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The role of local knowledge in developing context sensitive agroforestry options for smallholder farmers

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The role of local knowledge in developing context sensitive agroforestry options for smallholder farmers

A thesis submitted in fulfilment of the degree of

Doctor of Philosophy in Agroforestry

School of Environment, Natural Resources and Geography (SENRGy)

Bangor University, Bangor, United Kingdom

By Emilie Smith

February 2018

The role of local knowledge in developing context sensitive agroforestry options for smallholder farmers

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15th February 2018

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Doctoral committee:

- Fergus Sinclair, PhD - Doctoral supervision
- Tim Pagella, PhD - Doctoral supervision
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Full time Phd research programme conducted at place of employment with the World Agroforestry Centre, ICRAF headquarters Nairobi, Kenya

SUMMARY

There is increasing worldwide interest in agroforestry as a multifunctional land-use strategy that can improve farm productivity while generating multiple ecosystem services necessary for human populations trying to adapt to and mitigate climate change and restore degraded landscapes. However there are critical knowledge gaps in our scientific understanding of how a diversity of woody species under given management practices can be enhanced across different landscapes to deliver a range of these benefits. Reflections on the agenda for scaling up agroforestry suggest that there is no 'one size fits all' technology that can be promoted across large areas; instead menus of options have to be tailored to local contextual variations. With the increasing evidence that systematic acquisition of local knowledge is a valuable way of complementing scientific information, there is an urgent need to develop novel techniques to further elicit local knowledge and integrate it into all efforts to develop more inclusive agroforestry options, co-designing them to build resilience in landscapes and livelihoods. The four papers presented in this thesis draw from research in diverse smallholder landscapes in Sub-Saharan Africa. I used different participatory research methods to explore farmers' tree management practices and knowledge of a diversity of trees, along with their functions and the agro-ecological interactions at play in land-use and livelihood dynamics. These contrasting contexts illustrate a diversity of major agricultural systems, encompassing cocoa farming in Côte d'Ivoire, coffee cultivation in Rwanda, and the management of native multiple purpose trees in the West African agroforestry parklands in Burkina Faso. The 'options-by-context' approach, applied through a multiple stakeholder engagement process to address the heterogeneity in the landscape and of land users in eastern Democratic Republic of Congo (DRC), holds general lessons for scaling up agroforestry.

The key findings of the research show that farmers' knowledge about a range of useful native and exotic trees, as well as the contextual variations associated with their management, is rich and complementary to science and can be articulated both qualitatively and quantitatively. The novel way of ranking trees by attributes and the explicit probability model, developed and tested in both the tropical highland context in Rwanda and in the semi-arid parklands in Burkina Faso, was found to be a quick and cost-effective way of classifying a broad range of trees managed by farmers based on ecological, management and utility attributes. The tree ranking estimates were consistent and in agreement with scientific assessments when they could be compared, thus allowing predictions for some of their agroecological effects. This knowledge can be explicitly integrated in tree-planting or agroforestry development initiatives to provide for more objective assessments of how a diverse range of tree species, largely unknown to science but important in farmers' practice, might be expected to affect farm production and other ecosystem services. The stakeholder engagement approach used in eastern DRC was innovative as it built on explicit acquisition of local knowledge to facilitate a systematic consideration of trees at field, farm and landscape scales. This enabled the consideration of different options, in terms of practices/technologies but also market interventions and institutional reform against the contexts for which they were relevant (covering ecological, economic, social and cultural factors). We found that this approach led to a change in the attitudes and knowledge around tree planting by stakeholders, with an important shift away from the promotion of a handful of exotic tree species in woodlots, largely benefiting wealthier men, to recommendations for over 70 tree species, 30 of them native, with management practices that addressed the needs of women, various ethnic groups and different types of farmers. I conclude that a knowledge-intensive framework is required to design more inclusive, locally adapted and diversified tree-based options that aim to deliver both environmental and socio-economic benefits to a wider range of stakeholders. This framework explicitly looks at integrating local and scientific knowledge through the facilitation of broad-based stakeholder participation to identify agroforestry options for different contexts and the preconditions that may require interventions in the enabling environment. The next steps would be to investigate whether, by being sensitive to the needs and context of different smallholders, a knowledge-intensive framework leads to more effective scaling up of agroforestry than do conventional approaches to tree planting.

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AKT: The Agro-ecological Knowledge Toolkit

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

CIFOR: Centre de Recherche Forestière Internationale

CIRAD: Centre de coopération internationale en recherche agronomique pour le développement

CGIAR: Consultative Group for International Agricultural Research

CNRA: Centre National de Recherche Agronomique

COOPAC: Cooperative pour la Promotion des Activities Café

CSSV: Cocoa Swollen Shoot Virus

DRC: Democratic Republic of Congo

FGD: Focus Group Discussions

FTA: Forest, Trees and Agroforestry

FCCC: Forêts et Changement Climatique au Congo

FIRCA: Le Fonds Interprofessionnel pour la Recherche et le Conseil Agricole

FMNR: Farmer Managed Natural Regeneration

ICCN : Institut Congolais pour la Conservation de la Nature

ICRAF: International Centre for Research in Agroforestry (Word Agroforestry Centre)

INERA: Institut de l'Environnement et de Recherches Agricoles (Burkina Faso)

IUCN: International Union for Conservation of Nature

NGOs: Non-Gouvernemental Organisations

OIPR: Office Ivoirien des Parcs et Réserves

PNVi : Parc National des Virunga

PRA: Participatory Research Action

SAN: Sustainable Agricultural Network

SATMACI: Societe d’Assistance Technique la Modernisation Agricole de la Côte d’Ivoire.

SD: Standard deviation

WWF: World Wide Fund for Nature

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In Cote d'Ivoire, I thank the Vision for Change (V4C) ICRAF/Mars project that provided co-funding for the research on cocoa farmers' knowledge and the V4C project team in Soubré and Abidjan for their logistical support; I thank our four field surveyors (Yeo, Mpoko, Yao Vincent and Claver), Laeticia Ohouo for her field engagement and Philippe Vaast of CIRAD for his precious scientific support.

The ranking survey conducted in the Western province of Rwanda was part of the project 'Connecting, enhancing and sustaining environmental services and market values of coffee agroforestry in Central America, East Africa and India' (CAFNET) financed by the European Commission Program on Environment in DevelopingCountries. I thank Fabrice Pinard and colleagues at CIRAD, and Emmanuel Rwakagera and his team at COOPAC for their support during the study. I am also very grateful to Elidad Uwiringiyimana for his facilitation and interpretation in the field.

The participatory survey in Burkina Faso was co-funded by the project Building Biocarbon and Rural Development in West Africa (BIODEV) itself financed by the Finnish Ministry for Foreign Affairs. I thank Nignan Luc and Diasso Jachet for their field interpretation, and Sabine and Barry for being such fun and professional colleagues. I also thank Josias Sanou of INERA for his support, colleagues at CIFOR for hosting us during the field study period and Catherine Dembele and Jules Bayala for the rich transdisciplinary exchanges.

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This doctoral research is centred on farmers and what they know about trees and land use management. I am immensely grateful to all the men and women in Cote d’Ivoire, Rwanda, Burkina Faso and DRC who took their precious time to welcome me in their fields and in their homes; who shared their knowledge, their laughter and often their food. I am humbled by the stories I heard, the incredible resilience I witnessed amongst those who work the land in the harsh contexts of post-conflict Eastern DRC or drought prone Burkina Faso, the inspiring altruism of some of the community leaders I met and the beautiful friendships I made on the way.

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AUTHORSHIP INFORMATION

I have prepared all the four data chapters in this thesis for peer review publications. Chapter one and four have already been published, Chapter two is in review in Agroforestry systems and Chapter three prepared for submission to Ecology and Society. Although I am the lead author and the foremost contributor to the papers with support from Fergus Sinclair my main supervisor, several co-authors have also contributed to the different publications in the research partnership context linking Bangor University and The World Agroforestry Centre (ICRAF headquarter and West and Central Africa region) but also CIRAD (France) and the national research I collaborated with such as CNRS (Cote d'Ivoire) and INERA (Burkina Faso). The first-person plural has been maintained throughout in the text and refers to respective co-authors that contributed to the data chapters.

Chapter 2 Smith Dumont, E., Gnahoua, G.M., Ohouo, L., Sinclair, F.L. and Vaast, P., 2014. Farmers in Côte d'Ivoire value integrating tree diversity in cocoa for the provision of ecosystem services. Agroforestry systems, 88(6), pp.1047-1066. https://doi.org/10.1007/s10457-014-9679-4

I designed this study with advice from PV. I conducted the field survey with L.O. and field enumerators. I conducted the statistical and qualitative analysis with help from PV. GG was responsible for the botanical identification of forest trees. I wrote the manuscript, which was reviewed by FS and PV and two anonymous reviewers.

Open access article - data and survey tools available in Harvard Dataverse repository doi:10.7910/DVN/25133

Chapter 3: Smith Dumont, E., Gassner, A., Lamond, G., Nansamba R., Sinclair, F.L. (Accepted and in review) The utility of farmer ranking of tree attributes for selecting companion trees in coffee production systems**.** Agroforestry systems

I designed the ranking study with advice from GL and FS. RN collected the initial local knowledge and I analyzed it. I collected the ranking data with 100 farmers with the help of a field interpreter. AG analyzed the ranking data with the Bradley Terry model and R script. I wrote the first version of the paper with edits from FS, GL and AG.

Data and survey tools available in Harvard dataverse repository doi:10.7910/DVN/25331,

Chapter 4: Smith Dumont, E., Ky-Dembele, C., Nadembega S., Silimana, B., Bayala, J., Coe, R., Sinclair. F.L. Integrating farmers' knowledge for context sensitive parkland agroforestry management - Manuscript prepared for submission to Ecology and Society

I designed the survey with advice from KC, I collected the data with help from SN and BS who I had trained in local knowledge acquisition methods. I analyzed the local knowledge data. RC led the statistical analysis of the ranking data and advised on the analysis and methods. FS and JB provided comments to the manuscript.

Chapter 5 : Smith Dumont, E., Bonhomme, S., Pagella, T. and Sinclair, F.L. (2017). Structured stakeholder engagement leads to development of more diverse and inclusive agroforestry options. Experimental Agriculture. DOI: https://doi.org/10.1017/S0014479716000788

I designed and facilitated the stakeholder workshops (and the local knowledge research prior to the workshops) with help from SB. FS and TP advised on the methodology. All co-authors and two anonymous reviewers provided edits and comments to the manuscript

1. INTRODUCTION

1.1. Background

1.1.1. Global environmental crisis and agroforestry

The current global environmental crisis is urgently calling for new strategies to sustainably manage agricultural landscapes so that they can provide a more balanced set of provisioning, regulating, supporting and cultural ecosystem services and improve human wellbeing (MA, 2005). The nexus between poverty, food insecurity and environmental degradation requires land use systems that promote multi-functionality, such as agroforestry, to restore degraded land and deliver resilience in socio-economic systems (Sayer et al., 2013; Mbow et al., 2014a). The potential of agroforestry to contribute to sustainable development has been recognised in international policy meetings, including the United Nations Framework Convention on Climate Change and the Convention on Biological Diversity (FAO, 2013). Agroforestry is commonly defined as land use practice involving a deliberate management of trees with crops and/or animals, in some form of spatial arrangement or temporal sequence (Nair, 1993), where the broad term tree encompasses all woody kinds of perennial plant (trees, shrubs, palms, bamboos). Although it is difficult to map the extent of agroforestry systems given the diversity of configurations entailed, a recent global assessment showed that 46% of total agricultural land has at least 10% tree cover (de Foresta et al., 2013). This suggests that ‘trees outside forests’, largely grown on smallholder land already contribute significantly to local livelihoods and to the multi-functionality of landscapes producing food and fibre for better nutritional security and provides income that can help alleviate poverty (Kalinganire et al., 2007; Jamnadass et al., 2011; Mbow et al., 2014a; Icowitz et al., 2014). Agroforestry includes both traditional and modern land-use practices and revolves around the concept of multiple agro-ecological and economic functions from different tree-crop-livestock combinations in different land use units (Sinclair, 1999). Amongst key agroforestry systems are parklands that run across the West Africa Sahelian belt where native fruit or multipurpose trees are maintained in cropland, to shaded agroforestry systems with coffee or cocoa or traditional homegardens (Nair, 1993). More modern practices include alley cropping or hedgerow intercropping where leguminous shrubs are intercropped with cereals, to fodder banks for dairy production

(Pollini, 2009; Franzel et al. 2001). Several types of agroforestry systems and practices are relevant to different socio-ecological context and the emphasis of different components is expected to vary for example, in the tropical highlands, one of the main considerations could be the soil conservation role of agroforestry on slopes and the intensification of land, whereas in sparsely-populated, semiarid savannas, silvo-agro-pastoral systems catering for livestock and fuelwood would be more common (Nair, 1993; Boffa, 1999). At a landscape scale, agroforestry can potentially enhance ecosystem services through carbon storage, prevention of deforestation, biodiversity conservation, erosion control and while both adapting to and mitigating climate change and to withstand events such as floods, drought (Jose, 2009; Jha et al. 2014; Mbow et al. 2014b). Although there has been several attempts at classifying agroforestry systems, it has been found more useful in many instances to describe agroforestry practices where trees are first intimately associated with agricultural components at a field scale, but where their distinct functions within the farm system and the broader landscape system is considered (Sinclair, 1999) It thus allows to efficiently group practices that have a similar underlying ecology and prospects for management which is important in order to be able to better share and improve knowledge. To combine the best practices of tree growing and agricultural systems, resulting in more sustainable use of land with livelihood benefits requires careful design and management principles (Coe et al., 2014; Mbow et al., 2014b). This includes not only species selection and the type of management practices in specific farm or landscape niches but a broader consideration of the contextual variations that influence farmers' decision-making in growing or retaining trees on their land (German et al., 2006; Meijers et al., 2015).

