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Local knowledge of impacts of tree cover on ecosystem services in smallholder coffee production systems

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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 always excluded. 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 on the services that trees provide, farmers classified trees according to water protection, soil formation, or contribution to 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. Lack of comprehension of local coffee knowledge could be expected to reduce the success of development programs and projects aimed at improving productivity or other ecosystem services.

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

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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 (Lyngbæk 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 shade on yield (Romero-Alvarado 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 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).

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

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).

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 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 6).

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 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 semi-structure the 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 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.

Table 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 ($3 \leqslant A \leqslant 7$ 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).

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). 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 35 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).

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.

Table 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.

3.1. Tree attributes and tree functional classifications

Coffee farmers create functional classifications of trees through the combination of tree attributes (Table 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 in 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 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 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.

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 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

Table 3
Relationships between tree attributes and local classifications 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 4
Attributes and classifications of all tree species mentioned 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[a]	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.
Cordia alliodora	Laurel	Hot	Yes	Difficult	Bad	Yes	Bad	High	Medium	High	Difficult	n. d.	Small	Open	Hard	n. d.	Hard	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.
Gliricidia sepium	Madero negro	Fresh	No	Easy	Good	No	Good	Medium	Fast	High	Easy	Evergreen	Small	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.
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
Cedrela odorata	Cedro	Hot	Yes	Difficult	Medium	Yes	Bad	High	Fast	High	Difficult	Deciduous	Medium	Open	Medium	n. d.	n. d.	Medium
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
Theobroma cacao	Cacao	Fresh	No	Easy	Good	No	Good	Low	Fast	High	Easy	n. d.	Big	Closed	Medium	n. d.	Medium	n. d.
Psidium guajava	Guayaba	Hot	No	Medium	Bad	No	Bad	Low	Medium	Medium	Medium	Evergreen	Small	Closed	Hard	n. d.	Hard	n. d.
Citrus aurontifolia	Limón	Hot	No	Easy	Bad	No	Medium	Low	Fast	Medium	Easy	Evergreen	Medium	Closed	Medium	n. d.	Hard	n. d.
Bactris gasipaes	Pejibaye	Hot	Yes	Difficult	Bad	Yes	Bad	High	Medium	Low	Difficult	n. d.	Medium	Open	Hard	Numerous	Hard	n. d.
Yucca elephantipes	Itabo	Hot	No	Easy	Good	No	Bad	Low	Fast	Low	Easy	n. d.	Big	Open	Hard	Numerous	Hard	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.
Cocos nucifera	Pipa	Medium	Yes	Difficult	Bad	No	Bad	High	Medium	Low	Difficult	Evergreen	Very big	Open	Hard	n. d.	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.
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.
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
Eriobotrya japonica	Níspero	Fresh	No	Medium	Good	No	Good	Medium	Medium	Medium	Medium	n. d.	Medium	Closed	Soft	n. d.	n. d.	n. d.
Citrus sinensis	Naranja	Hot	No	Medium	Bad	No	Medium	Low	Fast	Medium	Easy	Evergreen	Medium	Closed	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.
Byrsonima crassifolia	Nance	Fresh	No	Medium	Medium	No	Good	Medium	Fast	Medium	Medium	n. d.	Medium	Closed	Medium	n. d.	Soft	n. d.
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
Ficuspe rtusa	Higuito	Fresh	Yes	Difficult	Good	Yes	Good	Medium	Medium	High	Difficult	n. d.	Small	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.
Acnistus arborescens	Güitite	Fresh	Yes	Medium	Good	Yes	Good	Medium	Fast	High	Medium	n. d.	Big	Closed	Medium	Numerous	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.
Ocotea floribunda	Quizarra	Medium	Yes	Difficult	Medium	No	Medium	Medium	Fast	High	Medium	n. d.	Medium	Closed	Hard	Medium	Medium	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.
Syzygium malaccense	Manzana de agua	Fresh	Yes	Medium	Good	Yes	Good	High	Medium	High	Medium	Evergreen	Big	Closed	Medium	n. d.	Soft	n. d.

