Local knowledge about trees and ecosystem services in coffee plantations in Rubavu and Rutsiro districts, Rwanda

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Abstract

The research was conducted during June-August 2009, within CAFNET's areas of operation in Rubavu and Rutsiro districts, Rwanda. The main purpose of this research was to gather farmers' agro-ecological knowledge, about trees, their interactions with coffee and other components of the shaded coffee systems, farming practices and how they impacted on coffee production and ecosystem services provision as well as the surrounding environment. A systematic approach mainly using repeated semi-structured interviews was used for acquiring knowledge about the coffee farm components, their interactions and the environmental services realised from the system. Other methods used were; focus group discussions, ranking exercises, diagram sketching, visual aids and informal talks. At the end of fieldwork in each study site, a feedback session was held in the community. Major findings were; coffee (*C. Arabica*) was the main cash crop grown in the study area as well as the country, no intercropping (food crops) was permitted on coffee farms. Planting trees on coffee farms was a usual practice for it was inevitable because the area was hilly; the majority of farmers operated on a small scale and would hardly afford intensive management of full-sun coffee. Farmers had detailed knowledge about trees and ecosystems services from the coffee agroforostry system. Ecosystem services provision largely depended on the system's components. Farmers' rationale for selecting coffee shade trees was mainly based on the tree attributes and their preference differed between locations.

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I'm very grateful to Bangor University for the training and skills that I have acquired during my study period. My sincere thanks go to CAFNET project that met the field costs of this research and my supervisors Dr.Fergus Sinclair and Genevieve Lamond, for the guidance and help offered to ensure that this research is successfully done. All the facilitation or physical assistance offered by ICRAF staff, Rwanda and Nairobi, COOPAC is highly appreciated.

List of acronyms

CAFNET: Connecting, enhancing and sustaining environmental services and market values of coffee agroforestry in Central America, East Africa and India

COOPAC: Coopérative pour la Promotion des Activités Café

ICRAF: International centre for Research in Agroforestry

OCIR: Office de Culture Industriel du Rwanda

PCCV: Projet Cafe Culture Viviriere

PES : Payment for Environmental Services

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CHAPTER 1: INTRODUCTION

1.1 Background

1.1.1 Coffee agroforestry in Rwanda

Coffee is one of the most important cash crops contributing to the economy as an official source of foreign exchange in Rwanda (Balasubramanian and Egli, 1986; Pinners and Balasubramanian, 1991; Sellström and Wohlgemuth, 1996; Loveridge et al., 2003). The species of coffee mostly grown is *Coffea arabica.* A less widely cultivated species is *Coffea robusta* which though lower in quality than *Coffea arabica,* is able to grow at lower elevation and is said to have relatively higher pest and disease resistance (Klein et al., 2002). Generally speaking, coffee exports contributed 60–80% of Rwanda's state revenue within the period 1973–1994. Coffee farming was greatly subsidised, farmers were advised on the cultivation practices and forced to maintain their fields through Rwandan penal code of 1978 (Verwimp, 2003). However, farmer training, subsidies and new coffee varieties were not provided any more in 1995 after the war. Thus many farmers abandoned their fields, existing coffee trees were quite old and yields were low (Donovan et al., 2002).

Globally, coffee production has been facing a crisis due to overproduction and persistently low prices (Soto-Pinto et al., 2007) and Rwandan coffee sector and quality have lagged behind with regard to international standards. Rwanda reformed its policies giving farmer's the choice to intercrop coffee with trees and/or crops which was previously not allowed (Donovan et al., 2002). According to Loveridge et al. (2003), Rwanda's coffee exports have declined to less than half of what they used to be in the 1980s.

From a study conducted by Mpyisi et al. (2003), though there was an increase in the size of cultivated land (from 782,470ha in 1990 to 899,133ha in 2002), land occupied by coffee and other cash crops decreased from 59,215ha to 44,809ha in the same time period. From 1991 to 2002, smallholder coffee growers in Rwanda reduced from 55% to 30% at a national scale. By the year 2002, 18% of non-coffee growers had grown coffee in the past and by the same percentage, households not engaged in coffee farming showed interest in doing it in the future (Loveridge et al., 2003). There is therefore the likelihood that coffee farming in the country will expand.

Traditionally, coffee is grown under shade trees (Klein et al., 2002). Many farmers usually retain and/or plant and incorporate trees into their farms even though "well-managed agroforestry systems are not widely practised" (Balasubramanian and Egli, 1986, p. 273). Based on the

same authors, sustainable management of agroforestry systems to realise both production and environmental benefits is of great relevance to the prevailing situation in Rwanda as in many developing countries where most people are engaged in subsistence agriculture.

One of the problems faced by parts of Rwanda is soil erosion especially in steep cultivated mountain slopes. Agroforestry has been said to play a role in soil erosion control by providing mulching material for example in coffee, banana or cassava plantations (Roose and Ndayizigiye, 1997). Tree roots hold soil particles firmly together and this reduces soil erosion. In the study to fight soil erosion in the tropical mountains of Rwanda, the author reported that living hedges of *Calliandra calothyrsus*, *Leucaena spp* and *Setaria spp* reduced run off to less than 2% and erosion to 2tonnes/ha/year, provided high quality animal feeds, fuel wood and nutrient recycling (80-120 kg/ha/year of nitrogen, 3 kg/ha/year of phosphorus, 30 to 60 kg/ha/year of calcium and potassium, 10-20 kg/ha/year of magnesium).

Pinners and Balasubramanian (1991) reported that in Rwanda, trees are important in improving soil fertility through production of green manure or mulch and this role was increasingly recognised on farms without animals. However, Roose and Ndayizigiye (1997) commented that agroforestry did not restore soil productivity in tropical mountains of Rwanda, except with complementation by mineral fertilizers. This may depend on factors like the components of the agroforestry system, foliage density and quantity of litter produced, (Cabrera, et al., 2007), management regime, the extent of soil degradation and duration over which agroforestry is adopted for this purpose. *C. calothyrsus*, *L. leucocephala* and *Ficus spp* are trees that were preferred by farmers in Bugesera and Gisaka-Migongo regions of Rwanda for fodder production, (Pinners and Balasubramanian, 1991).

1.1.2 Ecosystem services from coffee agroforestry systems

The term “ecosystem services” is often used interchangeably with the terms, “environmental services” and “ecological services.” According to Marco and Coelho (2004) and Méndez and Lovell (2007), ecosystem services are “goods and services” derived from “natural processes and components of an ecosystem,” that are directly or ultimately beneficial to humans. Ecosystem services can be categorised as *provisioning services* (for example food), *regulation services* (such as water and soil regulation), *cultural services* (education, recreation, aesthetic, and spiritual values), and *supporting services* (for example nutrient cycling) (Millennium Ecosystem Assessment, 2005). Agroforestry systems, for example perennial crop plantations (shaded coffee in this case) have been recognised for provision of a wide range of ecological benefits besides the productive function (Soto-Pinto et al., 2007). Agroforestry systems in

which crops (like coffee, cocoa bananas and others) are planted with trees or shrubs are recognised for production, regulatory, cultural and supportive services like provision of food, carbon sequestration, facilitating aquifer recharge, providing recreational landscapes, plant and animal biodiversity conservation that enhances systems' ability to supply ecosystem services (Méndez and Lovell, 2007), prevention and control of soil erosion (Blackman et al., 2008), pest control, enhanced pollination and fruit set, nitrogen fixation and nutrient recycling (Gordon et al., 2007), reduction of heat-induced stress and lengthening of maturation period of coffee (Bosselmann et al., 2009).

Except for production, other ecosystem services from agro-ecosystems are in most cases, produced to a low level (Blackman et al., 2008). However, the extent of ecosystem service provision will depend on many natural and anthropogenic factors such as site characteristics, species composition and biodiversity, objectives, intensity and suitability of management. For example, conservation of indigenous trees by shade coffee systems requires that the significance of conserving threatened species in a region is incorporated into management of the plantation (Me´ndez et al., 2007). There are few areas that are still wild and given the current situation (population increase, carbon emissions and global warming), conservation of the remaining biodiversity should as well be focused on managed ecosystems. Agricultural lands in particular have vast "untapped potential in supporting a diversity of native species thus contributing to the conservation of global biodiversity" and by this, the potential of ecosystems to supply ecosystem services is enhanced (Gliessman et al., 1998, p. 294). Therefore, managed ecosystems are vital maintaining veracity of natural ecosystems and diversifying landscapes.

However, Méndez and Lovell (2007) highlighted that "agro-ecosystems" should not be perceived as equivalent to natural forests and that their prospective benefits vary depending on the context of countries or localities. In Mexico, it was reported that coffee agroforestry systems (shade coffee) are increasingly used to protect tree cover from human pressure and the "ecological benefits from the system depend on density of tree cover among other factors" (Blackman et al., 2008, p. 217).

Because of the intricate biophysical structure, shade coffee systems exhibit special potential for biodiversity conservation (Klein et al., 2002) of tropical flora and fauna, providing a variety of niches to different organisms. Shade trees form diversified and copious canopy that enhances biodiversity of plants and animals, including insects and birds (Me´ndez et al., 2007). Moreover "ecosystem processes (that influence plant productivity, soil fertility, water quality

and many others) are controlled by both the diversity and identity," of the flora, fauna, and microbial species living within given community and a decline in biodiversity affects many of those processes (Naeem et al., 1999, p.2). Therefore, biodiversity is important in maintaining the integrity of ecosystems.

Integrating trees on farms is of critical importance because, they can "renewably supply tree products that might otherwise be unsustainably removed from forests" and the tree cover on regional and landscape scales may affect the conservation value of the remaining forest fragments" (Sinclair and Laxman, 2000, p. 1). According to Bhagwat et al. (2008), agroforestry systems are vital in protecting habitat remnants in otherwise open landscapes even though this depends on density and type of shade trees. They protect species and habitats outside formally protected areas and enhance species movements between habitat remnants. A case in point; "the shade coffee plantations in Nicaragua can serve as alternative wildlife habitats and as corridors between forest fragments for mantled howling monkeys, *Alouatta palliate*" (Bhagwat et al., 2008, p. 263). Agro-ecosystems are also recognised for maintaining heterogeneity at the habitat and landscape scales. In semi-humid and humid regions, planting trees in agricultural watersheds controls non-point source pollution and improves water and environmental quality (Anderson et al., 2009).

Despite the numerous benefits, efforts being made to recognise the ecosystems services provided by trees in shade coffee systems are inadequate. Unlike tree species of global conservation importance, tree species of main concern to the farmers are not given enough attention and therefore, there is insufficient explanation of reasons why farmers retain or plant specific trees in particular sites (Me´ndez et al., 2007).

Usually, one of the prime objectives of most coffee farmers is profit maximization, therefore management practices and recommendations solely linked to biological functioning of the system but not production services, are less likely to be attractive and pursued in explicit terms. It is often assumed that there is a tradeoff between services (like maintenance of soil fertility, carbon sequestration, water quality maintenance) and profitability of ecosystems i.e. these services being achieved at the expense of profits accrued from the system and vice versa. However this is not necessarily the case as many studies have demonstrated beneficial interactions between ecosystem services naturally provided by shade-coffee and profitability of the whole system (Gordon et al., 2007). Soto-Pinto et al. (2007) recognised the fact that growing trees in coffee plantation has the potential to buffer environmental and economic

problems (Anderson et al., 2009) through provision of commercial and domestic goods as well as non-production ecosystem services. Shade coffee is said to exhibit beneficial relationships between production and provision of other ecosystem services. For example; reduction of production costs through pesticide substitution, risk prevention by natural pest control, maintenance of soil fertility and avoidance and control of soil erosion. However, the local knowledge about these relationships has not been economically valued thereby making it difficult to pay farmers for the ecosystem services (other than production) provided in order to enhance the sustainability of coffee production at the landscape level (Soto-Pinto et al., 2007).

1.1.3 Local knowledge

The term local knowledge has been used synonymously with the terms, indigenous, traditional or agro-ecological knowledge. As defined by Sinclair and Walker (1999, p. 252), local knowledge refers to the "locally derived understanding which is based on experience and real world observation." In this study, the terms local knowledge or agro-ecological knowledge will be adopted and in particular, the latter will be used to refer to farmers' knowledge about agro-ecosystems. Local knowledge is different from indigenous knowledge in that it can be detached from cultural beliefs and values. Therefore it is possible to learn from farmers' observations and firsthand experience to enhance our understanding of local agro-ecological knowledge and identify gaps that can be complemented by scientific findings (Sinclair and Walker, 1999).

Farmers usually have a lot of knowledge concerning various aspects (for example morphology, ecology and physiology) of native trees (Soto-Pinto et al., 2007). This is because farmers have been working with agro-ecosystems for so long, they have got rich agro-ecological knowledge and understanding of the functioning of these systems, based on hands-on experience and observations made over a long period of time (Sinclair and Walker, 1998). Local people normally understand aspects like seasonality that are difficult to know or predict given the fact that they vary according to locality. Thus local agro-ecological knowledge is essential in designing agro-ecosystems that are both ecologically and economically viable (Grossman, 2003; Soto-Pinto et al., 2007). Farmers' agro-ecological knowledge is very important because it forms a foundation upon which timely solutions to agroforestry research questions can be developed but its evaluation and validation are essential. Therefore, local knowledge is useful in planning and directing development research and extension programmes as well as providing useful information for policy formation (Sinclair and Walker, 1998; Sinclair and Walker, 1999; Soto-Pinto et al., 2007).

Hence community development projects and service provision should be demand driven after taking a close look at farmers' preferences and rationale for their decision-making. This is important in dealing with real life problems in the local communities. For example by using farmers' knowledge about broadleaved trees, the problem that high fodder-value, broadleaved trees caused splash erosion in Nepal was minimised by breeding smaller leaved trees that had similar fodder value (Sinclair and Laxman, 2000).

As indicated by Cabrera et al. (2007), there is diversity in farmers' perceptions of ecosystem services from coffee farms depending on factors like age and literacy level. The variation in farmers' agro-ecological knowledge based on the above mentioned factors may be different depending on the locality. In Mexico, Soto-Pinto et al. (2007, p. 426) listed factors that were important to the farmers in assessing suitability of tree species in coffee shade system and these included; "deciduousness, foliage density, impact on coffee yield, amount of litter and its decomposition rate, leaf size, crown shape and branch extension, height, growth rate, impact on micro-climate and impact on pest and disease incidence, weed control capacity, wind resistance, branch hardness, root strength, moisture maintenance, and additional goods and services offered by the trees."

1.2 Problem statement

Besides productive services, coffee agroforestry systems act as buffer systems, wildlife habitat and corridors as well as serving to relieve pressure (due to exploitation) on natural forests (Sinclair and Laxman, 2000) particularly when they are positioned near protected forest areas (Soto-Pinto et al., 2007). However, there is not much information available concerning regulatory, cultural and supportive ecosystem services from agroforestry systems at different levels for example on farms, landscape, regional and global scales (Méndez and Lovell, 2007). Moreover there is still a challenge of designing "bio-diverse, ecologically sound and economically acceptable" agro-ecosystems and this necessitates more research into local knowledge about coffee agroforestry systems (Soto-Pinto et al., 2007).

Farmers' agro-ecological knowledge is quite comprehensive and is very useful in fostering research, development and extension work (Sinclair and Walker, 1999) and thus should be well investigated. Farmers are rational in making decisions concerning where on their farms, to plant trees. They take into consideration tree characteristics like shade amount, root competition and the fertility derived from litter as it decomposes (Sinclair and Laxman, 2000). However, farmers' criteria for tree selection have not been sufficiently examined and/or reported (Soto-Pinto et al., 2007). Therefore local knowledge needs to be explored and

synthesized such that it can be compared, integrated with scientific knowledge and evidence, and be disseminated back to the community and decision makers to effect change in development.

1.3 Objectives and hypotheses

1.3.1 Objectives

The main objective of the study is to develop a detailed understanding of the local knowledge (farmers' perceptions) of trees and ecosystem services derived from coffee agroforestry in Gisenyi, Rwanda. The specific objectives are as follows;

- Evaluate farmers' perceptions of coffee shade trees and their interactions with the coffee plants
- Determine farmers' criteria for selecting tree species as shade trees in coffee agroforestry systems
- Evaluate farmers' knowledge of the ecosystem services provided by coffee agroforestry systems

1.3.2 Hypotheses

- Local people (farmers) have detailed knowledge about trees in coffee plantations and ecosystem services derived from coffee agroforestry systems
- Farmers have more knowledge about provisioning/production than other types of (regulatory, cultural and supportive) ecosystem services

CHAPTER 2: METHODOLOGY

2.1 Study site

The study was conducted from June to August, 2009 within CAFNET[1] sites in Nyamyumba sector (villages; Busoro, Kigufi and Rubona), in Rubavu district and in Kivumu (Rwinyoni village) and Kigeyo (villages; Gasereganya and Majyambere) sectors, in Rutsiro district, Rwanda. CAFNET sites in this case were next to Lake Kivu as indicated by figure 1 below. The figure shows location of the sectors where the study was conducted and their proximity to Lake Kivu, an important water body to the country. The research was carried out in collaboration with International Centre for Research in Agroforestry (ICFRAF)/CAFNET project. Coffee was found to be the main industrial crop cultivated in the area. According to Grimonie, (2007), farmers were well informed about coffee farming, factors affecting coffee yields and quality. Therefore, these were interesting areas to conduct this research.