1.1.2. Past limitations of agroforestry and tree planting approaches

Despite the promise of agroforestry innovations, reviews of adoption have highlighted their often-limited spread beyond project sites (Mercer 2004; Meijer et al., 2015). Where adoption has been widespread, it has often been restricted to a narrow group of stakeholders, such as those with higher resource endowment and secure land tenure (Pattanayak et al., 2003) whilst women, for example, have benefitted less frequently (Kiptot & Franzel, 2012). There has been a long history of researcher-led participatory diagnosis and design (D&D) in agroforestry (Raintree, 1987) but this has tended to lead to rich diversity of diagnoses but only a very restricted set of suggested interventions

(Sinclair and Walker, 1999; Kwesiga et al. 2003). Most agroforestry development and research projects have, in the past, focused on promoting prescriptive technology packages, such as improved fallows, alley cropping or fodder banks (Pollini, 2009). In general, conventional approaches to tree promotion have focused on identifying a few tree species through rapid participatory appraisal and preference ranking (Franzel et al., 1996, Franzel et al., 2007; Faye et al., 2011). Although these were useful in obtaining consensus on priorities for the domestication of tree species at regional or even national levels, one of the major shortcomings of such methods are that they fail to embrace the diversity of needs and conditions that farmers experience (Franzel et al. 2001; German et al., 2006). There is also a considerable lack of knowledge management tools available to support extension workers and farmers in making decisions about tree planting and management. (Franzel et al, 2005, Reubens et al., 2011). Another separate but related aspect is that donor-led agroforestry and reforestation projects have often led to the promotion of a few largely exotic tree species especially in Africa (Ashley et al., 2006). Driven by large quantitative targets, these programs often show little consideration for the type of species, the quality of seed supply, or its suitability to local conditions (Nyoka et al., 2015). Instead what ends up being raised in nurseries and planted in terms of germplasm is largely determined by national institutions and NGOs continuing to freely distribute species that can be quickly accessed in large quantities (Wiggins & Cromwell, 1995; Brandi-Hanson et al., 2007). A major issue is that the same traits that make species good candidates for mass seed production, also make them more susceptible to being invasive or aggressive, potentially posing threats to biodiversity (Ashley et al., 2006; Richardson & Rejmánek, 2011). A potential drawback with promoting only a few species is that if this is successful it may result in reducing the biodiversity of landscapes and hence their resilience (Harvey et al., 2011), while enhancing tree diversity could contribute to more complex systems that in turn generate more ecosystem services (Ordonez et al., 2014).

1.1.3. Calls for innovative approaches to scaling up agroforestry

There are now calls for different approaches to agroforestry promotion that go beyond prescriptive ‘one size fits all’ agroforestry technology designs, that promote only a few iconic agroforestry tree species in restricted packages (Coe et al., 2014). Innovative methods are therefore needed to integrate different knowledge systems and effectively build the evidence necessary to customize menus of agroforestry options with a range of different trees and management practices best suited to different discrete farm or landscape niches and farmers' needs (Franzel et al., 2001; German et al., 2006). The socio-ecological contextual variables that condition suitability of agroforestry options depend on which factors are important for a particular innovation to be adopted, and how much these factors vary across the geography of interest and the different scales at which they can deliver benefits (Coe et al., 2014). Common ecological contextual variables that need to be considered include various soil parameters, altitude and climate and water availability (Rubens et al., 2011; Ordonez et al., 2014). In addition, legislation, policy, cultural norms, technology and markets and farmers' knowledge, perceptions and natural resource management practices also impact the suitability of different options and the associated interventions that may be necessary to improve delivery mechanisms or the enabling market, policy or institutional environment (FAO 2013; Mbow et al. 2014a). However one of the major challenges in designing best-fit agroforestry options is the scantiness of data and large knowledge gaps not only about species and their socio-ecological interactions but also about these contextual elements (Mbow et al. 2014b; Ordonez et al. 2014; Coe et al. 2014).

1.1.4.The importance of local knowledge in natural resources management

Over recent decades, there has been increasing awareness that local knowledge and practices should be recognised and built upon when developing initiatives aimed at improving livelihoods of farming communities whilst preserving natural resources (Pretty, 1995; Chambers, 1997; Sayer & Campbell, 2004; Reynolds et al., 2007). Interest amongst research, education, conservation and development institutions to investigate and document local knowledge has also grown significantly (Raymond et al., 2010) ranging from classical anthropology that explores traditional/indigenous knowledge embedded in cultural narratives (Berkes, 1993; Warren, 1995); to the notion of local ecological knowledge that includes contemporary human–environment interactions and the interplay between organisms and their environment (Olsson and Folke, 2001). The incorporation of local knowledge is viewed as fundamental to address complex resource management issues in the context of environmental change and start to build resilience in socio-ecological systems (Berkes &Turner, 2005; Reynolds et al 2007). The complex nature of agroforestry that reflects tight relations between humans and the environment called early for methods to integrate local knowledge in an attempt to bridge the considerable knowledge gaps especially around tropical species and to better understand the scope of their interactions with crops, livestock and livelihoods in different contexts (Sinclair & Walker, 1999). This led to the development of knowledge-based systems approach (Agroecological knowledge Toolkit) for detailed and explicit acquisition of local ecological knowledge to be formally represented on computer (Walker & Sinclair 1998; Sinclair &Walker, 1998), which has since then been widely implemented in diverse agro-ecological contexts. The procedure and software allow flexible knowledge bases about any topic to be created and analysed from complex, qualitative information elicited from interviews with stakeholders or from any other written or oral material. In this approach, local knowledge is defined as encompassing the practical skills, know-how and wisdom held by a person or a community in a particular environment derived from multiple sources but largely from contemporary observation and experimentation. It is based on the premise that people understand natural processes in similar and predictable ways because knowledge is aggregated mainly by means of observations, (Sinclair & Joshi, 2000). Research about tree fodder attributes in Nepal (Thapa et al., 1997, Thorne et al., 1999) and more recently about shade tree suitability and ecosystem services in coffee and cocoa systems (Anglaare et al., 2011; Cerdan et al., 2012) demonstrated that local knowledge, when systematically collected, was sophisticated and comparable to scientific knowledge as well as useful and effective in broadening our understanding of biophysical interactions, local classification systems and tree attributes amongst others.

1.1.5. Multiple knowledge systems and stakeholder engagement

The pursuit of multifunctional landscapes requires both interdisciplinary and transdisciplinary engagement and the interaction and cooperation between researchers, land managers, various government and industry sectors and decision makers (O'Farrell & Anderson, 2010). The complementarity of local with scientific knowledge has granted much legitimacy and scope for its integration in negotiations about land use and natural resources management with different stakeholders (Silltoe, 1998; Raymond et al., 2010). So the collection of local knowledge must not be seen as an end product but rather needs to be carefully considered as a fundamental element in the social processes of knowledge sharing and of integrating multiple knowledge (also known as "epistemological pluralism"), that recognises there may be several valuable ways of knowing but focuses on values involved in the co-production of knowledge (Raymond et al. 2010). In agroforestry in particular, co-designing solutions by building on multiple knowledge systems and multi-stakeholder involvement is essential to foster collective learning (Kwesiga et al. 2003; German et al. 2006; Coe et al. 2014; Mbow et al., 2014b). The focus on ecological knowledge has shown great utility in being able to improve dialogue between researchers and resource users and identify problems faced by farmers, that external research, development or government services can then help to address (Sinclair and Joshi, 2000; Berkes & Turner, 2006; Coe et al. 2014)). Representations of local ecological knowledge, which are primarily about agro-ecological processes of practical relevance, does not entail the same sensitivity around intellectual property rights as ethnomedicinal information would (Sinclair and Joshi 2000), but there is an ethical responsibility that researchers have in sharing the knowledge elicited and, where appropriate, in actively engaging in social learning where they can play a important role in facilitating the integration of knowledge and fostering dialogue (Raymond et al. 2010; Neef and Neubert, 2011;) .

1.2. Aims and objectives of the research

The overarching aim of the research was to explore the role and contribution of local knowledge in the development of agroforestry options that can increase the delivery of ecosystem services whilst improving livelihoods in different smallholder farming contexts in Sub-Saharan Africa. The more specific objectives, for which different methodological approaches were applied, (Table 1.1.) intended to:

1. Analyse perceptions of tree diversity and knowledge about interactions between companion trees and cocoa and compare trends between farmers of native or migrant origins and between farmers who were or were not under an eco-certification scheme in the South-West of Cote d'Ivoire
2. Acquire farmers' knowledge about tree intercropping in coffee fields and apply an explicit probability model to estimate quantitatively the consistency and precision of farmers' knowledge about the relationship between tree attributes and suitability for coffee intercropping in western Rwanda
3. Acquire farmers' knowledge about tree and agroecological interactions in semi-arid parklands, test and refine the explicit probability model to quantitatively estimate knowledge of tree attributes underpinning management decisions including co-variate analysis between different groups of respondents
4. Explore processes for integrating local knowledge in stakeholder engagement to co-design diverse agroforestry options that are more inclusive of the contextual variations and the needs and conditions of smallholders.

The details of the study sites in the four countries are represented in Figure 1.1

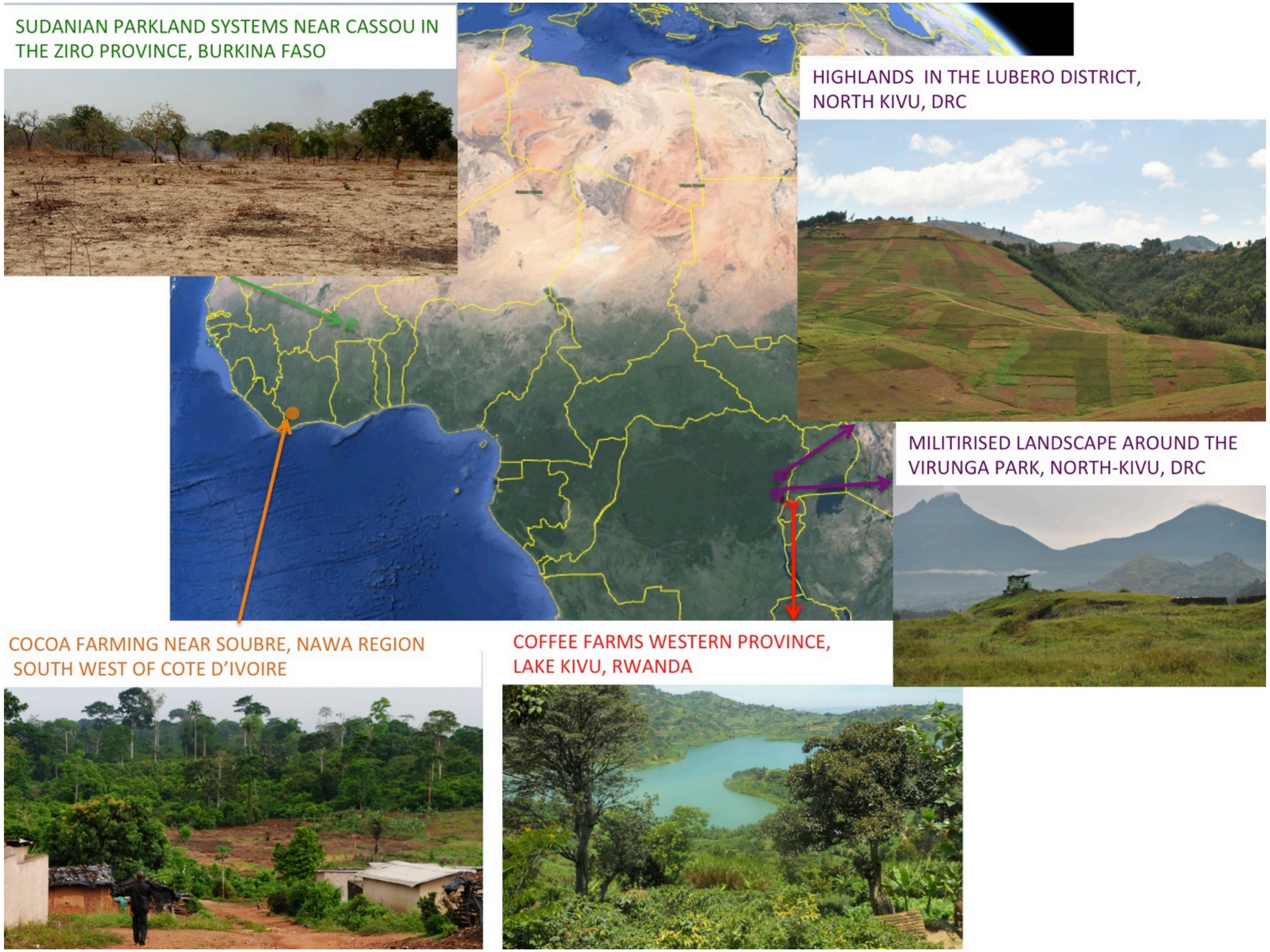

Figure 1.1 Representation of the study sites on a google satellite image with pictures of the different landscape in Cote d'Ivoire, Burkina Faso, DRC and Rwanda

Table 1.1. Overview of research objectives, location and methodological information by chapter

Chapter number	Research objectives	Location	Methodology
2	Elicit farmers' perceptions and knowledge about general and specific companion tree cocoa associations and compare trends between farmers of different origin and those who were or not under eco-certification schemes	Southwest of Cote d'Ivoire - Nawa region 4 villages in two 'districts' (Gligbeadji, Kragui, Petit Bouake, Buyo)	Structured questionnaire - 355 farmers (21 women head of household) stratified according to origin and eco-certification status - descriptive statistics and ANOVA performed with XLSAT 2013 with a comparisons of means according to the Newman-Keuls test
3	Acquire farmers' knowledge about incorporating trees in coffee fields and apply an explicit probability model to estimate, quantitatively, knowledge consistency about tree attributes determining suitability for coffee intercropping	Western Province two districts in Rwanda -Rubavu (Nyamyumba) and Rutsiru (Kivumu and Kigeyo)	Local knowledge acquisition using AKT with 26 farmers (Walker and Sinclair 1998) attribute ranking (Coe 2010) with 100 farmers (32 women) , 'Rank analyses' package in R that fits the Bradley-Terry model (BTm, Bradley and Terry 1952)
4	Acquire farmers' knowledge about tree and agroecological interactions in parklands, apply an explicit probability model to estimate, quantitatively,knowledge of tree attributes influencing the provision of ecosystem services	Centre-South region, Burkina Faso, Ziro Province - Four villages Cassou, Dao, Kou, Vrassan	Builds on PRA scoping work, attribute ranking with local knowledge acquisition using AKT (Walker and Sinclair 1998) with 120 individual or small groups of farmers (30 included women) (Coe 2010), 'Rank analyses' package in R that fits the Bradley-Terry model (BTm, Bradley and Terry 1952)
5	Explore processes for integrating local knowledge in stakeholder engagement to design diverse agroforestry options that are more inclusive of the variations in the needs and conditions of smallholders	North Kivu, Eastern Democratic Republic of Congo in three districts Masisi (Sake, Kitshanga), Nyaragongo and Lubero (Musienene, Mabaoya)) and sub-provincial workshops in Goma and Butembo	Local knowledge acquisition, stakeholder engagement, options by context matrices (Coe et al. 2014); structured workshop facilitation

1.3. Structure of the thesis

The first study I present (*Chapter 2*) looks at **landscapes in the South-West of Côte d'Ivoire,** the last frontier into the remaining guinea equatorial rainforest of the world's largest producer of cocoa, where the landscape appeared to be at a turning point experiencing decline in both cocoa productivity and conservation value (Gockowski et al, 2004; Clough et al. 2009; Koko et al. 2009). Historically full sun cocoa farming had been largely promoted by government policy along with advisory services recommendations to remove forest trees (SATMACI, 1984; Ruf and Zadi, 1998). There is a new interest in shade cocoa agroforestry driven by the growing national concern to protect forest resources and the recent rise of eco-certification schemes that cocoa farmers could join through their cooperative (Wessel & Foluke Quist-Wessel 2015). However scientific knowledge about species suitability for cocoa intercropping in the region remains scarce (Asare, 2006) and the linkages between cocoa productivity and vegetation structure are poorly understood (Deheuvels et al. 2012). There is increasing evidence that building on farmers' shade management practices and knowledge is valuable route to address some of these knowledge gaps and to better inform predictions of how tree configurations and species composition affect cocoa yields and the delivery of a range of ecosystem services (Soto-Pinto et al. 2007; Cerdan et al., 2012; Anglaare et al., 2014; Valencia et al., 2015). We explored local knowledge about companion trees and their interactions with cocoa and ecosystem services through a structured questionnaire (Parfitt, 1997; Patton, 2005) shared with 355 cocoa farmers of different origins around the district of Soubre, Meagui and Buyo in the Nawa region (Plate 1.1. and 1.2.). We elicited trends in tree species diversity and perceptions and knowledge about general and species-specific interactions and we compared the variations between eco-certified and non eco-certified cocoa farms and between farmers of different ethnic origin.

