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Local knowledge regarding trade-offs among coffee productivity and other ecosystem services in a range of different agroforestry systems in Central America

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Local knowledge regarding trade-offs among coffee productivity and others ecosystem services in a range of different agroforestry systems in Central America

A thesis submitted to the joint program for the degree of Doctor of Philosophy

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Acknowledgements

I don't have an idea on how many people will read this document entirely (probably few), what I am certain of is that almost everyone that has come to the point of having this document in their hands/screens will surely check this page. Acknowledge and try to thank all people that had influenced my life, up to date, would require more than the 162 pages that encompass this thesis. I will instead, list here those that supported my research. The many others that supported and support my life are in my heart.

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Abstract

This thesis gathers and analyses the local knowledge regarding ecosystem services in coffee producing regions of Costa Rica, Guatemala and Nicaragua, and compares this knowledge across a range of farming conditions. The extent to which coffee agroforestry systems provide ecosystem services depends on local context and management practices. There is paucity of information about how and why farmers manage their plantations in the way that they do and the local knowledge that underpins this. The present research compares local knowledge in coffee growing areas bordering key forest reserves in Nicaragua, Costa Rica and Guatemala. Knowledge was acquired from 99 coffee farmers in a stratified purposive sample, using established knowledge based systems methods. Farmers in all three countries had detailed knowledge about how trees affected ecosystem services such as soil formation, erosion control, provision of wildlife habitat and water conservation. A total of 135 tree species were mentioned by the farmers. Links between trees and biodiversity, pollination, biological pest control and micro-climate regulation were understood and species were classified according to their role in both provisioning and regulating services. Trees were said to produce ‘fresh’ shade that was suitable for coffee or ‘hot’ shade that was not suitable. This concept was widely used by farmers in the three countries; howerer, any coffee technician uses it. Fresh – hot dichotomy was explained in relation to leaf texture and size; foliage density, crown shape and root system attributes; as well as classification of trees regarding ecosystems functions such as water regulation or soil formation.Much of the local knowledge about how trees could improve provision of ecosystem services, however, was not practically applied because farmers were concerned that increasing levels of shade would decrease yields. A variety of tree species was maintained in coffee plantations at all sites but a few tree species were dominant. The degree of shade tolerated was the main difference across countries and this was strongly related to socio-economic factors such as the prevailing demand for fuel wood. Applicable knowledge across sites as well as the key factors that determine how knowledge was locally applied was identified.

Keywords: local knowledge, biodiversity conservation, ecosystem services, coffee agroforestry systems, Central America

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Chapter 1. General Introduction

Coffee Agroforestry Systems

Agroforestry can be generally defined as the practice of integrating trees with crop production in a common land unit. It satisfies three conditions: at least two plant species biologically interacting, at least one of the plant species is a tree, and at least one of the plant species is managed for consumption (Somarriba, 1992). Agroforestry is a traditional land use in the Tropics. Worldwide, over one billion hectares of land (46% of the total agricultural land) have a tree cover of at least 10%, which could be considered as agroforestry (Zomer *et al.*, 2009). It has been extensively researched and improved over the last decades to support rural people's livelihoods and environmental sustainability (Sanchez, 1995).

Coffee, cocoa and tea are the main crops grown as agroforestry systems in the tropics. These crops play a fundamental role in the economies of developing countries from which they are exported, and they are mostly grown on small-scale farms (Omont and Nicolas, 2006). In its area of origin, as well as when it was introduced to Central America decades ago, coffee was grown under a diverse canopy of native tree species as agro-forests (Fournier, 1987) which provided a number of ecosystem services and conserved biodiversity (Clough *et al.*, 2009); however, starting in the 1950s coffee systems were intensified by reducing shade cover and incorporating agrochemical use (Perfecto *et al.*, 1996). While intensification increased yield and revenue in many cases (Kessler *et al.*, 2007), it also increased the costs and dependence on chemical inputs (Bellamy, 2007) and the vulnerability of farmers to fluctuations in coffee prices (Larson, 2003). In northern Latin America alone, coffee production has been converted from highly diversified agroforestry systems to intensified unshaded systems (Jiménez Avila, 1979) (Figure 1.1). This evolution resulted in loss of biodiversity and decreased provision of environmental services (Moguel and Toledo, 1999). Such environmental impacts have generated costs to the society as a whole, but also to farmers which require these services (for example, supporting services such as soil formation). These environmental costs have been recently stressed and estimated at various scales, in order to be accounted for decision making processes (e.g. Costanza *et al.*, 1997).

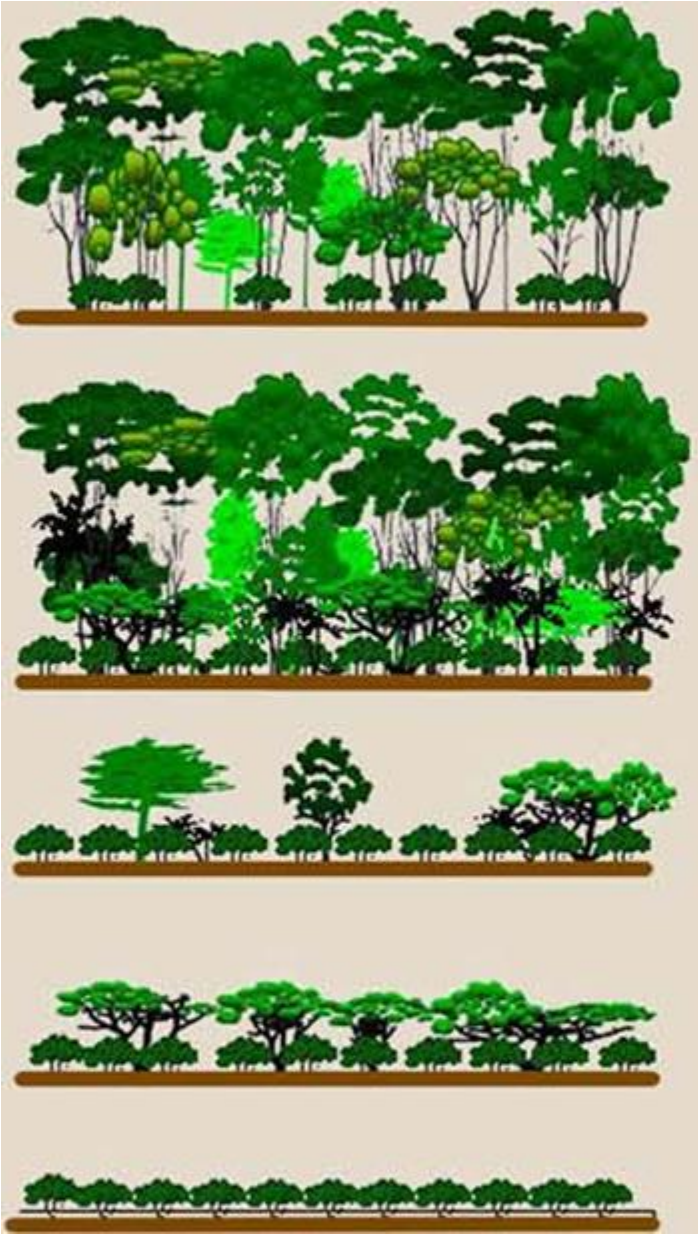

Figure 1.1. Schematic view of the different coffee management systems and how they range in shade cover and shade richness
From top to down: rustic system, traditional polyculture system, commercial polyculture, shaded monoculture, unshaded monoculture (Originally figure from Jiménez Avila, 1979, systems descriptions by Moguel and Toledo, 1999).

Importance of coffee in Central America

Coffee is worldwide the second most traded commodity by monetary volume after crude oil, with 5.6 million metric tons of green coffee exports in 2009/2010, valued at approximately US$15.4 billion (ICO, 2011). In 2010, that particular sector was comprised by approximately 26 million of coffee growers, mostly small landholders, in the 52 coffee producing countries members of the International Coffee Organization (ICO).

Worldwide, there are two coffee species that are grown commercially: *Coffea robusta* and *C. arabica*. Each species has a different role in the coffee market: *C. robusta* is high yielding (1 – 1.5 kg green coffee per plant per year) with low quality and high caffeine content, and growing at low elevation, while *C. arabica* has lower yields (0.5 – 0.8 kg green coffee per plant per year), with high quality, grown at elevations ranging from 500 to 2000 m.a.s.l., and it is susceptible to drought and frost. The most common species grown in Central America is *Coffea arabica*; cultivation of *C. canephora* is even prohibited in Costa Rica because the coffee sector tries to focus on coffee quality rather than on quantity, and wants to advertise this image to the coffee world; in the other Central American countries, although not prohibited, *C. canephora* is scarcely grown. Optimal conditions for the growth of *Coffea arabica* include mean annual temperature between 17 and 23^{o} C, mean annual precipitation between 1500 – 2800 mm and fertile volcanic or alluvial soils (ICAFE, 1998).

Worldwide coffee production has historically evolved through three periods: i) before 1950, coffee trade was organized as a free market; during that time, coffee shaped out the economies in Central American countries, with an opulent social class growing coffee; ii) during the next period, ending in 1989, the market was regulated through quotas by the International Coffee Organization (ICO); it was during these times that new techniques for intensive production were developed; the wealth of several Central American countries was built up during this period, and iii) from 1989 until present, the market has been liberalized again (Samper, 1999). Coffee makes up a large percentage of total agricultural export revenue in Central American countries[1]: 10.3% in Nicaragua (438 USD millions) (ECLAC, 2011), 7.3% in Costa Rica (258 USD millions) (MAG, 2011), and 6.3% in Guatemala (643 USD millions) (ECLAC, 2011). Throughout Central America, there are approximately 300,000 farmers producing coffee (ICAFE, 2005) and several million people depending on coffee production for their income (Nolasco, 1985).

Coffee in Central America is important not only economically, but also ecologically. The ecological importance of coffee is a consequence of where it is produced, rather

[1] Data from the coffee harvest 2010-2011

than how much land is under production. Coffee production areas are frequently bordering key forest habitats containing a large number of endemic species (Moguel and Toledo, 1999). Coffee is generally grown on mid elevation mountain ranges, largely deforested in Central America (Velázquez *et al.*, 2003). There is a scientific debate in regards to the role of coffee areas causing or avoiding deforestation. Some authors considered coffee plantations as causing deforestation of existing areas of forest, particularly highland pine-oak forests (e. g. Rappole *et al.*, 2003a, 2003b); on the other hand, coffee plantations are considered as a refuge for many species at the landscape level, that enhances connectivity and decreases the pressure of forests isolately (Philpott and Dietsch, 2003).

Much of the ecological importance of coffee plantations in Central America is directly related to its role providing a high quality agricultural matrix and related ecosystem services not provided by other agroecosystems (Vandermeer and Perfecto, 2007). Many studies have measured biodiversity loss across the coffee intensification gradient, from "rustic" systems to unshaded coffee plantations. Rustic coffee plantations conserve a large number and proportion of remnant forest species, with high density and diversity of trees (Greenberg *et al.*, 1997) and the reduction and simplification of tree cover is affecting species richness (Donald, 2004). The conservation benefits of shade coffee are further enhanced by the proximity and connectedness of intact natural habitats (Ricketts *et al.*, 2001), this proximity between coffee areas and forests a frequent condition in Central America.

Ecosystem Services (ES)

Ecosystems, which can be defined as "dynamic complexes of plant, animal, and microorganism communities and the non-living environment interacting as functional units" (MEA, 2005), are connected to humankind in several ways. These connections are called ecosystem services (ES), which were defined by Daily *et al.* (1997) as "the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life". The human race has been aware of the links between nature and our livelihoods since before the origins of agriculture. Ecosystems have changed worldwide at an unprecedented rate in the past 50 years, affecting and jeopardizing ecosystem services provisioning, so that, the formerly obvious links have to be re-called and re-emphasized (Rapidel *et al.*, 2011).

Considerable research has been done in the last twenty years regarding ecosystem services (Fisher *et al.*, 2009). Costanza *et al.* (1997) valued the services provided by all the ecosystems of the world at US$ 33 trillion, almost twice the gross world product, and claimed that the value of the services provided by ecosystems must be incorporated in national accounting systems. The study of these services increased exponentially during the following years and was synthesized in 2005 providing an overview of the state of the world's ecosystems (Millennium Ecosystem Assessment, 2005). The MEA definition of Ecosystem Services remained, "the benefits people obtain from ecosystems". However the MEA expanded the classification of ecosystem services by identifying out broad categories of services received: (1) provisioning, (2) regulating, (3) cultural, and (4) supporting (Figure 1.2). Notably absent from both Daily (1997) and the MEA (2005) definition is the explicit identification of biodiversity conservation as an ecosystem service; rather both definitions recognize the value of biodiversity through its effects on the other services. Fisher *et al.* (2009) argued that the stability, resilience and resistance roles of biodiversity in ecosystem functioning are, in fact, ecosystem services.

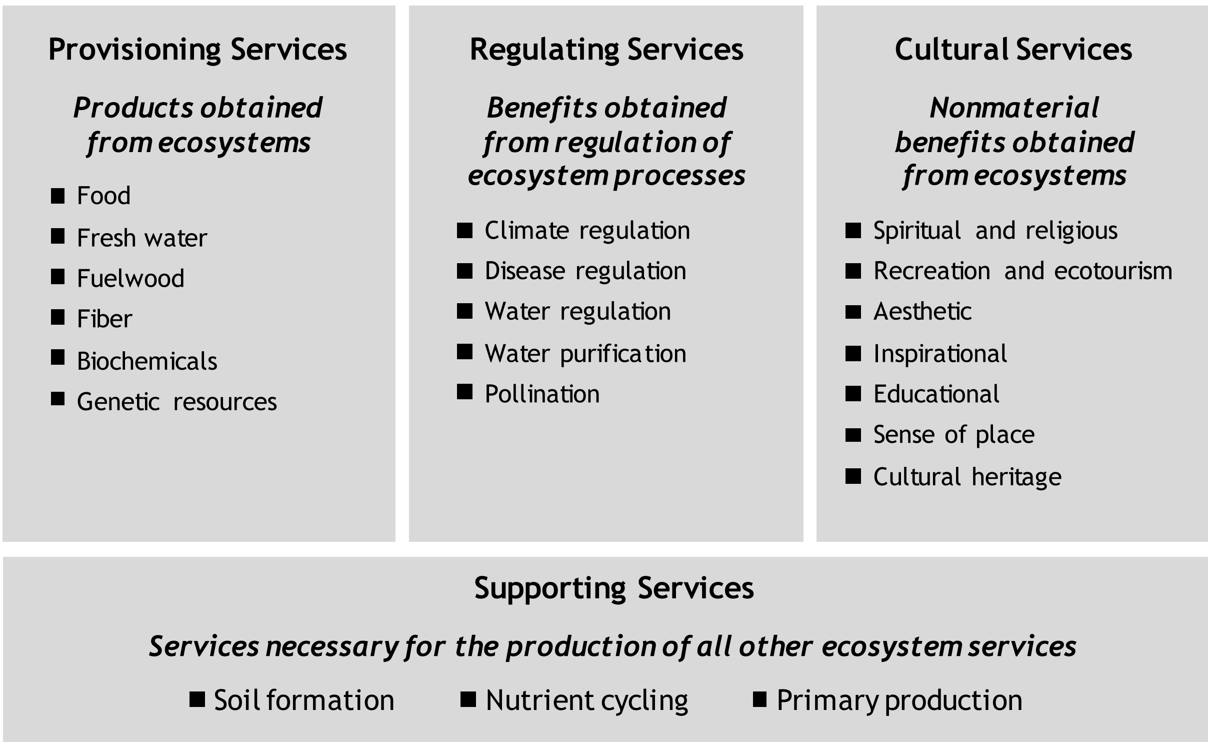

Figure 1.2. The services provided by ecosystems
(Millennium Ecosystem Assessment, 2005)

Ecosystems Services in Coffee Agroforestry Systems

There are five main sources of increased ecosystem services provision related to agroforestry systems (Nair, 2008): 1) soil protection and productivity is maintained by increased nutrient availability of trees (nitrogen fixation, deep root systems), prevention of soil erosion, increased microbial activity and improvement of physical soil properties; 2) water quality is maintained due to the reduction of pollution to streams and rivers (deep root systems) and better retention of water; 3) biological diversity is supported by increasing species diversity, increasing connectivity and decreasing pressure on the remaining forest patches; 4) carbon storage and mitigation of greenhouse gases are achieved through sequestration in biomass and the soil, through carbon substitution (use of wood in place of more fossil fuel dependent materials) and conservation (preventing further deforestation); and 5) food and nutrition is provisioned by increasing system productivity.

However, literature supporting the quantification of ecosystem services provided by agroforestry systems has focused on carbon sequestration, biodiversity conservation, and soil enrichment (Jose, 2009). Biodiversity and biodiversity conservation are most commonly researched and reported. Their importance cannot be underestimated due to the influence of biodiversity on the other ecosystem services, which will be provided according to the diversity of genes, species, and ecological processes (Fischer *et al.*, 2006). Directly, tree diversity is related to a diversity of goods obtained (provisioning ecosystem services), those in turn impact farmers' livelihoods (Méndez *et al.*, 2010). Nevertheless, the other functions that trees perform in agroforestry systems, and particularly those related to regulating services, deserve better attention.

Farmers' role as ecosystem managers is increasingly recognised: the provision of ecosystem services from coffee agroforestry clearly depends on their management decisions. These decisions depend on their knowledge of i) their productive activity, coffee production in our case; ii) the other ecosystem services provided by their plantations, in particular by the trees they contain, and iii) the trade-offs between ecosystem services, usually ending in trade-offs between shade trees and coffee productivity in their specific context. Compilation of the integrated vision on the functions (and trade-offs) of trees regarding ecosystem services is extremely relevant for the accurate multifunctional understanding of agroforestry systems.

Agricultural intensification, genetic improvement and the prevalence of monocultures have drastically reduced the genetic diversity of crops and forestry and have also contributed to the global decline of biodiversity (Nair, 2008); however, coffee farmers that keep a low tree diversity in their farms obtain, usually, better yields, and very frequently highest incomes than farmers that keep intense tree cover. This has been intensively debated (Barradas and Fanjul, 1986; Canell, 1985; DaMatta, 2004; Franck *et al.*, 2006).

Available scientific literature on the relationships between shade tree canopy cover, coffee yields and profits show contradictory results. Some studies report significant increase in yields when shade was removed (Matoso *et al.*, 2004; daMatta, 2004), whereas others found no effect of shade on yield (Romero *et al.*, 2002) or, shade trees increasing coffee productivity under certain conditions (Soto-Pinto *et al.*, 2000). It is reasonable to argue, that farmers, from years of experience, will know the consequences of their management practices in their particular environment, and how this will affect their livelihoods (Michon and Mary, 1994; Schulz *et al.*, 1994).

It is now widely recognised that efforts focused on conservation of biodiversity only in lands under designated protected areas is not feasible; protected areas are too small, isolated, frequently exploited, and not always managed to conserve biodiversity (Chazdon *et al.*, 2009; DeClerck *et al.*, 2010). The trade-off between productive and conserved areas has been debated with two competing options: wildlife-friendly farming (which boosts densities of wild populations on farmland but may decrease agricultural yields) (Rosenzweig, 2003) and land sparing (which minimizes demand for farmland by increasing yield in productive land) (Borlaug, 2002; Balmford *et al.*, 2012). Relative effectiveness of these two competing options is under debate (Green *et al.*, 2005; Vandermeer and Perfecto, 2005). The optimal decision regarding these options will be heavily dependent on the local context that determines the relations between ecosystem services. Farmers' knowledge, dependent on the local context, should be incorporated in this decision making when focusing on increasing conservation of biodiversity in general and within agroforestry systems in our specific case.

Local Knowledge (LK)

Local knowledge may be defined as the "understanding of the world that can be articulated by an informant" (Sinclair and Walker, 1998). This concept differs from "indigenous knowledge" because it does not reflect cultural values and beliefs, but it is focused on general explanatory ecological knowledge (Walker and Sinclair, 1998). LK is not simply information, it has to be information interpreted and understood. Another important distinction to be made is the difference between knowledge and practice; practice is only the technical knowledge that farmers apply every day, further, knowledge is the ecological rationality underlying practices (Sinclair and Walker, 1998).

Scientific and local knowledge are different; scientific knowledge aims to objectively explain natural variations, while local knowledge aims to explain local observations and experience (Sinclair and Walker, 1998). It has been shown that it is possible and meaningful to merge these two different kinds of knowledge, which complement and sometimes contradict one another, providing meaningful insights and highlighting areas for further consideration and exploration (Waliszewski *et al.*, 2005). LK is an important but underutilized resource (Walker *et al.*, 1999), which should be incorporated into projects and research to encourage participation, and to promote relevant and appropriate objectives within the local context (Sinclair and Walker, 1998).

Incorporation of local knowledge into agroforestry research

After the Green Revolution, it was widely recognized that developments in agricultural technologies are incompatible with the resources available to many small-landholders in suboptimal areas (Hildebrand *et al.*, 1993). This led to the development of the diagnosis and design (D & D) methodology with had the goal to generate, evaluate and diffuse agroforestry technologies in association with farmer participation (Raintree, 1987).

Studies have shown that successful adoption of agroforestry technologies required not only to adapt them to the resources available to farmers, but also to incorporate into on-farm research farmers' knowledge (Franzel, 1999). Using farmers' knowledge in order to establish research priorities thus leads to a more efficient use of resources (Muschler and Bonneman, 1997). In Latin America, development projects led by non-governmental organizations (NGOs) frequently incorporate farmers' knowledge in their interventions in rural areas (Altieri, 1999). Despite the importance and usefulness of the local knowledge as a resource in the design of multifunctional agroforestry systems, few studies have documented farmers' knowledge about coffee plantations in Central America (Albertin and Nair, 2004; Soto-Pinto *et al.*, 2007), and little has been reported about their knowledge on the interactions between trees and ecosystem services and their effects on coffee production.

A number of initiatives, such as local and national programmes for payment of ecosystem services (PES) and coffee certification schemes, have provided incentives for coffee farmers to provide a range of ecosystem services with trade-offs with coffee production (Rapidel *et al.*, 2011). If farmers know how to select and manage the right species and density of trees, they will be reducing these trade-offs and the consequent need of economic incentives promoting the provisioning of ecosystem services.

Agroecological Knowledge Toolkit (AKT)

Local knowledge was studied using a systematic methodology: Agroecological Knowledge Toolkit –AKT– (Walker and Sinclair 1998, Sinclair and Walker 1998). AKT is both a methodology to research local ecological knowledge and also a software program to store and analyse the collected knowledge. The methodology consists in presenting the knowledge so that may be stored in a computer readable-form, and the software allows the analysis of this data by performing searches and synthetizing causal effects relationships. The formal AKT methodology comprises four steps: scoping, delimiting, compilation and generalisation (Figure 1.3).

Scoping

This first step is set up in order to refine the objectives of knowledge acquisition. It is a period of familiarization on the context and orientation of the study purposes. Meetings have to be held with local institutions in order to identify possible informants for the compilation stage of the research as well as to list the factors they believed may modify the knowledge detained by these informants (e.g. the farm system, the location within the area, or the size of the farm).

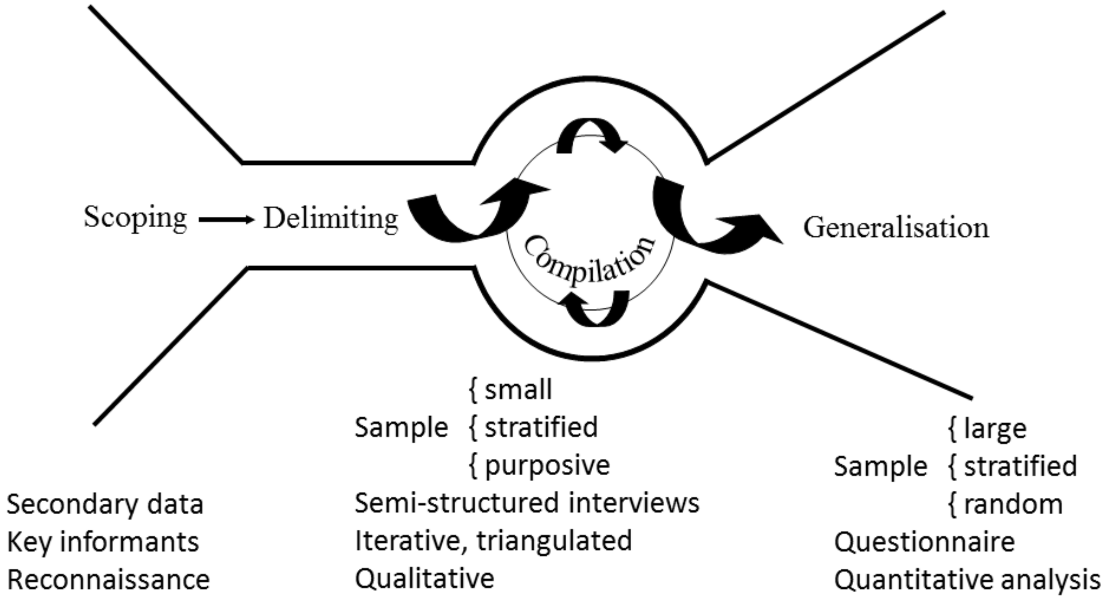

Figure 1.3. The four phases of the agroecological knowledge toolkit methodology (Source: Walker and Sinclair, 1998)

Delimiting

This step concerns the boundaries and the terminology of the interview protocol. Farmers have to be interviewed in order to adjust the research questions according to farmers' understanding. In addition, this phase is providing insights into how farmers express their knowledge. It was particularly important during this step to become familiarized with the local names and also with specific terms used by farmers.

Knowledge compilation

This third step in the AKT methodology is the collection and analysis of local knowledge. This step includes interviewing people, creating a comprehensive knowledge base, and analysing the knowledge.

Interviews: Semi-structured interviews are held with informants purposely selected during the scoping stage. Each informant, either farmer, technician or scientist, is referred to as a "source" of knowledge. The sources are included from all situations according to the variables identified as likely to influence knowledge held by people in the scoping stage (Walker and Sinclair 1998).

Knowledge base creation: The Agroecological Knowledge Toolkit (AKT software) is used to record, manage and represent the knowledge acquired through interviews (Walker and Sinclair 1998). AKT can be freely downloaded from the website http://akt.bangor.ac.uk. Formal representation of knowledge in AKT involves its disaggregation into “unitary statements” (which cannot be further broken down) and translation into a formal grammar (Dixon *et al.*, 2001). Four different kinds of unitary statements can be entered: causal, comparative, linking and descriptor of attributes and values. These unitary statements are based on “formal terms”, which are defined by the user and represent single words as objects, natural processes, or actions. This semantic has to be maintained throughout the whole knowledge base. This approach captures definitions, contextual information, and the relationships between formal terms and statements and facilitates the organization of formal terms into “hierarchies”. Hierarchies are sets of formal terms with the same properties and characteristics; for instance, the hierarchy called “rough rooted trees” grouped all the tree species that farmers considered as trees with rough textured roots. The use of hierarchies is a means of synthesizing knowledge. Instead of repeating statements referring processes or attributes to each member of a hierarchy, the definition of a meaningful hierarchy, i.e. a hierarchy where the attributes and processes actually shared among the hierarchy members are precisely identified and verified, allows the reduction of the statements to only those referring to the hierarchy itself. In the example of rough-rooted trees, the knowledge base contains the statement “rough rooted trees cause a decrease in soil fertility” instead of a repetition of the same statement for all individual species of “rough rooted trees”.

Knowledge can then be diagrammatically represented as nodes and links. Such visual representations of knowledge can improve clarity and understanding and facilitates simultaneous consideration of many related statements from different sources. Continuous evaluation of acquired knowledge with AKT throughout the collection process helped to identify gaps in understanding and to organize repetitive interviewing of sources, if required. Two separate knowledge bases were composed; one for each set of interviews mentioned previously.

Knowledge analysis: AKT allows the production of diagrams, in order to control the clarity of the knowledge and look for contradictory statements that require further explanations from farmers. An example of topics for diagramming is the set of factors that farmers consider to affect soil erosion. Contradictions are visualized by a double direction arrow in the diagrams, alerting the need to assess the sources of the contradictory statements to elucidate these contradictions or to ask more direct questions on the subject to others farmers. In the same way, the creation of diagrams showing statements on the same topic from different sources enables the visual comparison of the origin of the knowledge.

These diagrams can be further used to build conceptual models about a topic, showing the factors affecting the topic and the links between them. Each link can be characterized by statements originated from referred sources. The statements on the selected topic, however, are not automatically diagrammatised by AKT in an easily comprehensible way. As all statements related to the selected topic appear on the diagram, some manual arrangements are needed to improve its presentation and remove obvious or less-useful links.

Knowledge generalisation: This fourth step is set up in order to test how representative this knowledge is across the whole community. A representative sample size of sources has to be choosing for survey knowledge items analysed in the previous steps with larger samples.

Thesis outline

The objective of this thesis was to acquire coffee farmers' knowledge about how the trees present on their farms impact a range of ecosystem services, including biodiversity conservation and coffee production and how these impacts can be influenced by management. The structure and management of coffee agroforestry systems in Central America cover a wide range of conditions. In order to cover as much as possible this range of conditions, this research was carried out with different kinds of farmers in different countries (Table 1.1).

The quest for the appropriate coffee agroforestry system configuration that supplies environmental services while securing reasonable productivity should include local and scientific knowledge in order to achieve both environmental and productive goals. Accordingly, the general purpose of this study is: **to gather and analyse the local**

knowledge regarding ecosystem services in coffee producing regions of Central America, across a range of farming conditions.

Table 1.1. Range of farming conditions covered in each chapter

	Location	Geographical conditions	Main farmers' stratification
Chapter 2	Volcanica Central Talamanca Biological Corridor, Atlantic Costa Rica	Highly intensified production in a marginal coffee growing zone	Organic vs. Conventional
Chapter 3	El Cuá, Jinotega Department, Northern Nicaragua	Recently established area far away of urban centres, bordering a protected reserve	Farm management intensification
Chapter 4	El Hato Watershed, San Agustín Acasaguastlán, Guatemala	Coffee farms buffering a large protected reserve in an area over a wide altitudinal range	Farm location across altitudinal zones

Each study area was selected to include different kinds of farmers, which all together are covering much more diverse coffee farming conditions than could be found in a single area. Across the three locations, farming, socioeconomic and agro-ecological conditions differed, and these differences are related with the quantity and quality of the ecosystem services provided by coffee plantations.

The hypothesis for Costa Rica research area was that farmers' knowledge has been influenced by the intense process of extension to improve coffee yield which has carried out in the last decades. Consistently, it was expected high degree of knowledge sharing between farmers and scientists. It was also expected that farmers' knowledge would be detailed and largely similarly to knowledge held by extension workers and coffee processors. Costa Rican coffee farmers have, in average, better financial status than in neighboors countries; they also used to be more dependent on coffee production as income source. A decade ago, a coffee prices crisis drove many of them to seek alternative ways to earn money; such as coffee certification schemes, mainly organic in the study area. The implementation of these certification schemes influenced Costa Rican farmers' knowledge. In relation to this evolution towards organic agriculture, it was expected to find farmers in this study area with advanced knowledge in sustainable practices.

Nicaragua research area is a new productive area, where coffee has been planted in the last twenty years. The area was isolated and ecosystems stayed relatively pristine during the 1980s war. People has inmigrated there in the last years, causing deforestation to grow maize, beans, pastures and coffee. Coffee was planted under original forests; however, farmers are eliminating the original tree cover over the years. There are several projects in the area, working at the same time with conservation of natural resources and technical assistance to coffee. Farmers' knowledge was hypothetically expected to be detailed in trees. It was also deemed interesting to study the effect of the context area in farmers' knowledge. Knowledge origins were studied to look how part of the knowledge is acquired. Differences in agroforestry systems were also surveyed in order to see differences in knowledge and management.

Guatemalan study area is located between contrasting life zones: rainy forest above it, and thorn woodland below it. It is located close to a large biological reserve, from where diverse faunal species are interacting with coffee farms. Coffee plantations are sparced along a marked altitudinal gradient, creating zones with different climatic conditions over short distances. It was expected that farmers detain knowledge based on observations in their farm conditions, but also based on observations of different climatic condition or on communication with farmers in these different conditions. Furthermore, it was expected that farmers had knowledge related to biodiversity conservation –particularly– faunal on coffee plantations.

Comparing knowledge accross the three areas, it was expected to acquire coffee farmers' knowledge regarding how the trees present on a range of different conditions impact on ecosystem services, including biodiversity conservation and coffee production and how management can influence these impacts. Two general research questions arised: 1) how farmers' knowledge is shared among these three different areas; and 2) how useful is a systematic methodology designed specifically to analyse ecological knowledge in order to run this comparison.

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Chapter 2. Local knowledge of impacts of tree cover on ecosystem services in smallholder coffee production systems[2]

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Abstract

The potential for tree components of coffee agroforestry systems to provide ecosystem services is widely recognized. Management practices are a key factor in the amount and quality of ecosystem services provided. There is relatively abundant information on ecosystem services provision within agroforestry systems, but comparatively scant information regarding how coffee farmers manage their plantations, the factors influencing their farming practices and the extent to which farmers' local knowledge – as opposed to global scientific understanding – underpins management decisions. Policymakers and scientists too frequently design development programs and projects in the coffee sector. On occasion technicians are included in the design process, but farmers and their knowledge are rarely included. This research explores farmers' knowledge regarding how trees affect coffee productivity and ecosystem services in Costa Rica. Farmers' knowledge on the effects of trees on coffee productivity was compared with that of other knowledge sources: coffee processors, technicians and scientists. Farmers were shown to have detailed knowledge regarding ecosystem services that their coffee agroforestry systems provide as well as on the interactions between trees and coffee productivity. When asked about the services that trees provide, farmers classified trees according to water protection, soil formation, or contribution to

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biodiversity conservation. These classifications were related to tree attributes such as leaf size, biomass production or root abundance. Comparison of coffee productivity knowledge from different knowledge sources revealed considerable complementarity and little contradiction.

The effects of shade trees on biophysical conditions and their interactions with coffee productivity were well understood by farmers. They recorded and classified shade trees as ‘fresh’ (suitable for integration with coffee) or ‘hot’ (unsuitable) based on their leaf texture and size, foliage density, crown shape, and root system attributes. The fresh/hot classification significantly related to positive/negative provision of services. This classification was widely used by farmers, and unknown by coffee technicians.

Detailed local knowledge included several different topics, such as the role of trees in soil formation and in abundance of pollinators. Farmers were also aware of the influence of these ecosystem services on crop productivity. Generally, management decisions were made to maintain coffee productivity rather than ecosystem services. Based on these results, it is suggested that technical interventions addressing the improvement of coffee plantations are more likely to be successful if they take into account not only the scientific information on agroforestry interactions but also the knowledge possessed by farmers (e.g. the local classifications of trees and its utilisation in ecosystem functions). Lack of comprehension of local coffee knowledge could be expected to reduce the success of development programs and projects aimed at improving productivity and other ecosystem services.

Keywords: farmers’ knowledge; tree functional traits, shade-grown coffee; Costa Rica; Central America; AKT software

1. Introduction

Agro-ecosystems provide important goods and services that contribute to human wellbeing, economic development and poverty alleviation. Efficient and effective management of these agro-ecosystems can sustain the provision of vital ecosystem services such as climate stabilization, drinking water supply, flood regulation, crop pollination, recreation opportunities and amenity and cultural assets (Millennium Ecosystem Assessment, 2005). According to both the Millennium Ecosystem

Assessment (2005) and the International Assessment of Agricultural Science and Technology for Development (2008), both positive and negative externalities arising from agro-ecosystem management should be taken into account. Nowadays, there is a great deal of interest in providing financial benefits to landowners and farmers for land-use practices that supply valuable environmental services to the human population as well as farmers deriving income from their more traditional production functions (FAO, 2007).

Agroforestry systems are increasingly being viewed as significant providers of ecosystem services, including environmental benefits (Harvey *et al.*, 2006) and economic commodities, as part of multifunctional working landscapes (Perfecto and Vandermeer, 2006). The integration of trees and agricultural crops and/or animals into an agroforestry system has the potential to enhance soil fertility, reduce erosion, improve water quality, enhance biodiversity, increase aesthetics and sequester carbon (Garrett and McGraw, 2000; Garrity, 2004; Williams-Guillén *et al.*, 2008; Nair *et al.*, 2009). It has been well-recognized that the services and benefits provided by agroforestry systems occur over a range of spatial and temporal scales (Izac, 2003).

Coffee is an important crop in Central America, both economically and culturally. It is mainly grown with shade trees in some form of agroforestry. The role of coffee growing areas in providing ecosystem services is important not only because of the area covered but also because coffee farms are frequently close to priority areas for biodiversity conservation (Moguel and Toledo, 1999). Biodiversity conservation (Philpott *et al.*, 2008), carbon sequestration (Albrecht and Kandji, 2003), and soil erosion control (Beer *et al.*, 1998) are some of the benefits derived from trees within coffee plantations. A number of initiatives, such as local and national programmes for payment of ecosystem services (PESs) and coffee certification schemes, have provided incentives for coffee farmers to provide a range of ecosystem services in addition to producing coffee (LeCoq *et al.*, 2011).

Coffee production has played a strong role in shaping the Costa Rican agricultural landscape since its introduction in the early 1800s (Samper, 1999). Coffee is no longer the cornerstone of Costa Rica's economy but it remains an important crop. Around 50 thousand coffee growers produce over 90 thousand tons of coffee beans annually, 85%

of which is exported, generating an annual export revenue of over $US 250 million (ICAFE, 2010). Traditionally, coffee in Costa Rica was grown under diverse, dense and largely native tree cover (Beer *et al.*, 1979). However, since the 1970's, many coffee farms have been converted to high-yielding simplified systems in which coffee is grown with fewer shade-trees and intensive use of agrochemicals. This 'technified' management was pioneered in Costa Rica, and then extended to other countries in the region (Rice, 1999). More recently, depressed international coffee prices have led to a search for coffee niche markets, offering greater economic premiums to coffee grown under shade tree certification schemes. Many Costa Rican farmers have adopted coffee certification or quality assurance schemes to obtain higher prices for their coffee (LeCoq *et al.,* 2011), including organic production in the Turrialba area (Lyngbaeck *et al.*, 2001). Trees within coffee plantations may also diversify the product mix and in the case of timber represent a saleable commodity; particularly important when coffee prices are low (Beer *et al.*, 1998).

Ecosystem services and biodiversity conservation in coffee agroforestry systems have frequently been studied in isolation from coffee productivity. Although it is becoming increasingly clear that diverse and abundant tree cover in association with coffee contributes to biodiversity conservation (Philpott *et al.*, 2008), the expansion of the area of coffee with little or no tree shade suggests that farmers perceive that too many trees within their coffee plots reduce coffee yields. Available scientific literature on the relationships between shade tree canopy cover, coffee yields and profits show contradictory results. Some studies report significant increase in yields when shade was removed (Matoso *et al.*, 2004; daMatta, 2004), whereas others found no effect of the species composition and the type of shade on yield (Romero *et al.*, 2002) or maximum yields at intermediate levels of canopy cover (Perfecto *et al.*, 2005). Under certain conditions, shade trees favour the coffee crop, increasing its productivity (Soto-Pinto *et al.*, 2000) with the greatest yields found under 35–65% shade cover (Staver *et al.*, 2001; Perfecto *et al.*, 2005). The trade-offs between coffee profitability, other ecosystem services and biodiversity clearly depend on the specific local conditions, such as the altitude and orientation of slope, climate and soil conditions, coffee prices and local wages. It is reasonable to posit, that from years of experience, farmers will understand the consequences of their management practices in their particular environment, and how this will affect their livelihoods (Michon and Mary, 1994; Schulz *et al.*, 1994).

Farmers are increasingly recognised as having a role as ecosystem managers and the provision of ecosystem services from coffee agroforestry clearly depends on their management decisions. Their decisions, in turn, depend on their knowledge of both the ecosystem services provided by their plantations, in particular, by the trees they contain, and the trade-offs between shade trees and coffee productivity in their specific context. While a few studies have documented farmers' knowledge on tree diversity in coffee plantations in Central America (Albertin and Nair, 2004; Soto-Pinto *et al.*, 2007), little has been reported regarding their knowledge of the interactions between trees and ecosystem services or how they affect coffee production. This is in stark contrast to farmers' knowledge on trees in cocoa systems in West Africa, where detailed farmer knowledge about effects of trees on cocoa production has been shown to influence what types of trees are retained and how they are managed (Nomo *et al.*, 2008; Anglaaere *et al.*, 2011).

The primary objective of the research reported here was to acquire coffee farmers' knowledge regarding how the trees present on their farms impact a range of ecosystem services, including biodiversity conservation and coffee production and how management can influence these impacts. We expected that this knowledge would be detailed and largely complementary to knowledge held by extension workers, coffee processors and scientists so that when combined, a richer understanding of the role of trees in coffee production systems would emerge. We also anticipated that communication amongst farmers, extension staff and scientists would be improved by a greater mutual understanding of each other's knowledge.

2. Methodology

The research was carried out in the coffee communities within the Volcanica Central Talamanca Biological Corridor, in Cartago Province, at the Atlantic slope of Costa Rica (Figure 2.1). Local knowledge was acquired using the Agroecological Knowledge Toolkit (AKT) knowledge-based systems methodology and software system (Sinclair and Walker 1998). This methodology involves a series of iterative cycles of eliciting knowledge from a small purposive sample of farmers, through semi-structured interview, and then representation and evaluation of the knowledge obtained using an explicit knowledge-based systems approach. Each new round of interviews is informed by the previous evaluation cycle and the process is complete when further interviews do not result in a change to the knowledge base. The knowledge base remains a durable and accessible record of the knowledge acquired and is subjected to validation in a generalisation phase where a questionnaire instrument is used with a large random sample of informants to explore the occurrence of knowledge amongst people within the community (Walker and Sinclair, 1998).