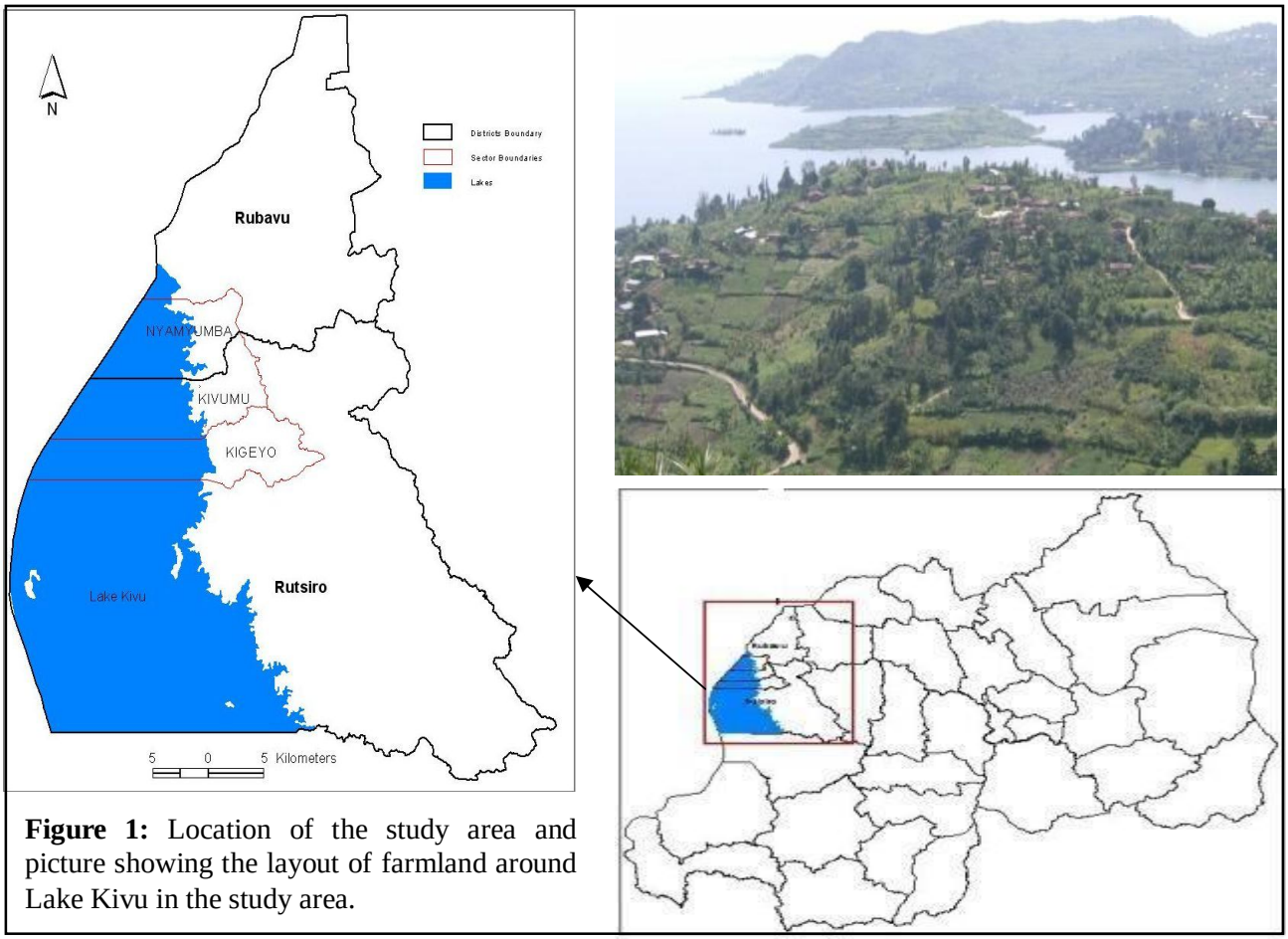

Figure 1: Location of the study area and picture showing the layout of farmland around Lake Kivu in the study area.

[1] CAFNET stand for Connecting, enhancing and sustaining environmental services and market values of coffee agroforestry in Central America, East Africa and India.

2.2 Sampling strategy

A group of key informants (mostly coffee farmers but also, other related stakeholders for example Coopérative pour la Promotion des Activités Café (COOPAC) and ICRAF extension officers in the area) considered to have useful agro-ecological knowledge were purposively selected based on depth of their agro-ecological knowledge and ability to express it, interest in the study, willingness and availability to participate in the study as recommended by Walker and Sinclair, (1998). The selected sample was stratified according to factors like different management practices within coffee farming system (shaded coffee or full-sun coffee, organic or conventional coffee farming), age and occupation. Originally, the size of coffee fields had been identified as one of the factors for stratifying selected farmers and thus compare and contrast their knowledge. However, it was left out after the scoping phase in the field because; it was found out that there were no significant differences in farmers' agro-ecological knowledge in relation to the size of their coffee farms.

2.3 Knowledge acquisition

A Knowledge based systems (KBS) approach that is, Agro-ecological Knowledge Toolkit (AKT) methodology was used and the knowledge acquisition process as illustrated by Sinclair and Walker (1998) and Walker and Sinclair (1998), was followed (figure 2).

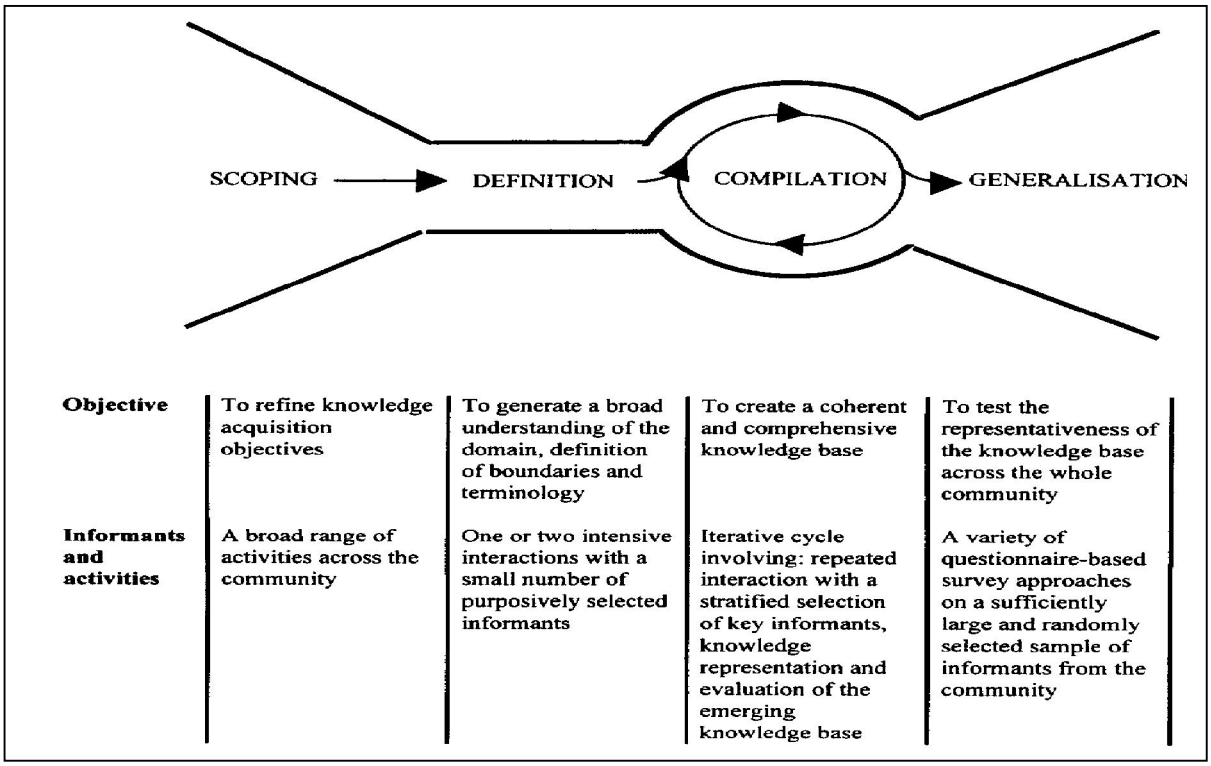

Figure 2: The stages of knowledge acquisition of the AKT methodology, as illustrated by Walker and Sinclair, (1998)

From figure 2 above, the knowledge acquisition process involves four stages as illustrated below;

2.3.1 Scoping

This stage involved introduction to the community (from which knowledge was collected). Unstructured interviews were held with some of the key coffee farmers and ICRAF extension officers and employees at the coffee factory (COOPAC). Through these interviews, onsite walks, sketching diagrams for farm layouts and location of different farming practices in the landscape, an overview of the areas' ecology and the coffee farming system was captured. Based on this information, the problem statement was refined and the study objectives, adjusted. Important issues to ask about were noted and a set of semi-structured questions were formulated to guide subsequent interviews with the key informants. Suitable informants were identified and factors that were likely to influence the kind of agro-ecological knowledge held by people were noted as well.

2.3.2 Defining

The boundaries of the study area were defined i.e. the sectors in which research fieldwork was done were Nyamyumba in Rubavu district, Kivumu and Kigeyo sectors Rutsiro district. After having talked to extension officers, coffee factory employees and some coffee farmers, the terminology used locally in the area was identified and their meaning clarified to ensure proper understanding of what they communicated and then speak back in a way they understood. Based on this, suitable ways of expressing technical terms (like ecosystem services, biodiversity and many others) in relatively simple terms were identified. Key informants were purposively selected depending on their "interest, articulateness, depth of the agro-ecological knowledge and willingness to participate" (Walker and Sinclair, 1998: 375). Based on the background knowledge about each stratum of key informants, the main areas of agro-ecological knowledge in relation to the research topic were defined for example for the organic coffee farmers, soil fertility maintenance, pest and disease control on their coffee farms were some of the most important areas.

Guided by a set of predetermined questions, interviews with the key informants were conducted in a semi-structured manner. To ensure close attention and thought given to what informants were saying and where appropriate, probe for further information before going on to some thing else, a digital voice recorder was used after seeking for consent. This was useful in that interview sessions were replayed as soon as possible (the next day) to note the bits which had not been captured at the time interviews are conduced. In addition, replaying interview sessions helped to clarify issues which had not been so clearly noted during the interviews. Where possible, interviews were conducted on the site (in farmers' coffee fields) as this was important in enabling the farmers to express their agro-ecological knowledge by

pointing at features talked about. It also ensured observation of different features on coffee farms and in the landscape as a whole; where necessary, questions relating to those features were asked. This was an essential tool in gathering as much agro-ecological knowledge as possible and understanding it better.

The whole process of knowledge acquisition was mainly iterative. After every interview, the acquired agro-ecological knowledge was sorted out and the bits that were useful and relevant to research topic were entered into the computer using AKT software, synthesised and issues for which further information was needed were identified and clarified during the subsequent interviews. To increase reliability of the agro-ecological knowledge acquired by AKT methods, triangulation with the key informants, through field observations and use of other participatory methods for example field visits, sketching farm layouts and diagrams for location of farming practices within the landscape, focus group discussions and ranking exercises were done. Visual aids like pictures of trees, birds and other features were used where appropriate, to help farmers express what they knew. During the interviews, trees, birds and other items that farmers were not able to identify, samples (leaves) and pictures were taken for future reference to enable identification.

2.3.3 Compilation

Detailed agro-ecological knowledge about trees and ecosystem services derived from the coffee agroforestry systems was accumulated from repeated interviews with the selected sample of key informants and was systematically recorded into the computer using AKT software and grammar, hence forming a knowledge base. During the recording phase, knowledge was as much as possible differentiated from farming practices. Using the AKT software, agro-ecological knowledge was analysed and patterns in the knowledge were identified, object hierarchies, links between statements and causal diagrams were developed.

The knowledge compiled in the knowledge base was sorted out of a vast pack of information and farmers' understanding of issues related to coffee agroforestry, collected from a selected group of coffee farmers. Thus the kind of knowledge picked out might be dependent on what the researcher thought was useful in relation to the study objectives. Knowledge compiled by different people may differ depending on their main interests and ability to recognise and differentiate knowledge from practices and the representation of the useful aspects of it.

2.3.4 Focus group discussions

In Rubavu, two focus group discussions were held in Busoro village and they involved conventional coffee farmers. Quite a few Women were available at the appointed times for the interviews and discussions especially if the household head was a male. Therefore each discussion group consisted mainly of males and just one or two women. Thus it was not possible to hold discussions with women as a separate group; though this might have been valuable in bringing out some issues and specific knowledge in relation to roles played men and/or women, in the coffee agroforestry system. Also, in some cultures, women might not be comfortable to express their opinions in the presence of men.

A group interview had been held with the organic coffee farmers in Busoro village (Rubavu district); this served the same purpose as a focus group discussion. In Rutsiro, one focus group discussion with conventional coffee farmers was conducted in Rwinyoni village; the other villages (Gasereganya and Majyambere) were far away and had just one informant in each. The focus group discussion in Rutsiro was attended by fewer people compared to those conducted in Rubavu because some farmers wanted to be paid for their service (time taken in giving knowledge). Thus during recording in the knowledge base, the knowledge accumulated from the focus group discussion in Rutsiro, was attributed to individuals since they were just a few. In addition, there were no organic coffee farmers among those who were available and willing to participate in the study in the villages within Rutsiro, where fieldwork was conducted. Each focus group discussion was guided by predetermined themes and some semi structured questions. During the discussions, comparison was between shaded and full-sun coffee systems.

Focus group discussions helped to clear up controversies about some issues that would not have been made clear by talking to individual coffee farmers only, for example, the location of trees on coffee farms and reasons for their positions, whether or not farmers needed a license to harvest tree products (timber) on their farms. Also, being in a group, much more knowledge was presented by farmers within a relatively short time, that is, different farmers would easily point out things that would have been difficult to remember as individuals, for example, the names of some coffee pests, birds observed in coffee farms and many others. It was also good exercise in which people learned from each other while at the same time; new ideas and knowledge were appraised.

2.3.5 Ranking exercises

The attributes which were considered important in selecting trees to plant on coffee farms were identified first by the farmers who participated in the exercise, as a group. Ranking involved arranging the attributes into order of importance, whereby 1 represented the most important one. The ranking exercises were carried out in slightly different ways in the two areas; in Rubavu it was not possible to stratify farmers into small groups or the exercise to be done by individuals as they claimed it would take them so much time which they were not willing to offer. All the selected coffee farmers in that area together in one group ranked each of the attributes by majority vote after discussions. In Rutsiro, ranking was done by individual farmers and average rank for each attribute was taken.

2.3.6 Sketching diagrams for farm layouts and layout of farming practices

Some farm layouts were sketched by farmers, with the researcher's facilitation. In some cases, farmers were reluctant to make drawings themselves, therefore they pointed out all the different farms they had, their location in relation to the house, the type of crops grown on each farm and I drew the sketches. The sketches displaying farming practices in the landscape were drawn in each study area (Rubavu and Rutsiro) by observing what was in the landscape, noting the location of coffee and other crops. Different features and their location as were sketched out on the diagrams were then confirmed by farmers who later came up with a simplified general sketch diagram indicating the layout of different farming practices within the landscape.

2.3.7 Feedback to the community

Feedback sessions were arranged and held within the communities from which agro-ecological knowledge had been collected. This was important in that local people shared the agro-ecological knowledge accumulated from them; and learnt new things from one another. In addition, they discussed what was presented, made clarifications on issues that were still uncertain and further knowledge was gathered as well. Knowledge from the feedback sessions was used to refine the knowledge base.

CHAPTER 3: RESULTS

The following results are an output of the various methods used to investigate the local agro-ecological knowledge of coffee farmers in a context-specific environment. In this study, the main focus was on coffee agroforestry systems thus emphasis was on coffee farms though in some cases, other farms (with different crops other than coffee) were considered to have a better picture of the system and the local circumstances of the community from which local agro-ecological knowledge was collected. The initial sections of results illustrate the context within which this knowledge was situated while the latter ones display results synthesised from the knowledge base.

3.1 Government policy in relation to coffee farming in the study areas

There were factors which influenced coffee farming in the study areas among which; government policy was the most important. The study areas were very close to Lake Kivu (figure 1 above) and there were regulations concerning coffee farming in the area. From discussions with the farmers and extension officers, land which was next to the banks of the lake (most immediate land from the lake banks) was regarded as productive and suitable for coffee production thus was supposed to be used for this purpose (KB statement 251).

According to the environmental policy in relation to protection of water bodies in the country, coffee farms ought to start at a distance of 50m and beyond from the banks of the lake (KB statement 250). Lake banks had been mainly planted with elephant grass to stabilise the soil (KB statement 223). According to KB statement 101**,** there was a belt of trees (*Alnus acuminata*, *Grevillea robusta* and others) within the 50m from the lake banks, so as to bind soil together and minimise soil erosion risks. It was prohibited to grow food crops with coffee or change the land-use once the land was put under coffee production (KB statement 139). An important thing noted was that; though the farmers who were interviewed in this study had their coffee farms on privately owned land, the above obligation still applied. It was an obligation to maintain coffee farms well, carrying out all the management practices in time. This was ensured through the periodic check-ups by government officers.

3.2 Characteristics of farms in the study area

The farmers in the study area were mainly smallholders who not only relied on coffee (*Coffea Arabica*) but other crops as well; which were grown on separate pieces of land within the same farm or scattered in various places in the landscape. The layouts of farms and different farming practices within the landscape are illustrated in the following sections.

3.2.1 Crops grown and coffee farm size

Coffee (*Coffea arabica)* was the main cash crop, predominantly grown by farmers. However, one large-scale tea estate was observed in the area, being owned by a company. Local people in the study areas never grew tea. Farmers commonly had sugar cane and eucalyptus plantations for the purpose of getting supplementary income as well as meeting their own domestic needs. Other crops grown included; maize, beans, sweet potatoes, cassava, bananas, sorghum, yams, pumpkins and vegetables like Amaranth (*Amaranthus dubius)*, cabbage, different varieties of eggplants (*Solanum melongena)*, different varieties of chilli pepper, tomatoes and christophenes/chayote. Farmers in some places also grew carrots and lettuce mainly for commercial purpose. Crop residues for example of beans, maize, sorghum and bananas were used as mulch on coffee farms. Thus knowing the crops grown on other farms gave an idea of the interactions between coffee and them. It also indicated some possibilities and alternatives of agroforestry practices which could be implemented or promoted to increase production as well as maintaining or increasing tree diversity and ecosystem services provision in agricultural landscapes, of which coffee plantations were very much a part.

All the farms including those of coffee and of other crops, in the study area were typically small-size holdings. The size of coffee farms in particular ranged from less than a hectare (0.1 ha) to 6 ha. Out of the 30 coffee farms visited, only one farm was 6.0 ha, 2 farms were 4.0 ha and one farm was 3.0 ha. The majority of the coffee farms were between 0.1 ha and 1.0 ha. When the farms were small, farmers had limited land on which to grow crops as well as integrating trees. This influenced decision concerning whether or not to include certain trees (like fruit trees) on coffee farms.

3.2.2 Farm layout

The following farm layouts presented (figures 3-5) were got from a small proportion of the interviewed farmers. They gave an idea of typical smallholder farms in the area and the extent of intercropping on farms which had crops other than coffee. A plot indicated to be for coffee implied a shaded coffee system (i.e. coffee, trees and some times, grasses) unless stated otherwise.

