Dissertation Report

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BUILDING A BIOPHYSICAL CONCEPTUAL MODEL OF AGROFORESTRY SYSTEMS (AFS) WITH COFFEE INCORPORATING SCIENTIFIC, EXPERT AND FARMERS KNOWLEDGE

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INTRODUCTION

In central America coffee trees are mainly cultivated under shade trees (Hernandez et al., 1997). *Coffea arabica* originated from Ethiopian highland forests (Huxley and Cannell, 1970), therefore inclusion of shade trees in a plantation may bring beneficial effects. However coffee plants have a big plasticity, and if enough fertilizers are supplied, yields may be substantially increased in full sun (Da Matta, 2004).

Farmers from developing countries are concern with increasing revenues. Improving generation of income from coffee is an important criterion. However developing Agroforestry systems (AFS) practices may reduce the productivity of coffee crops, for example decreasing productivity when tree cover is increased above a certain threshold to enhance environmental benefits. On the other hand AFS practices may increase the quality of coffee beans. For example in Nicaragua Vaast et al. (2006) reported that altitude and shade enabled a better growth of coffee cherries resulting in a higher quality of coffee beverage.

In order to contribute to maintaining and/or increasing the competitiveness and sustainability of the agricultural sector of Mesoamerica a partnership platform (PCP) was launched in 2007 by CIRAD,CATIE and other 4 research and development regional institutions. One of its objectives is to design, in collaboration with farmers, competitive, sustainable and diversified management strategies for AFS, suitable for particular biophysical as well as economic constraints and opportunities.

Farmers knowledge of agroecological processes in a range of contexts has been found to be remarkably detailed and a potent resource for research (Thapa et al., 1995). Thus, gathering local knowledge from stakeholders could be used to complete scientific knowledge in order to produce a useful model integrating coffee productivity and environmental services.

On a first stage of the PCP project there is a need to gather knowledge. Thus, the aim of the research was to build a conceptual model, assessing local knowledge about the effect of the environment and management on coffee farming systems, specifically the effect of the inclusion of shade trees on yield and quality elaboration.

The first chapter placed the study in the context of agroforestry research and Costa Rican coffee production system. Chapter 2 outlines the objectives and research questions. Chapter 3 presents the methodology and provides a brief description of the study area. The forth chapter presents the main findings of the research and chapter 5 discusses some of the main issues, makes some recommendations. Finally chapter 6 suggests further lines of the research.

1. Research context

1.1. Coffee production in Costa Rica

Since Costa Rica's independence in 1821, its agrarian history has been linked with the development of coffee plantations (exclusively *Coffea arabica*). This labor-demanding crop has been cultivated in a wide range of farm size and intensity of production factors (Samper, 1999)

The coffee marketing chain is formed by farmers, who produce and sell fresh coffee cherries to primary processors "beneficios". This first process transforms cherries into green coffee (dry coffee beans). Coffee is mainly bought to the Beneficios by exporters, and exported as green coffee. Some of it is roasted for the developing internal market. During the recent coffee crisis, at the beginning of this century, direct transactions have appeared, either between farmers and exporters, or between beneficios' owners and clients abroad..

The Costa Rican coffee Institute (ICAFE) regulates this chain, mainly by determining each year the minimum price primary processors have to pay to farmers. Moreover ICAFE technicians are in charge of research on coffee, whose results are transferred to farmers.

In central America coffee trees are mainly cultivated under shade trees (Hernandez et al., 1997). Coffea arabica originated from Ethiopian highland forests (Huxley and Cannell, 1970), therefore inclusion of shade trees in a plantation may bring beneficial effects. However coffee plants have a big plasticity, and if enough fertilizers are supplied, yields may be substantially increased in full sun (Da Matta, 2004).

High input coffee production has been questioned because of its financial vulnerability even for successful farmers (Haggar, 2007). From 2001 to 2006 yields in Costa Rica decreased from 30 fanegas[1]/ha to 24 fanegas/ha (ICAFE, 2006). For experts this is the result of the world coffee price crisis, leading to the reduction of coffee assistance and of investments for renovation of coffee production techniques. Besides there is an important reduction on coffee areas: 13.9% from 2000 to 2006 (ICAFE, 2006). At the same time, the crisis in the coffee market provided an opportunity to explore alternative cropping systems and markets.

Agroforestry Systems (AFS) are a mixture of different plant species, including perennial, cultivated together in the same plot. Even if the effects of shade trees on coffee productivity are questioned, agroforestry systems in the Tropics are suggested to provide a promising combination of natural resources conservation and productivity (Steffan-Dewenter et al., 2007)). Indeed, there is in Costa Rica an increasing concern about the use of natural resources by agricultural systems, particularly about loss of biodiversity (Gordon et al., 2007), excessive pesticide and fertilizer use (Aranguren et al., 1982) and consequent water pollution, soil erosion and nutrients loss (Romero-Alvarado et al., 2002).

The estimation of environmental services provided by AFS and their valorization could be a way to improve the economic sustainability of rural communities and reduce they vulnerability by increasing the revenue diversification.

Furthermore, AFS with its reduction on chemical inputs and increased bean quality open new marketing opportunities as organic, nature friendly or specialty coffees. The current strategy of ICAFE is to improve the Costa Rican coffee quality and its image for a better access to the market. However, organic coffee production represented only 0.7% of national production in 2005-2006 (ICAFE, 2006).

1.2. Coffee productivity in shade systems

A shade tree will be considered appropriate when there is not competition with coffee and when its improvements of soil fertility, soil conservation and microclimate are high. (Ong, 1996)

Shade trees improve soil fertility and moisture. Soil fertility is enhanced by nitrogen fixation and recycling of nutrients. Soil moisture is enhanced due to the mulch created by increased rate of falling leaves and residues from tree pruning. However, coffee mineral nutrition will also depend on the synchronization between release from the mineralization of the diverse organic compounds, and extraction by the roots. Moreover, the net effect of shade trees on the resource depend on the balance between the tree own extraction and its return to the system (Beer, 1987).

Shade trees can modify the environment or the coffee crop development, and therefore indirectly alter pest and disease incidence. Shade trees can compete for nutrients, water and light with weeds. In Costa Rica the competition for light has been show to be a valuable way to control weeds, pests and diseases (Staver et al., 2001) . Nevertheless pest and disease problems may increase (ICAFE, 1989) or decrease (Beer et al., 1998) with increased shade, depending on the pest and on the environment. Excessive shade increases the infestation rate of *Mycena citricolor*. However *Hemileia vastatrix* causes defoliation in unshaded and shade conditions (Avelino et al., 2004). Shade trees can also host pathogens. For example Inga spp, may be infected by M. citricolor and act as a source of inocula. Shade trees can increase the effectiveness of biological agents without contributing to increased *Hemileia vastatrix* levels or reducing yields. For example *Bauveria bassiana*, an entompathogenic fungus, and *Cephalonomia stephanoderis*, a parasitic wasp, persist better under shade.

The main effects of tree crop interactions can be modified by tree management: (i) the spatial arrangement and density of trees, (ii) frequency of pruning, (iii) trees diversity. Besides tree management depend on site conditions. For example to ensure a beneficial effect of shade trees, it is recommended that the proportion of shade has to be lower for cloudy and humid zones, and higher for

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[1] Measure unit used by farmers and processors in Costa Rica. 1 Fanega = 256 kg of coffee cherries, the quantity supposedly needed to produce 100 lbs of green coffee.

dry and sunny zones (ICAFE, 1989). During humid conditions, the proportion of shade can be decreased to avoid the incidence of *Mycena citricolor* by pruning shade trees.

The inconsistency of the results of the effect of shade trees on coffee productivity reported in the literature lies probably on widely varying site conditions and management. Thus it is necessary to adapt each AFS to its site condition.

1.3. Designing productive AFS

To explore and propose AFS on a short term, systematic modelling appears as a solution. However there are not proved models taking into account (i) coffee behaviour in AFS,(ii) the perennial coffee plants characteristic, and (iii)the importance of quality.

In Costa Rica there was a trial of coffee mechanistic modelling "COFFEA" developed by Rojas (1995) based on coffee distribution of photosynthetic assimilates. However it doesn't include the dynamic of shade trees.