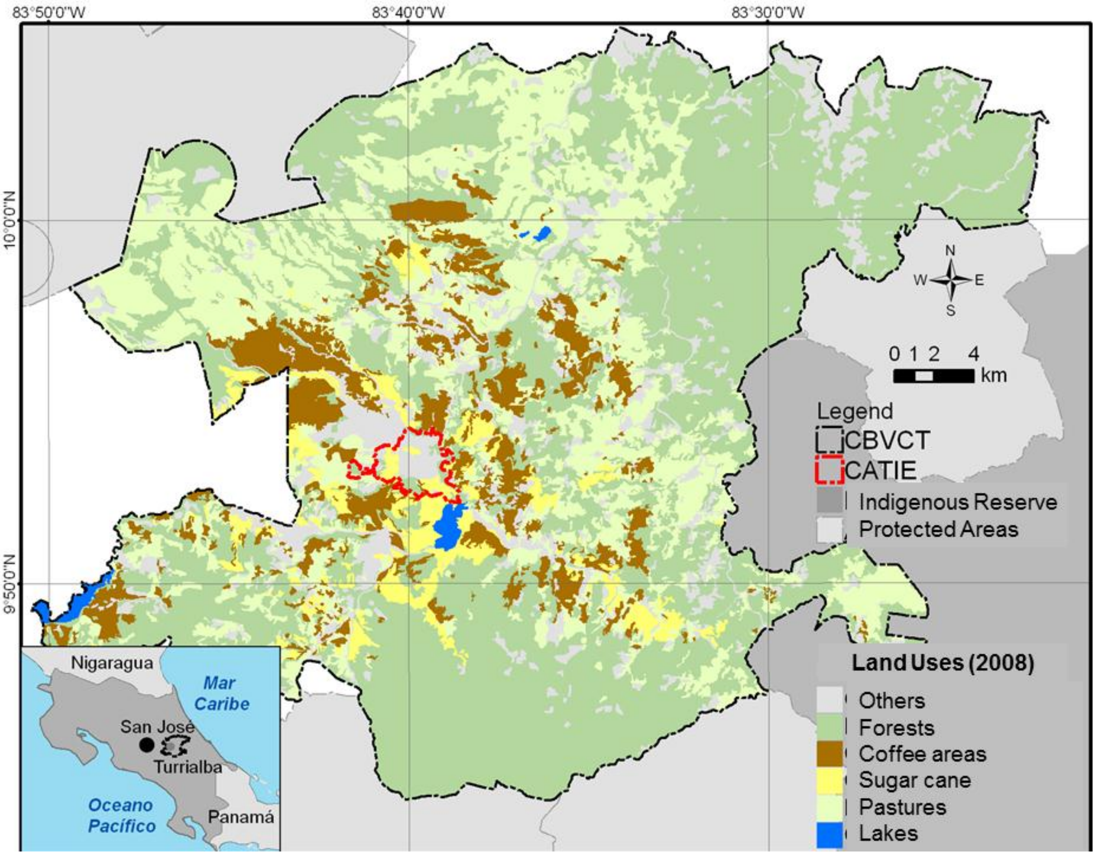

Figure 2.1. Location of the Costa Rican study area

Prior to compiling a knowledge base, several scoping meetings were held with key informants from the Costa Rican Coffee Institute (ICAFE), the Organic Farmers Association of Turrialba (APOT), the manager of a large coffee estate, and several scientists working with coffee based at CATIE. Information from these key informants was used to define the knowledge domain and stratify the selection of the purposive sample of farmers to be interviewed during knowledge base compilation. Two different types of coffee farmers were identified that were expected to differ in their knowledge regarding trees and ecosystem services: organic and conventional. Organic farmers were coffee farmers with organic certification and members of APOT. Amongst the farmers associated with APOT were some Cabécar Indians who were *de facto* organic, living in remote areas, and operating a low input coffee management system. The Cabécar managed to retain a high degree of independence and isolation from European influence during the settlement of Costa Rica, well into the twentieth century, and remain ethnically distinct from settlers of largely European descent (Bozzoli de Wille, 1972), including with respect to their approach to natural resource management (Garcia-Serrano and Del Monte, 2004). Conventional farmers used chemical inputs and were not part of any certification scheme. The vast majority of coffee farmers in the study area (2600) were conventional with only 145 organic, of which 30 were indigenous. Considerable variation in wealth and management intensity in the coffee farming areas likely had an influence on farmers' knowledge. The large number of conventional farmers was spread over altitudinal, rainfall and temperature gradients. This range could be expected to lead to heterogeneity in knowledge, which required a sample of informants spread over the range of conditions. These considerations led to a stratified sample of 50 farmers selected for interview for a knowledge base compilation (Table 2.1). The vast majority (88.5%) of coffee farmers in the area were men (ICAFE, 2003) and no specific hypotheses related to variation in knowledge according to gender were generated during scoping interviews. Therefore, women were passively sampled at roughly the rate they occurred in the coffee farmer population rather than as a distinct sampling stratum. This resulted in 10% of interviewees being women (one conventional and four organic farmers, one of which was indigenous, all in the small land holding category). The APOT extension staff identified all organic farmers sampled. ICAFE extension staff assisted in selecting conventional farmer to be interviewed in areas where they were familiar with the farming population and the researcher supplemented the sample with farmers randomly selected from other locations.

In the generalisation phase, a sample of coffee farmers was randomly selected (n=93) in order to explore how representative the knowledge base was of farmers in the study area as a whole. Coffee farmers interviewed at this stage were randomly selected from the 2003 Costa Rican Coffee Census (ICAFE, 2003). They answered questions on seven topics, chosen in discussion with extension staff and scientists, because of their relevance to development of future technical interventions (Table 2.6).

Table 2.1. Characteristics of sources interviewed and number of unitary statements given by each group of sources

	Farmers with **small** land holding **(A< 3 ha)**		Farmers with **medium** land holding **(3≤ A ≤7 ha)**		Farmers with **large** land holding **(A > 7 ha)**	**Extension workers**	**Processors**
Type of farm management	Conventional	Organic	Conventional	Organic	Conventional		
Number of people interviewed	15	18(3)	7	3	7	8	6

A= Coffee area; for organic farmers, the ( ) equals the number of indigenous people contributing to the total sample

Note: In the compilation stage, a small purposive sample of farmers willing to cooperate was selected in order to cover variation in major factors likely to cause differences in knowledge. How representative the knowledge acquired from this sample is of the wider community is evaluated later in the generalisation stage. Common knowledge generally held by farmers and used in making management decisions was sought rather than unique knowledge. The minimum sample size for any category is three, following D'Andrade (1970) cited in Werner and Schoepfle (1987) who observed that for relatively homogenous communities: shared knowledge rarely exceeded 60%, unique knowledge rarely less than 30% and knowledge shared between any two members (beyond what was shared by all) rarely exceeded 5%, thus if knowledge was shared amongst three or more people it was probably shared by all (Walker and Sinclair, 1998).

In the compilation phase, two focal subject areas for interview were developed, the first probing knowledge regarding how trees impact ecosystem services within coffee farms; and the second on impacts of trees on coffee productivity and quality. In addition to farmers, a sample of ICAFE coffee extension staff and coffee processors at local factories purchasing coffee were interviewed in regards to the second subject (Table 2.1). Interviews used a semi-structured format (Pretty, 1995), where the purpose was to probe the chosen subject area for the interview using non-leading questions to encourage interviewees to talk about their knowledge as freely as possible (Laws *et al.*, 2003). The power of the interview process comes from the iterative cycle of: interview, representation of knowledge acquired, evaluation and identification of new questions for clarification and further exploration of the knowledge domain (Walker and Sinclair, 1998). The main areas of knowledge probed in the first set of interviews regarding impacts of trees on ecosystem services were: farm characteristics, coffee management calendar, reasons for doing management activities, shade canopy management, utilities of trees, tree attributes and classifications; what mammals and birds were associated with trees, soil conservation practices, water conservation practices, and the environmental impact of coffee plantations at landscape scales. For the second set of interviews regarding the effects of trees on coffee productivity and quality, the knowledge base created in the first set of interviews was evaluated to extract causal relationships amongst factors affecting coffee productivity. This, together with a conceptual model of coffee phenological phases related to yield components developed in discussion with scientists at CATIE, was used to construct the semi-structured interviews. Leading questions were still avoided but the interview structure ensured that local knowledge regarding all stages of the production cycle was elicited.

Formal representation of knowledge in AKT involved its disaggregation into ‘unitary statements’. Unitary statements in the AKT methodology are meaningful items of knowledge that cannot be further broken down and they are recorded using a parsimonious and restricted syntax (Sinclair and Walker, 1998). The syntax recognizes three key elements of agroecology: objects, natural processes and human actions. Statements may be of four types: descriptive statements associating attributes and values with objects, natural processes or human actions; causal statements on interactions amongst these components; comparisons, or, a catch all category of link statements in which the knowledge base developer can define the nature of the link (Walker and Sinclair, 1998). In addition to unitary statements, the AKT methodology stores contextual information including definitions and taxonomies of terms used in statements, information on who articulated each statement and the conditions under which any statement is valid (Sinclair and Walker, 1998).

Knowledge of farmers was compared to that in scientific literature and with knowledge recorded from extension staff and processors. In comparison of knowledge from any two groups of people or sets of defined literature, three categories were recognised. Knowledge unique to one group (referred to as complementary), knowledge shared – and agreed – amongst the groups (referred to as common knowledge) and contradictory knowledge where the groups disagreed.

3. Results

Two knowledge bases were created: the first one contains the farmers’ knowledge regarding ecosystem services and biodiversity within coffee farms, the second one comprises knowledge from farmers, processors, and technicians on coffee productivity and quality. The farmers’ knowledge base consisted of 579 statements supplied by 50 sources on ecosystem services and biodiversity conservation within coffee farms (Table 2.2). Almost 70% of the statements were explicitly about causal relationships, indicating considerable explanatory content. There were 176 objects defined in the farmers’ knowledge base, arranged in thirty-five taxonomic hierarchies, for which information was held locally on classes of objects (e.g. all soft-leaved trees, all big-leaved trees, all deep-rooted trees).

Table 2.2. Contents of the local knowledge base about ecosystem services and biodiversity detained by coffee farmers

Formal terms	309
Unitary statements	579 (100%)
Causal statements	402 (69%)
Attribute-value statements	99 (17%)
Link statements	68 (11%)
Comparative statements	10 (2%)
Object hierarchies	57
Sources	50
• Number of unitary statements including those derived using hierarchies	3092

Note: Object hierarchies are sets of formal terms with the same properties and characteristics.

The total 579 unitary statements do not represent all the knowledge expressed by the sources. It represents only the knowledge that, after analysing the interviews, was considered useful to be reported in the knowledge base related to ecosystem services. Organic farmers with small land holding mentioned almost twice the unitary statements than conventional ones. Similarly, organic farmers with medium land holding mentioned proportionally more unitary statements when compared with conventional ones (3 organic farmers with 84 statements and 7 conventional farmers with 85). From these numbers it could be inferred that organic farmers' knowledge was quantitatively higher than conventional ones. This quantitative difference was not found related to land holding size: farmers with small land holding mentioned on average 15.3 statements, with 17.8 statements for medium land holding and 14.6 statements for large land holding.

3.1 Tree attributes and tree functional classifications

Coffee farmers create functional classifications of trees through the combination of tree attributes (Table 2.3), such as leaf size, root depth, growth rate, and canopy. Farmers, for example, determine whether a tree is good, neutral or bad for soil fertility, taking into account how much biomass is produced by the tree (leaf production), how big its leaves are, if they are fast-degrading (called 'soft') or slow-degrading ('hard'), how frequently and at what time of year the leaves fall, and how much the root system competes with the coffee for resources. Farmers use a 'fresh/hot' classification for trees that involves many different attributes and overlaps with classifications relating to soil and water. Trees that were classified as 'fresh' were thought to be good for water conservation, whereas 'hot' trees were strongly related to low water conservation.

Table 2.3. Relationships between tree attributes and local classification of trees

Tree attributes \ Tree classifications	Fresh or hot shade	Dense or sparse shade	Easy or difficult to manage	Does or does not improve soil	Does or does not cause "dripping"	Is or is not good for water
Height		X	X		X	
Woody growth rate			X			
Leaf production	X			X		X
Ease of pruning		X	X			
Leaf size	X			X	X	X
Leaf texture	X			X		
Canopy phenology				X	X	
Crown openness	X				X	
Root texture				X		X
Root depth						X
Root abundance	X					X

Table 2.4 lists all 36 species mentioned by farmers, including the classifications and their different attribute values. As an example, 'poró' (*Erythrina poeppigiana*) is classed as a fresh, easily managed, non-dripping tree, good for soil and water. These classifications took into account the following attributes: short height with fast growth, high biomass production, ease of pruning, open crown to let in light, large and very soft textured leaves; and soft and numerous roots. Farmers showed an understanding of which trees were useful in terms of improving soil fertility and protecting water resources. However, the reasons for keeping particular trees in coffee plantations were not only related to these functions; multipurpose-trees were frequently more abundant than those that were reported as having the highest positive impacts on soil and water, but which do not produce non-timber forest products.

Table 2.4. Attibutes and classifications of all trees species mentioned by farmers during the interviews

Tree species		Local functional classifications						Tree attributes										
Scientific name	**Local name**	"Fresh/ hot" shade	High shade	Shade management	"Impact on soil"	"Dripping"	"Water protection"	Height	Growth rate	Biomass production	Ease of pruning	Canopy phenology	Leaf size	Crown openness	Leaf texture	Root abundance	Root texture	Root depth
Erythrina poeppigiana	***Poró***	Fresh	No	Easy	Good	No	Good	Low*	Fast	High	Easy	Evergreen, with high rate of leaf turnover	Big	Open	Very soft	Numerous	Soft	n. d.
Musa paradisiaca	***Banano***	Fresh	No	Easy	Good	No	Good	Low	Fast	High	Easy	Evergreen	Very big	Open	Soft	Numerous	Soft	n. d.
Gliricidia sepium	***Madero negro***	Fresh	No	Easy	Good	No	Good	Medium	Fast	High	Easy	Evergreen	Small	Closed	Soft	Numerous	Soft	n. d.
Theobroma cacao	***Cacao***	Fresh	No	Easy	Good	No	Good	Low	Fast	High	Easy	n. d.	Big	Closed	Medium	n. d.	Medium	n. d.
Ricinus communis	***Higuerilla***	Fresh	No	Easy	Good	No	Good	Low	Fast	Low	Easy	n. d.	Very big	Open	Soft	n. d.	Soft	n. d.
Zygia longifolia	***Sotacaballo***	Fresh	No	Easy	Good	No	Good	Medium	Medium	High	Medium	n. d.	Medium	Closed	Medium	Numerous	n. d.	n. d.
***Inga* spp.**	***Guaba***	Fresh	Yes	Easy	Good	No	Good	Medium	Fast	High	Medium	Evergreen, with high rate of leaf turnover	Medium	Closed	Soft	Numerous	Soft	n. d.
Cecropia obstusifolia	***Guarumo***	Fresh	Yes	Medium	Good	Yes	Good	High	Fast	High	Medium	Evergreen	Very big	Open	Soft	n. d.	Soft	n. d.
Persea americana	***Aguacate***	Fresh	Yes	Medium	Good	Yes	Good	Medium	Fast	High	Medium	Evergreen	Medium	Open	Medium	n. d.	Medium	Medium
Mangifera indica	***Mango***	Fresh	Yes	Medium	Good	Yes	Good	Medium	Fast	High	Medium	Evergreen, with high rate of leaf turnover	Medium	Closed	Medium	n. d.	n. d.	Medium
Lauracea family	***Aguacatillo***	Fresh	Yes	Medium	Good	Yes	Good	Medium	Medium	High	Medium	n. d.	Big	Open	Medium	Medium	Medium	Medium
***Ficus* spp.**	***Higuerón***	Fresh	Yes	Medium	Good	Yes	Good	High	Medium	High	Difficult	n. d.	Medium	Closed	Medium	Numerous	Soft	Deep
Acnistus arborescens	***Güitite***	Fresh	Yes	Medium	Good	Yes	Good	Medium	Fast	High	Medium	n. d.	Big	Closed	Medium	Numerous	Soft	n. d.
Syzygium malaccense	***Manzana de agua***	Fresh	Yes	Medium	Good	Yes	Good	High	Medium	High	Medium	Evergreen	Big	Closed	Medium	n. d.	Soft	n. d.
Eriobotrya japonica	***Níspero***	Fresh	No	Medium	Good	No	Good	Medium	Medium	Medium	Medium	n. d.	Medium	Closed	Soft	n. d.	n. d.	n. d.
Ficus pertusa	***Higuito***	Fresh	Yes	Difficult	Good	Yes	Good	Medium	Medium	High	Difficult	n. d.	Small	Closed	Medium	n. d.	Soft	n. d.
Trichilia martiana	***Manteco***	Medium	No	Difficult	Good	No	Medium	Low	Medium	Medium	Difficult	n. d.	Big	Closed	Hard	Medium	n. d.	n. d.
Eugenia uniflora	***Pitanga***	Fresh	No	Easy	Medium	No	Good	Medium	Fast	High	Easy	n. d.	Medium	Open	Medium	n. d.	Soft	n. d.
Manilkara zapota	***Zapote***	Fresh	Yes	Easy	Medium	Yes	Good	High	Medium	High	Easy	Evergreen	Big	Closed	Medium	n. d.	Soft	n. d.
Byrsonima crassifolia	***Nance***	Fresh	No	Medium	Medium	No	Good	Medium	Fast	Medium	Medium	n. d.	Medium	Closed	Medium	n. d.	Soft	n. d.
***Ficus* spp.**	***Chilamate***	Fresh	Yes	Difficult	Medium	Yes	Good	Medium	Fast	High	Medium	n. d.	Medium	Closed	Medium	n. d.	Soft	n. d.
Ocotea floribunda	***Quizarra***	Medium	Yes	Difficult	Medium	No	Medium	Medium	Fast	High	Medium	n. d.	Medium	Closed	Hard	Medium	Medium	n. d.
Yucca elephantipes	***Itabo***	Hot	No	Easy	Good	No	Bad	Low	Fast	Low	Easy	n. d.	Big	Open	Hard	Numerous	Hard	n. d.
Cedrela odorata	***Cedro***	Hot	Yes	Difficult	Medium	Yes	Bad	High	Fast	High	Difficult	Deciduous	Medium	Open	Medium	n. d.	n. d.	Medium

Tree species were ordered according to their impact on soil and water, putting those with positive impacts at the top.

Table 2.4. Attributes and classifications of all tree species mentioned by farmers during the interviews (cont)

Tree species		Local functional classifications						Tree attributes										
Scientific name	Local name	"Fresh/ hot" shade	High shade	Shade management	"Impact on soil"	"Dripping"	"Water protection"	Height	Growth rate	Biomass production	Ease of pruning	Canopy phenology	Leaf size	Crown openness	Leaf texture	Root abundance	Root texture	Root depth
Citrus aurontifolia	***Limón***	Hot	No	Easy	Bad	No	Medium	Low	Fast	Medium	Easy	Evergreen	Medium	Closed	Medium	n. d.	Hard	n. d.
Citrus sinensis	***Naranja***	Hot	No	Medium	Bad	No	Medium	Low	Fast	Medium	Easy	Evergreen	Medium	Closed	Medium	n. d.	Hard	n. d.
Cocos nucifera	***Pipa***	Medium	Yes	Difficult	Bad	No	Bad	High	Medium	Low	Difficult	Evergreen	Very big	Open	Hard	n. d.	Hard	n. d.
Psidium guajava	***Guayaba***	Hot	No	Medium	Bad	No	Bad	Low	Medium	Medium	Medium	Evergreen	Small	Closed	Hard	n. d.	Hard	n. d.
Psidium friedrichsthalianum	***Cas***	Hot	No	Medium	Bad	No	Bad	Low	Medium	Medium	Medium	n. d.	Medium	Closed	Hard	n. d.	Hard	n. d.
Tabebuia rosea	***Roble***	Hot	Yes	Medium	Bad	Yes	Bad	High	Medium	High	Difficult	n. d.	Medium	Closed	Hard	n. d.	Hard	Deep
Bactris gasipaes	***Pejibaye***	Hot	Yes	Difficult	Bad	Yes	Bad	High	Medium	Low	Difficult	n. d.	Medium	Open	Hard	Numerous	Hard	n. d.
Casuarina equisetifolia	***Casuarina***	Hot	Yes	Difficult	Bad	Yes	Bad	High	Medium	Medium	Difficult	n. d.	Small	Open	Medium	n. d.	Hard	n. d.
Cupressus lusitanica	***Ciprés***	Hot	Yes	Difficult	Bad	Yes	Bad	High	Medium	High	Difficult	n. d.	Small	Closed	Medium	n. d.	Hard	n. d.
Cordia alliodora	***Laurel***	Hot	Yes	Difficult	Bad	Yes	Bad	High	Medium	High	Difficult	n. d.	Small	Open	Hard	n. d.	Hard	n. d.
Pinus oocarpa	***Pino***	Hot	Yes	Difficult	Bad	Yes	Bad	High	Slow	Medium	Difficult	Evergreen	Medium	Open	Hard	n. d.	Hard	Deep
Eucalyptus deglupta	***Eucalipto***	Hot	Yes	Difficult	Bad	Yes	Bad	High	Slow	Medium	Difficult	n. d.	Medium	Open	Hard	n. d.	Hard	Deep

Tree species were ordered according to their impact on soil and water, putting those with positive impacts at the top.

Key: For soil and water classifications, 'Good' means that the tree was said to improve soils and protect water sources. The opposite is true for 'Bad'. **Erythrina poeppigiana* is a tall tree when it grows naturally, but because of pruning management it was classed as a short tree.

3.2 Farmers' coffee productivity knowledge

Knowledge statements regarding trees and coffee productivity were arranged according to five factors: pests and diseases, weeds, soil erosion, soil fertility and pollination. For each factor, statements directly relating to the factor were searched for, and then followed until reaching a statement involving trees (Table 2.5). The sequences were sorted into three categories: knowledge that is shared among farmers and scientists, knowledge unique to farmers, and contradictions between farmers and scientists. With regards to soil fertility, farmers and scientists shared much of the knowledge, but much of the local knowledge regarding soil erosion and trees was unique to farmers. Pests and diseases, weeds and pollination have both unique and shared knowledge. Contradictory knowledge, which could be explained by specific conditions or could not be explained, perhaps indicating topics that need additional research, was only found in pest and diseases.

Farmers mentioned pests and diseases as the main factor affecting coffee productivity in relation to trees. Management and selection of trees within the coffee plantations could increase or decrease the incidence of pests and diseases. There were ten sequence statements in this topic reported by a total of 32 farmers. The effect of shade trees reducing weed pressure was clearly stated by farmers and shared with scientists. Farmers mentioned that trees shading coffee increased light interception, thereby reducing weed growth. Natural leaf litter from all the trees and pruning residues, particularly for *E. poeppigiana*, were also related to weed growth reduction. There was a clear distinction between weeds, which were considered invasive species difficult to eliminate, and beneficial herbs, which were considered the opposite.

Soil erosion and fertility were mentioned by many sources as a factor related to coffee productivity and affected by trees. In particular, the sequence of statements relating to soil fertility (a same source mentioned all the causal statements of the sequence) were cited more often than for other factors, and were shared by scientists and farmers. Farmers' knowledge of the soil biological component was always shared with scientists and technicians. Coffee farmers' knowledge of soil biological components was divided into what farmers could easily observe and the non-'visible' elements of soils (Grossman, 2003). Macrofauna, especially earthworms, were frequently observed by farmers and were related to farmers with fertile soils. They were unable to explain the reason for the macrofauna abundance; however both organic and conventional farmers considered the abundance of earthworms as an indicator of high soil fertility. On the other hand, soil microorganisms were mentioned as the most important element of soils, even when farmers were not able to observe this. Clearly this knowledge was learnt through trainings and lectures (according to ICAFE, 2003, over 75% of Costa Rican coffee farmers have received trainings). Organic and conventional farmers were able to explain the role of soil microorganisms, identify nodules in the roots of *E. poeppigiana*, and mention the importance of *E. poeppigiana* in biological nitrogen fixation. The percentage of conventional farmers who mentioned soil microbiological knowledge was lower (18%) than organic farmers (100% excluding indigenous farmers).

Farmers retained soil erosion knowledge and often mentioned tree height as the factor in increasing raindrop size. In addition farmers stated that keeping *Cordia alliodora* (a common timber tree) in sloped fields could increase soil erosion, whereas in contrast trees with an extensive root system could decrease erosion.

The farmers' knowledge regarding coffee phenology is shown in Figure 2.2. General processes of shade and biophysical interactions related to coffee phenology were well understood by farmers, who knew all the stages proposed in the conceptual model and even proposed new processes not reported in the literature (represented by dotted nodes in Figure 2.2). For farmers, flower formation timing influences fruit size. The first flowers formed are larger and produce larger fruits. This could illustrate a source/sink link well known by plant physiologists: the first flowers formed after the end of the vegetative phase would have more carbon available for their development, hence for fruit growth (Franck *et al.*, 2006).

Another key element for all knowledge sources was the distribution of flowering over time; this was considered a process that affects the amount of floral buds (according to processors and farmers) or flowers (according to farmers). It was expressed in a number of ways, such as 'crazy flowering, frequency of flowering', meaning the undesirable effect of having a longer harvest season due to scattered rains during flowering and a strong dry period, which helps with a strong and grouped flowering (daMatta, 2004). There were other areas of knowledge unique to the literature and not mentioned by farmers (e.g. initiation and induction processes), but general processes (falling, fruit formation, ripening) were well understood by all knowledge sources. The comparison of farmers' knowledge with knowledge exclusive to other stakeholders in the coffee value chain did not provide expected information difference. Processors were more knowledgeable on coffee quality, but they did not relate this quality to field conditions. Interviews with technicians provided very little information. Almost all the knowledge showed by technicians was similar to the knowledge possessed by farmers. This could be due to a bias in the interview, whereby technicians felt 'like they were passing an exam', and thus mainly presented the knowledge they had from literature rather than presenting their own observations and experiences.

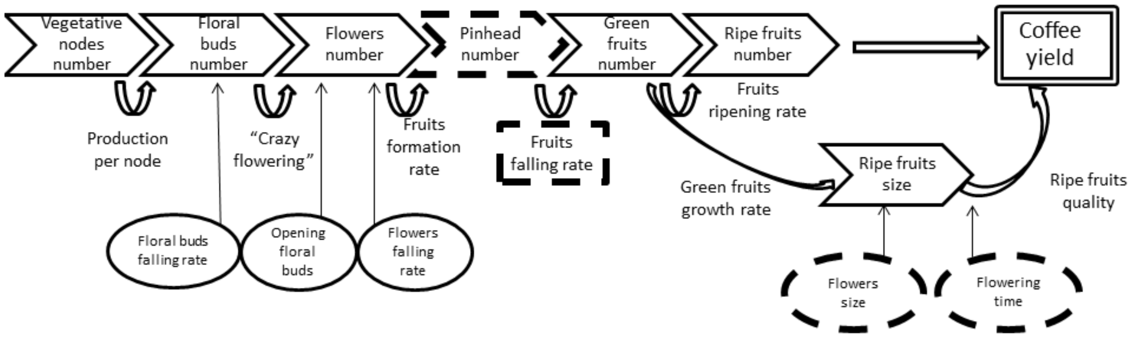

Figure 2.2. Farmers' knowledge about the fruiting cycle and yield formation of the coffee

Main nodes represent the 7 physiological yield components confirmed by farmers. Arrows connecting components show the processes that relate one to another. Dotted nodes show processes that farmers mentioned which are not reported by the literature.

Table 2.5. Farmers' knowledge about trees and factors affecting coffee productivity: pests and diseases, weeds, soil erosion, soil fertility and pollination

		Type of knowledge		
		Shared	Unique	Contra-dictory
Pests and diseases	Good soil trees increase soil fertility (12), high soil fertility increases coffee biomass production (8),high coffee biomass production decreases the incidence of coffee diseases (2) -- ((0))	X		
	Tall *Erythrina* increases sun light penetration (5),high sun light penetration decreases air humidity (11), low air humidity decreases the incidence of coffee diseases (11) -- ((4))	X		
	Crown of tree species good for water decreases sun light penetration (6), low sun light penetration increases air humidity (11), high air humidity increases the incidence of coffee diseases (11) -- ((1))	X		
	Reduction in distance between coffee plantations and forests increases air humidity (2), high air humidity increases the incidence of coffee diseases (11) -- ((2))	X		
	Tall trees increase dripping (11),dripping increases the incidence of American leaf spot (11) -- ((3))		X	
	Big leaved trees increase dripping (2), dripping increases the incidence of American leaf spot (11) -- ((1))		X	
	Roots of tree species good for soil increase soil moisture (12),high soil moisture increases the incidence of American leaf spot (2) -- ((1))			X[a]
	Cecropia tree hosts a small black ant (2) which decreases coffee borer population(2) -- ((2))	X		
	Inga trees host coffee borer population (1)			X[b]
	Tree species good for soil increase soil fertility (11),high soil fertility increases the amount of coffee fruits (3), high amount of coffee fruits increases coffee borer population (1) -- ((0))	X		
Weeds	Roots of pines and cypress decrease the amount of weeds, however also affects coffee biomass production (2)		X	
	Leaves of tree species good for soil increase litter (11), increased litter decreases germination of weeds (12) -- ((11))	X		
	Roots of tree species good for soil increases soil fertility (11), high soil fertility increases the amount of good herbs (1), high amount of good herbs decreases weeds (1) -- ((0))	X		
Soil erosion	Tall trees cause dripping (11), dripping increases soil erosion (4) -- ((1))		X	
	Falling leaves of tree species good for soil increase litter (12), increased litter decreases run-off (10), low run-off decreases soil erosion (12) -- ((5))	X		
	Roots of erosion-controlling trees decrease run-off (12), low run-off decreases soil erosion (12) -- ((10))		X	
	Roots of *Cordia alliodora* increases soil erosion in sloped areas (1)		X	
Soil fertility	Falling leaves of tree species good for soil increase litter (13), increased litter increases soil fertility (10) -- ((5))	X		
	Roots of *Inga* and *Erythrina* increase soil nitrogen (11), increased soil nitrogen increases soil fertility (13) -- ((11))	X		
	Roots of tree species good for soil increase soil moisture (12)	X		
	Eucalyptus decreases soil moisture (6)	X		
Pollination	Synchronisation of tree flowering with coffee flowering increases the amount of coffee pollinators (6), more coffee pollinators increase coffee pollination (10) -- ((6))		X	
	Resin of *Cordia alliodora* increases the amount of coffee pollinators (2), more coffee pollinators increases coffee pollination (10) -- ((2))		X	
	Reduction in distance between coffee plantations and forests increases the amount of coffee pollinators (2), more coffee pollinators increases coffee pollination (10) -- ((2))	X		

Key: Digits between brackets ( ) show the number of sources for each sentence of knowledge. Digits between double brackets (( )) show the number of sources that mentioned the whole series of statements. For instance, the first whole idea presented –fertility due to tree species good for soil decreases coffee diseases– is known by 0 farmers, even though 12 farmers knew the role of trees in increasing soil fertility, 8 farmers knew that soil fertility increases coffee growing rate, and 2 farmers mentioned that coffee plants with a high growing rate are less vulnerable to diseases. Letters indicate the references refusing these farmers asseverations ([a] Avelino *et al.* 2007, [b] Soto-Pinto *et al.* 2002)

3.3 Farmers' knowledge regarding biodiversity within the coffee farms

Coffee farmers identified the usefulness of each tree species present in their farm in regards to small mammal and bird diversity conservation and the type of resource each tree provides (Figure 2.3). Coffee farmers were knowledgeable on bird and mammal behaviour in relation to the trees in their farms, such as feeding patterns and habitat preferences for nesting or protection. Some tree species were considered bad for biodiversity conservation; for example *Pinus oocarpa* and *Eucalyptus deglupta* were mentioned as trees with potential to reduce the presence of animals. The reason why they were considered detrimental for biodiversity is not clear; however, both species were exotic and classed as 'hot'. Farmers mentioned that birds or mammals are not using the exotic species for nesting because the local fauna were not adapted to these species. This detrimental effect was attributed to the 'hotness' classification, while the local fauna were seeking 'fresh' environments. The lack of edible fruits for animals was also mentioned as a negative characteristic of these species. On the other hand, *E. poeppigiana* was the species most mentioned by farmers as being useful for many faunal species. However, the great dominance of *E. poeppigiana* in the coffee agroforestry systems within the study area probably increased the positive perception that farmers have of this species. Moreover, even when *E. poeppigiana* was considered beneficial for the resources given to birds and mammals, farmers recognize that if trees are frequently pruned the benefits for biodiversity will be considerably diminished.

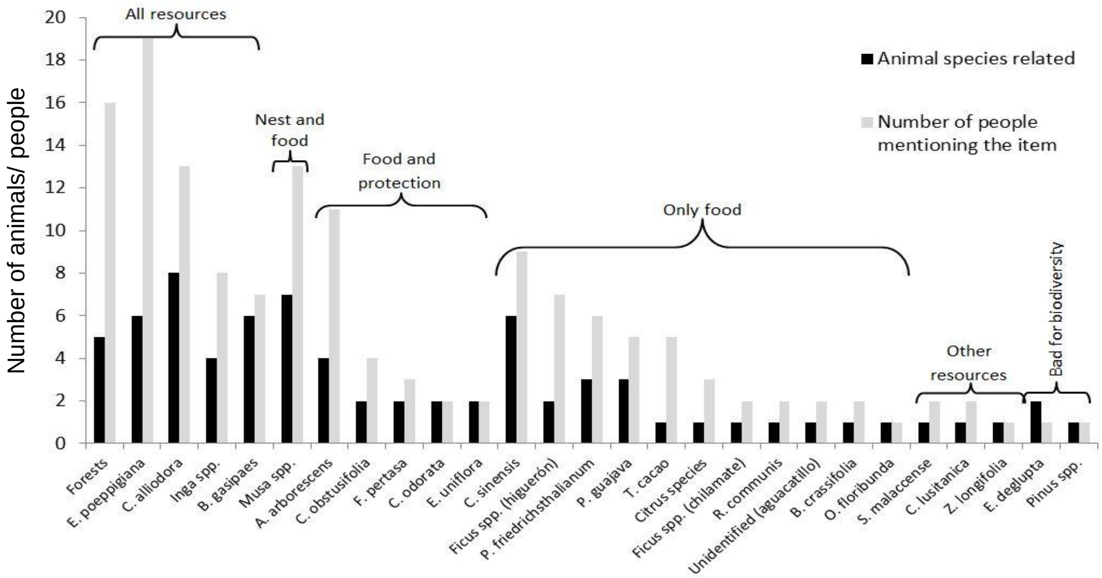

Figure 2.3. Farmers' classification of trees within coffee farms according with the type of resources (nest, food and protection) provided to biodiversity

Black columns show how many species (mainly birds and mammals) are related with the tree species, while grey lines show the number of sources who mentioned the tree species.

3.4 Coffee farmers' water balance knowledge

The diagramming capabilities of AKT combined with farmers' knowledge were utilised to build a conceptual model of the effects of tree presence on water in coffee plantations (Figure 2.4). The maintenance of an appropriate level of humidity for optimum growth of coffee was an important aspect of shade tree management, and farmers explained that at different times of year more or less soil water content is needed according to the coffee phenology.

Tree canopies played an important role in water conservation, as they are the medium through which sun and rainfall are filtered. Farmers considered rainfall interception by the tree canopy as beneficial. The ensuing decrease in the amount of rainfall reaching soil directly was mentioned as a form of regulation of water input into the system. Farmers showed an understanding of water resources protection in regards to which tree species were the most effective at protecting water resources and therefore should be kept close to a water source; e.g. *Zygia longifolia* is considered beneficial because its roots protect against erosion near water sources, whereas *E. deglupta's* high water consumption will dry out a water source and is considered detrimental to that resource. Farmers in general were careful and tended not to disturb the natural species composition around these areas to prevent a possible decrease in water supply.

There were some knowledge differences between organic and conventional farmers. For instance, organic farmers frequently mentioned in their discourse the importance of water provision for human consumption, as well as how water could be polluted through the utilisation of chemical inputs. Similarly, the management of soil moisture balance due to the litter and soil organic matter was mentioned by a higher number of organic farmers than conventional ones. There was a general concern among all the farmers about soil and water conservation and not using chemical inputs. Both organic and conventional farmers were concerned about the residual effect of herbicides on soils; however, organic farmers were more concerned than conventional farmers regarding the effects of chemical fertilisers.

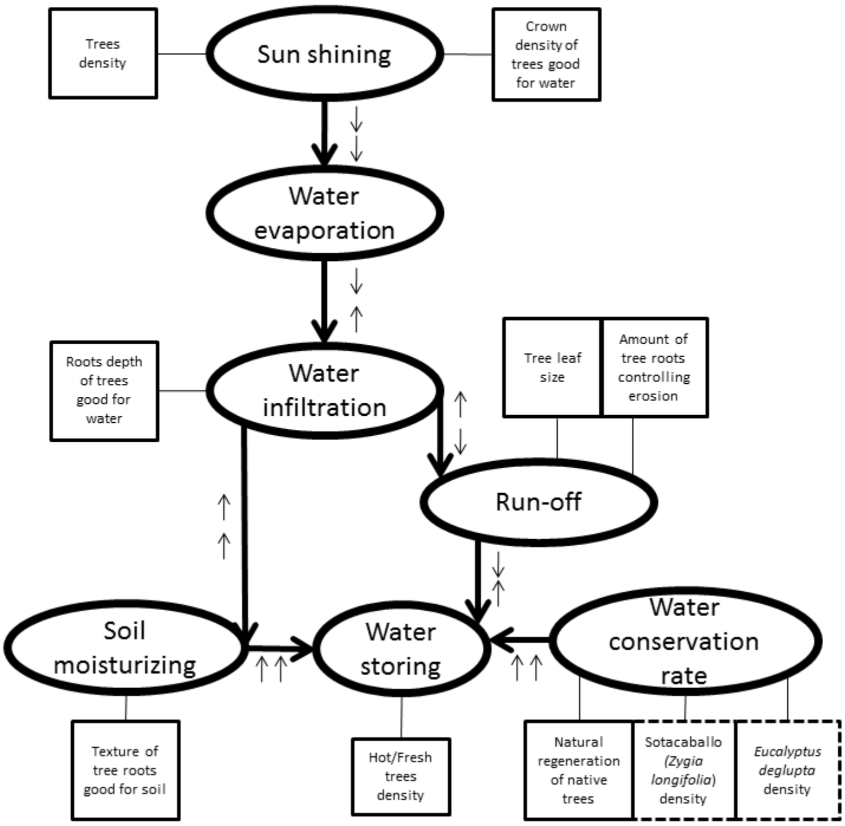

Figure 2.4. Costa Rican coffee farmers' knowledge regarding the factors affecting water balance and how trees relate to these factors

Circular nodes represent the processes related to water balance. Square boxes represent the role of shade trees in each process and the tree attributes related to these roles. Dotted boxes represent tree species. Arrows connecting nodes show the direction of causal influence. Small arrows on a link indicate the nature of the relationship: for example, on the top link, farmers indicated that a decrease (first arrow) of sun caused a decrease (second arrow) in water evaporation.

Farmers' knowledge related to the effectiveness of shade trees in regulating humidity to manage fungal diseases was also found (Table 2.5). Farmers frequently mentioned two fungal diseases: coffee rust (caused by *Hemileia vastatrix*) and American leaf spot (caused by *Mycena citricolor*). Almost all farmers expressed that in order to avoid American leaf spot, shade percentage should be kept high throughout the year (this was always compared with other coffee areas in Costa Rica). Due to its ease of pruning and resilience to frequent severe pruning, farmers consider *E. poeppigiana* as the best tree for the area. In general, trees should be pruned twice a year to favour drying within the plantations during certain months of the year.

3.5 Generalisation of farmers' knowledge regarding ecosystem services

Farmers' knowledge compiled within the purposive sample was different from the knowledge expressed within a bigger sample of farmers during the stage of generalisation (Table 2.6). Not all farmers knew or understood the same issues and each farmer knew the different issues to various degrees.

Even if the causes of climate change are not well understood, its consequences were strongly perceived and affected coffee farming practices during the year. For example, farmers mentioned that fluctuations in the distribution of the rainy season have increased the duration of coffee flowering. They also mentioned an increase in the severity of coffee fungal diseases due to climate change in the past few years. In some low areas, tree-pruning regimes have been modified in order to provide a fresher microclimate for coffee plants. Farmers used to prune severely twice a year, pollarding all branches of *E. poeppigiana*. Now farmers are pruning with the same frequency but keeping two or three branches without pollarding.

The discourse on ecosystem services was found to differ with the farmers' specific necessities and conditions. For instance, tree species diversity within the farm was mentioned more frequently among organic farmers, as well as the perceived resources that animals obtained from different trees. Organic farmers constantly mentioned that conserving forests surrounding coffee plots is very important for faunal conservation. Organic farmers were also the only farmers to mention secondary succession by tree species pioneers and other specific issues.

Table 2.6. Topics selected from the farmers' knowledge compilation stage to be asked in the generalisation stage

Topic questioned	Interesting fact
Erythrina poeppigiana (poró) as the main shade tree	
Utilities of the main shade species[1,*]	Majority use to give coffee accurate micro-climate and to increase the fertility of soils. Only 4% of farmers believe that litter is useful to manage weeds
Severe pruning of poró[1,2,*]	82% of farmers prune poró severely to increase light availability for coffee, 18% to reduce the conditions favourable to fungal coffee diseases, 8% to avoid "dripping" and 4% don't know the reason but they see that their neighbours prune and imitate them
Nitrogen fixation of poró[1]	60% of farmers know that poró increases soil fertility, but just 36% know that "poró" supplies Nitrogen, and only 18% know about biological fixation
Soils erosion, conservation and fertility	
Soil formation by mulch degradation[1]	69% of farmers mentioned this process as important, but only 5% considered it could replace chemical fertilisation
Good trees to soil[1]	33% of farmers considered that *E. poeppigiana* is the only tree species useful to improve soils within coffee plots
Appropriate soil conditions for coffee[1]	20% of farmers believe that their management of litter keeps appropriate soil moisture for coffee growing
Root attributes of good trees for soil[3,*]	54% of farmers have no knowledge about the root attributes of good trees for soil
Impact of *C. alliodora* (laurel), *B. gasipaes* (pejibaye) and *Y. elephantipes* (itabo)[2]	11% of farmers considered that laurel (a very common native timber tree within the plantations) decreases soil fertility and damages soil structure
Changes in soil over time[2]	82 % of farmers considered that soils in their plantations have been degraded since they become farmers
Soil pollution[1]	68% of farmers considered that the use of chemical inputs is polluting their soils
Use of herbicides	
Consequences of the use of herbicides[1]	87% of farmers use herbicides and 80% considered that this decreases the fertility or changes the structure of soils.
Role of herbs	
Differences between herbs and weeds[1]	87% of farmers are able to identify weeds from beneficial herbs
Attributes of "good" herbs[3,*]	Good herbs are known by their interaction with coffee but farmers identify the specific good species; only 5% of farmers mentioned the texture of herb leaves as an attribute to identify them
"Dripping"	
Attributes of trees causing dripping[3,*]	54% of farmers mentioned tree height, 8% mentioned crown type and 2% mentioned leaf attributes
Consequences of dripping in coffee plantations[2,3]	95% of farmers knew about dripping, and 73% mentioned this as a problem to coffee production (30% considered it causes American leaf spot disease, 31% falling of coffee leaves, flowers or fruits, and 12% considered it causes erosion)
Pollination	
Importance of pollinators[2]	73% of farmers considered an abundance of pollinators important to coffee
Possible ways to increase the abundance of pollinators[1,3,*]	28% established bee hives, 18% avoided insecticides, 15% synchronized the flowering of trees with coffee, and 7% utilized forest distance
Climatic change	
Changes on climate over the time[2]	93% have felt a change in climate in the last 10 years
Effects of climatic change on coffee production[3]	34% of farmers considered that the climate is hotter now, 31% said there is less rain, 25% said the dry/rainy season patterns have changed, and 9% indicated there is more rain. However, only 37% of farmers considered these changes as a problem to coffee
Coffee management practices for adaptation to CC[1,3]	80% of farmers are doing nothing to adapt to changes, whereas 8% have increased the number of shade tree and 4% are pruning trees less severely
Effects of climatic change on other activities[1]	73% of farmers don't feel the consequences of climate change in their lives (excluding coffee production). 14 % considered that labour in the farm is more difficult now, and 3% the seasons for some edible fruits have changed

Table 2.6 Codes
Questions were selected based on: 1) Importance to technical interventions, 2) Contradictions between sources, or 3) knowledge not reported elsewhere. In some questions (*) farmers mentioned more than 1 answer, therefore the percentage is more than 100%.
Notes: In the generalisation stage, questions were directly asked on each topic, whereas farmers had to mention them freely during the compilation stage.