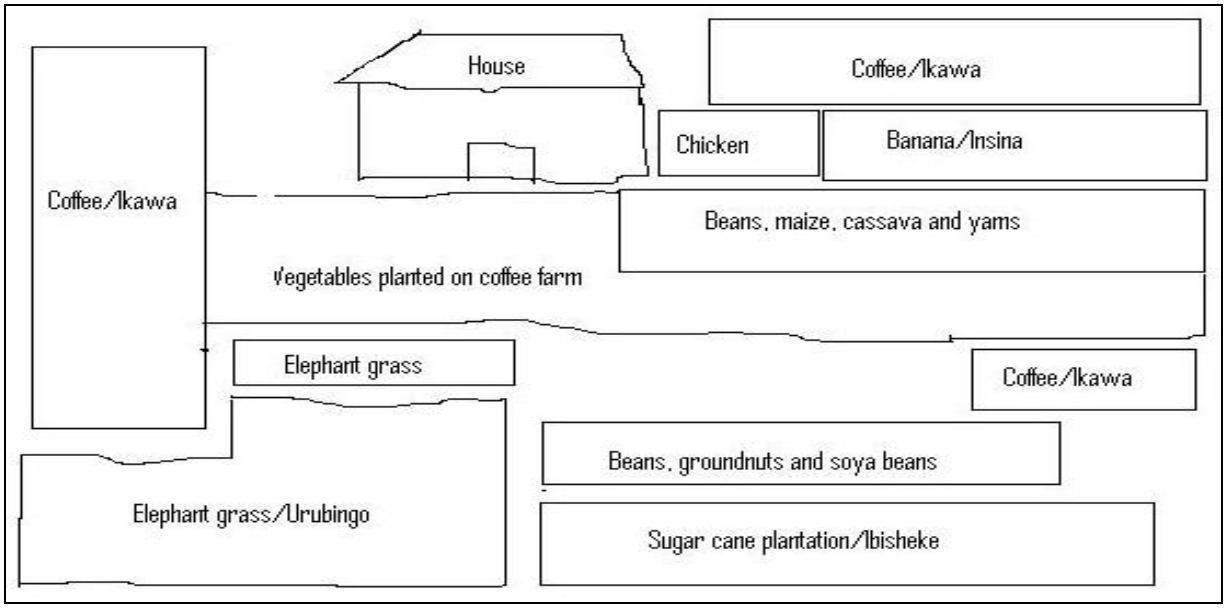

Figure 3: Farm layout showing location of coffee plots and farms of other crops in relation to the house, adapted from sketch by Alloys Nzabonima, Rwinyoni village, Kivumu sector, Rutsiro district 13th/July/2009.

Since the components of the coffee agroforestry systems were defined in a strict sense, intercropping food of crops remained an option to be undertaken mainly on other farms as shown by figure 3. However, vegetables were grown on the coffee farm and the reason for this was the proximity to the house, as it was the case with vegetable gardens. The farmer was hesitant to include the vegetable garden and chicken because the birds reared were few; but also, the farmers never thought that these components were important to be included. However, these were useful to know because they contributed to the household's diet and thus saving money that would have been used to buy them. Some plots were exclusively for some crops or grasses like sugar cane and elephant grass; provision of mulch on coffee farms was one of the roles they played. Sugar canes were also a source of income.

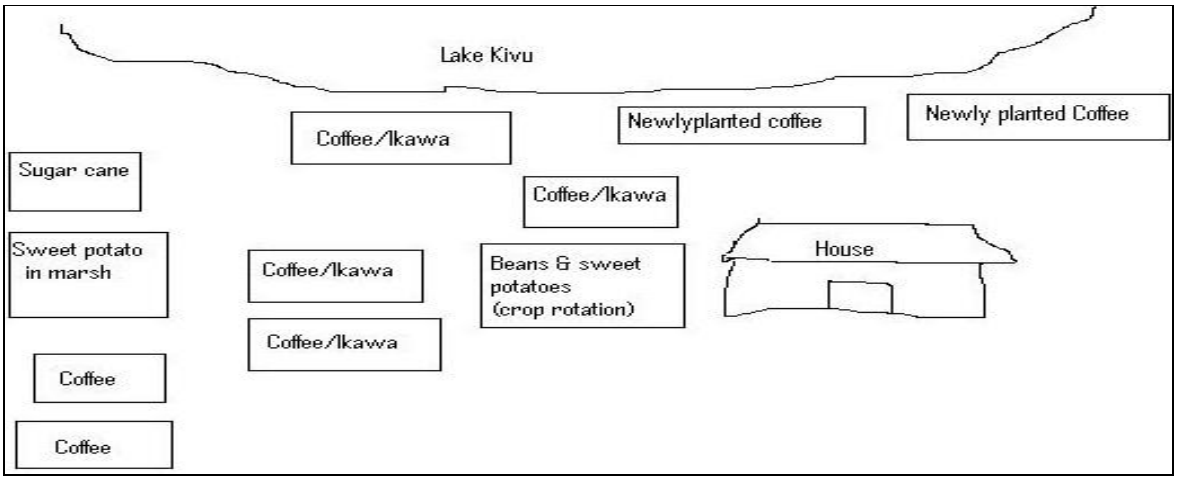

Figure 4: Farm layout showing location of coffee plots and farms of other crops in relation to the house, adapted from sketch by Laurent Sanmehutu, Busoro village, Nyamyumba sector, Rubavu district 21st/July/2009.

Some farmlands were observed to be in close proximity to Lake Kivu as represented in figure 4 above. Based on government policy regulation, coffee farms were established at a distance of 50m and beyond from the banks of the lake. Crop rotation played an important role in maintaining soil fertility.

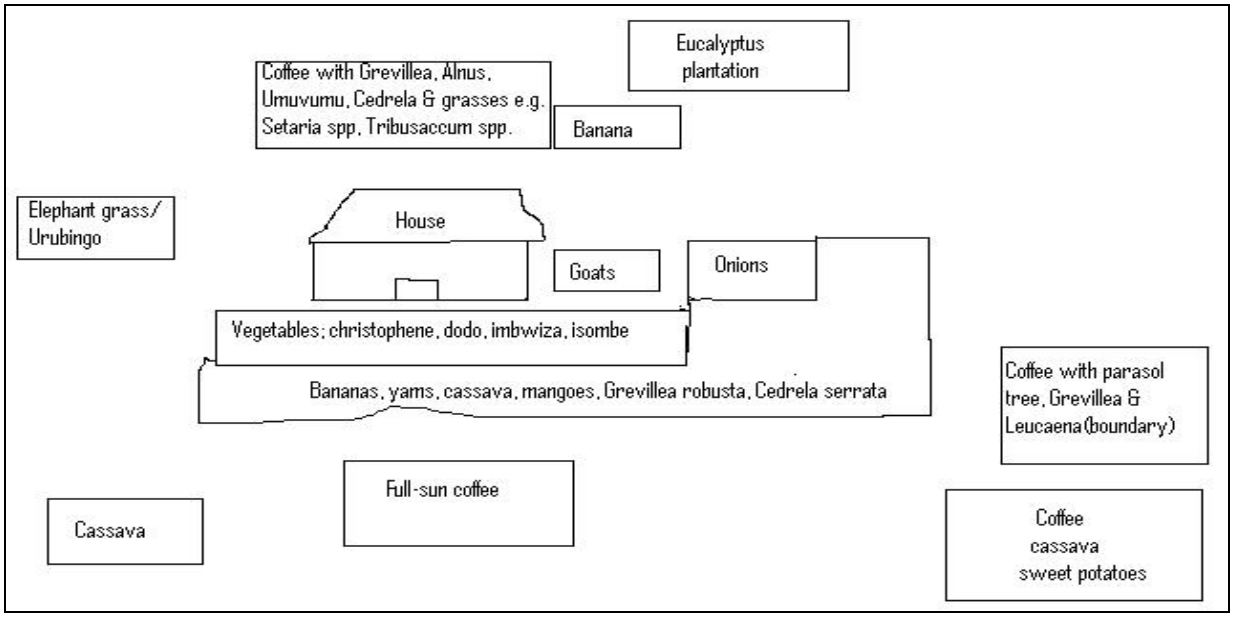

Figure 5: Farm layout showing location of coffee plots and farms of other crops with reference to the house, adapted from sketch by Pio Erinigumugabo, Majyambere village, Kigeyo sector, Rutsiro district, 17th/July/2009.

Some of the farmers interviewed had both shaded and full-sun coffee systems as indicated in figure 5. Trees were planted on coffee farms as well as on other farms with food crops. Thus inadequacy of tree seedlings supplied to farmers was one of the reasons for maintaining coffee farms without shade trees. An important thing noted between shaded and full-sun coffee systems was, the difference in level of some farm management activities; the workload of mulching by "cut and carry method" and weeding was much more in the full-sun than the shaded coffee systems. Knowing the components of coffee farms i.e. trees and grasses, gave a better picture of a typical coffee agroforestry system in the research sites.

In some few cases, food crops were grown on coffee farms (mostly on boundaries) even though such a practice was not permitted. This indicated the inadequacy of land for food production. The lands cultivated for food were small, farm inputs like fertilisers and pesticides were not affordable by most farmers. Thus the majority of the households in the area lacked food self sufficiency. Moreover, the income from coffee was persistently reported to be insufficient due to the small size of coffee farms and low coffee price in relation to the increase in the cost of farm inputs and foodstuffs by that time (KB statements 192, 58 and 196). Thus some farmers

were compelled to intercrop some food crops on boundaries of coffee farms even though this practice was not permitted. The causes and effects of low coffee income are further explored section 3.4.5.1 below.

Animals were commonly part of the farming systems and they were highly valued for manure since many farmers were not in position to buy chemical fertilisers for their food crops. There was also a separate plot for Eucalyptus woodlot which was for the production of poles, timber, fuel wood and charcoal. These products were mainly for sale to get income. Such woodlots were commonly observed in the landscape of the study area for the same purposes. Bananas, just as other fruits, were commonly grown next to homes but in some cases, they were observed being grown by the side of coffee farms. This eased the workload of mulching on coffee farms using banana leaves. Otherwise, the mulch used to be brought to the coffee farms by "cut and carry method."

3.2.3 Layout of farming practices in the landscape

Coffee production was the main farming activity in the area and contributed most of the household income. However, other crops like sugar cane and fruits trees also contributed some money when sold. Growing of food crops was an important activity in the community because it was a way of meeting farmers' food needs. The general layout of different farming practices in the landscape as sketched out by farmers is presented in figure 6. It was also useful to correlate farmers' representation in the figure with the field reality as shown by plate 1.

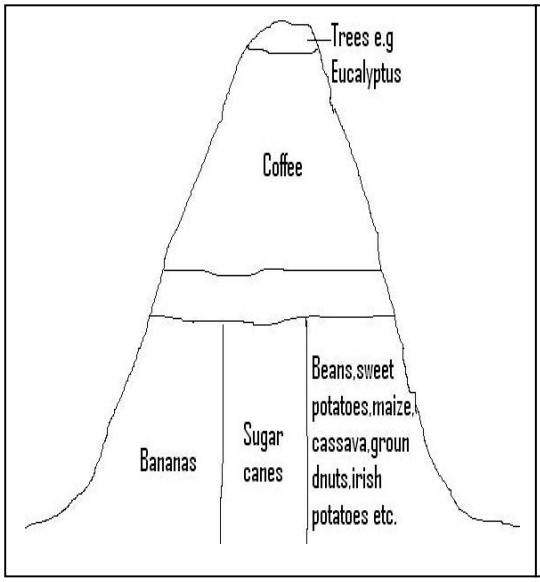

Figure 6: Layout of farming practices within the landscape adapted from Paulin & Venant, Rwinyoni village, 22/07/09.

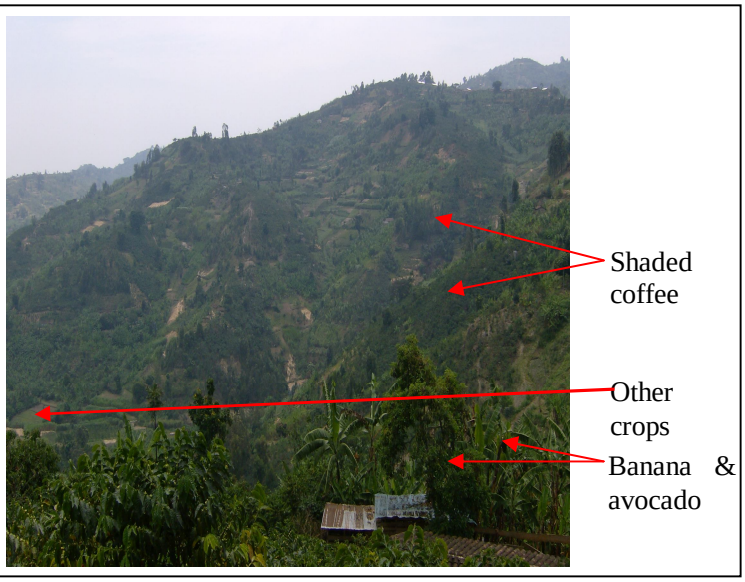

Plate 1: The field reality of the layout of farming practices within the landscape; taken on 17th/July/2009, in Gasereganya village.

Coffee was mostly grown on upslope though it was not preferred at the very top of the hill because of the shallowness of the soil profile and high exposure to wind which was said to cause a drying effect through accelerated rate of evapo-transpiration. Therefore hilltops were usually planted with trees in woodlots for example eucalyptus. Trees among other plants easily grew easily and sustained in adverse climatic and edaphic conditions like high wind exposure, low soil fertility, inadequate soil moisture and others. Moreover very low elevation areas like valleys and low slope foothills were recognised not suitable for coffee farming because of the likely problem of water logging and high risk of frost thus making the yield very low. Therefore areas at high altitude were said to be the most suitable for coffee production if farmers had a choice. However in reality, farmers who did not have plots at high altitude still grew coffee on those they had even when they were on relatively low elevations, not in the valleys though.

Farmers' knowledge from discussions also indicated that altitude affected coffee quality; the maturation period of coffee was longer when it was grown at high elevations thus would be of better quality. Personal communication with researchers confirmed that, longer maturation period enhanced the process of bean filling which improved coffee quality. Presence of trees on coffee farms was known to ameliorate the microclimate (cool temperatures and reduced wind effect) thus reducing heat-induced stress and elongating the maturation period. It is important to note the aspects of coffee quality which the farmers referred to and these included; colour of ripe fruits should be red and high amount of mucilage in the berries made it easy to take off the husk and was also a symbol of quality.

From the discussion with a coffee quality consultant, the following were the characteristics assessed when determining coffee quality; Aroma, sweetness, acidity, flavour[2], body[3] and finish (i.e. good or bad finish). From the expert's point of view; coffee quality would be good if the coffee were to be grown at high altitude to avoid heat induced stress and elongate the maturation period, the recommended agronomic practices including the timing for coffee harvesting, done right. Ripe cherries were supposed to be processed soon after harvesting; otherwise they would ferment and affect the taste after processing. Also, standard processing procedures were regarded necessary for good coffee quality.

[2] It can be chocolate, berry, vanilla or another kind of flavour as found out by the cupper.

[3] It refers to the feel in the mouth i.e. heavy or light drink.

Below coffee farms, were plots of elephant grass ("Urubingo") thus their location lessened the workload of carrying mulch. The food crops were mainly planted in low elevations including valleys and foothills. However, fruit trees for example banana, avocado and others were commonly found near homes as indicated in plate 1.

It was also important to note the location of crops especially coffee in this case, in relation to the slope gradient of the landscape because this influenced the choice of trees to be planted on coffee farms and the management practices carried out on farms. The slope of coffee farms was also useful in choice of erosion control measures to minimise negative effects on the water (Lake Kivu), crop production and the provision of other ecosystem services. Since coffee was mainly grown at relatively high altitude, the kind of ecosystem services provided by coffee agroforestry systems most likely would be different from those provided by forests at similar altitudinal levels and according to Blackman et al. (2008), this is because of the difference in tree cover density. In addition, forests displayed much more floral diversity and greater mosaic of environmental conditions which supported more biodiversity and a greater level of ecosystem services provision.

3.2.4 Cropping calendar

Farmers had a series of activities carried on different farms through out the year (appendices I and II). Cropping calendars indicated productive periods and the timing when specific management practices were carried out. This was important in understanding the knowledge underlying the timing of management practices on coffee farms for example, weeding was done mostly in rain season because that was when their growth was at peak, pruning and thinning were carried out in dry season after coffee harvesting in order to reduce incidence of fungal attacks through wounds created on coffee plants and to enhance sprouting. Production pruning[4] was done before September when coffee usually flowered, in order to enhance coffee production while maintenance pruning[5] was done any time the unproductive vegetative growth appeared on coffee plants.

3.3 CAFNET Rwanda Knowledge base

Rwanda knowledge base (KB) contains statements representing agro-ecological knowledge extracted from interviews with 30 people including coffee farmers, extension officers and a coffee consultant. Interviews were conducted in six villages as highlighted in section 2.1 above.

[4] The removal of old and less productive coffee branches (with few leaves and productive nodes along the branch length) in order to concentrate the nutrients on the more productive ones.
[5] Removal of vegetative branches which do not produce fruits; they use up nutrients in vain.

Rwanda KB has been explored to illustrate what the coffee farmers knew about coffee farming and the interactions within the system and with the surrounding environment. From the interviews, knowledge entered into the knowledge base totalled up to 282 statements and 75 of directly linked to coffee. The rest of the statements were about other components of coffee agroforestry system and practices. Most of the statements (251) in the knowledge base were "causal," expressing cause and effect relationships. Farmers in many cases expressed their knowledge of the processes and actions by explaining interactions between them; pointing out causes and effects. This indicated a detailed level of farmers' understanding in relation to the subject discussed. In addition, 18 comparison and 10 attribute statements were entered into the knowledge base.

3.3.1 Components of coffee agroforestry system

The components of coffee agroforestry system were mainly coffee and trees or shrubs. It should be noted that in this study, the word "trees" is not used in a strict sense but encompasses trees and shrubs. Any thing naturally growing beneath coffee and trees was regarded a weed and was cleared off the farm. Only grasses which were purposefully planted on coffee farms were acceptable. Further details are discussed in the following sections.

3.3.1.1 Trees and their location on coffee farms

Trees and shrubs were planted in particular positions on coffee farms (figure 7). The trees which were inter-planted with coffee, were those considered; to give much leaf litter and these were mostly the ones with spreading crowns, did not compete with coffee for soil nutrients and moisture and their shade in terms of light amount through the tree crown was not dense.

Trees planted on coffee farm boundaries were the ones which had narrow crowns and did not give much leaf litter or grew very slowly, for example *Entandrophragma excelsum*. However, trees like *Maesopsis emnii*, about which farmers did not have much experience, were planted both on the coffee farm boundary and in the midst of coffee. This tree was one of those which had been recently distributed to the coffee farmers by extension officers. Therefore farmers did not have much experience of some trees' interactions with coffee but planted them because they had been recommended by extension officers. This does not imply though, that farmers blindly took actions; they were keen to notice the interactions of these trees with coffee in relation to their position on the farm. Farmers were confident of their knowledge about trees more especially if they had developed it through first hand experience as most of it was.

Shade tree composition included both indigenous and exotic species and there was a tendency that the latter were the majority of the promoted agroforestry trees. This points to the fact that research in agrofrestry has not very much centred on indigenous species. Thus not as much research information is available, concerning the interactions and suitability of indigenous tree species and shrubs in agroforestry systems. Some of the trees were said to be indigenous or existed in the area so many years ago but were not incorporated into coffee farms then. For example, *Ficus thonningii* used to be found in different niches i.e. near homes and sites for compost manure but due to advice from extension organisations which started operating in the area some time later, farmers realised how important such trees were in coffee farming. Therefore they largely incorporated (planted) them into coffee agroforestry system.

