de 36 cm y la altura 25 cm.
- Lisímetros : 4 a 30, 60 et 120 cm, y 3 a 200 cm de profundidad.

Los niveles de fertilización son presentados en el cuadro1:

Cuadro 1: Programa de fertilización

| Fecha | Fertilizante | Fertilización ¹⁵ N |
|----------|---|--|
| 24/05/04 | Fórmula completa con N urea (18N, 3P, 10K, 8Mg) – 90 kg N.ha ⁻¹ | - Urea marcada 10% para las matas (0,83 kg ¹⁵ N.ha ⁻¹) - 50% en los cilindros de medición de gases (4,15 kg ¹⁵ N.ha ⁻¹) |
| 03/08/04 | Fórmula completa con N urea (18N, 3P, 10K, 8Mg) – 90 kg N.ha ⁻¹ | Urea marcada 10% para las matas (0,83 kg ¹⁵ N.ha ⁻¹) |
| 25/10/04 | NO ₃ NH ₄ – 70 kg N.ha ⁻¹ | No aportes |

El protocolo de trabajo esta presentado en el **cuadro 3 (Protocolo de trabajo)**:

| Compartimento | Método | Frecuencia | Elementos analizados | Laboratorio |
|---|---|--|---|----------------------|
| Gases N ₂ O y N ₂ | - Cilindros tapados durante 2 horas - Muestreo a los tiempos 0 y 2 horas con circulación de aire | Mediciones 1 vez por día durante 8 días después de la primera fertilización | N ₂ O, N ₂ , ¹⁵ N ₂ O, ¹⁵ N ₂ | INRA Nancy (Francia) |
| Solución del suelo | Muestreo en los lisimetros a 30, 60, 120 y 200 cm de prof. | Cada 10 días durante toda la estación lluviosa. | NO ₃ ⁻ , NH ₄ ⁺ , ¹⁵ NO ₃ ⁻ , ¹⁵ NH ₄ ⁺ | CATIE /INRA |
| N en el suelo | - Muestreo en capas de suelo de 20 a 30 cm cada una. - Extracción K ₂ SO ₄ | Antes de la primera y segunda fertilización, y al final de la estación lluviosa (Febrero 2005) | NO ₃ ⁻ , NH ₄ ⁺ , ¹⁵ NO ₃ ⁻ , ¹⁵ NH ₄ ⁺ | CATIE /INRA |
| N en la biomasa vegetal | Muestreo de raíces, hojas, ramas, tronco (café e Inga) | Antes de la primera y segunda fertilización, y al final de la estación lluviosa (Febrero 2005) | N y ¹⁵ N | INRA |

Balance hídrico y modelización

La modelización del balance hídrico será realizado sobre 2 tipos de cultivos de café fertilizados, INGA y PS. El interés de comparar esos 2 sistemas es de estudiar la influencia del árbol de sombra sobre el ciclo del agua y la lixiviación de N.

Para establecer el balance hídrico, varias medidas físicas del suelo fueron necesarias. Se analizaron la conductividad hidráulica con saturación en agua, la densidad aparente del suelo y la curva de retención en agua hasta 2 m de profundidad en los 2 sistemas, en 2 calicatas. Las profundidades de medición fueron 15, 60, 120 y 180 cm.

Las 2 parcelas tienen los instrumentos siguientes :

- Sondas TDR : 6 sondas en el sistema PS, 9 en el sistema INGA para medir la humedad del suelo en las capas 0-30, 30-60, 60-90, 90-120 y 120-150 cm.
- Pluviómetros y estación meteorológica (Davis).
- Parcelas de escorrentía (3 por sistema).
- Medición de transpiración vegetal y intercepción foliar (ver WP2).

El modelo PASTIS será utilizado para modelizar el ciclo del agua y la lixiviación N. Es un modelo mecanista integrando también los ciclos de C y N, la denitrificación y el transporte de gas en el suelo. Fue desarrollado por el INRA de Francia.

Resultados y discusión

Al menos 23,5% del ¹⁵N aplicado se encontró en la biomasa vegetal antes de la segunda fertilización. En la mata de café el más fuerte porcentaje de ¹⁵N se encontró en los frutos, después en las hojas. Las raíces tienen un nivel de ¹⁵N bastante alto y principalmente en los 60 primeros centímetros del suelo. No se midió el ¹⁵N en el árbol de *Inga*. Pero se supone que la cantidad de ¹⁵N absorbida fue más baja que para la mata de café. Pero se podría estimar una absorción de 5-10% del ¹⁵N.

Si se suman los porcentajes de ¹⁵N en las diferentes partes del sistema agroforestal, llegamos a un balance global de 96 %. En este balance hay que tener en cuenta del error de medición muy importante del ¹⁵N presente en forma de nitratos en el suelo. El coeficiente de variación entre las repeticiones fue de 60% en la capa 0-20 cm, confirmando una fuerte variabilidad espacial del N en la superficie del suelo que podría variar entre 40 y 60% del ¹⁵N aplicado.

La figura siguiente resume el balance ^{15}N antes de la segunda fertilización:



Figura 5: Balance provisional del ^{15}N en el sistema agroforestal Inga + Café antes de la segunda fertilización

Propiedades físicas de los sistemas INGA y PS

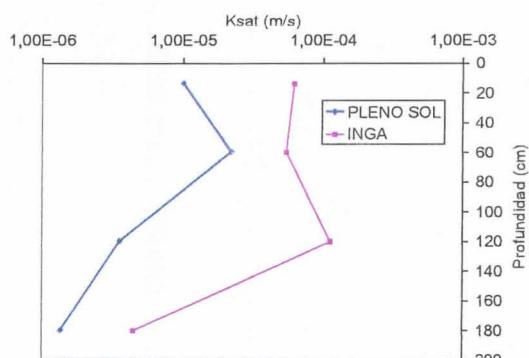


Figura 6: Conductividad hidráulica con saturación en los 2 sistemas

El suelo del sistema INGA muestra una capacidad de drenaje más importante que el suelo del sistema PS con valores de conductividades hidráulicas más altas (figura 6). Este resultado fue confirmado por los valores de densidades aparente más altos en sistema PS que INGA (cuadro 5). Además, el sistema PS presenta un efecto de compactación significativo en los primeros centímetros de profundidad. La presencia de raíces más profundas y más numerosas en sistema INGA puede explicar el potencial más alto de drenaje de agua.

Ciclo del agua y lixiviación de N

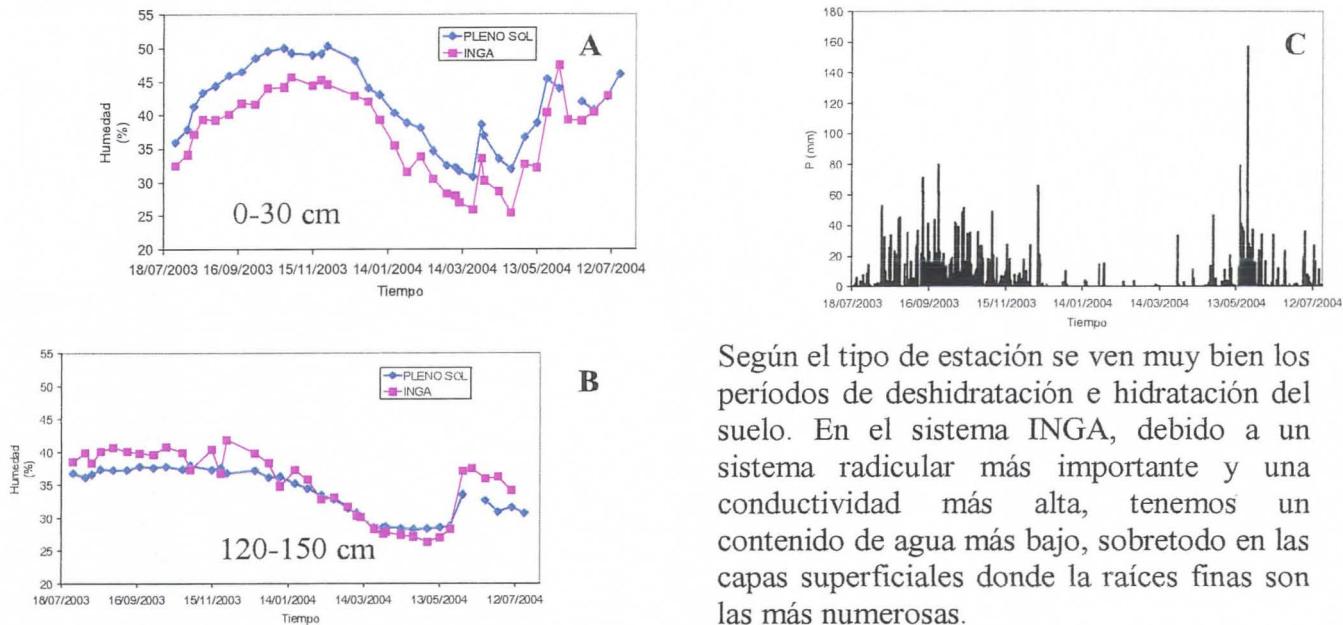


Figura 7: Humedad volumétrica en la capa 0-30 (A) y 120-150 cm (B) del suelo y precipitaciones (C)

Gracias a los datos de humedad del suelo, se pudo hacer una estimación del drenaje en agua para la estación lluviosa 2003. En el cuadro siguiente están varios parámetros necesarios para el balance hídrico:

Cuadro 6: Balance hídrico provisional en los sistemas PS y INGA para 2003

| Sistema | Lluvia (mm) | Intercepción (%) / Transpiración (mm.d ⁻¹) | ETR (mm) | Escorrentía (mm) | Drenaje a 120 cm (mm) | Ascensos Capilares (verano, mm.d ⁻¹) |
|---------|-------------|--|----------|------------------|-----------------------|--|
| INGA | 2910 | 17 / 4 | 1263 | 168 | 1449 | 4,7 |
| PS | 2910 | 11 / 3 | 896 | 274 | 1675 | 3,5 |

La biomasa foliar más importante en sistema INGA explica la evapotranspiración más alta que en sistema PS. Además, la escorrentía es más baja en sistema INGA debido a una hojarasca más importante, limitando la escorrentía (ver detalles en WP2). También, el suelo del sistema PS es compactado en la superficie favorizando la escorrentía. En verano, se observaron ascensos capilares importantes donde el agua presente en capas profundas alimenta las capas más superficiales.

A partir de estas estimaciones de drenaje para el año 2003, y conociendo las concentraciones en NO_3^- en ambos sistemas durante esta estación lluviosa, se estimaron aproximadamente los valores de lixiviación de NO_3^- a 120 cm de profundidad de 131 y 152 kg N.ha^{-1} en los sistemas INGA y PS respectivamente. Estos valores corresponden a una fertilización anual de 250 kg N.ha^{-1} .

Conclusiones y perspectivas

- El primer balance de N con el análisis de ^{15}N mostró que durante un periodo de 1,5 mes despues de la primera fertilización, una gran parte del ^{15}N se quedó inmovilizada en el suelo

Según el tipo de estación se ven muy bien los períodos de deshidratación e hidratación del suelo. En el sistema INGA, debido a un sistema radicular más importante y una conductividad más alta, tenemos un contenido de agua más bajo, sobretodo en las capas superficiales donde la raíces finas son las más numerosas.

mientras que solo 28% fueron absorbidos por la biomasa vegetal. Aunque hubo una variabilidad espacial bastante importante, esto supone un peligro para el riesgo de contaminación de las capas profundas por el N. Se notó un aumento muy fuerte de ^{15}N a 200 cm de profundidad después de la segunda fertilización con concentraciones de mas de 60mg N/litro.

- En la biomasa vegetal faltó la cantidad de ^{15}N exportada por el árbol de *Inga*. Si se supone una pequeña exportación, en el próximo mes de Febrero se estudiará este componente.

Al final de la estación lluviosa (Febrero 2005) un nuevo balance ^{15}N será realizado para estimar las pérdidas, que se esperan más fuertes, de N por lixiviación. Además, se conocerán las cantidades finales de ^{15}N inmobilizada por cada parte de la biomasa vegetal, la exportación de ^{15}N en el fruto maduro de café y la inmobilización de N en el suelo.

- Con los datos climatológicos (precipitación, evapotranspiración, escorrentía), los contenidos en agua del suelo, y algunos parámetros ecofisiológicos (biomasa de hojas, índice de superficie foliar) va a ser posible calibrar el modelo de balance hidráulico :

- Calibración del modelo en la estación seca y lluviosa
- Simulación sobre un año de cultivo
- Estimación con más precisión de los ascensos capilares, conductividades hidráulicas
- Estimación precisa del drenaje del agua y de la lixiviación de N

3. Fijación biológica de N₂ por la leguminosa de sombra en diferentes sistemas agroforestales de café (*Coffea arabica*)

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

31. Introducción

En este estudio se estimó la capacidad de fijación biológica de N de parte de la leguminosa de sombra en dos sistemas agroforestales de café, uno convencional con aporte de fertilizante nitrogenado (250 kg N/ha) y uno orgánico que recibe abono orgánico a razón de 150 kg N/ha/año.

32. Materiales y métodos

Sitio experimental

El sitio experimental se encontró en la Finca Experimental del ICAFE, CICAFE; ubicada en San Pedro de Barva, a una altitud de 1180 msnm.

Los ensayos agroforestales de *Coffea arabica* estudiados fueron:

- café bajo sombra de *Inga densiflora* (*Inga*) y café a pleno sol (PS) con un manejo convencional con 250 kg N/ha/año,
- café bajo sombra de *Erythrina poeppigiana* (poro) y café a pleno sol que reciben solamente abono orgánico a razón de 150 kg N/ha/año.

Fijación biológica

La fijación biológica de nitrógeno en los árboles de *E. poeppigiana* y *I. densiflora* se realizó por medio del método de abundancia natural de ^{15}N . Para eso se tomaron hojas de árbol de los diferentes estratos del follaje (parte inferior, media y superior). También se tomaron muestras de hojas de las plantas de café (planta no fijadora). Se realizaron 5 repeticiones para cada tipo de especie vegetal. Las muestras de hojarasca se secaron a 60° C por 72 horas, se molieron finamente y se analizaron en el INRA en Nancy (Francia) para determinar el contenido de ^{15}N natural, a través del Espectrómetro de masa.

El porcentaje de N derivado de la atmósfera (%Nda) de la muestra se calculó de acuerdo a la siguiente ecuación:

$$\%Nda = (d^{15}N_{Ca} - d^{15}N_{Arb}) / (d^{15}N_{Ca} - d^{15}N_{N-libre}) * 100$$

Donde:

$$d^{15}N = [\%^{15}N_{muestra} / \%^{15}N_{aire} - 1] * 100$$

$d^{15}N_{Ca}$ = es la abundancia natural isotópica en *C. Arabica*, planta de referencia no fijadora de N.

$d^{15}N_{Arb}$ = es la abundancia natural isotópica en *I. Densiflora* ó *E. Poeppigiana*.

$d^{15}N_{N-libre}$ = es el ^{15}N medido en las hojas de *E. Poeppigiana* creciendo en medio libre, con valores entre 0 y -2.

33. Resultados

En el cuadro 2 se presentan los valores de fijación biológica.

Cuadro 2: Fijación biológica de N por las dos leguminosas

| Tipo de hoja | $d^{15}N$ | %Nda con $d^{15}N_{N-libre} = -2$ | %Nda con $d^{15}N_{N-libre} = 0$ |
|----------------------------------|-----------|--------------------------------------|-------------------------------------|
| <i>E. poeppigiana</i> | -0,573 | 72% | 100% |
| <i>C. arabica</i> bajo poro | 3,230 | | |
| <i>C. arabica</i> en sistema PSO | 3,047 | | |
| <i>I. densiflora</i> | 3,759 | 15% | 21% |
| <i>C. arabica</i> bajo INGA | 4,776 | | |
| <i>C. arabica</i> en sistema PS | 1,362 | | |

En el sistema PO, el valor $d^{15}N$ del *E. Poeppigiana* fue muy bajo (negativo), lo que corresponde a una tasa de fijación alta. La tasa de N derivada de la atmósfera varió entre 71 y 100% para *E. Poeppigiana* en el sistema orgánico. Con valores muy similares de $d^{15}N$ de hojas de café en el sistema bajo poro como en pleno sol, no se observó una transferencia del N fijado a la planta de café.

En el sistema INGA, la fijación fue más baja. Utilizando el $d^{15}N$ de la planta de café bajo *I. densiflora*, la fijación del *I. densiflora* varió entre 15 y 21%. Este bajo valor de fijación biológica del N_2 se explica por el alto aporte de N mineral al sistema (250 kg N / ha / año).

4. Variación estacional de la extracción de Nitrógeno en la planta de café

Víctor Chaves (CICAFE, Costa Rica), Jean-Michel Harmand (CIRAD, France), Philippe Vaast (CIRAD, 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 uno 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 % 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%.

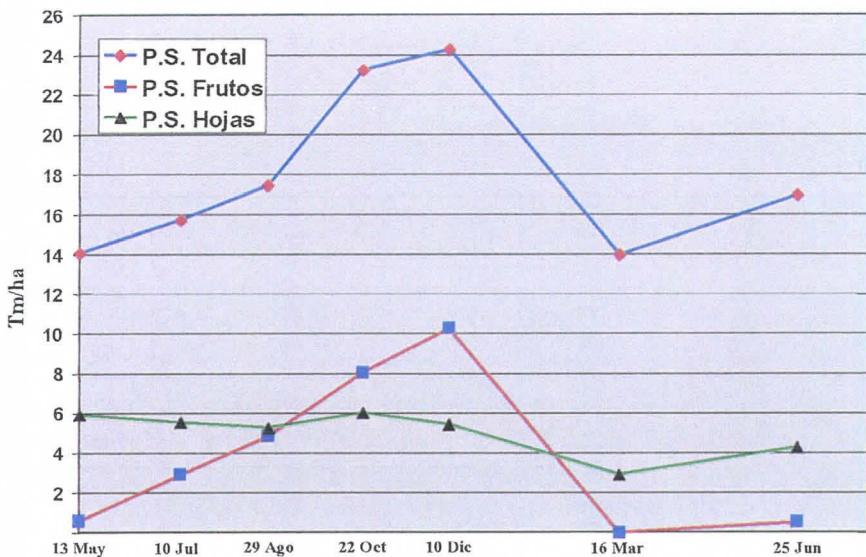


Figura 1 Variación estacional en peso seco (Tm/ha) de la biomasa total, biomasa de hojas y biomasa de frutos. Poas, mayo 2003 – Junio 2004.

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 %).

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 2) el principal reservorio del elemento en la planta.

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

| Fecha | Kg/ha | | | |
|-----------------|-------|-----|-----|----|
| | 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 |

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 18.123 Tm/ha y la extracción de nitrógeno en 281 kg/ha. Para K, Ca y Mg la extracción fue de 336, 75 y 21 kg/ha respectivamente.

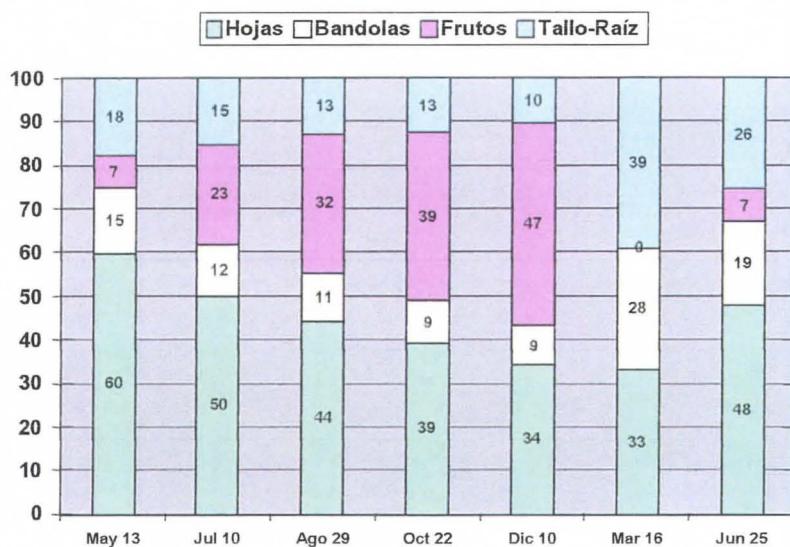


Figura 2 Variación estacional de la contribución porcentual de los órganos en el contenido de N en la planta. Poas, mayo 2003 – Junio, 2004.