4. Discussion

Shared, unique and contradictory knowledge approach

The importance of participatory research methods and the recognition of the role of local knowledge in the design and management of agroforestry systems have been frequently stated. This study found that farmers have a very clear, explanatory, and coherent way of understanding the diverse natural processes that happen in their farms and how these processes relate to coffee production, provision of ecosystem services and biodiversity conservation. They clearly know how coffee practices and natural resources management affect many relationships within their farms. Farmers consistently stated that coffee productivity, ecosystem services production, and biodiversity conservation are balanced due to the presence, abundance, diversity and management of tree species. They build their own tree functional classifications related to the provision of environmental services, based on diverse tree attributes.

While this is the first formal research on this topic using AKT, the knowledge found agrees with earlier study reports. Budowski and Russo (1993) listed which species are used as live fences in Costa Rica, as well as the ways farmers manage them. Albertin and Nair (2004) described, specifically for Costa Rican coffee farms, the tree attributes that farmers consider as beneficial for shade trees. Soto-Pinto *et al.* (2007), in turn, described these desirable attributes. They also concluded that trees are retained by farmers within coffee plantations because of their interactions with coffee plants and because they provide ecosystem services. These previous studies provide a basis for more rigorous investigations of the nature and extent of coffee farmers' knowledge. However, it was not possible to access the knowledge acquired during these previous studies and further develop the analysis of local explanations of system functions.

Coffee farmers' knowledge was categorised according to: (a) issues shared with science; (b) unique knowledge, owned only by the farmers; and (c) knowledge in contradiction with the knowledge available in current literature. Few contradictions were found and shared knowledge is not considered novel. Therefore, the following discussion presents the knowledge considered by this study as uniquely owned by coffee farmers, based on three examples that, to the knowledge of the authors, have not been previously reported.

Coffee entomophily pollination: Farmers discussed different ways of increasing coffee pollination by insects. Farmers mentioned coffee plantation distance from forests as a factor related to the abundance of coffee pollinators, agreeing with the work of Rickets *et al.* (2004). A novel aspect that was noted by farmers was that *C. alliodora*, a very common native timber tree, is particularly beneficial in attracting pollinators as the nectar of its flowers attracts the same insects that pollinate coffee. According to research, *C. alliodora* flowers are present during at least half of the year. Farmers reported no pollination competition between *C. alliodora* and coffee, even if the flowering time of both species overlaps, due to the large number of insects that this tree attracts. To the authors' knowledge, there is no scientific research on this topic to confirm this.

Dripping related to tree height: Coffee farmers in Costa Rica were found to be concerned by a process termed 'gotera'. This process is the name for the damage caused by raindrops formed on the leaves of trees when the tree crown intercepts. Costa Rican coffee farmers mentioned tree height and crown type as the main factors related to this process. During the generalisation stage, farmers mentioned that droplets falling from trees increased the incidence of American leaf spot disease caused by the fungus *M. citricolor*, as well as soil erosion and loss of coffee leaves and flowers. However, farmers could not explain the relationship between droplets falling from trees and the increase in the incidence of American leaf spot. A possible explanation could be that falling rain droplets increase the dispersion of *M. citricolor* spores (Avelino *et al.*, 2007); however, many farmers say that the fungus grows in the exact same place where the droplets fall (e.g. no dispersion).

Similar findings were reported in Nepal by Thapa *et al.* (1995) where livestock farmers termed '*tapkan*' the process where water droplets falling from tree leaves had an erosive effect on soil and consequently reduced crop yield. However, Costa Rican farmers were concerned by the effect of rain droplets on incidence and severity of fungal diseases rather than soil erosion. Further, Nepali farmers noted leaf size and texture to be the variables affecting the size of droplets falling from leaves and therefore their erosive effect on soil, whereas Costa Rican farmers mentioned tree height as the main factor affecting this process, and leaf size as a trait of secondary importance.

Fresh and hot trees classification: Farmers were found to classify most tree species either as 'fresh' or 'hot', depending on attributes such as tree crown type and leaf size and texture. It has been reported that Central American coffee farmers often characterize trees as hot or fresh and that this is connected to their effects on coffee plants (Staver *et al.*, 2001). However, it was observed in the present study that the 'freshness and hotness' of trees is related not only to their effect on coffee plants but also on ecosystem services such as water provision and soil formation.

The different classifications farmers use for shade trees were also found to be partially overlapping, particularly the 'hot/fresh', 'good to water' and 'good for soil' classifications (Table 2.4). Water was associated with 'freshness'. Consequently, riparian forests and water sources are 'fresh' places, as are the trees associated with them (trees 'good for water'). Trees whose roots, leaves, stems or fruits are fleshy are 'fresh' trees. Fresh trees are also associated with 'good for soil' trees. Species with soft wood, containing water and capable of rapidly producing biomass after being pruned, are classified among the fresh trees and are also included in the good for soil class. *E. poeppigiana*, the dominant shade specie found in the study area, was classed as a fresh, good for water and good for soil species.

It is interesting to note that the farmers' 'fresh/hot' classification has been found in other locations: for example, Southern (1994, cited by Joshi *et al.*, 2004) found it in Sri Lanka where fresh trees were called '*sitelaiy*' and hot trees '*seraiy*'. Aumeeruddy (1994) reported that agroforestry farmers in Indonesia also use this fresh/hot classification, as it also related to water and soil fertility. Indonesian farmers particularly mentioned two species of *Erythrina* (*E. variegata* and *E. subumbrans*) as 'fresh' trees with fertilising properties. Indonesian farmers also have another classification, dividing plants into 'male' and 'female' according to attributes such as the fruit size, internode length, and leaf pilosity. Generally this classification is for varieties of the same species, where 'male' varieties are bigger than 'female' varieties. However, Costa Rican farmers did not mention this Indonesian classification.

It is necessary to be aware of farmers' knowledge in order to understand the potential barriers to carrying out sustainable practices (Kiptot *et al.*, 2006). Indeed, the knowledge from all relevant stakeholders (from farmers to governmental institutions), as well as the kind of networks among the stakeholders, needs to be taken into account for any management plan for natural resources (Isaac, 2012). Difficulties arise when conflicts or contradictions occur between these sources of knowledge (Walker *et al.*, 2001). Categorizing stakeholders' knowledge as "shared", "contradictory" or "unique" could be a solution to prevent such difficulties, giving local knowledge appropriate weight and value.

AKT as a methodology to analyse local knowledge

The use of AKT methodology overcomes some of the limitations of previous studies by allowing for a systematic evaluation of knowledge from the collection time, thereby decreasing the likelihood of contradictions amongst different sources. The systematic analysis is also useful for exploring the knowledge base in more detail. For example, to find not only the list of desirable and undesirable tree characteristics but also how these attributes are used to classify trees and the relationships among the different tree classes in regards to coffee productivity, ecosystem services and biodiversity conservation. This analysis also allows for a deeper understanding of farmers' perceptions of trade-offs between productivity and service provisions within their farms.

Another advantage of AKT is that all of the knowledge is stored in a computer file, which makes the dissemination of information and results among other users easier (users could include local people, researchers, policymakers, agricultural technicians, students, etc.). To have all of the knowledge compiled systematically and traceably allows for comparisons between other similar studies. The current research file is available for free from the AKT website, and can be viewed in English or Spanish (akt.bangor.ac.uk).

These obvious advantages do not come without some drawbacks, the biggest one being the need for training on the method and tools. Grammar used within the software is complex in order to capture all the local knowledge and not underestimate farmers' understanding. At least two weeks are needed to be train in AKT. Knowledge bases could be developed in any language, but software tools are essentially in English, which could be a limitation in non-English speaking areas.

Creating a knowledge base involves a significant investment of time, particularly when many people have to be interviewed. Elucidating contradictions also means more interviews. The recording of and subsequent listening to the interviews needed for an accurate generation of the unitary statements from the dialogues also requires time. Finally, the building of the database on the basis of formal terms and grammar requires large amounts of initial input before being able to produce useful analysis. The final product therefore should be a resource that is suitable for many purposes; however, time availability should be considered if the whole methodology is to be applied.

CONCLUSION

Costa Rican coffee farmers have a wealth of experience in coffee cultivation. They know which factors affect coffee productivity as well as how to increase the provision of ecosystem services within coffee farms. Farmers understand in detail the role of trees in both coffee productivity and provision of other ecosystem services. Frequently they mentioned trade-offs between some ecosystem services provision and productivity. Soil formation and erosion avoidance is perceived synergistically with productivity, while biodiversity conservation the opposite. Much of this local knowledge should be validated. Categorizing knowledge as shared, unique and contradictory is an approach in finding new research opportunities. Shared knowledge could be considered scientifically valid, while unique knowledge could include both true and false findings and should be tested.

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Chapter 3. Farmers' knowledge in coffee plantations of Northern Nicaragua[3]

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Abstract

Agroforestry systems have been recognized as dual productive and conserving land use, and local knowledge has been studied due to its potential for the design of this kind of agroforestry system; however, knowledge is varying according to many factors, such as the degree of farming intensification, the landscape context, and the personal history of each farmer. Little information is published about the knowledge regarding interactions and trade-off among productions, biodiversity conservation and ecosystem services. This research explores farmers' knowledge about coffee productivity and ecosystem services in a relatively new and remote area of Northern Nicaragua. Farmers were shown to have detailed knowledge about the trees, classifications and its attributes, and less knowledge regarding coffee production. Knowledge of trees was coming mainly from their direct observations, whilst the knowledge regarding productivity was received in trainings. These differences in knowledge origin affected the utilisation of knowledge. The effects of shade trees on biophysical conditions and their interactions with coffee productivity were understood, and related with the classification of trees into 'fresh' or 'hot'; this classification was based on tree attributes and it is overlapped with different ecosystem services. However, not only were the considerations for the factors that influenced the coffee productivity taken into account in the selection and management of shade trees by the farmers in the area, but also the provision of goods for the needs of the family.

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Keywords: Tree functional traits, Shade-grown coffee, Central America, AKT software

1. Introduction

The value of agricultural land for the provision of ecosystem services and biodiversity conservation has been emphasized recently (FAO, 2007). Agro-ecosystems under certain management and in specific locations are providing important goods and services that contribute to human wellbeing, economic development and poverty alleviation across the globe. Efficient and effective management of these agro-ecosystems can sustain the provision of vital ecosystem services such as climate stabilization, drinking water supply, flood alleviation, crop pollination, recreation opportunities and amenity and cultural assets (Millennium Ecosystem Assessment, 2005)

Agroforestry is proposed as a promising strategy to produce goods and conserve natural resources at the same time and in an efficient way (Perfecto and Vandermeer, 2006). The integration of trees and agricultural crops and/or animals into an agroforestry system has the potential to enhance soil fertility, reduce erosion, improve water quality, enhance biodiversity, increase aesthetics and sequester carbon (Garrity, 2004; Jose, 2009; Nair *et al*., 2009). Nevertheless, agroforestry systems involve complex interactions, and they will succeed in providing balanced ecosystem services if adapted to local conditions. The design of sustainable agroforestry systems will require additional knowledge than the current available; this knowledge must concern the trade-offs between productivity of goods, biodiversity conservation, and other ecosystem services.

Coffee agroforestry systems are widespread in different regions of the world, and therefore constitute a great opportunity to study agroforestry systems and their possible contribution to global goals. Farmers' knowledge on coffee agroforestry systems has been reported mainly in specific services, such as soil formation (Grossman, 2003) or biodiversity conservation (Soto-Pinto *et al*., 2007; López del Toro *et al.*, 2009), but little on trade-offs between coffee productivity and the provision of other ecosystem services (Cerdán *et al.*, 2012). These trade-offs among coffee profitability, ecosystem services and biodiversity clearly depend on the specific local conditions (Meylan *et al.*, *in press*).

The few literature regarding trade-offs among coffee production and ecosystem services has been produced in highly input intensive coffee countries (such as Costa Rica). There is a lack of information in less intensive coffee countries with more diversified tree cover shading coffee. The objective of this study was to capture coffee farmers' knowledge about the trees present on their farms, the ecosystem services they provide, and the trade-offs involving them in a remote coffee growing area of Nicaragua, buffering a biological reserve, where coffee is the main income for the families, but the management is heterogeneous in intensity. AKT methodology was used in order to have an explicit and accessible record of the knowledge that can be used later to help in decision making. We expected that this knowledge would be useful in the design of balanced environmental and productive coffee agroforestry systems.

2. Methodology

2.1. Study area

The research was carried out in Northern Nicaragua, in El Cua Municipality, at the frontier between the departments of Jinotega and Matagalpa, in the coffee producing villages around the Macizo Peñas Blancas Biological Reserve (Longitudes 85° 37" and 85° 44" W, and Latitudes 13° 15" and 13° 24" N). Villages throughout the study area were generally similar in cultural aspects such as: language, social organisation and livelihood strategies. Most of the coffee farms in the region were located in villages along the dirt road bordering the Macizo Peñas Blancas reserve,. Eight of these villages were selected for the present research to span the geographical extent of coffee growing in the municipality, taking into account the altitudinal range over which coffee was grown (principally 600-900 m but some < 600 m): La Chata, El Cuá, Los Andes, Colonía Agrícola, Divisiones del Cuá, Santa Rosa, Pavona Central and Peñas Blancas (Figure 3.1).

Rainfall averaged 1858 mm per annum (1982–2012) at El Cua, with a dry season from December to mid-May while mean monthly temperatures ranged between 19 °C and 24 °C, with an annual average of 21.6 °C (Figure 3.2). The dominant soils of the study area have been classified as Altisols, Ultisols and Molisols. These are moderately good agricultural soils with near-neutral to acid pH.

The population of the Municipality stood at 44,831 based on the 2005 housing and population estimation with an annual growth rate of 2.6 %. 92% of the population lives in the rural settlements whilst 8% lives in the urban area (El Cua Municipality, 2005). El Cua Municipality staff estimated the total population of all eight villages to lie between 6000 and 7000 persons. Technicians working in local development projects estimated that there were around 350 coffee growers in all eight villages.

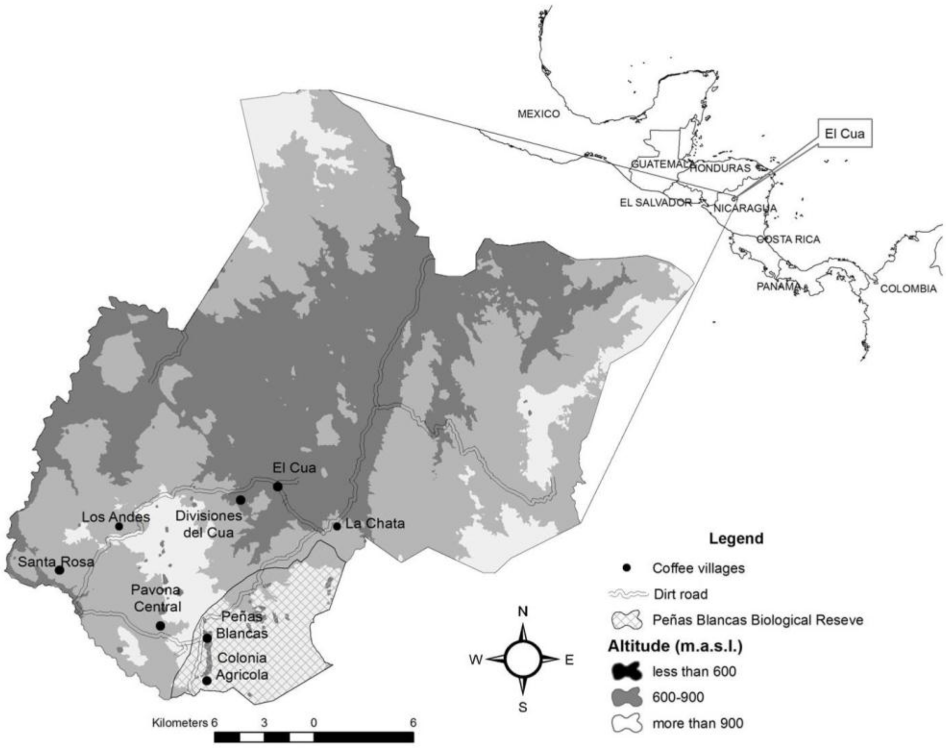


Figure 3.1. Location of the eight coffee villages sampled within the Nicaraguan study area

Coffee farms in the municipality were relatively homogeneous in natural and socioeconomic conditions. In addition to coffee, farmers also cultivated maize and beans for home consumption, bananas and very occasionally cocoa, citrus fruits and malanga (*Xanthosoma* spp.) for sale. Almost all the farmers had small land holdings, with a mean of 7.4 ha (65% with less than 7 ha, and 33% with less 3.5 ha). Most farmers were recent migrants, having established their farms within the last 20 years (75 % of the farms were established since 1990); however there were some large coffee estates inside the nucleus of the Biological Reserve, at higher altitude. Outside the larger plantations coffee was often grown in association with *Musa* spp. as a cash crop, under shade of *Inga* spp. and other tree species.

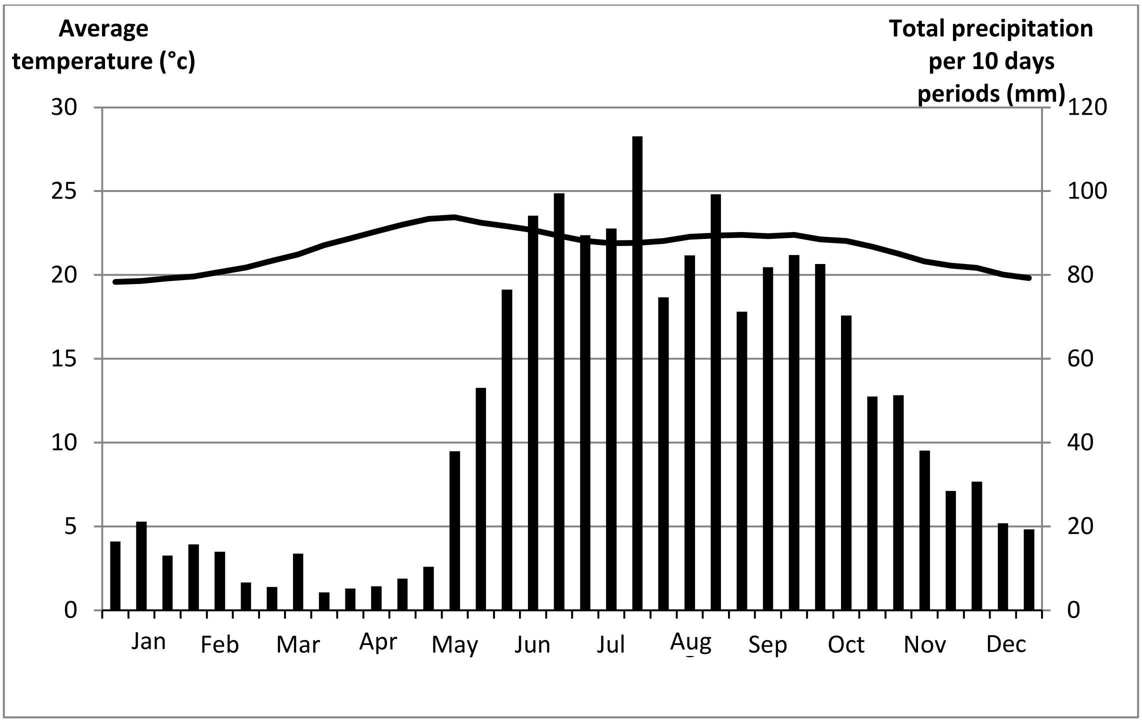


Figure 3.2. Thirty year average of total precipitation in 10 days periods and mean daily temperatures measured at El Cua, Nicaragua from 1982-2012

Coffee farms in the municipality were relatively homogeneous in natural and socioeconomic conditions. In addition to coffee, farmers also cultivated maize and beans for home consumption, bananas and very occasionally cocoa, citrus fruits and malanga (*Xanthosoma* spp.) for sale. Almost all the farmers had small land holdings, with a mean of 7.4 ha (65% with less than 7 ha, and 33% with less 3.5 ha). Most farmers were recent migrants, having established their farms within the last 20 years (75 % of the farms were established since 1990); however there were some large coffee estates inside the nucleus of the Biological Reserve, at higher altitude. Outside the larger plantations coffee was often grown in association with *Musa* spp. as a cash crop, under shade of *Inga* spp. and other tree species.

2.2. Local knowledge collection and analysis

Local knowledge was acquired using knowledge-based systems methodology and software (Sinclair and Walker 1998). This methodology involves a series of iterative cycles of eliciting knowledge from a small purposive sample of farmers, through semi-structured interview, and then representation and evaluation of the knowledge obtained using an explicit knowledge-based systems approach. The knowledge base remains a durable and accessible record of the knowledge acquired and is subjected to validation in a generalisation phase where a questionnaire instrument is used with a large random sample of informants to explore the occurrence of knowledge amongst people within the community (Walker and Sinclair, 1998).

Prior to compiling knowledge bases, a short scoping study with key informants was completed in order to refine the objectives of knowledge acquisition. Meetings were held with seven coffee extension staff and eight farmers. Local coffee technicians, knowledgeable about farmers and farms, explained the variation in management intensity within the research area that varied from low intensity diversified farms thought to be providers of environmental services to the high intensity but less diverse farms where coffee production was the overriding goal.

A stratification of farmers, based on the intensity of management of coffee was constructed in discussion with coffee extension staff. Coffee farmers in the area were classified into three groups: a) farmers who applied coffee management practices for high coffee productivity labelled intensive coffee producers, b) farmers who does not managed coffee practices, and supossedly have more complex and diversified tree cover, labelled as environmental service providers, and c) farmers who applied some coffee management practices and have an intermediate complexed tree cover in their plantations, labelled as balanced farmers (Figure 3.3). Coffee technicians suggested the coffee farmers in each group to be interviewed. Most coffee farmers in the area were men and gender was not used as a stratification criterion since we were not pursuing hypotheses related to differences in knowledge by gender (there was one woman in the sample of farmers interviewed). The age of informants was recorded and most (13) were between 35 and 60 years old with four younger than this and three older.

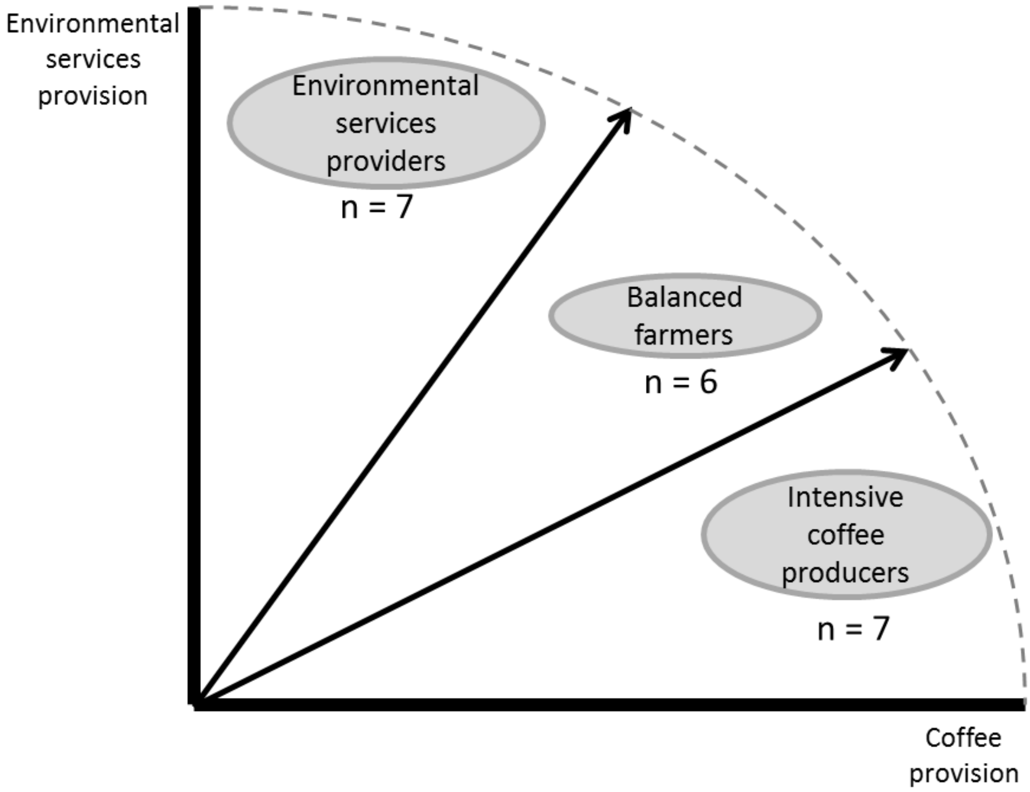


Figure 3.3. Framework for stratification of farm management intensity and environmental service provision within the study area according to local extension staff, and the number of farmers interviewed from each group

Interviews comprised four sections. The first focused on farm characteristics, coffee management calendar, soil conservation practices, water conservation practices and reasons for doing management activities. The second section focused on trees: shade canopy management, usefulness of trees, tree attributes and classifications; and what mammals and birds were associated with trees. The third section focused on the positive and negative impacts on ecosystem services of the trees mentioned previously. The fourth and last section focused on the trade-offs among ecosystem services and coffee productivity.

A set of 47 interviews were held with 20 farmers in an iterative cycle of interview, representation, evaluation and then further interviews as required to clarify or probe more deeply. The interview cycle continued until further interviews did not result in a change in the knowledge representation, with 13 farmers interviewed twice, eight three times, five four times and one five times. Interviews were a combination of semi-structured (Pretty, 1995) and depth interviews (Laws *et al.*, 2003) that probed farmers' knowledge about topics indicated above. Each interview lasted no more than 90 minutes, unless the farmer was keen to continue. Interviews were always initiated with a full description of the purpose of the research. Interviews were held in the farmer's coffee farm, where possible, so that farmers' explanations were articulated in context, and farmers were able to support their assertions with examples from the surrounding environment. Non-leading questions were used to elicit farmers' knowledge without influencing their answers. Care was taken to ensure that farmers felt comfortable during interviews and focused on the topics that farmers were knowledgeable about.

Local knowledge was recorded using the AKT software system (Dixon *et al*. 2001) that involved disaggregation of knowledge into sets of unitary statements represented using a formal grammar (Walker and Sinclair 1998), with associated contextual information about the definition and taxonomy of terms (Sinclair and Walker 1998). The knowledge was evaluated for coherence and consistency as it was collected, using a suite of automated reasoning tools and a diagrammatic interface to explore connections among statements (Walker *et al*., 1997).

Notes were taken during interviews and a digital recording was made with permission from the interviewee, to facilitate representation. During knowledge acquisition, farmers were asked how they came to know the items of knowledge that they articulated.

This information was used to classify unitary statements as being either observed (directly observed by the informant), perceived (believed to be true, often from self-evident reasoning, but had not been directly observed), or received (contributed to the informant from another source, such as a person, book, radio or other media but not corroborated by direct observation).

2.3. Measurements in coffee plots

A 20 m x 50 m quadrat was randomly located in the coffee farm of each sampled farmer who was interviewed. Every tree >10 cm diameter at breast height (DBH) within the quadrat was identified and their height and DBH were measured. For the purposes of the present study all plants described as trees by farmers were inventoried which included shrubs, bamboo and palms. Information about species uses and their common names were supplied by the farmer, who was present during the inventory. Frequency, density and dominance were calculated for each species; the Shannon-Wiener index for each plot was calculated using natural logarithms. The shade percentage in each quadrat was estimated as the mean of five spherical densiometer measurements at random co-ordinates within the quadrat (Lemmon, 1957). Soil cover was assessed using "shoe tip monitoring of ground cover type" at 200 points per quadrat (Staver, 1999). Coffee productivity was assessed on a sample of 25 plants per quadrat, and then the mean was multiplied by the number of coffee plants within the whole quadrat and divided by area. For each plant, the number of productive shoots were counted (*S*), followed by the number of coffee berries on the two lowest and two uppermost productive shoots from which a mean number of berries per shoot (*B*) was calculated. A standard mass for a coffee berry (*M*) found in the literature (Ramirez *et al.*, 2002) was then used to estimate production per plant (*P*) by multiplying *B*, *S* and *M*.

3. Results

3.1. Measured tree diversity, coffee productivity and environmental services

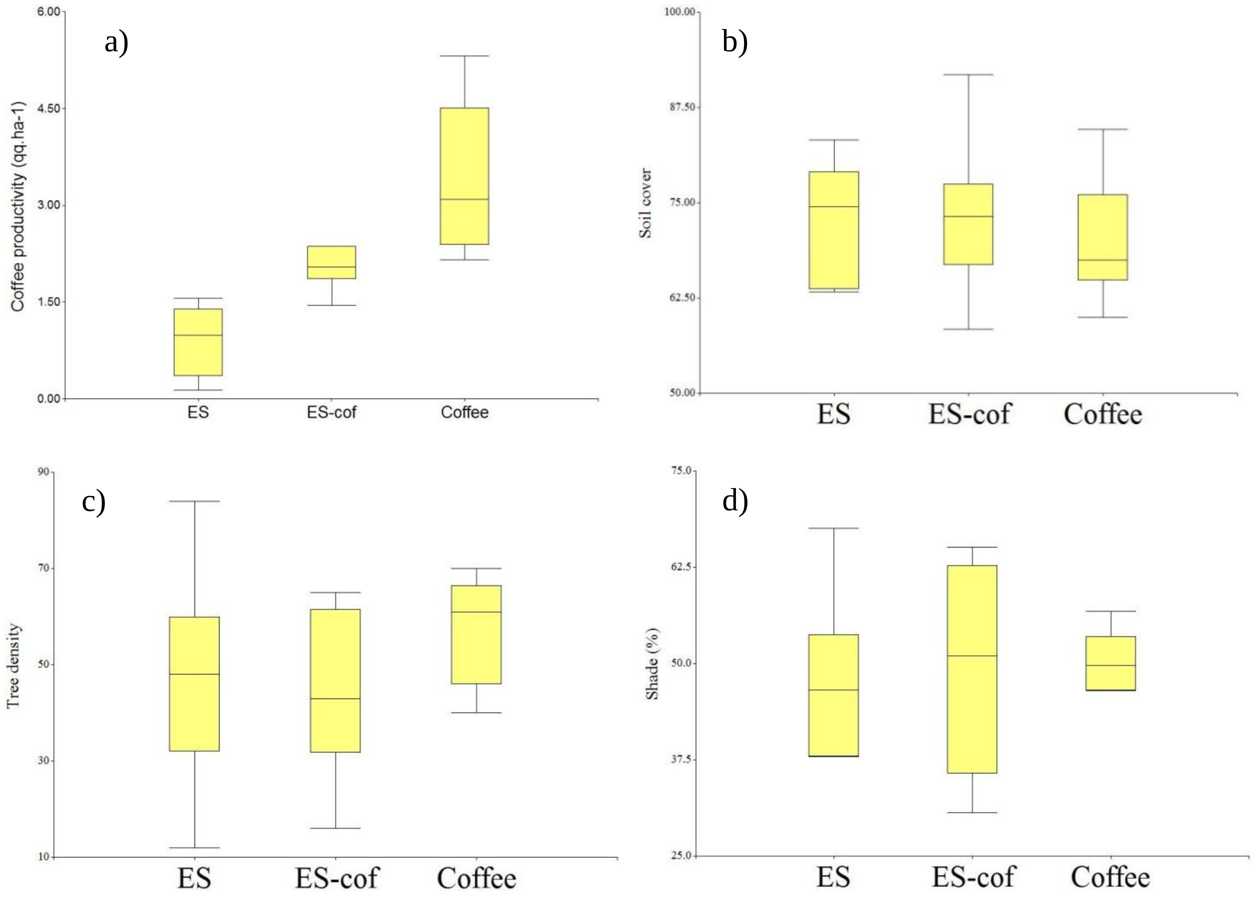
By far the most common tree species within farmers' coffee plots were two Musaceae (guineo blanco and plátano) and *Inga oerstediana* (Table 3.1). Most of the commonly encountered tree species had utilities other than as shade for coffee. Farmers did not mention during interviews 19 out of the 45 tree species encountered on their coffee plots during the inventory, plus five species that were not possible to identify botanically.

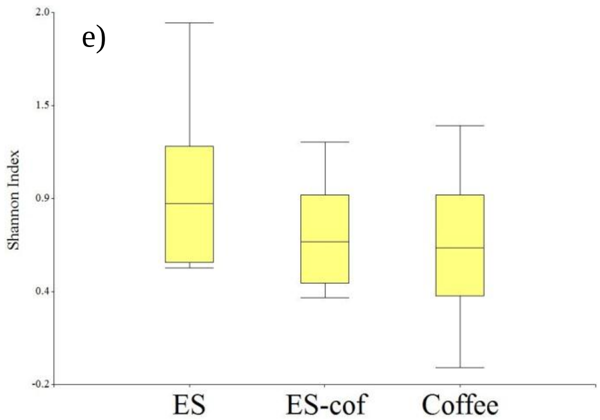
The stratification of farms proposed by the extension staff was consistent with estimated coffee productivity in that intensive farms had significantly higher productivity than environmental service providers but there were no significant differences in indicators of environmental services amongst the strata of farmers (Figure 3.4).

Table 3.1. Frequency, density and utilization of tree species in 20 coffee plots within the study area

Scientific name	Local name	Frequency (% plots where sp. was found)	Density (individuals per ha)	Farmers' use or reason to have it
Musa spp.	Guineo blanco	95	357	Fruits selling to national market
Inga oerstediana	Guaba roja	80	41.5	Firewood, ease of pruning
Musa paradisiaca	Plátano	35	24.5	Fruits selling to national market
Cordia alliodora	Laurel	25	6	Timber, natural regeneration
Juglans olanchana	Nogal	20	4	Timber
Inga punctata	Guaba negra	20	3.5	Firewood
Theobroma cacao	Cacao	15	8.5	Fruits selling locally
Persea americana	Aguacate	15	3.5	Fruits consumption
Citrus sinensis	Naranja	15	3.5	Fruits selling locally
Erythrina berteroana	Helequeme	15	2.5	Pruning easiness
Mangifera indica L.	Mango	15	1.5	Fruits consumption
Musa spp.	Guineo datil	10	39	Fruits selling locally
Ceiba pentandra	Ceiba	10	2	
Cedrela odorata	Cedro real	10	1	Timber
Terminalia lucida	Guayabo	10	1	Timber and firewood
Pouteria sapota	Sapote	5	2.5	*
Acacia angustissima,	Acacia	5	2	
Lippia myriocephala	Mampaz	5	1.5	*
Erythrina fusca	Bucaro	5	1	Pruning easiness
Cinnamomum costaricanum	Aguacate canelo	5	1	*
Carapa guianensis	Cedro macho	5	0.5	Timber
Albizia adinocephala	Chaperno	5	0.5	Firewood
Pentaclethra macroloba	Gavilan	5	0.5	Timber
Cecropia obtusifolia	Guarumo	5	0.5	Temporal shade
Dalbergia tucurensis	Granadillo	5	0.5	Timber
Lysiloma divaricatum	Quebracho	5	0.5	
Citrus aurantifolia	Lima-limón	5	0.5	Fruits consumption
Gliricidia sepium	Madero negro	5	0.5	
Pterocarpus rohrii	Sangregado	5	0.5	
Bambusa arundinacea	Bambú verde	5	0.5	*
Theobroma grandiflorum	Cacao blanco	5	0.5	*
Chrysophyllum oliviforme	Caimito montés	5	0.5	*
Annona muricata	Guanabana	5	0.5	*
Alibertia edulis	Guayabillo	5	0.5	*
Ficus carica	Higuera	5	0.5	*
Bauhinia divaricata L.	Pata de cabra	5	0.5	*
Sapindus saponaria L.	Patacón	5	0.5	*
Syzygium malaccense	Pera de agua	5	0.5	*
Ocotea spp.	Posan	5	0.5	*
Pouteria fossicola	Sapote de monte	5	0.5	*
A Species unidentified		5	1.5	*
B Species unidentified		5	1	*
C Species unidentified		5	1	*
D Species unidentified		5	0.5	*
E Species unidentified		5	0.5	*

Density of trees per hectare was calculated over the whole sample of plots
* Tree species found in the plots that were not mentioned by coffee farmers during interviews.





f) median values and their statistical significance

	ES	ES-cof	Coffee
Coffee productivity*	1.04 a	2.22 a, b	4.10 b
Soil cover (%)	70.67 a	74.88 a	70.68 a
Shade cover (%)	49.72 a	52.35 a	50.82 a
Density of trees	48.14 a	48.17 a	60.29 a

Figure 3.4. Productive and environmental services indicators of the sampled farms according to their management stratification by extension staff

a) coffee productivity in q ha^{-1}, b) percentage of soil covered, c) tree density ha^{-1}, d) percentage of shade, e) Shannon Index of tree diversity. Median values in the table with the same letters are not significantly different –LSD test at $p < 0.05$–). **Codes: ES:** Environmental services providers; **ES-cof:** Balanced farmers; **Coffee:** Intensive coffee producers.

3.2. The electronic knowledge base

The knowledge base comprised 685 unitary statements from 20 farmers of which more than two-thirds described causal relationships (Table 3.2), indicating that mainly explanatory knowledge was contributed by farmers. There were 28 'object hierarchies' that farmers used to classify tree and animal species according to their agro-ecological attributes and associated functions that farmers recognised for each taxon (e.g., 'Trees that assist soil formation').

Table 3.2. Contents of the knowledge base

Formal terms	390
Unitary statements	685 (100%)
Causal statements	466 (68%)
Attribute-value statements	106 (15%)
Link statements	94 (14%)
Comparative statements	19 (3%)
Object hierarchies	28
Sources	20
• Number of unitary statements including those derived using hierarchies	6928

Note: Object hierarchies are sets of formal terms with the same properties and characteristics

3.3. Origin of farmers' knowledge

The vast majority of unitary statements (93%) represented knowledge that farmers had directly observed but there were 28 statements that were perceived and 37 that were received (Table 3.3). Some perceived and received statements comprised key information likely to influence management decisions. Most of the received statements were derived from interaction with extension staff or from participation in training events. Received knowledge sometimes consisted of isolated information that could not always be coherently explained by farmers or fully integrated with their observed knowledge. For example, one farmer said that glyphosate had less negative effects on soil microorganisms than other herbicides, but he could not substantiate the statement any further. Nearly all the statements about soil microrganisms were received (seven out of eight) and the one that was observed comprised understanding how moisture affected a fungus that farmers themselves observed after having been shown the organism during farmer training. Biological nitrogen fixation was another example of received knowledge. Farmers had learnt from extension staff to associate nitrogen fixation with attributes of the *Inga* genus (pod-shaped fruits and root nodules) and they were then able to observe effects that they attributed to nitrogen fixation in other species such as *Prosopis juliflora* themselves.

Table 3.3. Examples of mentioned statements	Origin and number of farmers mentions
Application of herbicides destroys soil microorganisms.	Received / 3 farmers
Nitrogen fixation increases soil fertility.	Received / 6 farmers
The absence of trees around water sources causes deeper water infiltration, which diminishes water availability on the farm.	Perceived / 3 farmers
Cutting trees up in the mountain affects the temperature in low lands.	Perceived / 3 farmers
Roots of weeds modify soil structure.	Observed / 4 farmers
Litter from falling leaves increases soil fertility.	Observed / 8 farmers

3.4. Local classifications of trees and their attributes

Farmers contributed knowledge about 69 tree species (Table 3.4). This included not only species integrated within coffee plots, but also those that farmers were familiar with from other farm and landscape niches, including the nearby forest. These trees were used for multiple purposes including fencing, timber, fruit important for the family diet and medicine. The species were classified by farmers according both to these utilities and in terms of how they interact with the environment.

There was a pragmatic classification of the suitability of trees for intercropping with coffee, with trees either ‘unsuitable’, ‘intermediate’ or ‘suitable’ depending on their impact on coffee and ease of management, which farmers traded-off against productive benefits from the trees. The eleven trees that farmers classified as suitable were said to provide good shade for coffee and were deemed the most appropriate to intercrop in coffee plots. Farmers on the one hand, favoured tree species that readily regenerated in plots and did not require management attention while on the other hand considered planted species with low survival rates less suitable for intercropping. Trees classified as intermediate or unsuitable were still found in coffee plots because their usefulness outweighed their negative impact on coffee (e.g., fruit production from avocado or *Citrus* spp. like lemon or orange, often outweighed their competitive effects on coffee). Negative impacts of trees included hosting coffee pests, for example *Andira inermis* was thought to increase the presence of coffee borer (*Hypothenemus hampei*) but was valued for protecting streams and timber production.

Table 3.4. Attributes and classifications of all tree species mentioned during the interviews

Last column shows the trees species that were also mentioned in Costa Rica (Cerdán *et al*., 2012). Grey cells show the differences between Costa Rica and Nicaragua.