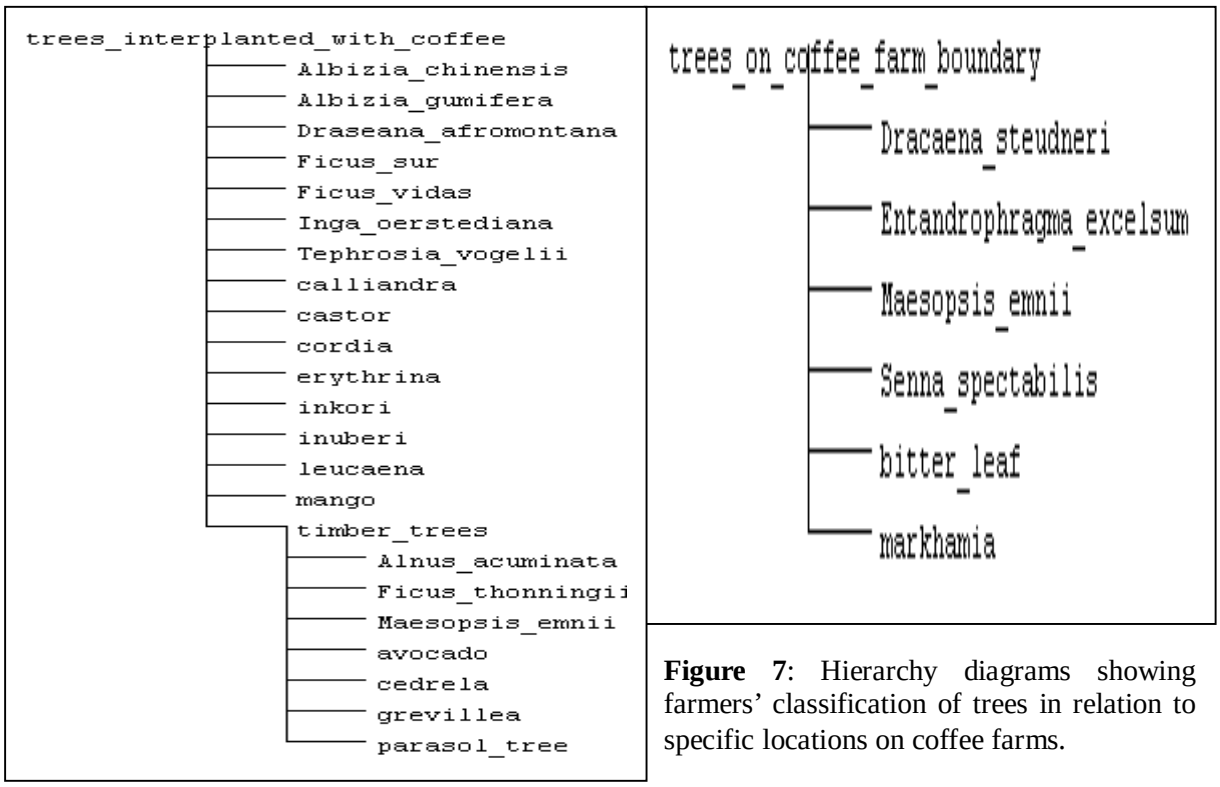

Figure 7: Hierarchy diagrams showing farmers' classification of trees in relation to specific locations on coffee farms.

In relation to the figure 7 above, there was a difference in farmers' knowledge and practice. For example, according to farmers' knowledge, timber trees were preferred to be planted on coffee farm boundaries because at the time of harvesting timber and other wood products, damage to coffee would be minimized. The rationale for the location of timber trees on coffee farms was common knowledge among farmers but they were strongly influenced by extension advice and thus their practice did not reflect their knowledge in this case. Further details about the impact of extension advice on farmers' practice, is presented in section 3.4.7.1.

Besides the influence of extension advice, farmers own practices in some cases conflicted with

their knowledge for various reasons, for example, the location of avocado on coffee farms. As pointed out by farmers at a feedback meeting in Busoro village, avocado was considered good for leaf litter but soil moisture competition would be high and the shade would be dense if many of them were planted. Farmers therefore planted just a few on coffee farms. Ideally, it was known that trees with dense shades would be managed by pruning but in the case of avocado, this meant reduction in fruit production yet the fruits were so much valued as a source of income as well as being part of farmers' diet. Hence avocado shade management involved tradeoffs between fruit and coffee production but in practice, farmers rarely pruned avocado. In addition, coffee flowers and fruits were said to be damaged when avocado fruits fell or if branches broke due to much weight of the fruits (KB statements 172, 175 and 173).

Despite these drawbacks, avocado was commonly inter-planted with coffee. This is a good illustration that practice did not necessarily tell what people knew and that people's decisions and actions concerning location of trees in the agricultural landscape were based on rationale which often differed among farmers and between places. Generally, farmers were more willing to plant more trees on farm boundaries in order to retain more land for crop production. Thus trees were more acceptable in certain niches than others on farms (Biggelaar and Gold, 1995). Some trees and shrubs for example, *Sesbania sesban* were recognized to be good by extension officers but were not found practically integrated into the coffee farming system, most likely because farmers might have lacked access to planting materials or this knowledge might have not yet reached the farmers in an effective manner for them to take action. This may be an indication of some areas which need to be addressed in order to close gaps in agroforestry services and extension.

It was also useful to take note of trees which were observed growing either naturally or being planted in other parts of the landscape other than the coffee farms. In addition, there were trees which were found growing in the landscape but were not on coffee farms. The details of trees and their location in the landscape, origin, regeneration and utilities to which they were put, are presented in appendix III. Note that the term, "landscape" has in this case been used to mean coffee farms, farms of other crops, open areas without crops or the wild. Close examination of trees which were not on coffee farms then is important because many of them may have the potential to grow well with coffee and thus provide various ecosystem services.

3.3.1.2 Grasses and herbs in coffee farms

Some grasses and herbs, excluding elephant or Napier grass and bamboo (figure 8), were also often planted as living hedges or cover-crop (silver grass) on the coffee farms for the purpose

of soil erosion control, especially if farm slope was high. Some of them provided animal fodder. Elephant grass and bamboo were however cut and carried to coffee farms as mulch but were not planted on coffee plots because of root competition with coffee. Quite a few people had domestic animals and their sheds were usually near homes. Thus fodder provided by the grasses would be cut and taken to feed them. Fodder grasses were mainly fed to cattle, goats and sheep though silver grass was also fodder for rabbits. It was reported that presence of silver grass on coffee farms increase attracted wild rabbits.

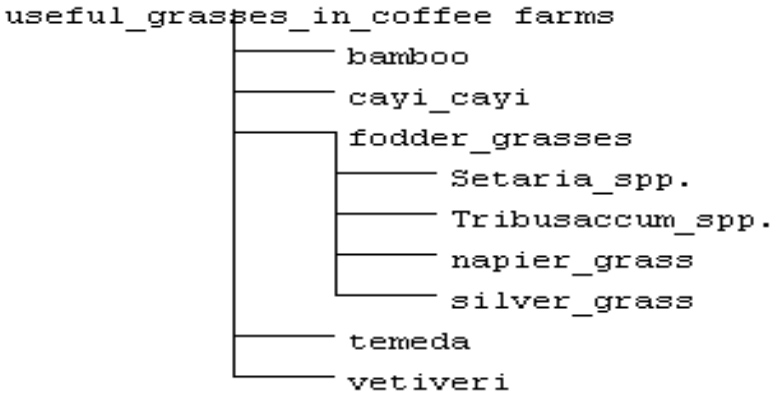

Figure 8: A hierarchy diagram to show farmers' classification of grasses used for soil erosion control, coffee farm mulch and animal fodder.

3.3.1.3 Trees not to be planted on coffee farms

According to farmers' knowledge, some trees were not supposed to be planted on coffee farms, for reasons illustrated in table 1 below. Farmers also did not want to plant trees from which products or benefits would take too long to be realised. Thus extremely slow growth was one of the tree attributes which farmers used to select against trees or identify them as ones that should not be planted on coffee farms (KB statement 153). For example a story about what happened in the past was told of a tree locally called "Imihambwe," which was openly rejected by farmers when extension officers distributed planting materials to them (KB statement 191). This resulted from farmers' knowledge that it would take too long (up to 100 years) to harvest products like timber from this tree.

Table 1: Trees which should never be planted on coffee farms

Trees	Reasons for not planting them	Comments
Acacia mearnsii (Black wattle)	High soil moisture requirements	Only farmers in Rubavu included black wattle on this list possibly because they had more experience with it, compared to farmers in Rutsiro.
Psidium guajava (Guava)	High soil moisture requirements	Only farmers in Rubavu included guavas on this list but some farmers in both study areas inter-planted them with coffee.
Cupressus lustanica (Cypress)	High soil moisture and nutrient requirements	These trees were never found on coffee farms. Eucalyptus and pine were found in separate plantations while cypress was usually found in live fences near homes. Tree-tomato was planted farms other than those of coffee.
Pinus spp. (Pine)	High soil moisture and nutrient requirements	
	Increase soil acidity	
Eucalyptus spp. (Bluegum)	High soil moisture and nutrient requirements	
	Increase soil acidity	
	Allelopathic effect	
Cyphomandra betacea (Tree-tomato)	Attracts *Antestiopsis spp*, a coffee pest.	

3.3.2 Farmers rationale for selecting coffee shade trees

Tree composition on coffee farms differed among farmers depending on the farmer's interests and/or needs. The attributes considered when selecting the type of trees to plant on coffee farms were mainly of trees though the farm slope was also considered. Attributes and their ranks in the two research sites are presented in table 2 below.

Soil nutrient and moisture uptake and root structure were related. They both pointed to the root competition of trees with coffee. In this case, the goal was to minimise any form of competition with coffee. Farmers' knowledge indicated that leaf biomass was linked to foliage density and deciduousness of the tree. Trees with high leaf biomass were preferred because they reduced the need to mulch, suppressed weed growth and released nutrients after leaf litter decomposition. Nutrient release from leaf litter, was the main aspect that farmers referred to when they talked of soil fertility improvement by trees, thus the attributes were not mutually exclusive but inter-related in some ways. Nitrogen fixation was another aspect of soil fertility improvement but was not well understood by farmers involved in this study. However, they followed extension advice concerning and planting trees recommended for this purpose.

Shade cast by the tree meant the amount of light through the crown; too light or too dense shade was selected against. Shape of the tree was related to the crown size; branch extension and height of individual trees. Trees with spreading crowns, wide-spread branches, not too short or tall, were preferred because they provided shade and distributed leaves (leaf litter) over a wide area of the coffee farm. Farmers did not want to plant trees at close spacing or in large numbers on coffee farms, so as to minimise competition with coffee. It was also interesting to find out how easy it was to miss out some things expressed by farmers if careful attention and follow up with the actual meaning was not rendered during communication. Farmers often used abstract terms which needed further explanation to capture the exact meaning of what was said. In terms of slope, trees with firm root systems binding the soil together were selected the most if the coffee farm slope was high, in order to curb down soil erosion problem.

Table 2: Attributes considered when selecting coffee shade trees and their ranks in the research sites

Attributes	Ranks[6] in relation to location	
	Rutsiro	**Rubavu**
Level of soil nutrient and moisture uptake by the tree	1	2
Leaf biomass of the tree	2	4
Economic value of the tree products	**3**	**8**
Tree fodder for animals	4	N/A
Ability of a tree to improve soil fertility	5	6
Shade cast by the tree	6	5
Shape of the tree	**7**	**1**
Coffee farm slope	8	7
Root structure of the tree	N/A	3

Note: N/A means that the attribute was not identified during the ranking exercise.

There was a noticeable difference in ranks given to economic value of the tree products and shape of the tree between the two areas (table 2). The choice of trees basing on the economic value of the products was related to farm size which signified the farmer's economic status. A higher proportion of farmers in Rutsiro had relatively big land under coffee production

[6] A tree attribute ranked 1 is the most important while the one with the 9th rank is the least important. Ranks in Rubavu were as result of majority vote in a group discussion while in Rutsiro, individual farmers did the ranking and an average was taken.

compared to those in Rubavu. Thus there was a noticeable difference in coffee farm size among farmers in the former area unlike in the latter where it was not the case. In Rutsiro, those with large coffee farms were mainly old people who did not make it to the ranking sessions thus ideas captured might have been mainly of the relatively poor people. This relates one of the farmer's statement that; "Poor farmers tend to select and plant trees for which the products (more specially timber) are of high economic value." Also, there might have been difference in availability of market for wood products in the two areas; the commercial value of timber or charcoal for example, was more important to farmers if buyers were available and the price was good.

The ranks in the table also indicate that farmers in Rutsiro might have had more animals than those in Rubavu thus a higher degree of income diversification. So farmers in Rubavu might have depended much more on coffee production; thus below and above ground competition of trees with coffee (as implied by root structure, soil nutrients and moisture uptake and tree shape) was more important to them than farmers in Rutsiro. Also, farmers' knowledge was often expressed in abstract terms; tree shape might have been as well related the wind-breaking role and that wind exposure of coffee farms in both areas was an important factor. Possibly, this was why farmers in Rutsiro did not attach much importance to shape of the tree and never mentioned root structure as an attributed that would be considered in selecting coffee shade trees.

Moreover, there could also have been possible differences in soils, other topographic aspects and socio-economic conditions between these two areas, thus different attributes were considered more important in one place compared to other. Thus the difference in ranks of the tree shape, root structure and animal fodder being identified and ranked important by farmers in one study location but not those in another. It was also reported that people in different localities usually planted and/or used certain trees for different purposes; therefore local agro-ecological knowledge about them could easily be different.

3.3.2.1 Other factors which influenced choice of trees on coffee farms

One farmer cited that, the farms on which food crops were grown were small and this compelled some people to plant fruit trees on coffee farms (KB statement 186). Otherwise fruit trees were supposed to be grown in home gardens or crop farms. Farmers chose different sets of trees to plant on coffee farms depending on the size of coffee farms which reflected the economic status. A farmer who had big coffee farm(s) was regarded rich and vice versa. The

rich farmers tended to prioritise coffee production maximisation by planting more of the tree for leaf litter and soil fertility improvement. The choices of trees by the poor farmers covered a wider range including those mentioned above but also, those for timber and fruits to increase get income (KB statements 187, 186). Therefore knowledge of farmers' preference for trees is important in this case. In this case, farmers preferred to plant on coffee farms, trees which were regarded very important for example, trees for shade and leaf litter which enhanced growth and production of coffee plants, timber trees and fruit trees (especially avocado and mangoes) which were sources of income but also, supplemented the household's diet.

3.4 Ecosystem services

There were various ecosystem services associated with trees and other components of coffee agroforestry system. In this study, the main categories of ecosystem services that farmers relied on and were familiar with the most were the provisioning and regulatory services. But even under these categories, farmers were more familiar and knowledgeable about some services than others, for example, flood control, pest and disease control which are regulatory services, were hardly known. Thus farmers were most knowledgeable about provisioning services and about trees which they often used in daily life situations. Soil fertility improvement was the only one supportive service mentioned while cultural services like aesthetic beauty and cultural value were acknowledged by a few farmers. Only one old man, mentioned trees being culturally important in providing materials for making the cultural cloth called "bark cloth"[7] (KB statement 255). Therefore provisioning, regulatory and supportive services were the most relevant to this study

3.4.1 Ecosystem services associated with trees and other plants in the coffee agroforestry system

For any coffee agroforestry system, the services derived from it would partly depend on the set of trees planted on the coffee farms. Trees, grasses and herbs on the coffee farms were valued and associated with various ecosystem services as presented in table 3.

[7] Was some kind of cloth made out of *Ficus thonningii* bark and specifically used for cultural purposes.

Table 3: Coffee farm trees, shrubs and other plants associated with provision of specific ecosystem services, classifications derived from the KB object hierarchies.

Trees, shrubs & grasses	Ecosystem services								
	Provisioning					Regulatory			Supportive
	F	C	Fr	FW	T	SC	SEC	SMC	SFI
Albizia chinensis		x		x		x		x	x
Albizia gumifera		x		x		x		x	x
Ficus sur				x		x			
Ficus thoningii	x	x		x	x	x	x	x	x
Ficus vidas	x	x		x		x		x	x
Maesopsis emnii				x	x	x			
Alnus acuminata	x			x	x	x		x	x
Avocado	x	x	x	x	x				
Banana			x						
Bitter leaf						x			
Calliandra calothyrsus	x			x		x	x	x	x
castor						x			
Cedrela serrata	x				x	x			
Cordia aficana						x			
Cypress		x		x					
Erythrina abyssinica						x	x		
Eucalyptus spp.		x		x					
Grevillea robusta		x		x	x	x	x		
Guava			x	x					
Tree tomato			x						
Entandrophragma excelsum					x				
Inga oerstediana (Pai pai)				x		x		x	x
Inuberi[8]				x		x			
Lemons			x						
Inkori[9]									x
Leucaena spp,	x			x		x	x	x	x
Mango			x			x			x
Markhamia lutea				x	x	x	x		
Murenda[10]			x						
Oranges			x						
Parasol tree					x	x			
Pawpaw			x						
Pigeon pea			x						
Senna spectabilis				x		x	x		
Sesbania sesban									x
Tephrosia vogelii						x		x	x
Draseana afromontana						x		x	x
Christophene/chayote			x						

[8]A tree with a relatively narrow crown, usually grows tall and sprouts easily. Some of them existed on coffee farms (not planted) while others had been planted by farmers.
[9] A leguminous shrub with sticky pods; it resembled pigeon pea.
[10]A shrub with slender edible fruits and was grow on coffee farm.

Passion fruit			x						
Silver grass	x						x	x	x
Elephant grass	x								
Setaria spp.	x								
Tribusaccum spp.	x								

F-Fodder, **C**-Charcoal, **Fr**-Fruits, **FW**-Fuel wood, **T**-Timber, **SC**-Coffee shade, **SEC**-Soil erosion control, **SFI**-Soil fertility improvement, **SMC**-Soil moisture conservation, **WS**-Weed growth suppression.

Some of the trees presented in the table above may potentially be able to supply certain ecosystem services for which they have not been recognised; because farmers attributed services to trees which they were familiar with in terms of uses and interactions with coffee and the soil. It should also be noted that, farmers recognised the fact that most of the trees or shrubs could provide some kind of fuel wood, but this service was only attributed to some of them as represented in the above table. This was partly due to farmers' classification of trees based on attributes considered for good fuel wood. For example, *Senna spectabilis* was liked by farmers in Busoro village for this purpose because, it dried very fast thus could address very urgent cooking energy needs in their homes (KB statement 81). According to KB statement 226, the amount of smoke produced when wood is burning was another attribute used to assess fuel wood quality. Farmers' knowledge of tree attributes was important in making choice of trees to be planted on coffee farms, (see section 3.3.2 above).

Trees on coffee farms were further valued for provision of other ecosystem services not represented in the table 3 because either the farmers did not specify trees which provided them or very few trees were recognised for provision of the service or the service was not considered very important in their lives or in relation to coffee farming. Additional ecosystem services included; maintenance of water quality, medicine for humans and domestic animals, wind breaking, rain formation, aesthetic value, air refreshment and pest control. In terms of pest control, presence of *Albizia chinensis* on coffee farms reduced the attack of coffee by black ants; which fed on sap from the leaves of that tree (KB statement 155). *Tephrosia vogeli* leaves squeezed into water (1 kg of leaves in 20l of water) were said to provide an organic insecticide for coffee and livestock pests as represented by KB statement 249.