An unpublished work of Van Oijen et al developed a plot scale dynamic model of coffee and shade trees growth. It included the physiology of coffee plants and its daily response to different growing conditions (management treatments, competition for light, water and nutrients). The model parameterisation remains uncertain and outputs are concentred on yields, stem volume and environmental impact. Factors as quality and the effect of pests, diseases and weeds are not taken into account.

Thus on a first stage of the PCP project there is a need to gather knowledge and to find out the main aspects that will organise the simulation model about coffee-shade tree interactions and its effects on the biophysical system, thus in coffee yields and quality.

1.4. Knowledge in Agroforestry systems

Agroforestry is a recent science, but it is also a traditional practice and local agroforesters may detain valuable knowledge on its management (Sanchez, 1995). Therefore, the knowledge needed to identify the best management strategy may be more scattered between different kinds of stakeholders than is the case for more industrial crops.

Local knowledge has been defined as knowledge based on real life observations and experience (Walker et al., 1995). Farmers based their practices on their understanding about natural process and biological interactions in particular environments. Local knowledge studies in Kenya showed that the widespread recommendation on shade trees wasn't followed by many farmers. In fact, based on their experience farmers were able to find out which trees could be grown without adverse effect on coffee production (Lamond, 2007).

Research involving looking at local knowledge in Costa Rica has proved to be useful. For example it was reported a classification for trees according to their effect on biodiversity and soil conservation, showing farmer's preference for particular shade tree specie (Cerdan, 2008). However until now there is not a detailed study on coffee productivity knowledge in the PCP project.

Diverse knowledge must be stored in a form that allows different sorts of analysis and interpretation to be done. An explicit representation of the knowledge as it is collected is needed. Such techniques for representing knowledge on computers exist. Agroforestry Knowledge Toolkit (AKT)[2] is a tool for a systematic collection of ecological knowledge. This tool is intended to be used as a part of a participatory Rural Appraisal exercise to help researchers maximize use of existing information. It enables to create a knowledge base about a chosen topic by collating knowledge from a variety of sources -farmers, scientists, extension workers (Walker et al., 1995). Data are recorded as a set of qualitative or quantitative observations. Inputs are a collection of statements. Each statement is referenced with the source of the knowledge. Outputs of the analysis can be display as diagrams to investigate causal processes (appendix 1). Thus, this function could be used to build conceptual models, and compare knowledge of different origins.

[2] KBS methodology has been developed by university of Wales, Bangor.

Finally AKT proposes a methodology to perform the knowledge collection. It includes 4 stages: (i) Scoping stage where the researcher identifies any variability within the community that could influence the study: who knows what, and who would be useful to interview in terms of the research objectives; (ii) Definition of domain to set preliminary boundaries to what the knowledge base will be about and the areas to cover, (Dixon et al., 2001); (iii) compilation where selective key informants are repeatedly interviewed and (iv) Testing the representativeness of the acquired knowledge across the study area, requiring random sampling statistical analysis (Walker et al., 1995).

2. Objectives and research questions

2.1.1. Objectives

The aim of this study is to build a conceptual model of the effect of the environment and management of a coffee plantation on yield and quality elaboration. The model focused on the effects of the inclusion of shade trees. Knowledge from different origins is brought together in this conceptual model, in order to achieve a comprehensive representation of the system, which is shared among stakeholders.

To create a complete representation of knowledge on coffee yield and quality elaboration, we interviewed actors in the coffee productive chain: Farmers, technicians, and first coffee processors (Beneficios). Besides we looked for academic knowledge. Once each knowledge representation was created, we undertook a comparative analysis.

Our work is based on two hypotheses:

- Knowledge from different origins on coffee productivity and quality is complementary and its gathering can improve the comprehensiveness of a conceptual model.
- AKT is a suitable tool to gather and represent information from different sources, including academic literature.

2.1.2. Research questions

(1) An exploration of farmers, technicians and processors understanding provides a complementary source of scientific understanding about biophysical interactions in coffee AFS in Costa Rica?

(2)Is AKT a useful tool to build conceptual models and compare knowledge to identify and prioritize research objectives?

3. Materials and Methods

3.1. Location of research

To increase the diversity of knowledge gathered and enrich our scientific model we looked for coffee plantations in different agroecological situations. Agroecological situations determine shade coffee management diversity. Therefore covering a large range of situations provides a diversity of information valuable for the knowledge base.

Our regions were selected among the coffee productive zones in Costa Rica (Figure 1): Turrialba, Orosi (both located in the Turrialba region) and Tarrazú. Costa Rica is divided by folded mountains in two versants, the Atlantic one (Orosi, Turrialba) and the Pacific one (Tarrazú). The proximity to mountains, hence their altitude, is the other difference between the three regions. The resulting ecological situations are presented in (Table 1).

Differences in altitude and rain distribution are called to be the main differences between coffee production in Turrialba, Orosi and Tarrazú.Coffee yield are considered low in Turrialba and Orosi when values are less than 20 fanegas/ha/year and high when there are between 25 and 40 fanegas/ha/year. In tarrazu less than 30 fanegas/ha/year is considered low.

Turrialba low altitudes and high frequency of rains are said to be the main causes of low yields and coffee quality. The main yield is around 20 fanegas/ha, lower than the national mean (25 fanegas/ha). Some farmers opted for organic coffee.

.Relatively large coffee plantations are frequent in Orosi, allowing higher technification. Furthermore, there is a market looking for Orosi coffee qualities, in particular its big beans and sweet flavor, therefore coffee reach higher prices than in Turrialba. Yields are around the national mean. Organic farming is rare, probably in relation to the size of the farms and to the quality niche.

Tarrazu is considered as a very good region for coffee production: productivity can achieve 35 to 40 fanegas/ha. Tarrazu coffee is known in the market for its good quality (acidity, small size coffee beans). It has a defined dry season, and coffee plantations are located at high altitudes. Organic coffee is rare.

3.2. Coffee practices

Coffee practices differ in the three regions (Figure 2). The only difference between Turrialba and Orosi was the beginning of harvest. However Tarrazú differed in 6 out of 10 practices. From technician's point of view, the presence of a well defined dry season from December until March was the primary cause of that difference.

Coffea Arabica most used varieties are dwarf mutants Caturra, Catuai, Catimor, Costa Rica 95, and some typica like Geisha, Villalobos, or Bourbon, favored for their cup quality.

Coffee is a perennial shrub with continual growth, its centrifugal fructification causes an increase in branch growing and old unproductive wood. Pruning is necessary to decrease the amount of old branches and stimulate the production of new productive tissues. Besides, a certain number of trees will wither and die each year, they must be replaced. A coffee plant can produce between 15 to 25 years depending on its assistance(Coste, 1968).

The main pathogens that farmers have to face are the fungal disease *Mycena Citricolor* called ojo de gallo (American leaf spot) causing damage to leaves and fruits, and the insect *Hypothenemus hampei* named broca affecting berries and beans. Organic control agents are presented as an alternative for chemical control, usually done with an organochloride insecticide, endosulfan. However, the survival of the fungi used for organic control of berry borer can be problematic, depending on site conditions and reduces its use (Guharay et al., 2001). From ICAFE point of view there is a decreasing concern on controlling nematodes and rust.

Shade is variable in number, species, and management. There is not an optimal density advised for shade trees management. However it is considered that poró (*Erythrina poeppigiana)* will help increase yields. In fact this introduced species is a rapid-growing, nitrogen-fixing trees. But it has to be pruned once a year and thinned at least two times per year, increasingly whith a higher ambient humidity. Planting density might be between 6 X 6 m and 12 X 12 m depending on ambient humidity. Other shade trees are plantain and banana (*Musa spp*), laurel (*Cordial Alliodora*) and guava (*Inga spp)*

In Costa Rica when coffee production factors are reduced, farmers avoid: (i) atomization with fungicide, nematicide, insecticide or fertilizers, (ii) complete Berry borer control (iii) application of herbicides, and (iv)thinning coffee trees. This occurs during periods of low prices, or in farm where production factors are scarce, particularly capital and workforce for crop management.

The effect of management on coffee plants yield and quality will depend on environmental factors, in AFS the association of two or more species lead to a more complex biophysical system.