Plate 1.1 Cocoa grown with 'Akpi' a locally high valued multipurpose shade tree, *Ricinodendron heudelotti* near Petit Bouake, Soubre, Nawa region, Cote d'Ivoire. (E.Smith)

Plate 1.2. Farmer discussing pest and disease in cocoa, near Meagui, Nawa region, Cote d'Ivoire (E.Smith)

Chapter 3 takes us to another shade agroforestry system where we also looked at local knowledge of companion trees, this time on **smallholder coffee farms in the tropical highlands in Western Rwanda.** Similarly to cocoa, coffee naturally grows in shade, and agroforestry practices around the world sit along a gradient of complexity from simple mixtures involving one or two companion tree species in regular arrangements to very species diverse multistrata systems (Somarriba et al., 2004). The governmental policy context of Western Rwanda was akin to Cote d'Ivoire in that full sun coffee had also been historically promoted, and in this case intercropping food and other trees with coffee had been forbidden (Donavan et al., 2002). This had been changing since the late 2000s with new shade management recommendations being promoted alongside limited number of tree species, often freely distributed through eco-certification initiatives (Pinard et al. 2014). We first conducted a local knowledge study using the agro-ecological knowledge toolkit (Walker and Sinclair 1998) involving a small purposive sample of 26 farmers about interactions between companion trees and coffee, including how farmers perceived tree attributes to influence agronomic services and disservices (Plate 1.3.)

Plate 1.3. Coffee farm overlooking Lake Kivu, Rubavu, Westerm province, Rwanda (E.smith)

Building on this knowledge we then used a novel method to conduct a participatory attribute survey with 100 farmers across the Rubavu and Rutsiro districts to rank twenty trees commonly occurring in coffee plots against a range of ecology, management and utility attributes (Coe et al. 2010). We developed an explicit probability model to estimate, quantitatively, how consistent and precise their knowledge was about tree attributes associated with suitability for intercropping trees with coffee.

We tested and expanded on the ranking attribute survey method in a very different socio-ecological context, **the agroforestry parklands in the semiarid zone of Burkina Faso** (*Chapter 4*). Our aim was to better understand the knowledge of agro-ecological interactions that underpins tree management. The ranking survey was conducted with 120 farmers of native and migrant origins across four villages in the district of Cassou and Gao in the Ziro Province. Twenty-one useful tree species were ranked against eight ecological, management and utility attributes. We used the AKT approach (Walker and Sinclair 1998) to systematically record and analyse the explanatory information articulated by farmers about the reasons for their ranking choices in particular for composite tree attributes like soil fertility (Plate 1.4.) We developed a co-variate model to further compare estimates between groups of people and a test for polarisation when perceptions appear divergent.

Plate 1.4. Farmer showing leaf litter management in his field near Cassou, Ziro Province, Burkina Faso

Before synthesising and concluding on the series of findings presented in this thesis, Chapter 5 documents a structured stakeholder engagement process that builds on local knowledge acquisition to design agroforestry options in the challenging context of the **landscape around the Virunga National Park in the East of the Democratic Republic of Congo (DRC)**. This is a global biodiversity hotspot that has been subject to prolonged environmental degradation and conflict. Over the last three decades, there have been various reforestation initiatives attempting to promote tree planting to reduce the pressure on protected natural forests. These have focused on the promotion of energy woodlots, using a few fast growing exotic species, managed mostly by men who have large enough holdings to devote some land exclusively to trees (Lejeune et al., 2013). We adopted a participatory action research approach (Chevalier and Buckles, 2013), working closely with development and conservation partners, in particular the World Wide Fund for Nature (WWF), a key regional actor involved in promoting energy woodlots on farms since 1987. Through an 'options by context' structure (Coe et al. 2014) we explored the extent to which greater involvement of stakeholders and the integration of their knowledge in designing agroforestry interventions would lead to more diverse and inclusive options being identified for promotion in the region (Plate 1.5.).

Plate 1.5. Farming landscape in the Lubero district, in the periphery of Mount Tshiaberimu in the Virunga National park, North Kivu, DRC (E.Smith)

1.4. Ethical considerations

The socio-ecological research conducted in this thesis followed the ethical policy guidelines and standards of the World Agroforestry Centre and of the College of Natural Sciences of Bangor University. Each of the four study involved interviews and participatory research techniques amongst farmers and extension agents in rural communities. The World Agroforestry Centre's DDG-Research office at Headquarters Nairobi, Kenya cleared the research designs, and in coutries where work was conducted, local scientific and government partners were also consulted on permits and regulations.

Oral consent was also sought from all interviewees and participants to focus group discussions after clearly communicating through an interpreter/field assistant in the local language about the research objective and questions and how the results would be used. Care was taken to ensure no one would feel pressured into participating by explicitly mentioning that the participation was voluntary with no consequence attached. Interviews were scheduled to meet the farmers' availability and choice of venue (e.g. field, home) to minimise any disruption with planned activities.

Respect for privacy and confidentiality was ensured through the confidentiality of the survey process and data storage. Permissions were asked to take and use photographs with identifiable persons. For inclusiveness of different social groups, special attention was made to engage with the diversity of ethnic groups with field interpreters hired with relevant linguistic ability. The researchers also took measures to include the opinions of women in the surveys although it was often difficult to obtain similar samples due to women's overburdened schedules in rural communities and the gender sensitivities in excluding men from household interviews when these joined in.

Farmers did not receive direct cash payment for their participation in interviews since these were based on voluntary participation and didn't last more than one and a half hour (unless the farmer were keen to discuss and show his/her farm or landscape features). Drinks and snacks were shared during focus groups discussions and feedback sessions. In some communities in post-conflict Eastern DRC, we often offered salt and soap as a token of our appreciation for farmers' time. Photographs taken during fieldwork were printed and shared amongst interviewees and their family.

The potential risks associated with the research were assessed in a non-arbitrary, systematic way. As mentioned above (1.1.5) since the primary focus was on agro-ecological interactions of practical relevance of farming systems, the documentation of the knowledge acquired does not entail sensitivities around intellectual property rights as in the case of ethnomedicinal research. The ethical responsibility lies in fostering the integration of knowledge and dialogue. Feedback sessions were provided in all the study sites at different scale. This took the form of meetings at community level (often using existing farmer group networks) but also in workshops and fora at national level (including scientific platform) as is the case in Cote d'Ivoire. In DRC, extension material derived from the research conducted in this thesis included recommendations targeting women and different ethnic groups was produced and widely disseminated through trainings and printed and online material.

One of the potential risks involved in conducting participatory research especially as a European person in Africa is the building of unrealistic expectations amongst farming communities about development related outcomes. To mitigate this risk, it was very important to explain clearly the objectives and outcome of the different research work and to build trust in dialogues and exchanges at different level of the community (e.g. chiefs, opinion leaders, farmer groups). All the studies comprising this thesis were embedded in donor-funded development projects. Research was conducted honestly and thoroughly with no conflict of interest even when results and outcomes could contradict the views or interests of stakeholders. Data and methodological tools used in this thesis as well as all published articles and resulting extension and outreach outputs are easily and freely accessible online (open access articles and Harvard database)

2. FARMERS IN CÔTE D'IVOIRE VALUE INTEGRATING TREE DIVERSITY IN COCOA FOR THE PROVISION OF ECOSYSTEM SERVICES

ABSTRACT

Côte d'Ivoire produces 40% of the world supply of cocoa but much of the plantation area is aging and declining in productivity, while opportunities for land expansion into new forest land are quickly disappearing. Rejuvenation strategies for cocoa presently coalesce either around improved varieties and greater use of agro-chemical inputs in full sun systems or eco-certification that requires trees to be integrated with cocoa. Here, we explore the possibility of uniting these approaches through building on current farmer practice of incorporating trees in their cocoa fields to improve cocoa productivity and diversify their livelihoods. We interviewed 355 farmers about trees integrated in their cocoa fields across four locations in the South-West of Côte d'Ivoire in 2012, stratified by whether or not farmers were eco-certified. Despite the massive deforestation, a rich diversity of trees was found in cocoa fields and an overwhelming majority of farmers (95%) wanted more trees and/or more tree species, regardless of their certification status or ethnic origin. There was a consensus that most trees were compatible with cocoa, but farmers also traded off negative impacts of some species against their productive contribution to their livelihood. Farmers valued tree diversity on their cocoa plots and provided detailed information on how 32 tree species interacted with cocoa in terms of soil moisture retention, soil fertility improvement and pest and disease interactions but also had key gaps in knowledge about alternative hosts of mirids and mistletoe. The majority of farmers were not aware of the certification requirements for tree species and shade cover but a much higher proportion of certified farmers (76%) had received information about shade trees than non-certified farmers, although advice only related to eight tree species. Scope for building on local knowledge and practice to sustainably increase cocoa productivity through promoting tree diversity while enhancing other ecosystem service provision was identified and the next steps required to realize this set out.

Key words: Agroforestry, Eco-certification, Shade, Tree diversity, Tree suitability, Local knowledge

2.1. INTRODUCTION

Côte d'Ivoire produces 40% of the world's cocoa, an important global commodity, with an annual value of over 10 billion USD of unprocessed beans (World Cocoa Foundation 2012). The economic and political significance of cocoa is of great importance for the country; not only as a key source of foreign exchange revenue but also as a cash crop grown by 700 000 smallholders and sustaining the livelihoods of over four million people (MINEFI-DGTPE 2005). In the South-West of Cote d'Ivoire, over the last forty years, the growth of the cocoa sector, driven by a favorable policy environment, has attracted a large influx of migrants from neighboring countries and led to the massive destruction of large parts of the Guinea Rainforest, a global biodiversity hotspot (Clough et al., 2009; Gockowski et al., 2004). Ivorian forest cover was estimated to be 14.5 million ha in 1900, reduced to 9 million ha in 1965 and to 2.5 million ha in 1992 (Oszwald, 2005). The severe impacts of widespread cocoa-led deforestation on the provision of ecosystem services, including biodiversity loss, has raised significant concern, notably amongst conservationists, about the sustainability of cocoa land use (Rice and Greenberg, 2000; Schroth and Harvey, 2007; Clough et al., 2009). Historically, cocoa production in Côte d'Ivoire has increased by extending the cultivated area and taking advantage of soil fertility built up under forest cover (Ruf and Zadi 1998). Today, in West Africa and particularly Côte d'Ivoire, declining yields, resulting from ageing cocoa fields with low fertility, pest and disease problems, coupled with scarcity of forest are posing severe challenges to both the farmers and the industry (Ruf, 2011; Tscharntke et al., 2011). Concerns over the future supply of cocoa to meet a predicted annual increase in world demand of 2-3% has prompted the industry and governments in West Africa to support research and development activities aimed at rejuvenating ageing fields to increase their productivity (Asare, 2005).

Cocoa is traditionally grown in agroforestry systems with permanent shade management resulting from thinning the original forest canopy and retaining a diversity of trees, planting useful fruit trees and timber species as well as protecting valuable trees from natural regeneration. Although complex multi-strata shaded systems still prevail in Cameroon and parts of Nigeria, there has been an increasing move in West Africa towards intensification of cocoa management with shade removal and monoculture practices (Gockowski et al., 2004; Ruf, 2011). In the South-West of

Cote d'Ivoire, the majority of cocoa farms were established on forestland, mainly planted with unselected cocoa genetic material and a mixture of Amelonado and hybrids, temporarily established under *Musa* spp. shade and predominantly managed with low shade or no shade (Gockowski and Sonwa 2011; Sonwa et al 2014). Agricultural extension services in Côte d'Ivoire have traditionally promoted intensive systems in full sun to maximize short-term yield (N'Goran, 1998; Asare, 2005). Complete forest clearance was encouraged (Ruf and Zadi, 1998) and a list of 45 forest tree species identified that should not be associated with cocoa for a number of antagonistic reasons such as pest and disease relationships, allellopatic behavior, or low shade quality because of their dense or low canopy (SATMACI, 1985; FIRCA, 2008). More recently, as part of the Cocoa Swollen Shoot Virus (CSSV) control strategy a new list of trees that should be excluded from cocoa fields is being disseminated to farmers (CNRA, 2011), further limiting their options for tree management. Little or no scientific evidence exists as to the compatibility of most of these tree species or their host status for CSSV.

Tree removal has been synonymous with intensification practices linked to superior hybrids and external chemical inputs that result in short term increases in cocoa yield. However, in the longer term, the social and economic value of associated trees in cocoa fields has been shown to contribute to reducing household vulnerability to climatic stress, pest and diseases infestations, cocoa price fluctuations and food insecurity (Tscharntke et al., 2011). Diverse shaded cocoa systems provide a range of products and environmental services, key for the sustainability of cocoa systems and local farmers' livelihoods (Duguma et al., 2001; Bisseleua et al. 2009). Trees on cocoa farms support rural communities by meeting household demand for essential products such as timber, fuel wood and fruits and by enabling the diversification of income sources with high value products that can reduce the risks associated with relying solely on cocoa revenues (Herzog, 1994; Sonwa et al., 2007, 2014; Cerda et al., 2014). From a conservation point of view, agroforestry systems involving perennial tree crops associated with a diversity of trees can be important systems when replacing tropical forest because they constitute reservoirs of biodiversity (Rice and Greenberg 2000) and hold important carbon storage potential (Somarriba et al., 2013; Saj et al., 2013). Furthermore, research into cocoa agroforestry systems has shown that trees can increase and sustain cocoa system productivity through eco-physiological, economic and environmental interactions (Clough et al., 2009). With the appropriate species and management regimes, the productivity of cocoa farms can be enhanced through amongst others; soil fertility improvement (Isaac et al., 2007), microclimatic amelioration (Tscharnkte et al., 2011), reduction in pests and diseases (Schroth and Harvey 2000; Bos et al., 2007) and increasing resilience to climate change (Duguma et al., 2001; Franzen and Mulder, 2007). Linkages between cocoa productivity and vegetation structure are still poorly understood and research on farmers' shade management strategies is important to understand how spatial distribution, tree density and species composition affect productivity (Deheuvels et al., 2012).