Trees as well supported the health of farmers and their animals. For example the solution made from leaves of bitter leaf (*Vernonia amygdalina*) killed parasitic worms in human and animal stomachs (KB statement 129). KB statement 128 also indicates that feeding *Ficus thonningii* to goats helped to alleviate the same problem. Further discussions with the farmers pointed out

that some trees were also used in making fishing boats; *Ficus thonningii* and *Grevillea robusta*, mortars and pestles; *Ficus thonningii, Ficus vidas, Albizia chinensis* and *Albizia gumifera*, stools from *Ficus thonningii*, wooden plates and spoons from *Ficus thonningii*, *Ficus vidas*, *Alnus acuuminata, Leucaena diversifolia* and *Polyscias fulva*. Farmers' knowledge was mainly accumulated by hands-on experimentation and observation over a long time period. Farmers had detailed knowledge about trees which were often used. The more farmers worked with trees, the more they knew their interactions with coffee and various uses they could be put to.

It is also important to note that farmers' naming of trees some times differed from the scientific naming system; trees scientifically recognised as different species were known by the same local name. Thus farmers' knowledge exhibited a tendency to aggregate things for example, *Albizia gumifera* and *Albizia chinensis* were both locally called "Umusebeya". This was not because farmers did not understand the naming system; the local names given to trees were often related to their uses. Table 3 above illustrates this in relation to the two mentioned species.

3.4.2 Coffee farm management and trees in relation to water quality

It was a common practice to establish many trenches across the slope, on coffee farms near Lake Kivu (at 50m from the bank). The main purpose of the trenches was to trap runoff down the hill which might go into the water. More grass hedges and the cover crop (silver grass) were also observed on the farms for the purpose of stabilising the soil, to reduce the risk of soil erosion. Two tree belts were established along the bank of the lake and in-between them, was the grass belt of *Paspalum notatum*. The purpose of trees and the grass belts was to stabilise soil at and near the bank Lake Kivu. More trenches had been made within the grass belt, to trap and stop any runoff. The interaction of trees on the coffee farms and those in the tree belts, in relation to water quality, is illustrated in figure 9 below.

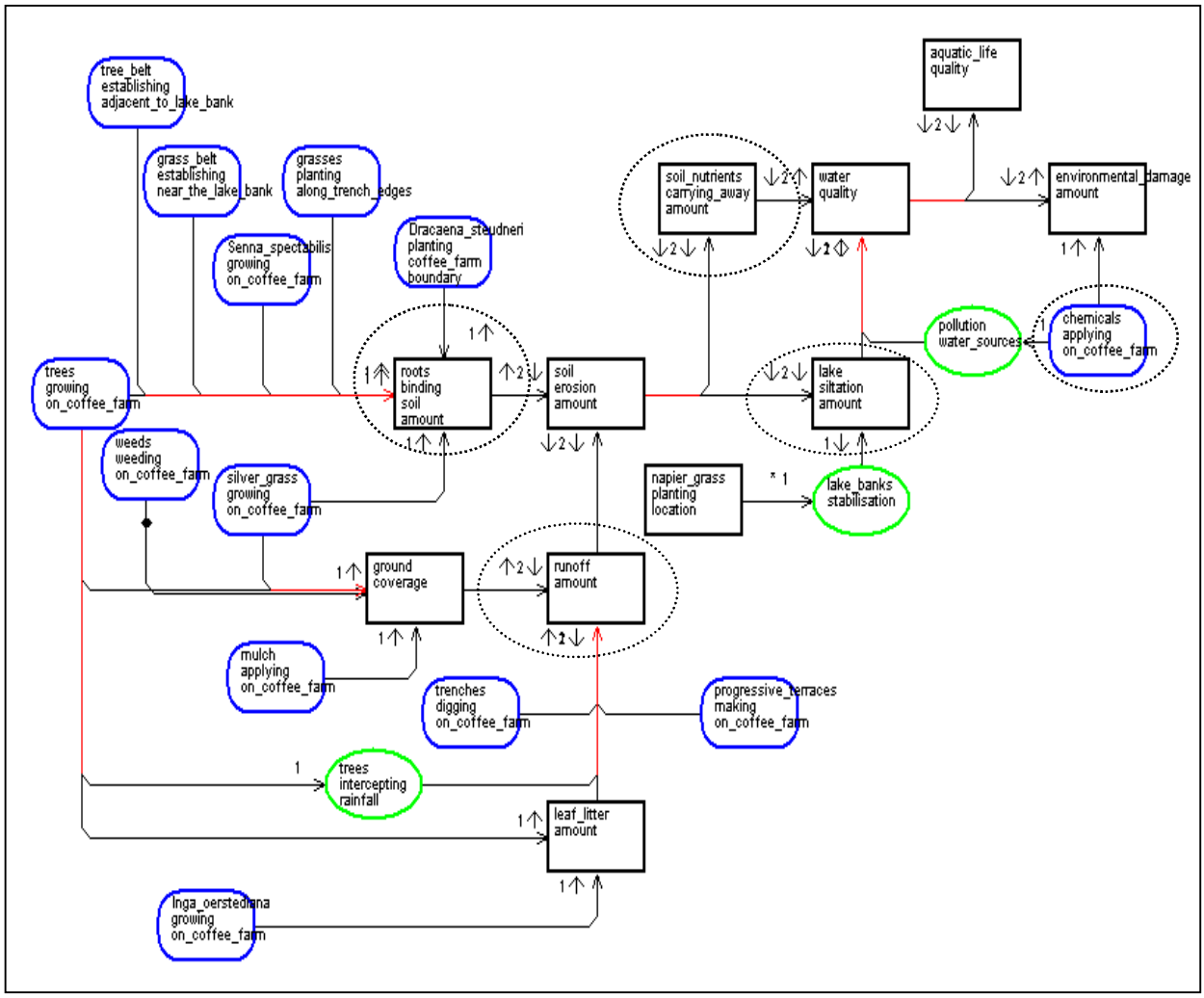

Figure 9: Causal diagram representing interaction of coffee agroforestry system with water through soil erosion control mechanisms and on-farm activities. Nodes; Boxes with straight edges represent attributes of objects, processes (ovals) or actions (boxes with round edges). Arrows connecting nodes denote 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. Numbers between small arrows indicate whether the relationship is two-way (2), in which case ↑A causing ↓B also implies ↓A causing ↑B, or one-way (1), which indicates that this reversibility does not apply. A black dot on a causal arrow indicates a negation of the node it is coming from or going to (e.g. **not** weeding weeds on coffee farm causes ground cover to increase).

From figure 9, coffee farm components (trees and other plants) and on-farm activities formed pathways (indicated by nodes in dotted oval shapes) which impacted on the water quality mainly, of Lake Kivu. Most of the pathways were directly linked to soil erosion control on coffee farms and its relationship with water quality. Trees planted on coffee farms, grasses planted on the edges of trenches, tree belts along the lake banks, *Senna spectabilis* and *Dracaena steudneri* planted on coffee farm boundaries contribute to binding of soil together by roots. Trees, grasses and mulch brought onto coffee farms provided ground cover. Further more, trees gave leaf litter and were valued to intercept rainfall. Coupled with the role of trenches and progressive terraces on coffee farms, runoff was minimised thus reducing the risk of soil erosion. Control of erosion decreased the risk of siltation and contamination of water

bodies. However, management activities on conventional coffee farms i.e. fertiliser application increased the risk of water pollution which could result into decrease of water quality and the aquatic life therein.

3.4.3 Factors affecting coffee yield

When discussing with the farmers, coffee pests and diseases was one of the major factors which affected coffee yield. Farmers had relatively more detailed knowledge about coffee pests rather than diseases (KB statement 270). Most farmers managed to explain the observed symptoms but were not able to identify the disease causing them. In most cases, farmers were unable to distinguish symptoms of one coffee disease from those of another neither were they sure of the control measures. From personal communication with some researchers later coffee wilt disease and coffee leaf rust were the main disease problems on the farms visited. Thus farmers' knowledge about some issues was scanty and based on hearsay sources rather than evidence-based/experience. There were various pests which farmers recognised for coffee damage (figure 10).

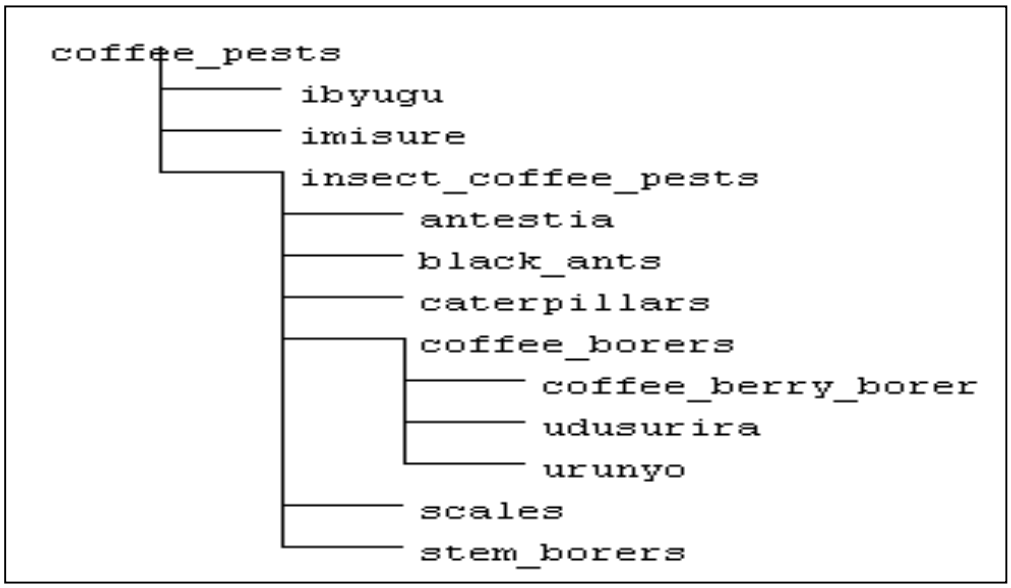

Figure 10: An object hierarchy showing farmers' classification of coffee pests.

Lizards which were locally called "Ibyugu," sucked fluid from ripe cherries[11] while "imisure"[12] were said to eat whole cherries thus were claimed to be pests because they reduced coffee yields to some extent. In fact the numbers of these birds were reported to increase during coffee harvesting season. *Antestiopsis spp.* was often observed on the underside of coffee leaves, causing them to roll up. Some caterpillars massively damaged the leaves of new coffee shoots.

[11] "Cherries" was a local terminology to mean coffee fruits; farmers mainly sold freshly cherries after harvest.

[12] Imisure were medium-size birds which ate ripe cherries in the field.

Black ants travelled in huge numbers along the coffee stems, branches, flowers and fruits. Their excretory materials made the cherries look black and damaged flowers as well. They were attracted by scales which attacked coffee plants and covered up most their leaf area thus affecting their photosynthesis. Presence of scales in coffee was known to increase numbers of black ants which fed on their sugary excretes. The coffee berry borers, "udusurira"[13] and "urunyo"[14] made holes into the cherries, fed on coffee beans and multiplied inside them while stem borers were said to get into on "heart" of the coffee stems through roots or stem base, causing them to dry up.

Soil nutrients availability was another main factor in relation to coffee productivity. Soil erosion was a major concern since the area was predominantly hilly. The risk of runoff was high; therefore management practices carried out on farms were critical in determining soil nutrients availability on farms. Despite the fact that pests, diseases and soil nutrients availability were mentioned as the main aspects which influenced coffee yield, other factors were as well important. Interactions between the factors were important as they impacted on coffee productivity (figure 11).

Predators for example, birds and chameleons were deemed very important in controlling insect pest populations. Despite the farmers' knowledge of the role played by those organisms on the coffee farms, farmers did not care about their numbers; whether they declined or not. As explained above, certain trees were valued for pest control on coffee farms. However, presence of some other trees like the tree tomato was reported to increase incidence of *Antestiopsis spp.*, a coffee pest. Although farmers acknowledged the biological pest control, they relied mainly on pesticides which were supplied by Office de Culture Industriel du Rwanda (OCIR)[15]. Some farmers, mainly those with organic coffee, used insect pest traps[16] to reduce pest damage and the underlying knowledge is presented in section 3.4.7.2.2. When they were asked if trees were important in pest and disease control, most of them reported that there was no difference between full-sun coffee and shaded coffee in this respect.

[13]It was an insect pest (unidentified) which made holes into coffee cherries and damaged the coffee beans.
[14]It was an insect (unidentified) which made holes into coffee cherries and reproduced inside, forming many yellow worms.
[15] OCIR was a government project implemented by agriculture industry in Rwanda; it provided some farm inputs as well.
[16] Traps consisting of a bottled mixture of ethanol and methanol which smelt like ripe coffee fruits and attracted insect pests which died as they fell in water enclosed in the bigger container.

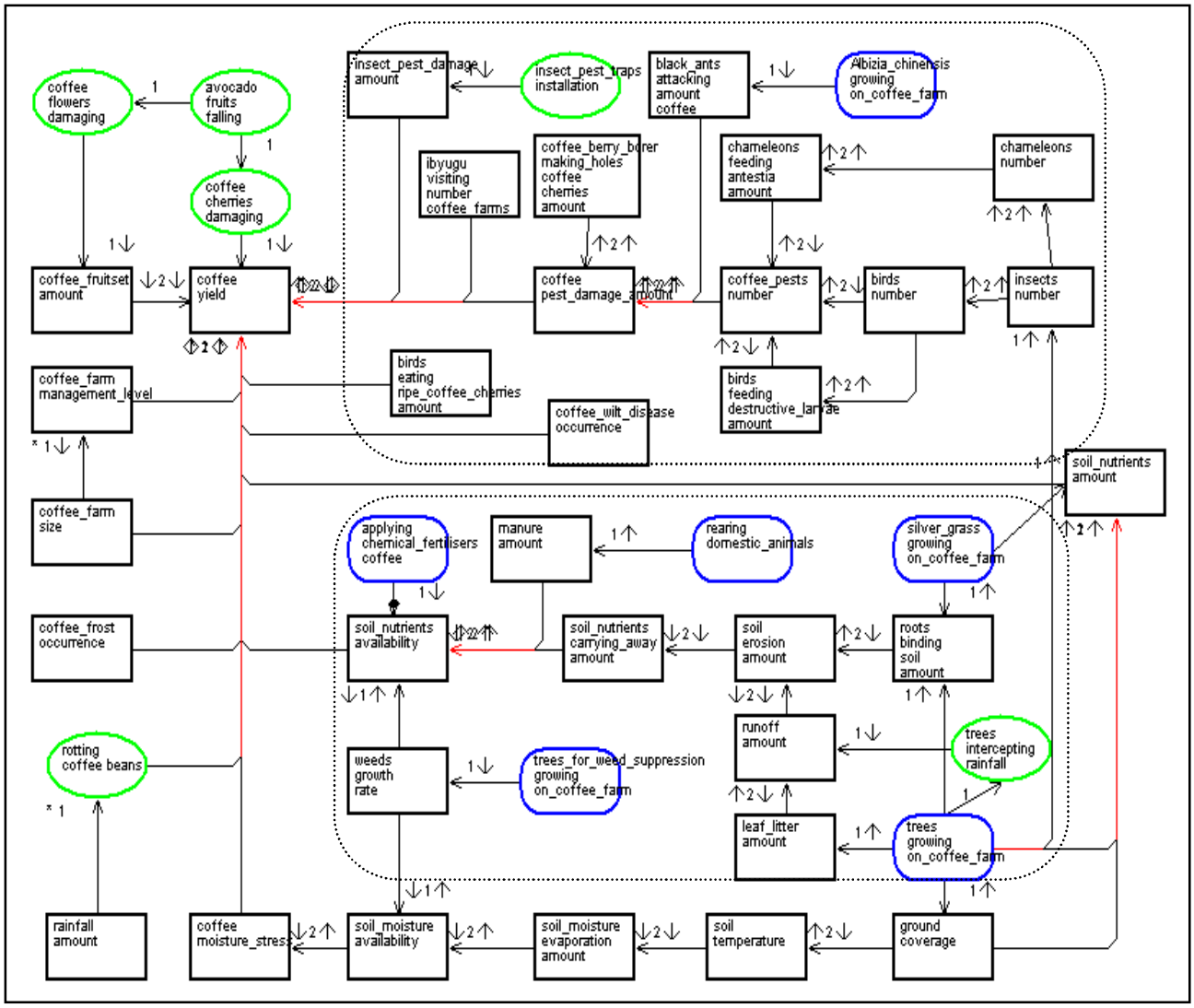

Figure 11: Causal diagram showing farmers' knowledge of the factors affecting coffee yield. The diagrammatical symbols are the same as described in figure 9.

From the field observation, soil erosion was a major problem if farmers never took the necessary measures; one of which was tree integration on coffee farms. Trees were largely valued for controlling soil erosion by their roots binding the soil, their crowns intercepting rainfall and the leaf litter they provided thus minimising the carrying away of soil nutrients. In addition, progressive terraces and living hedges planted with *Leucaena lecocephala*, *Calliandra calothyrsus* and some grasses (figure 8 above) were commonly found on coffee farms. Trees were also recognised for nutrient recycling through leaf litter decomposition though the extent, to which the service was provided, was said to vary among tree species. Some trees, shrubs and herbs were classified to be nitrogen fixing thus were recommended to be planted in abundance on coffee farms because they improved soil fertility (figure 12).

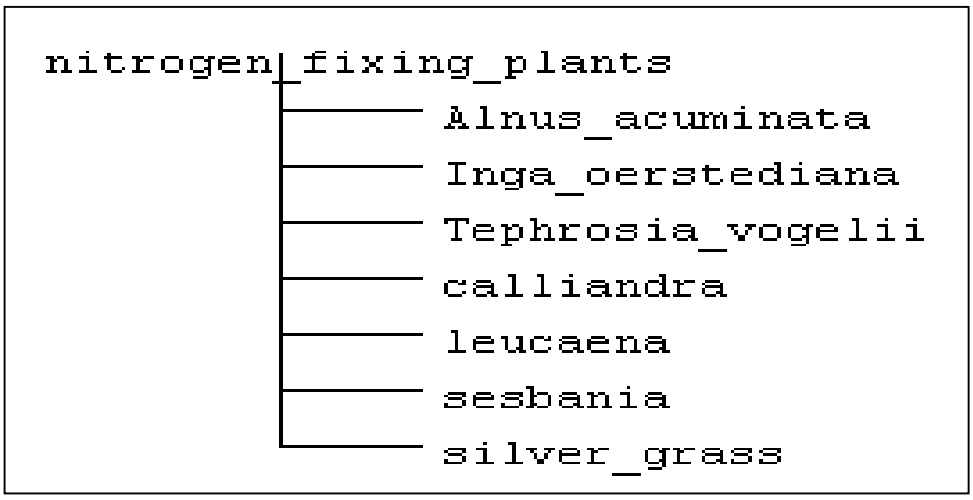

Figure 12: A hierarchy diagram to show farmers' classification of nitrogen fixing trees and herbs.