Tree species		**Tree attributes**								**Local functional classifications**						**Costa Rica**
Scientific name	**Local name**	Height	Woody growth rate	Ease of pruning	Leaf size	Leaf texture	Root texture	Root depth	Root abundance	Fresh/ hot	Intercrop suitability	Impact on soil fertility	Impact on soil erosion	Impact on soil moisture	Protec-tion of streams	
Erythrina berteroana	***Helequeme***	High	Fast	Medium	Big	Very soft	Soft	n.d.	Abundant	Fresh	Good	Good	Good	Good	Good	
Erythrina fusca	***Bucaro***	High	Fast	Easy	Big	Very soft	Soft	n.d.	Abundant	Fresh	Good	Good	Good	Medium	Good	
***Inga* vera**	***Guabilla***	Interme.	Fast	Easy	Medium	Soft	Soft	n.d.	Abundant	Fresh	Good	Good	Good	Medium	Good	X
				Medium												
Inga sapintoides	***Guaba blanca***	Interme.	Medium	Easy	Medium	Soft	Soft	n.d.	Abundant	Fresh	Good	Good	Good	Medium	Good	
Inga oerstediana	***Guaba colorada***	Interme.	Medium	Easy	Big	Soft	Soft	n.d.	Abundant	Fresh	Good	Good	Medium	Medium	Good	
Inga nobilis	***Guaba negra***	Interme.	Medium	Easy	Medium	Soft	Soft	n.d.	Abundant	Fresh	Good	Good	Medium	Medium	Good	
Cordia collococca	***Muñeco***	Interme.	Medium	Not pruned	Big	Hard	n.d.	n.d.	Medium	Fresh	Good	Good	Medium	Medium	Good	
Gliricidia sepium	***Madero negro***	Short	Fast	Medium	Medium	Soft	Soft	n.d.	Abundant	Fresh	Good	Good	Medium	Medium	n.d.	X
															Good	
Ricinus communis	***Higuerilla***	Short	Fast	Not pruned	Big	Soft	Soft	n.d.	n.d.	Fresh	Good	Good	n.d.	Medium	n.d.	X
				Easy	Very big										Good	
Solanum bansii	***Cuernavaco***	Interme.	Fast	Easy	Medium	Soft	Soft	n.d.	Abundant	Fresh	Good	Good	Good.	n.d.	n.d.	
***Ficus* spp.**	***Chilamate***	Interme.	Fast	Not pruned	Medium	Medium	Soft	n.d.	n.d.	Fresh	Medium	Good	Good	Good	Good	X
				Medium								Medium				
Ceiba pentandra	***Ceibo***	High	Slow	Not pruned	Small	Medium	Soft	n.d.	n.d.	Fresh	Medium	Good	Medium	Medium	Good	
Inga jinicuil	***Guaba cuajinicuil***	Interme	Medium	Easy	Medium	Medium	Soft	n.d.	Abundant	Fresh	Medium	Medium	Medium	n.d.	Mediu m	

Table 3.4. Attributes and classifications of all tree species mentioned during the interviews. (cont.)

Tree species		Tree attributes								Local functional classifications						Costa Rica
Scientific name	**Local name**	Height	Woody growth rate	Ease of pruning	Leaf size	Leaf texture	Root texture	Root depth	Root abundance	Fresh/ hot	Intercrop suitability	Impact on soil fertility	Impact on soil erosion	Impact on soil moisture	Protec-tion of streams	
Inga punctata	***Guaba cuajilote***	Interme.	Medium	Easy	Medium	Medium	Soft	n.d.	Abundant	Fresh	Medium	Medium	Medium	n.d.	Mediu m	
***Musa* spp.**	***Banano***	Short	Fast	Easy	Big	Soft	Soft	n.d.	n.d.	Fresh	Medium	Good	Medium	Good	n.d.	X
					Very big				Abundant						Good	
Cecropia obstusifolia	***Guarumo***	High	Fast	Not pruned	Very big	Soft	Soft	n.d.	n.d.	Fresh	Medium	Good	n.d.	Good	n.d.	X
				Medium											Good	
Leucaena magnifica	***Vaina de casio***	Short	Fast	Easy	Small	Soft	Soft	n.d.	Abundant	Fresh	Medium	Good	Medium	n.d.	n.d.	
Andira inermis	***Almendro***	Interme.	Slow	Not pruned	Big	Medium	Soft	n.d.	Abundant	Fresh	Bad	Medium	Medium	Good	Good	
Mangifera indica	***Mango***	Interme.	Fast	Medium	Medium	Medium	n.d.	n.d.	Medium	Fresh	Bad	Good	Good	Medium	Good	X
								Medium								
Rhizophora mangle	***Mangle***	Interme.	Medium	Not pruned	Medium	Medium	Soft	n.d.	n.d.	Fresh	n.d.	Good	n.d.	n.d.	Good	
Leucaena salvadorensis	***Leucaena***	Short	Fast	Medium	Small	Soft	Soft	n.d.	n.d.	Fresh	n.d.	Good	n.d.	n.d.	n.d.	
Carapa guianensis	***Cedro cocula***	High	Medium	Easy	Big	Medium	Soft	n.d.	n.d.	Medium	Good	Medium	n.d.	Good	n.d.	
Persea americana	***Aguacate***	Interme.	Fast	Medium	Medium	Medium	n.d.	Deep	Medium	Medium	Medium	Medium	Medium	Medium	Good	X
							Medium	Medium		Fresh		Good				
***Ficus* spp.**	***Matapalo***	High	Fast	Difficult	Medium	Medium	Hard	n.d.	n.d.	Medium	n.d.	Medium	n.d.	Medium	Good	X
			Medium							Fresh		Good				
Melicoccus bijugatus	***Mamón chino***	High	Slow	Not pruned	Medium	Medium	n.d.	n.d.	Medium	Medium	n.d.	Medium	n.d.	Medium	Good	
Moringa oleifera	***Marango***	Interme.	Fast	Not pruned	Small	Soft	n.d.	Deep	n.d.	Medium	n.d.	Medium	n.d.	Medium	Good	

Table 3.4. Attributes and classifications of all tree species mentioned during the interviews. (cont.)

Tree species		Tree attributes								Local functional classifications						Costa Rica
Scientific name	**Local name**	Height	Woody growth rate	Ease of pruning	Leaf size	Leaf texture	Root texture	Root depth	Root abundance	Fresh/ hot	Intercrop suitability	Impact on soil fertility	Impact on soil erosion	Impact on soil moisture	Protection of streams	
Cedrela odorata	***Cedro real***	High	Fast	Not pruned	Medium	Medium	n.d.	n.d.	Medium	Medium	n.d.	Medium	n.d.	n.d.	n.d.	X
				Difficult						Hot					Bad	
Prosopis juliflora	***Acacia***	Short	Fast	Not pruned	Medium	Medium	Hard	n.d.	n.d.	Medium	n.d.	Medium	n.d.	Bad	n.d.	
Cinnamomum verum	***Canela***	Interme.	Medium	Not pruned	Medium	Medium	Hard	n.d.	Medium	Medium	n.d.	Medium	n.d.	Bad	n.d.	
Swietenia macrophylla	***Caoba***	High	Slow	Not pruned	Medium	Medium	Hard	n.d.	Medium	Medium	n.d.	Medium	n.d.	Bad	n.d.	
Tamarindus indica	***Comenegro o tamarindo***	Interme.	Medium	Not pruned	Small	Medium	Soft	n.d.	n.d.	Medium	n.d.	Medium	n.d.	n.d.	n.d.	
Platymiscium pinnatum	***Coyote***	Interme.	Slow	Not pruned	Small	Soft	Soft	n.d.	n.d.	Medium	n.d.	n.d.	n.d.	Good	n.d.	
Guazuma ulmifolia	***Guacimo***	Short	Fast	Not pruned	Small	Soft	n.d.	n.d.	Medium	Medium	n.d.	n.d.	n.d.	Good	n.d.	
Calycophyllum candidissimum	***Madroño***	High	Slow	Not pruned	Medium	Soft	n.d.	n.d.	Medium	Medium	n.d.	n.d.	n.d.	Good	n.d.	
Pseudosamanea guachapele	***Gavilán***	High	Medium	Not pruned	Medium	Soft	Soft	n.d.	Abundant	Medium	n.d.	n.d.	Good	Good	Bad	
Bombacopsis quinata	***Pochote***	Interme.	Medium	Not pruned	Small	Medium	n.d.	Deep	n.d.	Medium	n.d.	Bad	Medium	Bad	n.d.	
Theobroma cacao	***Cacao***	Short	Fast	Easy	Big	Medium	n.d.	n.d.	Medium	Medium	Bad	Good	Medium	Good	n.d.	X
							Medium			Fresh					Good	
Lonchocarpus minimiflorus	***Chaperno***	High	Fast	Not pruned	Big	Medium	Soft	n.d.	n.d.	Medium	Bad	Medium	Medium	Good	Good	
Undefined	***Coralito***	Interme.	Medium	Not pruned	Medium	Soft	Soft	n.d.	Abundant	Medium	Bad	Medium	Medium	Good	Good	
Brosimum alicastrum	***Ojoche***	High	Slow	Difficult	Small	Medium	Hard	Superficial	n.d.	Medium	Bad	n.d.	Medium	Good	Good	

Table 3.4. **Attributes and classifications of all tree species mentioned during the interviews. (cont.)**

Tree species		Tree attributes								Local functional classifications						Costa Rica
Scientific name	**Local name**	Height	Woody growth rate	Ease of pruning	Leaf size	Leaf texture	Root texture	Root depth	Root abundance	Fresh/ hot	Intercrop suitability	Impact on soil fertility	Impact on soil erosion	Impact on soil moisture	Protec-tion of streams	
Citrus reticulata	***Mandarina***	Short	Fast	Medium	Small	Medium	n.d.	n.d.	Medium	Medium	Bad	n.d.	Medium	Medium	n.d.	
Undefined	***Guacamaya roja***	Interme.	Slow	Not pruned	Medium	Hard	Medium	n.d.	Medium	Medium	Bad	n.d.	Medium	Medium	Bad	
Citrus aurontifolia	***Limón***	Short	Fast	Medium	Medium	Medium	Hard	n.d.	n.d.	Medium	Bad	Bad	Medium	n.d.	n.d.	X
				Easy						Hot					Medium	
Citrus sinensis	***Naranja***	Short	Fast	Medium	Medium	Medium	Hard	n.d.	n.d.	Medium	Bad	Bad	Medium	n.d.	n.d.	X
				Easy						Hot					Medium	
Undefined	***Guacamaya blanca***	Interme.	Slow	Not pruned	Medium	Hard	Hard	n.d.	n.d.	Medium	Bad	Bad	Medium	Bad	Bad	
Enterolobium cyclocarpum	***Guanacaste***	Interme.	Fast	Not pruned	Medium	Soft	Soft	n.d.	Abundant	Medium	n.d.	Good	Medium	Good	Good	
Bursera simaruba	***Jiñocuao o Indio pelado***	Interme.	Fast	Easy	Small	Soft	n.d.	n.d.	Medium	Medium	n.d.	Good	Medium	Good	n.d.	
Cordia gerascanthus	***Laurel de la India***	High	Medium	Not pruned	Medium	Medium	n.d.	Deep	n.d.	Medium	n.d.	Medium	Medium	Medium	Good	
Trichilia hirta	***Alamo***	Interme.	Medium	Not pruned	Medium	Medium	n.d.	n.d.	Medium	Medium	n.d.	Medium	n.d.	n.d.	n.d.	
Spondias purpurea	***Jocote ciruelo***	Short	Medium	Easy	Big	Medium	Medium	n.d.	Medium	Medium	n.d.	n.d.	n.d.	n.d.	n.d.	
Delonix regia	***Malinche***	Interme.	Fast	Difficult	Medium	Medium	n.d.	n.d.	Medium	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	
Vernonia patens	***Tatascame***	Short	Fast	Not pruned	Medium	Soft	n.d.	n.d.	Medium	n.d.	n.d.	n.d.	Medium	Good	n.d.	
Azadirachta indica	***Nim***	Short	Slow	Easy	Small	Medium	Medium	n.d.	n.d.	n.d.	n.d.	Bad	Medium	n.d.	n.d.	
Ochroma pyramidale	***Guano***	High	Fast	Not pruned	Big	Medium	Hard	n.d.	n.d.	Hot	Medium	Medium	Medium	Bad	Medium	

Table 3.4. Attributes and classifications of all tree species mentioned during the interviews. (cont.)

Tree species		Tree attributes								Local functional classifications						Costa Rica
Scientific name	**Local name**	Height	Woody growth rate	Ease of pruning	Leaf size	Leaf texture	Root texture	Root depth	Root abundance	Fresh/ hot	Intercrop suitability	Impact on soil fertility	Impact on soil erosion	Impact on soil moisture	Protec-tion of streams	
Pinus oocarpa	***Pino***	High	Fast	Not pruned	Small	Hard	Hard	n.d.	n.d.	Hot	Medium	Bad	Bad	Bad	Bad	X
			Slow	Difficult	Medium			Deep								
Undefined	***Acacia Africana***	Interme.	Medium	Not pruned	Medium	Hard	Hard	n.d.	n.d.	Hot	Medium	Bad	Bad	Bad	Bad	
Acosmium panamense	***Granadillo***	High	Slow	Not pruned	Medium	Hard	Hard	n.d.	n.d.	Hot	Medium	Bad	Bad	Bad	Bad	
Juglans olanchana	***Nogal***	High	Fast	Not pruned	Small	Hard	Hard	Superficial	n.d.	Hot	Medium	Bad	n.d.	Bad	Bad	
Undefined	***Capulin***	Interme.	Medium	Not pruned	Medium	Hard	Hard	n.d.	n.d.	Hot	Bad	Medium	n.d.	Bad	n.d.	
Hymenaea courbaril	***Guapinol***	Interme.	Slow	Not pruned	Small	Hard	n.d.	Deep	n.d.	Hot	Bad	Medium	n.d.	Bad	Bad	
Liquidambar styraciflua	***Liquidambar***	High	Fast	Not pruned	Big	Soft	n.d.	Deep	n.d.	Hot	Bad	n.d.	Bad	Bad	n.d.	
Croton draco	***Sangriento o sangredado***	Interme.	Medium	Not pruned	Medium	Hard	Hard	n.d.	n.d.	Hot	Bad	n.d.	Bad	Bad	n.d.	
Tabebuia rosea	***Roble***	High	Medium	Not pruned	Medium	Medium	Hard	n.d.	n.d.	Hot	Bad	Bad	Bad	Bad	n.d.	X
				Difficult		Hard		Deep							Bad	
Cordia alliodora	***Laurel***	High	Fast	Not pruned	Small	Hard	Hard	n.d.	n.d.	Hot	Bad	Bad	Bad	Bad	Bad	X
			Medium	Difficult												
Eucalyptus deglupta	***Eucalipto***	High	Medium	Not pruned	Medium	Hard	Hard	n.d.	n.d.	Hot	Bad	Bad	Bad	Bad	Bad	X
			Slow	Difficult				Deep								
Bactris gasipaes	***Pejibaye***	High	Medium	Not pruned	Medium	Hard	Hard	n.d.	n.d.	Hot	Bad	Bad	Bad	Bad	Bad	X
				Difficult					Abundant							

Table 3.4. **Attributes and classifications of all tree species mentioned during the interviews. (cont.)**

Tree species		Tree attributes								Local functional classifications						Costa Rica
Scientific name	Local name	Height	Woody growth rate	Ease of pruning	Leaf size	Leaf texture	Root texture	Root depth	Root abundance	Fresh/ hot	Intercrop suitability	Impact on soil fertility	Impact on soil erosion	Impact on soil moisture	Protec-tion of streams	
Psidium guajava	***Guayabo***	Short	Medium	Medium	Small	Hard	Hard	n.d.	n.d.	Hot	Bad	Bad	n.d.	Bad	Bad	X
Cocos nucifera	***Coco***	High	Medium	Not pruned	Big	Hard	Hard	n.d.	n.d.	Hot	Bad	Bad	n.d.	Bad	Bad	X
				Difficult	Very big					Medium						
Terminalia oblonga	***Guayabo liso***	High	Slow	Not pruned	Small	Hard	Hard	n.d.	n.d.	Hot	n.d.	Bad	n.d.	Bad	Bad	

Relationships between tree attributes and functional classification schemes

There were six main functional tree classification schemes mentioned by farmers that they associated with combinations of nine tree attributes (Table 3.5).

Table 3.5. Relationships between tree attributes and local classifications of trees

Tree Attributes \ Tree classifications	Fresh or hot	Intercrop suitability	Impact on soil erosion	Impact on soil fertility	Impact on soil moisture	Protection of streams
Height		X				X
Woody growth rate	X	X				
Ease of pruning		X				
Leaf size	X	X	X			X
Leaf texture	X	X		X		
Leaf colour	X	X				
Root texture	X			X	X	
Root depth			X	X	X	X
Root abundance	X		X			

Tree height

Tree height was related to protection of streams and intercropping suitability for coffee. Tall trees with dense canopies (e.g. 'chilamate', an unidentified *Ficus* spp.) were associated with protection of streams. Farmers did not explain this relationship further. Apparently, height was mentioned as an indicator of the disturbance of vegetation around streams: undisturbed areas have tall trees. All the trees reported as protecting streams were tall or intermediate in height (none were short). Regarding suitability for intercropping with coffee, short trees were considered bad shade, impeding air circulation; however, there was no general positive link between tall trees and suitability for intercropping with coffee because this was species management dependent – a tree would have to have other attributes than just being tall to be considered suitable for intercropping with coffee.

Woody growth rate

Woody growth rate relates to overall growth of the tree as reflected in an increase in stem volume contrasting with speed of resprouting and leaf regrowth after pruning. There were 32 tree species that farmers said had a fast woody growth rate, a little over half of these (19) were also suitable or intermediate in terms of intercropping with coffee. None of the 12 tree species with low growth rate were considered suitable to intercrop with coffee. Trees intercropped with coffee are pruned according to the requirements of the coffee which makes a fast growth rate after pruning desirable because shade above coffee plants is easily regulated. Farmers generally associate fast growth rate with suitability for intercropping with coffee. *Inga vera* was mentioned as a fast growing species, and the rest of the *Inga* genus as species with medium growth rate. Species of the *Inga* genus were the most common trees intercropped with coffee.

Ease of pruning

Ease of pruning was an important attribute determining suitability for intercropping with coffee. In general trees that farmers thought were difficult to prune were considered unsuitable for intercropping with coffee. Farmers said that excessive shade, which occurs when trees are not pruned, promoted fungal coffee diseases and reduced light incident on coffee. Only two of the 45 trees that farmers mentioned as suitable for coffee did not respond well to pruning. The first, *Ricinus communis*, is a shrub used as a temporary shade when establishing new coffee plots, while the second, *Cordia collococca*, is a valuable native timber tree that farmers thought did not compete with coffee.

Leaf size, texture and colour

Leaf size was related to intercrop suitability, impact on soil erosion and protection of streams. The link between leaf size and intercrop suitability was unclear. Big leaved trees fell into all three classes of suitability for intercropping with coffee but no small-leaved trees were classified as suitable. In the case of soil erosion control, big leaved trees were always considered good for combating soil erosion because of the area of ground they could cover and protect. Farmers stated that big leaves, combined with the amount of leaves, mean more litter; therefore more soil covered and protected from erosion. Finally, leaf size was linked to protection of streams; however, this relationship was species dependent. Many big leaved species were positively related to protection of streams, the exception was coconut (*Cocos nucifera*).

Leaf texture was one of the most consistently applied attributes used by farmers to classify trees. Soft leaves were said to decompose quickly thereby contributing to soil fertility. No soft leaved trees were considered as having a ‘bad’ impact on soil fertility and only one tree, *Cordia collococca* (‘muñeco’), with hard leaves was classed as good for soil because it did not compete for nutrients with coffee, and, even though the leaves were hard it was recognised as contributing to long term soil fertility. The relationship between the texture of leaves and the suitability for intercropping with coffee reflected that of their impact on soil fertility. There were no trees that were suitable for intercropping that also had hard leaves (with the exception of *C. collococca* as explained above) and, among the 18 species unsuitable for intercropping with coffee, only one was soft leaved, *Liquidambar styraciflua* because it was considered competitive with coffee for nutrients.

Although leaf colour in itself was not said to impact shade quality of coffee, tree leaf colour lightness was an attribute used by few farmers to appraise it at first glance. Farmers stated that leaves of ‘fresh’ trees (see description of the fresh/hot classification below) were a brighter green and looked more flemsy than leaves of hot trees. They also stated that lighter tree leaf colour caused lighter colour of coffee leaves and distinguished healthy and productive coffee plants from non-productive coffee through their leaf colour.

Root abundance, depth and texture

Belowground attributes were less frequently mentioned by farmers than attributes related to aboveground parts of the tree, consistent with farmers being more easily able to observe the canopy and leaves than the roots. Nevertheless, farmers mentioned three root attributes: abundance, depth and texture. These root attributes were used to classify species regarding their impact on soil erosion, fertility and moisture. Additionally, root depth was related to the protection of streams.

The impact on soil erosion was related to root abundance and depth. There were 14 tree species with abundant roots, all classed as good or medium for controlling erosion. Farmers only mentioned the abundance of roots positively: no farmer classified any tree species as having few roots. Root depth was not frequently mentioned and only eight species were classified in this respect, two with superficial roots and six with deep roots. One deep rooted species also had a bad impact on soil erosion, three deep and one superficial rooted species had a medium impact, and the other three species did not have data on their impact on erosion. In spite of this, farmers mentioned frequently that depth of the root as an attribute was related to soil erosion. So farmers were inconsistent in describing general relationships between root depth and soil erosion without being able to specify sufficient species with different rooting depth to substantiate this.

The impact of tree roots on soil fertility was related to both texture and depth. Among the 69 tree species, there were 22 species with “hard” root texture; none of them was reported as having positive impacts on soil fertility. On the other hand, there were 25 tree species with “soft” root texture; and none of them was reported as impacting negatively soil fertility. As for soil erosion, tree root depth was not consistently related to fertility, superficial roots were associated with competitiveness that may sometimes be conflated with impacts on fertility.

Root texture and depth were also related to impacts of trees on soil moisture and frequently linked to protection of streams. There were 22 trees species listed with ‘hard roots’. None of them had a positive impact on soil moisture, and only two (‘matapalo’ - an undefined *Ficus* spp.- and ‘ojoche’ *Brosimum alicastrum*) were considered as good species for stream protection These are big native trees which are naturally found near water sources, so farmers classed them as ‘protecting streams’ in spite of their ‘hard roots’. On the other hand, soft textured roots were related in a positive way to the impact of the tree on soil moisture. There were 26 tree species listed with ‘soft roots’, none of them was classed as bad for soil moisture and only one (gavilán - *Pseudosamanea guachapele*-) was considered as having a negative impact on stream protection, because of its deciduousness

- Fresh and hot trees as umbrella classification

Farmers use an overall classification of trees as either ‘fresh’ with positive impacts on soils and protection of streams and suitable for intercropping with coffee, or ‘hot’ with opposite impacts. All 20 ‘fresh’ trees had a positive impact on soil fertility, and 13 of these were positive in protection of streams. In the case of ‘hot’ trees, 11 out of 17 had negative impact on soil fertility, all 17 were negative for soil moisture, and 11 species were negative for protection of streams. In a few cases, ‘hot’ and ‘fresh’ tree species were classed as having ‘medium’ impact on soils and protection of streams. For instance, guano (*Ochroma pyramidale*) was classed as a ‘hot tree’ but some farmers perceived it as a ‘medium’ tree for protecting streams, ‘medium’ impact on soil fertility, ‘medium’ impact on erosion control, and providing ‘medium’ quality of shade for coffee. Furthermore, vaina de casio (*Leucaena magnifica*) was a ‘fresh tree’ but was only considered a ‘medium’ tree for both protecting streams and suitability for coffee.

Other ‘fresh’ tree exceptions included guaba cuajinicuil (*Inga jinicuil*) and guaba cuajilote (*Inga punctata*) which were regarded as having ‘medium’ value for both coffee suitability and impact on soil in comparison to other species. Consistently, however, there were no ‘hot’ trees considered having ‘good’ impacts or ‘fresh’ trees having ‘bad’ impacts on soil and water (Table 3.4).

Inga spp. were considered by farmers to have the most desirable attributes for growing within coffee plantations. All *Inga* spp. were ‘fresh’ trees, and were kept on farms for various reasons, including impact on soil fertility and avoidance of erosion; they were also stated to require less strenuous management than other shade trees. Four species of *Inga* (*I. vera*, *I. sapintoides, I. nobilis* and *I. oerstediana*) were mentioned as impacting in a ‘good’ way with soils, protecting streams and shading coffee, while two (*I. punctata* and *I. jinicuil*) were ‘medium’ species. The differences between these species were minimal but observable by farmers, one of the differences being the leaf texture of *I. punctata* and *I. jinicuil*; they were said to have leaves not as ‘soft’ as the other four *Inga* species mentioned above. *Inga vera* was the second dominant species, after bananas (*Musa* spp.), and farmers argued that this is because of its easy reproduction and management. Firewood utilization, plus the ease of management, was the major reason why farmers preferred *Inga* instead of *Erythrina* species, even though *Erythrina* was said to be very similar in its interactions with coffee and providing water and soil benefits.

The most abundant tree found within the coffee plantations was a type of banana locally called guineo blanco (*Musa* spp.)[4], classed as a fresh tree and grown primarily for its fruit. Although banana was considered a fresh tree with positive impacts on soil, and medium shade quality for coffee, farmers explicitly mentioned that intercropping bananas with coffee had an adverse effect on coffee growth, despite banana leaves and stem contributing to soil organic matter. This was because of high nutrient competition between banana and coffee plants so that farmers recognised threshold densities of banana above which the competition outweighed the positive contributions to soil. Farmers with a high density of bananas in their coffee fields mentioned that they applied more fertiliser to meet both banana and coffee nutrient requirements. Banana

[4] *Musa* spp. (bananas and plantains) are not botanically classified as trees but they are presented as trees here because this is how farmers classified them.

fruits from the research area were well valued on the national market; banana trees produce fruit throughout the year; the steady and possibly substantial income derived from banana selling were mentioned as reasons for farmers for keeping banana within their coffee plantations.

3.5. Farmers' understanding of soil

While there were individual differences in the complexity of knowledge about soil that farmers articulated; their collective understanding was focused around impacts on soil moisture, erosion and fertility (Figure 3.5). Soil moisture was mentioned in relation to its impact on soil temperature, which in turn affected soil structure.

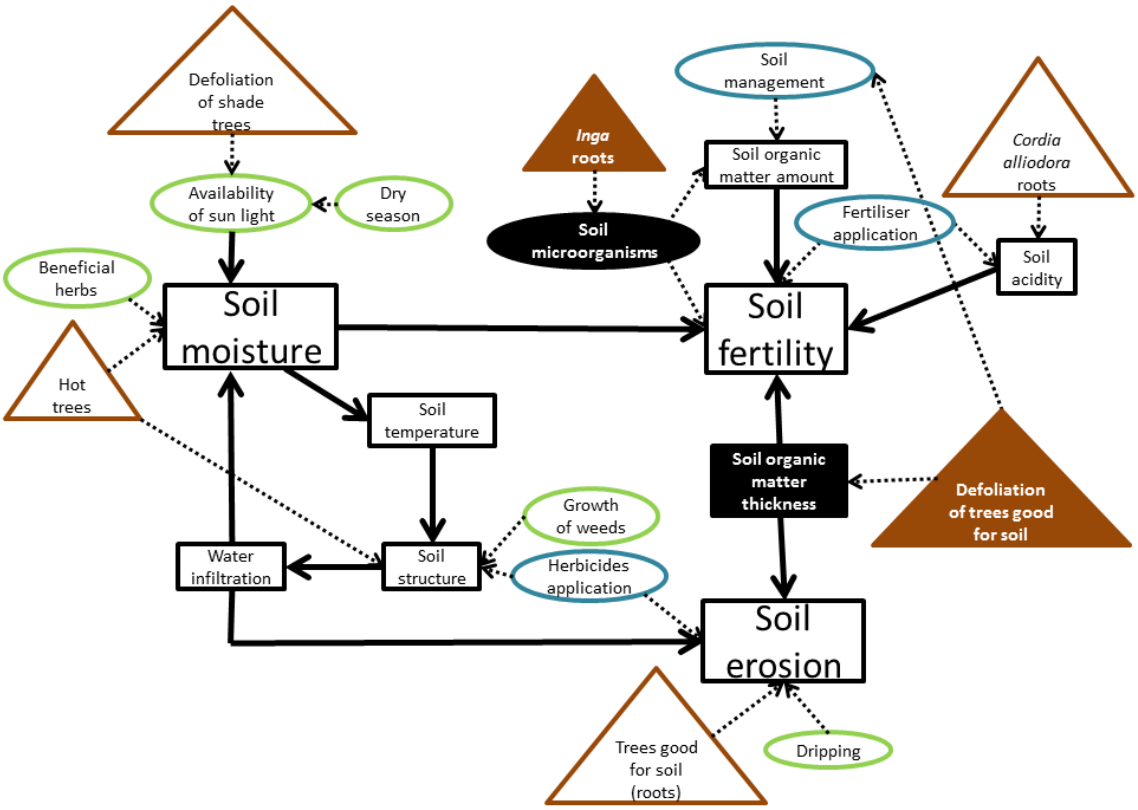


Figure 3.5. Farmers' knowledge about factors related to soil functions
Black square boxes represent the main knowable elements in soils. Green ellipses represent elements or processes related to the environment; blue ellipses represent farmers' practices; brown triangles represent classes or species of trees. Arrows connecting boxes show the direction of the influence. Solid lines show the relationshipss mentioned by five or more farmers, dashed lines by four or less farmers. The distinction between received knowledge is shown with the solid boxes and triangles.

Received knowledge referred mainly to soil organic matter processes, while other knowledge came from farmers' direct observations. One difference between received and observed knowledge was expressed in the relationships between soil organic matter and fertility. Sixteen farmers observed that the litterfall and residues after pruning 'good trees **for soil**' increased the **amount** of soil organic matter, while four farmers only said (because they had learnt that during trainings) that the defoliation of 'good trees **for soil**' produced a thick **layer** of litter. In both cases, leaf texture is considered by farmers as the most valuable characteristic because of its relationship to degradability.

The majority of farmers managed the trees within their coffee plantations in similar ways, keeping a high density of shade trees (average of 524 trees per hectare), with different levels of pruning depending on their perception of the dry season and on the intensification level of coffee production. Pruning residues were recognized as affecting soil fertility and moisture. However, farmers said that the main reasons for pruning trees are related to coffee physiology.

A common native timber tree, *Cordia alliodora*, was the only species with a specific mention by farmers because of its relationships with soil. Farmers mentioned that *C. alliodora* roots cause 'acidity' and negatively affect the fertility of soils. The rest of the relationships between trees and soils were related to tree classes and not to particular species.

Herbicide applications were considered as a factor related to soil erosion and changes in soil structure. It is easier for farmers to appreciate soil erosion in areas with steep slopes (only one farmer interviewed was located in a flat area). Farmers considered that weed roots help to prevent soil erosion. However, the role of weeds in soils was mentioned just by a small proportion of farmers. They said that some weeds are beneficial because they keep soil moisture, improve soil structure and their roots avoide erosion.

Other farming practices mentioned that influence soils are the tree pruning, fertiliser application and 'soil management'. Pruning and 'soil management' are related to soil organic matter. 'Soil management' includes the management of pruning residues or the banana stems. Fertiliser application was related to soil fertility. A new farmers' term appeared: 'soil acidity'. Farmers mentioned that fertiliser application remedied the problems of 'acidity' of the soils. The term 'acidity' was used by farmers as a concept distinct from fertility, however, when farmers were asked about the opposite term of “acid” soils they only mentioned fertile soils.

3.6. Coffee productivity and its relationship with trees

Farmers understood very well the relationship between tree density in coffee plantations, shade and the concomitant reduction of coffee productivity. We used the AKT diagramming tools to synthesize farmer’s knowledge of these relationships (Figure 3.6). The results describe the different pathways through which shade coffee trees affect coffee productivity and detail the tree attributes that may modify these relationships, according to the farmers interviewed.

The first factor influenced by shade trees is the amount of sun radiation coffee plants receive. Farmers said there should be a balance between the availability of sunlight for coffee plants and protection from excessive radiation. Coffee farmers perceived that low sunlight causes a reduction in the number of coffee plant leaves and, consequently, a reduction in energy availability for flowering and fruit formation. Leaves that are less green than normal are an indicator of lack of sunlight for coffee. Good yields could be obtained with low shade level during the dry season, which increase number of coffee plant leaves; and higher shade level during the rainy season, to protect fruits during ripening. The tree attribute that allows this shade plasticity is ease of pruning (which probably encompasses the actual ease, how much effort is required, and the tolerance of trees to frequent pruning).

Coffee farmers have noticed changes in climate, primarily in length of the rainy season. Farmers understand that coffee productivity is directly related to climate where higher temperatures in the region may negatively affect coffee quality and productivity. Eleven farmers mentioned this issue, some of whom stated they are increasing shading rate in order to create appropriate conditions for coffee plant development, especially under current variable and extreme climatic conditions.

Farmers indicated that shade trees also affect the severity of fungal diseases in coffee plantations. Thirteen out of 20 farmers mentioned fungal coffee diseases as a key factor affecting productivity. Three factors were mentioned as the main causes: availability of sunlight, circulation of wind, and air temperature under the shade tree canopy.

Availability of sunlight, as well as circulation of wind, was negatively related with the level of fungal diseases (more sunlight and less wind discourages diseases). These two factors are related to tree attributes such as tree height and ease of pruning. Farmers indicated that the temperature under the canopy is negatively related to fungal diseases, because coffee plants under trees are subjected to lower temperatures and are more vulnerable to fungal diseases. Moreover, five tree species were mentioned by three farmers (from different communities) as alternative hosts of the coffee borer (*Hypothenemus hampei*): 'vaina de casio' (*Leucaena magnifica*), 'comenegro' (*Tamarindus indica*), 'almendro' (*Andira inermis*), 'acacia' (*Prosopis juliflora*) and 'cuernavaco' (*Solanum* spp.). These farmers do not use these tree species for shading coffee in order to not increase the amount of coffee borers.

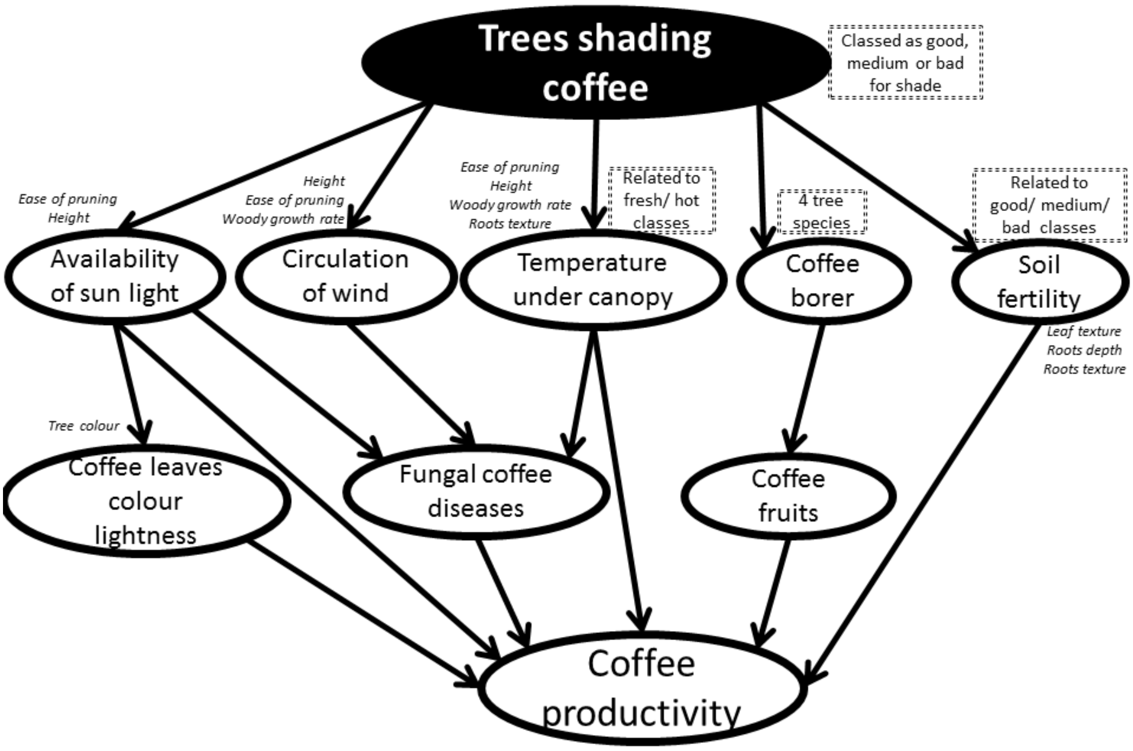


Figure 3.6. Primary shade tree effects on coffee productivity according to farmer knowledge

Soil formation was the factor most frequently mentioned by farmers. Farmers considered soil formation as a link between trees and coffee productivity. Leaf texture, continuous losses of tree leaves, root depth and root texture were the attributes used by farmers to classify trees as having a good, medium or bad impact on soil fertility. Generally soft and short roots are related to increase in soil fertility.

4. Discussion

4.1. Few novel results

Coffee farmers' knowledge research has frequently reported many and novel results regarding the site specific conditions where farmers are growing coffee (e. g. Soto-Pinto *et al*., 2007, Cerdán *et al*., 2012). This was not the case in this study. Even when the number of tree species known by farmers was greater than in other neighbouring coffee country[5], there was minimal detailed knowledge about the environment, coffee, trees and the relationships among these factors. The predominant knowledge essentially focused on soils formation and tree interactions with coffee plants.

Current coffee plots originated from different former land-uses, mainly from pristine forests or secondary forests formed during the Nicaraguan war. These initial conditions of the plots are probably influencing the amount and species composition of trees within the three farmers' groups.

The relative scarcity of insights could be explained by the history of the research area. Coffee cultivation is a new activity for many of the farmers, because during the war of the 1980s, this area was under conflict and few people remained and developed agriculture, consequently this region was protected from environmental degradation (Rice, 1989), and deforestation. Many of the current citizens of the area arrived in the last 20 years, and many of them were not coffee growers before their arrival. The government established new communities of people after the war with peasants from other regions of the country (especially from the lowlands and cities, three farmers interviewed used to live in urban areas). It has been shown that the knowledge retained by farmers is related to the history of the plot cultivation (Anglaaere *et al.*, 2011), and that the number of years of farming experience increases the knowledge (Altieri, 2004; Berkes and Turner, 2006). The scarcity of novel findings on local knowledge is likely related to the short coffee cultivation history of the research area and the personal trajectory of each farmer.

[5] Cerdán *et al*. (2012) reports 36 tree species in Costa Rica

4.2. Shared, unique and contradictory knowledge approach

Cerdán *et al.* (2012) utilised the shared, unique and contradictory knowledge approach developed by Waliszewski *et al.* (2005) with coffee farmers in framing local knowledge. Considering the lack of novelty of the shared and contradictory knowledge, the main 'unique' knowledge is presented in the following sections.

Coffee borer hosted by shade trees

The coffee borer (*H. hampei*) is recognized as the most harmful pest to coffee worldwide (Dufour *et al.*, 1999). There are no reports of the impact of coffee borer damage for the study area, but during the productivity measurement of coffee the pest was found in 15 of 20 plots. Despite farmers were not well acquainted with its management, they mentioned five tree species as hosting coffee borer: 'vaina de casio' (*Leucaena magnifica*), 'comenegro' (*Tamarindus indica*), 'acacia' (*Prosopis juliflora*), 'almendro' (*Andira inermis*) and 'cuernavaco' (*Solanum* spp.).

There is little information about the role of trees hosting coffee borer. Apparently *H. hampei* is a monophagous species, exclusive to fruits of several species of the genus *Coffea* (Hiroshi *et al.*, 2010). It is found in other plants when there are no coffee fruits available, but as a refuge and not as a real host (Johanneson and Mansingh, 1984). Nevertheless, recently it has been reported that coffee borer can colonize and complete its reproductive cycle in a Brazilian nut (*Bertholletia excelsa*) (Gumer-Costa, 2009). Damon (2000) and Waller *et al.*, (2007) presented worldwide reviews of species where coffee borer has been found, and they found, respectively, 38 (herbs, shrubs and trees) and 28 tree species. None of the five species mentioned by the farmers were in these reviews; although there are two species of the genus *Leucaena* in Damon (2000). Both reviews mentioned that the genus *Coffea* is the main host of coffee borer, and they stated that the trees listed were probably exploratory attacks of *H. hampei*. However, they did not discard the possibility of coffee borer hosted by trees, especially leguminous trees.

Excepting *Solanum* spp., the species mentioned by farmers are leguminous, and to the authors' awareness, there is no scientific research on this to confirm this possible hosting role of the four leguminous trees. The hosting role of the *Solanum* spp. has to be double checked: firstly, because it is not a leguminous, and secondly because farmers stated that they observed the coffee borer in the fruits, while, due to the soft fruits characteristics of the Solanaceae family it seems unlike that fruits of this tree species could be attacked by the pest.

The hosting role of these five tree species seems to be a “unique” knowledge detained by farmers. However, it has to be confirmed wheter these alternative hosts are used only when the availability of coffee fruits is low, or permanently through the whole year. If it is proved that these trees are not actual alternate hosts, but only temporary shelters, it would be interesting to understand their role in subsequent infestations of the coffee plots where they are grown. Additionally, it is needed to confirm wheter the coffee borer that farmers observed is, in fact, *H. hampei;* considering that its accurate identification without genetic analyses is complicated even for scientists (Mitchell and Maddox, 2010). Additionally, there are many species of “borers” that farmers would be confounding, especially because farmers that mentioned the five alternative hosts are located in communities were also cocoa is grown, least 34 species of borers have been found in cacao plantations -6 of them of the genus *Hypothenemus*- (Pérez de la Cruz *et al.*, 2009).

4.3. Site specificity of the results

The value of local knowledge in the search of solutions for site-specific problems has been widely accepted (Altieri, 1993). This useful local knowledge is valid only in site specific conditions. There are some characteristics of the area that have to be discussed to understand some of the results, and to avoid erroneous generalisations.

It has been recognized that *Musa* spp. offers stronger competition to coffee than some other shade trees (Beer *et al.*, 1998); nevertheless, intercropping banana in coffee plantations is very common in the area, with a density of more than 420 *Musa* spp. per hectare (considering guineo blanco, platáno and guineo datil together). However, farmers in the area negated this competition stating that both crops are compatible. Coffee plantations in this area are not densely planted (less than 4000 coffee plants per hectare) and exhibit moderate productivity (average coffee yields lower than 14 quintals per hectare); moreover, Musa spp. has a recognized market, is sold throughout the year and is an easy trade for farmers. Van Asten *et al.* (2011) suggested that the banana-coffee intercropping is not leading to significant yield declines of either crop under certain conditions. Farmers observed similar results in this region, but this observation is probably related to the low coffee densities and yields. Coffee yields in the area are more than 35% lower than the national average (MAGFOR, 2012).