Despite the growing evidence that more complex multi-strata shaded cocoa systems can improve livelihood and landscape management, there is still a lack of both fundamental and applied research into cocoa agroforestry systems in West Africa. In Côte d'Ivoire in particular, efforts have focused mainly on the agronomic intensification of high yielding hybrids with a recent interest in leguminous tree species in fallow rehabilitation and cocoa replanting strategies (Asare, 2006; Tscharnkte et al., 2011). Challenges associated with ageing and maintenance of cocoa farms, as well as questions related to the economic and environmental sustainability of such systems, require the design of new cocoa agroforestry management strategies. Consumers worldwide have fuelled an increasing demand for eco-certified cocoa through which farmers receive a premium for cultivating cocoa under a diverse layer of native shade trees and for following more environmentally-friendly practices (Franzen and Mulder, 2007). New knowledge is required to understand how to manage more diverse shade systems to restore and enhance ecosystem service provision in the broader landscape. Cocoa fields have mainly been established on forestland and trees now found associated with cocoa are influenced by a combination of factors that include; the native tree cover, farmer preferences, research recommendations and the activities of extension services (Asare, 2006). How local people manage natural resources is dependent on their knowledge and on the opportunities, constraints and trade-offs that may exist around integrating trees with cocoa. The aim of this research was to improve our understanding of associated trees in cocoa systems in the South-West of Côte d'Ivoire. The main objective is to increase both productivity and sustainability of cocoa farming in the region of Soubré through improved genetic material and the promotion of good cocoa farming practices. With the aim of exploring opportunities for integrating trees that increase the delivery of ecosystem services on cocoa farms, the specific objectives of our study were to identify trends in tree species diversity in 1) eco-certified and non eco-certified cocoa farms and 2) between farmers of different ethnic origin, to compare perceptions and knowledge about general and specific tree cocoa associations.

2.2. MATERIAL AND METHODS

2.2.1. Study area

The study area covered four villages and the surrounding ‘campements’ with different migrant communities in two departements: Gligbaeudji (San Pedro), Kragui, Petit Bouaké and Buyo (Soubré) and across the Nawa region in the South-West of Côte d’Ivoire. The sites were selected because they represented a diversity of zones covered by the ICRAF/MARS Vision for Change (V4C) project and due to the presence of eco-certified cooperatives that have been active for at least 3 years. The climate is subequatorial, following a bimodal seasonal regime with two wet seasons, one from March to June and one from September to October. The annual average temperatures range from 24 to 29°C and average annual rainfall ranges from 1600 to 1800 mm (Brou et al., 2005). The soils are ferralitic and highly prone to leaching. The natural vegetation of the South-West of Côte d’Ivoire is evergreen forest belonging to the Guinea-Congo Basin massif forest. The main land uses are cocoa, oil palm and rubber. Total population of this zone was estimated at over 950.000 inhabitants, with approximately 74% living in rural areas. Once a sparsely populated forest area, the population density of the Soubré department is today significantly higher than the national average (48 inhabitant per $km^{2)}$, and averaged 76 inhabitant per km^2 (ICRAF, 2011). This is mainly due to the expansion of the cocoa sector, which has attracted both national and foreign migrants. Native population (mainly Bakoué, Bete and Kouzie) constitutes only about 30% of the total population. National migrants (Baoulé, Agni, Abron, Wan, Sénoufo and Malinké) account for 45% and foreign migrants, primarily from neighbouring Burkina Faso and Mali, account for 23% (Assiri et al., 2009).

2.2.2. Data collection

A structured questionnaire was used to collect data (Appendix 2.1.) In the first part of the questionnaire, we collected characterization information about the farmers and their cocoa fields (number and size of fields, mode of acquisition, associated crops and tree species). The second part of the questionnaire contained open-ended questions about the general perceptions of production benefits and drawbacks linked to associated tree species in cocoa fields. A series of specific questions covering tree uses and direct tree cocoa interactions such as physical damage from branches, competition for nutrients and relationship with key cocoa pests and diseases (*Phytophtora* spp, mirids, rodents, mistletoe) were asked systematically for ten of the tree species present in cocoa fields. If the farmer had more than 10 species present in his fields, the trees evaluated by farmers were randomly selected from the list of trees species present. During the interviews that were conducted in cocoa fields, the trees present were counted and recorded. However in cases where the farms were large or were composed of isolated plots that were not easily reachable, the list of trees inventoried was completed with farmers' recollection of trees present in the cocoa fields. Trees were recorded using local vernacular names (Appendix 2.2.). A visual aid folder based on the floristic guide of the Tai National Parc (OIPR/GTZ, 2000) was used to facilitate the identification of trees with images and local names. A field visit was conducted by one of the authors, Dr. Gnahoua, a forest botanist, for botanical verification of as many unidentified forest tree species as possible (Plate 2.1.). The Floristic Institute of Cocody University provided additional help in species identification. Only tree species that were described by at least 20 farmers are included in the results section.

Plate.1.1 G. Gnahoua Identifying natural regeneration in cocoa fields, near Petit Bondoukou, Soubre, Nawa region, Cote d'Ivoire (E.Smith)

2.2.3. *Sampling strategy*

The objective was to survey the persons that make management decisions about their cocoa farms. The sample was stratified according to ethnic origin, participation in eco-certification schemes and location (Table 2.1). Whether or not farmers were eco-certified (Rainforest Alliance or UTZ) was a second stratification criterion. With respect to location, 90 farmers were interviewed in Kragui, 91 in Petit Bouaké, 90 in Buyo and 85 in Gilgbeaudji. A total of 21 women were included in the sample.

Number of farmers interviewed in the survey in the South-West of Côte d'Ivoire according to ethnic origin and eco-certification status

Table 2.1 Number of farmers interviewed in the survey in the South-West of Côte d'Ivoire according to ethnic origin and eco-certification status

Ethnic origin	Eco-certified	Non eco-certified	Total
Local	59	57	116
National migrant	66	57	123
Foreign migrant	64	52	116
Total	**189**	**166**	**355**

2.2.4. *Data analysis*

Means and standard deviations for two variables; number of associated tree species and tree density in cocoa fields were computed. Anova analysis was performed with XLSTAT 2013 (Version 4.05) with a comparison of the means according to the Newman-Keuls test at the significance level of 5% to explore statistical differences between certification status and ethnic origin on the number and density of trees in cocoa fields.

2.3. RESULTS

2.3.1. *Characterization of cocoa farms*

The area of cocoa in the study area was expanding rapidly from the mid 1970's to mid 1980's, almost a quarter (24.2%) of cocoa fields in the sample were established in the 1960s, the vast majority (88%) were over 20 years old with well over half (59%) being more than 30 years old. There was a decrease in the establishment of new cocoa fields from the mid-1980s, with only 2% of cocoa fields in the survey having been established after 2000. Whereas most of the local farmers in the survey had established their cocoa fields by the end of the 1970s, many of the national and foreign migrants established their farms in the 1980s (Figure 2.1.).

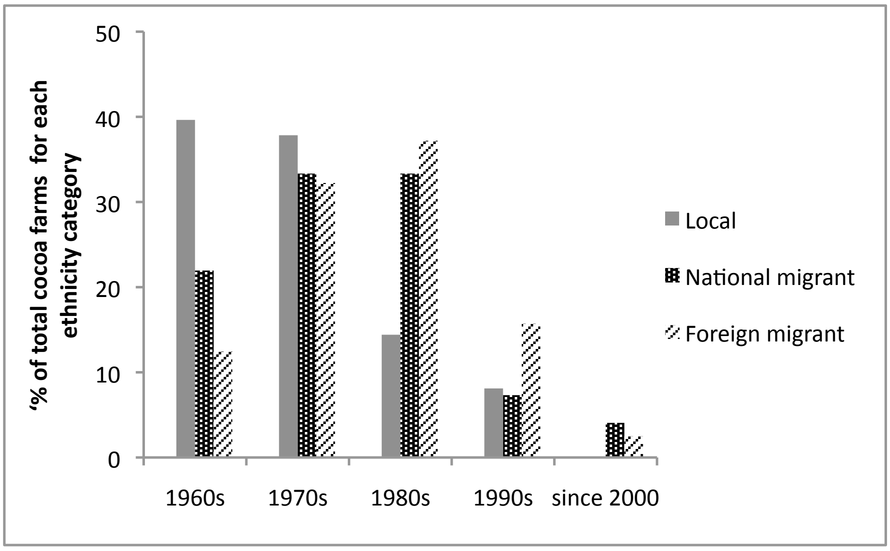

Figure 2.1 Proportion of the total number of cocoa fields for each ethnicity category of farmers that were established in each of the last five decades in the South-West of Côte d'Ivoire

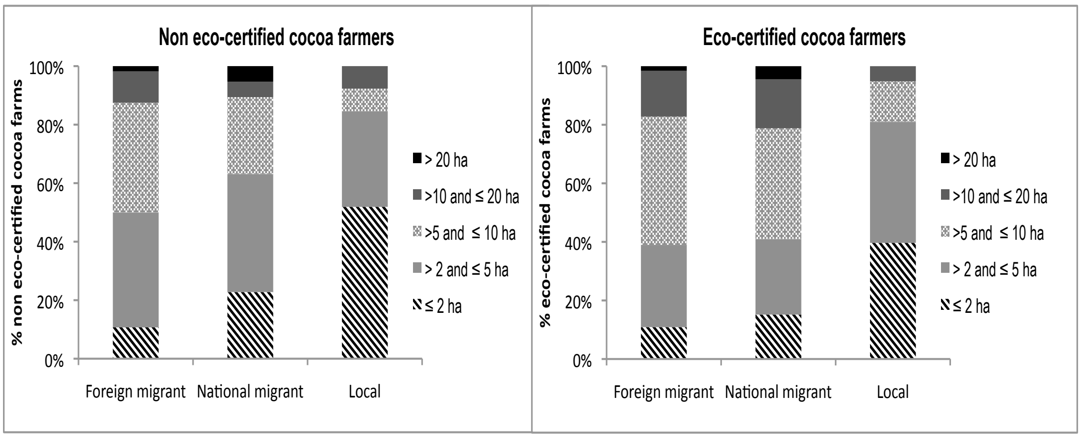

Figure 2.2 Percentages of eco-certified and non eco-certified cocoa farms in different size categories according to ethnic origin of farmers in the South-West of Côte d'Ivoire

Most local farmers had small cocoa fields (less than 5 ha) compared to national and foreign migrants, who had fields ranging between 2 and 10 ha (Figure 2.3). There were no local farmers and very few migrant farmers that had cocoa fields larger than 20 ha. Field size was not significantly affected by farmers' eco-certification status. The majority of farmers cultivated a single cocoa field (76%) whilst 19% had two, 4% three and 3% had four separate cocoa fields. In terms of crops associated with cocoa, taro (*Colocasia esculenta)* was the dominant crop grown (82%), although farmers said that it was increasingly threatened by the use of herbicides in cocoa fields. Almost a third (30%) of farmers did not grow any food crops in their cocoa fields, while the majority (70%) used empty spaces in the field for growing food crops. These were mainly *Musa* spp. (on 53% of farms), yam (*Dioscorea rotundata)* (47%) and cassava (*Manihot esculenta*) (30%) but also included vegetables like aubergine (*Solanum melongena),* chili pepper (*Capsicum* spp.) and pineapple (*Ananas comosus*) mainly planted on field boundaries. Ten farmers also intercropped coffee in their cocoa fields.

2.3.2. Tree diversity and density in cocoa fields

The mean number of tree species found on cocoa plots was highly variable, both within and between certified and non-certified farmers and ethnic origin categories and hence there were no significant difference amongst them (Table 2.2). Overall, there were almost ten species per farm (mean of 9.6 ± 4.6) with more naturally regenerated (6.0±3.4) than planted tree species (4.0±1.8).

Table 2.2 Means and standard deviations of numbers of tree species (planted and naturally regenerated) in cocoa fields, according to eco-certification status and ethnic origin in the South-West of Côte d'Ivoire. No significant differences ($p<0.05$) were observed between means within the same colum

Type of farmer	Total number of tree species	Number of naturally regenerating species	Number of planted species
Eco-certified	10.0±4.6	5.8±3.3	4.2±1.9
Local	9.6±4.9	5.9±3.5	3.7±1.7
National migrant	10.3±4.6	6.1±3.3	4.2±1.9
Foreign migrant	10.0±4.4	5.5±3.1	4.6±2.0
Non eco-certified	9.2±4.6	5.3±3.6	3.9±1.6
Local	8.3±4.6	5.0±3.6	3.3±1.7
National migrant	10.1±4.7	5.8±3.6	4.3±1.5
Foreign migrant	9.0±4.4	5.0±3.6	4.0±1.5
Grand Average	9.6±4.6	6.0±3.4	4.0±1.8

There was a clear trend of decreasing tree density with increasing field size (Table 2.3). The highest tree densities were observed in the smallest cocoa fields, especially those less than 2 ha. Although the trend of decreasing tree density with field size was more distinct for eco-certified farms, there was no significant difference in mean tree densities between eco-certified and non eco-certified farmers. Overall, 74 tree species were botanically identified and evaluated by farmers. A further 84 vernacular tree names, in more than six local dialects, were also recorded but their botanical equivalents could not be verified, and 39 farmers, of different ethnic origins, described one or more trees without being able to give them a vernacular name.

Table 2.3 Mean values and standard deviations of tree density in cocoa fields based on interviews with farmers according to eco-certification status, ethnic origin and size of cocoa field in the South-West of Côte d'Ivoire. Mean values with the same letter within the same row are not significantly different (p<0.05)

Farm size Type of farmer	≤ 2 ha	> 2 and ≤ 5 ha	>5 and ≤ 10 ha	>10 and ≤ 20 ha	> 20 ha
Eco-certified	**14.8±12.3a**	**8.8±6.7b**	**5.9±4.8c**	**4.0±2.4c**	**3.1±2.1c**
Local	14.0±12.2a	7.6±4.5b	3.9±1.6c	2.6±1.5c	-
National migrant	21.0±13.2a	10.6±10.0ab	6.7±5.6b	4.4±2.7b	3.5±2.4b
Foreign migrant	8.2±5.0a	8.7±4.6a	5.8±4.5ab	3.9±2.1b	2.1±0.0b
Non eco-certified	**17.1±17.5a**	**8.1±5.9ab**	**4.7±4.1ab**	**2.2±1.7b**	**4.6±2.5ab**
Local	14.9±15.7a	5.4±2.8b	4.8±3.2b	1.6±0.8c	-
National migrant	20.4±21.7a	10.4±7.3ab	5.2±4.7b	3.8±2.6b	4.4±2.8b
Foreign migrant	19.7±13.3a	7.9±5.2ab	4.4±3.7b	1.8±0.9c	5.3±0.0b
Grand average	**16.0±15.4**	**8.5±6.3**	**5.4±4.6**	**3.4±2.3**	**3.9±2.4**

Over 50 tree species (7 exotic and 44 native) from 27 botanical families were present on at least three cocoa farms and ranked according to their frequency of occurrence on farms (Table 2.4). The overwhelming majority of tree species in cocoa fields were native and naturally regenerated but the most frequently encountered species were exotic fruit trees planted by farmers and used for nutrition and income. Ten species found on cocoa farms were listed in the IUCN red list of endangered species with different conservation ratings; lower risk/least concern (5), lower risk/near threatened (2), vulnerable (2) and endangered (1).