Farmers also made trenches and progressive terraces on coffee farms in order to reduce runoff. This together with weed growth suppression by trees (like *Inga oerstediana*, avocado, *Ficus thonningii* and others) and manure or chemical fertilizer application influenced availability of soil nutrients the increase of which led to an increase in coffee yield. The farmers highlighted though that it was not just enough to apply manure or chemical fertilisers, other factors like pest and disease control had to be as well considered in order to realise an increase in coffee yield. More still, trees were important in soil moisture conservation especially in dry seasons when the ambient temperatures were relatively high. Even though some farms were next to Lake Kivu, others were relatively far away and since the land was hill, soil moisture conservation was important so as to reduce incidents of moisture stress which reduced coffee yield if it occurred over a significantly a long period.

Too much rainfall which was commonly the case for farms which were so close to the lake, impacted on coffee production as it encouraged more vegetative growth than coffee production. Frost especially if the farms were located at low elevations were a problem, birds and "ibyugu" eating ripe coffee fruits and coffee farms being small, reduced the anticipated yield as well as the management level. Despite the damage of avocado on coffee, it was widely integrated on the farms. For conventional coffee farmers, missing out on chemical fertiliser application resulted in catastrophic effects on the yield especially if they did not apply manure. Not many farmers had domestic animals so manure was not applied by all farmers.

3.4.4 Biodiversity in coffee agroforestry systems

It was clearly known by farmers that coffee agroforestry systems had more biodiversity

compared to coffee monoculture plantations (KB statement 259). According to field observation, biodiversity in coffee agroforestry systems largely depended on their components. Due to the fact that the components of coffee farms in the study area were strictly defined to be coffee and trees, this was believed to have influenced the kind and abundance of different forms of biodiversity in coffee agroforestry systems. Wild animals were reported to visit coffee farms especially at night. However, their number was said to be low. Coffee farm management was intensive thus natural conditions favourable for animals and other wildlife forms were minimal. In addition, the restriction on intercropping coffee with fruits (banana, guavas and avocado) and other food crops limited plant diversity of the system which negatively impacted on the numbers of birds, animals and presumably, insects (figure 13). Plant diversity was critically important in terms of biodiversity conservation because of the role of primary production. Farmers in one of the focus group discussions in Busoro recognised birds as indicator species and that their presence reflected ecosystems health (KB statement 260).

In most cases, birds and wild animals were positively perceived in relation to coffee farming except "Imisure." Bird pests for other crops were; "Amasandi" which fed on bean flowers and "Nyiramahingura which made holes in premature tomato and egg-plant fruits. On the other hand, the majority of insects were recognised as coffee pests. In farmers' point of view, insects were not a good thing on coffee farms except some of them like bees; which were recognised for pollination of coffee. In this case, pest damage was the main concern in relation to insects because they directly affected coffee yield and quality. Farmers' knowledge centred mainly on, issues which were directly important in coffee farming. However, issues important to the farmers often do not attract much attention of the scientists. Like other farming systems, coffee agroforestry was practically operated by farmers many of whom were smallholders. In order to increase biodiversity and enhance capacity for ecosystem services provision in such systems, farmers' knowledge and priorities should be taken serious.

Figure 13: Object hierarchies showing farmers' classification of birds, animals and insects in coffee agroforestry system.

Farm management practices for example, pruning and weeding, had some negative effects on the different biodiversity components (figure 14 below). On the other hand, some practices for example, planting trees and herbs or grasses had a positive impacts on plant diversity, birds and insects numbers on coffee farms. However the negative effects of management activities seemed to be over-riding the positive impacts of flora on biodiversity. Therefore the restriction on intercropping and the intensive farm management regimes were the major limitations to the species diversity and abundance in the visited coffee farms. Despite the fact that human interventions were the predominant shapers of biodiversity, natural phenomena also played a part in reducing the abundance of some species. For example, some shrubs (locally called "Umwicanzoka") which regenerated naturally repelled snakes from coffee farms. Hence such natural tendencies need to be keenly observed and verified to ensure that efforts to increase and maintain biodiversity in agroforestry systems are not countered by confounded factors.

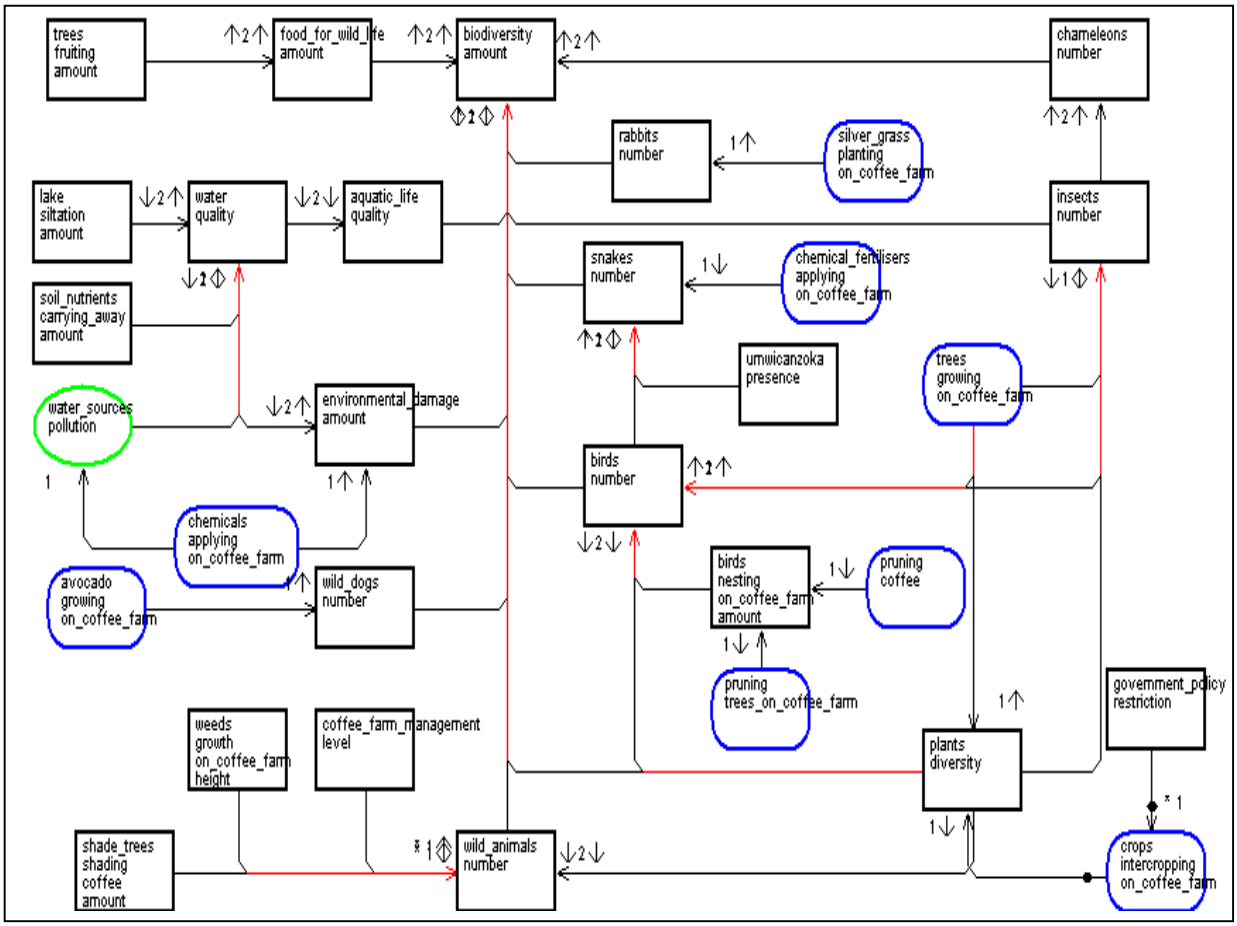

Figure 14: Causal diagram showing farmers' perception of factors which affected biodiversity in coffee agroforestry systems. The diagrammatical symbols are the same as described in figure 9.

3.4.5 Main drivers of coffee farming in the study sites

There were various interplaying factors which shaped coffee farming and issues related to coffee agroforestry systems in different ways. The following sub-sections below illustrate factors which were identified as the most important.

3.4.5.1 Coffee income

Through the discussions held with the coffee famers who were involved in this study, coffee price was identified as a main factor affecting coffee income (figure 15). Nation wide, the price of coffee slightly varied every year (appendix IV) and was determined by OCIR. It was cited that the income from coffee was not enough because the costs in terms of the workload, price of farm inputs and other items necessary for daily life as well as time, were way higher than the income from the sale of cherries. It was said that smallholder coffee farmers had no market for fresh cherries in the past; farmers had to process cherries locally (by drying them). Coffee price then was numerically lower in the past than it was at that time but coffee farming seemed less profitable at that time because; the price of farm inputs and food stuffs had increased so much without a significant increase in the price offered for coffee.

It had been recommended that chemical fertilisers should be applied every three months but the amount supplied at subsidised price was only enough to be applied twice a year. Many farmers desired to buy more fertilisers and supplement what was received but it was not affordable to many of them. Thus much time and energy was devoted to cutting and carrying mulching materials to coffee farms.

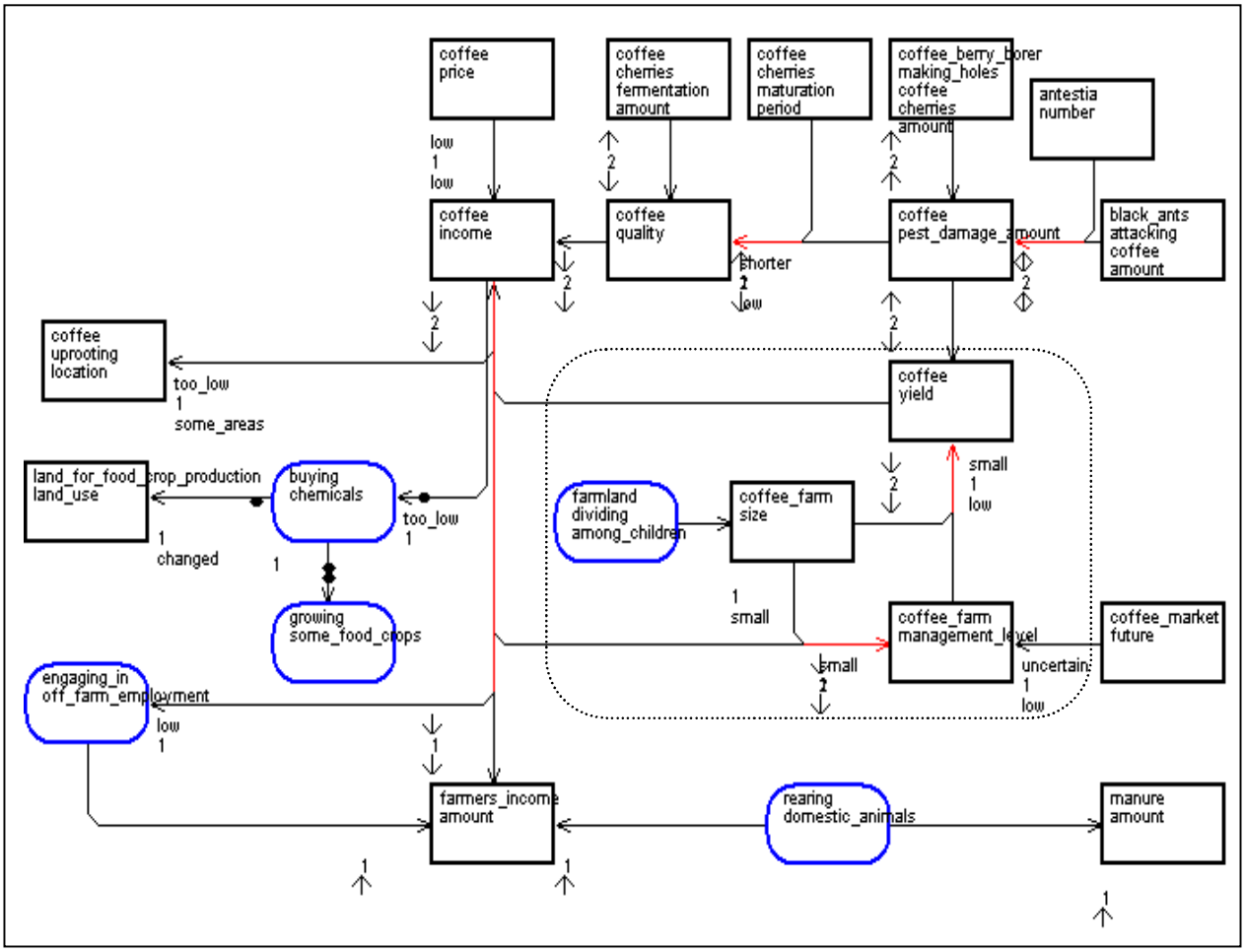

Figure 15: Causal diagram to show farmers' knowledge of the causes and effects of low coffee income. Diagrammatical symbols are the same as described in Figure 9 as well as, words instead of small arrows denote value of the node other than increase or decrease (e.g. the coffee farm size being **small** causes a decrease in farmers' management level of the farm).

Farmers reported that pest and disease damage (sections 3.4.3 and 3.4.7.2.2) was the most important factor which lowered coffee quality. It is important to note the reinforcing cycle (enclosed in a dotted box) which was initiated by the small size of coffee farms affecting the management level and the total coffee yields, resulting in low coffee income. Such cycles may be self-sustaining and then hard to break if the root cause of the problem is not addressed. In addition, similar loopholes in agrofrestry designs and interventions may slow down or even hinder realisation of expected outcomes if they are not detected earlier enough.

Because of low income, some of the male farmers engaged in off-farm employment in order to diversify and increase the household income. In such cases, wives and children were the ones left taking care of coffee farms. This has important relationship to the pattern of local agro-ecological knowledge obtained the local community because; women were interested in different aspects of coffee farming and in many cases, took on roles different from those of men (table 4). Some times, children also helped in some farm tasks. But also, there were some shared tasks among men and women; thus knowledge related to them was likely to be more balanced between the sexes. Farmers' knowledge was mainly related to the roles they performed on coffee farms. Continuation of the trend of off-farm employment by men might have some impacts on the agro-ecological knowledge about different aspects of coffee agrforestry system, practices and the ecosystem services provided. Thus the knowledge specifically captured by men, might be missed out in a long-run if the majority of people available and willing to participate community-based research studies, are women and children. This is important because men and women capture and articulate knowledge in different ways even if it is about similar aspects.

Table 4: Farmers' allocation of farm tasks in relation to gender

Gender	Tasks on farms	Comments
Men	Thinning of coffee	These were exclusively men's tasks. Women and grown-up children would sell coffee cherries only if men were away or too busy to do it themselves but still; the money would be registered in the man's name except if the household head was a woman.
	Pruning of coffee	
	Selling coffee cherries	
Women	Sowing food crops	These were exclusively women's tasks.
	weeding food crops	
Men and women	Planting coffee and shade trees on coffee farms	Coffee was planted in October and shade trees; from October-November (rain season).
	Weeding and mulching on coffee farms	Weeding was mainly done in rain season. Coffee farms were mulched in dry season.
	Manure, chemical fertiliser and pesticide application	Chemical fertilisers and pesticides were applied on coffee farms only; manure would as well be applied on farms of food crops.
	Harvesting of coffee and other crops	Coffee was mainly harvested in March-May
	Collecting livestock fodder	It was done all year round.

3.4.5.2 Development organisations

There were different organisations operating within the study areas. They included; coffee factories like COOPAC, Nkora centre, extension organisations for instance ICRAF, OCIR and Projet Cafe Culture Viviriere (PCCV)[17]. ICRAF and COOPAC worked collaboratively by providing farmers with extension advice concerning farming practices, for example integrating trees in coffee and other farms and soil erosion control measures. They also disseminated planting materials (seeds and seedlings) of agroforestry trees to farmers.

From the interviews with factory employees, farmers sold fresh cherries to COOPAC and other coffee factories in the area. Thus they had to abide with coffee factory recommendations and specifications concerning coffee farming. For example, coffee factories and extension organisations were as well, against intercropping food crops on coffee farms and they recommended that coffee farm management activities should be carried out regularly and in time including coffee harvesting. Ripe cherries which were not harvested in time or taken to the coffee factory immediately after harvesting, were rejected because they were said to have fermented and that their cup quality would be low. Therefore, farmers locally processed the rejected cherries before selling them. Coffee factories in the area were highly recognised for providing market for fresh cherries, which had been almost non-existent to smallholders in the past. Therefore farmers followed the recommendations given by coffee factories and extension organisations. However, there was also fear that if they did not adhere to the advice, they might lose market for their coffee.

During discussions held in the feedback sessions, farmers were open to taken up extension advice, for example concerning trees to plant on coffee farms (*Maesopsis emnii*, *Polyscais fulva* and others) even when they formerly had not incorporated them in coffee farms. This doesn't mean that farmers were blindly practicing everything offered; they gradually experimented and were keen to note the effects of those trees on coffee plants, based on which they would decide whether or not to remove them or to continue planting them. Farmers assessed and accepted mainly, what was reasonable to them. Thus it is advisable to conduct a preference and needs assessment before the implementation of a community-based project. This ensures that both farmers and project's interests are considered from the very beginning and mechanisms for the balance and tradeoffs can be developed thus enhancing acceptance, relevance and success of the intervention.

[17] PCCV was a project dealing in coffee farming, offering advice to farmers.

OCIR and PCCV projects gave extension advice as well as coffee farm inputs and equipments like chemical fertilisers, pesticides ("Tiyoda"[18] and "Konfidoro,"[19]), secateurs for coffee pruning and wheel barrows. The chemical fertilisers, mainly Nitrogen Phosphate and Potassiun (NPK) were distributed to farmers at subsidised price and were strictly to be applied to coffee plants only. Payment was usually done in kind i.e. a proportion of coffee harvest would be subtracted off at the coffee factory to cover this cost. Thus other crops were mainly grown without fertiliser application if the farmer did not have animals to give manure. The lack of capacity to buy fertilisers for other crops and availability of coffee market were some of the main factors which gradually compelled farmers to change farming practice from food crop production to coffee farming thus the increase number of coffee farmers over the years.

Chemical fertiliser application seemed to have positive results on coffee production but the sustainability of the system remained questionable and besides; its environmental effects were obvious. Since most farmers would not afford buying chemical fertilisers without subsidy, integration of trees into coffee farming systems was a good alternative in order to maintain or increase coffee productivity.