4.4. Observed knowledge

The vast majority of the knowledge retained by farmers came from their own observations. The topics on which more knowledge unitary statements were gathered concerned observable aspects of trees and soils (and many interactions between them). Nevertheless, there were some differences among these topics. The knowledge regarding trees was more complex, detailed and articulated, containing details of each species, classes, attributes and the relationships among them; on the other hand, the soil knowledge was comparatively less complex. The differences in the degree of knowledge between soils and trees are probably related to the facility to observe aboveground attributes.

Though farmers' knowledge concerning soils had different origins (mainly observed and received), it was shared and exhibited a large degree of coherency and consistency. As well as recognizing soils with high organic matter, farmers were able to explain the principal causes of fertility decline, the roles of soil organic matter, litter and soil macro-fauna in sustaining soil fertility, similarly to findings reported by Dawoe *et al*. (2012). Farmer knowledge of the biological component of soil was, however, limited to organisms that were visible to the human eye, as Grossman (2003) also found with coffee farmers. Farmers had a confused understanding regarding soil microorganisms; obviously they did not observe microorganisms and sometimes only repeated the knowledge they received in trainings. Despite these confusions, we observed that the received knowledge is considered in farming management decisions. Currently, farmers have a dual knowledge system about their observations, made up of experiences and phenomena that they can visualize and information retained from training workshops.

4.5. Fresh / hot classification of trees

The "fresh / hot" trees classification is widely used by farmers and has been reported in other locations, such as Sri Lanka (Southern 1994, cited by Joshi *et al.*, 2004), Indonesia (Aumeeruddy, 1994), other regions of Nicaragua (Staver *et al.*, 2001), Mexico (Soto-

Pinto *et al.*, 2007) and Costa Rica (Cerdán *et al.*, 2012). The importance of this classification relied on its wide utilisation by farmers. All the previous references pointed out in varying degrees, how the classification is used in farming decisions and primarily in the selection of trees. In spite of its worldwide use by farmers, it seems that technicians, conservationists, scientists and other stakeholders do not frequently take the "fresh / hot" trees classification into account when they interact with farmers.

Many of the species classified as hot by farmers were timber trees. Some of these species have been recommended as a way to obtain additional income through timber harvest if the trees are not decreasing crop yields under certain conditions (Somarriba and Beer, 2011). It is clear that farmers found some hot trees desirable by selling their timber or fruits, and the economic gains outweighed the –many or few– negative effects of the tree species "hotness" affecting the crop yields. However, these widely used farmer classifications are currently not being used in technical recommendations or promotion of species.

The complexity of this classification is a limitation of its utilization. When farmers were asked to better explain the classification system they were unable to further clarify the systems attributes or to give additional examples. In addition, literature reviews were unable to shed further light on the subject, only describing the classification as suitable (fresh) and unsuitable (hot) (Soto-Pinto *et al.*, 2007), how the "hot/fresh" classification overlapped with the tree impacts on soil and water conservation, and how some tree attributes are related to this hot/fresh class (Cerdán *et al*., 2012). There are additional tree attributes that we reported here, as well as the relationship between this classification and others regarding ecosystem services; however additional efforts need to be further defined.

Conclusions

The diversity of tree species used by farmers as shade for coffee is greater than what is found in the majority of coffee plantations of the Costa Rican research area. As another difference, Nicaraguan farmers valued coffee agroforestry systems as important to them to obtain firewood and timber, and fruits in lower degree. Farmers' knowledge regarding the relationships among coffee production, ecosystem services and tree diversity in a new coffee was detailed in trees information and less detailed about coffee. Trees were classified by farmers according to their different attributes, which is consistent with findings in other coffee areas. Farmers' knowledge regarding coffee productions was strongly influenced by trainings and interventions of coffee promoting projects; however this knowledge is sometimes misunderstand or not corroborated by farmers direct observations, decreasing the possible positive impacts of technical assistance.

A combination of the factors that influenced the coffee productivity known by farmers, plus the provision of goods for family needs, were the main considerations in the selection and management of shade trees by farmers in the area. Tree diversity and abundance did not vary among the three groups of farmes. Coffee production, however, was significant different among them. This mean that farmers with low coffee productivity would potentially increase yields with management practices without affect the tree cover.

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Chapter 4. Ecological knowledge and utilisation of biodiversity by Guatemalan coffee farmers[6]

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Abstract

Biodiversity is conserved and ecosystem services are provided not only in protected reserves, but also in agricultural landscapes. Strengthening management of biodiversity and ecosystem services in agricultural landscapes requires as much knowledge as possible, because people inhabitant these landscapes have a great range of conditions and needs. This knowledge includes scientific research results as well as local knowledge derived from people with long traditions of land use and management. Mesoamerican coffee growing landscapes buffering protected reserves are key places to study local knowledge regarding biodiversity conservation and its relations to agricultural production because farmers conditions and needs are changing in relatively small areas. Farmers' knowledge of ecosystem services and biodiversity conservation was studied in a diversified shade coffee area buffering Sierra de las Minas Reserve, the second largest reserve in Guatemala; where farmers are strongly related to forests. The Agroecological Knowledge Toolkit (AKT), an iterative cyclic methodology, was used. The contribution of coffee farmers' knowledge to sustainability management in diverse fields such as biodiversity conservation and ecosystem services maintenance is presented here. Sustainable management consisted predominantly of farmers' detailed classification, selection and management of coffee shade trees. There were 51 tree species within coffee plantations that farmers recognized as supporters for the conservation of faunal species. The role of coffee agroforestry systems in connectivity within a forest-dominated landscape is well understood by farmers. The knowledge regarding trees had also similarities to theory of functional diversity, but with the

[6] Manuscript in preparation to *Biological Conservation*

inclusion of the farmers' overview and needs. For instance, there are clusters of tree attributes related to ecosystem functions. The detailed farmers' knowledge on trees in the study area could be attributed to the range of altitudinal zones in this region. Farmers differentiated the landscape in three different zones, where coffee management differs, especially in relation to its tree cover. Findings regarding biodiversity were novel compared to coffee farmers' knowledge in other Central American countries; however, findings with respect to crop management and its supporting services (soil formation, pest' regulation, pollination, water balance, among others) were not surprisingly novel. It is suggested that results presented would potentially improve natural resources management and planning in similar forest-buffering landscapes.

Keywords: Local knowledge, Shade coffee, biodiversity conservation, functional diversity, ecosystem services

1. Introduction

Coffee is a very important crop in Central America, both economically and culturally. It is mainly grown as an agroforestry system; and these systems have been increasingly viewed as providers of ecosystem services, including environmental benefits (Harvey *et al.*, 2006) and economic commodities, as part of a multifunctional working landscape.

Recently, the important role that coffee agroforestry plays in biodiversity conservation has been well illustrated by various studies, both generally (Perfecto *et al*., 1996) and focusing on different taxa: trees (Correia *et al.*, 2010), epiphytes (Cruz-Angón *et al.*, 2005), birds (Dietsch, 2000), mammals (Gallina *et al.*, 1996), butterflies (Mas and Diestsch, 2003), among many other publications. The role of coffee production areas in conserving biodiversity is important not only because of the spatial extension of coffee plantations (around two million hectares in Mesoamerica) but also because coffee production regions are frequently overlapping with priority areas for biodiversity conservation (Moguel and Toledo, 1999) that have been particularly hard hit by deforestation (Perfecto *et al.*, 1996).

Biodiversity of coffee agroforestry systems depends on two main aspects: the current management of the plantation and the tree cover remnant, when agroforestry systems are originally established in either pristine or secondary forests (Thscharntke *et al.*, 2011). The role of agroforestry systems in biodiversity conservation is well recognized, but there are few reports on the importance of biodiversity for farmers, and consequently if this biodiversity is likely to be retained under farmers' future management.

Local knowledge regarding tree cover in coffee agroforestry systems and its relationships with ecosystem services and coffee management were presented in previous studies (Cerdán *et al.*, 2012). However, this knowledge focused on coffee production and its supporting ecosystem services, such as soil formation in productive areas of Costa Rica and in less productive and relatively isolated areas in Nicaragua. It is still unclear how farmers, the "managers" of biodiversity, perceive the high biodiversity conserved in coffee agroforestry systems.

The objective of this study was to capture coffee farmers' knowledge of tree species present in their landscape, and in particular, the biodiversity that these trees support. This study was conducted near the Sierra de Las Minas Biosphere Reserve in Guatemala in a coffee producing region of high altitudinal range (farms located from 900 up to 1700 m.a.s.l).

2. Methodology

Study area

The El Hato watershed feeds the Motagua River and is located at the southern border of the Sierra de Las Minas Biosphere Reserve (Figure 4.1). This reserve encompasses over 240 000 ha, is the second largest protected area in Guatemala, and is mentioned for its high species diversity: 2000 tree species have been recorded including at least 15 endemic species; around 385 mammals and reptiles species, and more than 400 bird species (MAGA and CONAP, n.d.). El Hato Watershed covers 19,786 hectares, with over 18,000 ha of forest cover. It ranges in altitude from 250 to 2,600 m.a.s.l. from the River Motagua at the bottom of the valley to the Sierra de Las Minas. This range encompasses a great diversity of micro-environments with associated diversity in species (Ellis and Taylor 2007). The total coffee area is estimated at 600 hectares, and is the main economic activity for approximately 200 families that live there (IARNA, 2006). The proximity of the watershed to Sierra de Las Minas, the range of climatic zones present in the area, and the language proximity (all farmers are non-Indigenous and Spanish speakers), were the factors considered in selecting El Hato Watershed as the study area to research farmers' knowledge regarding biodiversity within coffee agroforestry systems. First and second factors because they potentially increase farmers' knowledge on biodiversity, third factor to avoid etnich differences that make difficult to compare the study with other countries.

The high altitudinal range covered by the relatively small watershed implies steep slopes: 50% of the total area has a slope steeper than 40 degrees and 44% of the area has a slope between 28 and 40 degrees (SEGEPLAN, 2001). Meteorological conditions change considerably from the lowest to the highest altitudes. A weather station was established in 1995 in Los Albores, a coffee community in the low altitude growing-coffee zone (1200 m.a.s.l), by the Guatemalan National Institute of Seismology, Volcanology, Meteorology and Hydrology (INSIVUMEH). This station has reported an average rainfall of 1893 mm for the last 15 years, with a concentration of rainfall from May to October (Fig. 4.2). The average annual temperature is 17.8 ºC, with a minimum of 11.2 ºC, and a maximum of 24.1 ºC. The mean rainfall range over the watershed was estimated at 700-3000 mm, and the mean annual temperature varies between 13 and 32 °C.

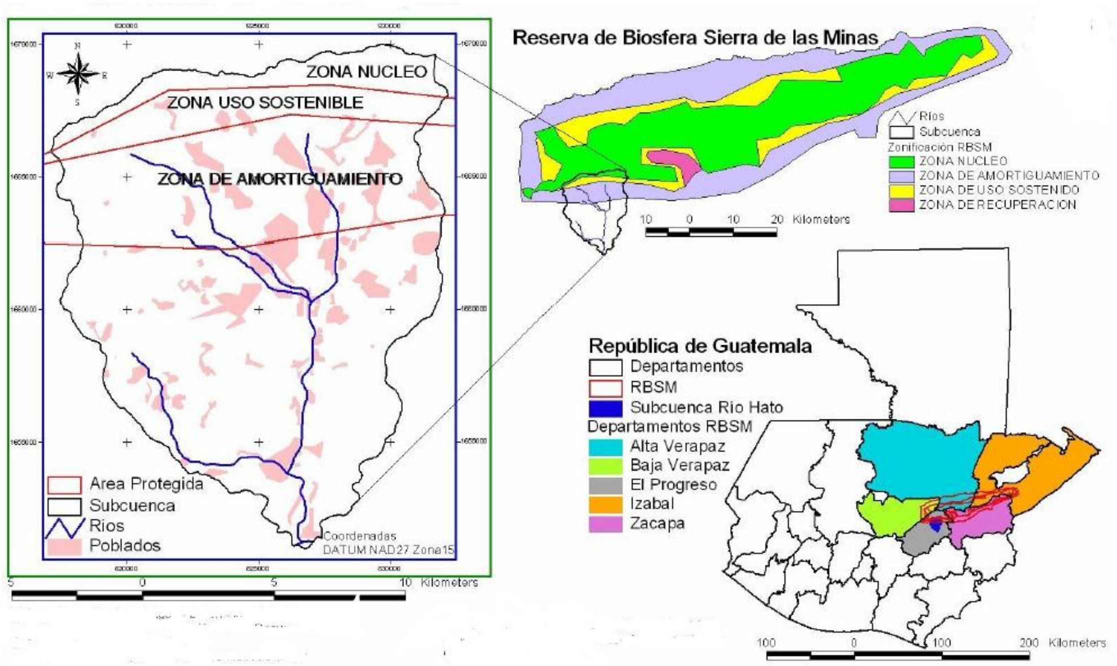

Figure 4.1. Location of the Guatemalan study area

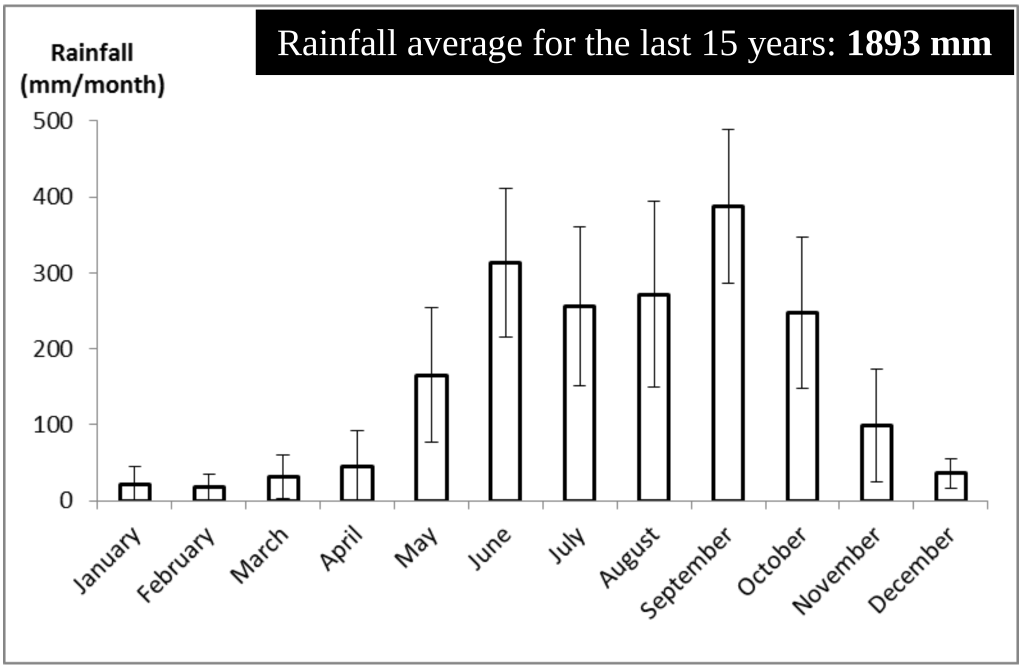

Figure 4.2. Monthly rainfall average for the last 15 years in Los Albores coffee community

As with the majority of Guatemalan coffee plantations, farmers of El Hato watershed planted coffee under the shade of *Inga* spp., a leguminous native tree species. Additionally, other native and exotic trees would often form part of the shade canopy to provide fruits, timber or firewood for the farmers. In the low zone of the Watershed, cardamom (*Eletaria cardamomum*) was also intercropped with coffee. Coffee and cardamom were the only tradable agricultural products in the area. Fruit trees are more common on low farms, while timber trees are more commonly found in medium and high areas. It is very common that farmers also grow basic grains, such as beans and maize, and a few had pastures for livestock. Both grains and livestock are for self-consumption.

The around 200 families living in the area are not part of any cooperative, however they maintain close links –particularly family links-. There are two farmers' organizations: ADIPSA (Asociación de Desarrollo Integral Progresista de San Agustín Acasaguastlán - *Progressive Development Association of San Agustín Acasaguastlán*) with 21 farmers, and "Los Albores Association" with 22 farmers. Both are related to coffee; the first is a certified organic organization, the second is Starbucks certified. The 150 remaining farmers are selling their coffee to a farmer who lives in Los Albores community (Hocdé, 2009).

Farmers' knowledge compilation and analysis

Farmers' knowledge was acquired using the Agroecological Knowledge Toolkit (AKT) knowledge-based systems methodology and software system (Sinclair and Walker 1998). This methodology involves a series of iterative cycles of eliciting knowledge from a small purposive sample of farmers, through semi-structured interview, and then representation and evaluation of the knowledge obtained using an explicit knowledge-based systems approach (Walker and Sinclair, 1998).

Prior to compiling a knowledge base, a short scoping study with key informants was completed in order to refine the objectives of knowledge acquisition and to define the itinerary of visits to the coffee communities. Meetings were held independently with six coffee technicians of ANACAFE (Asociación Nacional de Café en Guatemala – Guatemalan Coffee Association–) and four environmental research assistants of Defensores de la Naturaleza (the NGO in charge of the Sierra de las Minas reserve management plan). Informally we met a recognized leader of the watershed, Don Jesus Ramirez, in order to present to him the purpose of the research. This local businessman, coffee grower and trader, is also a religious leader and his approval opened the doors of many households to us.

Research assistants knowledgeable about the area explained the range of altitudinal zones within the coffee growing area and suggested stratifying farmers according to the location of their communities in these altitudinal zones. While most of the coffee farms were located in communities at high altitudinal range in the watershed, coffee was also being produced on plantations that experienced a warmer and drier climate due to altitude and/or micro-climatic conditions. Differences in composition of tree species and management of coffee were deemed likely. We interviewed 29 farmers from three communities in the high altitudinal zone, two from the medium zone and three from the low zone.

Interviews were divided into two main sections. The first section focused on farm characteristics, coffee management calendar, management practices, and reasons for management activities. This section was designed to characterize the farm (and the farmer) and not all the information obtained was analysed through the AKT (e.g. the management calendar –Fig. 4.3–). The second section focused on trees: shade canopy management, usefulness of trees, tree attributes and classifications; and what mammals and birds were associated with trees. Sets of iterative interviews were conducted with the 29 farmers and consisted of a combination of semi-structured interviews (Pretty, 1995) and in depth interviews (Laws et al., 2003). Interviews lasted no more than 90 minutes, unless the farmer was keen to continue, and were always initiated with a full description of the purpose of the research.

The local knowledge was recorded using the AKT software system (Dixon *et al*. 2001) that involved disaggregation of knowledge into sets of unitary statements represented using a formal grammar (Walker and Sinclair 1998), with associated contextual information about the definition and taxonomy of terms (Sinclair and Walker 1998). The knowledge was evaluated for coherence and consistency as it was collected, using a suite of automated reasoning tools and a diagrammatic interface to explore connections among statements (Walker *et al*., 1997). This methodology has already been used with coffee farmers in Costa Rica (Cerdán *et al*., 2012).

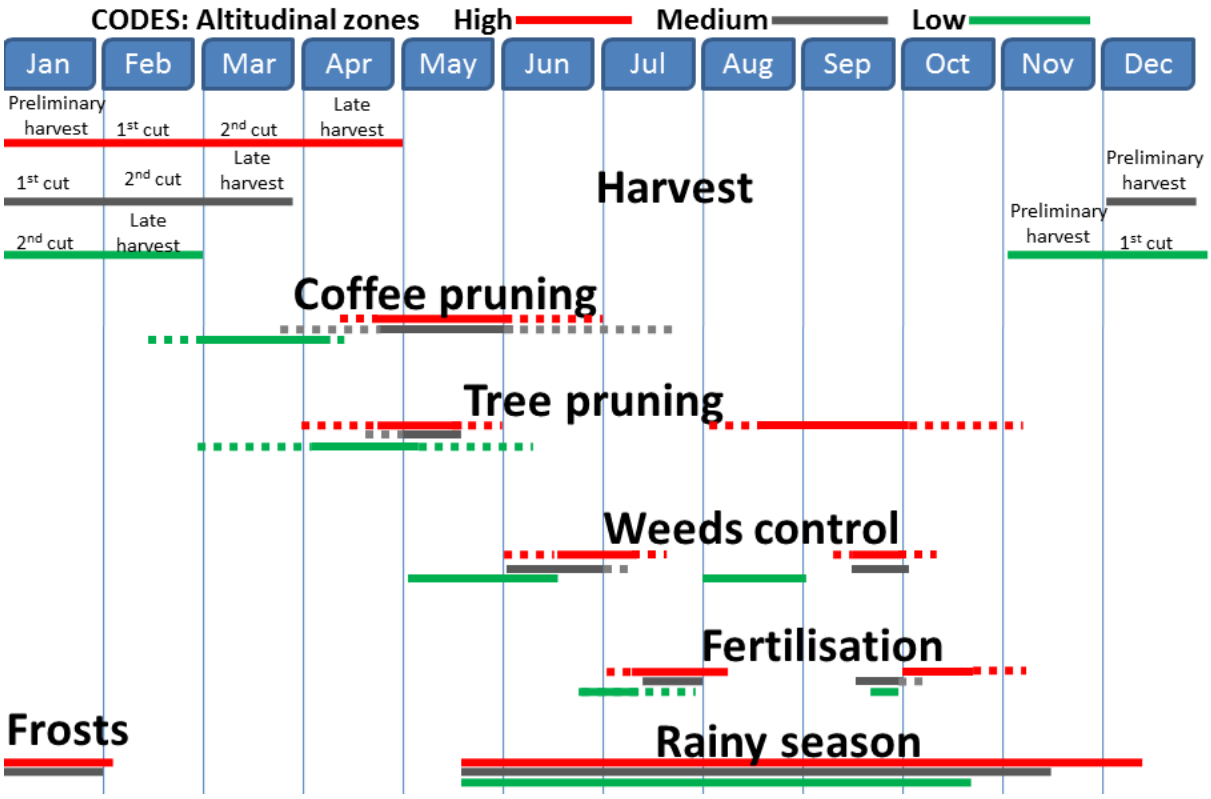

Figure 4.3. Coffee management practices for the different altitudinal zones
Red lines show the farming practices for farmers in the high altitudinal zone, grey lines for farmers in the medium altitudinal zones, and green lines for farmers in the low altitudinal zones. Solid lines show the averaged timing for farmers in each zone, while dotted lines show how long before and after the practice could be carried out.

Farmers' knowledge was analysed through the creation of diagrams with the software. These diagrams can be further used to build conceptual models about a topic, showing the factors affecting the topic and the links between them, according to the farmers interviewed. Each link can be characterized by statements originated from referred farmers.

3. Results

The knowledge base

There were a total of 654 statements in the Knowledge Base (KB) with 576 (88%) of these demonstrating causal relationships (Table 4.1). A high number of causal statements indicate a fairly high level of explanatory knowledge articulated by the coffee farmers. There are 136 conditions attached to the 654 statements; this means that there are particular conditions that need to be in place for many statements to be applicable and these should be considered carefully when analysing the knowledge base.

There are 34 object hierarchies that classify tree and animal species according to the agro-ecological interactions the farmers mentioned they had with the ecosystem (e.g., 'evergreen trees'). The object hierarchies show the importance of particular functions of trees for them to be maintained in a farm. Between these functions, some trade-offs are evident, either on the short or long term: for instance, there might be trees that attract many animal species but have a negative impact when used as coffee shade.

Table 4.1. Contents of the knowledge base

Formal terms	563
Unitary statements	654 (100%)
Causal statements	576 (88%)
Attribute-value statements	41 (6%)
Link statements	25 (4%)
Comparative statements	12 (2%)
Sources	29
Object hierarchies	34

Note: Object hierarchies are sets of formal terms with the same properties and characteristics.

The knowledge base is available for free from the AKT website (akt.bangor.ac.uk), and can be viewed in English or Spanish. Its content was arranged into five topic hierarchies that organise the farmers' knowledge under useful headings that can be searched easily by the user. The five topic hierarchies are entitled 'Commonly held knowledge' (broken down into sections according to altitudinal zone), 'Habitat provision' (for mammals, birds and insects), 'Phenology of tree and plant species' (times of flowering, fruiting and pollination), 'Trees and biodiversity' (interactions between trees and animal species), and 'Trees and water' (complex tree, soil and water interactions).

Farms were classified as small (less than 5 manzanas[7]), medium (between 5 and 10 manzanas), and large (above 10 manzanas). Distinction could be made between coffee farms of different sizes due to differences in the composition and diversity of tree species planted with coffee; small producers were likely to retain more shade trees within coffee plantations to supplement their income and for subsistence purposes. The main characteristics of the farms (yield, extension, farming management) are presented in Table 4.2.

Local classification of trees and their attributes

A total of 75 tree species were mentioned by farmers as present in their farms, either shading or not the coffee. Farmers used six tree classifications related to their functions within the agroecosystems: quality for shade coffee plants, impact on soil fertility, impact on soil erosion, impact on soil moisture, impact on stream protection and, finally, there was a classification according to hotness or freshness of the trees. This last classification is not related to any specific function, it is a sort of overarching classification that groups different functions of the trees; generally a fresh tree sums up the positive side of the attributes, whilst a hot tree has negative impacts. Farmers used seven tree attributes to classify the trees: height, woody growth rate, canopy phenology, crown openness, leaf size, leaf texture and root abundance. A detailed list on classifications and attributes for the 75 species is presented in Table 4.3.

Such tree attributes and classification were found in other countries (Costa Rica and Nicaragua) and have been presented previously (Cerdán *et al*., 2012; Cerdán *et al.*, in prep.). The last column in Table 4.3 indicates if the species was mentioned in other countries. Eventual discrepancies between the knowledge reported for these countries

[7] 1 manzana is equal to 0.69 hectares.

are highlighted with grey shading of the cells (light or dark, depending on the gravity of the discrepancy). Out of the 75 species, 23 were mentioned in the studies done in the two other countries: three only in Costa Rica, seven only in Nicaragua, and 13 in both countries. There were differences in the knowledge reported for 21 species (exceptions were *Citrus sinensis* and *Citrus reticulata*); however, most of these differences were slight and did not suggest fundamental contradictions in the functions or attributes of the trees in the different areas, e.g. a tree was classed as having a positive impact on soil erosion control for farmers in one country, while this same tree was only considered as having a medium impact for farmers in the other country. There were only four tree species with contradictory classifications: *Psidium guajava*, *Pinus oocarpa*, *Liquidambar styraciflua* and *Mangifera indica*. These species were classed by the farmers of the area as having the opposite impacts on soil fertility, erosion and moisture as it was mentioned in other areas. *M. indica* was even classed as a hot species, while in Nicaragua and Costa Rica it was classed as a fresh species. These contradictions are probably caused because of the genetic differences that a same species could have.

Table 4.2. Characteristics of the coffee farmers of the different altitudinal zones

Altitudinal zones	High	Medium	Low
Communities	**3**	**3**	**2**
Mean meters above sea level	**1512** ±113	**1227** ±192	**1119** ±180
Mean landholding (manzanas)	**1.33** ±3.1	**12.8** ±43.4	**5.5** ±6.3
Landholding categories	Small	Large and small	Medium and small
Farming system	Organic and conventional	Conventional	Organic and conventional
Coffee yield (qq manzana^{-1})	**7** ±4.9	**13.5** ±11.1	**23** ±6.7
Predominant coffee varieties	Maragojipe	Maragojipe, Catimor, Pache cubano	Catuai, Caturra, Pache cubano
Predominant shade trees	*Inga* spp. + fruit trees	*Inga* spp. + timber trees	*Inga* spp.

Note: This table is expressing the averages and predominant values of each zone

There is a gradient in the suitability of tree species for the overall functions, from the most suitable at the top of Table 4.3 to unsuitable at the bottom. At a first glance: farmers stated that “good and suitable” trees are fresh, high quality for shade coffee, with positive impacts on soil fertility and moisture, controlling erosion, and protecting streams; while on the other hand the “bad and unsuitable” trees are hot, not used to shade coffee, negatively impacting soils, and with a negative impact on stream protection. The bottom ten species are, in fact, hot and not used to shade coffee plants, apparently they are unsuitable trees with minimal effects on moisture; only 3 of them have positive impacts on protecting streams.

Farmers expressed that the presence and abundance of trees within their farms are not only related to the functions of the trees, but also to the goods they provide. The goods provided by each species –timber, firewood, food or medicine- are detailed in Table 4.4. The respective orders of the trees in Table 4.3 and Table 4.4 are very contrasted: four among the first five species in Table 4.4 (providing most goods) are ranked among the last ten species in Table 4.3 (most unsuitable trees in their interaction with the ecosystem and the coffee plantation): (*Q. penduncularis*; *Q. sapotifolia*, *C. lusitanica*, and *T. americana*). They provide timber and firewood. On the other hand, there were five species within the plantations that apparently have no use (Table 4.4) nor function (Table 4.3): *S. humilis*, *D. arboreus*, *P aduncum*, *C. guatemalensis* and “tres puntas” (unidentified).

Table 4.3. Attibutes and classifications of all trees species mentioned by farmers during the interviews

Common name	Scientific name	Local functional classifications						Tree attributes							Presence in other countries
		Fresh/Hot	Used like shade tree	Soil fertility	Soil erosion	Soil moisture	Streams protection	Height	Growth rate	Canopy phenology	Crown openness	Leaf size	Leaf texture	Root abundance	
Cuje grande	*Inga edulis*	Fresh	Good	Positive	Positive	Positive	Positive	n.d.	n.d.	Leaf turnover	n.d.	Medium	Soft	Medium	
Cuje paterna	*Inga jinicuil*	Fresh	Good	Positive	Positive	Positive	Positive	n.d.	n.d.	Leaf turnover	n.d.	Medium	Soft	Medium	
Cuje caspirol	*Inga laurina*	Fresh	Good	Positive	Positive	Positive	Positive	n.d.	n.d.	Leaf turnover	n.d.	Medium	Soft	n.d.	
Cuje cushín	*Inga oerstediana*	Fresh	Good	Positive	Positive Medium	Positive Medium	Positive	n.d. Medium	Fast Medium	Leaf turnover	n.d. n.d.	Small Big	Soft	Medium Numerous	Ni
Cuje	*Inga vera*	Fresh	Good	Positive	Positive	Positive	Positive	n.d. Medium	n.d. Fast	Leaf turnover	n.d. Closed	Big Medium	Soft	Medium Numerous	CR-Ni
Yaje	*Acacia acanthophylla*	Fresh	Good	Positive	Positive	Positive	Positive	n.d.	Slow	Evergreen	n.d.	Small	Soft	Medium	
Banano	*Musa paradisiaca*	Fresh	Good	Positive	Positive Medium (Ni)	Positive	n.d.	n.d. Low	Fast	Evergreen	n.d. Open	Big	Soft	n.d. Numerous	CR-Ni
Banano coco	*Musa paradisiaca*	Fresh	Good	Positive	Positive	Positive	n.d.	n.d.	Fast	Evergreen	n.d.	Big	Soft	n.d.	
Banano hab. amarillo	*Musa paradisiaca*	Fresh	Good	Positive	Positive	Positive	n.d.	Low	Fast	Evergreen	n.d.	Big	Soft	n.d.	
Banano hab. morado	*Musa paradisiaca*	Fresh	Good	Positive	Positive	Positive	n.d.	Low	Fast	Evergreen	n.d.	Big	Soft	n.d.	
Banano majunche	*Musa paradisiaca*	Fresh	Good	Positive	Positive	Positive	n.d.	n.d.	Fast	Evergreen	n.d.	Big	Soft	n.d.	
Banano manzanito	*Musa paradisiaca*	Fresh	Good	Positive	Positive	Positive	n.d.	n.d.	Fast	Evergreen	n.d.	Big	Soft	n.d.	

Table 4.3. Attributes and classifications of all tree species mentioned during the interviews. (cont.)

Common name	Scientific name	Local functional classifications						Tree attributes							Presence in other countries
		Fresh/Hot	Used like shade tree	Soil fertility	Soil erosion	Soil moisture	Streams protection	Height	Growth rate	Canopy phenology	Crown openness	Leaf size	Leaf texture	Root abundance	
Gravilea	*Grevillea robusta*	Fresh	Good	Positive	Positive	Positive	n.d.	n.d.	n.d.	Evergreen	n.d.	Small	n.d.	n.d.	
Pacaya	*Chamaedorea tepejilote*	Fresh	Good	n.d.	Positive	Medium	n.d.	Low	n.d.	Evergreen	n.d.	Big	n.d.	n.d.	
Madre cacao	*Gliricidia sepium*	Fresh	Medium Good	Positive	Positive Medium	Positive Medium	n.d.	n.d. Low	n.d. Fast	Evergreen	n.d. Closed	Small Medium	Soft	Medium n.d.	CR-Ni
Pito	*Erythrina berteroana*	Fresh	Medium Good	Positive	Positive	Positive	n.d. Positive	n.d. High	n.d. Fast	Evergreen	n.d.	Medium Big	n.d. Soft	n.d. Numerous	Ni
Guachipilin	*Diphysa americana*	Fresh	Medium	Positive	Positive	Positive	n.d.	n.d.	Slow	Leaf turnover	n.d.	Small	Soft	Numerous	
Cuernavaca	*Solanum spp.*	Fresh	Medium	Positive	Positive	Positive	n.d.	n.d.	n.d.	Evergreen	n.d.	Big	n.d.	n.d.	
Tefrosia	*Tephrosia vogelli*	Fresh	Medium	Medium	Positive	Medium	n.d.	n.d.	n.d.	Leaf turnover	n.d.	Small	n.d.	n.d.	
Capulin comestible	*Muntingia calabura*	Fresh	Medium	n.d.	Medium	Positive	Positive	n.d.	Fast	Evergreen	n.d.	Medium	n.d.	Numerous	
Maicena	Unidentified	Fresh	Medium	n.d.	n.d.	Positive	Positive	n.d.	n.d.	Evergreen	n.d.	Big	n.d.	n.d.	
Amate	*Ficus glabrata*	Fresh	Medium*	n.d. Positive	Positive	Positive	Positive	n.d. High	n.d. Fast	Evergreen n.d.	Closed	Big Medium	n.d. Medium	Medium n.d.	CR-Ni
Manzanillo	*Hieronyma guatemalensis*	Fresh	Medium*	n.d.	Medium	Positive	n.d.	n.d.	n.d.	Evergreen	n.d.	Small	n.d.	n.d.	
Palma	*Sabal mexicana*	Medium	Good	Positive	Positive	Positive	n.d.	n.d.	n.d.	Evergreen	Closed	Big	n.d.	Numerous	
Níspero	*Eriobotrya japonica*	Medium Fresh	Good	n.d.	Positive	Medium	n.d.	Low Medium	Fast Medium	Evergreen n.d.	Closed	Medium	Stiff Soft	Numerous n.d.	CR
Izote	*Yucca elephantipes*	Medium Hot	Good	n.d.	Positive	Negative	Negative	n.d. Low	Fast	Evergreen n.d.	n.d. Open	Big	Stiff	Numerous	CR

Table 4.3. Attributes and classifications of all tree species mentioned during the interviews. (cont.)

Common name	Scientific name	Local functional classifications						Tree attributes							Presence in other countries
		Fresh/Hot	Used like shade tree	Soil fertility	Soil erosion	Soil moisture	Streams protection	Height	Growth rate	Canopy phenology	Crown openness	Leaf size	Leaf texture	Root abundance	
Aguacate de montaña	*Persea americana*	Medium	Medium	Positive Medium	Positive Medium	Positive Medium	n.d. Positive	n.d. Medium	n.d. Fast	Evergreen	Closed Open	Big Medium	n.d. Medium	Numerous Medium	CR-Ni
Frutillo	Unidentified	Medium	Medium	Positive	Negative	Positive	n.d.	n.d.	n.d.	Leaf turnover	Closed	Small	n.d.	Numerous	
Guayabo	*Psidium guajava*	Medium Hot	Medium	Positive Negative	Negative	Positive Negative	Negative	Low	n.d. Medium	Evergreen	n.d. Closed	Small	n.d. Stiff	n.d.	CR-Ni
Zapote	*Manilkara zapota*	Medium Fresh	Medium	Medium	Medium	Positive	Positive	n.d. High	n.d. Medium	Evergreen	n.d. Closed	Big	n.d. Medium	n.d.	CR
Jocote	*Spondias mombin*	Medium	Medium	Medium	Medium	Positive	n.d.	n.d.	n.d.	Evergreen	Closed	Small	Stiff	n.d.	
Siguapate	Unidentified	Medium	Medium	Medium	Medium	Medium	n.d.	n.d.	n.d.	Evergreen	n.d.	Medium	n.d.	n.d.	
Chupte	*Saurauia laevigata*	Medium	Medium	n.d.	Positive	Positive	Positive	n.d.	n.d.	Leaf turnover	n.d.	Big	n.d.	n.d.	
Cedro de montaña	*Cedrela tonduzii*	Medium	Medium	n.d.	Positive	Positive	n.d.	n.d.	n.d.	Evergreen	n.d.	Medium	Stiff	n.d.	
Cedro	*Cedrela odorata*	Medium	Medium	n.d. Medium	Positive	Positive	n.d.	n.d. High	n.d. Fast	Leaf turnover Deciduous	n.d. Open	Medium	Stiff Medium	n.d. Medium	CR-Ni
Guarumbo	*Cecropia obstusifolia*	Medium Fresh	Medium	n.d. Positive	Medium	Positive	n.d.	n.d. High	Fast Fast	Evergreen	Open	Big	Stiff Soft	Medium n.d.	CR-Ni
Mandarina	*Citrus reticulata*	Medium	Medium	n.d.	Medium	Medium	n.d.	n.d. Low	n.d. Fast	Evergreen	n.d.	Small	n.d. Medium	Medium	Ni
Naranja	*Citrus sinensis*	Medium	Medium	n.d. Negative	Medium	Medium n.d.	Negative n.d.	Low	n.d. Fast	Evergreen	Closed	Medium	n.d. Medium	n.d.	CR-Ni
Durazno	*Prunus persica*	Medium	Medium	n.d.	Medium	Negative	n.d.	n.d.	n.d.	Leaf turnover	Closed	Medium	Soft	n.d.	

Table 4.3. Attributes and classifications of all tree species mentioned during the interviews. (cont.)

Common name	Scientific name	Local functional classifications						Tree attributes							Presence in other countries
		Fresh/Hot	Used like shade tree	Soil fertility	Soil erosion	Soil moisture	Streams protection	Height	Growth rate	Canopy phenology	Crown openness	Leaf size	Leaf texture	Root abundance	
Lima-limón	*Citrus paradisi*	Medium	Medium	n.d.	Negative	Positive	n.d.	Low	n.d.	Evergreen	Closed	Medium	n.d.	Numerous	
Limón real	*Citrus limonia*	Medium	Medium	n.d.	Negative	Positive	Negative	Low	n.d.	Evergreen	Closed	Medium	n.d.	Numerous	
Limón criollo	*Citrus aurontifolia*	Medium	Medium	n.d. Negative	Negative Medium	Positive	Negative	Low	n.d.	Evergreen	Closed	Medium	n.d.	Numerous	CR-Ni
Higuerillo	*Ricinus communis*	Medium Fresh	Medium Good	Medium Positive	n.d.	Negative Medium	n.d.	n.d. Low	Fast	Evergreen	n.d. Open	Big	n.d. Medium	Numerous n.d.	CR-Ni
Capulin	*Trema micrantha*	Medium	Medium	n.d.	Medium	Positive	n.d.	High	Fast	Leaf turnover	n.d.	Medium	n.d.	Numerous	
Caulote	*Guazuma ulmifolia*	Medium	Medium	Positive	Positive	Positive	Medium	n.d. Low	n.d. Fast	Evergreen	Closed	Medium Small	n.d. Soft	n.d. Medium	Ni
Matasano	*Casimiroa edulis*	Medium	Medium	Medium	Medium	Positive	n.d.	n.d.	n.d.	Evergreen	n.d.	Medium	n.d.	n.d.	
Ixcatama	Unidentified	Medium	Medium	Medium	Negative	Negative	n.d.	n.d.	n.d.	Leaf turnover	n.d.	Medium	n.d.	n.d.	
Manzana rosa	*Syzygium jambos*	Medium	Not used	Medium	Medium	Positive	Medium	n.d.	n.d.	Evergreen	Closed	Medium	Stiff	Numerous	
Achiote	*Bixa orellana*	Medium	Not used	n.d.	Positive	Medium	n.d.	n.d.	n.d.	Leaf turnover	n.d.	Medium	n.d.	n.d.	
Ceibillo	*Ceiba aesculifolia*	Medium	Not used	n.d.	Medium	Positive	n.d.	n.d.	n.d.	Evergreen	n.d.	Medium	n.d.	Numerous	
Chaperno	*Lonchocarpus minimiflorus*	Medium	Not used	n.d. Medium	Medium	Positive	n.d. Positive	n.d. High	n.d. Fast	Evergreen	n.d.	Medium Big	n.d. Medium	n.d.	Ni
Mielero	*Salvia karwinskii*	Medium	Not used	n.d.	Negative	Positive	n.d.	n.d.	n.d.	Leaf turnover	n.d.	Medium	n.d.	n.d.	

Table 4.3. Attributes and classifications of all tree species mentioned during the interviews. (cont.)

Common name	Scientific name	Local functional classifications						Tree attributes							Presence in other countries
		Fresh/Hot	Used like shade tree	Soil fertility	Soil erosion	Soil moisture	Streams protection	Height	Growth rate	Canopy phenology	Crown openness	Leaf size	Leaf texture	Root abundance	
Cinco negros	*Lantana camara*	Medium	Not used	n.d.	Negative	Positive	n.d.	n.d.	n.d.	Evergreen	n.d.	Medium	n.d.	n.d.	
Naranjilla	*Zanthoxylum caribaum*	Medium	Not used	n.d.	Negative	Medium	n.d.	Low	n.d.	Evergreen	n.d.	Big	n.d.	n.d.	
Cajeto	*Bernandia interrupta*	Medium	Not used	Negative	Positive	Positive	Negative	n.d.	n.d.	Evergreen	n.d.	Medium	n.d.	n.d.	
Maracuya	*Passiflora edulis*	n.d.	Not used	n.d.	Medium	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	
Anono	*Annona squamosa*	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	Low	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	
Arrayán	*Myrica cerifora*	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	Small	n.d.	n.d.	
Suquinay	*Vernonia patens*	Hot n.d.	Medium n.d.	Positive n.d.	Medium	Medium Positive	Negative n.d.	n.d. Low	Fast	Evergreen	Open	Medium	Soft	Medium	Ni
Llama de fuego	*Spatodea campanulata*	Hot	Medium	Medium	Medium	Positive	Negative	n.d.	n.d.	Deciduos	n.d.	Medium	n.d.	n.d.	
Pino blanco	*Pinus maximinoi*	Hot	Medium	Negative	Positive	Positive	n.d.	High	n.d.	Evergreen	n.d.	Medium	Stiff	Numerous	
Pino de ocote	*Pinus oocarpa*	Hot	Medium	Negative	Positive Negative	Positive Negative	n.d. Negative	High	n.d. Fast	Evergreen	n.d. Open	Medium Small	Stiff Medium	Numerous n.d.	CR-Ni
Bálsamo	*Liquidambar styraciflua*	Hot	Medium	Negative n.d.	Positive Negative	Positive Negative	n.d.	High	n.d. Fast	Evergreen	Closed	Medium Big	n.d. Soft	Numerous n.d.	Ni
Tatascamite	*Perymenium grande*	Hot	Medium	Negative	Medium	Negative	Negative	n.d.	n.d.	Evergreen	Closed	Medium	Soft	Numerous	
Mango	*Mangifera indica*	Hot Fresh	Medium	Negative Positive	Negative Positive	Positive Medium	n.d. Positive	High Medium	n.d. Fast	Leaf turnover	Closed	Medium	Stiff Medium	n.d. Medium	CR-Ni

Table 4.3. Attributes and classifications of all tree species mentioned during the interviews. (cont.)