3.3. Building an academic model

3.3.1. Conceptual model: Coffee yield and quality elaboration

Representing a system by its biophysical interaction with practices and climate is a way to integrate into a model the knowledge about yield and quality elaboration. Coffee productivity is site specific but the mechanisms governing it are of general significance.

Conceptual models are used to gather knowledge of complex systems. These models may eventually lead to the development of simulation models, or make a tool for discussion between different actors.

On participatory research farmers can be asked to help with the model making. However it is necessary to take into account that it is risky way because farmers do not have the possibility to prove their hypothesis (Doré et al., 2008). Moreover, even if there is a large amount of interviews it is necessary to confirm it by in field measures (Rapidel et al., 2006).

Conceptual models can be based on yields components, where the value of each yield component depends on the previously formed components and environmental factors during the formation of the yield component (Doré et al., 2008). A crop yield is usually defined as the quantity of useful biomass harvested annually per hectare, for coffee it correspond to the volume of cherries harvested per hectare and per year. For coffee, we built an equation representing the variables or components affecting the final yield:

Yield (bean weight/ha): Number of (N) plants/ha
X N vegetative nodes/plant
X N floral buds/vegetative node
X N flowers/floral bud
X N pinhead/flower
X N green fruits/pinhead
X N ripe fruits/green fruit
X mean fruit weight
X (bean weight/fruit weight)
.

Thus, it is possible to divide the study of coffee productivity within its components, however it is necessary to take into account that coffee is a perennial crop, and its growth is indeterminate. Yields on successive years are interlinked and this pattern is part of the yield elaboration scheme.

Fruit weight will not only influence yield but as well its quality. The physic quality of coffee cherries depends on beans size and uniformity. However its chemical and organoleptic values are important criteria (Guyot et al., 1996). Chemical composition lies on coffee beans fat, acidity, caffeine and sucrose contents. Sucrose and acidity will determine some organoleptic characteristics as the aroma. Other organoleptic characteristics are body, bitterness, and astringency. The absence of residues is called "clean cup", and is a criteria used to classify toasted coffees (ICAFE, 2008).

Some quality variables depend as well on post harvest techniques and on the preparation of beverage (Bertrand et al., 2006). However our biophysical model will only take into account agronomic factors affecting final quality of green coffee.

3.3.2. Building the academic conceptual model

A literature review and interviews were used to build an academic conceptual model. It is based on the physiology of coffee, and outputs are coffee yield and quality. Coffee phenological phases were chosen in function of their easy identification in the field and their importance to determine final coffee yield and quality. The value of each yield component (e.g. floral buds) depends on the previously formed components (e.g. vegetative nodes) and environmental factors during the formation of the yield component (e.g. Radiation).

Because the academic model is based on literature review most of the interactions cited are based on monofactorial analyses. The period considered is one year corresponding in Costa Rica to one reproductive cycle (Cannell, 1970) lasting from 8 to 10 months (Frank, 2005).

The review was resumed in a Power point presentation showing five stages (Figure 3). For each stage we then detailed factors as Carbon allocation and environmental factors cited below (see appendix 2).

The presentation was used as an iterative diagramming to guide the interview with four researchers working with coffee at Agroforestry department, in CATIE. Our aim was to (i) validate the model, (ii) add cause and effect relationships, (iii) find out particularities for Costa Rican conditions.

Questions to the researchers focused on the accuracy of the selection of each stage and non-identified causal relationships. We also asked to make a hierarchy of factors for each stage, to simplify the model.

The model was presented in a scientific meeting on AFS modeling in CATIE, to get inputs from other researchers.

Entering the information on a knowledge base system, AKT and use its diagram function was proposed as a methodological modification to build the conceptual model. It was also meant to document each relationship (qualifying a each relation introduced in AKT only).

3.4. Knowledge incorporation to the academic model

Based on some hypotheses about the kind of knowledge retained by each type of actor, we chose and designate four groups to assess a diversity of knowledge and discuss the academic model. The hypothesis were (1) Scientist knowledge is academic, based on literature information, unpublished observations, experience and site specific evaluations (Walker et al., 1995) (2) Knowledge from technical experts is a result of experience, coffee farms evaluations and unpublished observations (Thapa et al., 1995) (3) Coffee processors are the only ones having an understanding of coffee quality aspects in their region (Larrain, 2004) (4) farmers knowledge is local, build from their observations and work in the field and results from a relatively large time span, they have much more intimate experience of their production practices than external professionals (Thapa et al., 1995).

3.4.1. Interviewers

The aim of our study was to gather the most diversified understanding of factors affecting coffee productivity. We were not looking for a group description, but for a diversified knowledge. Therefore selection is a non-random sampling method and the sample was not intended to be representative of the population under study. Rather, we looked for key informants. A key informant is a farmer, technician or coffee processor with experience in coffee work and possessing an ample understanding of the relations between coffee management, coffee biology and their effects on coffee productivity and quality.

a) Farmers

Our objective is to cover a diversity of coffee managements to obtain an ample range of qualitative knowledge. We hypothesized that interviewing farmers with a wide range of coffee practices will give us access to a diversity of knowledge.

From already existent coffee farms typologies in Turrialba, based on a description of practices, (Cerdan, 2008; Llanderal Ocampo, 1998; Porras, 2006),differences in coffee yield between an intensive, and a traditional (less intensive) crop management and between organic and conventional farms on the other side are reported. Moreover it is argued that organic farmers have a lot of knowledge about agronomic interactions.

A more detailed description of practices in coffee plantations has been done in CATIE for Costa Rica and Nicaragua (Haggar and De Melo, 2008) (see appendix 3).We add yields estimations, shade trees pruning for each group given by ICAFE technicians.

Following that farmers stratification the selection of experimented, available, "like to talk" farmers was made enquiring some ICAFE technicians, Catie students, farmers and some technicians from processors plant of the Tarrazú zone.

Finally 24 key informants were interviewed (Table 2).From the initial objective to interview 2 informants from each category, we had to adapt the sample to take into account the actual existence of such farmer in each zone. For example, organic farmers in the Tarrazú region are rare, and we could interview only one farmer for each category, and therefore we interviewed 2 more farmers in conventional categories.

Table 2 Farmers interviewed

	Extensive organic	Intensive organic	Moderate Conventional	Intensive Conventional
Turrialba	2 farmers	2 farmers	2 farmers	2 farmers
Tarrazu	1 farmer	1 farmer	2 farmers	4 farmers
Orosi	1 farmer	1 farmer	2 farmers	4 farmers

The number of non shaded coffee plantations in the sample was low, but this was congruent with the situation in the regions, were few such plantations did exist. In the region of Tarrazú there is just one farmer and he wasn't recommended as a key informant. In Orosi most of non shaded farms were introducing shade trees, we interviewed two cases. In Turrialba we visited one intensive full sun farm, but its interest on coffee production was decreasing and they were replacing some coffee trees with palmito trees.

b) Technicians

In total 8 Technicians were interviewed: 4 in Turrialba and Orosi, 1 in Orosi, and 3 in Tarrazú. To select technicians and processors we asked in Turrialba and Los Santos regional offices of ICAFE to select the most ancient and experimented on coffee production. ICAFE regional office for Turrialba also covers the Orosi region. Not all technicians worked at ICAFE, some also worked at Beneficios. We just made sure that they were in charge of visiting farms and not in processing coffee.

c) Processors

We visited 6 processors: 1 in Turrialba, 2 in Orosi, and 4 in Tarrazú. In Tarrazú there is an increasing number of farms with their own beneficio. Thus, we included 2 farmers in such situation because we thought they might have more knowledge about quality and its relation to coffee management.

3.4.2. Interviewing

Based on the knowledge learnt from the construction of the academic model, we build the interviews. A diagram based on yield components and general themes was built and used differently depending on the group interviewed.

All interviews were recorded for later processing using AKT software. Farmers and processors interviews lasted at least 2 hours, while technician's interviews took no more than 1 hour.

a) Farmers

In the interviews we delimited with farmers a coffee plot, unit of similar management and site conditions (soil conditions, shade amount, shade diversity, coffee plant age and varieties). We then identified yield components, we did not ask directly for each yield component. For this coffee plants were used as a support to find out morphological differences and elucidate knowledge.