Un ensayo similar al anterior se está desarrollando en la actualidad en Barva de Heredia, Costa Rica y en él se contempla el estudio de la evolución de la biomasa y la extracción de nitrógeno en períodos de alta y baja producción. Este estudio se lleva a cabo 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 consideran 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.

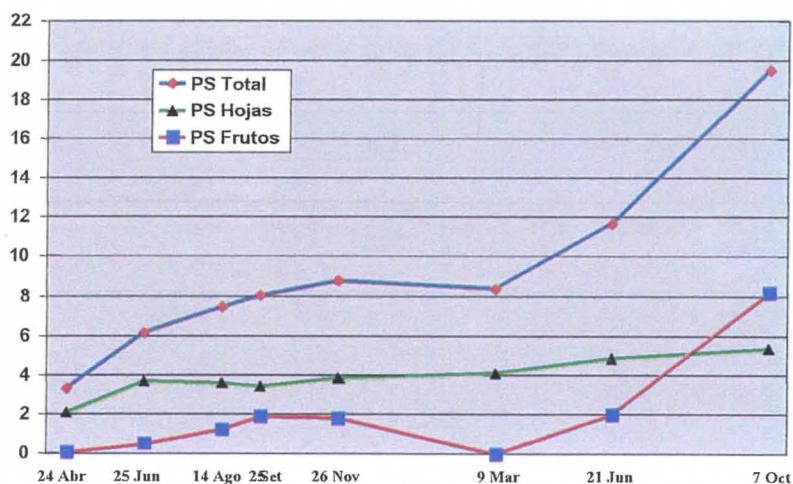


Figura 4 Variación estacional en peso seco (Tm/ha) de la biomasa total, biomasa de hojas y biomasa de frutos. Barva, abril 2003 – Octubre, 2004.

Durante el primer ciclo anual de producción, la biomasa estuvo dominada por el crecimiento vegetativo (figura 4), alcanzándose el pico de biomasa total en la evaluación de noviembre 2003 con 8.8 Tm/ha, de las cuales tan solo un 21 % (figura 5) correspondieron a los frutos.

En el segundo ciclo productivo se experimentó un fuerte desarrollo de los frutos, de modo que en octubre 2004, la biomasa representa 19.5 Tm/ha de la cual un 42 % correspondieron a los frutos.

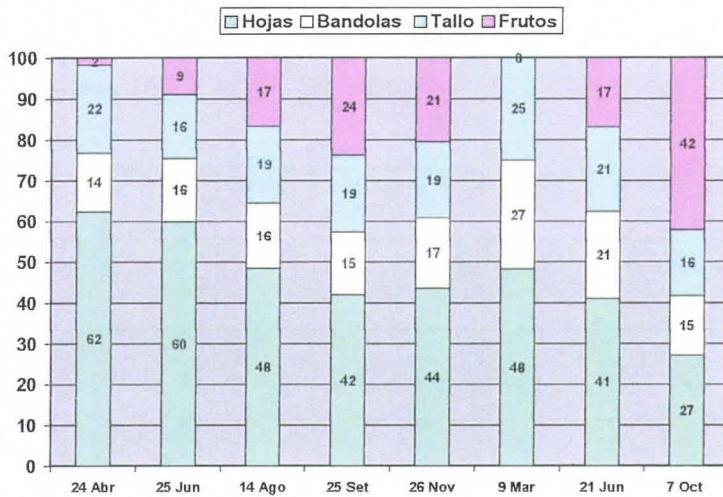


Figura 5 Variación estacional de la contribución porcentual de los órganos en la biomasa total. Barva, abril 2003 – Octubre, 2004.

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

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

1. Objectives and background

Nitrous oxide is a long-lived greenhouse gas, with a high global warming potential (1 molecule of N₂O is equivalent to 250 molecules of carbon dioxide). The soil contributes to more than 60% of the total global emission of N₂O.

In soil, the microbial processes nitrification and denitrification are responsible for N₂O production. There are no non-biological processes in the soil known to produce this gas. Wet soils, high inputs of nitrogen, high soil pH, high carbon content are optimal for maximum N₂O production and emission.

In the INCO-CASCA project, we want to establish how much denitrification and N₂O release occurs under different coffee management practices.

2. Laboratory experiments

21. Objective and methodology

In 2004, two experiments¹ were carried out on soils from different coffee systems of Cicafé, Central Valley of Costa Rica.

The first one, in aerobic conditions, focused on N₂O production by nitrification and denitrification, N₂ production by denitrification. Soils of a coffee system shaded by *I. densiflora* were adjusted to approximately 40, 60, 80% and 90% WFPS (Water Filled Pore Space) and incubated during a six day period.

Three C₂H₂ treatments were established: a first one without C₂H₂ where N₂O was produced by nitrification and denitrification, a second one with 0.1% C₂H₂ where N₂O was produced only by denitrification (nitrification inhibited), a third one with 10% C₂H₂ where N₂O was produced only by denitrification and includes N₂O normally produced as N₂ (inhibition of N₂O reductase). All soil samples received 0.27 mg N g⁻¹ soil as NH₄⁺NO₃⁻. Gas samples were collected in evacuated blood-collection tubes, sealed with thick wax and analysed by ECD gas chromatography, at CEH, Edinburgh.

The second experiment, in anaerobic conditions, focused on N₂O and N₂ production by denitrification. Soils from a full sun and a shaded system by *Inga densiflora* both fertilised (250 kg N ha⁻¹ yr⁻¹ of mineral fertiliser), and from a full sun and a shaded system by *Erythrina poeppigiana* both organically fertilised (150 kg N ha⁻¹ yr⁻¹ of organic fertiliser) were studied. Kinetics of N₂O and N₂ production (treatment without and with 10% C₂H₂) by soils adjusted at 60% WFPS were measured during nine days of incubation. Soils from the conventional systems didn't receive any addition of N (fertilisation was done in the field a few days before sampling) while for the organic soils two treatments were established: without and with addition of 0,04 mg N g⁻¹ soil. Gas samples' collection and analyses were identical as described above.

22. Results

The results of the first experiment showed that:

- N₂O was mainly produced by the nitrification process and N₂O emission increased with increasing soil moisture content,
- N₂ production by denitrification only started at 90% WFPS,
- N₂O effective production by denitrification only started at 90% WFPS.

The results of the second experiment (figure 1) showed that:

- N mineral fertiliser addition increased N₂O and N₂ production by denitrification (comparison between the two full sun systems and between Po-SE and Po-SE+KNO₃),
- there was no difference in N₂O production by denitrification between full sun systems and shaded systems.
- for the organic systems, denitrification potential is much higher in the shaded system than in the full sun one.

¹ HERGOUALC'H, K. (2004). Formation d'oxyde nitreux par nitrification et dénitrification en fonction de l'humidité du sol. Étude d'un sol volcanique sous différents systèmes cafiers au Costa Rica. ENSAIA. Nancy, INPL, France: 29.

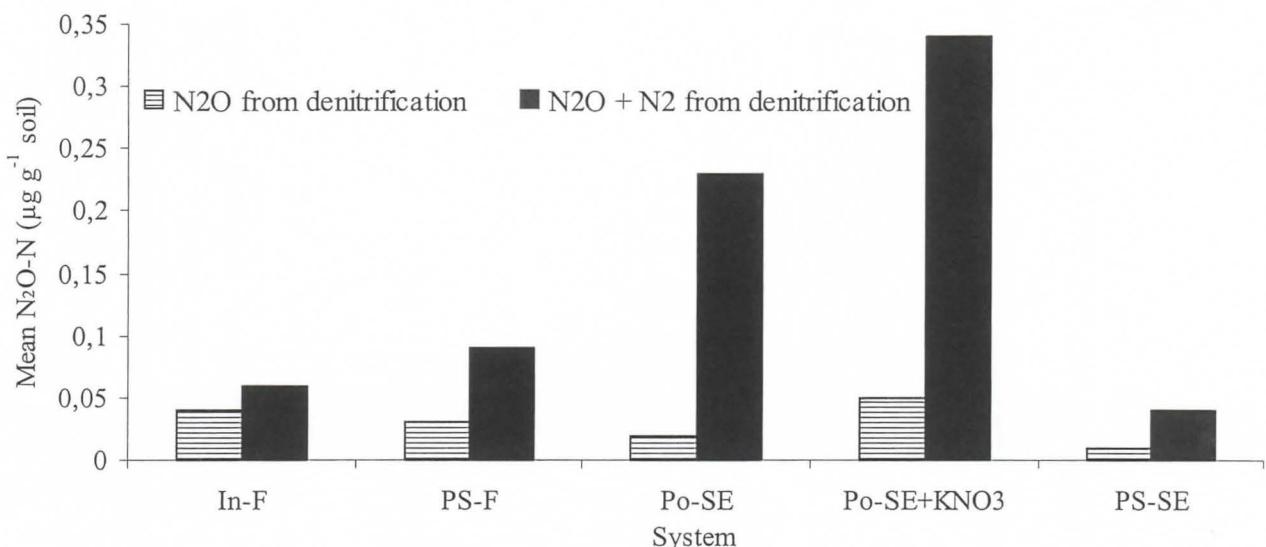


Figure 1: Mean N₂O production over a 9 days incubation period for conventional coffee systems (In-F and PS-F (shaded by *Inga densiflora* and full sun), organic coffee systems : Po-SE and PS-SE (shaded by *Erythrina poeppigiana* and full sun), the shaded organic system to which KNO₃ was added : Po-SE+KNO₃.

23. Conclusion

These experiments suggest that the main process involved in N₂O emissions from soils of Cicafé is nitrification. N₂O production by denitrification was low and not emphasised by the presence of trees while the denitrification potential was higher in the organic coffee system shaded with legume trees. N₂O production by denitrification was higher when N mineral fertiliser was applied to the soil sample.

3. Field measurements

31. Background and objectives

Previous measurements done in 2002 and 2003 showed that:

- The influence of shade trees on N₂O emissions is not clear and may be different according to the type of soil,
- There was a linear relationship between N applied and N₂O emissions (Fertiliser trial in Cicafé).

Studies carried out on the 3rd year of Casca project were limited to only one site (Cicafé), in order to restrict parameters influencing N₂O emissions such as soil type and climate.

32. Material and methods

N₂O fluxes from soil were measured by the static chamber method. The systems studied, located at Cicafé, were:

- full sun coffee and coffee shaded by *Erythrina poeppigiana* (Poró) both organically fertilised (150 kg N ha⁻¹ yr⁻¹ of organic fertiliser),
- full sun coffee and coffee shaded by *Inga densiflora* both conventionally fertilised (250 kg N ha⁻¹ yr⁻¹ of mineral fertiliser),
- full sun mineral fertiliser trial (0, 150, 250 and 350 kg N ha⁻¹ yr⁻¹).

33. Results

- a) N₂O fluxes from the studied systems are presented in table 1:
- at Cicafé, organic systems do emit less N₂O than conventional systems,
 - the influence of shade trees on N₂O emissions is still not clear. It looks like for the organic systems, legume shade tree favoured N₂O emissions whereas it does not in conventional systems, and even reduces N₂O emissions (see results b).
 - N applied still affect N₂O emissions, but the relationship between both is not totally linear as measured in 02.

| Treatment | Date of sampling | N ₂ O ($\mu\text{g N-N}_2\text{O m}^{-2} \text{ h}^{-1}$) | | Stdev | Min | Max | n |
|------------------------|------------------|--|-------|--------|--------|-----|---|
| | | Mean | n | | | | |
| Full sun (150 organic) | 31/05/04 | 10,38 | 3,8 | 5,04 | 13,97 | 4 | |
| Poró (150 organic) | 31/05/04 | 22,47 | 14,63 | 12,91 | 44,2 | 4 | |
| Full sun (250) | 25/05/04 | 52,33 | 21,71 | 24,94 | 95,94 | 7 | |
| Inga (250) | 25/05/04 | 52,29 | 54,16 | -29,84 | 139,71 | 7 | |
| Control | 25/06/04 | 8,60 | 10,80 | -3,83 | 15,69 | 3 | |
| 150 | 25/06/04 | 17,98 | 7,29 | 7,15 | 22,95 | 4 | |
| 250 | 25/06/04 | 30,38 | 11,70 | 22,21 | 47,72 | 4 | |
| 350 | 25/06/04 | 24,02 | 3,60 | 21,47 | 26,56 | 2 | |

Table 1: N₂O emissions from 2 organic coffee systems (full sun and shaded by *Erythrina poeppigiana*), 2 conventional systems (full sun and shaded by *Inga densiflora*) and a coffee full sun fertiliser trial, in Costa Rica (Stdev: standard deviation of the mean, Min : minimum value, Max : maximum value, n : number of observations).

b) Measurements of N₂O fluxes since 2002 from the two conventional systems are summarised in Figure 2. These results showed higher N₂O emissions for the full sun system than for the shaded one after fertiliser apply during the rainy season. But, N₂O emissions seem to be higher for the shaded system during the dry season (from December to April mid-May).

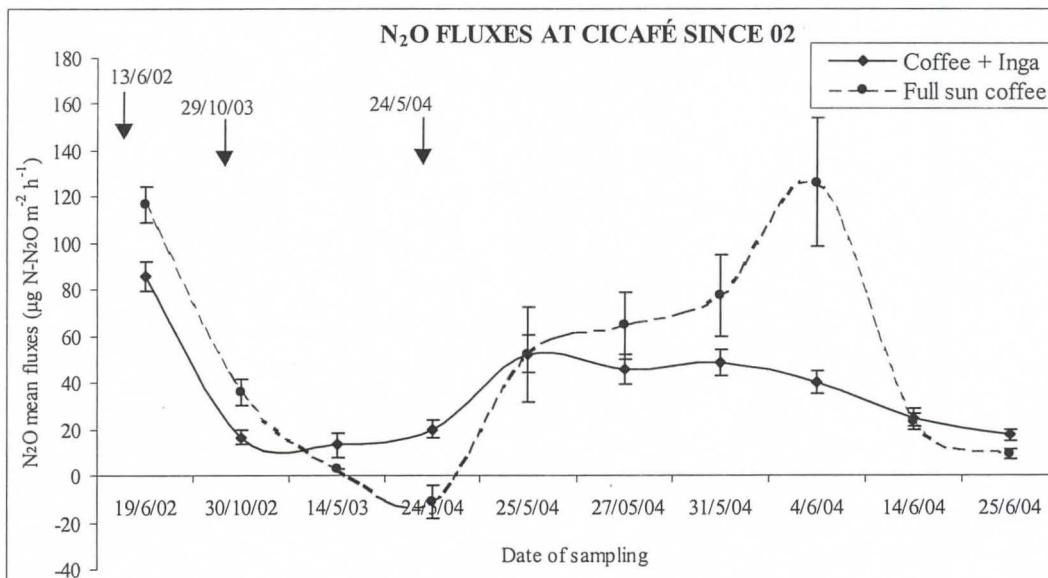


Figure 2: Mean N₂O fluxes measured on two coffee systems at Cicafé since mid 2002. The arrows indicate days of fertilization. Vertical bars represent standard errors (n = 4 before 04, n = 7 and 8 after 04 respectively for full sun and coffee + Inga systems).

Conclusion and perspectives:

Increased N₂O emissions with increasing N fertiliser inputs, shown in laboratory experiments, were confirmed by “in situ” measurements. The comparison between organic and conventional systems at Cicafé showed that organic systems emit less N₂O than conventional systems. Nevertheless, as far as denitrification potential of the organic coffee system shaded with legume tree gave much higher values than all the other systems we need further measurements to compare N₂O emission in organic coffee system with or without legume shade tree. As nitrification has been found to be the main process in N₂O production in laboratory experiments, it would be interesting to compare systems on N₂O production by nitrification. The distinction between nitrification and denitrification “in situ” is only possible using isotope ¹⁵N, methodology difficult and expensive.

A new model proposed by Hénault (NOE, in press) makes “in situ” N₂O emissions prediction possible, on the basis of laboratory experiments on denitrification potential, N₂O accumulation during denitrification and N₂O production by nitrification. The validation of the model, performed by comparison between N₂O emissions predicted and measured, would enable the evaluation of nitrification and denitrification role in N₂O emissions. Another objective is to model N₂O emissions with the DNDC simulator, in function of the climate, type of soil, type and dose of fertilisation.

Tesis presentadas en 2004:

Kristell Hergoualc'h, 2004. Formation d'oxyde nitreux par nitrification et dénitrification en fonction de l'humidité du sol. Étude d'un sol volcanique sous différents systèmes caféiers au Costa Rica. ENSAIA. Nancy, INPL, France: 29.

Victoria Eugenia Osorio Moreno, 2004. Descomposición y liberación de nitrógeno de material foliar y radicular de siete especies de sombra en un sistema agroforestal con café. Tesis M.Sc., CATIE, Turrialba, Costa Rica. 75p.

Articulos en edicion:

Avila H., Harmand J.M, Dambrine E., Jiménez F., Beer J., Oliver R., 2004. Dinámica del nitrógeno en el sistema agroforestal *Coffea arabica* con *Eucalyptus deglupta*, en la zona sur de Costa Rica. Agroforesteria en las Américas.

Gutiérrez Castillo M., Harmand J.M., Dambrine E., 2004. Disponibilidad de nitrógeno en el suelo bajo especies maderables y leguminosas usadas como sombra en sistemas de *Coffea arabica*. Agroforesteria en las Américas.

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. Agroforesteria en las Américas.

Comunicación presentada al Primero Congreso Mundial de Agroforesteria en Miami en Julio 2004:

Jean-Michel Harmand, Hector Avila, Etienne Dambrine, Francisco Jiménez, John Beer. 2004. Nitrogen dynamics and nitrate water contamination in a *Coffea arabica* - *Eucalyptus deglupta* agroforestry system in Southern Costa Rica.

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

Contract ICA4-2001-10071

Third Annual Report WORK PACKAGE 5

1 November 2003 - 31 October 2004

WP5 : Carbon sequestration

Workpackage leader: Jean-Michel Harmand (Cirad)

The three objectives of the WP “Carbon sequestration” are:

- To elaborate a database and a model of carbon (C) stored in coffee systems in Central America
- To improve the understanding of C dynamics in biomass and soil of coffee systems with respect to types and intensity of management
- To link C model prediction at the site scale to the regional scale for economical analyses and environmental assessments

In 2004, the task 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 below ground) and soil organic C was undertaken to establish C budgets. In existing long term experiments in Costa Rica with and without leguminous shade trees, soil C measurements were done to establish C sequestered in soil over a 3-4 year period.

On pseudo-chronosequences of the *Eucalyptus deglupta* – coffee system (sub-plots of increasing age) where above ground biomass had been quantified in 2002, other measurements were taken two years later in 2004, in order to characterise above ground C dynamics in this agrosystem. From surveys of 66 coffee farms in three contrasting regions of Costa Rica, the biomass and the amount of carbon sequestered were estimated in the aerial tree part of *Eucalyptus deglupta* in the optimal region, *Cordia alliodora* and *Terminalia amazonia* in sub-optimal regions for coffee cultivation.

1. Biomasa aerea del sistema de café con *Inga densiflora*

Patrice Cannavo (Cirad-Forêt, CATIE), Pablo Siles (CATIE), Luis Dionisio (CICAFE, Costa Rica), Jean-Michel Harmand (Cirad-Forêt, CATIE), Philippe Vaast (Cirad-CP, CATIE)

1.1. Introducción

En este trabajo se presentan las mediciones de biomasa de cada parte de las plantas de café y de árbol de *Inga densiflora* en dos sistemas con y sin sombra de *Inga*. Los objetivos del estudio eran los siguientes: (1) establecer relaciones alométricas que permitan la estimación de la biomasa aerea del árbol de *Inga densiflora*, utilizando un parámetro fácil de medir en el campo; (2) estimar la biomasa de café a partir de muestreos de plantas de tamaño promedio.