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'.
[a] *Erythrina poeppigiana* is a tall tree when it grows naturally, but because of pruning management it was classed as a short tree.

Table 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	Contradictory
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).

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).

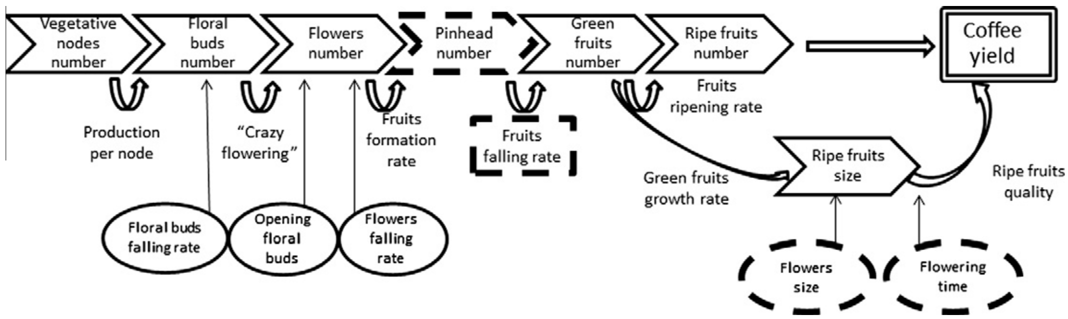

Fig. 1. Farmers' knowledge about the fruiting cycle and yield formation of coffee. Main nodes represent the seven physiological yield components confirmed by farmers. Arrows connecting components show the processes that relate one to another. Dotted nodes show processes that farmers mentioned which are not reported by the literature.

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 Fig. 1. 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 Fig. 1). 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 scattering 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.

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 (Fig. 2). 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.

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 (Fig. 3). 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 source. 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 on soil and water conservation and not using chemical inputs. Both organic and conventional farmers were concerned about

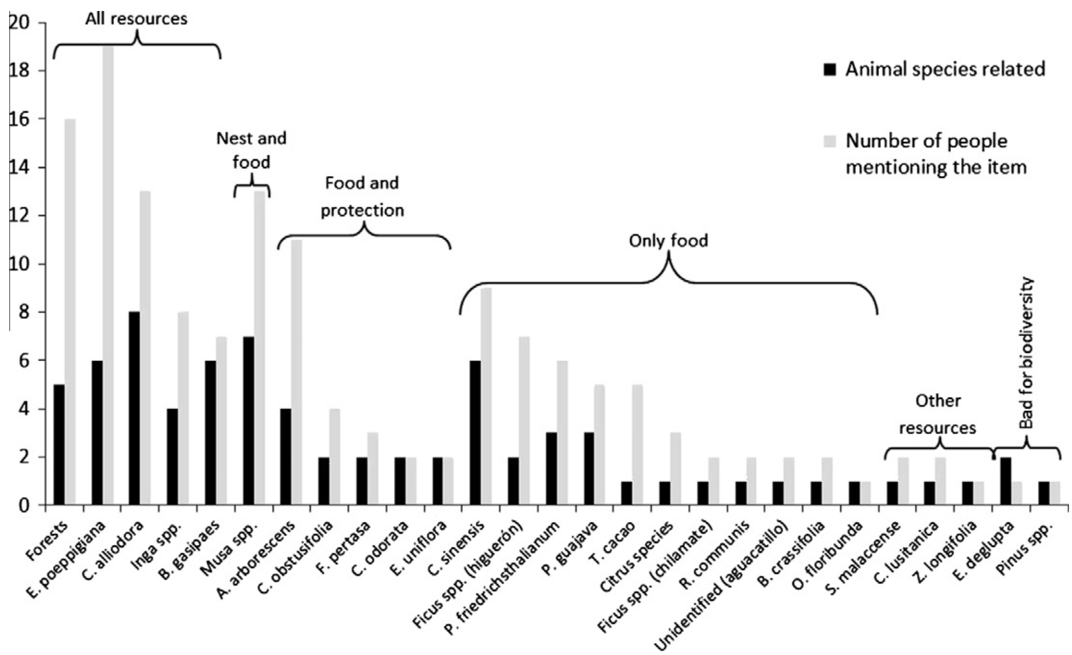

Fig. 2. Farmers' classification of trees within coffee farms according to the resources (nest, food and protection) provided to biodiversity. Black columns show how many species (mainly birds and mammals) are related with the tree species, while grey lines show the number of sources who mentioned the tree species.