Then we looked for how environment affected those components, and finally we tried to find out how shade trees could modify those relationships. Asking for practices was a way to make a relation between what farmers do and what they see on their field, besides it let us to have a brief description of practices for our classification.

A diagramming was used to follow the knowledge elicitation (appendix 3).It allows the interviewer to follow the keywords to check if all the big themes were treated, and at the same time ask open questions in a semi structured way on the basis of what interviewees saw in their coffee plots. We use occasionally as well a detailed questionnaire accompanying this diagram to ensure a more detailed support (appendix 3)

When there were responses that seemed to be incoherent we tried to ask questions in slightly different ways to check if knowledge was there and just needed to be triggered off by the right questions. Incoherencies between knowledge and actual practices were frequent when we interviewed the manager, as he had to do what the owner of the plantation ordered.

b) Technicians

The same semi-structured interviews used for farmers' interviews were used for technicians. However the diagram, which was used as a check list with farmers, was used in this case as an iterative diagramming. Thus, technicians were called individually to complete cases and explain interactions. This method was useful to involve technicians giving them a support for their answers and to organize their knowledge about factors affecting productivity on one productive year and at plot scale.

Interviews began defining different stages of coffee yield elaboration. Then based on what the interviewee defined as a stage, we draw it on a paper and see how factors like: climate, coffee management, pest and diseases affected each stage, and therefore yield. Finally we find out how shade trees have a direct or indirect effect (modifying practices, diseases, pests, and climate) on yield elaboration stages.

c) Coffee processors

Processors interviews were carried out in two times. The interview used for the technicians was used as a first step. However, the processors did not provide much detail on the first four phenological phases and we spent more time on the fifth phase. For each quality characteristic cited we asked to link it to conditions or practices in the field. When the answer was considered too general, we tried to put the interviewee in the situation of a producer asking what he would do to improve coffee quality.

For the second part we visited the processing plant, while processors explained each step of the process, we ask for coffee bean characteristics obtained at the end of each step. Then we ask to link those characteristics to field.

Just 2 from 6 interviews were not realized on two parts because the meetings did not took place in the processing plant.

3.4.3. Processing with AKT software

As a result of the workshop presentation we find out that our power point model version needed a more detailed presentation. AKT toolkit has been designed for the representation of knowledge elicited through semi-structured interviews. Therefore AKT toolkit was presented as a way to (i) organize information as a knowledge base, (ii) explain arrows connecting cause and effect, and (iii) with an objective of comparison, the use of a dynamic diagram representation letting to hide or show paths we wanted to explore, was interesting.

a) Entering interviews

Each record of interview was processed in the office. Entering interviews the same day it was done, as it is recommended on AKT manual, was not always possible. Processing an interview of 2 hours with AKT took 4 hours. We tried to concentrate various interviews in the same field trip. Therefore, processing was done some days after the interview. However, we visited each region at least twice; this allowed to check some interviewee to check for some incoherencies or needed precisions that appeared when processing the interview.

Each interview has its referent, so each piece of knowledge is attributed to its source. In the case of the academic model built with literature we called the source “scientific literature”, and to complete the scientific database we added scientist interviews. For farmers, technicians and processors, each source was identified by its name and some farm characteristics referred as a “Memo”.

To process each interview we (i) looked for and collected knowledge about coffee productivity, (ii) build a statement and entered it into the knowledge base on AKT5 software, (iii) make detailed diagrams.

Conceptual model were obtained by a diagram function on AKT. Each cause and effect linkage was diagramed from stored statements, and each link has a value qualifying each relationship (examples given in results section).Therefore each statement had two terms: one is a cause, and the other an effect. Each causal statement can be built converting each term into a process (natural events), action (practices), or objects. The relation is entered as an attribute value for each term.

For example a farmer from Orosi (Jose Francisco) said: "*More shade on coffee plants diminish the amount of leaves falling, this is good because the amount of leaves on the plant increase*". This statement has 2 causal statements:

1. More shade on coffee plant diminish the amount of leaves falling, becomes: att_value(process(shading,coffee_plant),rate,increase)causes1way att_value(process(falling, coffee_leaves),rate,decrease)
2. A reduction in the amount of leaves falling increase the amount of leaves on the coffee plant, becomes: att_value(process(falling, coffee_leaves),rate,decrease)causes1way att_value(coffee_leaves,amount,increase)

Then if another farmer said the same it is appended to the statement. If farmers reported some condition for the causal relationship it was added to the statement, and written on the diagram.

It was possible to differentiate from what interviewers have seen and what they have learnt from other sources. Before we entered the statement, the software ask if it is an observed, a literature, or a heard statement.

Moreover AKT gave a way to detect incomplete or incoherent information. Each region was visited on two times, at the end of the first visit we looked at dispended statements using an option of AKT. Those relationships correspond to statements without any link in the model.On the second visit we try to do more precise questions to append those statements to our model.(appendix 3)

For each group of actors we made one knowledge base, to make easier the diagram construction for each group and comparisons.

b) Analyzing the knowledge

The purpose was to analyze the knowledge and elicit any possible gaps in scientific knowledge or richness of each knowledge base.

An option called "Boolean search" let us to select what we wanted to diagram. For example if we wanted to see what factors affect the amount of floral buds, we select floral buds on the option. This allows us to zoom on each stage, and compare by a visual superposition and highlight gaps between different groups. However all the statements were not diagramed in a comprehensive way. We had to organize each statement, with its variables, and the description of the relationship between them.

A final model including all knowledge bases was not realized because the program did not allow us to diagram all the knowledge bases together.

4. Results and discussion

We entered 228 statements in the knowledge base for the academic model, 520 statements in the farmers' knowledge base, 150 statements in that of the processors and 190 statements in that of the technicians.

In the next pages, we present the models produced from the AKT knowledge bases. The main processes responsible for the yield components elaboration are presented first. All the four models, produced from the four knowledge bases are presented. The subsequent sections detail the processes and the factors acting on each yield component, including shade. In this section, we will follow the same scheme: the academic model is presented first, and the contributions of the models produced from the other knowledge bases are then studied.

Each stakeholder's group produced its own model. These models are presented in appendices (5 to 8) as they are relatively repetitive and their detailed examination is cumbersome. Only the main differences are detailed in this text.

4.1. . Description of yield components

We obtained four diagrams showing the succession of components: Vegetative nodes, floral buds, flowers, pinhead, green fruits, and ripe fruits amount.

To validate the consideration of each yield component by the different groups, we have to look at (i) the connection with the previously and the following formed component (blue zone) and (ii) the processes modifying it (green zone). Component and processes related to quality (orange zone) are illustrated in the diagrams.

For easier interpretation of diagrams arrows and boxes were arranged at different places in each model. In the academic model some information was not contained in boxes and was represented as conditional statements under the arrows, this was a different way to link to boxes when we entered the literature information

Yield components were 6 for the academic (Figure 4) and farmers' models (appendix 5), 7 for technicians' model (appendix 5) and 5 for processors' model (appendix 5). For the academic model, we validated the components and processes founded in the literature; however, for the other sources we let them to build the "history" of the ripe fruit. This shows what components were mentioned as important by the different sources.

Processors did not mention the vegetative nodes stage. The details for the quality zone are the most numerous, thus confirming that their knowledge is important for quality aspects. Farmer's model is more detailed than technician's model. It could be because while technicians were interviewed they felt "like they were passing an exam", thus they presented mainly the knowledge they had from literature, and did not take the chance to present their own observations and experiences.

Finally red circles show processes that do not appear on the academic model. For farmers the moment the flowers were formed influences the size of fruits. The first flowers formed are bigger and produce bigger fruits. This illustrates the link with the amount of carbon available: first flowers would have more carbon available for their development, hence for fruit growth.

Therefore were areas of knowledge where the academic model was more explicit (eg. Initiation and induction processes), but general process (Falling, fruit formation, ripening) were well understood by local informants. In farmers model it was confusion with the meaning of flowering (see 4.4) but this did not stop the interviews.