Table 2.4 Diversity of tree species found in cocoa fields, ranked according to frequency and with information on their origin and main local uses as discussed with farmers in the South-West of Côte d'Ivoire (n=355)

Scientific name	Family name	Frequency of occurrence on farms (%)	ORIGIN		USES						
			Planted	Natural regeneration	Food	Medicine	Income	Fodder	Timber	Firewood	Charcoal
Persea Americana (e)	Lauraceae	87	*	*	Frui	*	*	*		*	
Citrus sinensis (e)	Rutaceae	82	*		Frui		*				*
Cola nitida (n)	Sterculiaceae	74	*	*	Nut	*	*			*	
Mangifera indica (e)	Anacardiacea	67	*		Frui		*			*	
Ceiba pentandra (n)	Bombacaceae	59		*	Leaf				*	*	
Ficus exasperata (n)	Moraceae	46		*		*		*		*	
Ricinodendron heudelotii (n)	Euphorbiacea	45	º	*	See	*	*				*
Cocos nucifera (e)	Arecaceae	31	*	*	Frui	*	*				
Milicia excelsa[a] *(n)*	Moraceae	30	º	*			*		*	*	
Bombax buonopozense (n)	Bombacaceae	28		*	Flo	*			*	*	
Elaeis guineensis (n)	Arecaceae	28	*	*	See		*				*
Alstonia boonei (n)	Apocynaceae	27		*		*					
Pycnanthus angolensis (n)	Myristicaceae	23		*		*			*	*	
Spathodea campanulata (n)	Bignoniaceae	21		*		*				*	*
Holarrhena floribunda (n)	Apocynaceae	20		*					*	*	
Terminalia superba (n)	Combretacea	18	º	*					*	*	
Terminalia ivorensis[b] *(n)*	Combretacea	18	º	*					*	*	
Spondias mombin (n)	Anacardiacea	16		*	Frui	*					
Citrus reticulata (e)	Rutaceae	15	*		Frui		*			*	*
Psidium guajava (e)	Myrtaceae	15	*		Frui	*	*				*
Albizia spp. *(n)*	Mimosaceae	14		*						*	
Triplochiton scleroxylon[c] *(n)*	Sterculiaceae	14		*					*	*	
Entandrophragma utile[b] *(n)*	Meliaceae	11		*					*	*	
Piptadeniastrum africanum	Mimosaceae	10		*		*			*	*	
Sterculia tragacantha (n)	Sterculiaceae	8		*		*					
Citrus maxima (e)	Rutaceae	8	*		Frui					*	
Artocarpus altilis (e)	Moraceae	7	*		Frui		*				
Pterygota macrocarpa[b] *(n)*	Sterculiaceae	6		*					*	*	
Nauclea diderrichii[b] *(n)*	Rubiaceae	5		*		*			*		
Ficus sur (n)	Moraceae	5		*		*					
Celtis zenkeri (n)	Celtidaceae	5		*							*
Musanga cecropioides (n)	Cecropiaceae	5		*							
Dacryodes klaineana (n)	Burseraceae	4		*		*			*	*	
Morinda lucida (n)	Rubiaceae	4		*		*			*		
Nesogordonia papaverifera[b]	Sterculiaceae	4		*					*		
Vernonia sp. *(n)*	Asteraceae	2		*		*					
Irvingia gabonensis[a] *(n)*	Irvingiaceae	2		*	Frui	*	*				
Raphia hookeri (n)	Arecaceae	2		*							
Erythrophleum ivorense (n)	Caesalpiniace	2		*							
Tieghemella heckelii[d] *(n)*	Sapotaceae	1		*	See		*				
Monodora myristica (n)	Annonaceae	1		*		*					
Coula edulis(n)	Olacaceae	1		*	See						
Antiaris toxicaria (n)	Moraceae	1		*		*					
Anthocleista djalonensis (n)	Loganiaceae	1		*		*					
Beilschmiedia mannii (n)	Lauraceae	1		*							
Cordia millenii[c] *(n)*	Boraginaceae	1		*							
Funtumia elastica (n)	Apocynaceae	1		*							
Parkia bicolor (n)	Mimosaceae	1		*	See						
Rauvolfia vomitoria (n)	Apocynaceae	1		*		*					

Species with superscript letter are listed in IUCN red list of endangered species as [a:] Lower Risk/near threatened [b:]Vulnerable A1cd, [c]Lower Risk/least concern, [d]Endangered A1cd -
º*: Species recently planted by a few eco-certified farmers (e): exotic species – (n): native species*

2.3.3. Farmers' perceptions about tree species grown with cocoa

An overwhelming majority of cocoa farmers (338 out of 355) expressed a generally favourable opinion about integrating trees in their cocoa fields. The most important benefits of trees mentioned by farmers were related to ecosystem services including protection of cocoa trees from heat stress, especially in the dry season, and soil fertility improvement, both mentioned by over half the farmers (Table 2.5). The value of trees for 'bringing rain', increasing soil moisture availability and controlling soil erosion, was mentioned by over 20% of farmers. The most important drawbacks of trees in cocoa plots were that they could cause physical damage to cocoa, mentioned by almost a third of farmers, and that they attracted rodents (mentioned by almost a quarter of farmers). Other drawbacks such as competing with cocoa for nutrients, increasing the incidence of black pod disease (*Phytophtora* spp.) and shade decreasing cocoa production, were mentioned by less than 10% of farmers. Overall, farmers mentioned benefits of trees much more frequently than drawbacks.

Farmers were aware of a diverse set of tree species that were grown with cocoa, this included 26 tree species, which 20 or more farmers were able to evaluate in detail. There was a general consensus amongst farmers that most of the tree species present in cocoa fields were compatible with cocoa (Figure 2.2) and the vast majority of them (> 90%) considered *Artocarpus altilis*, *Terminalia superba*, *T. ivorensis, Spathodea campanulata* and *Ricinodendron heudelotii* compatible with cocoa. Twelve species were described as incompatible with cocoa by 25% or more farmers, with oil palm (*Elaeis guineensis*) and mango (*Mangifera indica*) being the most frequently mentioned (42% and 40% of farmers, respectively).

Table 2.5 Main production benefits and drawbacks of integrating trees with cocoa reported by eco-certified and non eco-certified farmers in the South-West of Côte d'Ivoire (n=355)

Benefits	% Total farmers	% Eco-certified	% Non eco-certified	Drawbacks	% Total farmers	% Eco-certified	% Non eco-certified
Protect cocoa against heat stress	70.1	72.3	68.7	Physical damage	32.7	34.6	30.7
Increase soil fertility	52.7	57.4	47.6	Rodents increase	23.9	26.1	21.7
'Bring rain'	28.2	30.3	25.9	Nutrient competition	6.8	7.4	6.0
Increase soil moisture	23.7	25.5	21.7	Pod rot increase	6.8	8.5	4.8
Control erosion	21.7	26.6	24.1	Shading decreases yield	4.5	3.2	6.0
Increase cocoa production	9.9	9.6	10.2	Increase parasitic plant	3.7	2.7	4.8
Protect cocoa from wind	5.1	3.7	6.6	Excessive humidity	3.1	5.3	0.6
No benefits	4	4	5	Mortality of neighbouring cocoa	2.8	3.2	2.4
Provide shade for farmer to rest under	3.7	2.7	4.8	No problems identified	2.5	1.1	4.2
Increase cocoa resistance pests and diseases	2.0	1.6	2.4	Decrease in yields	2.5	2.1	3.0
No answer provided	0	0	0	No answer provided	43	43.1	42.2

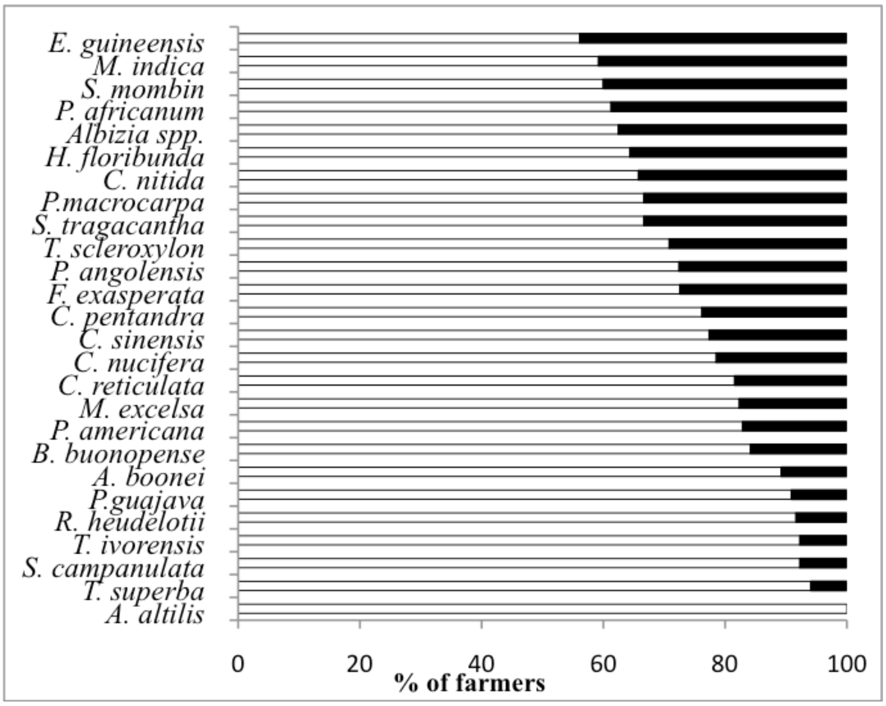

Figure 2.3 General compatibility of tree species associated with cocoa as perceived by farmers in the South-West of Côte d'Ivoire (❑: compatible; ■: incompatible) (n=355)

The species-specific benefits that farmers described from trees included products and services such as providing high quality shade and soil fertilization while drawbacks were related to attracting pests and diseases and competition for nutrients and water (Table 2.6).

Some tree species were clearly identified as negative for specific issues such as attracting small rodents, competing for nutrients and hosting parasitic plants (Figure 2.3). For example, *Elaeis guineensis* was perceived by 82% of farmers as attracting rodents, *Psidium guajava* by 100% of farmers for nutrient competition and *Cola nitida* by 76% of farmers for being an alternative host for parasitical plants (*Tapinanthus* spp.). On the other hand, very few trees were perceived as a threat in terms of doing physical damage from branches falling on cocoa. The two trees most associated with physical damage were *Ceiba pentandra* and *Triplochiton scleroxylon* mentioned by almost two thirds of farmers (62% and 60%, respectively). Farmers did not perceive the large majority of tree species grown with cocoa as attracting mirids (*Sahlbergella* sp. and *Distantiella* sp.). Trees commonly identified as hosts of mirids were *C. nitida* and *M. indica* with 38% and 30%, respectively. Similarly, most trees were not perceived by farmers as causing the spread of black pod disease (*Phytophtora* spp.) with only *C. nitida* frequently being reported by 38% of farmers.

Table 2.6 Summary of farmers' perceptions of key benefits and drawbacks associated with the five most compatible and the five least compatible tree species grown with cocoa in the South-West of Côte d'Ivoire

Tree name	Benefits	Drawbacks
Terminalia superba	Good shade quality, increases soil moisture, soil fertility improvement, timber	Attracts rodents, unclear timber value,
Terminalia ivorensis	Good shade quality, soil fertility improvement, timber	Attracts rodents, unclear timber value
Ricinodendron heudelotii	Nutrition, income and cultural value, increases soil humidity, good shade quality, soil fertility improvement	Attracts rodents
Spathodea campanulata	Increases soil moisture, soil fertility improvement because of fast decomposing litter	Attracts rodents and mistletoe
Albizia spp.	Good firewood species	Competitive for nutrients and water, attracts rodents, causes physical damage
Piptadeniastrum africanum	Timber	Competitive for nutrients and water, physical damage, attracts rodents, negative shade
Spondias monbin	Soil fertility improvement and good shade quality	Attracts mistletoe and rodents, few uses
Mangifera indica	Nutrition, income	Competitive for nutrients, dense shade, attracts mirids and rodents
Eleais guineensis	Nutrition, cultural value, income	Low quality shade and cumbersome crown, attracts rodents, competitive for water and nutrients

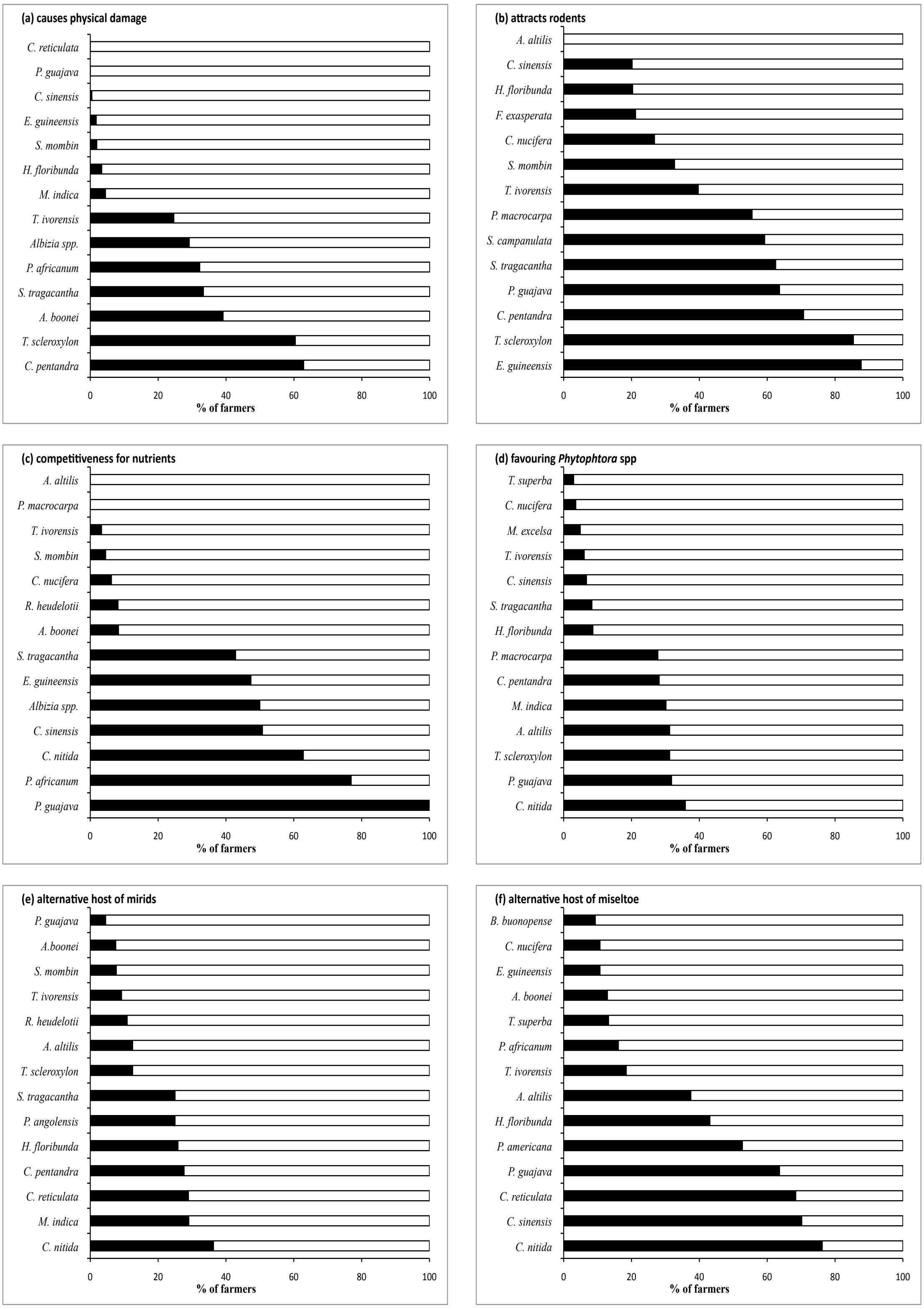

Figure 2.4 Status of tree species associated with cocoa perceived by farmers in the South-West of Côte d'Ivoire with respect to: (a) physical damage by branches, (b) attractiveness to rodents, (c) competitiveness for nutrients, (d) favouring Phytophtora spp., (e) alternative host of mirids, and (f) alternative host of mistletoe (Tapinanthus spp). Data shown only for the seven most and seven least susceptible species (❑: no; ■: yes) (n=355)