1.2. Materiales y métodos

El sitio experimental se encuentra en la Finca Experimental del ICAFE, CICAFE; ubicada en San Pedro de Barva, en la provincia de Heredia, entre las coordenadas geográficas 10.03°N y 84.14°O, a una altitud de 1180 msnm. La temperatura y lluvia promedios son de 23°C y 2500 mm aproximadamente. Las parcelas estudiadas son cultivadas en *Coffea Arabica* con sombra de *Inga densiflora* (INGA) y sin sombra (PS), sembradas en 1997. Las densidades de plantas de café y de *Inga* son de 4684.ha⁻¹ y 316.ha⁻¹ respectivamente en el sistema INGA. La densidad de planta de café en sistema PS es de 5000.ha⁻¹. El suelo es un Andisol.

En Mayo 2004 se sacaron 8 plantas de café de tamaño promedio en ambos sistemas, donde se separaron: las hojas, los frutos, las ramas, el tronco, la raíz pivotante y las raíces secundarias. Se pesaron cada parte y se secaron submuestras a 60°C durante 72h para determinar la humedad de cada parte de la planta. En Julio 2004 se midieron todos los diámetros de las ramas de *Inga densiflora* a 1,30 m de altura (DAP) desde el nivel del suelo. Se estableció un diagrama de frecuencia para definir 10 clases de diámetro y elegir al azar una rama de cada clase que se cortó. De esta rama se separaron: las hojas, las ramas y el tronco. Se pesaron cada parte y se secaron submuestras a 60°C durante 72h para determinar la humedad de cada parte del árbol. Con estos resultados se establecieron relaciones alométricas para estimar la biomasa de *Inga densiflora*.

2. Resultados y discusión

Cada árbol de *Inga densiflora* tuvo un nombre de ramas promedio de 2.4. El DAP de las 99 ramas presentes en el sistema INGA varió entre 7,5 y 17,2 cm (**figura 1**).

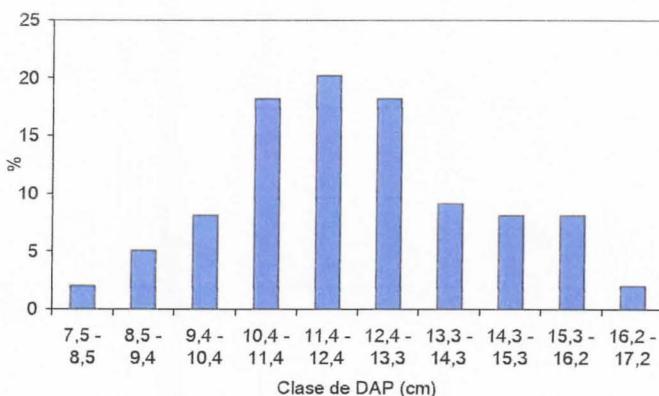


Figura 1: Diagrama de frecuencia del diámetro de las ramas de *Inga densiflora*

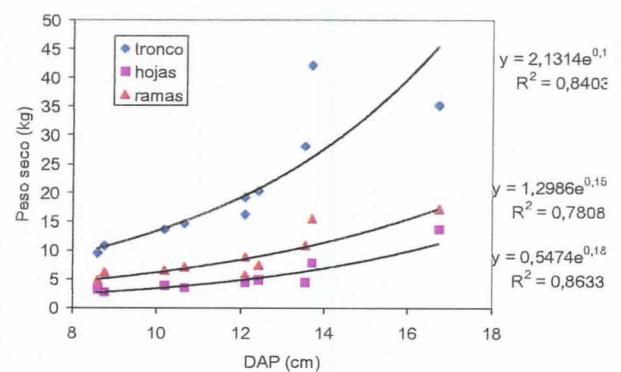


Figura 2: Relación alométrica para la rama de *Inga densiflora*

Las relaciones alométricas obtenidas (figura 2) fueron aplicadas al inventario para estimar la biomasa de *Inga densiflora* a nivel de la parcela.

Cuadro 1: Biomasa aerea de cada componente del sistema café -árbol de *Inga densiflora*

| Componente | Organo | Materia seca (kg .ha ⁻¹) | |
|----------------------------------|-------------------------|--------------------------------------|--|
| | | Pleno sol | Sistema agroforestal Café + <i>Inga</i> |
| Café | Hojas | 3779 | 3621 |
| | Ramas | 4974 | 5224 |
| | Frutos | 763 | 300 |
| | Tronco | 9243 | 9980 |
| Total Café | | 18759 | 19125 |
| Inga | Tronco + Rama principal | | 22742 |
| | Hojas | | 6779 |
| | Ramas secundarias | | 3982 |
| Total Inga | | | 33503 |
| Total sistema (sin hojarasca) | | 18759 | 52628 |

Si se comparan los dos sistemas, el sistema PS tiene más frutos que el sistema INGA pero tiene menos biomasa vegetativa (**Cuadro 1**). Con la hipótesis de un contenido en C en la biomasa de 48%, se estimó un contenido de C de 9 y de 25 ton C.ha⁻¹ en los sistemas PS e INGA respectivamente. Es decir que el sistema INGA tuvo un nivel de C en su biomasa aerea 2.7 más importante que el del sistema PS.

En Febrero 2005 se sacará un arbol entero de *Inga densiflora* y cafetos enteros para estimar la biomasa de raíces pivotantes y secundarias. Se estimarán también las biomassas de hojarasca en ambos sistemas.

2. Dinámica de la materia orgánica del suelo en sistemas agroforestales de café con *Erythrina poeppigiana* en Costa Rica

Zuluaga Peláez John Jairo (CATIE, Costa Rica), Harmand Jean-Michel (CIRAD, France), Fidel Payan (CATIE, Costa Rica)

21. Introducción

En el siguiente estudio se presenta la evaluación de la dinámica de la materia orgánica del suelo, dentro de un periodo de cuatro años en fincas cafetaleras y tres años en parcelas de un ensayo de sistemas agroforestales con café del CATIE, con el propósito de determinar como el árbol de *E. poeppigiana* y el manejo orgánico y convencional tienen efectos sobre los contenidos de C y N del suelo.

22. Materiales y métodos

El estudio se realizó en cuatro pares de fincas en las localidades de Aserri, CATIE, Paraíso y Pejibaye en Costa Rica, así como en tres tratamientos del ensayo de SAF con café del CATIE. Para el caso de las fincas, el muestreo de suelos siguió el mismo procedimiento en 2000 y 2004. Se seleccionaron dentro de cada par de fincas (orgánica y convencional) un área experimental de 30 x 50 m, en la cual se establecieron tres sub-unidades de muestreo al azar, cada una determinada por la presencia de cuatro árboles de poro (*E. Poeppigiana*) y aproximadamente tres hiladas de café. En cada sub-unidad de muestreo se seleccionó al azar un árbol de poro donde se localizaron dos sitios A y B de muestreo: Sitio A = debajo de una planta de café a 40 cm de su tallo y a menos de 1 m del árbol de *E. Poeppigiana*, sitio B = debajo de una planta de café a 40 cm de su tallo y a más de 2 m del árbol de *E. Poeppigiana*. Las muestras fueron tomadas en las profundidades 0-5 y 5-10 cm. Para determinar C y N total del suelo, las muestras fueron analizadas por combustión total en el laboratorio de suelos del CATIE.

Para el caso del ensayo de sistemas se seleccionaron los siguientes tres tratamientos:

- café mas poró bajo manejo medio orgánico (MO poró). El tipo de enmienda aplicado al suelo son abonos orgánicos (pulpa de café, gallinaza, piedra mineral molida y cal), el manejo de malezas es con manejo de sombra, cobertura de hojarasca y guadaña, el manejo de plagas y enfermedades con control biológico y productos orgánicos.
- café más poró bajo manejo medio convencional (MC poró). El tipo de enmienda aplicado al suelo son fertilizantes químicos, el manejo de malezas es con manejo de sombra, cobertura de hojarasca, guadaña y herbicidas, el manejo de plagas y enfermedades con insecticidas y fungicidas.
- café a pleno sol bajo manejo medio convencional (MC PS). Este presenta el mismo manejo que el anterior.

El muestreo de suelos siguió el mismo procedimiento en 2001 y 2004. En cada una de las parcelas se identificó la unidad experimental donde se realizó el muestreo tres años atrás, en las cuales se establecieron cuatro sub-unidades de muestreo (repeticiones) al azar. Dentro de cada una de ellas se establecieron tres unidades de muestreo, cada una determinada por la presencia de cuatro árboles de poro (*E. Poeppigiana*) y aproximadamente tres hiladas de café, esto para el caso de las dos parcelas de café con poró y para la parcela a pleno sol estuvo determinada por la presencia de 21 plantas de café. Las muestras fueron tomadas con barreno en la profundidad 0-10 cm. Para determinar C y N total del suelo, las muestras fueron analizadas por combustión total en el laboratorio de suelos del CATIE.

23. Resultados principales

231. Estudio de la dinamica de C del suelo en fincas cafetaleras con *Erythrina poeppigiana*

El primer estudio fue echo en 2000 por Fidel Payan y la figura 3 presenta los resultados principales. Payan *et al.* (2002) encontraron que en los sistemas orgánicos no se encontraron diferencias espaciales con respecto a los árboles de sombra mientras que en los sistemas convencionales, las posiciones de muestreo situadas a mas de 2 m de los árboles resultaron con menores valores de C y N. Las áreas cercanas a los árboles presentaron valores similares para C y N en los dos sistemas, indicando que los residuos de árboles ejercieron una acción benéfica en los sistemas convencionales. En esos sistemas convencionales, el uso frecuente de herbicidas eliminó la cobertura vegetal lo que aumentó el proceso de erosión y limitó la incorporación de materia organica al suelo, por lo tanto puede reducir las concentraciones de C y N del suelo. El aporte de hojarasca y de residuos de poda del arbol en esos sitemas pudo contrarestar esos efectos negativos alrededor del arbol. La capa 0-5 cm fue la más adecuada para observar las diferencias entre sistemas.

De los datos analizados se desprendió como hipótesis, que las fincas orgánicas tuvieron más C en el suelo por la mayor producción de biomasa de las arveses que fueron cortadas, por el uso de abonos orgánicos y en algunos casos, por una mayor densidad de sombra. En los sistemas convencionales los árboles elevaron la concentración de C en el suelo en un área circundante del arbol que puede llegar a representar 20 por ciento del área total en altas densidades de población de *E. poeppigiana* ($625 \text{ árboles ha}^{-1}$).

En el sistema convencional, en el año 2000, se partió de un contenido de C en el sitio B (a más de 2m del arbol) significativamente más bajo que en el sitio A (menos de 1 m del arbol) y durante 4 años, se aumentó el C en el sitio B hasta el mismo nivel que en el sitio A (figura 3). Eso se puede explicar por el cambio de manejo que ocurrió durante este tiempo. Debido a los altos costos de producción por los precios de fertilizantes y herbicidas, las fincas convencionales disminuyeron la aplicación de estos insumos. Por lo tanto, hubo más malezas en el sistema. Otro aspecto que pudo haber influido en el mayor incremento de C lejos del

arbol, en el sistema convencional (figura 4), es la presencia de plantas de plátano (*Musa sp*) que han sido sembradas entre los árboles, las cuales una vez cosechadas son picadas sobre el suelo incorporando su biomasa como abono verde.

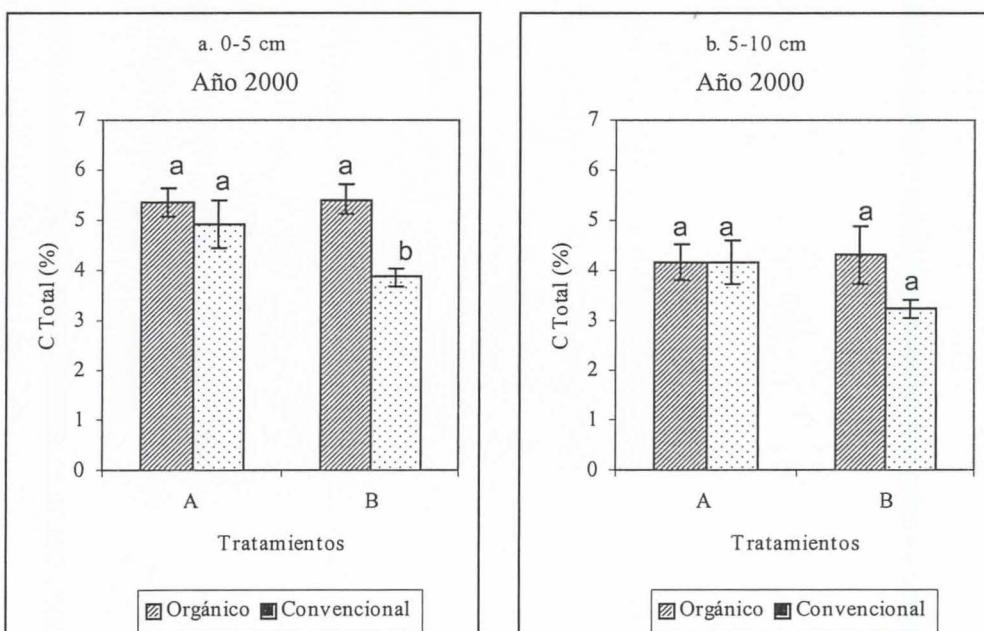
Segun el sitio y la capa (0-5 cm o 5-10 cm), el aumento de la reserva de C durante 4 años, vario de 1 a 3 toneladas de C por ha en el sistema organico establecido desde hace mas de 8 años. En el sistema convencional que ha cambiado de manejo, el incremento de C varió de 3 a 6 toneladas de C por ha en la capa 0-5 cm y de 1 a 2 toneladas de C por ha en la capa 5-10 cm (figura 4).

232. Estudio de la dinamica del C del suelo en tres tratamientos del ensayo de sistemas agroforestales con café del CATIE en Turrialba

En el ensayo de sistemas del CATIE, el uso anterior del suelo fue caña de azucar durante más de 10 años y en 2000 fue quemada y cortada la caña por ultima vez y reemplazada por sistemas de café. Por eso, hubo volteo del suelo y limpieza constante de las malezas hasta abril 2001, fecha del primer muestreo. Despues todos los sistemas de café estudiados : (1) manejo (medio) organico con poro, (2) manejo (medio) convencional con poro y (3) manejo (medio) convencional en pleno sol presentaron incremento de C, N y C/N durante los 3 años (2001a 2004) (figuras 5 y 6).

Eso significa que hubo incorporación de materia organica y secuestro de C en el suelo a partir de 2001. Sin embargo, el manejo organico con poro presentó una tendencia con mayor incremento de C y N que los manejos convencionales con y sin sombra. Eso se tradujo por un contenido significativamente mayor de C y N de la fraccion de macromateria organica > 53 μm en el manejo organico con poro en 2004 (2.12 g C/100g de suelo) seguido por el manejo convencional en pleno sol y con poro (1.62 y 1.42 g C/100g de suelo respectivamente). En este ensayo de sistemas se determino las tasas de mineralizacion del N del suelo mediante incubaciones de 5 semanas en el laboratorio. Esas tazas fueron significativamente más altas en los sistemas con sombra de poro (1.27 y 1.24 mg N/ kg de suelo/ día para manejo organico y manejo convencional respectivamente) que en pleno sol (0.59 mg N / kg suelo/día).

En conclusión, la introducción de poro en el sistema de café no tuvo efecto positivo en el incremento de C del suelo en 3 años pero tuvo efecto positivo sobre la movilización de N. La tendencia a presentarse mayor contenidos de C y N en el sistema organico pudo ser debido a la addición de abono organico.



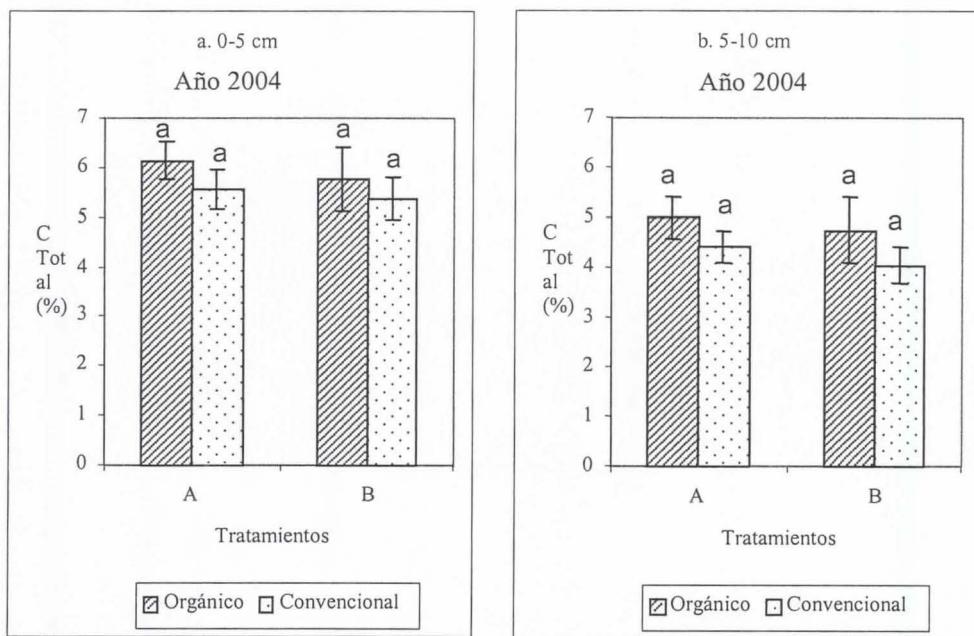


Figura 3. Contenidos de C total (%) de la capa 0-5 cm del suelo en los años 2000 y 2004 para cada sitio en fincas cafetaleras con manejo orgánico y convencional. Costa Rica 2004.

Sitio A = debajo de un cafeto a 40 cm de su tallo y a menos de 1 m de *E. poeppigiana*

Sitio B = debajo de un cafeto a 40 cm de su tallo y a más de 2 m de *E. poeppigiana*

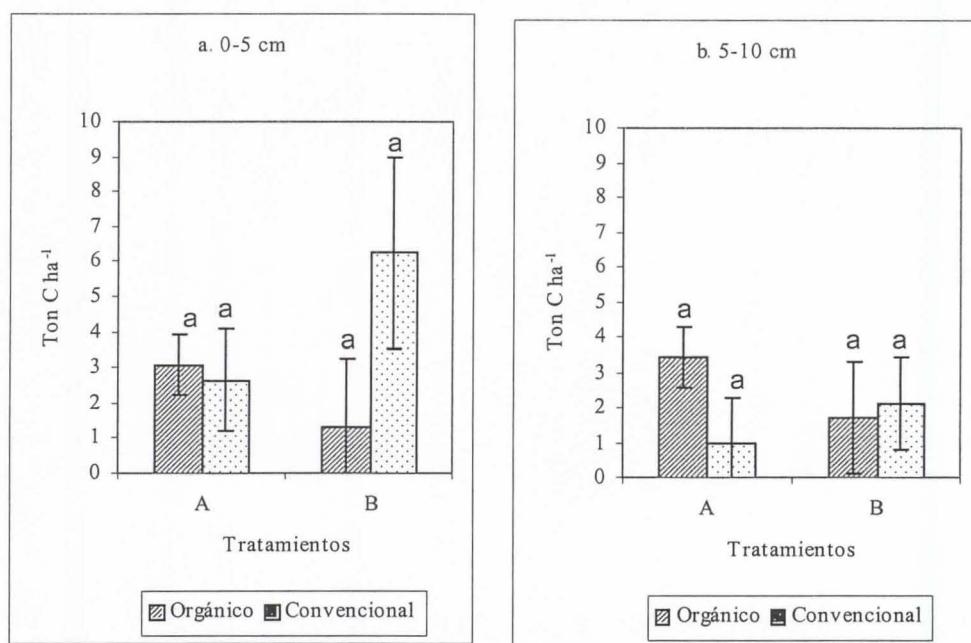


Figura 4. Incremento de C total (ton/ha) durante cuatro años por cada profundidad y sitio en el suelo de fincas cafetaleras con manejo orgánico y convencional, Costa Rica 2004. A= debajo de un cafeto a 40 cm de su tallo y a menos de 1 m de *E. poeppigiana*. B= debajo de un cafeto a 40 cm de su tallo y a más de 2 m de *E. poeppigiana*

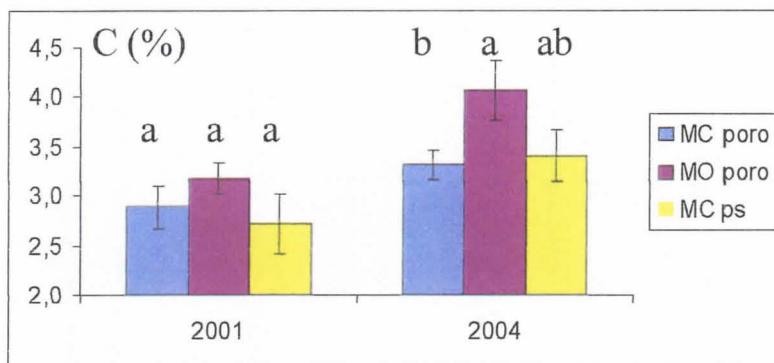


Figura 5. Contenidos de C (%) de la capa à-10 cm del suelo en 2001 y 2004, en tres tratamientos del ensayo de sistemas agroforestales con café del CATIE, Costa Rica, 2004.
MC poro : Café bajo poro con manejo convencional; **MO poro :** Café bajo poro con manejo organico; **MC ps :** Café a pleno sol con manejo convencional

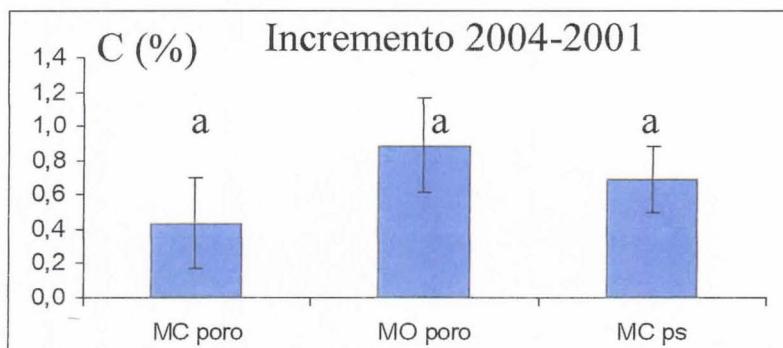


Figura 6. Incrementos en los contenidos de C de la capa 0-10cm del suelo durante tres años, en tres tratamientos del ensayo de sistemas agroforestales con café del CATIE, Costa Rica. 2004.