Comparison of these models revealed complementarities, with each knowledge system also providing added individual detail that did not contradict the other. Higher events of flowering were considered as a process affecting the amount of floral buds (Processors and farmers) or flowers (farmers). It is expressed differently "crazy flowering, frequency of flowering" however it expresses the undesirable effect of rains, explored in 4.4

Farmers reported other interactions that were relevant to their site conditions and questioned the academic model. They reported that falling of green fruit was not just during the pinhead stage, it is the only group who linked the process of falling affecting the amount of green fruits.

In the processors model we see that the rate of falling fruits decreases the amount of ripe fruits and reduces coffee quality because farmers pick fermented fruits from soil.

Thus for the amount and quality of fruits depending on the competition for carbon is a process that is included in the models, in an explicit way or not. This model has been explicitly included in the academic model, and less explicitly in the farmers' model, who described the tiredness of coffee plants.

4.2. Carbon production and allocation

The amount of carbon available for organs development depends on: (i) Carbon interception and conversion (photosynthesis rate, the sources), (ii) the different uses of this carbon in respiration, growth, accumulation as reserves etc. (the sinks).

Photosynthesis depends on factors like radiation, temperature, water and nutrients availability, CO_2 atmospheric concentration, leaf age, and plant genotype (Alvin, 1953). Besides Silva et al. (2004a) show that stomatal limitations reduced carbon assimilation. This vegetative carbon assimilation is affected by microclimate, when the effect of fruits as a sink is eliminated. Cannell and Huxley, (1970) proposed a seasonal pattern: roots development during the dry season and aerial development during the rainy season resulting from a modification of carbon assimilation. Studies on those patterns are shown on (table 3).

Table 3 Expression of different patterns on vegetative growth for branches without fruits

	Rainy season: vegetative growing	Dry season : absence of vegetative growing
Net carbon assimilation (Cannell and Huxley.P.A, 1970; Silva et al., 2004b)	Increase	Decrease
Aerial vegetative growth (Da Matta and Cochicho Ramalho, 2006)	Increase	Decrease
Number of leaves (Morais et al., 2003)	Increase	Decrease
New leaves size (Morais et al., 2003)	Increase	Decrease
Falling leaves rate (Morais et al., 2003)	Decrease	Increase
Carbon allocation preference (Huxley.P.A and Ismail.S.A.H, 1970)	Leaves and branches	Trunk and roots

This seasonal pattern was observed in regions where dry and rainy season were well defined, however the photosynthetic rate could be determined by variations in solar radiation and temperature. For Costa Rica conditions, Frank (2005) reported that in hot or dry conditions stomatal conductance and photoinhibition are factors decreasing carbon assimilation.

Other environmental factors can modify that carbon assimilation, therefore growth (Table 4). For example in extreme temperature, radiation and water stress conditions nitrate fertilization improve coffee plant vegetative growth (Coste, 1968). In fact nitrate activate mechanisms protecting the photosynthetic apparatus and increase water assimilation efficiency (Carelli et al., 2006).

Processes and organs determining the initial amount of carbohydrates are illustrated in the academic model (Figure 5).

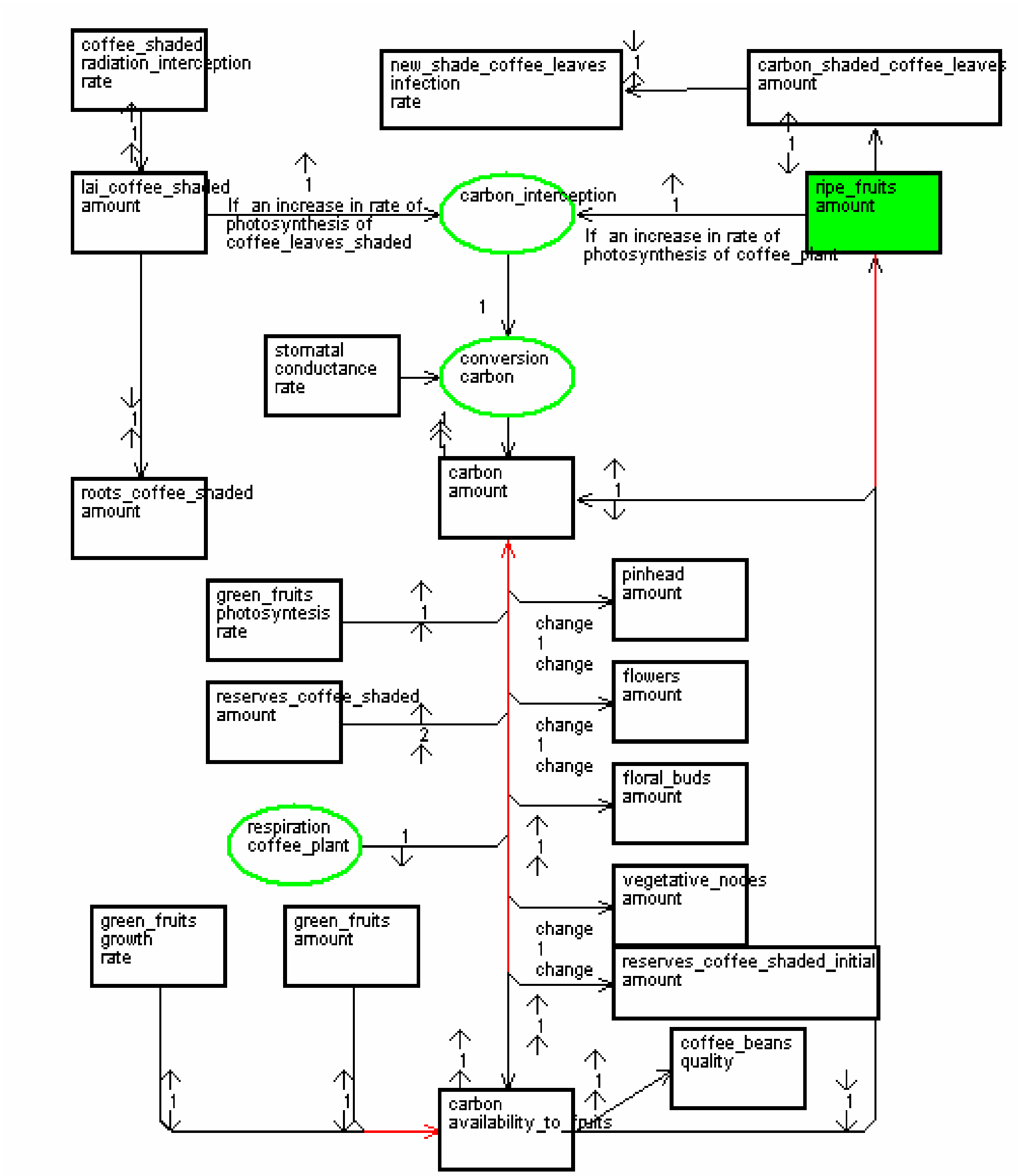


Figure 5 Carbon conversion and allocation diagram : Academic source

A lack of production regulation by coffee plants can cause a shortage on C in comparison to the amount of sources and C available in reserves. Competition for carbohydrates between cherries and branches were studied in Costa Rica, showing the importance of cherry sink strength (Vaast et al., 2005).Even if the production and conversion of carbon increases and taking into account that green fruits have a photosynthetic activity satisfying around of 12% of total carbon fruit need (Frank, 2005)), the amount of carbon available for growth decreases in the presence of fruits. The effect of fruits competition on yield components or processes is show in (table 5).

A "tired coffee plant" was reported by farmers and technicians as a condition of the plant affecting quality and yield. It is reflected by a change in the amount, size and colour of leaves (Figure 6). From technicians point of view this occurs when the age and/or the rate of productivity are high. In addition to that harvest (destructive and frequent), a high rate of diseases, and a decrease in the amount of shading were reported as factors increasing the "tired" status of the coffee plant.

An increase in the amount of tired coffee branches, increase the probability to have a tired coffee plant. To avoid this, farmers can: (i) increase pruning, or (ii) shade or (iii) select a less productive variety. Thus, it was a way to avoid a shortage on carbon, hence favour flowering and controlling fungal diseases.