Common name	Scientific name	Local functional classifications						Tree attributes							Presence in other countries
		Fresh/Hot	Used like shade tree	Soil fertility	Soil erosion	Soil moisture	Streams protection	Height	Growth rate	Canopy phenology	Crown openness	Leaf size	Leaf texture	Root abundance	
Salaqué	*Cupania glabra*	Hot	Temporal	Negative	Negative	Negative	Negative	n.d.	Fast	Leaf turnover	n.d.	Medium	Soft	Numerous	
Mezcal	*Ulmus mexicana*	Hot	Not used	Medium	Medium	Positive	Negative	n.d.	n.d.	Evergreen	n.d.	Medium	n.d.	n.d.	
Cabo de hacha	*Trichilia americana*	Hot	Not used	Negative	Positive	Positive	Positive	High	n.d.	Deciduos	Closed	Medium	Stiff	n.d.	
Encino blanco	*Quercus peduncularis*	Hot	Not used	Negative	Positive	Positive	n.d.	High	n.d.	Deciduos	Closed	Big	Stiff	Numerous	
Encino negro	*Quercus sapotifolia*	Hot	Not used	Negative	Positive	Positive	n.d.	High	n.d.	Leaf turnover	Closed	Big	Stiff	Numerous	
Ciprés	*Cupressus lusitanica*	Hot	Not used	Negative	Positive	Positive	n.d.	High	n.d.	Evergreen	Closed	Small	n.d.	Numerous	
Zapotón	*Swietenia humilis*	Hot	Not used	Negative	Negative	Positive	Positive	n.d.	n.d.	Evergreen	n.d.	Big	Stiff	n.d.	
Mano de león	*Dendropanax arboreus*	Hot	Not used	Negative	Negative	Positive	Negative	n.d.	n.d.	Evergreen	n.d.	Big	n.d.	Medium	
Cordoncillo	*Piper aduncum*	Hot	Not used	Negative	Negative	Negative	Positive	n.d.	n.d.	Leaf turnover	n.d.	Medium	n.d.	Numerous	
Guesillo	*Colubrina guatemalensis*	Hot	Not used	Negative	Negative	Negative	Negative	n.d.	n.d.	Leaf turnover	n.d.	Medium	n.d.	n.d.	
Tres puntas	Unidentified	Hot	Not used	Negative	Negative	Negative	Negative	n.d.	n.d.	Evergreen	n.d.	Medium	n.d.	n.d.	

The last column indicates the countries (Costa Rica and Nicaragua) where similar studies were done and the species was also described. The second line of each cell shows the eventual discrepancies with farmers of the other countries. If the space is left blank, there is concordance. A slight discrepancy is highlighted with a light grey cell; a strong discrepancy is indicated with a dark grey cell.

Table 4.4. Impact of trees on goods provision: timber, firewood, nutrition and medicinal

Scientific name	Timber quality	Firewood quality	Human edible	Medicinal
Manilkara zapota	Good	Good	Yes	Yes
Quercus peduncularis	Good	Good	No	Yes
Quercus sapotifolia	Good	Good	No	Yes
Trichilia americana ϴ	Good	Good	No	No
Cupressus lusitanica ϴ	Good	Medium	No	Yes
Pinus maximinoi	Good	Medium	No	Yes
Pinus oocarpa	Good	Medium	No	Yes
Diphysa americana	Good	Medium	No	No
Lonchocarpus minimiflorus	Good	Medium	No	No
Perymenium grande	Good	Bad	No	No
Cedrela odorata	Good	n.d.	No	No
Cedrela tonduzii	Good	n.d.	No	No
Gliricidia sepium	Medium	Medium	Yes	No
Saurauia laevigata	Medium	Medium	Yes	No
Liquidambar styraciflua	Medium	Medium	No	Yes
Bernandia interrupta	Medium	Medium	No	No
Ulmus mexicana	Medium	Medium	No	No
Sabal mexicana	Medium	Not used	Yes	No
Guazuma ulmifolia	Bad	Medium	Yes	Yes
Mangifera indica	Bad	Medium	Yes	Yes
Inga edulis ϴ	Bad	Medium	Yes	No
Inga jinicuil	Bad	Medium	Yes	No
Inga laurina	Bad	Medium	Yes	No
Inga oerstediana	Bad	Medium	Yes	No
Ceiba aesculifolia	Bad	Medium	No	No
Cupania glabra	Bad	Medium	No	No
Inga vera ϴ	Bad	Medium	No	No
Annona squamosa	n.d.	n.d.	Yes	n.d.
Passiflora edulis	n.d.	n.d.	Yes	No
Myrica cerifora	n.d.	n.d.	n.d.	n.d.
Psidium guajava	Not used	Good	Yes	Yes
Syzygium jambos	Not used	Medium	Yes	Yes
Acacia acanthophylla	Not used	Medium	No	No
Grevillea robusta	Not used	Medium	No	No
Lantana camara	Not used	Medium	No	No
Spatodea campanulata	Not used	Medium	No	No
Trema micrantha	Not used	Medium	No	No
Citrus sinensis ϴ	Not used	Bad	Yes	Yes
Casimiroa edulis	Not used	Bad	Yes	No
Eriobotrya japonica ϴ	Not used	Bad	Yes	No
Prunus persica	Not used	Bad	Yes	No
Spondias mombin	Not used	Bad	Yes	No
Vernonia patens	Not used	Bad	No	Yes
Colubrina guatemalensis	Not used	Bad	No	No
Dendropanax arboreus	Not used	Bad	No	No
Solanum spp.	Not used	Bad	No	No
Unidentified (frutillo)	Not used	Bad	No	No
Bixa orellana	Not used	Not used	Yes	Yes
C aurontifolia	Not used	Not used	Yes	Yes
C. limonia	Not used	Not used	Yes	Yes
Persea ϴ *americana*	Not used	Not used	Yes	Yes
Yucca ϴ *elephantipes*	Not used	Not used	Yes	Yes
Chamaedorea tepejilote	Not used	Not used	Yes	No
C. paradisi	Not used	Not used	Yes	No
C. reticulata	Not used	Not used	Yes	No
Erythrina berteroana	Not used	Not used	Yes	No
Hieronyma guatemalensis	Not used	Not used	Yes	No
Muntingia calabura	Not used	Not used	Yes	No
Musa ϴ *paradisiaca*	Not used	Not used	Yes	No
Persea ϴ *schiedana*	Not used	Not used	Yes	No
Salvia karwinskii	Not used	Not used	Yes	No
Unidentified (ixcatama)	Not used	Not used	Yes	No
Zanthoxylum caribaum	Not used	Not used	Yes	No
Cecropia obstusifolia	Not used	Not used	No	Yes
(siguapate)	Not used	Not used	No	Yes
(tres puntas)	Not used	Not used	No	Yes
Ficus glabrata	Not used	Not used	No	Yes
Piper aduncum	Not used	Not used	No	No
Ricinus communis	Not used	Not used	No	No
Swietenia humilis	Not used	Not used	No	No
Tephrosia vogelli	Not used	Not used	No	No

ϴ Indicates the top 10 prefered shade species.

Differences across altitudinal areas

Across the coffee zone of El Hato Watershed, farmers illustrated how their coffee farming practices differed throughout the year. The timing of specific management practices was related to climatic conditions, which was also affecting the abundance and growth of various tree species in the research communities. Figure 4.3 was drawn up to illustrate these differences. Coffee harvest occurs over four months in the three zones; however, it begins one month later in the medium zone than in the lower zone, and two months later in the higher zone. After the harvest, coffee is pruned in the three zones. Shade is regulated through the pruning of the shade trees. Farmers from the high zone stated coffee required less shade during the rainy season, and more shade during the frosts, in comparison to farmers from the low and medium zones. This difference results in trees being pruned twice a year. Fertilisation is done twice a year, during coffee fruits growth and then during maturation. Generally weeds are cut before fertilizer applications.

The altitude of the study area was between approx. 300 meters, in the Motagua River, to above 2400, at the head of the Sierra de las Minas protected area, with the majority of coffee plantations situated between 900 and 1600 meters above sea level. This 'coffee growing' altitudinal range was located in a transect of less than 15 kilometres, meaning that farmers could easily visit the other altitudinal zones and compare their coffee farms to neighbouring farms. Coffee farmers made distinctions between altitudinal zones and generally classified the surrounding area into four types: low areas where coffee did not grow, low areas conducive to growing coffee, high areas conducive to growing coffee, and high areas where coffee did not grow. However, these identified 'zones' should not be regarded as exclusive, because, overlapping the high and low areas where coffee was able to grow, some farmers recognised a 'medium' area. The farmers' description of coffee growing zones was closely related to altitude, but there were more complex layers influencing why a farm would be regarded as being in a 'high', 'medium' or 'low' coffee area. The location within the watershed and topography factors could be seen as influencing the weather patterns, specifically the sunlight received, and consequently the temperature. For example, farmers mentioned the orientation of the farm with respect to the sunrise; a coffee farm oriented in such a way would receive sunlight early in the morning, when there are fewer clouds as compared to the usually cloudy afternoon. A farm facing the sunrise is warmer than a farm facing the sunset.

Other topographic elements were mentioned as influencing coffee growth: if there is a mountain directly in front of a plantation then the amount of daylight hours will be reduced; if a plantation is on steeply sloped land, it will receive less sunlight than a plantation located on flat land. However, farmers appreciated sloped lands facing the sunrise. These topographic elements, combined with altitude, were creating the various climatic conditions that farmers were working under to produce coffee.

Farmers said that during the dry season the weather is hotter in low areas; therefore, more shade and more organic matter was required in these areas to maintain the moisture content of the soil and keep the coffee plants healthy. Shading of coffee was deemed to be less advantageous in high areas because of the level of cloudiness in these places, but shade trees were still valued, particularly at specific times of the year. For example, shade trees were stated as helping to reduce the damage that coffee plants could suffer from frosts in the high areas at the end of the rainy season. Figure 4.3 shows how the rainy season was said to differ depending on the altitudinal zones. These differences were influencing coffee management practices. Colder temperatures in the high zone were stated by coffee farmers as the reason why coffee harvest occurs up to two months later than in the lower zones.

Farmers' differentiation of zones does not only concern coffee management, but also tree presence and abundance. Farmers suggested that tree species were an indicator of differences among zones. The knowledge farmers had of their own local area and other altitudinal zones in terms of tree species abundance and growth is represented in Table 4.5. Some species were found in all areas but with abnormal features (e.g. fruit trees growing but not producing fruit) while some trees were having problems surviving and just a few individuals could be found. There were 63 species in Table 4.5: 19 growing in all altitudinal zones, 18 in the high and medium zones, 12 in the medium and low zones, nine species in the high zone only, two in the middle, and 3 in the low. No information was given on the altitudinal presence range of the remaining 12 species.

Farmers' knowledge about the growth and attributes of specific tree species in different zones was not dependent on the communities the farmers were from. Because the low, medium and high areas were within a relatively close distance to one another (in two cases communities had farms located across different areas), the knowledge associated with these altitudinal areas was relatively widespread (Table 4.6). Farmers talked about trees both present and absent in their zone, however farmers from the high and medium altitudinal zones talked more about trees present in their zone, whereas farmers from the low altitudinal area talked more about trees absent from their zone. From the total number of statements referring to trees present only in the high zone, 19% were made by farmers from other zones; and 33% and 23 %, respectively, for trees exclusive to medium and low zones. This is particularly striking because part of the interview was done in the coffee plantation, and farmers were consequently encouraged to talk about the trees they saw at that moment (i.e. present in their altitudinal zone).

The local agro-ecological knowledge retained by farmers should differ depending on the altitudinal zone where they had their farm, as this location had an impact on coffee management and on tree species found on the farms. In spite of the different tree species, farmers reported the same quantity of unitary statements independently of the altitudinal zone in which their farms are located (Table 4.7). When looking at the issues that these statements addressed, it appeared that farmers from the high zone were more knowledgeable on shade management: they mentioned almost twice as many statements as farmers from the low zone, and four times as many than farmers from the middle zone. As was commented before, the shade management is more complex in the higher zone (two interventions per year to customize the shade to the coffee needs).

Farmers from the different zones mentioned the role of trees regulating sunlight for coffee plants. They expressed how pruning affects the availability of sunlight, and how it has to be managed during the rainy season. The amount of sunlight affects the amount of coffee beans and their maturation. In addition to this common knowledge, farmers from the high zone expressed that pruning affects two factors, which are indirectly impacting the coffee plants (Figure 4.4). Coffee anthracnose (*Colletotrichum* spp.) is a fungal disease which severity was related by farmers in the high zone to the circulation of air; when shade tree pruning was more intense there was more air circulation provoking a decrease in the susceptibility of coffee trees to anthracnose; on the other hand, intense pruning leading to more circulation of air was mentioned as a problem, especially in January: farmers observed that pruned plantations were more damaged by frost than shaded plantations, and they related this higher susceptibility to a better circulation of the air.

Table 4.5. Presence across the altitudinal zones of all the tree species according with farmers

Tree species		High	Medium	Low
Spanish name	**Scientific synonym**			
Yaje ^	*Acacia acanthophylla*	Many	Many	Many
Pacaya ^	*Chamaedorea tepejilote*	Many	Many	Many
Limon puro	*Citrus aurantifolia*	Many	Many	Many
Naranja ^	*Citrus sinensis*	Many	Many	Many
Jocote	*Spondias mombin*	Many	Many	Many
Suquinay ^	*Vernonia patens*	Many	Many	Many
Guarumbo	*Cecropia obstusifolia*	Many	Many	Few
Limon dulce	*Citrus paradisi*	Many	Many	Few
Nispero	*Eryobotria japónica*	Many	Many	Few
Cuje cushin	*Inga oerstediana*	Many	Many	Few
Limon real	*Citrus limonia*	Many	Many	Few – 2
Pito	*Erythrina berteroana*	Few	Few	Many
Amate	*Ficus glabrata*	Few	Many	Many
Cuje grande	*Inga edulis*	Few	Many	Many
Guayabo	*Psidium guajava*	Few	Many	Few
Higuerillo	*Ricinus communis*	Few	Many	Many
Izote	*Yucca elephantipes*	Few	Many	Many
Banano	*Musa paradisiaca*	Few – 1	Many	Many
Banano manzanito	*Musa paradisiaca*	Few	Many	Many
Banano coco	*Musa paradisiaca*	Many	Many	
Ceibillo	*Ceiba aesculifolia*	Many	Many	
Tatascamite	*Perymenium grande*	Many	Many	
Pino blanco†	*Pinus maximinoi*	Many	Many	
Cordoncillo	*Piper aduncum*	Many	Many	
Palma	*Sabal mexicana*	Many	Many	
Cabo de hacha	*Trichilia americana*	Many	Many	
Ciprés†	*Cupressus lusitanica*	Many	Few	
Guachipilin	*Diphysa americana*	Many	Few	
Cuje	*Inga vera*	Many	Few	
Capulín comestible	*Muntingia calabura*	Many	Few	
Encino blanco	*Quercus peduncularis*	Many	Few	
Capulín†	*Trema micrantha*	Many	Few	
Zapotón	*Swietenia humilis*	Many	Few	
Naranjilla	*Zanthoxylum caribaum*	Many	Few	
Aguacate de montaña	*Persea americana*	Many	Few – 3	
Chaperno	*Lonchocarpus minimiflorus*	Few	Many	
Encino negro	*Quercus sapotifolia*	Few	Many	
Matasano	*Casimiroa edulis*	Many		
Cedro de montaña†	*Cedrela tonduzii*	Many		
Gravilea	*Grevillea robusta*	Many		

Cinco negro	*Lantana camara*	Many		
Balsamo	*Liquidambar styraciflua*	Many		
Durazno	*Prunus persica*	Many		
Cuernavaca	*Solanum* spp.	Many		
Salaqué†	*Cupania glabra*	Many		
Mielero	*Salvia karwinskii*	Many		
Mandarina	*Citrus reticulata*		Many	Many
Cuje paterna	*Inga jinicuil*		Many	Many
Banano majunche	*Musa paradisiaca*		Many	Many
Banano hab. amarillo	*Musa paradisiaca*		Many	Many
Banano hab. Morado	*Musa paradisiaca*		Many	Many
Pino de ocote	*Pinus oocarpa*		Many	Few
Cedro	*Cedrela odorata*		Few	Many
Manzana rosa	*Syzygium jambos*		Few	Many
Madre cacao	*Gliricidia sepium*		Few	Many
Mango	*Mangifera indica*		Few – 3	Many
Zapote	*Manilkara zapota*		Few –2	Many
Aguacate de bajío	*Persea schiedeana*		Few – 3	Many
Guesillo	*Colubrina guatemalensis*		Many	
Mano de leon	*Dendropanax arboreus*		Many	
Caulote	*Guazuma ulmifolia*			Many
Cuje caspirol	*Inga laurina*			Many
Chupte	*Saurauia laevigata*			Many

Notes: Information on growth and abundance was not available for the following species: arrayán (*Myrica cerifera*), anono (*Annona squamosa*), cajeto (*Bernandia interrupta*), frutillo (unidentified), ixcatama (unidentified), llama de fuego (*Spatodea campanulata*), maicena (unidentified), manzanillo (*Hieronyma guatemalensis*), maracuyá (*Passiflora edulis*), mezcal (*Ulmus mexicana*), siguapate (unidentified), tefrosia (*Tephrosia vogelli*) and tres puntas (unidentified).

^ These trees were said to also be present in regions of lower altitude than the coffee zone.

† These trees were said to also be present at regions higher than the coffee zone.

1: Tree that does not produce fruits in this altitudinal zone.

2: Tree with less fruits than in the other altitudinal zones.

3: Tree with smaller fruits than in other altitudinal zones.

Table 4.6. Farmers' mentions of trees present and absent in their zones

	% of trees absent in each altitudinal zone	% of statements by farmers of each zone concerning trees absent in the zone	% of the statements concerning non-shared trees made by farmers in zone where species is absent
High zone	27	2	19
Medium zone	19	15	33
Low zone	46	82	23

Table 4.7. Knowledge expressed in each altitudinal zone

Altitudinal zones	**High**	**Medium**	**Low**
Unitary statements average per source	**38**	**38**	**45**
Management of shade (28) *[1]	21	5	11
Coffee and soil (29)	23	19	21
Coffee growing (43)	31	24	29

Numbers between brackets indicate the total unitary statements in each topic.
*[1] Differences in farmers' knowledge regarding shade management is detailed in Figure 4.2

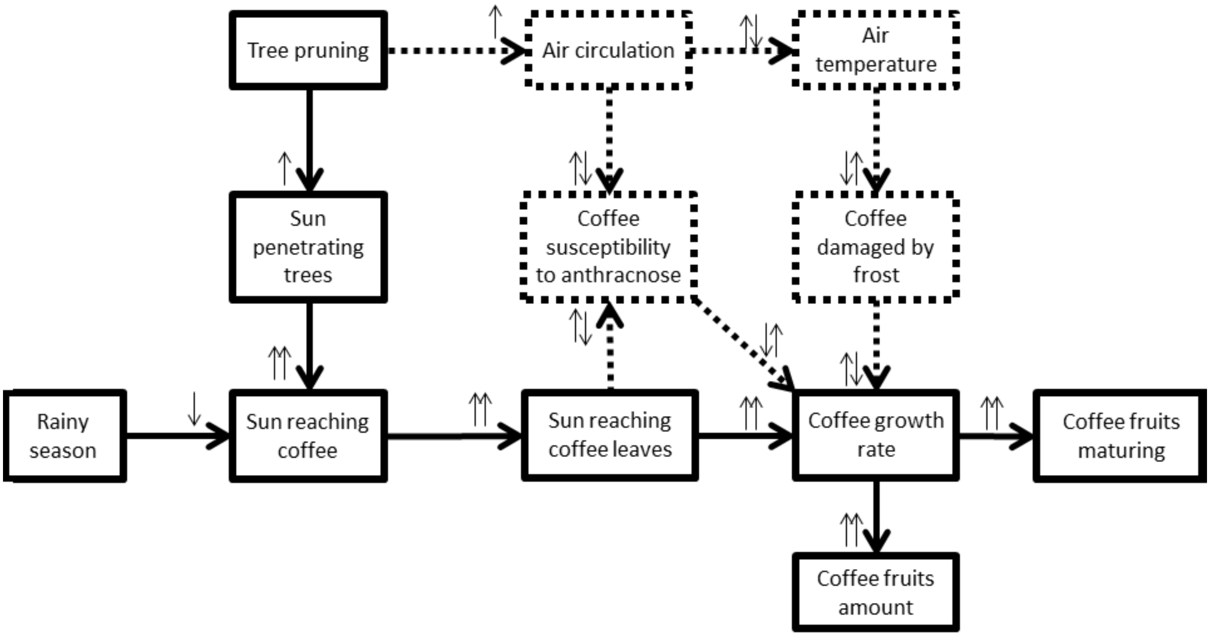

Figure 4.4. Knowledge regarding shade trees management differences by farmers' altitudinal location

Lines express the common knowledge to all farmers; dotted lines express the specific knowledge of farmers in high areas. Arrows connecting nodes denote the direction of causal influence. The first small arrow on a link indicates either an increase (↑) or decrease (↓) in the causal node, and the second arrow on a link refers to an increase (↑) or decrease (↓) in the effect node

Shared and unique local knowledge

The approach of shared, unique and contradictory knowledge (Waliszewski *et al*. 2005) was used previously to analyse Costa Rica and Nicaraguan coffee farmers' knowledge. There were two novel issues mentioned by the farmers in El Hato Watershed:

- Unique knowledge: Inga spp. attacked by insects

The most common species described by coffee farmers were cuje (*Inga vera*), cuje caspirol (*Inga laurina*), cuje cushin (*Inga oerstediana*), cuje grande (*Inga edulis*) and cuje paterna (*Inga jinicuil*). These species were classified by farmers as ‘cuje trees’ and were generally considered as the best trees shading coffee. This genus is widespread as a shade tree in Latin American coffee regions, and it is known either by farmers and coffee technicians. There is, however, at the authors’ knowledge, little information about pests attacking these trees. In the AgroforesTree database (ICRAF, 1998) it is mentioned that *Inga edulis* is attacked by a Lepidoptera larvae. Farmers mentioned that this Lepidoptera larvae, called “harmful worm” by them, (and it is its formal name in the knowledge base –KB–) attacks *Inga* spp. leaves mainly during the rainy season. They also mentioned that *Inga laurina* is more resistant to the attacks than *Inga edulis*, moreover one farmer stated that she was using both species because even when *I. edulis* is a better tree shade, *I. laurina* is more resistant to the Lepidoptera pest. Farmers also mentioned some birds that ate the larvae, and consequently are considered as pest control: charras (*Calocitta formosa*), guardabarrancos (*Myadestes occidentalis*), clarinero (*Dives dives*), cheje (*Centurus aurifrons*) and unidentified hummingbirds.

- Shared knowledge: Cecropia spp. hosting beneficial ants

Farmers observed ants hosted in guarumbo trees (*Cecropia obstusifolia*) and stated this ant is controlling the coffee borer (*Hypothenemus hampei*). Farmers were unable to add further details regarding this bio control mechanism, but they know that it happens. The relationships among the ant *Azteca* spp., *Cecropia* spp. and *H. hampei* within coffee plantations has been described in recent literature (Vandermeer *et al.* 2010). Two farmers also stated that yaje (*Acacia acanthophylla*) is also hosting a coffee borer-controller ant, one of them said it is the same species of ant, the other farmer didn’t know. To the authors’ knowledge, there is no information about *A. acanthophylla* hosting beneficial ants. Coffee borer is a minor pest problem in the study area, and that is probably the reason that explains this knowledge is not used by the farmers in the selection of shade tree species, and these tree species are not commonly found in the coffee plantations.

Biodiversity interactions within the coffee plantations

Coffee farmers within the area know the behaviour of the majority of the birds and animals they have identified, including feeding patterns and habitat preferences, which also reflects their interactions between each other and with various tree species. Farmers made general statements about birds, but they also had more detailed knowledge of where specific birds usually nest (Table 4.8). Farmers mentioned a total of 51 tree species supporting animal species, the most mentioned were *Quercus sapotifolia* and *Q. peduncularis* supporting nine animal species. Farmers mentioned 20 out the 51 tree species supporting only one animal species (Figure 4.5). Each tree species was mentioned on average by 2.2 farmers.

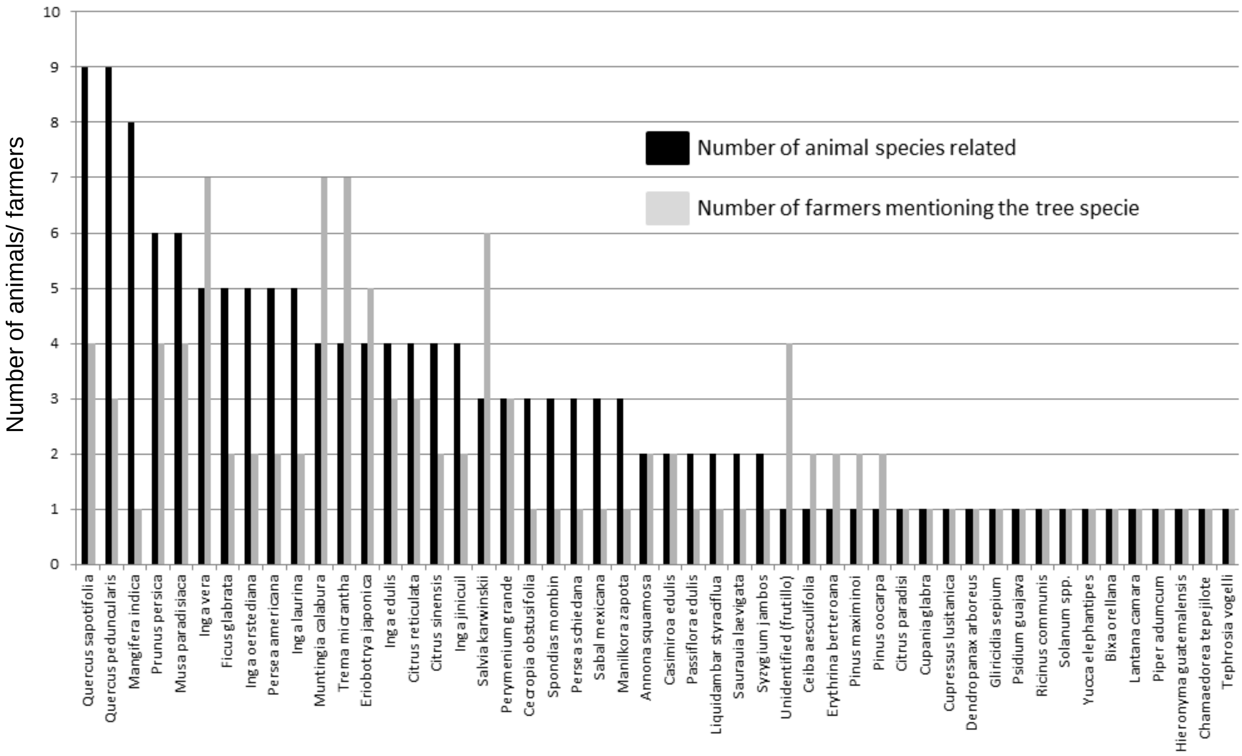

Figure 4.5. Relationships between the trees within coffee farms and biodiversity (mainly birds and mammals)
Black columns show how many species are related with the tree species, while grey lines show the number of sources who mentioned the tree species.

Farmers described all the various faunal taxa and species they identified as being from the coffee zone rather than the cloud forest areas. Forest species were said not to visit the coffee farms both because they were adapted to the cooler climate at higher altitude and due to the greater inhabitation of people in the cultivated areas. Aside from forest species, there were many mammals and birds that foraged and nested in coffee farms in the research area. Informants highlighted a decrease in certain mammal populations due to hunting, namely tepezcuintles (*Cuniculus paca*), deer (*Mazama americana*), tacuasines (*Didelphis marsupialis*), mapaches (*Procyon lotor*), armadillos (*Dasypus novemcinctus*) and rabbits (*Oryctolagus spp.*); excessive hunting of tepezcuintles has led to their being classed as endangered.

Trees and understory plants within coffee farms were understood to attract particular species of animals, birds and insects to live and/or feed. These species were observed to take advantage of the various vegetative layers in the coffee farms. Depending on farming practices, such habitat strata were observed to provide many nesting and feeding opportunities as well as protection against predators. Although not discussed in terms of its role in maintaining and increasing biodiversity, farmers identified the preferred habitat for a number of species as being at a specific stratum: the ground with stones, burrows in the soil, leaf litter, and weeds were associated with small birds, rodents, bats and snakes; the coffee plants, bushes and thickets were associated with snakes, small birds and mammals, and the trees were associated with large birds, squirrels and other mammals. While different structural levels were said to provide habitat for different fauna, farmers recognised that other spatial features across strata within coffee farms were also important for particular species, with each feature providing a unique habitat. An example of this would be the thickets that grew on the edge of coffee farms; these were said to be used by species such as the pheasant (unidentified of the Order Galliformes and Subfamily Phasianinae).

Attributes of different trees were also observed to influence which species used them, for example, tasiscovo with its straight branches attracted squirrels (KB statement no. 131) and mano de leon with its o pen crown was preferred by some birds because it meant they could fly from their nests easily (KB statement no. 181). Farmers said that, in general, trees with dense crowns provided protection for birds against the elements and predators. They emphasised, however, that each bird or animal would have its own requirements and preferences, so dense crowned trees would not suit all. Phenological attributes of trees, such as timing of fruiting, were considered major factors in attracting mammals and birds to coffee farms throughout the seasons (KB statements no. 136, 137 and 158), particularly if there was a high abundance of sweet fruits such as those of nispero, amate and capulin trees (KB statement no. 586).

Farmers made general statements about birds (Figure 4.6), but they also had more detailed knowledge of where specific birds were nesting, amongst other species like squirrels and bees. Farmers further pointed to the role that birds themselves play in increasing tree diversity through bringing fruits and seeds from other coffee farms or from the forest, and contributing to natural regeneration and the establishment of new tree species.

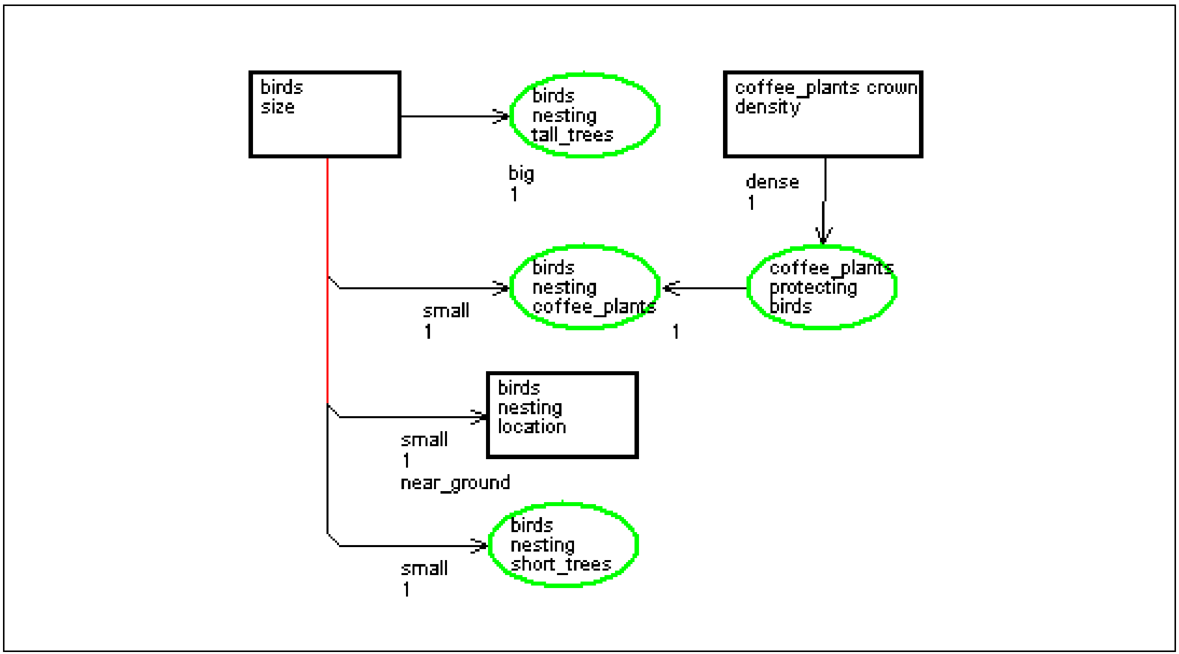

Figure 4.6. AKT causal diagram representing general statements about bird nesting locations in coffee farms

Nodes represent natural processes (ovals) or attributes of objects, processes or actions (rectangles with straight edges). Words denote a value of the node other than increase or decrease (e.g. when bird size is **small**, their nesting location is **near_ground**). Number (1) indicate one-way relationship (increment in node A cause increment on node B, or decrement in node A cause decrement in node B).

Table 4.8. Relationships between trees and fauna within coffee agroforestry systems

Local name	Scientific name	Interaction
Achiote	*Bixa orellana*	Unidentified birds eat seeds
Aguacate de montaña	*Persea americana*	Squirrel (*Sciurus* spp.), tacuasin (*Didelphis marsupielis)*, tepezcuintle (*Cuniculus paca*) and unidentified birds eat fruits; *C. paca* eats tree bark
Aguacate de bajío	*Persea schiedana*	*Sciurus* spp., *Didelphis marsupielis* and unidentified birds eat fruits
Amate	*Ficus glabrata*	*Sciurus* spp., bat (Chiroptera), *Cuniculus paca*, *Didelphis marsupielis* and unidentified birds eat fruits
Anono	*Annona squamosa*	*Cuniculus paca* and *Didelphis marsupielis* eat fruits
Bálsamo	*Liquidambar styraciflua*	Nests of *Sciurus* spp. and unidentified birds
Banano	*Musa paradisiaca*	*Didelphis marsupielis*, unidentified mouse, chorcha (*Psilorhinus morio*), cheje (*Centurus aurifron*), chara (*Calocitta formosa*) and unidentified birds eat fruits
Capulin and capulin comestible	*Trema micrantha* and *Muntingia calabura*	Many unidentified birds, *Psilorhinus morio*, *Centurus aurifron* and *Calocitta formosa* eat fruits
Ceibillo	*Ceiba aesculifolia*	Unidentified birds eat fruits
Chupte	*Saurauia laevigata*	*Didelphis marsupielis* and unidentified birds eat fruits
Ciprés	*Cupressus lusitanica*	Unidentified birds eat fruits
Cinco negros	*Lantana camara*	Unidentified birds eat seeds
Cordoncillo	*Piper aduncum*	Unidentified birds eat seeds
Cuernavaca	*Solanum* spp.	Unidentified birds eat fruits
Cuje cushín	*Inga oerstediana*	*Centurus aurifron*, *Psilorhinus morio* and *Calocitta formosa* eat fruits, hummingbirds and bees visit flowers
Cuje	*Inga vera*	*Centurus aurifron*, *Psilorhinus morio* and *Calocitta formosa* eat fruits, hummingbirds and bees visit flowers
Cuje caspirol	*Inga laurina*	*Centurus aurifron*, *Psilorhinus morio* and *Calocitta formosa* eat fruits, hummingbirds and bees visit flowers
Cuje grande	*Inga edulis*	*Centurus aurifron* and *Sciurus* spp. eat fruits, hummingbirds and bees visit flowers
Cuje paterna	*Inga jinicuil*	*Centurus aurifron* and *Sciurus* spp eat fruits, hummingbirds and bees visit flowers
Durazno	*Prunus persica*	*Centurus aurifron*, *Psilorhinus morio*, *Calocitta formosa* and Chiroptera eat fruits, hummingbirds and bees visit flowers
Encino blanco and encino negro	*Quercus peduncularis and Q. sapotifolia*	*Sciurus* spp. eat fruits, many ants in litter, pizco (*Piaya cayana*) and others unidentified birds arrive to eat earthworms, many honeycomb of native and exotic bees and wasps, *Centurus aurifron* eats encino's pest, armadillo (*Dasypus novemcintus*) seek food in the litter, many snakes in litter
Frutillo	Unidentified	Unidentified birds eat fruits
Guarumbo	*Cecropia*	*Psilorhinus morio*, *Centurus aurifron* and unidentified birds eat seeds

	obstusifolia	
Guayabo	*Psidium guajava*	Unidentified birds eat fruits
Higuerillo	*Ricinus communis*	Unidentified birds eat fruits
Izote	*Yucca elephantipes*	Nest of “porosoco” (unidentified bird)
Jocote	*Spondias mombin*	*Sciurus* spp., Chiroptera and unknown birds eat fruits
Lima-limón	*Citrus paradisi*	Nest of “porosoco” (unidentified bird)
Madre cacao	*Gliricidia sepium*	Bees arrive to flowers
Mango	*Mangifera indica*	*Sciurus* spp, *Didelphis marsupielis*, *Psilorhinus morio*, *Centurus aurifron* zanate, *Calocitta formosa*, Chiroptera and an unidentified bird eat fruits
Mandarina	*Citrus reticulata*	*Psilorhinus morio*, *Centurus aurifron*, *Calocitta formosa*, zenzontle (*Turdus grayi*) eat fruits
Mano de león	*Dendropanax arboreus*	Nest of unidentified birds
Manzana rosa	*Syzygium jambos*	Chiroptera and unidentified birds eat fruits
Manzanillo	*Hieronyma guatemalensis*	Unidentified birds eat fruits
Maracuya	*Passiflora edulis*	Mouse and unidentified birds eat fruits
Matasano	*Casimiroa edulis*	Chiroptera and unidentified birds eat fruits
Mielero	*Salvia karwinskii*	*Psilorhinus morio*, *Calocitta formosa* and unidentified birds eat fruits
Naranja	*Citrus sinensis*	*Psilorhinus morio*, *Centurus aurifron*, *Calocitta formosa*, *Turdus grayi* eat fruits
Níspero	*Eriobotrya japonica*	*Sciurus* spp. *Centurus aurifron*, Chiroptera and unidentified birds eat fruits
Pacaya	*Chamaedorea tepejilote*	Unidentified birds eat seeds
Palma	*Sabal mexicana*	Gato de monte (*Urocyn cineroargenteus*), Chiroptera and unidentified birds eat seed
Pino blanco	*Pinus maximinoi*	*Sciurus* spp. eat seed
Pino de ocote	*Pinus oocarpa*	*Sciurus* spp. eat seed
Pito	*Erythrina berteroana*	Unidentified birds eat fruits
Salaqué	*Cupania glabra*	Unidentified birds eat fruits
Tatascamite	*Perymenium grande*	Hummingbird and bee visit flowers. Nests of *Sciurus* spp.
Tefrosia	*Tephrosia vogelli*	Unidentified birds eat fruits
Zapote	*Manilkora zapota*	*Sciurus* spp., *Didelphis marsupielis* and unknown birds eat fruits

4. Discussion

Farmers' classification of trees

This classification is not exclusive to Guatemalan coffee growers. It has been presented and discussed widely for other coffee countries in the region (Cerdán *et al*., 2012, Cerdán *et al.*, in prep); neither is it exclusive to coffee growers (Aumeeruddy, 1994). In spite of its wide use by farmers, it is still unclear how exactly a tree is classified as hot or fresh. There are many tree attributes and functions related to this classification. Many of the trees that were classified as 'fresh' by the coffee growers in El Hato watershed were thought to be good for water, whereas, 'hot' trees were strongly related to low protection of streams. Similarly, the majority of the 'fresh' trees were thought to have a positive impact on soil fertility, moisture and erosion control, whereas, a majority of 'hot' trees were thought to have a negative impact on these three issues related to soils. Similarly, the 'good' shade trees for coffee were predominately classified as 'fresh' trees. Conversely, 'bad' shade trees were classified 'hot'.

Trees classifications according to tree impacts on soil, water and coffee are, in fact, "local functional classifications". Farmers stated that trees with a positive impact on soil moisture are those species that moisturized the soil in a favorable way for coffee plants, through avoidance of soil drying (crown diminishing sunlight) or the tree root abundance providing water to the coffee plants in the vicinity. This can be related to two scientific debates. On the one hand, shade trees are known to increase the total stand transpiration (van Kanten and Vaast, 2006), but also to buffer the plantation microclimate, reducing the evaporation from the soil surface and decreasing water stress on coffee caused by exposure to direct sunlight (Siles *et al.*, 2010). Shade trees get their water from deeper soil layers than the coffee plants (van Kanten *et al.*, 2005). Hydraulic lift has been observed in some cases where the shade tree root system improves the water redistribution from deep, moist soil horizons to dry, shallow layers (Caldwell *et al.*, 1998). The role of trees in soil water conservation has been reported elsewhere for canopy, crown (de Bello *et al.*, 2010) and roots (Burgess *et al.*, 1998).

Farmers stated that tree litter impacts soil fertility. Glover and Beer (1986) reported how the litter amount in coffee agroforestry systems influences the nutrient cycling, in turn, farmers related litter amount to tree leaf size and texture, which is in agreement with abundant literature (e.g. de Bello *et al.*, 2010).