MC poro : Café bajo poro con manejo convencional; **MO poro :** Café bajo poro con manejo organico; **MC ps :** Café a pleno sol con manejo convencional

3. Almacenamiento de carbono en árboles maderables en fincas cafetaleras de tres regiones contrastantes de Costa Rica

Benito Dzib (CATIE); Philippe Vaast (CIRAD); Jean-Michel Harmand (CIRAD); T. Llanderal (CIRAD)

31. Introducción

Los objetivos de este trabajo fueron estimar la biomasa y el carbono almacenado en la parte aérea de tres especies maderables (*Cordia alliodora*, *Eucalyptus deglupta* y *Terminalia amazonia*) predominantes en tres regiones contrastantes de Costa Rica.

22. Materiales y métodos

El estudio se realizó en tres regiones cafetaleras de Costa Rica seleccionadas por sus condiciones eco-climáticas contrastantes:

- la región de La Suiza, Turrialba, Cartago ($9^{\circ}47'14''$ N y $83^{\circ}34'03''$ O) con una precipitación media anual de 2.600 mm, temperatura media de 23°C y altura media de 616 msnm;
- la región de Grecia-Naranjo, Alajuela ($10^{\circ}24'44''$ N y $84^{\circ}12'56''$ O) con una precipitación media anual de 2.100 mm, altura media de 1.000 msnm y temperatura media de 21°C ;
- y la región de San Isidro, Pérez Zeledón, San José ($10^{\circ}01'59''$ N y $84^{\circ}02'41''$ O) con una precipitación media anual de 3.000 mm, altura media de 650 msnm y temperatura media de 24°C .

En esas regiones, se seleccionaron fincas cafetaleras con las especies maderables predominantes: 20 fincas con laurel (*C. alliodora*) en La Suiza; 21 con eucalipto (*E. deglupta*) en Grecia-Naranjo; y 25 con amarillón (*T. amazonia*) en San Isidro.

33. Resultados principales

Según las mediciones del presente estudio, se obtuvo una densidad media de 184 árboles ha^{-1} de *C. alliodora* en la Suiza y de 373 árboles ha^{-1} de *T. amazonia* en San Isidro, mientras que en la región óptima de Grecia-Naranjo la densidad media de *E. Deglupta* fue solamente de 78 árboles ha^{-1} .

Se observó que la biomasa y el carbono almacenado en la parte aérea de los maderables están influidos por la densidad y la edad de los árboles, y también el manejo proporcionado al café. Además, se estimó que los valores promedios de carbono almacenado en la parte aérea fueron de: $39 \pm 27 \text{ t ha}^{-1}$ para *C. alliodora* a la densidad de 184 árboles ha^{-1} y edad de 13 años; $32 \pm 16 \text{ t ha}^{-1}$ para *T. amazonia* a la densidad de 373 árboles ha^{-1} y edad de 8 años; y $14 \pm 10 \text{ t ha}^{-1}$ para *E. deglupta* a la densidad de 78 árboles ha^{-1} y edad de 8 años.

Cuadro 2. Rangos y valores promedios de densidad, biomasa y carbono almacenado en la parte aérea de tres especies forestales (*Cordia alliodora*, *Terminalia amazonia* y *Eucalyptus deglupta*) en fincas cafetaleras de tres regiones contrastantes de Costa Rica.

| Especie/región | Rango | Promedio | Desviación estándar |
|--|-----------|----------|---------------------|
| <i>Cordia alliodora</i> / La Suiza de Turrialba | | | |
| Densidad (árboles ha^{-1}) | 110 a 360 | 184 | 66 |
| Biomasa (t ha^{-1}) | 30 a 243 | 77 | 54 |
| Carbono (t ha^{-1}) | 15 a 122 | 39 | 27 |
| Edad (años) | 9 a 17 | 13 | 2 |
| <i>Terminalia amazonia</i> / San Isidro de Pérez Zeledón | | | |
| Densidad (árboles ha^{-1}) | 110 a 700 | 373 | 191 |
| Biomasa (t ha^{-1}) | 15 a 155 | 66 | 33 |
| Carbono (t ha^{-1}) | 7 a 75 | 32 | 16 |
| Edad (años) | 4 a 13 | 8 | 2 |
| <i>Eucalyptus deglupta</i> / Grecia-Naranjo | | | |
| Densidad (árboles ha^{-1}) | 30 a 190 | 78 | 44 |
| Biomasa (t ha^{-1}) | 10 a 97 | 28 | 20 |
| Carbono (t ha^{-1}) | 5 a 48 | 14 | 10 |
| Edad (años) | 4 a 15 | 8 | 3 |

Tesis presentadas en 2004:

John Jairo Zuluaga Peláez 2004. Dinámica de la materia orgánica del suelo en sistemas agroforestales de café con *Erythrina poeppigiana* (Walpers) O.F. Cook en Costa Rica. Magíster Scientiae, CATIE, Costa Rica, 120p.

Benito Bernardo Dzib Castillo. 2004. Crecimiento de tres especies forestales establecidas dentro de plantaciones de café en tres regiones de Costa Rica. Magíster Scientiae, CATIE, Costa Rica, 45p.

Articulos en edición :

De Miguel Magaña S., Harmand J.M., Hergoualc'h K., 2003. Cuantificación del carbono almacenado en la biomasa aérea y el mantillo en sistemas agroforestales de café en el Sur Oeste de Costa Rica. Agroforestería en las Américas.

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. Agroforestería en las Américas.

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

Contract ICA4-2001-10071

Third Annual Report WORK PACKAGE 6

1 November 2003 - 31 October 2004

M. van Oijen, CEH, United Kingdom, leader of WP6

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

WP6 develops a physiological model of the vegetative and reproductive growth of coffee plants in response to different levels of light, moisture and nitrogen and integrates 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 draws on the information provided by the other biophysical work packages (WP2, WP3, WP4, WP5), and will supply 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 2003 to 31 October 2004

In the First Annual Report, it was described how an initial version of the Integrated Plot Model was constructed to simulate coffee growth with and without accompanying trees. The model was implemented in the modelling software Matlab/Simulink, to allow both graphical representation of the model and efficient analysis. In the Second Annual Report, further developments in the WP6 modelling were reported and the two major remaining gaps in model development were identified: the nitrogen cycle and the competition between trees for soil resources. Further needs for development of the IP-model were identified at a meeting at CATIE (Turrialba, Costa Rica) in May 2004. In this Third Annual Report, we describe the progress made with addressing these model needs and other WP6 modelling activities in the third project year.

1. Model development

The overall model structure remained largely unchanged, and is depicted in Fig. 1.

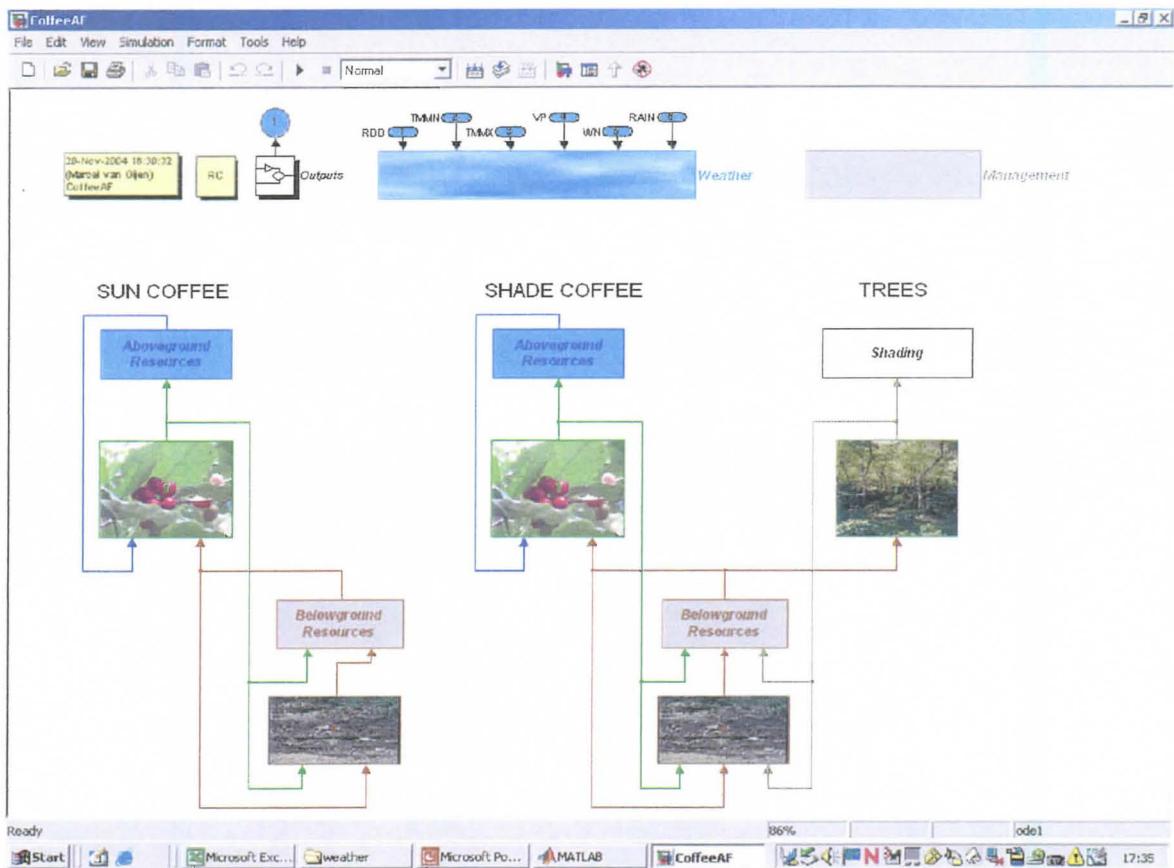


Fig. 1. Top-level view of the IP-model as implemented in MATLAB/Simulink. The coffee-submodel is represented twice in the model to distinguish between plants that are under tree-shade at any given time and those that are not. Soil is also represented twice because uptake of water and N from the soil, and the return of organic matter to the soil, also differ between the shaded and sunlit parts of the field.

The following sections describe the changes in the different submodels.

1.1 The *Soil submodel*.

During the third project year, nitrogen cycling was added, including the processes of mineralisation, emission, leaching, uptake by coffee and trees as well as the flow of nitrogen that is part of the decomposition-cascade from litter to soil organic matter and, finally, mineral N. In all cases, simple, robust model representations were chosen, with as few parameters as possible, to prevent a later mismatch between model data needs and data availability. In the soil, the water- and N-processes are coupled in that various processes depend on the concentration of mineral N in the soil water, which is calculated as the ratio of mineral N present in the rooted soil zone and the amount of water in the zone. Both N-leaching and N-emission are assumed to be directly proportional to mineral N concentration, whereas the supply of mineral N to both coffee and trees is modelled with a Michaelis-Menten equation.

1.2 The *Coffee submodel*.

During the third project year, various structural changes were made to the submodel for coffee growth. The two major changes were the introduction of nitrogen relations, and of algorithms that facilitate the simulation of coffee pruning. Pruning will be described below, in section 1.5 on Management.

Incorporating nitrogen relations included parameterising the nitrogen contents of the different organ systems of the simulated coffee plants, i.e. leaves, fruits, aboveground woody parts (= stems + branches) and roots. Nitrogen concentrations are assumed to be constant in all parts except the leaves, whose N-concentration changes with the balance between N-demand of the plants and N-supply from the soil. The coffee submodel had already been coupled to the soil water balance, but was now coupled to the soil N-balance as well.

1.3

The Tree submodel.

Tree nitrogen relations had already been included in the model, and coupled to the soil submodel, during the second year – only some refinement was needed. However, one major flux of carbon and nitrogen from trees to soil, i.e. that of pruned branches which constitute a major source of litter, required splitting the original tree component of woody aboveground material into the two components of stems and branches. This also required reformulating the tree allometric equations, which now consist of a stem biomass-dependent height equation and a branch-biomass dependent equation for crown area. Crown area together with tree density determines the fraction of the field area where the coffee is under shade. The degree of shade depends mainly on the LAI in the tree crown area. Tree growth rate, as before, depends on the availability of all three resources (light, water, N), and allocation between organs (leaves, stem, branches, roots) is determined by empirical relationships that account for the functional equilibrium between above- and belowground plant parts.

1.4

The Atmosphere submodel.

In year 1, the submodel for atmosphere, where weather data are processed, had already been made operational, and no further development was undertaken since.

1.5

Management processes.

Many management processes are part of the IP-model. N-fertilization had already been included before, but in year 3 simple algorithms were introduced for the pruning of the coffee and the trees, as well as for tree thinning. In all cases, the corresponding fluxes of carbon- and nitrogen-containing material to the soil are calculated.

1.6

Competition for resources between trees and coffee.

In year 3, competition algorithms were incorporated. With respect to light, the model is kept simple, with tree crowns being assumed to be higher than the coffee plants, so trees have first access to light. In contrast, there is true competition for soil water and mineral N, and the distribution of these resources between the two species depends on their relative resource demands, the relative root surface areas, and the specific uptake capacities of the root systems.

With the changes described above, the structure of the IP-model is now complete and operational. For the final project year, no further structural model development is envisaged, except for any model changes that may be prompted by feedback on the current model structure by CASCA-colleagues at the fourth plenary project meeting (Guatemala, November 2004). The current version of the model provides most of the biophysical coffee-tree production information required by WP7 and WP8. Table 1 shows a list of key model outputs for a 15-year rotation coffee-poro agroforestry system, simulated using the weather conditions of San Jose (Costa Rica, as input), with five-

yearly coffee pruning and yearly tree-pruning from year 4, and Fig. 1 shows results from the same simulation.

Table 1. Twenty-eight output variables of the IP-model. The table lists annual results for coffee-, tree- and soil-variables during one 15-year rotation of coffee with *E. poeppigiana* as shade trees at a density of 200 ha⁻¹. Weather conditions taken for San Jose (Costa Rica) from the FAO-database, and 200 kg N ha⁻¹ y⁻¹ fertilisation. Coffee pruned every five years, trees every year, starting from year 4. Note that all results are preliminary as no final model parameterisation has yet taken place.

| YEAR | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Coffee yield (t ha ⁻¹) | 0.0 | 0.0 | 0.0 | 1.5 | 1.5 | 0.2 | 1.6 | 1.6 | 1.6 | 1.6 | 0.2 | 1.7 | 1.7 | 1.7 | 1.8 |
| Carbon in coffee (t ha ⁻¹) | 3.9 | 6.1 | 7.4 | 8.1 | 1.5 | 3.2 | 4.5 | 5.7 | 6.8 | 1.4 | 3.3 | 4.7 | 6.0 | 7.2 | 1.4 |
| N-C ratio leaves (-) | 0.11 | 0.10 | 0.10 | 0.10 | 0.14 | 0.12 | 0.11 | 0.11 | 0.11 | 0.14 | 0.12 | 0.11 | 0.11 | 0.11 | 0.14 |
| Carbon in trees (t ha ⁻¹) | 0.5 | 2.4 | 6.1 | 6.9 | 8.9 | 11.0 | 12.9 | 14.8 | 16.7 | 18.7 | 20.9 | 22.9 | 24.9 | 26.9 | 29.0 |
| Wood (m ³) | 0.5 | 2.9 | 8.1 | 14.0 | 20.0 | 26.8 | 33.3 | 39.9 | 46.4 | 53.2 | 60.5 | 67.6 | 74.6 | 81.7 | 88.9 |
| Crown area (m ²) | 9.9 | 18.7 | 26.6 | 16.4 | 15.8 | 15.7 | 15.6 | 15.6 | 15.7 | 16.0 | 15.8 | 15.8 | 15.8 | 15.8 | 16.2 |
| Height (m) | 2.4 | 3.5 | 4.3 | 4.8 | 5.1 | 5.4 | 5.7 | 5.9 | 6.1 | 6.2 | 6.4 | 6.5 | 6.7 | 6.8 | 6.9 |
| Carbon in soil (t ha ⁻¹) | 92 | 91 | 91 | 94 | 101 | 103 | 104 | 106 | 108 | 114 | 116 | 117 | 119 | 121 | 128 |
| Water in soil (mm) | 372 | 364 | 362 | 366 | 370 | 367 | 366 | 366 | 366 | 370 | 366 | 366 | 366 | 365 | 369 |
| Mineral N in soil (mm) | 6.3 | 5.6 | 5.2 | 6.3 | 14.4 | 8.2 | 7.4 | 7.5 | 7.5 | 17.0 | 9.3 | 8.1 | 8.1 | 8.2 | 19.7 |
| Rain interception coff. (mm d ⁻¹) | 0.5 | 0.5 | 0.4 | 0.3 | 0.2 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| Rain interception trees (mm d ⁻¹) | 0.0 | 0.1 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| Drainage + runoff (mm d ⁻¹) | 2.1 | 1.5 | 1.4 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 |
| Evaporation from soil (mm d ⁻¹) | 0.9 | 0.8 | 0.7 | 1.0 | 1.4 | 1.0 | 1.1 | 1.1 | 1.1 | 1.3 | 1.0 | 1.1 | 1.1 | 1.0 | 1.3 |
| Transpiration coffee (mm d ⁻¹) | 1.9 | 1.6 | 1.0 | 0.8 | 0.7 | 0.9 | 0.9 | 0.9 | 0.9 | 0.7 | 1.0 | 0.9 | 0.9 | 0.9 | 0.7 |
| Transpiration trees (mm d ⁻¹) | 0.2 | 0.6 | 1.3 | 1.3 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.3 | 1.2 | 1.2 | 1.2 | 1.2 |
| N-fixation (kg N ha ⁻¹ y ⁻¹) | 4 | 18 | 40 | 44 | 44 | 49 | 47 | 47 | 48 | 49 | 53 | 52 | 51 | 51 | 52 |
| N-mineralisation (kg N ha ⁻¹ y ⁻¹) | 161 | 175 | 178 | 183 | 204 | 216 | 214 | 215 | 219 | 236 | 247 | 247 | 249 | 253 | 270 |
| N-leaching (kg N ha ⁻¹ y ⁻¹) | 25 | 19 | 13 | 12 | 11 | 11 | 10 | 10 | 10 | 10 | 11 | 10 | 10 | 10 | 10 |
| N-emission (kg N ha ⁻¹ y ⁻¹) | 4 | 4 | 3 | 3 | 4 | 4 | 3 | 3 | 3 | 4 | 4 | 4 | 3 | 4 | 4 |
| N-uptake coffee (kg N ha ⁻¹ y ⁻¹) | 304 | 282 | 211 | 177 | 162 | 205 | 192 | 191 | 192 | 169 | 226 | 209 | 209 | 211 | 181 |
| N-uptake trees (kg N ha ⁻¹ y ⁻¹) | 19 | 91 | 192 | 230 | 240 | 269 | 258 | 258 | 260 | 267 | 289 | 280 | 278 | 279 | 284 |
| NI-loss coffee (kg N ha ⁻¹ y ⁻¹) | 230 | 206 | 156 | 110 | 262 | 131 | 119 | 118 | 119 | 245 | 142 | 129 | 129 | 131 | 265 |
| N-loss trees (kg N ha ⁻¹ y ⁻¹) | 5 | 29 | 85 | 201 | 200 | 225 | 224 | 226 | 229 | 231 | 249 | 246 | 246 | 246 | 248 |
| LAI coffee (m ² m ⁻²) | 2.1 | 2.0 | 1.7 | 1.5 | 1.0 | 1.5 | 1.6 | 1.6 | 1.6 | 1.0 | 1.6 | 1.7 | 1.7 | 1.7 | 1.0 |
| LAI tree (m ² m ⁻²) | 1.1 | 1.9 | 2.4 | 2.5 | 2.6 | 2.5 | 2.5 | 2.5 | 2.5 | 2.6 | 2.5 | 2.5 | 2.5 | 2.5 | 2.6 |
| Shaded area (m ² m ⁻²) | 0.48 | 0.90 | 1.00 | 0.79 | 0.76 | 0.75 | 0.75 | 0.75 | 0.75 | 0.77 | 0.76 | 0.76 | 0.76 | 0.76 | 0.78 |