Comparing the academic and farmer's model we note that both take into account (i) the amount of fruits as a sink, and (ii) the effect of a lack of carbon on: fungal diseases, the amount of leaves, and the amount of flowers. These are factors affecting the rate of net photosynthesis and the amount of reserves leading to lower amounts of carbon available or to a "coffee plant tired". However farmers did not report fruits as a source.

A decrease in the amount of new coffee branches reported on farmer's model, and a change in the amount of vegetative nodes reported on academic model are affected by a shortage on carbon, thus decrease vegetative growth.

4.3. Vegetative nodes amount

This stage is the first yield component. These nodes are the ones developed during the preceding year, however fruiting can takes places on the preceding year productive nodes.

Beer et al., (1998) cited Montoya et al. (1961) who reported a positive correlation between the increase in the number of nodes per branch and yields per plant the following year.

Single variable studies on environmental factors affecting the amount of vegetative nodes are exposed on table 6. Shade trees can modify vegetative growth by a modification of those environmental factors. For example in Kenya (Cannell, 1985) showed that shade trees avoid an excess of temperatures decreasing the rate of radiation intercepted by coffee trees. This protected coffee leaves by maintaining their temperature at values below 20 to 25°C, promoting an optimal photosynthetic rate.

Adding the information from interviews the model realized in the amount of vegetative nodes and in the rate of growth is exposed on (Figure 7).

The effect of wind on the internodes length reported on literature, was argued on interviews as an effect on the water status of the plant. This changed the stomatal conductance, hence carbon assimilation and the strength of competition of carbon for growth

Table 6 Environment factors affecting the number of nodes (from literature)

Environment Factors	Number of nodes variables	Shade trees
Plant Nitrate status	Applying N, notably in NO_3 form, increases the amount of nodes per branch. (Maestri and Barros, 1975)	+/- Decrease soil loss and avoid a fast decomposition of residues on the superficial layer.(Coste, 1968) Positive balance for systems with inga.sp as a shade tree. (Aranguren et al., 1982).
Ambient Temperature	Low temperatures (less than 14°C) decrease branch growth rate, because they decrease stomatal conductance.(Amaral et al., 2006)	+ Maintains temperatures below sensibility photosynthetic threshold.(Cannell, 1985)
Wind	Decreases internode lenght (Da Matta and Cochicho Ramalho, 2006)	+ Diminish wind speed(Coste, 1968)

Montoya et al. (1961) and Castillo and López (1966) cited by (Beer et al., 1998) using artificial shade treatments, found significant increases in the number of nodes per coffee branch and flower buds per node as sunlight levels increased, in farmers model shade favours the amount of vegetative nodes. In fact farmers argued that increasing shade increases the size of plants and it was entered in the model as an increase in the amount of nodes.

In Costa Rica, because seasons are not defined as in our model, vegetative growth can take place at the same time as the growth of fruits. In that case the competition for carbon is higher, but it favours fruits. Shade avoiding overbearing will decrease the strength of fruits competition favouring growth. This explains why farmers reported an increase in size.

Radiation has an effect in the amount of nodes, however shade trees effect is not monofactorial, and farmers said that changes in temperature, soil humidity or soil nutrient status favours as well the amount of nodes (Table 7).

Finally the effect of altitude and fog on vegetative nodes amount can be related to the effect of low temperatures on growth explained in (Table 7). Those factors were said "impossible to change" even with shade trees.

An increase in the amount of vegetative nodes formed was positively correlated with the amount of floral buds (Alvin, 1962; Majerowicz and Söndahl, 2005). Thus, there is a link between vegetative nodes and floral buds.

4.4. Floral buds amount

Floral buds growth has four successive stages: Floral initiation, latency period, bud stimulation or induction and growing, and anthesis (Cannell, 1985).

The answer of initiation signal is the beginning of floral bud development; it determines the amount of floral buds per node.

Initiation depends on the presence of a signal, although there is not a common accordance on the signal: Temperature, radiation or water stress (Table 8). In addition, the time to arrive to a maturity stage to perceive signals as well as carbon competition with fruits are factors that can delay floral initiation. Majerowics and Söndahl,(2005) show that the first reproductive nodes initiated by light formed firstly the floral buds.

This signal arrives during the dry season, and it is expressed by GA and ABA accumulation. After the latency period floral bud substantially grow during the dry season (Rojas, 1995)

In the academic model (Figure 8) we observe that floral initiation (stimulation for floral buds growth) depends on the dry season and induction (stop of the latency period) of floral buds depends on the amount of radiation.

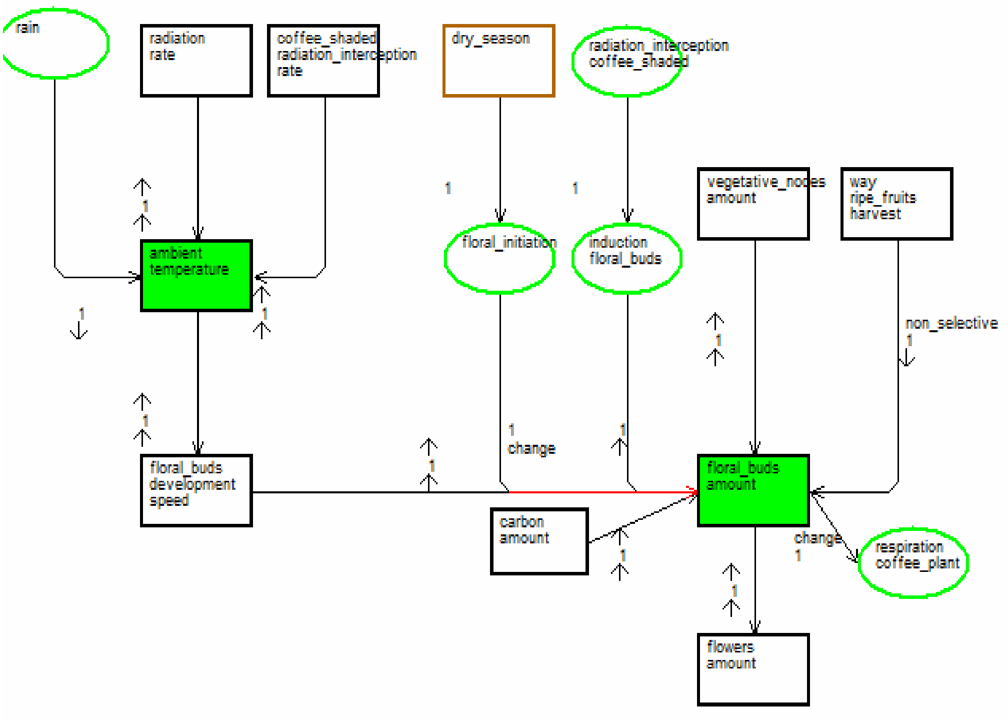


Figure 8 Academic model : Factors affecting floral buds amount

In all the 4 models we find the term "stress" (Figure 9). Behind this term is hiding the time and intensity of radiation exposition and water stress coffee plants had for floral buds induction and floral initiation.

For farmers an early arrival of rains or an increase in the amount of shade reduces coffee plant stress. Technicians' and processors' models show that the amount of radiation or an increase in temperatures causes coffee plant stress. Thus the higher stress is reached with an increasing in time and intensity of radiation, water stress, and soil or ambient high temperatures (Figure 9).Therefore even if the processes initiation and induction are not named, the term "stress" replaces them.

Farmers reported temperatures "hot summer" as a variable different to stress (Appendix 6). In fact farmers explain the complementary effects between radiation and water stress saying that if water stress was high there was no necessity to increase the rate of radiation, hence to prune shade trees.

Shade trees, by decreasing the stress of coffee plants, might reduce the amount of floral buds. This was the explanation given by farmers to justify the summer pruning of shade trees.

Finally farmers said that floral buds could fall by physical damage, or because the coffee plant was tired. This falling rate should be added to the academic model.

4.5. Flowers amount

Floral buds development is an important stage determining the amount of flowers ready to open. For Rojas, (1995) cytokinins coming from the root system, GA (Giberellins) liberation and a decrease in temperature caused by rains, activates floral buds growth and causes flowers opening. Frequent and heavy rains at the end of the dry season were positively correlated with flowering waves (Frank, 2005).