Tree knowledge discrepancies in respect to farmers from other areas

Four strong discrepancies were found regarding tree functional classifications by farmers in the area with respect to farmers from Nicaragua and Costa Rica (Table 4.3). The species with differences were *Psidium guajava*, *Pinus oocarpa*, *Mangifera indica* and *Liquidambar styraciflua*. *Mangifera indica* and *Psidium guajava* are low altitude fruit trees (León, 2000), lower than the Guatemalan farms where their impacts were described. In this case, we observe the reverse situation, these trees were mentioned as having positive impacts on soils in Nicaragua and Costa Rica, and negative impacts in Guatemala; it is likely the altitude changes the impact observed by farmers. The discrepancies were related to the trees impacts on soil fertility, erosion and moisture, as well as in the hot/fresh classification for *M. indica*. Additionally, coffee farmers classified *Piper aduncum* as a having a positive impact in protecting streams, when farmers of Papua New Guinea sometimes use this species to dry waterlogged soils (Siges *et al.*, 2005), discrepancies could arise from the factor that altitude and climates are different between these countries. When the total number of species reported is considered, these discrepancies represent a low proportion of the total knowledge expressed. Farmers from El Hato watershed classified *P. oocarpa* and *L. styraciflua* as having positive impacts on soil erosion and moisture, whilst in Costa Rica and Nicaragua these species were classified as having negative impacts (Cerdán *et al*., 2012, Cerdán *et al.*, in prep). Both species are Guatemala natives and grow naturally in our study region, whereas these same species were introduced to the warmer study areas of Nicaragua and Costa Rica. It is possible that they have more positive impacts on the ecosystem in their area of origin than in the places where they were introduced. Farmers never mentioned the origin of the trees as an attribute to be considered, but it is expected that trees can have different impacts depending on their relative suitability to the local environment.

Why do small landholder farms retent more non-shade tree species?

Trees reported by farmers as having negative effects on coffee plants were nevertheless found within coffee plantations. This is due in large part because elimination could be problematic (i.e. felling trees could cause more damage than keeping them). But these trees with negative effects on coffee plants could at the same time provide important resources for farmers (Méndez *et al*., 2007), such as timber, firewood (Rice, 2008), fruits (Rice, 2011), medicines or simply shelter for wild animals. Other social (e.g. family size), economic (e.g. farm size and the availability of land) (Kindt *et al.*, 2004) and political factors (Somarriba *et al.*, 2004) could also influence the tree diversity and the presence of species with negative impacts found within coffee plantations.

The most common trade-off between coffee productivity and other ecosystem service provision was farmers utilizing trees within the plantation as a source of timber or firewood, such as *Perymenium grande*. Even though farmers recognised that *P. grande* was highly competitive with coffee plants, it was still present at low densities on many farms because its wood is commonly used for making durable fences. It is important to highlight that timber species, which are frequently recommended to improve the long-term profitability of agroforestry plantations (Somarriba and Beer, 2011), were mainly classified as hot by farmers and having negative impacts on ecosystem services. For instance, *Colubrina guatemalensis*, *Cupressus lusitanica* and *Swietenia humilis* are species recommended[8] for intercropping with coffee. Farmers mentioned these species as having negative impacts on soil fertility and coffee plants. Farmers specifically pointed out *C. guatemalensis,* as having negative impacts in all the local functional classifications.

The predominant trade-offs between provision of ecosystem services mentioned, and clearly understood by farmers were those that concerned coffee productivity and other ecosystem services. Farmers also mentioned additional trade-offs between ecosystem services and services such as provisioning (with the exception of coffee provision) and regulating. For example many of the trees protecting water sources were not used as a timber source, either because of poor timber quality and/or because they were observed to provide a more important service by protecting valuable water sources. Amate (*Ficus glabrata*), capulín (*Trema micrantha*) and cordoncillo (*Piper aduncum*) were species that were all considered able to protect water sources, while their firewood or timber was deemed not useful. Another example of a trade-off between provisioning and regulating services could be seen between soil erosion control and fruits provision. Amate (*Ficus glabrata*), ciprés (*Cupressus lusitanica*), cuje (*Inga vera*), gravilea (*Grevillea robusta*), guachipelin (*Dyphisa americana*), bálsamo (*Liquidambar*

[8] Either in the AgroforesTree database (ICRAF, 1998) or Arboles de Centroamérica database (CATIE, 2003)

styraciflua), pino blanco (*Pinus maximinoi*), pino colorado (*Pinus oocarpa*) and yaje (*Acacia acanthophylla*) all had roots that were said to combat soil erosion, but none of them provided edible fruits for farmers' diets. Farmers were aware of the trade-offs between services provided by trees. The diversity of trees present on a farm is likely to be related to this need to obtain different ecosystem services.

Local knowledge regarding conservation in an area buffering a protected reserve

Tree diversity within coffee plantations has been acknowledged for its potential conservation value (Moguel and Toledo, 1999). However, this diversity is managed by farmers; either to enhance ecosystem services that they deem useful (e.g. regulating services) or to obtain valuable goods (e.g. provisioning services) (Rice, 2008), and not necessarily for the sake of conservation. Understanding the patterns of biodiversity in agricultural landscapes managed with a variety of purposes, as in the case of diversified coffee smallholder plantations buffering a biological reserve, is a key to understanding the status and future state of global biodiversity (Chazdon *et al.*, 2009).

The study of local knowledge has many obvious advantages in understanding and responding to ecological problems (Bart, 2006). The number of publications regarding local knowledge has been increasing in the last few years; however, the results of these studies (i.e. the documentation of local knowledge) have not been incorporated accordingly into the development of policies for natural resources management (Brook and McLachlan, 2008).

In this agricultural area at the boundary of a natural reserve, the local knowledge of the relationships between biodiversity and the trees is particularly developed. The role of 51 tree species feeding and hosting birds and mammals was expressed by farmers in the area. Farmers are generally most interested in "productive" biodiversity rather than in "non-productive" biodiversity (Altieri, 1999). Birds and mammals related to trees within coffee plantations would be called "non-productive" biodiversity. In reality, when farmers were asked they were unable to recognize the advantages and/or disadvantages of animals present on their farms, with the exception of snakes and the fact they enjoyed observing birds and small mammals on their farms. El Hato farmers' perception of animals on their farms coincides with those of coffee farmers in other regions (López del Toro *et al.*, 2009). The farmers' neutral perception (although slightly positive) about advantages of animals would be useful in the design of participatory conservation programs in the area.

Farmers also recognized the value that their farms have as biological corridors for animals, in particular for birds. They were able to identify if the bird species are exclusive to forest, “well-adapted” to coffee plantations, or only using coffee as a corridor. The value of trees in agricultural systems to support fauna has been stated in Harvey *et al.* (2006). Biodiversity conservation in agricultural landscapes cannot be effectively advanced if it cannot be defined and measured (Chazdon *et al.*, 2009). Farmers’ knowledge regarding the species specific relationships of trees and birds, after it has been scientifically probed, would be a useful tool in the development of indicators to participatory assessments of the condition of the El Hato watershed.

5. Conclusions

It was found in this region that farmers’ knowledge regarding tree cover and its relationships with ecosystem services, biodiversity conservation and coffee management is detailed, complementary and under-utilised, as is the case in coffee growing regions in other countries. Knowledge was detailed in situations that impact farmers’ livelihoods (e.g. tree species, functional classification of trees, understanding of climatic conditions); complementary not only among farmers from different altitudinal zones but also between farmers and scientists (e.g. the relationship *Azteca* ant – *Cecropia* tree – coffee borer); and under-utilised in the design and management by other stakeholders (e.g. the farmers’ knowledge regarding the relationships between trees and fauna).

Acknowledgments

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Note on land use change and plots to determine the trade-offs among coffee production and ecosystem services

The proposal presented in my PhD candidacy examination had originally two extra chapters that are not included in this manuscript. In order to have a better understanding of the farmers' management regarding trade-offs between coffee provision and ecosystem services, local knowledge research would be complemented with the historical context of the coffee areas, as well as the productive context of the farms. Fieldwork of both chapters was carried out in Nicaragua and data has been partially analyzed. Lack of time did not allow me to include them in the present dissertation. Though they are not part of the thesis, they are part of my global contribution to scientific knowledge and deserve therefore a short mention. The preliminary titles and abstracts of these studies are presented here:

Land use change typologies among Nicaraguan coffee farmers

In preparation for submission to *Landscape Ecology*

This research identifies patterns of land use change among coffee farmer settlers in the Northern Nicaragua and their relations to household characteristics. The research is framed within the household lifecycle theory as well as the CGIAR framework for forest and tree cover transition. Over 200 smallholders coffee farmers were interviewed in two contrasted coffee producing regions in Nicaragua (El Cuá and Jalapa) about their land use changes during the last 50 years (1960-2010). A "typology" of land use and land use changes patterns was built and considered in relation to household characteristics: age, household composition, and year of settlement. Findings suggest that "rich" farmers with high education level have proportionally more land under coffee, and they converted directly forest to coffee or pasture, whilst poor farmers with more family members have proportionally more land under basic grains. Elimination of forest was performed by all farmers alike, especially during the years of high coffee prices. The identification of distinct land use processes improves the understanding of the CGIAR forest cover transition model, which considers that agroforestry is the land use towards which agriculture should go in order to provide well balanced ecosystem services and dignified livelihoods. A good understanding of the local context and land use processes over time is important for the management of the agricultural landscape for sustained provision of environmental services. This is particularly important in areas such as El Cua and Jalapa, where shaded coffee plantations provide a large part of the tree cover in a buffer zone and water catchment areas, respectively, and therefore, play an important role in the delivery of ecosystem services.

Ecosystem services and productivity in coffee-based agroforestry systems in Nicaragua

In preparation for submission to *Agriculture, Ecosystems and Environment*

Many studies have measured biodiversity loss across the coffee intensification gradient; some studies have shown, with contradictory results, the trade-offs between biodiversity loss and coffee production increments. Plot assessments of tree diversity, soil conservation, carbon sequestration and coffee production are lacking. We characterized the structure, productivity, diversity, soil conservation and carbon sequestration of 40 coffee agroforestry systems in two different areas in Northern Nicaragua. Coffee management, environmental conditions and soils properties were also characterized to better understand the trade-offs among services within the plots and their dependence on the local environment. These agroforestry systems were chosen to maximize contrasts in terms of biophysical context, botanical composition and management practices. Results (preliminary) showed significant differences in the vegetation structure that enabled us to identify main clusters: CAFS with dense and diverse overstorey canopy, CAFS with high Musa density and CAFS with low density of overstorey canopy. Changes in vegetation structure reflected differences in farmers' strategies but did not affect the overall coffee yield or the conservation of soils. Coffee yields had strong variations among the plots, and this was mainly related to the amount of fertilizer applied. Neither carbon sequestered, soil conserved nor tree diversity have a significant negative relationship with coffee productivity. However, coffee yields were low comparing with other coffee areas in the region. These results open new perspectives to improve coffee agroforestry systems' structural complexity and their relative ecosystem services without affecting their overall productivity. Further investigations and a more stratified sampling to get a good grasp of the whole range of variability (in highly productive areas with less shade canopy) are needed to fully understand the mechanisms involved in trade-offs.

Chapter 5. General Discussion

Key findings

This thesis presented the knowledge retained by coffee farmers regarding trees across a range of agroforestry systems in Costa Rica, Guatemala and Nicaragua, in relation to biodiversity conservation, coffee production and other ecosystem services. The Agroecological Knowledge Toolkit (AKT) methodology was utilized and involved a series of iterative cycles eliciting knowledge from 99 farmers through semi-structured interview, representation, and finally evaluation of the knowledge obtained using an explicit knowledge-based systems approach. Three Knowledge Bases (KB) have been generated, one per country, and are freely accessible on a webpage (akt.bangor.ac.uk). User's manuals to explore and understand each KB using the AKT software were developed and are also available on the webpage.

The thesis is comprised of three main research chapters: **Chapter One** presents the results obtained from 50 Costa Rican farmers, plus the knowledge validation of the other 93 farmers surveyed. It was the study area that had fewest tree species mentioned by farmers (36). These farmers had detailed knowledge regarding ecological processes within coffee plantations. However, management practices focused on coffee production while biodiversity conservation and ecosystem services were clearly marginal, aimed at by farmers only if they were enhancing, or at the very least not decreasing coffee production. Knowledge from other stakeholders (coffee technicians, processors and scientists) was also studied, and it was complementary to farmers' knowledge. **Chapter Two** presents the results obtained in Nicaragua. The study area selected was a relatively new coffee region, located far from urban centres. In addition to the farmers' knowledge compilation, plots within the farms were established to observe agricultural practices and estimate tree diversity. The 20 farmers interviewed described almost twice as many trees as in Costa Rica (68); nevertheless knowledge between the two countries regarding trees was very similar. Nicaraguan farmers were less specific about coffee production topics and the origin of knowledge was also different. Many statements were learned in technical trainings and at times were not well understood by the farmers. Knowledge originating from farmers' experience and observations was better explained. Coffee plots measurements revealed a high heterogeneity in coffee productivity, while all plots showed similar impacts on the environment (soil conservation, tree density and diversity). **Chapter Three** presents the knowledge compiled from 29 Guatemalan coffee farmers. The study area was located in a coffee growing region buffering a large natural reserve. Moreover, the orographic characteristics of the area drive farmers from communities close to each other to adapt their farming management to different conditions. The results of this chapter show how the farmers' knowledge varies according to the agroecological conditions. Additionally, findings related to biodiversity were complementary to the knowledge found in the previous chapter about biodiversity (essentially mammals and birds) in relation to trees in coffee plantations. Due to different coffee growing histories, institutional contexts and biophysical conditions, the chapters describing farmers' knowledge are quite complementary with each other. The following pages will report conclusions that are valid for all of them.

Trees: their attributes and classifications

Farmers mentioned a total of 133 tree species, some shared between the different study areas. Costa Rica had the lowest number of tree species reported with 36, Nicaragua had almost twice that amount with 68, and Guatemala had the highest number with 77. There were nine tree species in common mentioned by farmers in Guatemala and Nicaragua, six in Nicaragua and Costa Rica, and four in Costa Rica and Guatemala. Farmers from all three countries mentioned twelve tree species. With the exception of six species, all species were botanically identified. The complete list of species mentioned in the chapters is presented in Anex 1 with their local classifications and attributes.

In the three study areas, coffee farmers reported functional classifications of trees through the combination of tree attributes. Attributes and classifications showed slight differences between the three countries: Costa Rican farmers mentioned the highest number of tree attributes (11), eight attributes were mentioned in Nicaragua and seven in Guatemala. Farmers in Nicaragua did not mentioned above groun attributes such as canopy phenology, biomass production, and crown openness. In Guatemala, farmers did not mention canopy phenology. Costa Rican farmers classed the trees according to their overall impact on soils, whilst Nicaraguan and Guatemalan farmers detailed the impacts on fertility, erosion, and moisture of soils. Costa Rican farmers were very explicit about canopy "dripping", caused by the accumulation of water in the tree canopy which, (before this thesis, this was reported by Beer *et al.*, 1998), affects soil erosion and dispersal of *Mycena citricolor* (fungal coffee disease). Costa Rican farmers included an extra classification according to whether trees caused dripping. On top of all these functional classifications, all farmers in each of the three countries used a “fresh/hot” classification for trees that involves many different attributes and overlaps with these functional classifications. This classification is scarcely used by scientists or technicians in these countries.

For tree classifications, a total of 60 discrepancies were noted among the farmers from each of the three countries for the 133 tree species. Of those 60 discrepancies, only nine were considered to have a strong discrepancy (Figure 5.1), accounting respectively for 9.3% and 1.4% of the data. The nine strong discrepancies were concentrated in four tree species: *Liquidambar styraciflua*, *Mangifera indica*, *Pinus oocarpa* and *Psidium guajava*. The “impacts on coffee” classification had the higher number of discrepancies; however all of them were slight.

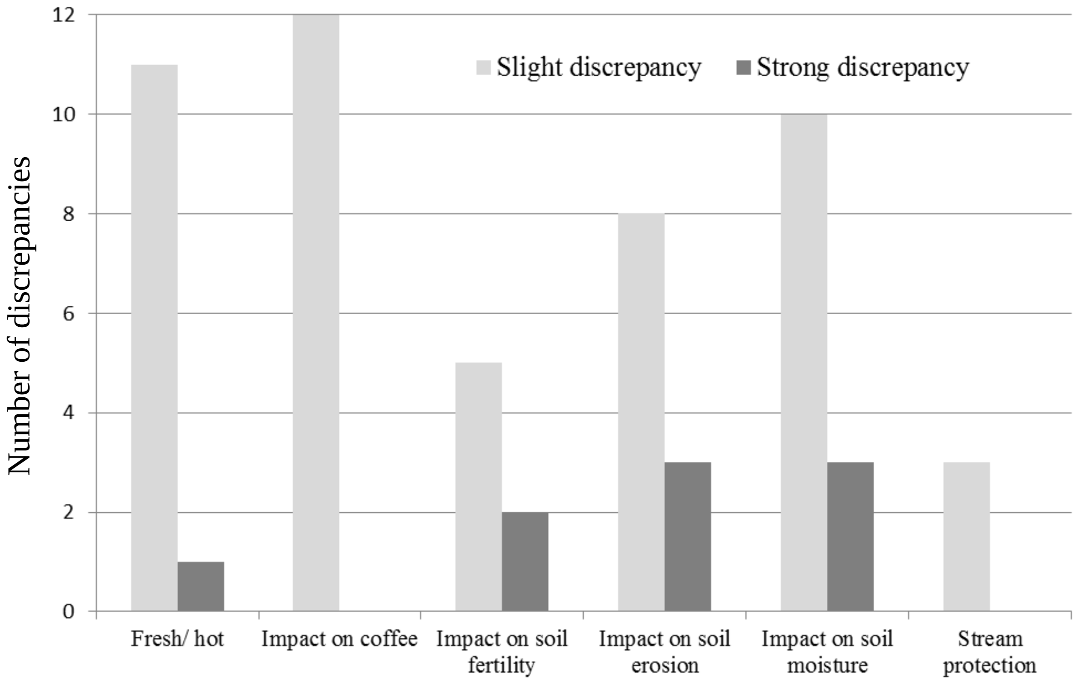

Figure 5.1. Discrepancies between farmers of different areas regarding the classification of trees

A total of 56 discrepancies were identified in regards to tree attributes; 48 attributes had slight discrepancies and eight had strong discrepancies (Figure 5.2). These discrepancies were equivalent to 6.9%, 5.9% and 1% respectively, of the total attributes mentioned. Of these attributes, leaf size and ease of pruning constituted more than the half of the total discrepancies. Crown openness and root depth were the least mentioned discrepant attributes. *Persea americana* and *Gliricidia sepium* had four slight discrepancies. *Cecropia obstusifolia* had two strong discrepancies, and the remaining strong discrepancies were scattered among different tree species.

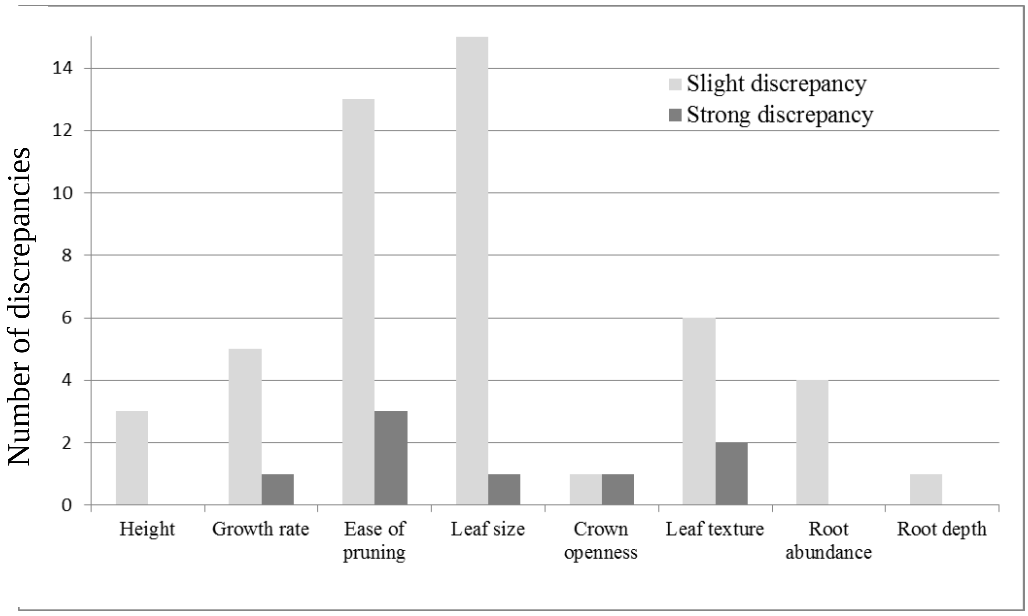

Figure 5.2. Discrepancies between farmers of different areas regarding attributes of trees

A high proportion of the data regarding tree classifications and atributtes is lacking (37% of the cells). This is explained by the fact that farmers talk freely about the topics and the trees they know best (data was not compiled through a survey covering all the tree species); additionally, farmers are not knowledgeable about all the tree attributes nor in which class the trees fits in. There were 155 classification data points lacking, 75% of which are part of the stream's protection, impact on coffee and impact on soil fertility (Figure 5.3) classification. The fresh/hot classification is extremely well informed (only 3% data lacking).

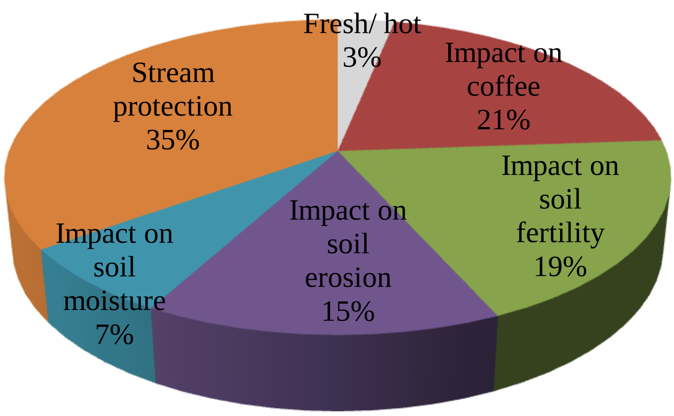

Figure 5.3. Distribution of data lacking in the classification of trees

Regarding tree attributes, farmers did not mention 683 data points for the 133 tree species. Root attributes were the most frequently lacking, conversely, leaf size was expressed for almost all the 133 tree species (Figure 5.4). Species where attributes were less well informed were reported in Guatemala. Guatemalan farmers mentioned the highest number of species, but also had the least species details. For instance, there was no attribute data for *Passiflora edulis*, and *Myrica cerifora* was listed only as a small leaved tree. The species with fewer attributes mentioned were classified mainly as having negative or medium compatibility with coffee, such as *Bernandia interrupta*, *Bixa orellana*, *Cedrela tonduzzi*, *Ceiba aesculifolia*, *Colubrina guatemalensis*, *Lantana camara*, *Salvia karwinskii*, *Saurauia laevigata*, *Spatodea campanulata*, *Tephrosia vogelli*, *Ulmus mexicana* and *Zanthoxylum caribaum*. Moreover, four of the six unidentified trees had data only for phenology and leaf size (locally the species were called ixtacama, maicena, siguapate and tres puntas). The only trees species that were classified as having a positive impact on coffee and were listed with few attributes were *Chamaedorea tepejilote, Grevillea robusta* and *Inga laurina*.

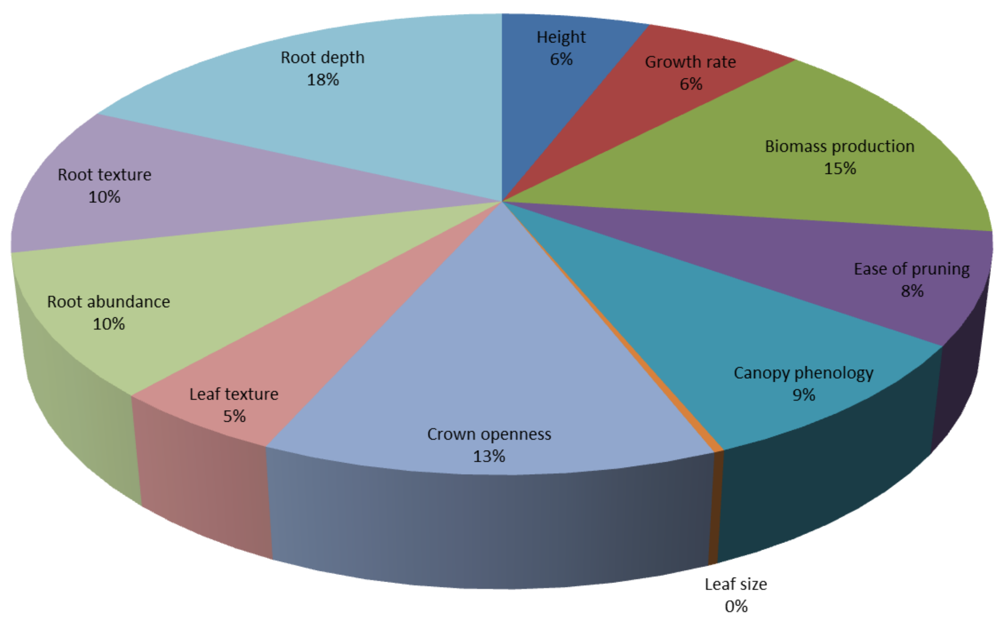

Figure 5.4. Distribution of data lacking in the attributes of trees

A common finding across the study areas was the farmers' classification of trees as 'fresh' or 'hot'. Each chapter reported how farmers in all the study countries classify most tree species either as 'fresh' or 'hot', depending on attributes such as tree crown type, leaf size and texture, and how these attributes affect coffee plants. Farmers stated that the 'freshness and hotness' of trees is related not only to their effect on coffee plants but also on ecosystem services such as water provision and soil formation. The different classifications farmers use for shade trees were also found to be partially overlapping, particularly the 'hot/fresh' and the positive impacts on water and soils classifications. A tree was classified overall as 'hot' (negative) or 'fresh' (positive) according to their functions in the system, for example quality of shade to coffee, avoidance of erosion, or protection of streams. Water was associated with 'freshness'. Riparian forests and water sources are 'fresh' places, and so are the trees associated with them ('trees protecting streams'). Fresh trees are related to positive impacts on soil and water as well as trees compatible with coffee; conversely, hot trees are related to negative impacts on soil and water and poor compatibility with coffee trees. Trees mentioned as having "medium" impacts to soil, water and compatibility with coffee trees were classified in between the 'fresh' and 'hot' trees (Figure 5.5). Fresh trees are similar to "positive" classified trees in regards to soil fertility impacts on, erosion control, stream protection and compatibility with coffee. Trees with a positive impact on soil moisture are a bit less close to fresh trees. On the other hand, hot trees are close to the "negative" classified trees in regards to fertility impacts, erosion control, and stream protection. The two "negative" shade trees classes (bad shade and not-used as a shade tree) are also close to hot trees. Both the "medium" classified trees and lacking data are in the middle of fresh and hot trees. The relationships among the fresh-hot classification and tree attributes are presented in Figure 5.6. Leaf and root texture, as well as the ease of pruning are slightly related to 'fresh' or 'hot'; however the relationships were not as clear as the relationships among classifications shown in Figure 5.5.

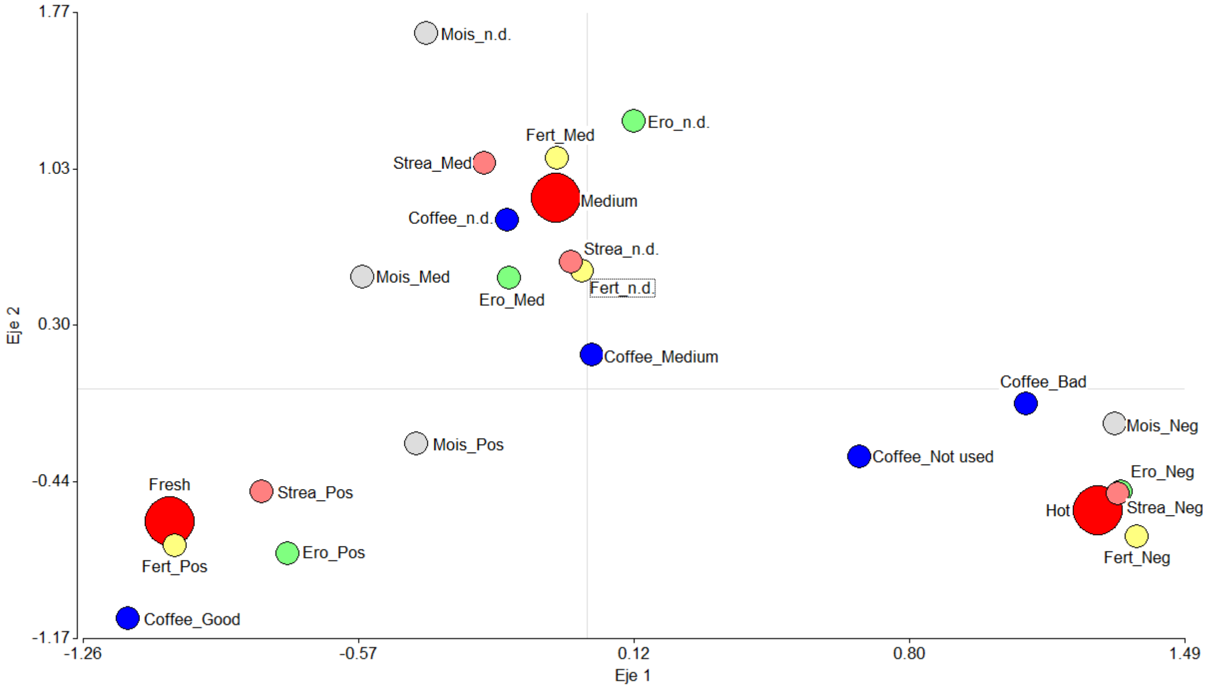

Figure 5.5. Correspondance analysis between tree classifications
Red colour for 'fresh' or 'hot' classification, blue for compatibility with coffee classification, pink for impacts on stream protection classification, yellow for impacts on soil fertility, grey for impacts on soil moisture, green for impacts on soil erosion control (Pos= positive, Neg= negative, 'n.d.'= no data)

As presented in the previous chapters, this fresh-hot classification is widely used by coffee farmers, but is almost unrecognized by technicians and scientists. Kiptot *et al.* (2006) mentioned the importance of being aware of farmers' knowledge in order to understand the potential barriers in carrying out sustainable practices. Numerous initiatives, such as local and national programs for payment of environmental services (PESs) and coffee certification schemes, are providing incentives and promoting tree species for coffee farmers in Latin America with the main objective to provide a range of ecosystem services in addition to producing coffee. As farmers handle this classification of trees regarding coffee and ES, technical interventions addressing the improvement of coffee plantations are more likely to be successful if they take the farmers' knowledge into account.

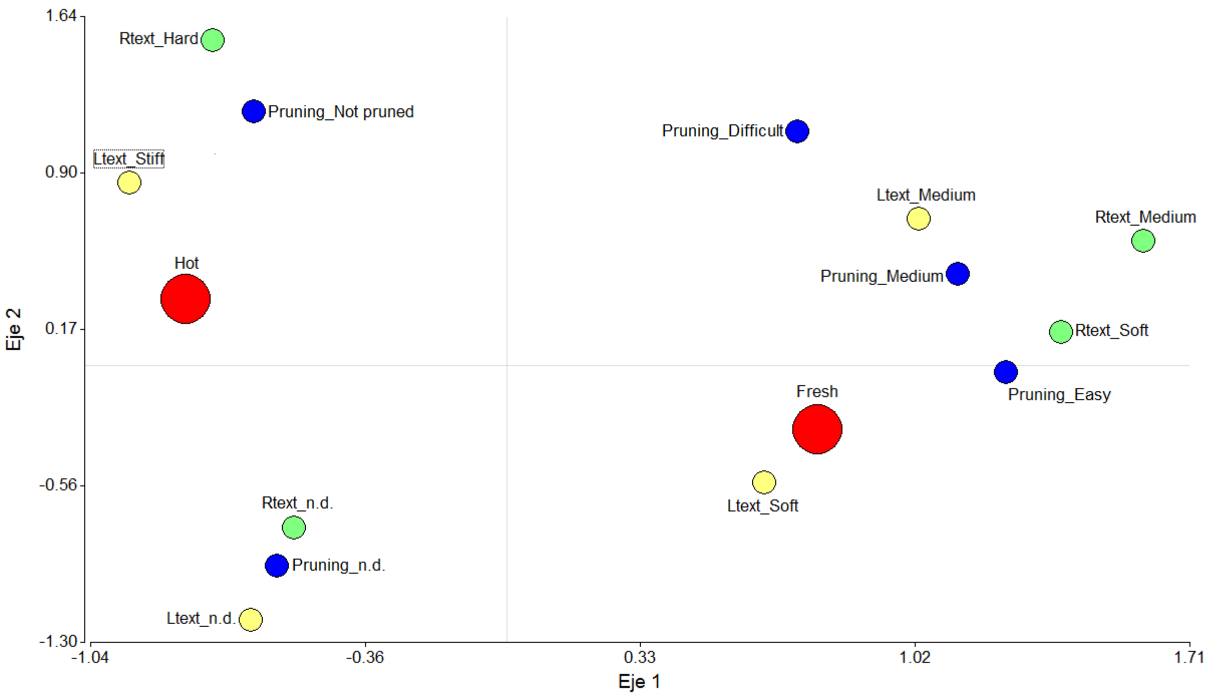

Figure 5.6. Correspondance analysis between fresh and hot trees and tree attributes
Red colour for 'fresh' or 'hot' trees, yellow for leaf texture, blue for ease of pruning, green for root texture.

Clustering tree attributes for ecosystem functions

The relationships between tree attributes and ecosystem services (and functions) have been documented for each country in the corresponding chapters. The relationships most often reported as tree attributes-ecosystem functions associations were in regards to five ecosystem functions: soil (fertility, erosion and moisture), water regulation and compatibility with coffee (Figure 5.7). The assessment of other ecosystem functions and services, such as biodiversity conservation or pollination, is species-specific and has been based on tree attributes to a much lesser extent.

According to the farmers in the three study areas, the combinations of tree attributes were important for the five main ecosystem functions, either impacting positively or negatively. Multiple tree attributes were connected to one function, leaf texture and leaf production, canopy phenology (deciduousness), root texture and depth were connected to soil fertility; height, leaf size and texture, woody growth rate and ease of pruning to compatibility with coffee. The combination of plant attributes impacting ES/functions is called trait-service clusters (de Bello *et al.*, 2010). The understanding of multiple linkages between tree attributes and functions should thus be scientifically validated and considered for the development of technical projects aimed at improving productivity or other ecosystem services within coffee agroforestry systems.

Figure 5.7 does not differentiate between tree attributes and functions as positive or negative; rather it illustrates which attributes the farmers mentioned during the interviews as influencing a function. It only shows responses regarding farmers' knowledge when they were asked about the correlations between classifications and tree attributes. Table 5.2 illustrates the value of tree attributes positively affecting main functions (e.g. 39% of the 67 tree species classified as compatible had a high plant height).

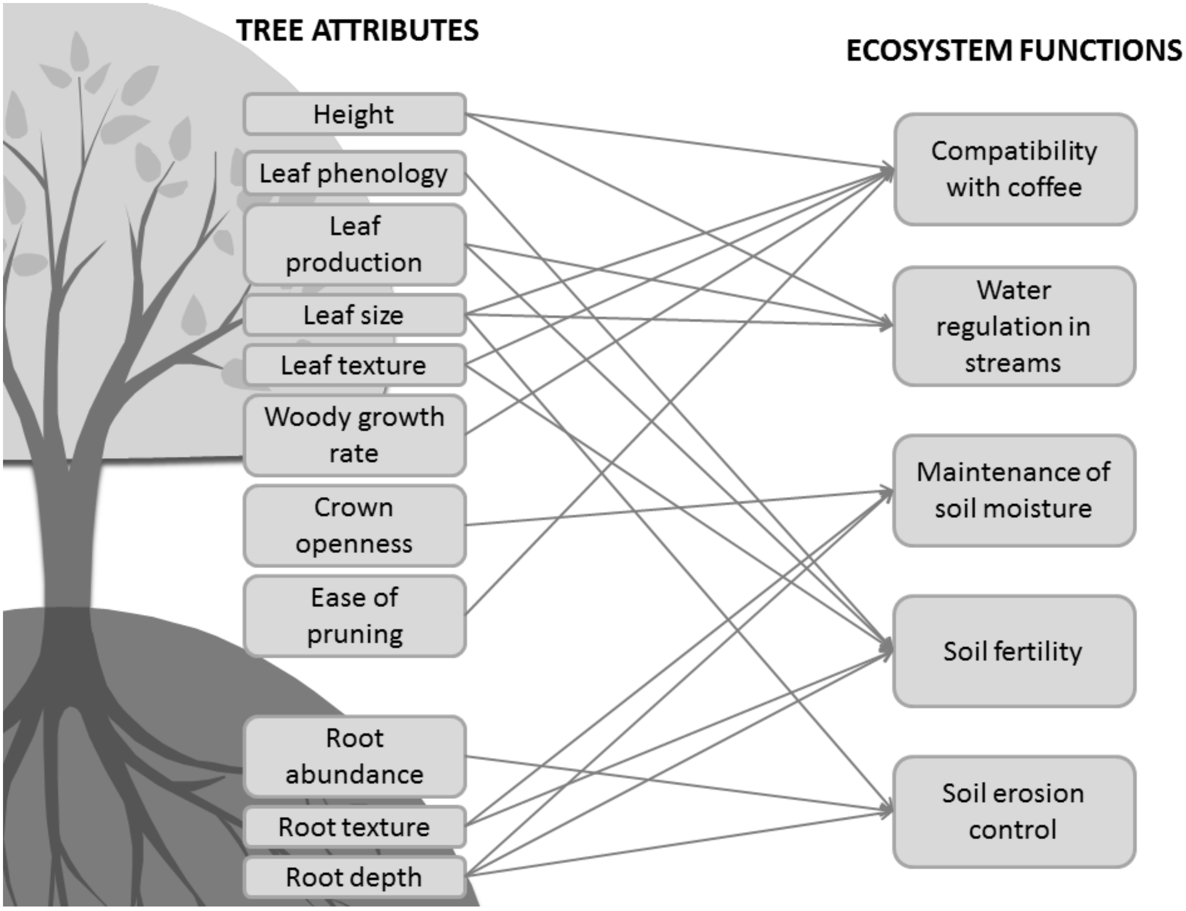

Figure 5.7. Most common tree attributes related, either positively or negatively, to ecosystem functions

When asked, farmers mentioned the main attributes impacting the five functions: leaf phenology, leaf texture, woody growth rate and root abundance. However, when the list of species was reviewed, different attributes were found to have a stronger positive impact on functions. For instance, abundance of roots was related only to soil erosion control (Figure 5.7); however, abundance of roots was found in the majority of the trees species positively impacting the five functions (Table 5.1). It seems that farmers observe some attributes as they gave examples during the interviews; however, they were not as able to link additional attributes with ecosystem functions.

Similarly, farmers related woody growth rate with only one function, compatibility of the tree with coffee, where fast growing trees were considered compatible and slow growing trees were not. However, a fast woody growth rate was found only in half of the tree species having an impact on compatibility and also for the other ecosystem functions.

Table 5.1. Tree attributes with positive impacts on ecosystem functions, expressed in percentage

Ecosytem functions	# Tree spp.	Height high	Cano. pheno evergreen	Leaf prod. high	Leaf size big	Leaf text. Soft	Woody growth fast	Crown openn. closed	Ease of pruni. not pruned	Root abun. abundant	Root text. soft	Root depth Deep
Comp. with coffee	67	39	75	21	21	54	58	24	27	58	33	6
Water regulation	52	67	50	40	40	75	75	35	54	67	58	12
Maint. of soil moisture	94	49	64	26	26	55	54	31	36	59	35	7
Soil fertility	74	57	50	27	27	74	72	26	47	58	47	9
Soil erosion control	87	49	60	25	25	60	59	30	36	59	39	7

Note: It was highlighted if the attribute was reported for more than the 50% of the tree species.

Overview of the farmers' knowledge regarding ecosystem services

Farmers have a vast knowledge about ecosystem services and biodiversity conservation, as well as the role of their own farms in the provision of them. When asked about the services provided in coffee plantations, farmers gave accurate information about soil formation, water regulation, as well as the provision of goods, such as timber, firewood, fruits, and, obviously, coffee. Farmers also mentioned the roll their farms play in biodiversity conservation.

Despite the complex and detailed knowledge possessed by coffee farmers, they understand and prioritize ecosystem services differently from the scientific community. As coffee growers, they are focused in the area of coffee "supporting" services, such as soil fertility, regulation of pests, avoidance of soil erosion, water regulation, and micro-climate regulation (for the coffee plants). They mentioned much less frequently pollination, pest bio control or cultural services as aesthetic value. Farmers are also knowledgeable about trade-offs among services affecting coffee. For Costa Rican farmers, coffee productivity is the overarching objective. However, farmers and scientists have different interests regarding the provision of services in coffee plantations. For instance, farmers have felt changes in climate, but they only talk about adaptations to regulate climate for plants. They are not concerned with climate on a higher scale. Moreover, none of the 99 farmers expressed knowledge relating to carbon sequestration. The extent of knowledge regarding different ecosystem services expressed by the farmers is shown in Figure 5.8, and illustrates at which spatial scale the ecosystem services are provided, as well as if the farmers had knowledge about those services at that scale.

Coffee farmers' knowledge was essentially expressed in: 1) Provisioning services. In the Nicaragua and Guatemala study areas, it was reported how farmers managed the trade-offs between coffee productivity and other ecosystem services. Trees reported by farmers as having negative effects on coffee plants were nevertheless found within coffee plantations, because these trees with negative effects on coffee plants could at the same time be providers of important resources for farmers, such as timber, firewood, fruits, medicines or simply shelter for wild animals. 2) Coffee farmers' knowledge was essentially expressed at small scales (plant, plot and farm). For instance, nutrient cycling knowledge was essentially the interaction between coffee and trees. Nothing was expressed about soil interaction with microorganisms, which farmers could not observe. Farmers mentioned litter degradation, competition of trees with coffee, but nothing on the smallest scales, and also nothing on the higher scales, for example, the nutrient balance at a farm scale. Primary production was the unique ecosystem service on which farmers did not express any knowledge.