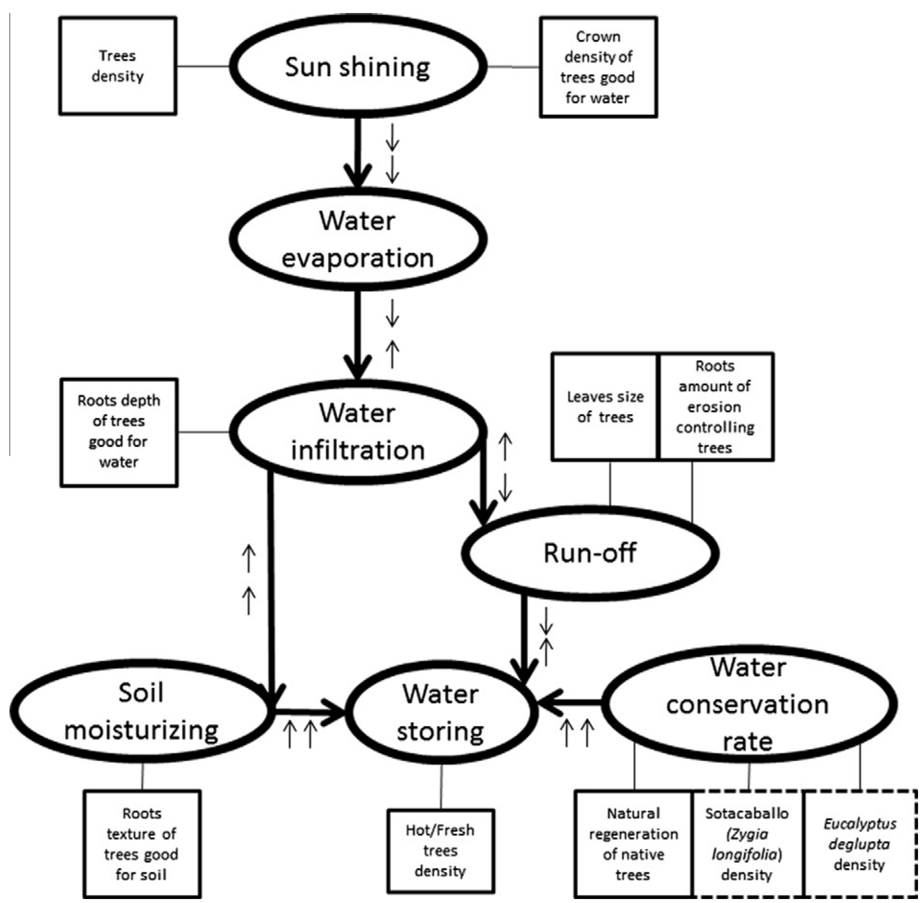

Fig. 3. Costa Rican coffee farmers' knowledge about the factors affecting water balance and how trees relate with this. Circular nodes represent the processes related to water balance. Square boxes represent the role of shade trees in each process and the tree attributes related to these roles. Dotted 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 an decrease (first arrow) of sun caused an decrease (second arrow) in water evaporation.

Table 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,*]	Use is majoritarian 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% do not 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
Accurate soil conditions for coffee[1]	20% of farmers believe that their management of litter keeps accurate 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 do not 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

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.

the residual effect of herbicides on soils; however, organic farmers were more concerned than conventional farmers regarding the effects of chemical fertilisers.

Farmers' knowledge related to the effectiveness of shade trees in regulating humidity to manage fungal diseases was also found (Table 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 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.

4. Discussion

4.1. 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 the 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 argued 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 base 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.

4.1.1. 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 Ricketts 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.

4.1.2. 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.

4.1.3. 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 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.

4.2. 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 (art.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 catch all the local knowledge and not underestimate farmers' understanding. At least 2 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.

5. 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 serivces. 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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