During 48h (Cannell, 1985) after anthesis the flowers can be pollinated. Coffee Arabica is a bi-pollinate species, the effect of wind or insects as pollinator is minimal.

After fecundation, fruit formation begins. In that case deformed or infertile flowers and physiological shedding can affect the formation of fruits.

In literature environment variables affecting the amount of flowers (Table 9) are mainly factors increasing the amount of infertile flowers (starflowers), which affects the rate of fruit formation.

Flowers amount were directly linked to fruit formation rate and yield by farmers (appendix 6). Farmers reported physical damage (rain drops, falling branches or shade trees damages) as a factor increasing the rate of flowers falling. Researchers and technicians added the effect of shortage on carbon determining the physiological shedding for flowers.

Wind was said by researchers as a factor that could affect the rate of pollination and decrease the water status of the plant. However for technicians it slows flowering and for farmers it increase the amount of falling leaves (Table 10).

Table 10 Factors affecting the amount of flowers non reported by the academic model

Environment Factors	Effect on Flowers	Shade trees
Wind	Increase the rate of falling leaves (Farmers) Slow flowering (Technicians)	+ by decreasing the speed of wind - if physical damage
Nutrient deficiency or soil humidity	Crazy flowering	No report.

In farmers model we see that fungal diseases as ojo de gallo and roya , or nematodes increase the amount of leaves falling (appendix 6). This affects the amount of flowers and the flowering rate. In fact for farmers the higher amount of leaves the higher amount of energy the plant dispose to withstand to the “stress” and emit flowers. High Mycena citricolor infestation rates have been reported in Costa Rica in zones and periods of excessive humidity and rains, and when the lesions of coffee leaves are abundant because it increases the amount of the residual inoculums. (Wang and Avelino, 1999)

Rain was reported by all sources as a factor moving forward anthesis. It divides flowering in different periods because for some floral buds the stress was not enough. Harvesting is a very labour intensive operation; the succession of flowerings causes a staggering on harvest. This is sometimes limiting because it is supposed to continuously mobilise the labour necessary to ensure high-quality harvesting. In the other hand some farmers reported that it could be advantageous when there is a shortage on labour because workers can be shared between farms.

Crazy flowering was reported by farmers as an event when flowers open on different times (Figure 10). it decrease the amount of flowers because flowers were more exposed to fall, and because it increase the heterogeneity in the formation of fruits leading to more harvest times.

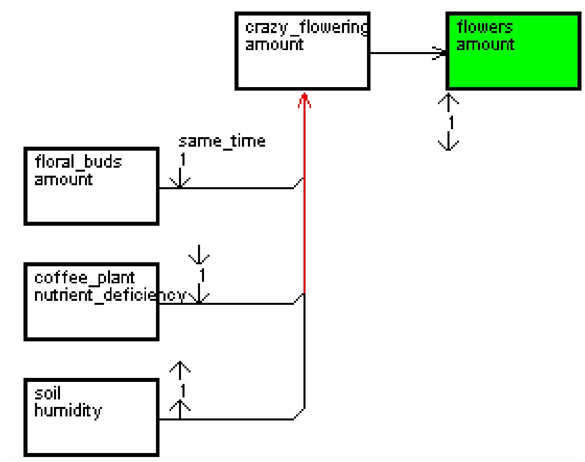


Figure 10 Farmers model: Factors affecting the amount of crazy flowering events

4.6. Pinhead and green fruits amount

After fruit formation the number potential of fruits is determined. Even if coffee plants might have fruits of different size, the development pattern is the same for all Arabica coffee varieties (De Castro and Marraccini, 2006): (A)The pinhead stage,(B) the rapid swelling stage, (C)the stage of suspended and slow growth, (D) the endosperm filling stage and the ripening stage (Figure 11).

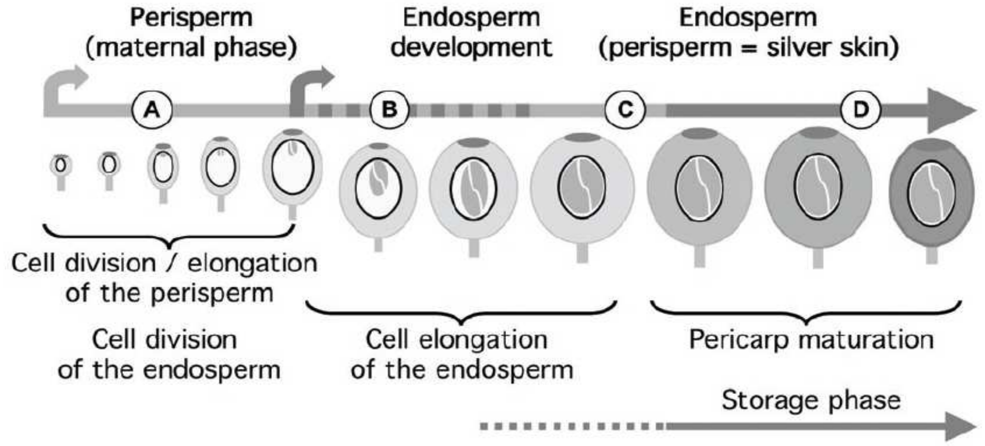
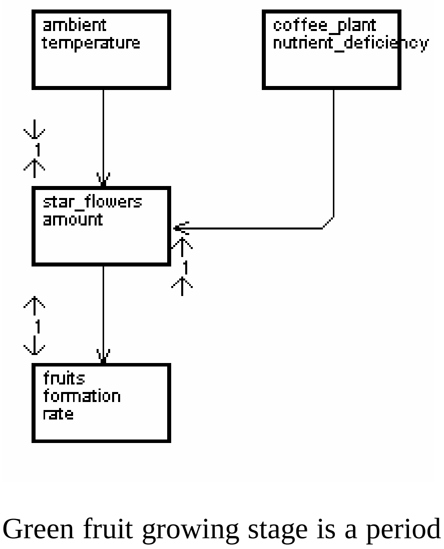


Figure 11 Key stages of C.Arabica var.fruit development (De Castro and Marraccini, 2006)

A low supply on carbohydrates causing physiological fruit shedding decreases the amount of fruits. Canell and Huxley (1970) reported shedding as a normal occurrence between 8 to 12 weeks after flowering, while cherries are in the rapid expansion stage. In latter stages fruits can also shed if the amount of carbon is low (Alvin, 1962). In Academic, farmers' and technicians' models, we see that fruit formation rate is affected mostly by the amount of nutrients in the soil and in the plant and by carbon available (farmers identify the first formed pinhead as the biggest ones).



The emission of non fertile flowers, affecting the formation of fruits, was cited in literature as a variable affecting the potential amount of flowers. However in the academic model (see appendix 7) researchers recommended not to take into account because it was not a current event in Costa Rica conditions. The amount of star flowers (sterile flowers) was reported by farmers as factors reducing the rate of formation of fruits This hasn't been reported in the technicians neither processors model.

Figure 12 Casual factors affecting the amount of star flowers (sterile flowers)

Green fruit growing stage is a period while the number of fruits can change, and the potential number of seeds per fruit is determined.

Fruit growth is substantially during endosperm cell division and cell elongation stages (A and B) see (Figure 11): the filling stage is the most carbohydrate consuming.

The size attained by the locules at this time determines the potential size of the bean (Frank, 2005). In Kenya it was found that practices as irrigation and mulching which improves water status increased bean size (Cannell, 1970). This hasn't be proved for Costa Rica conditions.

In literature we found that temperature and soil moisture act on green fruits growth (table 11).

To explain the importance of nutrients availability for coffee plant, we can see complementarities between knowledge sources (figure 13). In technicians model an "accurate" soil nutrient status will affect growth. In farmers and academic model we see that green fruits growth rate is increased with an increase in the amount of nutrients apply. Furthermore in farmers model a decrease in shading increases the growth of green fruits, in fact the academic model we see that it increases the rate of photosynthesis, thus the speed and rate of growth.

Growth determines the size of green fruits in all the models, thus quality. Details on quality elaboration will be developed on the next point.