2. Model parameterisation

The coffee agroforestry system is complex, both ecologically and in terms of management, and it is applied in Central America under very diverse soil and weather conditions. The system complexity and environmental heterogeneity are not matched by an abundance of environmental and system data. Therefore, the philosophy of model development in WP6 has been to aim for parameter-sparse, robust algorithms, with minimal data needs. However, unavoidably, the number of parameters of the current model version is still quite high (about 60 for coffee plus trees) and this poses problems for the quantification of the parameters. To solve this problem, we developed and implemented a Bayesian calibration method that allows the use of data on output variables not just for quantifying parameter values, but also for quantifying the uncertainty regarding the collection of model parameters in the form of a joint probability distribution. Essentially, the method is simple and consists of defining a prior probability distribution for the parameters (largely based on literature information) and updating this distribution by means of Bayes' Theorem applied to the likelihood of the data for different model parameterisations. The one weakness of Bayesian methods for parameterisation is their computational demand but this was solved by implementing the

application of Bayes' Theorem as a Markov Chain Monte Carlo algorithm, which is described in detail in a paper in press for Tree Physiology (Van Oijen, Rougier & Smith, 2005). This algorithm was shown to operate efficiently on the IP-model, and the uncertainty intervals shown in Figure 2 were derived by the method. The fact that most of the uncertainty intervals are quite wide reflects the unavoidable need for more data to more precisely calibrate the model. Using new data from CASCA-partners for this purpose will be a major task of the forthcoming final year of the project.

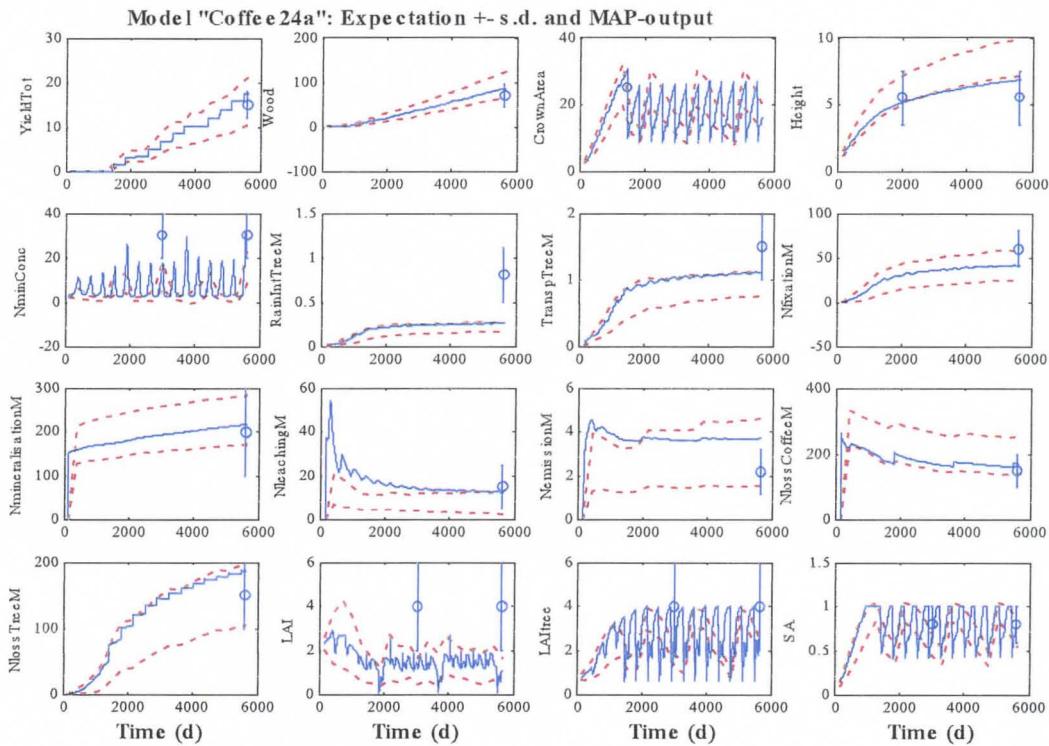


Fig. 2. Outputs of the IP-model.

Top row, from left to right : cumulative dry bean yield ($t \text{ DM ha}^{-1}$), wood production (m^3), crown area per tree (m^2), tree height (m). Second row: N-C ratio in coffee leaves, average rain interception by coffee ($mm d^{-1}$), average tree transpiration rate ($mm d^{-1}$), average N-fixation rate ($kg N ha^{-1} y^{-1}$). Third row: N-mineralisation, N-leaching, N-emission and N-flux to soil from coffee litter (all in $kg N ha^{-1} y^{-1}$). Fourth row: N-flux to soil from tree litter ($kg N ha^{-1} y^{-1}$), LAI of coffee and tree (both in $m^2 m^{-2}$) and the shaded-area fraction of the field (-). Broken lines represent uncertainty intervals, determined by means of Bayesian calibration using the data depicted by circles, with measurement error indicated by vertical bars (see section 3 of this report).

3. Results of preliminary model application

To test whether the current model version is applicable to the different conditions for which it is supposed to provide productivity estimates, we performed some preliminary model tests. Figure 3 shows the example of the effect of a doubling in N-fertilisation rate from 200 to 400 $kg N ha^{-1} y^{-1}$.

Similar exercises were carried out to test the model's capacity for simulating growth under different weather conditions, soil water holding capacities, tree pruning regimes, tree thinning regimes and the elevated CO_2 . The results seem realistic, but will

not be reported here as all these studies are preliminary and need to be repeated in year 4, after additional data for model calibration have been processed.

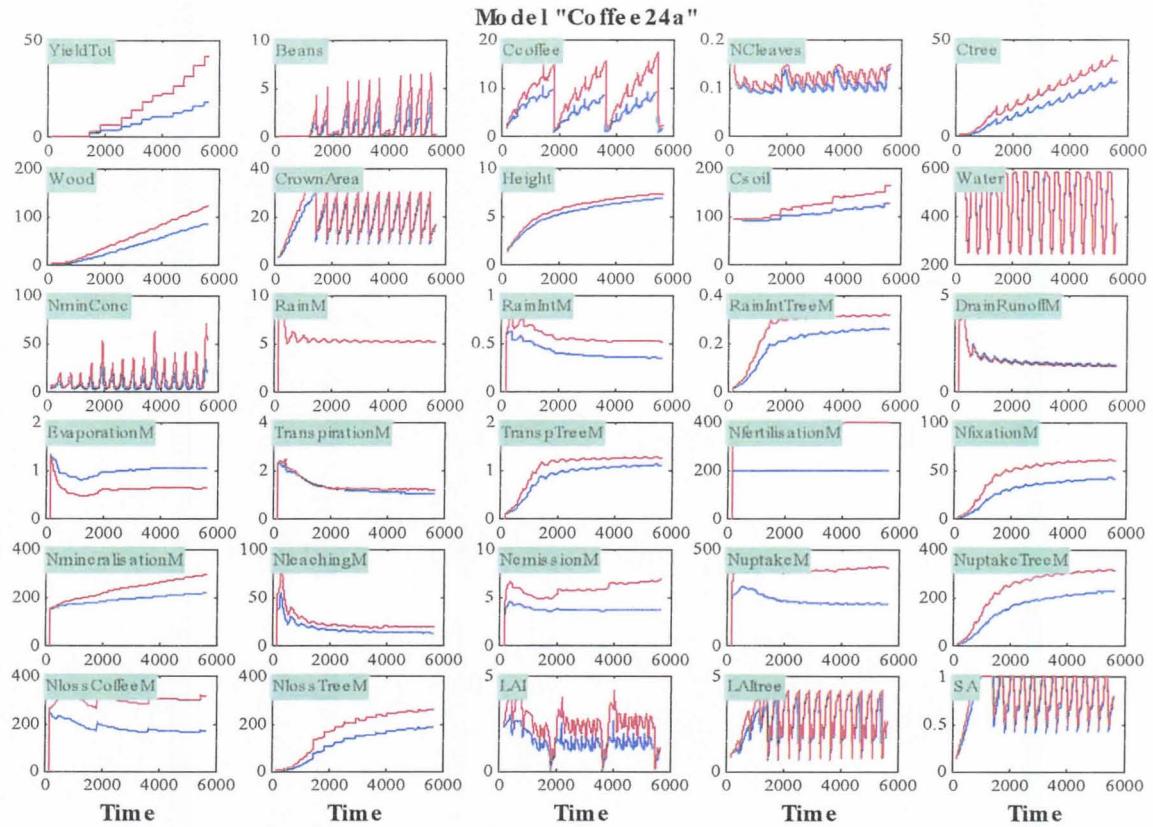


Fig. 3. Outputs of the IP-model for default conditions (as in Fig. 2, blue lines) and for conditions with a doubled input of N-fertiliser (red lines).

4. Data needs of the IP-model

For calibration of the IP-model a variety of data are needed:

- (1) Daily weather data. Most important are rain and temperature, then radiation, and finally wind speed and atmospheric humidity.
- (2) Soil information, in particular the maximum availability of water (i.e. mm of water in the rooted zone when the soil is at field capacity) and the amount of soil C and N.
- (3) Information on management: tree density and tree pruning regime, coffee pruning regime, and N-fertilization level.
- (4) Tree and coffee parameters, in particular fractions dry matter allocated to different organs, N-concentrations of different organs, SLA, and tree wood density and N-fixing capacity.

Moroever, these calibration data need to be available for a range of conditions relevant for CASCA, with respect to environment, shade tree choice and management.

Once the calibration is completed, data on parameters (category 4 in the data needs list above) are no longer needed, but site-specific data (categories 1-3) remain needed for model application.

5. Overall conclusions regarding WP6-activities in year 3

The major developments in year 3 were (i) the finalising of the structure of the IP-model, which now includes full biogeochemical cycling of water and nitrogen in the coffee-tree system, (ii) the implementation and testing on the model of a Bayesian calibration method, and (iii) a the execution of a series of preliminary tests for assessing model applicability. The main challenge for the final year will be to use new and more detailed data from CASCA-observations and experiments for improved model calibration, the application of the model, and the transfer of model results to WP7 and WP8.

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

Contract ICA4-2001-10071

Third Annual Report WORK PACKAGE 7

1 November 2003 - 31 October 2004

WP 7 – Modèle économique à l'échelle de la ferme cafrière

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Adnane Mouzaoui (CIRAD)
Damien Jourdain (CIRAD)
Anne Zanfini (CIRAD)
Benito Dzib (CATIE)
Axelle Boulay (CIRAD)

Les principaux objectifs du WP 7 sont :

- le développement d'un modèle représentant les principaux critères de prise de décision à utiliser par les agriculteurs sur la manière la plus adéquate d'allocation de leurs ressources en terre, travail et finance,
- la mesure de l'impact des différents scénarios de gestion sur le plan technique, social, économique et environnemental,
- la quantification des incidences des divers systèmes agro-forestiers et d'association de cultures dans les caférières.

Des diagnostics agro-économiques de régions caférières d'altitude au Costa Rica, Nicaragua et au Guatemala ont été réalisés en 2002-03 en collaboration avec le WP1. Ils ont permis de construire des bases de données consistantes à partir desquelles sont calculés les principaux paramètres technico-économiques nécessaires à la construction des modèles économiques.

La modélisation économique commence par la construction d'une typologie et se poursuit par la construction de deux modèles : le premier consiste en un modèle de simulation sous Olympe sans faire appel à l'optimisation, le second est d'un modèle d'optimisation d'une fonction multi-objectifs sous des contraintes de disponibilité en ressources (terre, travail, finance,...).

1. Typologie

1.1. Costa Rica

La typologie a été construite sur la base de 90 enquêtes retenues des différentes exploitations présentes dans la région d'étude. Pour chaque système de production (familial, patronal et entrepreneurial) nous définissons des types d'exploitations selon leurs systèmes d'activités.

Dans la catégorie des exploitations familiales, dont la caractéristique principale est la faible disponibilité en main d'œuvre, les types les plus remarquables sont :

10. Producteurs de café uniquement,
11. Producteurs de café en association avec d'autres cultures (maraîchage, horticulture, caña india, banane,...),
12. Producteurs de café et éleveurs (bovins, lait ou hors sol),
13. Producteurs de café ayant une activité salariale en dehors de leurs exploitations.

Dans la catégorie des exploitations patronales, contrairement au type familial où l'exploitant emploie de la main d'œuvre extérieure, nous avons également défini 4 types :

20. Producteurs de café uniquement,
21. Producteurs de café et d'autres cultures (diversification),
22. Producteurs de café et une activité d'élevage,
23. Producteurs de café ayant une activité salariale.

Dans la catégorie des exploitations entreprenariales, un seul type est retenu :

30. Producteurs de café uniquement.

TABLEAU 1. Costa Rica : répartition de ces producteurs selon les 3 classes d'altitude

| | | Types d'exploitations | | | | | | | | | |
|--------------------|---|-----------------------|----|----|----|----|----|----|----|----|-------|
| | | 10 | 11 | 12 | 13 | 20 | 21 | 22 | 23 | 30 | Total |
| classes d'altitude | 1 | 30 | 5 | 4 | 3 | 4 | 6 | 5 | 4 | | 61 |
| | 2 | 4 | 1 | 2 | 1 | 2 | | 6 | | | 16 |
| | 3 | 7 | | | | 2 | 1 | 1 | 1 | 1 | 13 |
| Total | | 41 | 6 | 6 | 4 | 8 | 7 | 12 | 5 | 1 | 90 |

Codes :

- 1 : Les exploitations qui se situent entre au dessous de 1200m d'altitude,
- 2 : Les exploitations au dessus de 1200m et au dessous de 1400m Et d'altitude,
- 3 : Les exploitations au delà de 1400m

TABLEAU 2. Costa Rica : moyenne des surfaces en café par type d'exploitation

| Classe d'altitude | | 10 | 11 | 12 | 13 | 20 | 21 | 22 | 23 | 30 |
|-------------------|-----------------------------------|------|------|--------|------|-------|-------|--------|-------|----------|
| 1 | Moyenne surface en café (ha) | 3,73 | 2,31 | 4,55 | 1,38 | 27,60 | 8,50 | 7,70 | 2,35 | |
| | Moyenne surface exploitation (ha) | 3,79 | 3,48 | 36,11 | 1,42 | 27,85 | 9,03 | 304,93 | 3,07 | |
| | Moy surf café/ Moy surf tot (%) | 98% | 66% | 13% | 98% | 99% | 94% | 3% | 77% | |
| 2 | Moyenne surface café (ha) | 5,69 | 3,50 | 2,80 | 1,80 | 11,20 | | | 8,51 | |
| | Moyenne surface exploitation (ha) | 6,04 | 4,00 | 101,90 | 1,80 | 11,73 | | | 59,87 | |
| | Moy surf café/ Moy surf tot (%) | 94% | 88% | 3% | 100% | 96% | | | 14% | |
| 3 | Moyenne surface café (ha) | 5,70 | | | | | 33,95 | 2,10 | 1,40 | 0,65 |
| | Moyenne surface exploitation (ha) | 7,40 | | | | | 33,95 | 7,70 | 7,00 | 0,66 |
| | Moy surf café/ Moy surf tot (%) | 77% | | | | | 100% | 27% | 20% | 98% 100% |

1.2. Guatemala

Le Guatemala présente une typologie différente de celle du Costa Rica du fait des activités forestières et de l'existence d'une forme de production extensive de café. La base de données est composée de 40 exploitations. Les types et sous-types identifiés et qui donneront lieu à la construction de modèles spécifiques sont les suivants :

En ce qui concerne les exploitations familiales

11. Agriculture seulement sans main d'œuvre salariale,
12. Agriculture seulement avec main d'œuvre salariale,
13. Agriculture à temps partiel sans main d'œuvre salariale
14. Agriculture à temps partiel avec d'œuvre salariale.

En ce qui concerne les exploitations patronales

21. Producteurs de café uniquement,
22. Exploitations diversifiées,
23. Producteurs de café avec activités touristiques,
24. Producteurs de café avec activités d'élevage.

En ce qui concerne les exploitations entrepreneuriales

31. Producteur et acheteurs de café (transformation),
32. Producteurs de café en fermes extensives avec des activités de foresterie.

En ce qui concerne les exploitations patrimoniales

40. Exploitation patrimoniale.

TABLEAU 3. Guatemala : répartition de ces producteurs selon les 3 classes d'altitude

| | | Types d'exploitations | | | | | | | | | | Total | |
|--------------------|---|-----------------------|----|----|----|----|----|----|----|----|----|-------|----|
| | | 11 | 12 | 13 | 14 | 21 | 22 | 23 | 24 | 31 | 32 | | |
| Classes d'altitude | 1 | 1 | | 2 | | | | | | 6 | | 9 | |
| | 2 | 3 | 3 | 2 | 5 | 4 | 1 | 1 | | 4 | 1 | 26 | |
| | 3 | | 2 | 1 | 1 | | | | 1 | | | 5 | |
| Total | | 4 | 5 | 5 | 6 | 4 | 1 | 1 | 1 | 4 | 7 | 2 | 40 |

Codes :

- 1 : Les exploitations en basse altitude (< 1360 m),
- 2 : Les exploitations en haute altitude (> 1360 m),
- 3 : Les exploitations ayant des parcelles appartenant à ces deux classes d'altitude

1.3. Nicaragua

99 exploitations ont été enquêtées. La typologie des exploitations, au Nicaragua, comporte deux types et 10 sous-types.

Les exploitations familiales et patronales :

11. Producteurs de café seulement,
12. Producteurs de café avec cultures de diversification,

13. Producteurs de café avec activité d'élevage,
14. Producteurs de café avec activité forestière,
15. Producteurs de café avec une activité simultanée d'élevage et de diversification.

Les exploitations entrepreneuriales :

21. Producteurs de café,
22. Producteurs de café avec cultures de diversification,
23. Producteurs de café avec activité d'élevage,
24. Producteurs de café avec activité forestière,
25. Producteurs de café avec une activité simultanée d'élevage et de diversification.