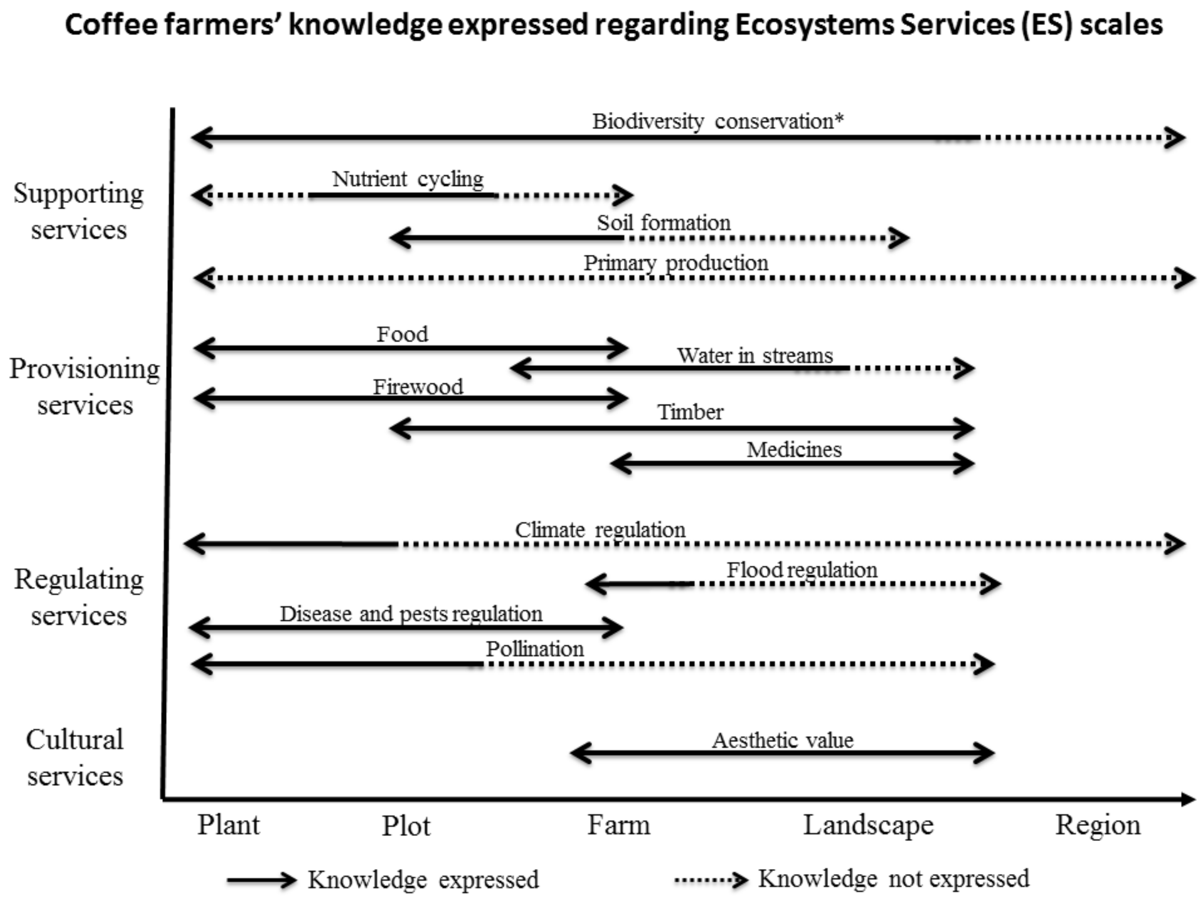

Figure 5.8. Coffee farmers' knowledge regarding the ecosystem services scales
Arrows extension indicates the scale in which ES are spatially explicit. Lineal arrows indicate the scale at which farmers expressed knowledge, while dotted arrows indicates the opposite. Ecosystem services were framed according to the Millennium Ecosystem Assessment (MEA, 2005). *Biodiversity conservation is not a proper service according to MEA (2005). However, it was included in the figure because farmers expressed knowledge regarding it.

Species-specific knowledge regarding biodiversity

Farmers had a deep understanding about interactions between fauna and vegetation composition on farms. As a difference with the other ecosystem services, knowledge regarding biodiversity is species-specific and cannot be related to tree functional classifications and scarcely to tree attributes, like the flowering frequency and timing. Farmers stated a total of 423 statements regarding biodiversity, many of them connecting trees with animal and birds. Guatemalan farmers stated almost twice as many statements (211) as in Costa Rica (114) or Nicaragua (108).

Farmers' knowledge regarding biodiversity is more novel than for the rest of the ecosystem services. To the author's knowledge, the relationships of tree species as a resource for feeding or nesting animals and birds have not been reported elsewhere. Attempts to promote biodiversity within agroforestry systems, like the coffee certification schemes, could take into account in their recommendations the species that farmers report as useful to animals and birds, especially those that farmers mentioned as not affecting coffee production. Guatemala was the country with the highest number of tree species mentioned as useful to biodiversity, with 51 species. Farmers also recognised the existence of a complex vertical structure within the coffee farms and the contribution this makes to providing habitat for fauna, similar to the *Bird Friendly* and *Rainforest Alliance* certification requirements (Philpott *et al.*, 2007). Although they did not discuss its role in maintaining and increasing biodiversity, they identified the preferred habitat for a number of species as being at a specific level or strata.

Farmers described all the various taxa and species they identified as being from the coffee zone (i.e. they did not originate from the forest). In Guatemala and Nicaragua, farmers also explained that "forest species" did not visit the coffee farms both because they were adapted to a colder climate at higher altitudes, and also due to the greater inhabitation by people. Farmers' knowledge on biodiversity is predominantly related to birds and mammals, but it also contains issues such as pollination, epiphytes, and natural regeneration of trees. Natural regeneration is mentioned in relation to the role that birds play in increasing tree diversity through bringing fruits and seeds from other coffee farms or from the forest, and contributing to natural regeneration and the establishment of new tree species.

Figure 5.9 illustrates the knowledge related to biodiversity expressed by the coffee farmers through word-clouds. On the upper part of the figure, the statements are separated per country: on the left are the 211 statements reported in Guatemala, in the centre are the 114 statements reported in Costa Rica, and on the right are the 108 statements reported in Nicaragua. The lower part of the figures shows a big word-cloud with the total 423 statements reported in the three countries. The main differences in knowledge content consists of how farmers in Guatemala considered the location of the coffee farm in respect to the protected reserve, and how farmers in Costa Rica related the amount of trees to fauna (two tree species were mentioned as decreasing biodiversity, as observed in the figure). In Nicaragua the consumption of different fruits by birds was the main knowledge expressed. The big word-cloud is dominated by Guatemalan farmers' knowledge (almost the half of the total statements). In order of importance of the words it would be read, that the general knowledge regarding biodiversity conservation among farmers from the three countries is:

“**coffee farm** with **fruits causes** an **increase (**in the **amount) of birds visiting**…” and in fact, the majority of the statements expressed by farmers are in that context, but each single statement details which birds or which fruit tree species are useful. Growth and location of the trees are also noted. The many small words not easily visible in the word cloud are the many specific species stated by farmers, which denoted detailed knowledge of farmers in their environments.

Figure 5.9. Word-clouds of the coffee farmers’ knowledge related to biodiversity conservation

Future use of local knowledge

Science and local knowledge are potentially complementary (Berkes *et al.,* 2000); however, publications regarding local knowledge have not been incorporated accordingly into the development of policies for natural resources management (Brook and McLachlan, 2008). Agroforestry as a traditional practice is carried out by local agroforesters that may retain valuable knowledge on its management (Sanchez, 1995). This valuable knowledge is particularly important in the search for solutions for site-specific problems (Altieri, 1993).

Shade coffee has been promoted as a commercial activity that is compatible with the conservation of forest and its related fauna (Dietsch *et al.*, 2004) since shade coffee maintains a high species diversity of animals and plants (Gallina *et al.*, 1996; Moguel and Toledo 1999). However, coffee is also associated with environmental damages, essentially with the deforestation that coffee plantations have caused in the farmers' search for new coffee areas (Rappole *et al.*, 2003; Tejeda Cruz *et al.*, 2010). The study of local knowledge has many advantages in understanding and responding to ecological problems (Bart, 2006). The local knowledge that underpins selection and management of tree species within coffee plantations should be regarded as a valuable resource. This is especially true at present, when governmental organisations, scientists, technicians and farmers are seeking to maintain diversity and complexity of vegetation structure in coffee farms, and at the same time conserving and taking advantage of new market niches simultaneously (Donald 2004). Findings presented in this thesis are potentially useful for tailoring the latest scientific advances on tree-coffee interactions through the development of guidelines that enhance tree cover in coffee systems. Adoption of sustainable practices would be increased with the farmers' knowledge specific for a range of different farming locations. Knowledge regarding trade-offs among services that farmers stated, as well as the conservation value of each tree species for local animals should be backing the multiple projects working with coffee and conservation in the region.

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Thesis Conclussions

Biodiversity conservation and provision of ecosystem services within coffee agroforestry systems are determined by the management that farmers carried out. Central American coffee farmers shown to have a wealth consolidated knowledge regarding the consequences of their management upon the environment. This knowledge, however, is not always determining the management carried out. Moreover, a combination of the factors that influenced the coffee productivity (known by farmers), plus the provision of goods for family needs, are frequently the main considerations to manage the coffee plantations.

Central American coffee farmers know, in general, which factors affect coffee production as well as how to increase the provision of ecosystem services within coffee farms, they also know the trade-offs among production and services. Farmers understand in detail the role of trees in both coffee productivity and provision of other ecosystem services. Trees were classified by farmers according to their different attributes, which are used to classify trees according to functions. Frequently they mentioned trade-offs between some ecosystem services provision and productivity. Soil formation and erosion avoidance is perceived synergistically with productivity, while biodiversity conservation the opposite.

Central American coffee farmers' knowledge varied according with contextual variables, such as the history of the area, the presence of extension services, the dependence on coffee production for income, and the landscape matrix where plantations are. In the Nicaraguan new coffee area, farmers' knowledge was detailed in trees information and less detailed about coffee. There, the farmers' knowledge regarding coffee productions was strongly influenced by trainings and interventions of coffee promoting projects. Guatemalan farmers, whom are constantly interacting with faunal species, mentioned 51 tres species supporting faunal species within the coffee farms. Knowledge in Costa Rica, where used to be a strong guvernamental program of coffee extension services, was very detailed in the management of coffee plants.

In spite of its detailness, farmers' knowledge regarding tree cover and its relationships with ecosystem services, biodiversity conservation and coffee management is generally under-utilised, either in development and research.Categorizing knowledge as shared, unique and contradictory is an approach in finding new research opportunities. Shared knowledge could be considered scientifically valid, while unique knowledge could include both true and false findings and should be tested. Findings presented in this thesis are potentially useful for tailoring the latest scientific advances on tree-coffee interactions through the development of guidelines that enhance tree cover in coffee systems. Knowledge regarding trade-offs among services that farmers stated, as well as the conservation value of each tree species for local animals should be backing the multiple projects working with coffee and conservation in the region.

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Annexes

Annex 1. Attributes and classifications of the 135 tree species mentioned by farmers of the three study areas

Scientific name	Fresh/ hot	Impact coffee	Soil fertility	Soil erosion	Soil moisture	Dripping	Stream protection	Height	Growth rate	Leaf produc-tion	Ease of pruning	Canopy pheno-logy	Leaf size	Crown openness	Leaf texture	Root abundance	Root texture	Root depth	Countries
Abarema jupunba	Medium	Bad	Neg	Med	Neg		Neg	Medium	Slow	n.d.	Not pruned	n.d.	Medium	n.d.	Stiff	n.d.	Hard	n.d.	N
Acacia acanthophylla	Fresh	Good	Pos	Pos	Pos		Pos	n.d.	Slow	n.d.	n.d.	Evergreen	Small	n.d.	Soft	Medium	n.d.	n.d.	G
Acacia horrida	Hot	Medium	Neg	Neg	Neg		Neg	Medium	Medium	n.d.	Not pruned	n.d.	Medium	n.d.	Stiff	n.d.	Hard	n.d.	N
Acnistus arborescens	Fresh	n.d.	Pos^	Pos^	Good^	Yes	Pos	Medium	Fast	High	Medium	n.d.	Big	Closed	Medium	Numerous	Soft	n.d.	C
Acosmium panamense	Hot	Medium	Neg	Neg	Neg		Neg	High	Slow	n.d.	Not pruned	n.d.	Medium	n.d.	Stiff	n.d.	Hard	n.d.	N
Andira inermis	Fresh	Bad	Med	Med	Pos		Pos	Medium	Slow	n.d.	Not pruned	n.d.	Big	n.d.	Medium	Numerous	Soft	n.d.	N
Annona squamosa	n.d.	n.d.	n.d.	n.d.	n.d.		n.d.	Low	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	G
Azadirachta indica	n.d.	n.d.	Neg	Med	n.d.		n.d.	Low	Slow	n.d.	Easy	n.d.	Small	n.d.	Medium	n.d.	Medium	n.d.	N
Bactris gasipaes	Hot	Bad	Neg	Neg	Neg	Yes	Neg	High	Medium	Low	Not pruned	n.d.	Medium	Open	Stiff	Numerous	Hard	n.d.	C-N
Bernandia interrupta	Medium	Not used	Neg	Pos	Pos		Neg	n.d.	n.d.	n.d.	n.d.	Evergreen	Medium	n.d.	n.d.	n.d.	n.d.	n.d.	G
Bixa orellana	Medium	Not used	n.d.	Pos	Med		n.d.	n.d.	n.d.	n.d.	n.d.	Evergreen, leaf turnover	Medium	n.d.	n.d.	n.d.	n.d.	n.d.	G
Bombacopsis quinata	Medium	n.d.	Neg	Med	Neg		n.d.	Medium	Medium	n.d.	Not pruned	n.d.	Small	n.d.	Medium	n.d.	n.d.	Deep	N
Brosimum alicastrum	Medium	Bad	n.d.	Med	Pos		Pos	High	Slow	n.d.	Difficult	n.d.	Small	n.d.	Medium	n.d.	Hard	Superficial	N
Bursera simaruba	Medium	n.d.	Pos	Med	Pos		n.d.	Medium	Fast	n.d.	Easy	n.d.	Small	n.d.	Soft	Medium	n.d.	n.d.	N
Byrsonima crassifolia	Fresh	Medium	Med^	Med^	Med^	No	Pos	Medium	Fast	Medium	Medium	n.d.	Medium	Closed	Medium	n.d.	Soft	n.d.	C
Calycophyllum candidissimum	Medium	n.d.	n.d.	n.d.	Pos		n.d.	High	Slow	n.d.	Not pruned	n.d.	Medium	n.d.	Soft	Medium	n.d.	n.d.	N
Carapa guianensis	Medium	Good	Med	n.d.	Pos		n.d.	High	Medium	n.d.	Easy	n.d.	Big	n.d.	Medium	n.d.	Soft	n.d.	N
Casimiroa edulis	Medium	Medium*	Med	Med	Pos		n.d.	n.d.	n.d.	n.d.	n.d.	Evergreen	Medium	n.d.	n.d.	n.d.	n.d.	n.d.	G

Scientific name	Fresh/ hot	Impact coffee	Soil fertility	Soil erosion	Soil moisture	Dripping	Stream protection	Height	Growth rate	Leaf produc-tion	Ease of pruning	Canopy pheno-logy	Leaf size	Crown openness	Leaf texture	Root abundance	Root texture	Root depth	Countries
Casuarina equisetifolia	Hot	n.d.	Bad^	Neg^	Neg^	Yes	Neg	High	Medium	Medium	Difficult	n.d.	Small	Open	Medium	n.d.	Hard	n.d.	C
Cecropia obstusifolia	Fresh	Medium	Pos	Med	Pos	Yes	Pos	High	Fast	High	Med-Not	Evergreen	Very-Big	Open	Soft-Stiff	Medium	Soft	n.d.	C-G-N
Cedrela odorata	Med-Hot	Medium	Med	Pos	Pos	Yes	Neg	High	Fast	High	Dif-Not	Deciduous	Medium	Open	Med-Stiff	Medium	n.d.	Medium	C-G-N
Cedrela tonduzii	Medium	Medium	n.d.	Pos	Pos		n.d.	n.d.	n.d.	n.d.	n.d.	Evergreen	Medium	n.d.	Stiff	n.d.	n.d.	n.d.	G
Ceiba aesculifolia	Medium	Not used	n.d.	Med	Pos		n.d.	n.d.	n.d.	n.d.	n.d.	Evergreen	Medium	n.d.	n.d.	Numerous	n.d.	n.d.	G
Ceiba pentandra	Fresh	Medium	Pos	Med	Med		Pos	High	Slow	n.d.	Not pruned	n.d.	Small	n.d.	Medium	n.d.	Soft	n.d.	N
Chamaedorea tepejilote	Fresh	Good	n.d.	Pos	Med		n.d.	Low	n.d.	n.d.	n.d.	Evergreen	Big	n.d.	n.d.	n.d.	n.d.	n.d.	G
Cinnamomum verum	Medium	n.d.	Med	n.d.	Neg		n.d.	Medium	Medium	n.d.	Not pruned	n.d.	Medium	n.d.	Medium	Medium	Hard	n.d.	N
Citrus aurontifolia	Med-Hot	Med-Neg	Neg	Med-Neg	Pos	No	Med-Neg	Low	Fast	Medium	Easy-Med	Evergreen	Medium	Closed	Medium	Numerous	Hard	n.d.	C-G
Citrus limonia	Medium	Medium	n.d.	Neg	Pos		Neg	Low	n.d.	n.d.	n.d.	Evergreen	Medium	Closed	n.d.	Numerous	n.d.	n.d.	G
Citrus paradisi	Medium	Medium	n.d.	Neg	Pos		n.d.	Low	n.d.	n.d.	n.d.	Evergreen	Medium	Closed	n.d.	Numerous	n.d.	n.d.	G
Citrus reticulata	Medium	Bad	n.d.	Med	Med		n.d.	Low	Fast	n.d.	Medium	n.d.	Small	n.d.	Medium	Medium	n.d.	n.d.	N
Citrus reticulata	Medium	Medium	n.d.	Med	Med		n.d.	n.d.	n.d.	n.d.	n.d.	Evergreen	Small	n.d.	n.d.	Medium	n.d.	n.d.	G-N
Citrus sinensis	Med-Hot	Med-Neg	Neg	Med	Med	No	Med-Neg	Low	Fast	Medium	Easy-Med	Evergreen	Medium	Closed	Medium	n.d.	Hard	n.d.	C-G-N
Cocos nucifera	Med-Hot	Bad	Neg	n.d.	Neg	No	Neg	High	Medium	Low	Dif-Not	Evergreen	Very-Big	Open	Stiff	n.d.	Hard	n.d.	C-N
Colubrina guatemalensis	Hot	Not used	Neg	Neg	Neg		Neg	n.d.	n.d.	n.d.	n.d.	Evergreen, leaf turnover	Medium	n.d.	n.d.	n.d.	n.d.	n.d.	G
Cordia alliodora	Hot	Bad	Neg	Neg	Neg	Yes	Neg	High	Fast-Med	High	Dif-Not	n.d.	Small	Open	Stiff	n.d.	Hard	n.d.	C-N
Cordia collococca	Fresh	Good	Pos	Med	Med		Pos	Medium	Medium	n.d.	Not pruned	n.d.	Big	n.d.	Stiff	Medium	n.d.	n.d.	N
Cordia gerascanthus	Medium	n.d.	Med	Med	Med		Pos	High	Medium	n.d.	Not pruned	n.d.	Medium	n.d.	Medium	n.d.	n.d.	Deep	N
Croton draco	Hot	Bad	n.d.	Neg	Neg		n.d.	Medium	Medium	n.d.	Not pruned	n.d.	Medium	n.d.	Stiff	n.d.	Hard	n.d.	N

Scientific name	Fresh/ hot	Impact coffee	Soil fertility	Soil erosion	Soil moisture	Dripping	Stream protection	Height	Growth rate	Leaf produc-tion	Ease of pruning	Canopy pheno-logy	Leaf size	Crown openness	Leaf texture	Root abundance	Root texture	Root depth	Countries
Cupania glabra	Hot	Med	Neg	Neg	Neg		Neg	n.d.	Fast	n.d.	n.d.	Evergreen, leaf turnover	Medium	n.d.	Soft	Numerous	n.d.	n.d.	G
Cupressus lusitanica	Hot	n.d.	Bad^	Neg^	Neg^	Yes	Neg	High	Medium	High	Difficult	n.d.	Small	Closed	Medium	n.d.	Hard	n.d.	C
Cupressus lusitanica	Hot	Not used	Neg	Pos	Pos		n.d.	High	n.d.	n.d.	n.d.	Evergreen	Small	Closed	n.d.	Numerous	n.d.	n.d.	G
Delonix regia	n.d.	n.d.	n.d.	n.d.	n.d.		n.d.	Medium	Fast	n.d.	Difficult	n.d.	Medium	n.d.	Medium	Medium	n.d.	n.d.	N
Dendropanax arboreus	Hot	Not used	Neg	Neg	Pos		Neg	n.d.	n.d.	n.d.	n.d.	Evergreen	Big	n.d.	n.d.	Medium	n.d.	n.d.	G
Diphysa americana	Fresh	Medium	Pos	Pos	Pos		n.d.	n.d.	Slow	n.d.	n.d.	Evergreen, leaf turnover	Small	n.d.	Soft	Numerous	n.d.	n.d.	G
Enterolobium cyclocarpum	Medium	n.d.	Pos	Med	Pos		Pos	Medium	Fast	n.d.	Not pruned	n.d.	Medium	n.d.	Soft	Numerous	Soft	n.d.	N
Eriobotrya japonica	Fresh-Med	Pos-Med	n.d.	Pos	Med	No	Pos	Med-Low	Fast-Med	Medium	Medium	Evergreen	Medium	Closed	Soft-Stiff	Numerous	n.d.	n.d.	C-G
Erythrina berteroana	Fresh	Pos-Med	Pos	Pos	Pos		Pos	High	Fast	n.d.	Medium	Evergreen	Big-Med	n.d.	Very soft	Numerous	Soft	n.d.	G-N
Erythrina caffra	Medium	Bad	Med	Med	Pos		Pos	Medium	Medium	n.d.	Not pruned	n.d.	Medium	n.d.	Soft	Numerous	Soft	n.d.	N
Erythrina fusca	Fresh	Good	Pos	Pos	Med		Pos	High	Fast	n.d.	Easy	n.d.	Big	n.d.	Very soft	Numerous	Soft	n.d.	N
Erythrina poeppigiana	Fresh	Good	Pos	Pos	Pos	No	Pos	Low*	Fast	High	Easy	Evergreen, leaf turnover	Big	Open	Very soft	Numerous	Soft	n.d.	C
Eucalyptus deglupta	Hot	Bad	Neg	Neg	Neg	Yes	Neg	High	Med-Slow	Medium	Dif-Not	n.d.	Medium	Open	Stiff	n.d.	Hard	Deep	C-N
Eugenia uniflora	Fresh	n.d.	Med^	Med^	Med^	No	Pos	Medium	Fast	High	Easy	n.d.	Medium	Open	Medium	n.d.	Soft	n.d.	C
Ficus glabrata	Fresh	Medium*	Pos	Pos	Pos	Yes	Pos	Medium	Fast	High	Med-Not	Evergreen	Big-Med	Closed	Medium	Medium	Soft	n.d.	C-G-N
Ficus pertusa	Fresh	n.d.	Pos^	Pos^	Pos^	Yes	Pos	Medium	Medium	High	Difficult	n.d.	Small	Closed	Medium	n.d.	Soft	n.d.	C
Ficus spp1.	Fresh	n.d.	Pos^	Pos^	Pos^	Yes	Pos	High	Medium	High	Difficult	n.d.	Medium	Closed	Medium	Numerous	Soft	Deep	C
Ficus spp2.	Medium	n.d.	Med	n.d.	Med		Pos	High	Fast	n.d.	Difficult	n.d.	Medium	n.d.	Medium	n.d.	Hard	n.d.	N

Scientific name	Fresh/ hot	Impact coffee	Soil fertility	Soil erosion	Soil moisture	Dripping	Stream protection	Height	Growth rate	Leaf produc-tion	Ease of pruning	Canopy pheno-logy	Leaf size	Crown openness	Leaf texture	Root abundance	Root texture	Root depth	Countries
Gliricidia sepium	Fresh	Pos-Med	Pos	Pos-Med	Pos-Med	No	Pos	Med-Low	Fast	High	Easy-Med	Evergreen	Med-Small	Closed	Soft	Num-Med	Soft	n.d.	C-G-N
Grevillea robusta	Fresh	Good	Pos	Pos	Pos		n.d.	n.d.	n.d.	n.d.	n.d.	Evergreen	Small	n.d.	n.d.	n.d.	n.d.	n.d.	G
Guazuma ulmifolia	Medium	Medium*	Pos	Pos	Pos		Med	Low	Fast	n.d.	Not pruned	Evergreen	Med-Small	Closed	Soft	Medium	n.d.	n.d.	G-N
Hieronyma guatemalensis	Fresh	Medium*	n.d.	Med	Pos		n.d.	n.d.	n.d.	n.d.	n.d.	Evergreen	Small	n.d.	n.d.	n.d.	n.d.	n.d.	G
Hymenaea courbaril	Hot	Bad	Med	n.d.	Neg		Neg	Medium	Slow	n.d.	Not pruned	n.d.	Small	n.d.	Stiff	n.d.	n.d.	Deep	N
Inga edulis	Fresh	Good	Pos	Pos	Pos		Pos	n.d.	n.d.	n.d.	n.d.	Evergreen, leaf turnover	Medium	n.d.	Soft	Medium	n.d.	n.d.	G
Inga jinicuil	Fresh	Pos-Med	Pos-Med	Pos-Med	Pos		Pos-Med	Medium	Medium	n.d.	Easy	Evergreen, leaf turnover	Medium	n.d.	Soft-Med	Numerous	Soft	n.d.	G-N
Inga laurina	Fresh	Good	Pos	Pos	Pos		Pos	n.d.	n.d.	n.d.	n.d.	Evergreen, leaf turnover	Medium	n.d.	Soft	n.d.	n.d.	n.d.	G
Inga nobilis	Fresh	Good	Pos	Med	Med		Pos	Medium	Medium	n.d.	Easy	n.d.	Medium	n.d.	Soft	Numerous	Soft	n.d.	N
Inga oerstediana	Fresh	Good	Pos	Pos-Med	Pos-Med		Pos	Medium	Fast-Med	n.d.	Easy	Evergreen, leaf turnover	Big-Small	n.d.	Soft	Num-Med	Soft	n.d.	G-N
Inga punctata	Fresh	Medium	Med	Med	n.d.		Med	Medium	Medium	n.d.	Easy	n.d.	Medium	n.d.	Medium	Numerous	Soft	n.d.	N
Inga sapintoides	Fresh	Good	Pos	Pos	Med		Pos	Medium	Medium	n.d.	Easy	n.d.	Medium	n.d.	Soft	Numerous	Soft	n.d.	N
Inga vera	Fresh	Good	Pos	Pos	Pos-Med	No	Pos	Medium	Fast	High	Easy-Med	Evergreen, leaf turnover	Big-Med	Closed	Soft	Num-Med	Soft	n.d.	C-G-N
Juglans olanchana	Hot	Medium	Neg	n.d.	Neg		Neg	High	Fast	n.d.	Not pruned	n.d.	Small	n.d.	Stiff	n.d.	Hard	Superficial	N
Lantana camara	Medium	Not used	n.d.	Neg	Pos		n.d.	n.d.	n.d.	n.d.	n.d.	Evergreen	Medium	n.d.	n.d.	n.d.	n.d.	n.d.	G
Leucaena magnifica	Fresh	Medium	Pos	Med	n.d.		n.d.	Low	Fast	n.d.	Easy	n.d.	Small	n.d.	Soft	Numerous	Soft	n.d.	N
Leucaena salvadorensis	Fresh	n.d.	Pos	n.d.	n.d.		n.d.	Low	Fast	n.d.	Medium	n.d.	Small	n.d.	Soft	n.d.	Soft	n.d.	N
Liquidambar styraciflua	Hot	Med-Neg	Neg	Pos-Neg	Pos-Neg		n.d.	High	Fast	n.d.	Not pruned	Evergreen	Big-Med	Closed	Soft	Numerous	n.d.	Deep	G-N

Scientific name	Fresh/ hot	Impact coffee	Soil fertility	Soil erosion	Soil moisture	Dripping	Stream protection	Height	Growth rate	Leaf produc-tion	Ease of pruning	Canopy pheno-logy	Leaf size	Crown openness	Leaf texture	Root abundance	Root texture	Root depth	Countries
Lonchocarpus minimiflorus	Medium	Med-Neg	Med	Med	Pos		Pos	High	Fast	n.d.	Not pruned	Evergreen	Big-Med	n.d.	Medium	n.d.	Soft	n.d.	G-N
Mangifera indica	Fresh-Hot	Med-Neg	Pos-Neg	Pos-Neg	Pos-Med	Yes	Pos	High-Med	Fast	High	Medium	Evergreen, leaf turnover	Medium	Closed	Med-Stiff	Medium	n.d.	Medium	C-G-N
Manilkara zapota	Fresh-Med	Medium	Med	Med	Pos	Yes	Pos	High	Medium	High	Easy	Evergreen	Big	Closed	Medium	n.d.	Soft	n.d.	C-G
Melicoccus bijugatus	Medium	n.d.	Med	n.d.	Med		Pos	High	Slow	n.d.	Not pruned	n.d.	Medium	n.d.	Medium	Medium	n.d.	n.d.	N
Moringa oleifera	Medium	n.d.	Med	n.d.	Med		Pos	Medium	Fast	n.d.	Not pruned	n.d.	Small	n.d.	Soft	n.d.	n.d.	Deep	N
Muntingia calabura	Fresh	Medium	n.d.	Med	Pos		Pos	n.d.	Fast	n.d.	n.d.	Evergreen	Medium	n.d.	n.d.	Numerous	n.d.	n.d.	G
Musa paradisiaca	Fresh	Good	Pos	Pos	Pos	No	Pos	Low	Fast	High	Easy	Evergreen	Very-Big	Open	Soft	Numerous	Soft	n.d.	C-G-N
Myrica cerifora	n.d.	n.d.	n.d.	n.d.	n.d.		n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	Small	n.d.	n.d.	n.d.	n.d.	n.d.	G
Ochroma pyramidale	Hot	Medium	Med	Med	Neg		Med	High	Fast	n.d.	Not pruned	n.d.	Big	n.d.	Medium	n.d.	Hard	n.d.	N
Ocotea floribunda	Medium	n.d.	Med^	Med^	Med^	No	Med	Medium	Fast	High	Medium	n.d.	Medium	Closed	Stiff	Medium	Medium	n.d.	C
Passiflora edulis	n.d.	Not used	n.d.	Med	n.d.		n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	G
Persea americana	Fresh-Med	Medium	Pos-Med	Pos-Med	Pos-Med	Yes	Pos	Medium	Fast	High	Medium	Evergreen	Big-Med	Open-Clos	Medium	Num-Med	Medium	Deep-Med	C-G-N
Persea schiedana	Medium	Medium	Pos	Med	Pos		n.d.	n.d.	n.d.	n.d.	n.d.	Evergreen	Big	Closed	n.d.	Medium	n.d.	n.d.	G
Persea spp.	Fresh	Medium	Pos^	Pos^	Pos^	Yes	Pos	Medium	Medium	High	Medium	n.d.	Big	Open	Medium	Medium	Medium	Medium	C
Perymenium grande	Hot	Medium	Neg	Med	Neg		Neg	n.d.	n.d.	n.d.	n.d.	Evergreen	Medium	Closed	Soft	Numerous	n.d.	n.d.	G
Pinus maximinoi	Hot	Medium	Neg	Pos	Pos		n.d.	High	n.d.	n.d.	n.d.	Evergreen	Medium	n.d.	Stiff	Numerous	n.d.	n.d.	G
Pinus oocarpa	Hot	Medium	Neg	Pos-Neg	Pos-Neg	Yes	Neg	High	Fast-Slow	Medium	Dif-Not	Evergreen	Med-Small	Open	Stiff	Numerous	Hard	Deep	C-G-N
Piper adumcum	Hot	Not used	Neg	Neg	Neg		Pos	n.d.	n.d.	n.d.	n.d.	Evergreen, leaf turnover	Medium	n.d.	n.d.	Numerous	n.d.	n.d.	G
Platymiscium pinnatum	Medium	n.d.	n.d.	n.d.	Pos		n.d.	Medium	Slow	n.d.	Not pruned	n.d.	Small	n.d.	Soft	n.d.	Soft	n.d.	N

Scientific name	Fresh/ hot	Impact coffee	Soil fertility	Soil erosion	Soil moisture	Dripping	Stream protection	Height	Growth rate	Leaf produc-tion	Ease of pruning	Canopy pheno-logy	Leaf size	Crown openness	Leaf texture	Root abundance	Root texture	Root depth	Countries
Prosopis juliflora	Medium	n.d.	Med	n.d.	Neg		n.d.	Low	Fast	n.d.	Not pruned	n.d.	Medium	n.d.	Medium	n.d.	Hard	n.d.	N
Prunus laurocerasus	Hot	Bad	Med	n.d.	Neg		n.d.	Medium	Medium	n.d.	Not pruned	n.d.	Medium	n.d.	Stiff	n.d.	Hard	n.d.	N
Prunus persica	Medium	Medium	n.d.	Med	Neg		n.d.	n.d.	n.d.	n.d.	n.d.	Evergreen, leaf turnover	Medium	Closed	Soft	n.d.	n.d.	n.d.	G
Pseudosamanea guachapele	Medium	n.d.	n.d.	Pos	Pos		Neg	High	Medium	n.d.	Not pruned	n.d.	Medium	n.d.	Soft	Numerous	Soft	n.d.	N
Psidium friedrichsthalianum	Hot	Medium	Bad^	Neg^	Neg^	No	Neg	Low	Medium	Medium	Medium	n.d.	Medium	Closed	Stiff	n.d.	Hard	n.d.	C
Psidium guajava	Med-Hot	Med-Neg	Pos-Neg	Neg	Pos-Neg	No	Neg	Low	Medium	Medium	Medium	Evergreen	Small	Closed	Stiff	n.d.	Hard	n.d.	C-G-N
Quercus peduncularis	Hot	Not used	Neg	Pos	Pos		n.d.	High	n.d.	n.d.	n.d.	Deciduous	Big	Closed	Stiff	Numerous	n.d.	n.d.	G
Quercus sapotifolia	Hot	Not used	Neg	Pos	Pos		n.d.	High	n.d.	n.d.	n.d.	Evergreen, leaf turnover	Big	Closed	Stiff	Numerous	n.d.	n.d.	G
Ricinus communis	Fresh-Med	Pos-Med	Pos-Med	n.d.	Med-Neg	No	Pos	Low	Fast	Low	Easy-Not	Evergreen	Very-Big	Open	Soft	Numerous	Soft	n.d.	C-G-N
Sabal mexicana	Medium	Good	Pos	Pos	Pos		n.d.	n.d.	n.d.	n.d.	n.d.	Evergreen	Big	Closed	n.d.	Numerous	n.d.	n.d.	G
Salvia karwinskii	Medium	Not used	n.d.	Neg	Pos		n.d.	n.d.	n.d.	n.d.	n.d.	Evergreen, leaf turnover	Medium	n.d.	n.d.	n.d.	n.d.	n.d.	G
Saurauia laevigata	Medium	Medium	n.d.	Pos	Pos		Pos	n.d.	n.d.	n.d.	n.d.	Evergreen, leaf turnover	Big	n.d.	n.d.	n.d.	n.d.	n.d.	G
Solanum spp.	Fresh	Pos-Med	Pos	Pos	Pos		n.d.	Medium	Fast	n.d.	Easy	Evergreen	Big-Med	n.d.	Soft	Numerous	Soft	n.d.	G-N
Spatodea campanulata	Hot	Medium	Med	Med	Pos		Neg	n.d.	n.d.	n.d.	n.d.	Deciduous	Medium	n.d.	n.d.	n.d.	n.d.	n.d.	G
Spondias mombin	Medium	Medium	Med	Med	Pos		n.d.	n.d.	n.d.	n.d.	n.d.	Evergreen	Small	Closed	Stiff	n.d.	n.d.	n.d.	G
Spondias purpurea	Medium	n.d.	n.d.	n.d.	n.d.		n.d.	Low	Medium	n.d.	Easy	n.d.	Big	n.d.	Medium	Medium	Medium	n.d.	N
Swietenia humilis	Hot	Not used	Neg	Neg	Pos		Pos	n.d.	n.d.	n.d.	n.d.	Evergreen	Big	n.d.	Stiff	n.d.	n.d.	n.d.	G
Swietenia macrophylla	Medium	n.d.	Med	n.d.	Neg		n.d.	High	Slow	n.d.	Not pruned	n.d.	Medium	n.d.	Medium	Medium	Hard	n.d.	N

Scientific name	Fresh/ hot	Impact coffee	Soil fertility	Soil erosion	Soil moisture	Dripping	Stream protection	Height	Growth rate	Leaf produc-tion	Ease of pruning	Canopy pheno-logy	Leaf size	Crown openness	Leaf texture	Root abundance	Root texture	Root depth	Countries
Syzygium malaccense	Fresh	n.d.	Pos^	Pos^	Pos^	Yes	Pos	High	Medium	High	Medium	Evergreen	Big	Closed	Medium	n.d.	Soft	n.d.	C
Syzygium jambos	Medium	Not used	Med	Med	Pos		Med	n.d.	n.d.	n.d.	n.d.	Evergreen	Medium	Closed	Stiff	Numerous	n.d.	n.d.	G
Tabebuia rosea	Hot	Bad	Neg	Neg	Neg	Yes	Neg	High	Medium	High	Dif-Not	n.d.	Medium	Closed	Med-Stiff	n.d.	Hard	Deep	C-N
Tamarindus indica	Medium	n.d.	Med	n.d.	n.d.		n.d.	Medium	Medium	n.d.	Not pruned	n.d.	Small	n.d.	Medium	n.d.	Soft	n.d.	N
Tephrosia vogelli	Fresh	Medium	Med	Pos	Med		n.d.	n.d.	n.d.	n.d.	n.d.	Evergreen, leaf turnover	Small	n.d.	n.d.	n.d.	n.d.	n.d.	G
Terminalia oblonga	Hot	n.d.	Neg	n.d.	Neg		Neg	High	Slow	n.d.	Not pruned	n.d.	Small	n.d.	Stiff	n.d.	Hard	n.d.	N
Theobroma cacao	Fresh-Med	Bad	Pos	Med	Pos	No	Pos	Low	Fast	High	Easy	n.d.	Big	Closed	Medium	Medium	Medium	n.d.	C-N
Trema micrantha	Medium	Medium	n.d.	Med	Pos		n.d.	High	Fast	n.d.	n.d.	Evergreen, leaf turnover	Medium	n.d.	n.d.	Numerous	n.d.	n.d.	G
Trichilia americana	Hot	Not used	Neg	Pos	Pos		Pos	High	n.d.	n.d.	n.d.	Deciduous	Medium	Closed	Stiff	n.d.	n.d.	n.d.	G
Trichilia hirta	Medium	n.d.	Med	n.d.	n.d.		n.d.	Medium	Medium	n.d.	Not pruned	n.d.	Medium	n.d.	Medium	Medium	n.d.	n.d.	N
Trichilia martiana	Medium	n.d.	Pos^	Pos^	Pos^	No	Med	Low	Medium	Medium	Difficult	n.d.	Big	Closed	Stiff	Medium	n.d.	n.d.	C
Ulmus mexicana	Hot	Not used	Med	Med	Pos		Neg	n.d.	n.d.	n.d.	n.d.	Evergreen	Medium	n.d.	n.d.	n.d.	n.d.	n.d.	G
Vernonia patens	Hot	Medium	Pos	Med	Pos-Med		Neg	Low	Fast	n.d.	Not pruned	Evergreen	Medium	Open	Soft	Medium	n.d.	n.d.	G-N
Yucca elephantipes	Hot	Good	n.d.	Pos	Neg	No	Neg	Low	Fast	Low	Easy	Evergreen	Big	Open	Stiff	Numerous	Hard	n.d.	C-G
Zanthoxylum caribaum	Medium	Not used	n.d.	Neg	Med		n.d.	Low	n.d.	n.d.	n.d.	Evergreen	Big	n.d.	n.d.	n.d.	n.d.	n.d.	G
Zygia longifolia	Fresh	n.d.	Pos^	Pos	Pos^	No	Pos	Medium	Medium	High	Medium	n.d.	Medium	Closed	Medium	Numerous	n.d.	n.d.	C
Unidentified 1 (guacamaya roja)	Medium	Bad	n.d.	Med	Med		Neg	Medium	Slow	n.d.	Not pruned	n.d.	Medium	n.d.	Stiff	Medium	Medium	n.d.	N

Scientific name	Fresh/ hot	npact coffee	oil fertility	oil erosion	oil moisture	ripping	Stream protection	Height	Growth rate	Leaf produc-tion	Ease of pruning	Canopy pheno-logy	Leaf size	Crown openness	Leaf texture	Root abundance	Root texture	Root depth	Countries
Unidentified 2 (frutillo)	Medium	Medium	Pos	Neg	Pos		n.d.	n.d.	n.d.	n.d.	n.d.	Evergreen, leaf turnover	Small	Closed	n.d.	Numerous	n.d.	n.d.	G
Unidentified 3 (ixtacama)	Medium	Medium*	Med	Neg	Neg		n.d.	n.d.	n.d.	n.d.	n.d.	Evergreen, leaf turnover	Medium	n.d.	n.d.	n.d.	n.d.	n.d.	G
Unidentified 4 (maicena)	Fresh	Medium	n.d.	n.d.	Pos		Pos	n.d.	n.d.	n.d.	n.d.	Evergreen	Big	n.d.	n.d.	n.d.	n.d.	n.d.	G
Unidentified 5 (siguapate)	Medium	Medium	Med	Med	Med		n.d.	n.d.	n.d.	n.d.	n.d.	Evergreen	Medium	n.d.	n.d.	n.d.	n.d.	n.d.	G
Unidentified 6 (tres puntas)	Hot	Not used	Neg	Neg	Neg		Neg	n.d.	n.d.	n.d.	n.d.	Evergreen	Medium	n.d.	n.d.	n.d.	n.d.	n.d.	G

Tree species were ordered alphabetically according to their scientific name. First column indicates the scientific name, second to seventh columns indicate the classification of the species, eighth to eighteenth columns indicate the tree attributes. Last column at right indicates the countries where each specie was mentioned (C: Costa Rica, G: Guatemala, N: Nicaragua).

For impact on soil fertility, erosion, moisture and stream protection. ‘Pos’ means that the tree was said to have positive impacts, ‘Med’ to have a medium impact, and ‘Neg’ to have a negative impact. ‘n.d.’ in the whole table means no data were reported.
For impacts on soil, ^ indicate that the data came from Costa Rica where an overall impact was stated, and it was extrapolated for the other impacts in this table. For impacts on coffee, * indicate that trees are considered with medium impact, but these are trees remnant of the original tree cover. Discrepancies between farmers of different countries are highlighted. If the cell is left blank, there is concordance. A slight discrepancy is highlighted with a light grey cell, a strong discrepancy is highlighted with a dark grey cell.