On the other side the amount of green fruits depend on berry borer entrances, and falling of fruits. Berry borer *(Hypothenemus hampei*) lives on coffee berries. Humidity, rains, and wind promote its dispersion, and infestation of coffee berries. It causes big damages on yield and physical quality (Dufour et al., 1999). Control biological agents are presented as an alternative for chemical control. However for berry borer this is not well expanded, mostly due to its variation of effect in accordance with site conditions. However farmers reported soil microorganisms as affecting the amount of berry borer on soil fruits.

Comparing the technicians and farmers models we find out that not only recommendations of technicians are reported, but as well that altitude and the frequency of harvest decrease the presence of berry borer.

4.6.1. <u>The amount of ripe fruits</u>

The final number of fruits depends on the rate of falling of fruit before harvest. After ripening cherries tend to fall on a short time. This time varies in function of coffee specie. C.arabica ripening is faster than C.Canephora (Coste, 1968).

The amount of nutrients available for plant, and diseases as Berry borer and Mycena citricolor are environmental factors affecting the amount of fruits harvested cited on literature, this is described in Table 12.

Table 12 Environment variables affecting ripe fruits amount (literature)

Environment Factors	Ripe fruits amount variables	Shade trees
Soil nutrient status	Ripening needs high amounts of nitrate. The 95% of total nitrate consumed by fruits is absorbed at this stage (Majerowicz and Söndahl, 2005)	+/-
Ambient temperatures	Increasing temperatures speed up ripening (Huxley and Cannell, 1970)	Slowdown ripening
Berry borer	Decrease the amount of ripe fruits	See table 14
Mycena citricolor	Decrease the amount of ripe fruits	+ if Avoid excessive shading in humid zones(Wang and Avelino, 1999)

Comparing the four models these effects are distinguished (i) The competition for carbon detailed in 4.2, (ii) the importance of nutrients (iii) the effect of shading on ripening and (iv) the effect of harvest techniques (see appendix 8)

That knowledge is in accordance to farmers practices. An early (before fruits are mature) and non selective (picking fruit by fruit) harvest are the ways reported as decreasing yield and quality because the final amount of green fruits is high. To improve the rate of ripening farmers prune shade to accelerate ripening and pick selectively the ripe fruits ("granea") to decrease the competition for carbon with the other fruits. However it has been demonstrated that a slow ripening improves coffee beans quality.

4.6.2. *Cherries quality*

Coffee quality is mainly assessed thought the physical aspects of coffee beans such as bean colour, size, density and physical defects, whereas cup quality is the main criterion in consuming countries.

Beans quality is determined by endosperm absorption of 70% of the total carbohydrates produced by the coffee tree, slowing the growth of the tree (Vaast et al., 2006).

In literature we see that quality depends mainly on coffee varieties, altitude, roast quality process and the use of shade (Table 13). It was demonstrated that the effect of shade is similar to the effect of altitude and that in low elevated conditions shade increases coffee qualities, thus there are complementarities between shade and altitude. However shade experiments along environmental gradients like different altitudes should help to quantify the effect of shade in different environments.

Coffee quality was defined differently between technicians, farmers and processors (Table 14).

Table 14 Coffee quality definition

Quality	Researchers	Farmers	Technicians	Processors
Physic	Granulometry, Plot homogeneity	Beans structure, fissures, size, holes, form: “caracolillo”, Ripe fruits: colour, fermentation density.	Colour, size ripe fruits	Beans: size, density, structure, holes, form: “caracolillo” Ripe fruits: colour,fermentation
Organoleptic	Acidity, Aroma	Acidity, amount on honey of beans, beans color.		Acidity, fermented chocolate, fruti or sweet taste
Biochemical	Fat content, sacharose	Pesticides as residues.	“Fruit composition”	Residues: pesticides

Processors and researchers were the only that make a link between quality characteristics, for example a hard coffee bean increases the final acidity. Farmers knowledge don’t reflect knew knowledge, however it show the transfer of processors knowledge. Finally technicians detailed less the quality aspects.

5. Discussion

A model for each yield component was proposed. The information suggested to be added to the academic model was represented in synthesized tables. These suggestions were based on agronomic factors affecting the yield components.

A synthesis of literature in tables permits an easier comparison with the output as diagrams, and help to find out gaps, inconsistencies or complementarities in knowledge.

Components take into account in the academic model proved to be easy to identify with by field experts. However the pinhead component, even if it was easy visible in field, factors affecting it were not too different from factors affecting the precedent (flowers) and the following component (green fruits). Thus, it is proposed to include (i) the effect of sterile flowers on the fruit formation in the precedent component, (ii) the shortage of carbon causing shedding and the effect of nutrients in the amount of green fruits.

Studying the different sources was useful to: (i) Elucidate how process as carbon allocation and water stress are represented by field workers, (ii) show other environmental factors affecting each component, and that could affect the monofactorial academic relationship (eg. The effect of temperature on flowering) (iii) Detailed factors affecting quality and show the gap between processors and experts. The last point limited the definition of practices-site conditions interactions improving quality.

It is clear that to increase the information on quality characteristics it was good to see processors. For quality knowledge is divided. For experts in fields physic characteristics are reported as well as environmental factors affecting it. Although processors reported the same, their knowledge on biochemical and organoleptic qualities is more detailed. However this is not always linked with practices on field or with physical quality aspects.

There was no new knowledge on factors affecting green fruits and ripe fruits amount. However the other components and processes reported (star flowers, floral buds falling) were not linked with shade trees.

In fact new knowledge about the direct effect of shade trees on productivity did not appear. The effect of (i)decreasing the amount of carbon avoiding overbearing , (ii)the negative effect of reducing coffee plant stress and (iii)the reduction of *Mycena citricolor*, were the only direct effects on yield components. Besides indirect effects like reducing the amount of weeds, increasing soil structure and nutrients conservation, or favouring control organisms were considered and linked to the amount of nutrients or water available to coffee plant and to the disease rate.

Some knowledge as the amount of nutrients provided by shade trees (“poro” as a permanent fertilization :fast growth, permanent falling of leaves, and fast decomposition) but its impossibility to quantify did not lead to modify practices.

The lack of new knowledge about direct effects of shade trees on yield components can be due to the high technology of farms interviewed, having a close relation with technicians: they practice what technicians taught them. The organic farms should give us more information about interactions, in fact they know detailed aspects of indirect effects of shade trees, however when we talk about direct effects on productivity there was no new information.

Nevertheless some methodological limitations could be the reason of this gap. In fact more time is needed to do a quantitative analysis to validate causal and effect relationships. As it is recommended by Walker et al., (1995) a questionnaire survey will be needed to establish how representative the knowledge obtained from key informants is of the knowledge in the broader community, to make a hierarchy of factors from farmer’s experience.

On AKT methodology it is recommended to make repeatedly interviews, but this was not possible because there was some transport and time constraints. In fact each interview lasts at least 2 hours, and we came back to the regions one week after. When we ask for a new date farmers found it to hard. One way could be by having feedback sessions with farmers (Lamond, 2007). However farmers interviewed for each region where at least 24 km far away, it was difficult to determine a central point and a day when all where available.

AKT was proved to be useful to process interviews, to describe causal relationships and to detect gaps on scientific knowledge. Its diagram representation make easier the explanation and comparison of knowledge. But its diagrams outputs are not always clear. In fact its diagram function is not well adapted to show clearly many relationships, with its conditions at the same time. This is necessary when we have not the representativeness of the knowledge, and when we want to build conceptual diagrams showing the diversity of factors.

6. Conclusion

The conceptual models created can be used to build a numeric model taking into account that: (i) some relationships qualifications as “change” have to be review and qualified, (ii) knowledge representativeness has to be studied to validate exposed interactions.

Relations validated by interviews should be studied in a control field experiment; this will give quantitative information on factors affecting potential yield components. However this is time consuming, so the only existent unpublished plot scale model (Van Oijen et al.) of coffee and shade tree growth which includes a model for microclimate, coffee growth and production, tree growth, soil processes and competition between coffee plants and trees . This model could be used to evaluate the variability of these effects of the factors on productivity. However this model don’t take into account diseases, pathogens and weeds, and we show that yield components are directly dependent on it.

Much of this work remains descriptive but provides basis for pursuing a more rigorous and quantitative investigation of the nature and extent of local knowledge. Although the study interpret some processes from experts point of view, giving terms that could be used to built a discussion tool.