TABLEAU 4. Nicaragua : répartition de ces producteurs selon les 3 classes d'altitude

| | | Types d'exploitations | | | | | | | | | | Total |
|--------------------|---|-----------------------|----|----|----|----|----|----|----|----|----|--------------|
| | | 11 | 12 | 13 | 15 | 17 | 21 | 22 | 23 | 25 | 27 | |
| Classes d'altitude | 1 | | 11 | 3 | | 7 | 5 | 12 | 4 | 4 | 13 | 59 |
| | 2 | 3 | 3 | 1 | 2 | 3 | 3 | 3 | | 6 | 9 | 33 |
| | 3 | | | 1 | | | | 4 | | | 2 | 7 |
| Total | | 3 | 15 | 4 | 2 | 10 | 8 | 19 | 4 | 10 | 24 | 99 |

Codes :

- 1 : Les exploitations à moins de 900 m d'altitude,
- 2 : Les exploitations entre 900m et 1200m d'altitude,
- 3 : Les exploitation au de là de 1200m d'altitude.

2. Modèle de simulation sous Olympe :

Dans un premier temps, les données issues des études précédentes ont été utilisées pour construire des fiches technico-économiques correspondant aux différents types d'exploitations. Ces fiches résultent d'une combinaison entre les :

- les différentes classes d'altitude,
- les systèmes de production (familiaux, patronaux et entrepreneuriaux),
- les systèmes d'activité (Activité agricole, agriculture-élevage, salariat et agriculture),
- la main d'œuvre (familiales, permanente et temporaire),
- les variétés du café planté et durée de vie,
- les associations végétales au sein de la parcelle caféière
- les types d'ombrage (sans ombrage, ombrage à : 25%, 50%, 75%) compte tenu des espèces d'ombrage et les rentes qu'elle réalise.

Dans un second temps, les informations relatives aux charges de l'exploitation, à ses recettes et aux immobilisations ont été introduites dans le modèle afin de représenter le plus fidèlement possible la situation réelle des exploitations agricoles.

3. Les prochaines étapes à réaliser

L'étape suivante consistera à construire des scénarios de gestion concernant les différentes exploitations prises en compte existantes portant sur les variables qui influent directement la

performance des exploitations (stratégies de production, disponibilité en ressources, contraintes structurelles de l'exploitation,...).

Les simulations réalisées à partir de ces scénarios montreront l'impact des phénomènes pris en compte et la viabilité économique des différentes pratiques et système de gestion.

Lors de ces simulations, les principaux points à analyser seront :

- l'introduction de cultures associées dans les caférières et leurs impacts environnementaux et économiques,
- la variabilité du prix du café et du rendement et leurs impacts sur les résultats économiques de l'exploitation.

Enfin, des modèles régionaux seront construits en combinant et pondérant les différents types d'exploitations agricoles. Afin d'évaluer les incidences globales des scénarios.

Faisant suite à 6 mois de travaux d'enquêtes de terrain en 2003 au Costa Rica, une étudiante de doctorat du CIRAD, Anne Zanfini, a poursuivi ses travaux en 2005 au Nicaragua. Ses travaux ont porté sur le rôle et l'importance de l'arbre dans les caférières de deux régions contrastées (zone pacifique de basse altitude sub-optimale pour la caféculture et zone nord de montagnes aux conditions écologiques favorables pour le cafier). Cette étudiante défendra sa thèse en Juin 2005.

Un étudiant de Masters du CATIE, Benito Dzib, a mené des enquêtes dans 66 fermes de 3 régions contrastées du Costa Rica (2 régions sub-optimales pour la caféculture en raison de l'altitude basse <800m et une favorable >1100m) sur l'effet de la chute des prix du café durant ces 5 dernières années et de leur incidence sur les pratiques agricoles. Ces travaux ont montré que le rôle de l'arbre se trouvait renforcé en zones défavorables pour limiter l'utilisation d'intrants (engrais, herbicides..) et que le revenu de la vente de bois sur pied était important (voir détails dans rapport CATIE).

Une étudiante, Axelle Boulay, en Masters à l'ENGREF, France, a mené des enquêtes au Costa Rica sur les filières « bois d'œuvre » issues des systèmes cafiers et de son importance financière au niveau des divers acteurs (caficulteurs, scieurs, transporteurs, artisans). Elle a aussi comparé la rentabilité de diverses espèces de bois d'œuvre (*Eucalyptus deglupta*, *Cordia alliodora*, *Cedrela odorata*). Ces données sur la diversification du revenu seront utilisées dans les simulations de divers scénarios économiques à l'échelle de la ferme cafrière.

Activités planifiées en 2005 et Delivrables :

Le Delivable D12/D7.1 « synthèse des enquêtes socio-économiques à l'échelle de la ferme » prévue pour le mois 28 a été effectuée à partir des enquêtes menées au Costa Rica, Nicaragua et Guatemala. La dernière série d'enquêtes menées en 2004 au Nicaragua doit être incorporée dans cette synthèse au cours de l'année 2005.

Le modèle économique à l'échelle de la ferme est en cours de finalisation (Delivable D20/D7.2 au mois 40) et sera présenté et validé en 2005 (Delivable D27/D7.3 au mois 47).

Des études sur les filières « bois d'œuvre et bois de feu » seront menés en 2005 par un étudiant du CATIE au Guatemala et un étudiant de la UNA au Nicaragua afin de compléter les informations sur l'importance du revenu dérivé de la production arborée dans les systèmes agro-forestiers à base de cafiers dans les 3 pays étudiés dans le projet.

Annexes

Pertinence de la production de bois d'œuvre issu de systèmes agroforestiers cafiers au Costa Rica (Décembre 2004)

Axelle Boulay (Etudiante ENGREF-FIF)

Résumé de l'étude

Le modèle de monoculture intensive du café sans arbres d'ombrage, développé depuis les quarante dernières années en Amérique centrale, a permis de faire d'importants gains en productivité. Néanmoins, sa viabilité économique dans le long terme est remise en question à cause des variations des prix du café et de l'augmentation des prix des intrants agro-chimiques.

Les travaux conduits par le Catie et le Cirad montrent que les systèmes agro-forestiers, moins consommateurs d'intrants, incluant cafiers et arbres d'ombrage, sont mieux adaptés aux possibilités financières et aux besoins des petits agriculteurs, et sont susceptibles de produire de façon plus durable du café et des productions variées comme du bois d'œuvre.

Certains arbres producteurs de bois d'œuvre sont traditionnellement cultivés dans les cafierres. Cependant l'importance que peuvent représenter les revenus de leur vente pour les producteurs est trop souvent négligée. Cette étude vise à décrire les filières de commercialisation de ces bois.

La demande en bois d'œuvre est forte ; les possibilités de mises en marché des bois selon le niveau de transformation ont été recensées. Deux cas ont été plus particulièrement développés:

- la filière production de bois de menuiserie issu de *Cordia alliodora* (laurel) et *Cedrela odorata* (cedro);
- la filière production de palettes à partir de bois d'*Eucalyptus deglupta* (analyse des quantités de produits en fonction des volumes estimés sur les parcelles, étude du rendement des scieries) ;

Depuis 1985, les prix des bois précieux ont beaucoup augmenté. Les prix respectifs du bois de cedro et de laurel commercialisés au Costa Rica ont été multipliés par 6,3 et 5,7 entre 1985 et 2004.

Les meilleures alternatives possibles en fonction du contexte économique de la production de café à faible altitude au Costa Rica, ont été identifiées. D'une part, en louant les services de coupe et de transport, le propriétaire augmente ses bénéfices par rapport à la vente de bois sur pied et ce quelque soit l'essence ligneuse produite. Par exemple, son revenu est susceptible d'augmenter de 40% dans le cas du cedro, et de 100% dans le cas du laurel. D'autre part, les calculs sur l'importance des revenus du bois vendu sur pied par rapport à ceux du café ont été établis en considérant une production de café de 23 fanegas/ha correspondant à un revenu brut annuel de 782 \$US et à un revenu annuel net de 382 \$US. L'importance des revenus nets du bois par rapport à ceux du café varie entre 10 et 33% selon les essences, les sites et les produits. L'étude a montré l'intérêt de la vente de planches, de perches ou poteaux d'*Eucalyptus deglupta* avec une proportion des revenus nets du café de 25 à 33%. Cette plus forte compétitivité de l'eucalyptus par rapport aux autres essences (cedro et laurel) s'explique par un niveau de production plus élevé et une durée de rotation deux fois plus courte de l'eucalyptus.

Pour le cedro et le laurel, la part des revenus du bois par rapport à ceux du café varierait de 10 à 23% et pourrait augmenter avec la location des services de coupe et de transport du bois par le producteur. D'autre part, si le prix du bois des essences précieuses

continue à augmenter, leur utilisation sera plus rentable et leur débouché plus facilement assuré à un prix rémunérateur que celui des eucalyptus soumis davantage aux exigences du marché local et à la concurrence des marchés extérieurs.

De plus, il apparaît que la compétitivité de ces filières est pour partie déterminée par une augmentation de la production qui permettrait des économies d'échelles notamment sur le processus de transformation de l'aval ou l'exploitation. Or les incitations aux producteurs, compte tenu du fonctionnement de cette filière, restent faibles et peu organisées. Il semble nécessaire d'améliorer l'environnement informationnel (technique, commercial, organisationnel) des producteurs afin de créer un contexte plus favorable à une augmentation compétitive de la production.

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

Contract ICA4-2001-10071

Third Annual Report WORK PACKAGE 8

1 November 2003 - 31 October 2004

**WP#8 – CASCA – Regional Upscaling and Policy
Third Annual Report, December 2004**

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8.1 Introduction

Work-package 8: Regional Upscaling and Policy

Phase: Third Year

Start date: 1/11/2001

Completion date: 31/11/2005

Current status: Ongoing

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 |

8.2 Objectives

Objectives of this Workpackage deal with upscaling 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 third year the WP leader made a single visit to Costa Rica (9th May – 15th May) to attend a workshop on modelling. This contrasts with two field visits in year 1, and one in year 2. Two visits are planned in year 4. Significant progress has been made by Byron Medina (ANACAFE Guatemala) in identifying the water quality and quantify 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.

8.4 Progress during the third year

This Workpackage is the final one in the CASCA Project. Most of its reporting is due in year 4, although two milestones due for the end of year 3 have been missed. A revised timetable of Deliverables and Milestones is provided in Section 8.7.

8.4.1 Task 1 (Identification of Markets for Shade Coffee).

Interviews with European Traders are not due to commence until month 44 but contacts have been developed and literature collected. A key reference on Coffee Markets has recently been published by the World Bank¹, and the following section is largely summarised from this document.

About 20-25 million families in more than 50 developing nations produce and sell coffee but prices are now at 100-year lows in real terms (averaging averaged a 3%/yr annual decline for arabica 5%/yr for robusta. In Nicaragua between 1998 and 2001 poverty rates increased by more than 2% among those farmers who remained in the coffee sector whereas it fell by 6% in the rest of the rural population. Approximately 100 million people are directly affected economically by the coffee trade.

Brazil, Vietnam and Colombia now account for about 61 percent of total production and, in 2002, 55 percent of global exports. Increased access to financial and futures markets particularly in countries, such as Brazil, have enabled some producers to better manage risk and ensure smooth shipment.

Roasters have responded to the shift in supply by adapting their technology to increase their use of lower-cost natural arabicas and robustas. They also introduced greater flexibility in their blends to respond to lower-priced availability, working with lower inventories and pushing ‘just-in-time’ orders through to suppliers.

A consequence of the decline in coffee prices has been a decline in the share of the final retail price that is received by producing countries caused: a) because coffee roasting and retail industries have made profits by developing new products and by taking advantage of value-adding activities, and b) the non-coffee components included in the retail price of coffee, such as wages, packaging, and marketing, have grown and now represent a much more significant share of the total retail price than the actual coffee itself.

Volatility in the producers' share of the retail value is more and more influenced by changes in the price level of green coffee than by changes in any other cost component because the value-adding costs are independent of the price of green coffee. Producers' ability to capture fair value from their output will require that producer organizations and producer countries act to improve their capabilities and their bargaining position.

Many countries perceive the commodity trading system to be increasingly onerous and partly responsible for the loss of share of market value. However, a growing group of producers and coffee firms are pursuing strategies that are independent of commodity pricing and the exchanges. Many of these alternatives include some differentiation of the coffee, usually by either quality or cultivation processes. A number of companies in the industry, including some that are household names, are adopting standards or developing purchasing criteria that transparently link their buying to positive socioeconomic and environmental effects in developing countries. This trend offers some producers alternative ways to capture the long-term value of sustainability by linking superior prices to demonstrable advancements in both the quality of the coffee and to more sustainable cultivation and trade practices.

¹

[http://lnweb18.worldbank.org/ESSD/ardext.nsf/11ByDocName/CoffeeMarketsNewParadigmsinGlobalSupplyandDemand/\\$FILE/CoffeeMarkets-ArdDp3.pdf](http://lnweb18.worldbank.org/ESSD/ardext.nsf/11ByDocName/CoffeeMarketsNewParadigmsinGlobalSupplyandDemand/$FILE/CoffeeMarkets-ArdDp3.pdf)

Ecofriendly, organic and socially just coffees present a complex demand picture. There are structural changes in demand both at the consumer level and at the industry level. These changes include stagnant overall growth in the traditional major importing countries, increased demand for soluble coffee, increased demand for differentiated and higher-value products, new technology allowing greater fungibility in coffee supplies, and geographic-generational shifts in the popularity of different types of coffee products. At the same time, in many markets there is increasing preference for espresso-style coffees that do not depend as much on the flavour profiles of high-quality washed arabica coffees. These shifts, and the strong competitive response of the largest producers, particularly Brazil, are reducing the demand for certain types and origins of coffee, leaving the worst-affected countries with large social and economic costs.

Global coffee consumption has shown noticeable regional differences. Consumption has been mixed in producing countries but is typically low, and Brazil, now the world's second-largest consumer, still sets the benchmark for increasing domestic consumption. Markets are emerging in Asia, Eastern Europe, and the former Soviet Union, but is primarily for inexpensive, soluble coffees, though tastes are evolving toward improved quality and novel characteristics, such as premixed cappuccino. Soluble is an important key to developing these traditionally tea-drinking markets because most consumers are unfamiliar with coffee-brewing methods and paraphernalia and less able to afford these. North America and Japan are growing slowly. Northern European consumption, particularly in Germany is stagnant, but in southern Europe, there are some increases. It seems that in this region the differentiated product market is growing the fastest.

The differentiated product market requires that producers distinguish their products by distinct origin, defined processes, or exceptional characteristics, such as superior taste or few defects. These can be traded through more lucrative channels than the typical industrial grades that flow in the undifferentiated commodity channels and include:

- Geographic Indications of Origin (appellations)
- Gourmet and specialty
- Organic
- Fair trade
- Eco-friendly or shade grown
- Other certified coffees

While these differentiated segments can provide some producers with competitive advantages and added value, they are not necessarily easy to access and are still relatively small. Nevertheless, they are important because of their growth rates and their potential to provide better social, economic, or environmental benefits for farmers. Though much of the coffee industry feels that premiums paid to growers for differentiated coffees are reasonable, it may be prudent to de-emphasize price premiums as a reason for entering these markets because it is quite plausible, at least in some cases, that these premiums will diminish. These markets should not however be discounted because they can often have a considerable impact on the income of farmers. Besides premiums, there are several other convincing arguments for fostering the differentiated segments, particularly those certified as organic, fair trade, or eco-friendly because of their positive externalities in the field such as:

- Increased use of rural labour and organizational development
- Crop diversification and reduced input costs minimize financial risk
- Better natural resource management and biodiversity conservation
- Reduced risk due to improved drought and erosion resistance
- Crop resilience to adverse weather
- Fewer health risks due to potential mishandling of agrochemicals

Currently, the differentiated markets import roughly 6-8 million bags of green coffee which represents about 9-12 percent of the total to the developed markets in North America, Western Europe, and Japan, as well as a somewhat larger percentage of profits. Some of the extra value of these coffees is created and captured in consuming countries, but to the extent that some of this higher value is kept by

producers for their differentiation, these markets are breaking the pattern of a declining producer share of revenue.

Because many producers are showing strong interest in these coffees, a word of caution is warranted. **As more of these coffees come onto the market, the ensuing saturation could significantly diminish their prices.** These markets are still small and even modest changes in supply and demand can impact prices. Most of the major coffee companies are instituting increased requirements for sustainable growing practices that will require further adoption and certification of these practices. Several very large buyers that are now testing the market with these products claim that there is a limited supply if they should decide to make a stronger commitment.

As markets for differentiated coffees grow, there is an increasing need for consumers to understand the sometimes complex verification or certification processes that apply to the standards-oriented coffees, such as organic, fair trade, eco-friendly, Utz Kapeh, and those using Geographic Indicators of Origin (GIO). The legitimacy of third-party certification is a vital market mechanism that can prevent indiscriminate use of these terms. The alternative may be a loss of consumer confidence that would cost the entire industry by damaging one of its few fast-growing segments. Perhaps more importantly, failure to improve clarity of these standards and to support third-party verification could also damage one of the few niches in which small coffee producers have a chance to be competitive in a lucrative global trade. This is particularly important as various organizations, including corporations, are developing their own independent sustainability principles and standards. Differentiated coffees, particularly those espousing social and environmental benefits, can provide a unique and positive image for a beverage whose appeal has become stale in many of the more mature markets.

Differentiated coffees are not a panacea, and industry surveys indicate that two other factors are equally or, perhaps, more important to be competitive in today's coffee markets: quality and consistency. The high value placed on consistency underscores the industry's preference for steady and predictable quality given the costs and risks of sourcing from new suppliers. This critical competitive factor has several implications, particularly for smaller suppliers, regarding the need to improve basic business practices, as well as agronomic practices in their cooperatives and organizations.

Differentiation, while increasingly popular, is only a partial answer in the near term; other answers are needed for the majority of coffee producers. One often proposed is the diversification of some farmers away from a strong dependence on coffee. Though this can be conceptually sensible for some geographic areas, there are very few alternatives that either come close to coffee's valuable characteristics, such as its marketability and long shelf life, especially for remote rural areas, or which present realistic alternatives for the terrains in which coffee is currently grown. Trade protectionism in industrial country markets particularly continued high levels of subsidy in industrial countries for their own farmers, pose additional obstacles to diversification into other activities or into higher value or processed products and thereby leave producers with limited access to these markets.

Given the long-term historic cycles, it is highly likely that supply will eventually align more closely with market demand for a period and that prices will recover somewhat. While conditions for producers will certainly improve as that happens, it will not signal an end to their problems because the economic causes of these cycles suggest that they are likely to continue to repeat themselves regardless of the actual levels at which supply and demand would actually converge. Price recovery then, given the inherently cyclical nature of current coffee markets, is likely to be only temporary, while other issues of social, environmental, and economic sustainability will remain. Structural changes in the ability to manage and finance supplies and the reduction of the historically high weather-related risk also lower the likely frequency with which prices might return to the previously reached highs.

The structural changes in the global coffee industry over the past few years will have a powerful influence on the nature of these markets. This influence could be as important as the cyclical, often weather-related, shifts in supply and demand that have considerably influenced the coffee market in the past. Understanding these changes is important; otherwise in today's free markets there is little hope of relieving the considerable damage caused by market failures, such as imbalances in the trading chain and the persistent failure of private markets (coffee, credit, and risk). In order to thrive in this

new business environment, coffee producers must understand the characteristics and the nature of these structural changes. Their governments must be more agile in creating favourable business environments to allow them to successfully adapt to the new demands of the marketplace and to help them potentially shape it. In the current situation of liberalized markets and decreasing state support for agriculture it will be increasingly incumbent upon producer and trade organizations to provide necessary services. Fostering the necessary research, extension, risk management, diversification, and marketing will all require dedicated long-term programs to strengthen and train such organizations. As agriculture increasingly takes on industrial characteristics, these organizations will also need to establish closer relationships and direct linkages with buyers and roasters to adequately respond to market demand and form integrated value chains that help to assure the sustainability of each member.

More broadly, governments need to focus on rural development that will increase competitiveness and reduce dependency on a few primary commodities by broadening the range of products produced by the agriculture sector, improving production and marketing systems, and supporting the creating of non-farm activities. This will enable countries and sectors to more easily adjust to the kind of price swings and structural changes in world markets experienced by the coffee industry.