2.3.4. *Access to advice on integrating trees in cocoa fields*

Among the 189 eco-certified farmers interviewed, 150 farmers were affiliated to cooperatives engaged in the Rainforest Alliance eco-certification scheme and 46 were engaged in eco-certification with UTZ Certified in the Buyo area. There was a large difference between the numbers of eco-certified farmers (76.1%) and non eco-certified farmers (15.7%) that had received advice on growing trees in cocoa fields. Advice focused on the benefits of trees for soil fertility improvements and general benefits of shade (Table 2.7).

Table 2.7 Number of farmers who have received different types of advice about shade tree associations in cocoa fields according to eco-certification status in the South-West of Côte d'Ivoire

Nature of advice	Eco-certified	Non eco-certified
Soil fertility improvement	50	2
Shade is beneficial	45	3
Specific trees recommended	45	2
Increase cocoa productivity	17	1
Soil moisture retention	12	2

Cocoa farmers' knowledge of tree density required for eco-certification varied from 7 to 70 trees ha^{-1} (Table 2.8) with half of the farmers mentioning 18 trees ha^{-1}. Almost a third of eco-certified farmers were unaware of the number of trees required. Farmers' knowledge of the number of different tree species required for eco-certification also varied widely (from 1 to 18) with almost a third of farmers opting for three or less and almost half of the eco-certified farmers simply stating that they did not know the number of species required.

Table 2.8 Number of eco-certified and non-eco-certified farmers in the South-West of Côte d'Ivoire who stated that they had received advice on planting tree species in their cocoa fields

Scientific name	Eco-certified	Non eco-certified	Total
Terminalia superba	38	0	38
Terminalia ivorensis	17	0	17
Gliricidia sepium	4	1	5
Ricinodendron heudelotii	4	1	5
Spondias mombin	3	0	3
Milicia excelsa	0	2	2
Entandrophragma utile	1	0	1
Ceiba pentandra	0	1	1
Total	67	5	72

Only a small proportion of eco-certified farmers had received advice about specific tree species to grow with cocoa, with *Terminalia* spp. overwhelmingly promoted (Table 2.9).

Table 2.9 Cocoa farmers' knowledge about the number of trees and species per hectare required for eco-certification in the South-West of Côte d'Ivoire

Number of trees/ha	% Eco-certified farmers	Number of species/ha	% Eco-certified farmers
70	2.1	18	0.5
25	2.6	15	0.5
20	6.3	12	2.1
18	50.8	10	1.1
15	1.1	7	3.2
12	2.1	6	0.5
10	1.1	4	2.6
7	3.7	3	9.5
Does not know	31.7	2	18.5
		1	12.2
		Does not know	48.7

Overall, farmers expressed the desire to plant 52 different tree species in their cocoa fields. Amongst the twenty species most desired (Table 2.10), almost a third of farmers had a preference for five species that included native shade trees (*Terminalia* spp., *Ricinodendron heudelotii*, *Ceiba pentandra)* and two exotic fruit trees (*P. americana* and *C. sinensis)*. There was no difference in preferences between ethnic categories except for *C. nitida*, which was favored by foreign migrants. *Terminalia superba* was the tree most desired by eco-certified farmers when compared to non eco-certified farmers.

Table 2.10 Percentages of farmers who desired different tree species for cocoa association according to ethnic origin and eco-certification status in the South-West of Côte d'Ivoire (data shown for the twenty trees most desired) n=355

Tree species	% National migrants	% Foreign migrants	% Local	% Eco-certified	% Non eco-certified	Number of farmers
Terminalia superba	50	32	38	52	27	143
Ricinodendron heudelotii	46	32	35	39	37	134
Persea Americana	40	43	28	38	36	131
Citrus sinensis	33	41	27	32	36	119
Ceiba pentandra	40	38	19	37	27	115
Terminalia ivoriensis	36	26	28	35	23	106
Milicia excelsa	28	16	17	22	19	73
Mangifera indica	20	22	19	19	21	71
Cola nitida	15	30	13	15	23	68
Gliricidia sepium	0	19	9	20	10	54
Bombax buonopozense	15	16	3	13	10	41
Ficus exasperata	11	9	6	9	9	32
Cocos nucifera	8	12	5	10	7	30
Alstonia boonei	8	10	3	11	3	26
Citrus reticulata	6	3	10	4	9	23
Spondias mombin	9	7	3	10	3	23
Spathodea campunalata	12	2	4	6	7	22
Triplochiton scleroxylon	6	4	9	6	7	22
Entandrophragma utile	6	3	3	4	5	15
Eleais guineensis	4	3	4	5	2	14

2. 4. DISCUSSION

2.4.1. Characterization of cocoa farms

The times of establishment of cocoa plots by farmers of different ethnicity corresponds to the East to West progression of the cocoa pioneer front in the 1970s and 1980s, with an increasing number of migrants benefiting from soil fertility built up under forest, opportunities arising from the bridge constructed over the Sassandra river and a policy environment in the country that favoured cocoa cultivation (Léonard and Ibo 1994). The majority of cocoa fields in the project area were between 20 and 30 years old. A recent survey of cocoa farms showed that over 50% of cocoa farmers in the Soubré region have been using unselected material, only 8% using Amelonado varieties, and the average yield quoted for the region was 560 kg/ha without any information on variability provided (Assiri et al., 2009). Research in Ghana has shown that the economic lifespan of intensively managed hybrid cocoa ranges from around 18 to 29 years (Obiri et al., 2007), indicating that much of the cocoa in the study area is nearing the end of its productive life. In contrast, a recent study has shown that by constantly eliminating low yielding, damaged or diseased trees, farmers in complex cocoa agroforestry systems in Cameroon can extend the productive life of their plantation up to over 40 years (Jagoret et al 2011; 2014). The reduction in number of new cocoa farms established since 1985 coincides with forestland becoming scarce at the same time as world cocoa prices were declining (Ruf and Zadi, 1998). The farm size distribution confirms that cocoa has remained a predominantly smallholder enterprise in the country, with most farms less than 10 ha and almost a quarter less than 2 ha. In general, local farmers had smaller plots than migrant farmers who generally acquired larger areas to make the migration worthwhile.

2.4.2. Tree diversity in cocoa fields

Farmers described a rich diversity of tree species on their cocoa farms, including 74 species that could be botanically identified, 63 of which were native. A further 84 vernacular tree names in six different dialects were recorded, but were not botanically identified and hence may contain some overlap amongst themselves and with the 74 identified species. Consequently, the likelihood is that farmers recognized well over 100 different species that were growing in their cocoa fields. The difficulty and limitations of identifying species from vernacular names, inherent in ethno-botany (Wilkie and Saridan 1999), was further complicated in the present context by the linguistic diversity in the survey area, and, by the sparse knowledge about native flora amongst some migrant farmers, recently arrived from very different agroecological conditions in their home regions. This is an important result that underlines the challenges of communicating and sharing knowledge about trees associated with cocoa amongst farmers, extension workers and scientists. The tree species richness found on cocoa farms in the study area was significantly higher than those shown by previous inventories in the central region of Côte d'Ivoire, where 25 tree species were recorded (Herzog 1994). The results were also higher than those shown by a study in the Ondo State in Nigeria, with 45 species (Oke and Odebiye 2007) and by an inventory of mature cocoa farms in the Ashanti region of Ghana that recorded 66 species (Anglaaere et al., 2011). On the other hand, it was lower than the richness described in studies of traditional agroforestry systems in Cameroon where 206 tree species were inventoried (Sonwa et al., 2007) and cocoa agroforests in central Cameroon where 165 tree species were inventoried (Nomo et al., 2008). The survey results indicate that, despite the significant deforestation trends and the promotion of full-sun cocoa, the cocoa farms in the South-West of Côte d'Ivoire represent a refuge for a large number of native tree species. These include ten species on the IUCN red list of threatened species conservation status that include one endangered, five vulnerable, two near threatened and two at lower risks. More information on the abundance of these rare species would be required to assess the extent to which cocoa farms represent effective refugia.

While the diversity of native tree richness interests conservationists, the most frequent tree species were exotic fruit trees used for nutrition and income that had been planted by farmers. This trend is common across other Western and Central African regions where many farmers manage trees in cocoa plantations for the nutritional benefit they provide to the household as well as a range of other productive and service roles (Herzog 1994; Leakey and Tchoundjeu 2001; Asare 2005; Koko et al., 2013; Sonwa et al., 2014). Sixty percent of Ivorian farmers in the Bas-Sassandra region planted fruit trees in their cocoa plots, a situation slightly above the Ivorian average but similar to cocoa farms studies in Ghana and Nigeria (Gockowski et al., 2004). Cocoa fields appeared to be the only significant farm niche where fruit trees were planted and managed by farmers in the study area. Homesteads were generally kept free of trees because the land was used primarily for cocoa drying. Fallows were rare, cropland scarce and trees rarely associated with other local land uses such as food crops, paddies, rubber or oil palm. There were no significant differences between farmers of different ethnic origin, eco-certification status or the age of their plantations, in terms of the number of species found on cocoa plots but the variation was large within each of these categories as found in other studies in Cameroon (Nomo et al., 2004). The mean number of species found per plot was 9.6 with a higher proportion of native naturally regenerating species (6) than of planted species (4) which is higher than the 5.4 species previously recorded in Côte d'Ivoire (Herzog 1994) but lower than farms studied in Central Cameroon where means of 21 tree species ha^{-1} (Sonwa et al., 2007) and 25 tree species ha^{-1} were recorded (Jagoret et al., 2011).

Similar to previous results reported by N'Goran (1998), there was a significant variability in the densities of non-cocoa trees in cocoa fields, although our study did not show density consistently varying with age of the field. In the research area, tree density ranged from 2 to 21 trees ha^{-1} much lower than those recorded in cocoa agroforestry systems in Cameroon, which averaged around 120 trees ha^{-1} (Jagoret et al., 2011). Low tree densities are explained partly by the historical promotion of full-sun cocoa systems but are also by the fact that migrant cocoa farmers secure land ownership through the conversion of forestland to agricultural use (Ruf and Zadi, 1998, Asare, 2005). Densities varied according to the field size, with small fields having the highest densities and a clear decreasing trend in tree density as field size increased. This is consistent with cocoa fields being almost the only farm niche where trees are grown and managed for the household. Farmers with smaller land sizes would intercrop trees more densely in order to meet their needs. The present results were based on farmers' recall and it is possible that there could be systematic bias of recall with farm size. There was no significant difference in tree density between certified and non-certified farmers because most certified farmers had only recently engaged in eco-certification schemes at the time of the survey and had not taken steps to align with the shade tree requirements of between 12 to 18 trees ha^{-1} and the long term goal of providing 40% shade cover (SAN, 2009).

2.4.3. Perceptions about integrating trees in cocoa fields

The prevailing view within the cocoa industry is that cocoa farmers in Ghana and Côte d'Ivoire will progressively reduce and ultimately eliminate shade in their cocoa fields and, in keeping with this, full sun cocoa is the industry standard (Ruf, 2011). In Western Ghana, 90% of farmers were reported to be eliminating trees to reduce shade, largely as a result of their perception that new cocoa hybrids were intolerant of shade (Ruf et al., 2006). In marked contrast to this, we found that 95% of farmers in the Western part of Côte d'Ivoire valued the presence of trees associated with cocoa for both products and environmental services, regardless of their origin or certification status. Most of the cocoa in the Western part of Côte d'Ivoire is not of hybrid origin (Gockowski and Sonwa, 2011) and this could explain why farmers have a positive attitude towards integrating trees with cocoa. The most frequently planted trees in cocoa fields in Western Côte d'Ivoire reported here were fruit trees, used for both household nutrition and income. In addition to products derived from trees, farmers also expressed the importance of the environmental services that they provide. The major environmental benefit perceived by 70% of farmers was to protect cocoa trees from heat stress in the dry season. Over the last 20 years, there has been increasing report of climate change in southern Côte d'Ivoire, with trends towards reduced rainfall and increased length of the dry season (Brou, 2010). Farmers said that drier climatic conditions were the major driver for wanting shade in their fields, especially to protect cocoa trees from water stress in the dry months of January and February. This corroborates the view that changing climatic conditions, with an increase in the length of the dry season, is increasingly affecting cocoa productivity, and requires the design of new strategies, using shade trees to buffer cocoa from water and heat stress in the dry season (N'Goran, 1998). Soil fertility improvement was the second most frequently mentioned benefit of incorporating trees in cocoa fields, expressed by more than 50% of farmers. The soil conditions prevailing in Soubré make cocoa fields particularly prone to early senescence with attendant low yield and even cocoa mortality (Ruf and Zadi, 1998; Koko et al., 2009). Replanting has become increasingly difficult on land not recently cleared from forest (Ruf and Konan, 2001). In the absence of new forestland to clear, there is an increasing reliance on the use of chemical fertilizers to maintain yield, which many farmers cannot afford (Assiri et al., 2009). While exotic leguminous trees have recently been promoted in the context of soil fertility improvement, notably in the regional Sustainable Tree Crops Program (Asare, 2005), there is little information on the suitability of different tree species to improve both nutrient cycling and soil fertility in different contexts. Trees associated with cocoa systems have been shown to be important for improving soil quality and provide a high level of soil-related ecological services (Rousseau et al., 2012). Research on tree phenology, leaf decomposition rates and N-mineralization from litter of a broad range of tree species, is required to develop guidelines for farmers on which species to use to improve soil health (Barrios et al., 2012). Soil moisture conservation and erosion control were also important services that farmers associated with trees. Only a few farmers linked shade trees with prolonging the life span of cocoa, although this has been frequently observed by scientists (Ruf and Zadi, 1998; Obiri et al., 2007). Farmers also did not mention weed suppression as a benefit derived from trees, and this could be due, even with full sun cocoa, to the fact that cocoa density is high and hence shade from the cocoa itself is sufficient to suppress weeds (Assiri et al., 2009).