3.4.5.3 Fragmentation of farms

According to the reinforcing cycle related to farm size in figure 15 above, the likely danger which was noted and already going on in the area was that; coffee farms were progressively becoming smaller due to increase in human population and the division of land between children, especially the sons. For instance, one of the farmers reported that he had divided part of his land under coffee production among his children and each of them owned a small parcel of coffee farm. Land fragmentation limited landscape connectivity and conservation of biodiversity especially higher scales like the landscape. This in a way, undermined the capacity of ecosystem services provision.

3.4.6 Trends and concerns about coffee farming

From the focus group discussions and feedback sessions, the following were the farmers' issues of concern in relation to coffee farming; the small farms size as already explained in 3.4.5.3 section above was one of the main concerns in that, there was inadequate land to produce food as well as coffee which was the main source of livelihood. The farmlands had been continuously cultivated for so long that the soil fertility level was low. The burden of little

[18] "Tiyoda" was one of the pesticides which farmers were using, being supplied by OCIR.
[19] "Konfidoro" was a pesticide which had been recently introduced in the area. The intention was that it should replace "Tiyoda" because it was more effective in pest control.

household income aggravated the situation; farmers could not afford buying and applying chemical fertilisers and pesticides for their food crop production (KB statement 132).

Moreover some crops like sweet potatoes were reported to have been frequently attacked by pests if pesticides were not used. Bananas which had been a one of the main food crops in the area had been massively infested by banana wilt disease, which destroyed many large plantations. Therefore the hope in food crop production within the study area was progressively fading away. Many farmers had already converted lands on which food crops used to grown, into coffee production. This, together with farmer training and extension advice, coffee market availability and the obligation to maintain coffee farms once established, were said to be the major factors which had led to the increase in number of coffee farmers in the area, over the years. However, farmers were not certain of the future of coffee market and price as they varied every year, (KB statement 235).

Smallholder farmers, who participated in this study, were not in position to access international market since they mainly sold unprocessed coffee. KB statement 236 indicates that there was a trend to go organic as farmers were being encouraged by extension organisations operating in the area. Practices like use of manure instead of chemical fertilisers, mulching and use of insect pest traps rather than chemical pesticides were regarded to be eco-friendly. However, issues of organic coffee certification were still in the pipeline. Thus there was not yet price premium offered for organic coffee cherries which farmers supplied to coffee factories.

3.4.7 Comparative and contrasting knowledge

Generally, all coffee farmers had good knowledge about trees and ecosystem services from their coffee systems. However, there were also some differences in their knowledge in relation to the aspects explored in sub-sections below.

3.4.7.1 Difference between farmers' knowledge and practice in relation to extension advice

Interviews and focus groups discussions with the farmers revealed that there were some differences between their local agro-ecological knowledge and the practices carried out. Extension advice was pointed out to be a main driver of this. For example, the case of timber trees, as already discussed in section 3.3.1.1 above. In relation to the location of fruit trees, they were grown in home gardens as well as coffee farms thus farmers' practice was conflicting with extension advice for reasons explained in section 3.3.2.1 above.

According to extension advice, coffee farms were supposed to be kept free of weeds at all times. In this sense, weeds were totally regarded as sources of root competition; their ranks indicating the most notorious one first, are presented by appendix V. However, one of farmers explained that weeds could play an important role of reducing direct sunrays to the ground if they were left on coffee farm which was not mulched, with low density of shade trees and if it was a dry season. They provided ground cover which reduced the rate of soil moisture evaporation. On the other hand, some farmers also thought that weeds might be useful in reducing soil erosion during rain season if the farm is not mulched. In these cases, farmers' knowledge was antagonistic with extension advice and might not be scientifically valid. Generally, knowledge and practice differ due to presence of constraints in decision making context.

3.4.7.2 Local agro-ecological knowledge of organic versus conventional coffee farmers

There was a difference in some of the practices carried out by organic and conventional coffee farmers and thus the underlying agro-ecological knowledge was different. The difference in their knowledge is explored in sub-sections below.

3.4.7.2.1 Soil fertility maintenance

There were differences in the knowledge about soil fertility maintenance by organic and conventional coffee farmers. Many conventional farmers used chemical fertilisers supplied to them even though many knew that they were hazardous to the environment. Chemical fertilisers and compost manure were applied in rain season; when moisture availability was readily available to dissolve soil nutrients thus making them available to plants. The effectiveness fertilisers and/or manure application in dry season was low thus strategic practices to cope with this situation were observed on some coffee farms (plate 2).

Plate 2: Farmers' practice of conserving moisture and nutrients in manure, applied around coffee plants; Picture taken on organic coffee farm on 23rd/June/2009.

Based on farmers' knowledge (KB statement 265 and 204), manure was applied was around the coffee plants instead of spaces between them; so as to concentrate soil nutrients in a relatively small area; easily accessed by coffee roots. The top soil layer from around the coffee plants would be removed, manure applied and a thin layer of soil put back. Grasses were used to cover around the coffee plant in order to maintain a relatively cool environment thereby reducing evaporation of moisture from manure. Some nutrients were said to be lost as moisture from manure evaporated thus limiting the release of nutrients, especially in dry season. This also applied to chemical fertilisers as shown by KB statements 5). The stones arranged around the applied manure were to minimise runoff when it rained thus minimising washing away of soil nutrients. This practice was only observed on one of the organic coffee farms visited.

Generally, all farmers recognised the role of mulching coffee farms. However, organic coffee farmers attached greater value to mulching as it was one of the main means of maintaining soil fertility as indicated in KB statements 28 and 29. The role of trees in soil fertility maintenance was more acknowledged by organic rather than conventional farmers; their density was greater on organic coffee farms. KB statements 246 and 248 highlighted that organic farmers had relatively more Knowledge about nitrogen fixation though the idea was not yet so much assimilated by many farmers. Nitrogen fixing plants did not only improve soil fertility but also, provided other ecosystem services like soil erosion control, timber for example from *Alnus acuminata*. Thus nitrogen fixing trees were taken to be multipurpose in a way.

3.4.7.2.2 Pest and disease control

From group discussions with organic coffee farmers and the on-site observations, use of insect pest traps, locally called "umutego" (see plate 3) was valued to be more eco-friendly compared to chemical pesticide use (KB statement 272). KB statement 239 shows the underlying knowledge of painting the insect traps red, was to camouflage the colour of ripe coffee cherries thus attracting more insect pests. The smell of methanol and ethanol mixture was said to mimic that of ripe cherries. This was another way to divert attention on insect pests from coffee. This practice was a relative new idea which was not yet taken up by many farmers in the area and their effectiveness in pest control was not yet well established at that time.

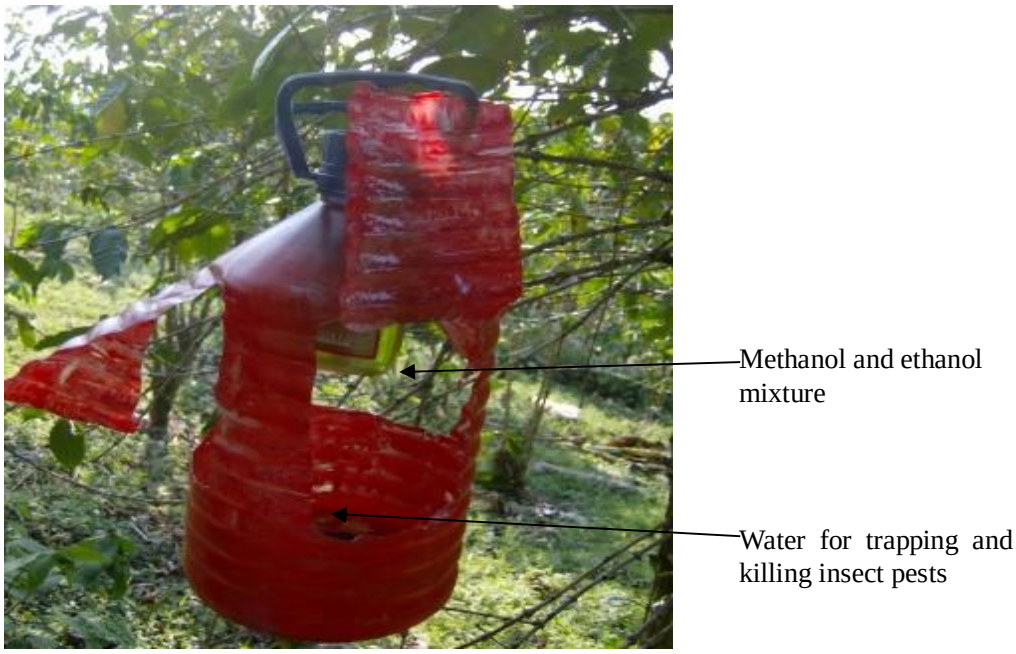

Plate 3: An insect pest trap installed on a coffee plant in an organic coffee farm; picture taken on 23rd/June/2009.

Organic coffee farmers also engaged in physical picking of infested cherries, more than the conventional farmers and this was one of the main pest control mechanisms. Farmers had been advised to put the infested cherries in boiling in order to kill the pests. This was a costly mechanism in terms of the physical and heating energy used. Chemical pesticide spray was the chief pest control method largely relied on by conventional farmers. Therefore,effective pest and disease control methods were needed.

3.4.7.3 Local agro-ecological knowledge according to age

The farmers involved in this study were in the age range of 20-79 years. The young people within the age range of 20-39 years expressed the most knowledge (125 KB statements), those of 40-59 years were attached to 107 KB statements and there were 70 KB statements were given by the last age category (60-79 years). This did not include KB statements (60) expressed by people in groups. From the interviews with the farmers, young farmers were more open to new ideas than old people and their engagement in coffee agroforestry activities was more because they were more energetic thus they were able to express knowledge about many things especially in relation to modern coffee farming practices adopted from extension advice. Older people had detailed knowledge more about traditional practices, knowledge related to historical events and the cultural values. Old people were better at telling changes over time for example, which trees used to be where and why they were in those places.

3.4.7.4 Differences in farmers' knowledge between places

From the feedback sessions in Rubavu, black wattle (*Acacia mearnsii*) and guavas were trees associated with draining the soil of moisture because they were regarded to take up too much of it. Thus they were not supposed to be grown on coffee farms **(KB statements 161 and 163**). However, this was not the case in Rutsiro. Black wattle was not observed on the coffee farms which were visited in Rutsiro; possibly the farmers had no experience with its below ground interactions.

Also, some trees and their roles on coffee farms were known in one area and not in another. For example, *Senna spectabilis* was known and valued for soil erosion control, only in Rubavu while *Cordia africana* was observed and recognized for leaf litter in Rutsiro. This was related to the geographical distribution of trees in the areas; there might have been low frequency of these trees in the areas where they were not known by the interviewed farmers.

Generally *Markhamia lutea* was a timber tree and was supposed to be on coffee farm boundary; otherwise it could as well be inter-planted with coffee because the root competition with coffee was said to be insignificant. Farmers in Rutsiro attached more value to the amount of leaf litter that a tree gave than those in Rubavu (table 2 above). Because this tree was said to give little leaf litter, it was in most cases strictly planted on coffee farm boundary in Rutsiro unlike Rubavu where some farmers did not mind inter-planting it with coffee and valued it for leaf litter.

Discussions with farmers revealed that there was a difference in the basis of farmers' knowledge in relation to whether or not avocado should be on coffee farms. In Rutsiro, the reason why avocado should not have been on coffee farms was mainly based on extension advice while farmers in Rubavu had experience with the interaction of this on coffee farms (section 3.3.1.1).

3.4.7.5 Conflicting and mixed ideas among coffee farmers

There was some level of conflict in the knowledge expressed by different farmers. They had different ideas about the trees which were indigenous. To some farmers, a tree was regarded as indigenous if it had been observed in the area for a long time (about 50 years or more). This was mainly the case with relatively young farmers. On the other hand, some people considered the origin of the trees. This was so challenging though because many people could not know which trees exactly came from where. Thus trees regarded as indigenous to one farmer might have been considered exotic by another. Another area which brought up mixed ideas among

farmers was the location of newly introduced shade trees on coffee farms for example, *Maesopsis emnii* (KB statement 256). Whenever farmers were not sure of the tree's interactions with coffee, they tended to plant it on the farm boundary in order to minimise any potential negative effects. However, some farmers inter-planted it with coffee.

Even though guavas were said to take up much water from the soil, some farmers still planted it on coffee farms for the purpose of fruits and leaf litter as some claimed. Generally, bananas were said to compete for water with coffee (Beer etal., 1998) and cast too much shade (KB statements 257, 63) but some farmers reported that they conserved soil moisture (KB statement 258). The main reason they would have liked to plant it with coffee might have not been water conservation per se, but rather the fact that it provided food and mulching material which reduced the workload to cut and carry it to coffee farms.

There were also aspects which where not well understood by the farmers; pollination, nitrogen fixation. Only two farmers cited bees to be important in plant pollination but were not able to explain how it happened. The majority of coffee farmers did not recognise pollination as an ecosystem service, mostly because they their understanding of the process was limited.

CHAPTER 4: DISCUSSION OF RESULTS

4.1 Farmers' perception of shade trees in the coffee agroforestry system

Farmers were knowledgeable about many aspects of trees in relation to coffee farming. The following sections illustrate the most outstanding ones. Trees were considered good and useful on coffee farms except when they had serious negative externalities associated with them for example, attracting coffee pests or extreme competition with coffee.

4.1.1 Local versus scientific nomenclature systems

It is important to note that farmers' nomenclature of trees was different from the scientific naming system; trees scientifically recognised as different species were known by the same local name. For example, the trees, *Albizia gumifera* and *Albizia chinensis* were both locally called "Umusebeya". Sinclair and Walker (1999) also found out that**,** local agro-ecological knowledge exhibited some level of aggregation and that farmers in Nepal identified and differentiated between varieties of the tree species. Farmers had more knowledge about the different features of indigenous tree species compared to exotic or recently introduced trees (Soto-Pinto etal., 2007). Thus the naming for native trees was more developed than for exotic ones.

4.1.2 Biodiversity in coffee agroforestry system

Trees and coffee were the main components of an intensively managed coffee agroforestry system; any thing which grew underneath was a weed and ought to be cleared except if grasses and herbs had been planted for soil erosion control, fodder or for mulching (section 3.3.1.2). Thus plant diversity was limited yet it is important in terms of biodiversity conservation because of the role of primary production. Low plant diversity might have serious impacts on other biodiversity especially if it occurred over a significantly large area and if keystone species were lost from the ecosystem. Moreover a decrease in biodiversity interferes with the processes related to the ecosystem's integrity and thus lowering its capacity to provide ecosystem services (Méndez and Lovell, 2007; Naeem et al., 1999).

Given the situation, presence of trees were cited to have attracted many birds by providing nesting sites, cool environment for animals to rest and as well, increased insect numbers especially during the flowering season. This matches the report that shade coffee systems exhibit special potential for biodiversity conservation; shade trees forming diversified and copious canopy that enhance diversity of animals, birds, insects and plants (Klein et al., 2002; Me´ndez et al., 2007). Bali etal. (2007) reported that the closeness of coffee farms to the neighbouring tropical forests, composition of native flora and human interventions like

pesticide application are said to be the main factors which influence the diversity and abundance of animals particularly, the mammals, in those coffee systems.

Scherr, (1995) who reported that, farmers adopt and adapt specific trees for their priority uses in particular sites. Likewise, farmers' had priorities and therefore their knowledge mainly centred on issues which were considered important, in relation to coffee farming. However, issues important to the farmers may not attract much attention of the scientists. Like other farming systems, coffee farms were practically operated by farmers many of whom were smallholders. In order to increase biodiversity and enhance capacity for ecosystem services provision in such systems; farmers' knowledge and priorities should be taken serious, (Sinclair and Laxman, 2000).

4.1.2.1 Tree diversity in coffee farms

Forests and other natural vegetation areas in Rwanda were said to have been lost due to population increase. Through integration of trees into farming landscapes over the years, tree cover was said to have increased as well as the accumulation of local agro-ecological knowledge about them, most especially, the indigenous ones, (Biggelaaw and Gold, 1995).

Farmers tended to plant some trees in greater abundance than others depending on their situation, determined by a relatively complex interplay of various factors. For example, poor farmers were known to plant timber trees more than others on their coffee farms to get money**.** Biggelaaw and Gold, (1995) found out that, there was more abundance and species diversity of trees on large farms because more land implied more room to plant them. However, high abundance of trees may not necessarily reflect diversity. Farmers planted more trees of their preference; sometimes just a couple of species. In addition, both the poor and rich farmers selected against slow growing trees on their coffee farms and this in long run, might tremendously reduce the abundance of such trees in coffee agroforestry systems yet human pressure on tree cover in natural forested areas increasingly growing. Based on Blackman et al. (2008), agroforestry systems were cited as alternatives to relieve pressure on tree resources as well as providing ecosystem services though the level to which this is achieved depends largely on the density of tree cover on farms.

There is need to continue involving farmers in research and development interventions while making wise and effective use of their knowledge; to ensure greater significance of the new knowledge accumulated from outcomes of studies in increasing tree diversity and ecosystem services provision from agroforestry systems (Steiner, 1998). To ensure that this happens in

coffee agroforestry systems, effective mechanisms fostering adoption of; trees which are desirable to the farmers but are in low frequency as well as those which are important for ecosystem services provision but not necessarily attractive to them. These include easy access by the farmers to improved tree planting materials, incentive-with-follow-up mechanisms which promote diversity of trees which are not desirable to the farmers but important for ecosystem functioning and service provision and many others. It is also important to note that technical factors for instance, matching species with sites need to be complemented with financial incentives for example ensuring market availability for tree products of promoted trees in order to realise tree diversity on farms. It is also stated that farmers usually take up agroforestry practices which give better benefits compared to the available alternatives or which provide services in the most effective manner (Scherr, 1995).

4.2 Farmers' local agro-ecological knowledge in decision making and practice

The decision that farmers make depend on the prevailing situation which in presence of constraints, have to involve tradeoffs. Thus farmers' practices often differs from their understanding (Sinclair and Walker, 1999). In addition, farmers in this study had developed local agro-ecological knowledge by first-hand experience and observations over a long time period. Their ability to articulate their understanding of natural processes (e.g. nutrient recycling and soil erosion) formed a basis for the criteria followed in choice of coffee shade trees (table 2) and the underlying reasons for their positions of coffee farms (section 3.3.1.1). Group influence might have been a main part in determining the results from ranking exercise of attributes considered in shade trees selection. Generally the main issues which farmers individually raised first, in relation to planting trees on coffee farms were competition level for resources, the amount of leaf litter given and shape of the tree (i.e. spreading or narrow crown, branch extension and tree height). This is related with the findings of (Soto-Pinto etal., 2007). This responds to the need to understand farmers' rationale for planting and/or retaining specific trees in particular sites, as pointed out by Me´ndez et al., (2007).

Knowledge of tree species characteristics is essential because, coupled with soil and climatic conditions of the farming area; they form a basis in ascertaining whether or not its interactions are beneficial (Beer, 1987). Farmers' knowledge was very rich; there was often a need to ask for further explanation in order to understand what was said or expressed. For example; when they talked of leaf biomass, they meant foliage density and deciduousness of the tree. Many of the desirable characteristics of shade trees stated by Beer, (1987) were similar to the findings of this study though farmers often expressed their knowledge in a summative manner; combining

things together (Sinclair and Walker,1999).