Payments for environmental services provided by 'ecofriendly' coffee systems could play an important part in this diversification and is considered in Section 8.4.4, and will be reported on in Deliverable 8.1

8.4.2 Task 2 (Extrapolation of Socio economic farm surveys to Regional Economic Scale)

WP8 has awaited completion of farm surveys and socio-economic survey in WP7 before commencing on upscaling. However contact has been made with ICAFE and preliminary results obtained on their surveys of producers in the Turrialba Area. This will be used in by month 46 to produce Deliverable 8.2.

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 upscaling 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 1);
- Some socio-economic socio economic information on coffee farmers was thought to have been collected by ICAFE;
- The ECOMAN project² 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 (Figure 2).

It is intended in year 4 that the Coffee model produced in WP6 be run in for a range of (soil/ climate/ slope/ altitude) polygons over the catchment (Deliverable 8.3).

To permit this, ICAFE has made much of their base map for the Turrialba catchment available to the CASCA Project, and this is gratefully acknowledged.

² <http://www.uatla.pt/ecoman/>

Figure 1. Coffee distribution and boundaries in portion of the Turrialba catchment (ICAFE)

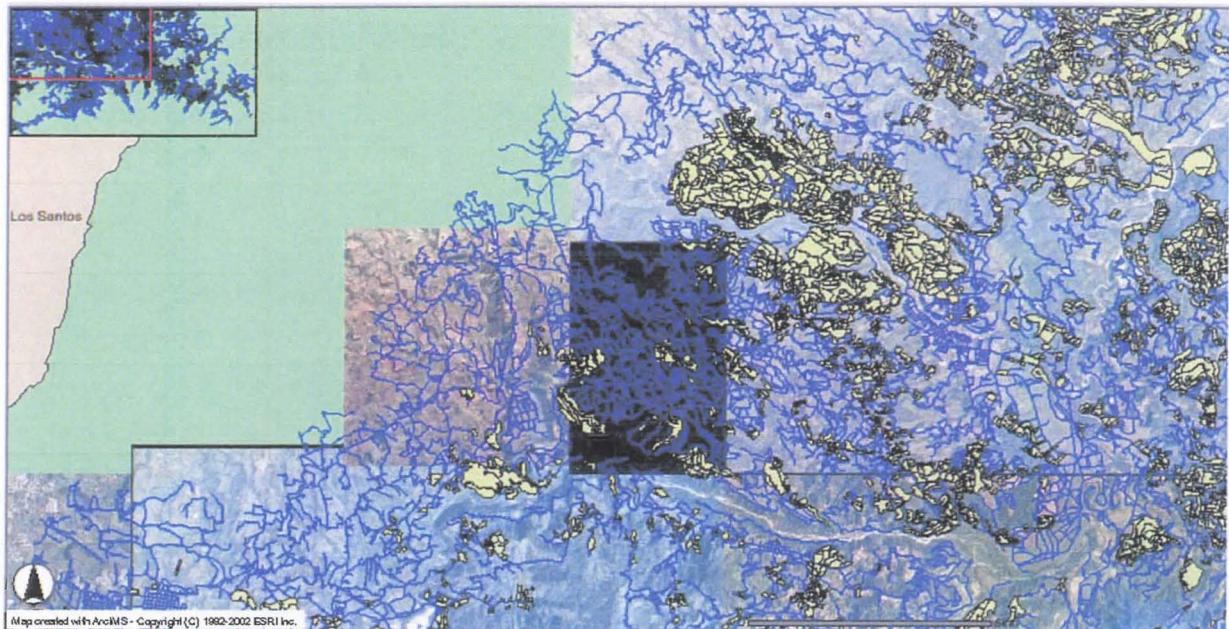
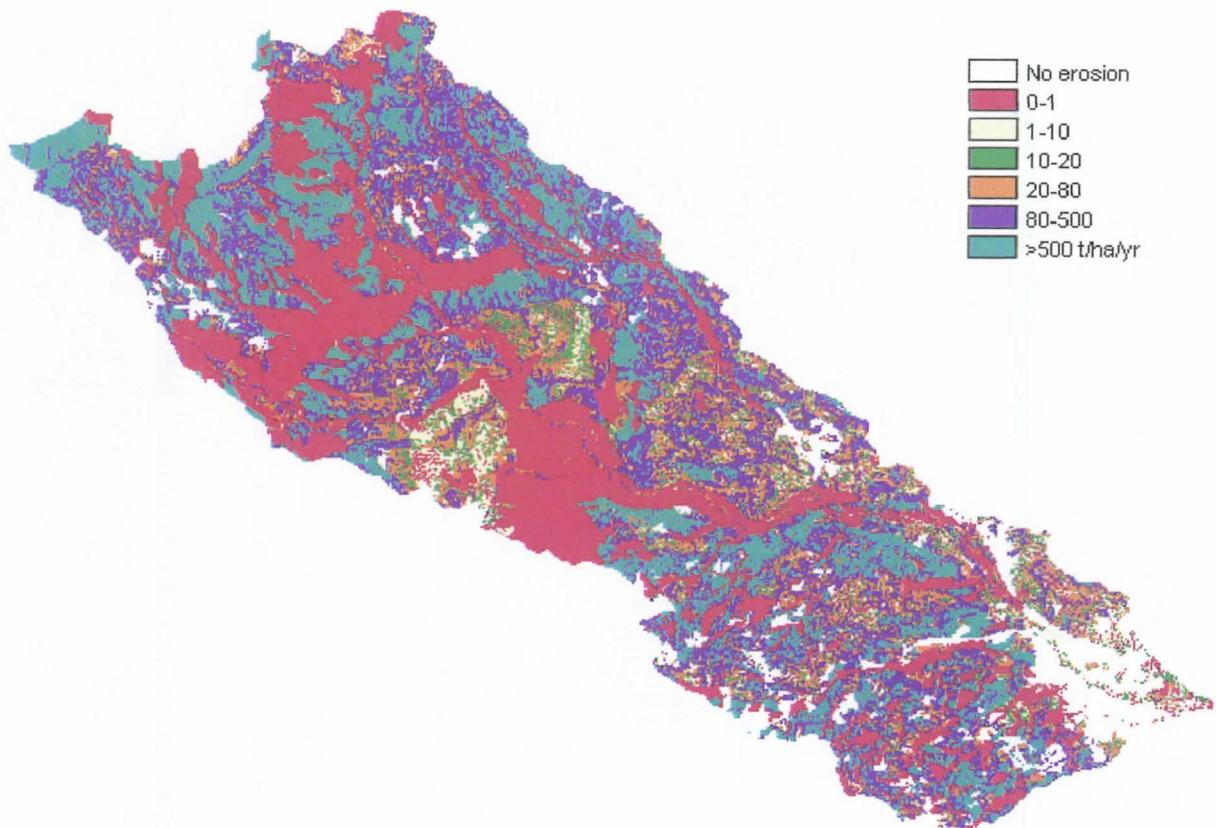


Figure 2. Actual Erosion Classes for the Turrialba Catcment (EU- ECOMAN project)



8.4.4 Task 4 (Environmental Services of Shade Coffee)

Collection of literature and entry into an Endnote bibliographic database has continued. The WP leader met with Byron Medina (Anacafe) during May at CATIE and exchanged methods and data. Appendix IV summarises information on Environmental Services, but more emphasis will be placed in year 4 on collecting and extrapolating information on the financial values and shadow costs of these services, to form the basis of Deliverable 8.3.

8.5 Deliverables

There were no deliverables anticipated in year 3. Deliverables are due in months 45, 46, 46, and 48. The last Deliverable (8.4) will be an output of the final workshop.

8.6 Milestones and expected results

There were two milestones due in at the end of year 3

Table 1)

8.7 Work Programme for Year 4

Limited progress has taken place in WP8 during year 3.

Table 1 gives a revised timetable for Year 4 needed to meet the final deadline.

Table 1: Workplan for Year 4

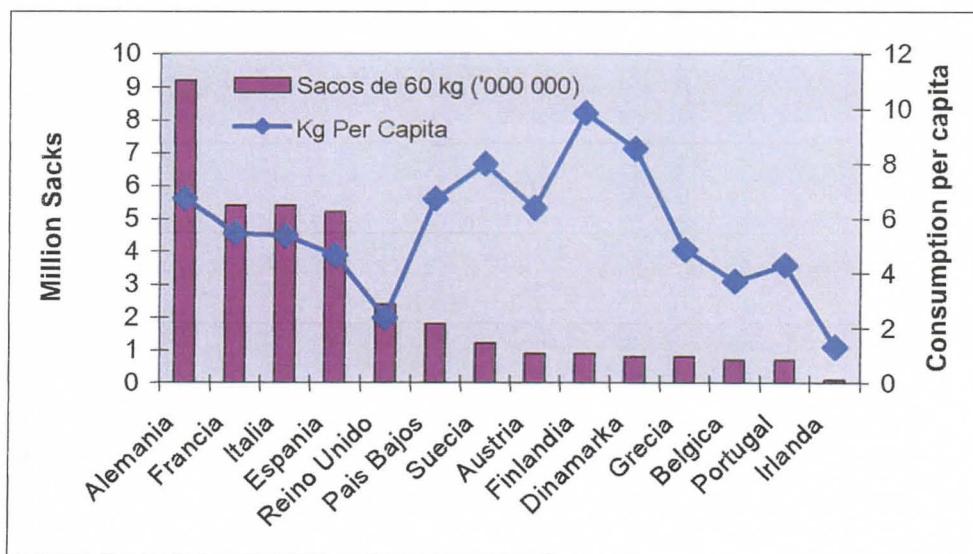
| No. | Milestone/Task | Original month | Revised month |
|------|---|----------------|---------------|
| D8.1 | Report on prospective marked for eco-friendly coffee in Europe | 45 | 48 |
| D8.2 | Report on extrapolation from socio-economic farm model to level of administrative region | 46 | 46 |
| D8.3 | Report on extrapolation of plot-scale biophysical model results to predict regional yield and environmental impacts | 46 | 46 |
| D8.4 | Delivery of management and policy guidelines taking into account different climate, soil, market price and incentive scenarios. | 48 | 48 |
| M8.1 | Completion of interviews with European traders and estimates of premium prices that European consumers are willing to pay for eco-friendly coffee | 42 | 47 |
| M8.2 | Extrapolation of outputs from the socio-economic farm model (WP7) to predict impacts of different management scenarios on farmers at the level of administrative region (Month 36). | 36 | 42 |
| M8.3 | Extrapolation of plot-scale biophysical model results to predict regional yield and environmental impact on a GIS grid, for at least one country (Month 36). | 36 | 42 |
| M8.4 | Integration of socio-economic-ecological impacts of coffee management systems in the context of broader environmental impacts on stakeholders (Month 40). | 40 | 44 |
| M8.5 | Completion of management and policy guidelines following workshops (Month 48) | 48 | 48 |

9 Appendix I: Coffee Labelling Schemes

9.1 Markets for Ecological Coffee

Four types of labelling scheme can be identified: a) organic coffee; b) conservation or shade-grown coffee; c) fair trade coffee; and d) retailer registration of producers. Additionally there are a number of schemes producing guidelines for 'environmental' or 'ecological' production which do not require certification or labelling. Each of these schemes has different criteria and indicators, different methods of certification and different benefits for the producer. There is no doubt that economic advantages are to be gained for the small producer, but there is now a great proliferation of schemes and labels available in the marketplace. Some of the schemes are being adopted by very large producers and the market for specialist certified coffee may become saturated. It is extremely difficult for the consumer to know what proportion of any premium paid will benefit the growers, and to compare the environmental benefits of rival certificates. There is a need for independent assessment of the certification schemes available to growers in Central America and for their classification according to social objective and environmental criteria. WP8 will complete this appendix during year 4 in conjunction with relevant NGOs and retailers in Europe, focusing on countries which have greatest imports.

Figure 3 Consumption of café in the EU en 2001 (33.2 million sacks of 60kg); US=18.6 Million sacks, Japan 8.3 M sacks



The small grower is most interested in:

- the premium guaranteed to certified produce;
- the time, cost and difficulty of pre-certification, certification and re-certification;
- the size of market for each type of certified coffee, and its reliability in future years;
- the increases in cost, and risk of disease, when using certified production methods;
- the requirements for changes in working and social conditions;
- the long-term environmental benefits for his own farm;
- possible local area premium paid for conserving catchment water quality and quantity;
- revenue and flexibility gained by producing timber and fuelwood on the coffee farm.

The consumer is most interested in:

- *A guarantee of environmental benefits from 'shade', 'organic' and 'ecological' coffee*
- *A guarantee that such coffee offers a fair return to the grower and does not involve social exploitation or dangerous use of herbicides and pesticides.*
- *A perception that such coffee has higher quality and is (perhaps) more 'healthy'.*

Specialist coffee trading companies are interested in environmental and social conditions on coffee farms. Larger companies are more influenced by profit and market share criteria, but will respond to consumer demands for better environmental and social growing conditions.

There are four types of coffee labelling scheme: a) organic coffee; b) conservation or shade-grown coffee; c) fair trade coffee; and d) industry sourcing schemes. Additionally there are a number of good practice guidelines.

9.2 Organic Coffee

Organic farming was originally 'maintenance of soil health and fertility' but has extended. IFOAM defines as

- *Organic agriculture includes all systems that promote the environmentally, socially and economically sound production of food and fibres. These systems take local soil fertility as the key to successful production. By respecting the natural capacity of plants, animals and the landscape, it aims to optimise quality in all aspects of agriculture and the environment*
- *Organic agriculture dramatically reduces external inputs by refraining from the use of chemico-synthetic fertilizers, pesticides and pharmaceuticals. Instead it allows the powerful laws of nature to increase both agricultural yields and disease resistance.*

The International Organic Accreditating Service has 600 members in 100 countries – but only 2 are registered in coffee producing countries (2000): BoliCert of Bolivia and Instituto Biodinamica of Brazil. Non-member organic certifiers include Eco-Logica in Costa Rica and Cenipae in Nicaragua.

The IFOAM organic coffee standards place numerous constraints on growers: a) Qualifying farms must devise a farm plan, including separation of non-organic production and the safe-guarding of uncultivated land to serve as natural habitat; b) genetically modified seeds of plant stock are prohibited; c) soil fertility must be maintained through natural means such as ground cover, leguminous 'companion plants' composting and natural supplements if necessary; d) pests and weeds must be controlled through preventative maintenance and mechanical control (e.g. insect traps, manual weeding) or by naturally derived substances; e) synthetic herbicides, fungicides and insecticides are prohibited; f) some naturally occurring chemicals (e.g. copper salts) are allowed but restricted; g) measures must be taken to conserve water and soil at all stages of production; h) roasters must ensure product separation and other procedures to prevent contamination by non-organic material; I) chemical extraction (e.g. chemical decaffeinating) is not allowed; j) roaster must have policies to minimise packaging

There are three other organic standards: a) the European Union Regulation 2092/91 is similar to IFOAM but has no specific criteria for conservation of soil water and biodiversity, nor for social criteria. It is more detailed on requirements for processors and testing programmes. 'Third country' certification is possible for the whole EU once a local certificate has been evaluated and accepted by one of the Member States; b) Codex Alimentarius is a set of food standards developed by FAO and the WHO, and draft guidelines for organic production and labelling have been published; c) the USDA-National Organic Programme standards will limit use of 'organic' to roasters who are not only buying-organically-grown coffee but who have also certified their roasting plants and warehouses.

9.3 Conservation or ‘Shade-Grown’ Coffee

Sustainable Coffee Congress (1996) was watershed in highlighting conservation attention in US – e.g. 150 species of migratory birds that breed in N America live in coffee plantations during winter (60 million bird enthusiasts in the US are a big market).

There are 6 initiatives: a) Smithsonian ‘bird friendly’ criteria; b) Eco-OK programme; c) Country Programmes; d) Industry Sourcing Programmes; e) Consideration of Coffee as a Non-Timber Forest Product; f) Inclusion of Shade in Organic Certification Requirements

Smithsonian Bird Friendly Coffee involves rustic or traditional polyculture³, in which coffee is planted under existing diverse forest cover is most desirable for birds. In the case of planted shade trees, native species with year-round foliage should be used. Species of Inga are recommended. A minimum of 10 species of shade trees is required, distributed evenly and creating different strata. There should be at least 40% shade cover from the canopy after pruning. The shade should be at least 12 meters high, and Stream buffers and living fences are also desirable.

The **ECO-OK Programme⁴** Developed was by Rainforest Alliance and Fundacion Interamericana de Investigacion Tropical (FIIT – Guatemala) & now managed by Conservation Agriculture Network (Costa Rica, Brazil, Ecuador, Guatemala & El Salvador). To qualify producers must: a) maintain or establish a canopy of mixed native trees, b) keep at least 10 species of native trees in the productive part of their farm with at least one representative of each species per manzana; c) ensure a density of shade trees of at least 70/ha; ensure that at least 40% of the productive part of the farm is shaded, with at least 70% of the trees evergreen; d) conserve epiphytes on shade trees, and ensure that at least 20% of the shade trees are emergent (15+ meters); e) pruning should be restricted to the dry season, and must leave at least 50% of fruits and flowers.

9.4 FairTrade Coffee

The **Fair Trade Programme** seeks to ensure that the vast majority of worlds coffee farmers get a fair price for their harvests’. It began in late 1950s as ‘alternative trade organisation’, in small outlets in Europe. The Max Havelaar Fair Trade Seal was launched 1988, and also offered to large coffee companies who could trade a proportion of output on ‘fair trade’ terms. Other EU national initiatives followed – e.g. ‘TransFair’ in Germany.

Fairtrade Labelling Organisations International (launched 1998) consists of 19 labelling organisations sharing common criteria for each product (coffee, tea, bananas, cocoa, sugar, honey & organge juice). Costs are paid by roasters in developed countries – not by the producers. Criteria include a) purchase directly from small farmers organized into democratically-run cooperatives (no criteria for coffee estates, as opposed to tea & bananas); b) guarantee a floor price when world market prices are low; d) offering farmers credit to help cover harvest costs; d) developing long-term trading relationships between importers and farmer co-operatives; e) including cooperatives in the ‘International Fair Trade Coffee Register’; f) providing credit is available at commercial rates once contract to purchase is signed – as advance on delivery;

There are no specified farm practices for Fairtrade Coffee, but the floor price is higher for organic coffee. Producer groups themselves have specified environmental protocols, but these are not yet adopted. So far there are 300 coffee producer co-operatives (550,000 small farmers), 100 importers & 19 Fair Trade Labels, 50 million Euros/year wholesale.

³ The Smithsonian Institute defines a cultivation intensity series of ‘rustic shade’ > ‘planted shade’ > ‘diverse commercial polyculture’ > ‘less diverse commercial polyculture’ > ‘specialised shade’ . The last two are not certifiable.

⁴ <http://www.practicalhippie.com/cache/coffee/ecoak.pdf>

The market share is 5% in Holland and Switzerland. The floor price is \$1.26/lb (\$1.41/lb organic) = \$127/qt (\$142.99/qt), and \$0.15/lb more than market price if above this. Roaster and importers pay a \$0.10/lb licence fee, with no cost to producer. Some coffees ‘double certified’ at no extra cost to producer.

Coffee certified as a non-timber forest product. is under consideration by Forest Certification groups like SmartWood and the Forest Stewardship Council, and sustainable criteria have been developed for other NTPFs such as nuts, oils, gum, woodland plants. The FSC is also collaborating in ‘joint inspections’ with organic certifiers.

9.5 Industry Sourcing Guidelines and Policies.

US examples include Thanksgiving Coffee (CA)⁵, Sustainable Harvest (CA), Elan Organic Coffee (CA), Counter Culture Coffee (NC), & Organic Products Trading (WA). The Speciality Coffee Association of America (SCAA) has guidelines which specify that: a) species composition of shade trees should be characterised by multiple species, with a predominance of regionally native species (not exotics); b) shade tree canopy should be structurally diverse, with a minimum of two layers above the coffee – the topmost layer should have a minimum canopy height of 10-12 meters; c) shade tree canopy foliage should provide a significant amount of shade (40% coverage or more after pruning)

The industry itself calls for further research to define a) the pruning of shade trees, b) the minimum number of shade tree species; c) the importance of epiphytes, vines and parasitic plants. Starbucks ‘Coffee Mission Statement’ was issued after pressure from Guatemala Labour Rights Project , and smaller roasters have significantly stronger mission statements regarding employment and environmental conditions on estates – e.g. ‘just cup’ criteria.