Farmers mentioned drawbacks of integrating trees with cocoa much less frequently than benefits. The most frequently cited drawback mentioned by about a third of farmers, was physical damage to cocoa or people caused by falling branches, but this was only a drawback with seven species (discussed further below). The second most frequent drawback, mentioned by more than a quarter of the farmers, was attracting rodents and fewer than 10% mentioned other drawbacks, including favoring an increase in incidence of black pod disease and competition for nutrients. This is broadly consistent with a recent study of cocoa farmer perceptions in Ghana that reported negative ecological interactions, principally attracting squirrels and increasing incidence of black pod disease, as the reason for almost a quarter of farmers (23%) removing shade trees from their cocoa fields (Ruf, 2011). The incidence of black pod disease was linked to high humidity, especially in areas of heavy rainfall. The lack of tree ownership by farmers and destructive practices associated with timber extraction was a constraint to managing timber trees on cocoa farms. The exclusion of farmers from the timber market is an important constraint to managing timber trees on cocoa farms in Ghana and Côte d'Ivoire (Anglaaere et al., 2011; Ruf, 2011) and this was often the reason why farmers were felling or burning high value timber trees in their cocoa plots (Ruf et al., 2006).

2.4.4. Consensus on compatibility of tree species with cocoa

In Côte d'Ivoire, despite the long-term promotion of full sun cocoa systems and the lack of information about compatible tree species for cocoa from the research and extension services, farmers shared common perceptions about the suitability of trees species for integrating with cocoa. Overall, most farmers considered most of the trees commonly found on farms to be compatible with cocoa but some species were considered more compatible than others. Amongst the most compatible species was *A. altilis* but this species was only present in one of the study locations (Kragui). *Terminalia ivorensis*, *T. superba, S. campanulata and R. heudelotii* were also generally mentioned as highly compatible with cocoa and have been previously identified as suitable for integrating with cocoa in Ghana (Asare, 2005). They were valued by farmers for the quality of shade, soil fertility improvement and in the case of *S. campanulata* and *R. heudelotii* for their positive role in increasing soil moisture availability, especially in the dry season. The role of *S. campanulata* in increasing soil moisture has been previously recorded in Ghana (Anim-Kwapong, 2009). *Ricinodendron heudelotii* is also known to root deeply, likely to reduce competition for water with cocoa, and because of the high market potential of its kernels, has been indentified as a promising tree species for domestication in West Africa (Tchoundjeu and Atangana, 2007). The least compatible tree species were oil palm (*E. guineensis*) and mango (*M. indica*) although mentioned by only 40% of farmers, suggesting the large divergence in responses probably arose from the different extent to which farmers were considering trade-offs when responding. In the case of oil palm, there was common knowledge that it provides a nesting environment for rodents and is competitive for nutrients and water but its cultural importance for nutrition explains why some farmers maintain oil palm in their cocoa fields despite its drawbacks. In the case of mango, present on 67% of cocoa fields, the importance for nutrition and income means that farmers tolerate individual trees in their fields, despite the trade-offs with cocoa production.

2.4.5. Species-specific knowledge

Farmers were aware that different tree species displayed different attributes that affected their compatibility with cocoa and their uses. For example, farmers said that *C. pentandra*, the tree most commonly identified as causing physical damage to cocoa or people from falling branches, was particularly problematic in this respect when old. As the most frequent forest tree relic found on cocoa farms, many trees were old, very tall and so difficult to prune. In terms of other species that cause damage, *T. scleroxylon* is a self-pruning tree from which branches can be expected to fall and *Alstonia boonei* and *S. tracagantha* are known to have brittle branches that bre,ak easily (Palla, 2005, Orwa et al., 2009). It is clear that the issue of trees causing damage to cocoa is limited to a few species. The development and implementation of appropriate species-specific management guidelines could minimize risk of damage, which may also be accepted by farmers as justifiable because of the economic value of the timber (Ryan et al., 2009).

Trees attracting rodents was relevant to a broader range of species but the most problematic tree was oil palm because the morphological characteristics of its fronds made it suitable for squirrels to nest in them. Other trees that particularly attracted rodents were *C. pentandra* and *T. scleroxylon*. Farmers explained that these trees frequently lose branches and limbs that open cavities that become ideal habitat for squirrels. Although cocoa pod damage by squirrels causes yield loss, farmers frequently mentioned that they hunted squirrels, which made a useful contribution to family nutrition. Given that the original forest fauna has largely disappeared, many farmers, especially national migrants, said that squirrels had become an important source of animal protein in the family diet.

Only seven, mainly fruit tree species were commonly identified as competitive for nutrients with cocoa. The most competitive species was unanimously *P. guajava*, followed by *Piptadeniastrum africanum* a leguminous timber species and fruit trees such as *C. nitida* and *C. sinensis.* Surprisingly, *Albizia* spp., although leguminous and known to improve soil, was considered to be competitive by almost half of the farmers.

Phytophthora megakarya is increasingly important in West Africa (Holmes et al., 2003), and has a variety of alternate host plants, notably native forest trees (Opoku et al., 2002). Ivorian farmers linked seven tree species with increased incidence of black pod disease, including *C. nitida, P. guajava, T. scleroxylon, A. altilis, M. indica* and *C. pentandra.* Opoku et al., (2002) have provided evidence of *P. megakarya* parasitism on *Sterculia tracagantha* and *R. heudelotii* but they found no visual evidence of higher infestation levels on cocoa plants nearer the host trees and concluded that it was unlikely that the presence of the identified host trees would have any significant influence on the levels of black pod disease on cocoa. In our survey, 8% of farmers identified *S. tracagantha* and 10% identified *R. heudelotii* as increasing black pod disease. Such effects may arise from the level and quality of shade affecting humidity rather than the host status of the tree (Schroth et al., 2000).

Scientific evidence has also shown that species taxonomically related to cocoa, i.e. members of the Sterculiaceae family, can share pests and diseases with cocoa. This is notably the case for mirids, one of the most important cocoa pests in West Africa (Schroth et al., 2000). Most farmers (79%) in our survey identified *C. nitida* as an alternative host for mirids, concurring with technical information available (SATMACI, 1984; Schroth et al., 2000), but this was the only member of the Sterculiaceae that they identified in this context. *Sterculia tracagantha* and *Pterygota macrocarpa,* for example, were not identified as alternate hosts for mirids and neither were most species of the Bombacaceae family, that have also been mentioned as possible alternate hosts (SATMACI, 1984; Schroth et al., 2000). One exception was *Bombax buonopense* mentioned by only 10% of farmers. No farmers mentioned *C. pentandra* in this regard despite its prevalence in the area. On the other hand, 75% of farmers identified *Citrus* species as alternative hosts of mirids, concurring with previous information (Padi and Owusu, 2003).

Mistletoes (*Tapinanthu*s spp.) are important parasitic plants affecting cocoa causing loss of cocoa tree vigor and yield decline, with heavy attacks sometimes causing cocoa mortality (Padi and Owusu, 2003). Our results show that farmers identified fruit trees such as C. *nitida, M. indica* and *C. reticulata* as alternative hosts in addition to forest tree species such as *C. pentandra*, *Holarrhena floribunda*, *Pycnanthus angolensis* and *T. scleroxylon*, corroborating previous results showing these species to be alternative hosts of *Tapinanthus* spp. in Ghana (Phillips, 1977). This knowledge was not evenly distributed amongst farmers. Despite the increasing threat of the Cocoa Swollen Shoot Virus (CSSV) in Côte d'Ivoire, only a few farmers were aware of the virus and the host status of tree species in their cocoa plots.

2.4.6. Certification and advice about integrating trees with cocoa

Engagement with eco-certified cooperatives was clearly an important source of advice about shade trees for protecting cocoa in the dry season. Only a minority (15%) of non certified farmers had received advice about cocoa shade trees compared to 76% of certified farmers, still showing that almost a quarter of eco-certified farmers had not received any advice on trees. Eco-certification schemes principally operating through the Sustainable Agriculture Network (SAN) have put forward shade management criteria and indicators for cocoa farms as part of good cocoa management practices. In Côte d'Ivoire, farmers are required to maintain or plant 12 native species ha^{-1} and 40% canopy cover (SAN, 2009). Our results show that both the number of tree species and the shade density in cocoa fields were well below certification requirements, even amongst certified farmers, consistent with the recent onset of certification in the area. Perhaps of greater concern was the large variation in knowledge amongst eco-certified farmers about both the number of trees and species required. Farmers only recalled eight species being recommended as shade trees for cocoa, dominated by *Terminalia* spp., despite the existence of an official list of 19 recommended species (SAN, 2009).

Although advice was concentrated on a limited list of species and had a clear influence on preferences shared by eco-certified farmers, overall, both eco-certified and non eco-certified farmers expressed a desire to use a broader diversity of trees to meet their needs for products and services.

2.5. CONCLUSION

Despite the cocoa frontier expanding at the expense of forest cover, and full sun cocoa being the predominant form of cultivation promoted over the last half century in Cote d'Ivoire, cocoa farms still contain a reservoir of forest tree species, including some of high conservation value. Farmers overwhelmingly want to have more trees on their farms, both to sustain their cocoa production and to diversify their livelihood, particularly in relation to their food security, as shown by the important presence of fruit trees in cocoa fields. Whether certified or not, farmers valued a variety of tree species in their cocoa fields because they believed that they protected cocoa from water stress in the dry season and improved soil fertility. Farmers were interested in integrating a diversity of tree species on their farms to meet their needs and had detailed knowledge about how different species affect a range of ecosystem services responsible for sustainable cocoa productivity, regardless of their ethnic origin or certification status. In addition there were notable knowledge gaps, particularly relating to trees as alternate hosts to pests and diseases such as *Phytophtora* spp. and CSSV. Assessing local knowledge about integrating trees with cocoa in the country remains a challenge because of the linguistic diversity of the ethnic groups involved and their diverse places of recent origin. Eliciting local knowledge would be the key next step in developing approaches to promoting tree diversity in cocoa. This would allow identification of gaps in knowledge that research and extension should address and help to refine current understanding of field, farm and landscape niches for different tree species. In the past, research recommendations for cocoa production in the region have often served as a barrier to farmer innovation instead of building on local knowledge and preferences and led at best to the promotion of a few key species rather than increasing tree diversity (Asare, 2005). The importance of knowledge transfer between farmers and scientists to improve shade-tree management and to implement certification schemes for cocoa has been identified (Tscharntke et al., 2011) and has been instrumental in promoting diversity in coffee agroforestry (Soto-Pinto et al., 2007; Cerdan et al., 2012). It is unlikely that the conservation value of trees in cocoa systems will be maintained without some deliberate action, since as time goes on, the regeneration of forest species diversity is likely to decline (Robiglio and Sinclair, 2011) and farmers will tend to preserve a limited set of species that most immediately meet their needs (Vaast et al., 2005; Harvey et al., 2012). The cocoa landscapes in the South-West of Côte d'Ivoire appear to be at a turning point. Their productivity is declining along with their conservation value. Both issues can be addressed by promoting appropriate tree diversity with good management practices, supported by a favorable policy environment, that includes security of land and tree tenure for farmers, certification schemes and better integration of producers in value chains to ensure higher economic returns to cocoa and other tree products. Integrated research embracing local knowledge, cocoa agronomy and ecosystem service provision is urgently required to achieve production and conservation objectives simultaneously.

3. THE UTILITY OF FARMER RANKING OF TREE ATTRIBUTES FOR SELECTING COMPANION TREES IN COFFEE PRODUCTION SYSTEMS

ABSTRACT

There is increasing interest in the potential of agroforestry to improve the productivity and sustainability of coffee production, but designing management options is knowledge intensive. Tree-crop interactions and the biophysical and socio-economic factors influencing farmers' decision-making about companion trees are complex and context-specific but fine scale data relating to them are rarely available. A novel method was used to analyse trees ranked by farmers for a range of attributes and evaluate the consistency of farmers' knowledge underpinning decisions about tree management in coffee production systems in Rwanda. Farmers' knowledge about tree planting was changing, in line with new shade management recommendations being promoted alongside a limited number of tree species, often freely distributed through eco-certification initiatives. Farmers had detailed knowledge about soil and water conservation processes associated with trees, but they traded these off against perceived competition for light, water and nutrients with coffee. The competitiveness of trees with coffee was influenced by combinations of attributes related to: crown architecture, foliage properties and growth patterns; as well as how trees responded to management, and, their utility. Farmers consistently ranked 20 tree species for 12 attributes (five related to ecology, four to management and three to utility). Given the paucity of data on tree attributes for many species, systematically acquired and consistent local knowledge complements global scientific information and can be useful in bridging knowledge gaps relating to the integration of tree diversity in coffee production systems, which is an increasingly important strategy for smallholder farmers adapting to climate change.

Key words: Rwanda; local knowledge; agroforestry; ecosystem services; shade

3.1. INTRODUCTION

Over the last forty years, the production of coffee, one of the most widely traded tropical commodities, has been driven by intensification strategies aiming to maximize short-term yields through the use of purchased inputs in full-sun production systems. The sustainability of intensive coffee monocultures, mostly grown on land recently converted from natural forests or located near conservation hotspots, has been increasingly questioned because of their environmental cost and the economic vulnerability of coffee farmers affected by fluctuating coffee prices (Philpott and Dietsch 2003). Over 25 million smallholder farmers are dependent on coffee for their livelihoods, of which more than 30% live in Sub-Saharan Africa, the world's most food insecure region. This, compounded with the increasing threat of climate change, creates an urgent imperative to develop sustainable coffee production systems that can improve smallholder livelihoods at same time as restoring ecosystem functions (Tscharntke et al. 2011).