4.3 Impact of trees on coffee productivity and quality; why keep trees on coffee farms?

Farmers' knowledge of coffee agroforestry indicated that there were trade-offs between coffee production and provision of ecosystem services. For example, it was reported that the yield from monoculture coffee plantations was higher compared to that of the shaded coffee system. However, the latter was associated with higher quality of coffee cherries and less workload (weeding and mulching). Coupled with provision of other ecological services some of which directly translated into fiscal terms (timber, poles and charcoal), the loss in coffee yield was in many cases covered. This is in agreement with Gordon et al., (2007) who reported beneficial interactions between ecosystem services provision and profitability the shade-coffee system. Anderson etal. (2009) also stated that agroforestry systems provide both financial and ecological benefits.

Beer (1987) pointed out that, the integration of shade trees is more acceptable in relation to smallholder farmers because of the sub-optimal conditions under which they usually operate. The explanation for this is; "Shade reduces photosynthesis, transpiration, metabolism and growth and therefore, the demand on soil nutrients and so enables a crop to be obtained on soils of lower fertility" (Beer, 1987, p. 4). Thus for smallholder farmers who are not in position to manage their farms so intensively especially with regard to fertiliser use, some density of shade trees is recommended for coffee as well as cocoa production.

4.3.1 Climate amelioration

The low temperature at high altitude was reported to increase the length of maturation period of coffee thus enhancing the process of bean filling and thus the increase in coffee quality. Presence of trees on coffee farms especially at low altitude, ameliorates the microclimate; cool temperatures and reduced wind effect, regulating humidity and improving soil moisture and nutrients available for plant growth and "heat-induced stress" thus enhancing coffee quality; the physical but not "sensory" (taste) quality (Bosselmann etal., 2009, p. 253-254). Shade trees are said to reduce the amount and quality of light thus minimising the tendency of "over-bearing" in coffee. However; trees may as well stiffen the competition for "growth resources" (Beer etal., 1998, p. 141).

To the farmers, quality was known in terms of size of the coffee beans, colour of ripe cherries, the amount of mucilage and insect damage. This might have been because they were not involved in coffee processing and never had access to international market. According to Bosselmann etal. (2009), the variation in shade effect on coffee quality was related to the difference in sites while Soto-Pinto et al. (2000) in Bosselmann etal. (2009) reported that more than 50% of shade density resulted into negative impacts on coffee quality.

4.3.2 Soil fertility maintenance

Farmers highly acknowledged the value of coffee shade trees in nutrient recycling in terms of giving leaf litter or branches being pruned for mulching. This is supported by the findings of Pinners and Balasubramanian (1991) in Rwanda. On the other hand, research by Roose and Ndayizigiye (1997) reported that agroforestry did not restore soil productivity in tropical mountains of Rwanda, except when mineral fertilizers were as well used. Cabrera, et al. (2007), remarked that the effectiveness of agro-forestry systems in restoring soil productivity depends on the system's components, foliage density of trees and other plants as well as the amount of litter produced. It is also important to note that different geographical sites often have natural differences in prevailing conditions and the level of degradation from past activities varies. Thus restoration of those places may require different measures. This is in line with research conducted in Rwanda by Steiner (1998) who reported that, there were small scale changes in soil and climate characteristics in tropical highlands, due to factors like topography, elevation level and others. These variations were said to intensify when with respect to multifaceted land use systems for example agroforestry.

4.3.3 Pest and disease control

Farmers recognized the role of birds and some trees in relation to pest control though their knowledge was not detailed. They also cited the role of some shade trees in pest control for example Albizia chinensis in reduction of coffee damage by black ants. However, too much shade was known to be not good for coffee growth and production. According to Beer etal. (1998), high shade density was reported to increase prevalence of some pests and diseases for example "*Phythphora palmivora* and *Mycena citricolor*" but may also reduce occurrence of others like "*Colletotrichum gloeosporioides* and *Cercospora coffeicola.*"

4.3.4 Soil erosion control

Soil erosion was a major problem in the study area and trees on coffee farms were reported to play an important role in its control. Roose and Ndayizigiye, (1997) reported the role of agroforestry systems in erosion control through provision of mulching material on farms.

Therefore trees were valued important in conservation of soil nutrients to ensure good coffee production and maintaining water quality especially in terms of Lake Kivu (figure 9). Similarly, it is reported that agroforestry practices are important in reducing non-point source pollution from farmlands (Anderson etal., 2009).

4.4 Other ecosystem services

Some farmers valued bees in pollination of coffee, thus enhancing coffee productivity. In relation to this, Carvalho and Krug (1996) in Marco and Coelho (2004) mentioned that wind was equally important as insects were in the pollination of coffee. However, it depends on the species or variety of coffee. *Coffee arabica* which was grown in the study areas is "autogamous" and therefore cross pollination is not necessarily a pre-requisite for fruit-set to take place (Ricketts, 2004). Klein etal., (2003) concluded that insect pollination enhanced not only fruitset of self-sterile coffee species but also the self-compatible ones. However, pollination issues are currently under "hot" debates, therefore more scientific and concrete reviewed evidence is needed.

4.5 Challenges to coffee agroforestry and provision of ecosystem services

Coffee farms were progressively becoming smaller due to increase in human population and the division of land between children, especially the sons. Land fragmentation limited landscape connectivity and conservation of biodiversity at landscape scale.

The uncertainty about coffee market and price were said to be related to the on-going economic crisis. As a way to diversify household income, some farmers engaged in off-farm employment, setting up woodlots especially of eucalyptus and high level of intercropping on farms where coffee was not grown. Many species of eucalyptus were said to be heavy feeders and their planting was discouraged. People's ability to express the understanding of some natural processes, influences actions they choose to implement in the environment. Similarly, research conducted in Rwanda by Biggelaaw and Gold, (1995) indicated that, knowing something was not enough; the ability to articulate and implement knowledge was rather important.

Knowledge can be derived through many ways some of which might limit farmers' understanding and capacity to articulate it thus slowing down knowledge transfer and its implementation among people. For instance, some farmers explained that eucalyptus caused allelopathy but could not explain how it happened. Young, (1989) pointed out that, some eucalyptus species were thought to produce chemical substances which inhibit germination or

growth of annual plants. Despite the farmers' knowledge, eucalyptus was in some cases observed growing on or near farms and commonly planted in woodlots. Challenges are usually a driver to seeking solutions to specific problems. However, not all solutions may be practical or result in sustainable results especially if the challenges are so pressing. In a long run, it may seem like running away from one problem into another with worse consequences.

4.6 Important fieldwork issues

An important thing about fieldwork which may some times be overlooked is the expectation of the communities from which the local agro-ecological knowledge is gathered. In the case of this study, farmers had the expectation that their time spent in giving knowledge should be paid for because the previous researchers in the area had initiated this. In reality, this may be relevant especially if the research benefits to the local community are not direct or sustainable. It is therefore important to be sure about informants' expectations before hand such that, appropriate measures are put in place. This ensures that fieldwork activities are not sabotaged and the quality of knowledge delivered by the informants is not affected.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Farmers had detailed knowledge about trees especially those that had existed in the area for a long period of time; including the indigenous and exotic species which were introduced long ago. That is, the longer the time farmers had worked with trees on their farms or in the landscape, the more detailed knowledge they accumulated through experimentation and experience. On the other hand, farmers had mixed ideas about trees which were indigenous and the ones which were exotic. The distribution and frequency of trees in the two research sites affected farmers' knowledge about them. Trees at low frequency were hardly known by farmers. Incorporation of some trees species into the coffee agroforestry system had been quite recent even though they were indigenous. Trees on coffee plantations mainly had positive interactions with coffee plants and the coffee agroforestry system as a whole, though negative effects could not be ruled out depending on the tree density and characteristics of individual trees and their management.

Farmer's criteria for selecting shade tree species to be incorporated into coffee agroforestry system were mainly based on tree attributes which included; level of soil nutrient and moisture uptake, leaf biomass, economic value of the tree products, tree fodder for animals, ability to improve soil fertility, shade cast by a tree, tree shape and the root structure. In addition, level of farm slope was also an attribute considered in selecting coffee shade trees. Most the attributes were similar in the two research sites but the level of importance (ranks) attached to them was different, most probably due to contextual differences of the two areas. Comparing results of this study with some other research findings, criteria for selecting coffee shade trees is context specific and therefore differs from place to place.

Farmers had good knowledge about ecosystem services derived from coffee agro-forestry systems and it was mainly centred on the provisioning services but to a less extent on regulatory, supportive and cultural services. Their knowledge exhibited some differences depending on whether the farmer was young or old, organic or conventional.

5.2 Recommendations

Validation of the farmers' agro-ecological knowledge is useful to ensure its representation in the whole community from which it was collected, to compare it with knowledge from other localities and identify useful patterns which are important in designing context specific, diverse and viable agro-ecosystems.

More research to estimate the money-value of ecosystem services provided by agroforestry systems is needed to enable development of effective environmental schemes like Payment for Environmental Services (PES), at scales which make it practical for smallholder farmers to actively participate and benefit while preserving the environment.

In order to enhance the level of acceptance, relevance and effectiveness of agroforestry interventions, it is valuable to conduct a preference and needs assessment before project implementation. It is also important to make wise use of the available local agro-ecological knowledge and to actively involve the target group (s) right from the project planning phase in order to identify the actual constraints which need to be addressed.

Local agro-ecological knowledge supports decision making; it needs to be systematically compared and contrasted with scientific evidence, gaps identified and bridged up and then incorporated together in order to provide a stronger basis for decision making and effect change at policy levels, which affect the provision of ecosystem services over large scale levels for example, landscapes and regions.

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Appendix I: Cropping calendar showing on-farm activities carried in a year, in Rutsiro

Cropping calendar made by coffee farmers in Rwinyoni village, Rutsiro district												
Activity	Months											
	January	February	March	April	May	June	July	August	September	October	November	December
Land preparation												
Manure application on other farms												
Manure application on coffee farms												
Sowing crops												
Planting coffee												
Planting seedlings of coffee shade trees												
Weeding on coffee farm												
Weeding other crops												
Staking beans												
Mulching coffee farms												
Chemical fertiliser application												
Pesticide application												
Collecting livestock fodder												
Coffee pruning												
Coffee thinning												
Cofee harvesting												
Coffee processing (drying it)												
Harvesting crops												

Legend

Land preparation; involved tilling land to make it ready for sowing crops.

Sowing; February-beans, maize, sorghum, sweet potatoes
August- beans and pumpkin
September-beans, sweet potatoes, cassava, sorghum, maize
November-sweet potatoes

Weeding other crops; January-sweet potatoes
March-maize, sorghum, bananas
April-beans, maize, sugarcane, sweet potatoes
October-cassava, beans (both planted in August & September), maize & sorghum (planted in September) and bananas
November-Sweet potatoes planted in September

Harvesting other crops; January-beans planted in September
February-maize and sorghum planted in September
April-sweet potatoes planted in September
May-beans, sweet potatoes planted in November
July-maize & sorghum planted in February, cassava (planted in September the previous year), sweet potatoes (planted in February)
Aug-Sweet potatoes (planted in February)
December-beans, maize (planted in August), sorghum and pumpkins

Note: In Rutsiro and Rubavu, fertilisers and pesticides were provided by OCIR, thus they were meant to be applied on coffee farms only.

Appendix II: Cropping calendar showing on-farm activities carried in a year, in Rubavu

Cropping calendar made by coffee farmers in Busoro village, Rubavu district												
Activity	Months											
	January	February	March	April	May	June	July	August	September	October	November	December
Land preparation												
Manure application on other farms												
Manure application on coffee farms												
Sowing crops												
Planting coffee												
Planting seedlings of coffee shade trees												
Weeding on coffee farm												
Weeding other crops												
Staking beans												
Mulching coffee farms												
Chemical fertiliser application												
Pesticide application												
Collecting livestock fodder												
Coffee pruning												
Coffee thinning												
Coffee harvesting												
Coffee processing (drying it)												
Harvesting crops												

Notes/Legend

Sowing; Jan- maize and sorghum, soya, egg plants and tomatoes
Feb-beans, maize, groundnuts, sorghum, soya and sweet potatoes
April-sweet potatoes
Aug-cassava, sweet potatoes, egg plants, tomatoes
Sept-beans and soya
Oct-beans

Weeding; Feb-cassava
April-beans, groundnuts, maize, sorghum, sweet potatoes (planted in Feb)
June-sweet potatoes (planted in April)
Oct- beans, soya, maize, sorghum, groundnuts & cassava (all crops planted in September)
Nov- beans, maize, groundnuts, sorghum, soya, cassava (crops planted in October) and sugar cane

Harvesting; Jan- beans, soya (planted in September)
Feb- Harvesting maize, sorghum, groundnuts (planted in September) and beans (planted in October)
March-maize planted in Oct, sweet potatoes planted in August
May- beans (planted in February) & soya (planted in January)
June- maize (planted in Jan & February), sorghum (planted when, in January), ground nuts, soya and beans (planted in February)
July-Aug-sweet potatoes planted in February & groundnuts (planted in February)
Dec- beans (planted in September), sweet potatoes (planted in April)

Appendix III: Trees on coffee farms and in the landscape

Scientific or available name	Codes	Location							Origin		Regeneration			Utilities (why they are left to grow there)																	
		With coffee	Coffee farm boundary	Plantation/Woodlot	In other farms	Boundary of other farms	Riparian	In open area/near farm	Exotic	Indigenous	Planted	Natural regeneration	Existed	Timber	Fuelwood	Charcoal	Edible Fruits/seeds	Poles	Fishing equipments (boats etc)	Medicines	Cattle Fodder	Goat Fodder	Sheep Fodder	Hives (for honey)	Mulch/leaf litter	Crop Support/stakes	Soil Stabilization	Soil Fertility	Fence posts(x)/Live fence (x')	Fishing (x`)/brewing (x^) boat
Markhamia lutea	*	x	x		x	x	x			x		x		X	X										x	x	x			
Erythrina abyssinica	*	x				x				x		x			x									x	x			x	x'	
Grevillea robusta	*	x	x	x		x	x		x		x			X	X	X	x								x	x	x			X`
Ficus thonningii	*	x								x	x			X	X	X				x	x	x	x	x	x	x		x	x	X^
Ficus vidas	*	x								x	x			X	x	X				x	x	x	x	x	x	x		x		
Leucaena diversifolia	*	x	x			x			x		x				x						x	x	x		x	x	x	x		
Calliandra calothyrsus	*	x	x			x			x		x				x						x	x	x		x	x	x	x		
Alnus acuminata	*	x	x			x	x		x		x			X	X						x	x	x		x	x		x		
Albizia chinensis	*	x				x				x	x		x*		X	x									x	x		x		
Albizia gumifera	*	x								x	x				X										x	x		x		
Inga oerstediana	*	x							x		x				x										x	x		x		
Cedrela serrata	*		x			x			x		x			X	x						x	x	x		x	x				
Mangifera indica	*	x				x				x	x				x		x								x	x		x		
Ficus sur	*	x								x		x			x										x					
Maesopsis emnii	*	x				x				x	x			X	X										x	x				
Cassia spectabilis	*		x							x	x				x										x	x			x	
Vernonia amygdalina	*		x			x	x			x	x				x					x	x	x							x	
Cupressus lustanica	*							x	x		x			X	x	X														
Pinus spp.	*			x					x		x			X	X															
Eucalyptus spp.	*			x					x		x			X	X	X		x												
Acacia mearnsii	*		x	x		x			x		x			X	x	x													x	
Musa spp.	*			x	x					x	x						X								x					
Carica papaya	*		x		x					x	x						x													
Persea americana	*	x				x	x			x	x			X	x	X	X				x	x	x	x	x					
Psidium guajava	*	x				x				x	x				x		x								x					

Scientific or available name	Codes	Location							Origin		Regeneration			Utilities (why they are left to grow there)																
		With coffee	Coffee farmboundary	Plantation/Woodlot	In other farms	Boundary of other farms	Riparian	In open area/near farm	Exotic	Indigenous	Planted	Natural regeneration	Existed	Timber	Fuelwood	Charcoal	Edible Fruits/seeds	Poles	Fishing equipments (boats etc)	Medicines	Cattle Fodder	Goat Fodder	Sheep Fodder	Hives (for honey)	Mulch/leaf litter	Crop Support/stakes	Soil Stabilization	Soil Fertility	Fence posts/Live fence (x')	Fishing (x`)/brewing (x^) boat
Draseana afromontana	*	x				x				x	x														x			x		
Ricinus spp.	*	x	x		x	x				x		x										x			x	x				
Tephrosia vogelii	*	x							x		x														x					
Citrus spp.	*	x				x				x	x						X													
Citrus spp.	*	x				x				x	x						x													
Cyphomandra betacea	*				x					x	x						x													
Spathodea campanulata	*				x					x		x													x					
Bambusa spp.	*							x		x		x													x					
Euphorbia candelabrum	*		x							x		x																		
Polyscias fulva	*	x				x					x			X	x				x					x	x	x				
Passiflora edulis	@																x													
Moringa oleifera	^				x				x		x						x			x										
Maesa lanceolata	*							x		x		x			x					x						x				
Jacaranda mimosifolia	*																													
Vemonia anriculifera	*						x	x			x																			
"Inkori"	* #	x									x														x					
Cajanus cajan	*				x						x						x													
Dombeya goetzenii	*				x			x		x		x			x											x				
Ficus asperifolia	*							x		x		x																		
Mellitia dura	*							x		x		x			x											x				
Acacia melanoxylon	*				x					x	x			X	x	X														
"Inuberi"	* #	x	x							x	x		x		x										x					
Cordia africana	*	x								x		x			x										x					
Entandrophragma excelsum	@		x			x				x	x			X	x															
Bridelia micrantha	*							x		x		x			x											x				
Dracaena steudneri	*		x			x				x	x																x		x'	

Codes section: * observed on farms, # Picture taken and attached in the knowledge base, ^ from book/related source, @ trees reported by farmers but were not seen on coffee farms visited

Utilities section: X-For sale, x -For domestic use/home consumption

Appendix IV: The price of coffee cherries (sold freshly) for different years

Year	Price per Kilogram of coffee (Rwanda francs)
2003	80
2004	100
2005	110
2006	120
2007	120
2008	130
2009	125

Source: Marketing officer of COOPAC coffee factory in Gisenyi, Rwanda.

Appendix V: Farmers' ranking of weed on coffee farms.

Weeds	Ranks of level of being notorious
Couch grass (*Digitaria scalarum*)	1
Oxalis spp.	2
Intagarago	3
Wandering Jew	4
Urusibandekwe	5
Black jack	6
Igihehe	7
Igifuranindi	8
Nyirabusogere	9
Ubulayi	10

Note: Ranks 1 and 10 indicate the most and least notorious weeds respectively.