During 2002-03 Starbuck has launched its favoured suppliers scheme⁶. This uses a points scheme to suppliers graded according to the following scheme:

Environmental Impacts: 50 points

- Soil management 5 points
- Water reduction 5 points
- Clean water 5 points
- Water buffer zone 5 points
- Forest and biodiversity conservation 5 points
- Use of shade 5 points
- Energy use 5 points
- Pest management 5 points
- Accepted agrochemical 5 points
- Waste management 5 points

Social Conditions

- Wages and benefits 10 points
- Health and safety 10 points
- Living conditions 10 points

Economic Issues: 20 points

- Transparency from supplier to farm level 20 points

There are also **country specific programmes** independent of the international licencing bodies.

Examples are: a) El Salvador (PROCAFE) is developing national programme to develop criteria for shade-grown coffee in conjunction with Salva Natura (with GEF funding). Organic farming is promoted but is not required. b) Chiapas, where the Union de Ejidos de La Selva and the MacArthur Foundation are assisting and marketing organic coffee in buffer zone for Montes Azules Biosphere

⁵ <http://www.thanksgivingcoffee.com/>

⁶ http://www.starbucks.com/aboutus/sup_div.asp

Reserve; c) Colombia and Ethiopia are also developing national organic certification and marketing programmes which include standards for shaded) Costa Rica, through COOCAFE has 9 cooperatives who are marketing 'Café Forestal; and 'EcoLogica'.

9.6 Good Practice Guidelines

An example of a voluntary code of practice has been developed for Jamaica and agreed by 42 NGOs and international organisations (Anon 2002).

Appendix II: Extrapolation of socio-economic farm surveys to a Regional Scale

Progress on this task is made difficult because of differences between regions in the way in which information is stored on producers, and confidentiality of such data, particularly in Costa Rica. The challenge is to know how typical the growers sampled in field campaigns of WP7 are of regional and national averages. Thus, it is planned to use a WP8 MSc student in year 4 to work with colleagues in ICAFE and UNACAFE to characterise the regional socio-economic variability of coffee producers in selected areas of Costa Rica and Nicaragua. Data to be collected include: a) number of producers per District & Canton; b) distribution of farm size; c) distribution of altitude; d) distribution of production (including previous years); e) use of fertilizers and other inputs. Ideally this data should be collected in parallel with GIS system developed by CATIE for ICAFE, but there are issues of confidentiality and access to survey data which require to be resolved at a senior level. Similar data will be collected in year 4 from Nicaragua in conjunction with UNICAFE.

10 Appendix III Extrapolation of Plot Scale predictions to a region

A database of information on the distribution of coffee farms in Costa Rica is starting to be available from ICAFE⁷. This provides information on the distribution of coffee in each of the Provinces and Cantons of Costa Rica (Figure 4). It also gives information on: a) the area of shade and sun coffee in each Province, Canton and District; b) comparison of the areas registered in 2001 with those in 1984; c) average yield by Province in 99-00 and 00-01; d) areas of coffee in the 7 zones recognised by ICAFE; e) distribution of coffee with altitude (5 zones, 7 regions); f) distribution of coffee against mean rainfall; g) areas displaced by urbanisation.

Figure 4 Distribution of Coffee Areas in Costa Rica (ICAFE 2003)



Similar data is available from the UNICAFFE Coffee Atlas of Nicaragua, where the distribution of shaded and unshaded coffee in each Department has been mapped (Figure 5), and overlaid against an initial estimate of the climatic, altitudinal and edaphic suitability of the country for coffee production (

Figure 6). The limits used by UNICAFFE to determine zones of optimal to poor suitability remain to be clarified. This survey identified that Nicaragua has some 30,400 growers, and 90 percent of them are small- and medium-scale farmers. The survey was funded internationally and conducted between November 2000 and April 2003. Samples were taken from 1,011 farms across four different growing elevations. Amongst other things the maps show that 73.2 percent of Nicaragua's coffee is of the Caturra variety, and 95 percent of the plantations are shade-grown⁸.

⁷ <http://196.40.25.187/> (through <http://www.icafe.go.cr/icafe/index.htm>)

⁸ http://biz.yahoo.com/rm/031111/food_coffee_nicaragua_1.html

Figure 5 Map of distribution of coffee farms in Pacific Region of Nicaragua (UNICAFE, 2003)

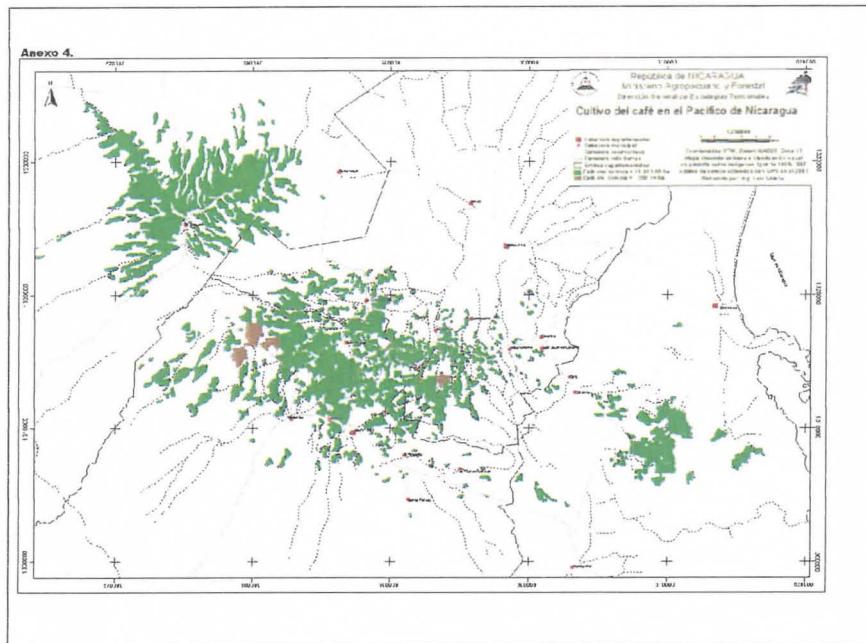
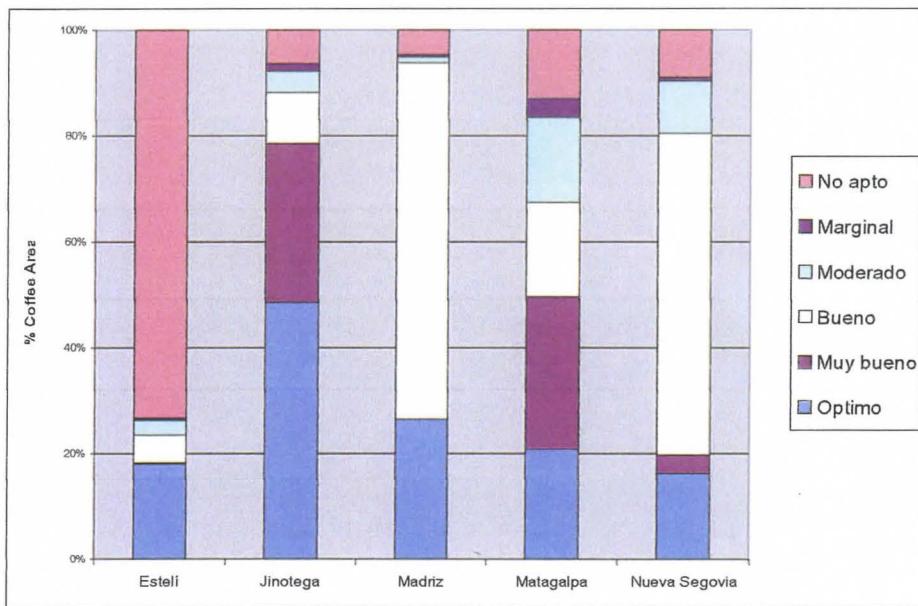


Figure 6 Percent ‘suitability’ of 5 main coffee regions in Nicaragua (Luis Valerio Hernandez, UNICAFE, unpublished).. Regions are Esteli (304ha) , Jinotega (15137ha) , Madriz (2282ha) , Matagalpa (9074ha) , Nueva Segovia (857ha).



11 Appendix IV Environmental Services of Shade Coffee

A literature review of the potential environmental services of coffee plantations has continued, together with measurements of water quality in the Antigua Region of Guatemala. Data on existing projects and studies is being collated in the following areas: a) carbon trading including the Kyoto Protocol ‘Clean Development Mechanism’ and valuation of C-stocks and greenhouse-gas emissions

(in conjunction with WP5); b) contribution of overstorey trees to sustainable timber and fuelwood production (as a mechanism to reduce pressure on natural forests); c) services of shade coffee systems to reduction of erosion and increases in water quality; d) services of shade coffee to water supply and flood control; e) implications for human health of reductions in herbicide and pesticide use; f) biodiversity enhancement both in-country and regionally, g) ecotourism. Some preliminary costings are available (Table 2).

Table 2 Tentative values of environmental and other services of plantations (PROCAFE 1999)

| Type of Benefit | Amount (US\$/ha) |
|---|------------------|
| Water supply | 8-16 |
| Loss of productivity of hydroelectric dam | 15-25 |
| Agricultural land preservation | 2-4 |
| Flood control | 4-8 |
| Carbon sequestration | 400-600 |
| Ecotourism | 6-12 |
| Firewood production | 10-20 |
| Timber production | 10-20 |
| Biodiversity | 4-10 |

Numerous techniques exist for the valuation of environmental benefits of different land use systems. These have been used, for example, to target conservation programmes in the US (Feather et al 1999); estimate impacts on human health (Dixon 1988); and to evaluate aid and loan projects (World Bank 1991).

Non-market values relate to benefits which are accrue through actual or potential use of land use system but which are not directly traded on the market. These include **direct benefits** which the system engenders for stakeholders in the neighbourhood, **indirect benefits** which are enjoyed by those further away, **option values** which reflect the value of maintaining an existing system which may be fulfilling services or protecting species whose value is not known until they are replaced and finally **knowledge of existence values** – which is simply the value that a population places on the existence of a system or land use even if they have little knowledge of it.

Economists assess these benefits using **indirect methods** which seek other economic measures of the utility put on an environmental system. Examples of this would be increased house prices near attractive countryside, or the price that visitors pay to travel to such sites. Such methods rely on a link between the measured variable and the totality of environmental services of a given land use. Yet this link is often tenuous. **Direct methods** are preferable. These can be speculative – such as asking stakeholders how much they would be willing to pay to protect a given land use system; or based on **imputed market values**, such as collating the subsidy which electricity companies are willing to pay to protect water-resources in feeder catchments, or the premium that industries in developed countries will pay per tonne of carbon with a scheme qualifying for the Kyoto Clean Development Mechanism.

This section will introduce a number of examples of real or imputed market valuations of environmental effects of shade coffee plantations.

11.1 Carbon Trading

Carbon storage in forests will be addressed by an appropriate accounting method recommended by the IPCC and approved by UNFCCC under the Clean Development Mechanism (CDM). Locatelli and Pedroni (2003) have calculated the minimum area that an hypothetical forest plantation project should have to be able to cover its transaction costs with the revenues from sales of carbon credits. Model results show that under current carbon price and average transaction costs, projects less than 500

hectares are excluded from the CDM, whatever accounting method is used. Temporary crediting appears to be the most favourable approach to account for non-permanent carbon storage in forests and also for the feasibility of smaller projects. However, the possibility of low price for credits with finite lifetimes is a risk that could prevent the establishment of CDM forestry projects. Plantation projects with low risk of unexpected carbon loss and sufficient capacity of insuring or buffering the risk of carbon re-emission would benefit from equivalence adjusted average carbon storage accounting rather than from temporary crediting.

Rapid developments are taking place in this area⁹ and will be summarised in the Year 4 report.

11.2 Sustainable production of timber and fuelwood

Currently 30% of the fuelwood used in Costa Rica comes from shade-coffee plantations, and 12.5% of the fuelwood consumption is carried out by processing factories (Anon 2000). A study has been conducted in 2004 by a graduate student from CIRAD studying the values of timber products originating from coffee AF systems in two regions of Costa Rica. Two additional studies will be conducted during the final year of CASCA in Nicaragua and Guatemala on both timber and fuelwood products. Consequently, the value of these timbers originating from coffee plantations will be assessed during year 4 in conjunction with WP1 and WP7 (Somariba 1994, 1995, 1996; Bishop 1999).

11.3 Erosion and water quality

Literature on erosion in coffee areas of Guatemala, Costa Rica and Nicaragua has not yet been collated. Oster (1981) suggests losses of 77-180 t/ha per year in the Chiriquí region of Panama. Lutz et al (1994) estimate that coffee yield in the Barva region of Costa Rica is declining by around 10% per decade largely due to soil erosion

The size and terminal velocity of raindrops depend on the intensity of each rainstorm. The big raindrops of a summer thunderstorm are about 5 millimeters in diameter and fall at a speed of more than 20 miles per hour. By contrast, during a light drizzle, raindrops are less than one millimeter in diameter and fall out of the sky at a leisurely rate of about 1.5 miles per hour. Still, even tiny raindrops are quite powerful when they strike bare soil. Their force on impact can detach soil particles from the land and erode them easily. Trees with large leaves

According to a recent erosion and land degradation survey, "two-thirds of Costa Rica's land under pasture, and practically all of the land under permanent crops, is subject to high to very high hydric erosion risk." (Table 3).

A large raindrop falling on exposed soil can impact with such force that soil particles are splattered three or more feet into the air. Sheet flow, which occurs when water accumulates in a thin sheet on a slope; moves soil particles across the surface of the land, often filling the landscape with tiny rills and rivulets and occasionally even gullies. It is possible for trees with large leaves to 'drip' large raindrops with higher erosive qualities than unimpeded rainfall & this potential erosive effect will be assessed during4.

Estimates of erosion caused by conversion of forests to grassland have been made in the Arenal and Rio Chiquito areas of Costa Rica (table 4) with maximum rates in grassland of up to 207 t/ha/yr, but a mean of around 40 t/ha/yr. The ECOMAN project has recently assessed erosion in the Turrialba catchment, an important coffee-growing area (Lourencou & Librerei 2003)

⁹ http://www.ecosecurities.com/200about_us/Taller%20MDL%20CCAD_agenda.pdf

Table 3 Effect of Soil Type on Erosion Risk (and other growth limitations)

| Soil | Nutrient deficiency | Nutrient toxicity | Structural deterioration | Compaction | Erosion/landslides | Effective rooting depth |
|--------------------|---------------------|-------------------|--------------------------------|---------------------------------|----------------------|-------------------------|
| Oxisols & Ultisols | N. P. Ca Zn | Al. Mn | Crusting, hard setting | Surface and sub-soil compaction | Sheet/riill erosion | Shallow to medium |
| Inceptisols | P | - | - | - | Gully erosion | - |
| Entisols | P | - | Single-grained loose structure | - | Gully erosion | Shallow |
| Alfisols | P | - | Crusting, hard setting | Surface and sub-soil compaction | Accelerated erosion | Shallow to medium |
| Histosols | - | - | - | - | - | - |
| Spodosols | N, P | Al | | Sub-soil compaction | Sheet erosion | Shallow to medium |
| Mollisols | - | - | - | - | - | - |
| Vertisols | P | - | Cracking trafficability | Sub-soil compaction | Severe sheet erosion | Medium |

Table 4 Erosion Measurements in Forests and Pasture in Costa Rica (Alward & Tognetti 2002)

| Study | Area | Forest Mean | Forest Range | Pasture Mean | Pasture Range |
|-------------------------------|--------------|-------------|--------------|--------------|---------------|
| Duisberg (1980)* | Arenal | 3.7 | - | 65.0 | - |
| Duisberg (1980)** | Arenal | 1.4 | - | 109.0 | - |
| Calvo and Quirós (1996) | Arenal | 3.7 | 0 a 4.8 | 11.6 | 6.2 a 22.95 |
| Vásquez and Rodríguez (1995) | Rio Chiquito | 3.1 | 0.07 a 5.08 | 35.2 | 0.89 a 66.05 |
| Saborio and Aylward (1997)*** | Rio Chiquito | 0.24 | 0 a 1.55 | 39.7 | 0 a 206.64 |

11.4 Water supply and flood intensity

These aspects will be addressed through a study in year 4 in Guatemala.

11.5 Health implications of herbicide and pesticide use

The incomplete literature on health impact of pesticide use in Central America is reviewed by Larsen and Perez (1999), who conclude that the direct costs of just acute pesticide poisonings in Central America are almost 2.5% of total agricultural GDP (about \$190 in 1995). Of this total cost, almost 50% is due to suicide-related intentional deaths, 25% is due to accidental deaths, and about 25% is due to non-fatal poisonings.

Alternatives to large-scale use of pesticides in coffee plantations are available (e.g. CABI Biosciences 1998), but there is not yet an assessment of the cost effectiveness of such methods. One study (Agne

2000) investigates pesticide taxation as an additional instrument in pesticide policies and assesses the impact of a tax on pesticide use and income in Costa Rica's coffee production. If implemented appropriately, seems a promising approach to internalise the external costs of pesticide use and would act as an effective adjunct to regulatory and moral suasion instruments in crop protection policy. Based on data from a farmer survey in Costa Rica, demand functions for pesticides were estimated. The use of agrochemicals and of labour in coffee production has increased significantly from 1993 to 1995. A detailed costs analysis displayed that the expenditure for pesticides on average totalled about 7% of the variable production costs. The own-price elasticity at means of aggregated pesticide demand was estimated at -0.99, and the cross-price elasticity between pesticide demand and the wage at 0.79, suggesting that labour is an important substitute for pesticides in coffee.

The impact of different pesticide tax scenarios on income from coffee production and pesticide demand was assessed. All scenarios led to a reduction in the gross margin of about 0.7%. The impact of a uniform ad valorem tax was simulated with the aid of the single equation panel model which suggested a significant decrease in pesticide demand: using the own-price elasticity computed at means, a 10% ad valorem tax on all pesticides would result in a decrease of 9.9% in pesticide use. The results obtained in the policy simulations led to the conclusion that a pesticide tax would affect income from coffee production to a fairly limited degree but would substantially reduce the pesticide use in this crop. The hypotheses of this research are therefore both confirmed: pesticide demand is not as inelastic as is frequently thought and a pesticide tax would not considerably affect income from coffee production.

11.6 Biodiversity enhancement

Research activity, concentrated during the 1980s and 1990s, investigated various conservation aspects of shade coffee production. It was found that a number of significant environmental benefits -- from natural resource conservation to biodiversity habitat -- were being provided by shade coffee farms. One of the most discussed findings was the importance of shade coffee as habitat for migratory birds and the converse lack of habitat provided by sun coffee plantations. Studies pioneered by Fuentes-Flores (1979) and Nolasco (1985), and further developed by Miguel and Toledo (1996), characterized five different coffee production systems present in Mexico according to their vegetative complexity, height of arboreal strata, and variety of components.

Beginning in the 1950s, farmers were encouraged to grow coffee in full sun to increase yields and reduce fungal infection (primarily in response to the spread of coffee leaf rust, *Hemileia vastatrix*, known as *la roya* in Spanish). (Sorby 2001) The sun coffee technique did not begin to expand rapidly until the 1970s. (Perfecto et al. 1996) In Mexico, the Mexican Coffee Institute (Inmecafe, which no longer operates) promoted a "technical package" that was centred on full or monoculture shade systems, pesticides and herbicides for pest and weed control, and synthetic fertilizers. (Gomez-Pompa 1996). By 1996 it was reported that the land under modern, reduced-shade coffee systems ranged from 17% in Mexico to 40% in Costa Rica and 69% in Colombia. (Rice, Ward 1996). This has had a significant effect on biodiversity which will be collated during year 4.

11.7 Ecotourism

During Year 4 the profitability of Coffee Tours and landscape diversity created by coffee plantations will be estimated.

12 Appendix III – Bibliography

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