Coffee naturally grows in shade, and coffee agroforestry practices around the world sit along a gradient of complexity from simple mixtures involving one or two companion tree species in regular arrangements to very species diverse multistrata systems (Somarriba et al. 2004). Companion trees can provide high-value marketable products that diversify income sources at the same time as agronomic benefits such as pest and disease control, soil nutrient enrichment and microclimate regulation (Jha et al. 2014). These benefits often offset or surpass yield losses associated with trees competing with coffee (Vaast et al. 2005). The relationship between shade and both coffee yield and quality varies with altitude, climate and soil conditions, as well as with the management of companion trees and coffee, creating the need for recommendations about shade to be site and context specific (Van Oijen et al. 2010). Along with their socio-economic value, the suitability of tree species for intercropping with coffee is largely determined by ecological attributes, which directly influence their competitiveness for light, nutrients and water. Other tree product attributes, such as wood burning properties, fodder value or fruit quality may also be important (Soto-Pinto et al. 2007). There is little scientific knowledge about ecological attributes of trees used in coffee agroforestry systems and developing a scientific understanding about them is complicated because expression of attributes varies with environmental and management factors, as well as the genetic makeup of the tree. Previous studies have shown local knowledge of farmers to be an important source of information to fill such knowledge gaps (Sinclair and Joshi 2001).

Farmers often have a detailed understanding of tree attributes derived from direct experience (Cerdan et al. 2012) and their knowledge has been used to pool site specific information to derive customized recommendations on tree management (van der Wolf et al. 2016). Farmers in Nepal were found to have sophisticated knowledge about leaf digestibility and palatability attributes that they used to classify tree fodder types, and they were able to consistently rank fodders based on these criteria (Walker et al., 1999), in ways that corresponded with scientific assessment of nutritive quality (Thorne et al. 1999). While previous studies of local knowledge about companion trees in coffee (Cerdan et al. 2012) and cocoa (Anglaaere et al. 2011) have elucidated tree attributes that affect their suitability for intercropping, the consistency of farmer knowledge about these attributes has not been rigorously compared across farmers or sites. Farmer ranking of tree attributes conferring suitability for intercropping with coffee from along an altitudinal gradient in Kenya were presented (Lamond et al. 2016) and while consistency of ranking varied for both tree species and attributes, it was not quantified.

In this research, we aimed to acquire farmers' knowledge about incorporating trees in coffee fields across two districts in Rwanda and to apply an explicit probability model to estimate, quantitatively, how consistent and precise their knowledge was about tree attributes associated with suitability for intercropping trees with coffee.

3.2. MATERIALS AND METHODS

3.2.1. Study area

The study was conducted between 2009 and 2012 in three sites situated in the densely populated Western Province of Rwanda, the Nyamyumba sector (Rubavu district) and the Kivumu and Kigeyo sectors (Rutsiro district near the Gishwati National Park), between S 1.730 and S 1.837 and between E 29.310 and E29.265. The sites are within the catchment of Lake Kivu; with a mean altitude of 1 500 m and bimodal annual rainfall of 1200 mm. Rubavu district has a population density of over 1000 km-2 who predominantly rely on agriculture (NISR 2012). The sampled farmers were from smallholdings ranging in size from <0.1 ha to 6.0 ha with coffee plots generally between 0.1 ha and 1 ha. The main land use activities were based on food crop production (maize, cassava, beans, sorghum and vegetables) for household consumption and sale. The main cash crops in the area were coffee (*Coffea arabica*) and banana (*Musa spp.*).

3.2.2. Local knowledge acquisition

Initial local knowledge acquisition was conducted in 2009 using a knowledge based systems (KBS) approach (Sinclair and Walker, 1998). The Agro-ecological Knowledge Toolkit (AKT5) methodology was followed and associated software used to create an electronic knowledge base and carry out analyses using automated reasoning procedures (Walker and Sinclair, 1998). A small purposive sample of 26 farmers affiliated with the coffee cooperatives in the Rubavu and Rutsiro district were interviewed during farm visits using semi-structured guidelines. In terms of gender, women farmers affiliated with coffee cooperatives represented less than a third of farmers, we included eight women and 18 men to ensure coverage of common knowledge of both genders. The topics explored were knowledge of shade tree interactions with coffee and tree management for the provision of ecosystem services. The selection of farmers was informed by extension agent's knowledge of farmers' engaged with shade coffee programs in the different communities and on their willingness/availability to participate in the interview. Three focus group discussions (total of 9 farmers) were held about tree attributes important to coffee intercropping and a feedback session was organized with farmers interviewed and extension officers (total 16 people). The causal diagrams presented in the results were generated from the knowledge represented in the AKT5 software as connected formal statements conforming to the diagram syntax (Cerdan et al. 2012; Lamond et al. 2016).

3.2.3. Tree attribute ranking

Ranking has been used in agroforestry research to assess the importance of tree use-categories, preferences or needs (Gausset 2004). Here we adapted the methodology to elicit information about tree attributes. In this survey, we investigated whether coffee farmers agreed on ranking commonly managed trees and shrubs in terms of the expression of a range of ecological, management and utility attributes influencing intercropping with coffee. One hundred farmers (67 men and 33 women) randomly selected from local coffee cooperative lists were interviewed, stratified according to three villages (Nyamyumba in Rubavu district, Kivumu and Kigeyo sectors in the Rutsiro district) because of their diversity in market access and proximity to forest resources. In each of the three villages, we purposefully selected all women affiliated to local cooperatives. However the sample size was too small to disaggregate the analysis based on gender. The interviews were facilitated with an interpreter and a local field guide organized appointments, in advance, based on farmers' availability. They lasted between 50 minutes to one and half hours based on the farmers' willingness to engage and discuss ranking results. Qualitative information was recorded when this was useful to explain ranking decisions. The twelve attributes used in the survey (Table 1) were derived from the initial local knowledge acquisition and were identified by farmers as properties influencing the suitability of trees for intercropping with coffee. Ecological attributes were observable properties of trees that farmers said influenced how competitive they were in capturing light, nutrients, water and space.

Table 3.1 Tree attributes ranked by farmers in the tree attribute ranking survey

Tree attribute	Description of ranking scale	Type of attribute	Impact
Crown spread	widest to narrowest	Ecological	Competition for light and space, microclimate, erosion control
Crown density	least to most dense	Ecological	
Root spread	widest to narrowest	Ecological	Competition for nutrients, water and space
Root depth	deepest to shallowest	Ecological	
Growth rate	fastest to slowest	Ecological	Return on investment, management, competition
Easiness to **prune**	easiest to hardest	Management	Shade management
Growth after **pruning**	fastest to slowest	Management	Shade management
Mulch speed of decomposition	fastest to slowest	Management	Nutrient release, erosion control
Mulch benefits to the soil	most to least beneficial	Management	Soil fertility improvement
Firewood burning length	longest to shortest	Utility	Suitability for firewood (quality)
Timber strength	strongest to weakest	Utility	Suitability for different timber uses
Timber durability	most to least durable	Utility	

Management attributes were composites (involving more than one trait) that described how trees responded to management interventions. Utility attributes (firewood burning length and timber strength and durability), were observable properties of trees affecting their usefulness to farmers. Twenty tree and shrub species were selected for ranking (encompassing all woody perennials and including *Carica papaya* and *Draceana afromontana* identified as trees by farmers) selected because they occurred on more than three farms in both: 1) a tree inventory of 60 farms (CAFNET project, unpublished), and 2) the initial local knowledge acquisition, ensuring that they were reasonably common species that farmers would be likely to have experience of (Appendix 3.1.). Clear pictures of each of these twenty trees were put on cards and shown to sample farmers (Plate 1.6).The farmer first identified those they had direct experience of, ten of which were then randomly selected for pairwise ranking for each attribute. (Appendix 3.2. and 3.3)

Plate 1.6. Elidad Uwiringiyimana facilitating the ranking survey in Rutsiro district, Western Rwanda (E.Smith)

The final ranking order given by farmers and explanations provided were recorded. Ranking data were analyzed using the 'Rank analyses' package in R (Lamond et al., 2016) that fits the Bradley-Terry model (BTm, Bradley and Terry 1952) to the data. The BTm model estimates the likelihood that farmers perceive one tree to be above another tree with respect to the attribute in question and allows statistical evaluation of the consistency with which farmers have ranked trees. The 'rank analysis' package also performs a Wald test that provides information about whether the difference between each pair of trees is significant and, therefore, allows the grouping of the trees into functional groups, with respect to the attribute in question.

3.3. RESULTS

3.3.1. Characterization of common tree species on coffee farms

Thirty-five tree species occurring within coffee plots or along coffee plot boundaries were identified and discussed with farmers during the initial local knowledge acquisition phase. We summarized the detailed information elicited from the local knowledge phase about the 20 species selected for ranking and indicated the percentage of farms on which each of those species occurred during the subsequent attribute ranking survey (Table 2).

Farmers involved in the ranking survey had a mean of 12.7 of these 20 selected species. Some of the trees were found in specific niches on farms in accordance with their perceived ecological attributes and end use; *Mangifeira indica* was viewed as highly competitive because of its large and dense crown and *Vernonia amygdalina* was commonly used as a live-fence, both were limited to boundaries. Several species of *Leucaena*, introduced to the area through soil erosion control programs, were used for stabilizing bench terraces and for fodder. Almost all trees in coffee plots were managed for multiple purposes. Fourteen species were managed for both shade and mulch. Five exotic fruit trees were amongst the most frequently occurring, with a mean of 4.6 fruit species per farm. There were ten native species and farmers had a mean of 4.8 per farm. *Markhamia lutea* was the most frequent tree that farmers nurtured from natural regeneration, present in 95% of coffee fields, while *Ficus thonningii, Erythrina abyssinica* and *Vernonia amygdalyna* were commonly propagated through cuttings when used as a live-fence on field boundaries. Native forest species such as *Maesa lanceolata*, *Milletia dura* and *Bridelia micrantha* were less common but still occurred on at least a quarter of farms and were retained for firewood, they occurred mainly in the village of Kigeyo, located near to Gishwati forest. *Grevillea robusta* was the most commonly planted exotic timber species, valued for its fast growth, timber and firewood as well as mulch production. A few shade and mulch trees had been introduced through project nurseries (from 2007 to 2010) for shading and mulching, including *Cedrela serrata, Polyscias fulva, Inga oerstediana* and *Alnus acuminata.*

Table 3.2 List of the 20 trees and shrubs most commonly found on coffee plots in the region of Gisenyi, Rwanda, with their frequency, propagation mode, provisioning, regulating and supporting services, and spatial arrangement

Tree species	Frequency (% of farms it occurred on)	Propagation method	Provisioning services	Regulating and supporting services	Spatial arrangement: Intercropped	Spatial arrangement: Boundary
Psidium guajava (e)	*98*	Farm (seed)	Fruit, income, firewood	Shade, erosion control	*	*
Ficus thonningii (n)	*97*	Farm (cutting)	Firewood, timber (planks, poles), medicine	Shade, mulch, erosion control	*	*
Markhamia lutea (n)	*95*	N. reg nursery	Timber (planks, poles), Firewood, charcoal	Shade, mulch	*	*
Persea americana (e)	*95*	Farm (seed)	Fruit, income, firewood, timber (poles)	Shade, mulch, weed suppression	*	*
Carica papaya (e)	*93*	Farm (seed)	Fruit		*	
Grevillea robusta[1] (e)	*87*	Nursery, Farm (seed)	Timber (planks, poles), charcoal, firewood, income	Shade, mulch, weed suppression, erosion control	*	*
Erythrina abyssinica (n)	*85*	Farm (cutting)	Firewood, medicine, timber (mortar)	Nitrogen fixing, mulch, shade, erosion control	*	*
Ricinus communis (n)	*81*	N. reg	Firewood, medicine, timber (stakes)	Mulch	*	*
Citrus limon (e)	*73*	Farm (seed)	Fruit, medicine, income	-	*	*
Mangifera indica (e)	*70*	Farm (seed)	Fruit, income, firewood, timber (poles, stakes)	Shade		*
Vernonia amygdalina (n)	*70*	Farm (seed) N. reg	Firewood, medicine, timber (poles, stakes)	Mulch, erosion control		*
Polyscias fulva (n)	*61*	Nursery	Timber (planks)	Shade, mulch	*	
Cedrela serrata (e)	*60*	Nursery	Timber (planks), income	Shade, mulch	*	*
Leucaena diversifolia[2] (e)	*43*	Nursery	Fodder, firewood, timber (stakes)	Nitrogen fixing, shade, mulch, erosion control	*	

Tree species	Frequency (% of farms it occurred on)	Propagation method	Provisioning services	Regulating and supporting services	Spatial arrangement	
					Intercropped	Boundary
Inga oerstedania (e)	*35*	Nursery	Firewood, timber (poles)	Shade, mulch, weed suppression	*	
Maesa lanceolata (n)	*31*	N. reg	Firewood, charcoal	Erosion control	*	
Millettia dura (n)	*29*	N. reg	Firewood, charcoal, timber (stakes, poles)		*	*
Dracaena afromontana (n)	*26*	N. reg	Fibre		*	*
Bridelia micrantha (n)	*24*	N. reg	Firewood, timber (poles, stakes), medicine	Mulch, shade, erosion control	*	
Alnus acuminata (e)	*20*	Nursery	Firewood, timber (planks, poles, stakes)	Nitrogen fixing, shade, mulch, erosion control	*	*

Legend: (e): exotic species, (n): native species, N.reg: natural regeneration
[1]occasionally planted as clumps (woodlot) [2] occasionally planted on terraces

3.3.2. Ecosystem services and competitiveness

During the local knowledge acquisition study, farmers expressed detailed knowledge of ecosystem services provided by trees in coffee fields and their impact on coffee yields and overall income. The analysis of statements in the knowledge base represents farmers' understanding of the complex causality influencing how companion trees affect soil conservation and other agronomic services on the one hand and adverse competitive effect on the other.

Soil nutrient cycling and erosion control

Farmers described how nutrient cycling of leaf litter to improve soil fertility and coffee yield was a benefit from companion trees. (Figure 3.1). While chemical fertilizers could be purchased through farmer cooperatives, costs were prohibitive. Instead, most farmers relied on recycling and transferring organic matter grown on various parts of the farm to meet soil fertility requirements. Several strategies were used including transfer of: grasses, crop residues, banana leaves, coffee pulp and husks, and pruned tree branches. There was a growing interest amongst farmers in intercropping trees with coffee to produce *in-situ* mulch because of: decreasing land availability, increasing demand for livestock fodder (driven by the One-Cow-Per-Poor-Family national programme), increasing incidence of banana wilt disease, and new knowledge disseminated by extension agents about the benefits of coffee agroforestry. By producing mulch from tree litter directly in coffee plots, farmers were able to reduce the land allocated solely to mulch production and the labour involved in transferring it. The main tree attributes known to influence soil nutrient cycling were related to the crown branch structure and foliage properties (density, size of the leaf, leaf phenology and leaf decomposition rate). Farmers were attempting to reduce soil erosion using trenches, progressive terraces, mulching, grass strips and tree belts. They mentioned that trees helped stabilize soil through their root systems, contributed to better infiltration of water, which was especially important on steep slopes and close to the lake. Farmers also said that trees intercepted rainfall, thereby reducing surface run-off across soil; with the magnitude of interception associated with crown architecture and leaf phenology.

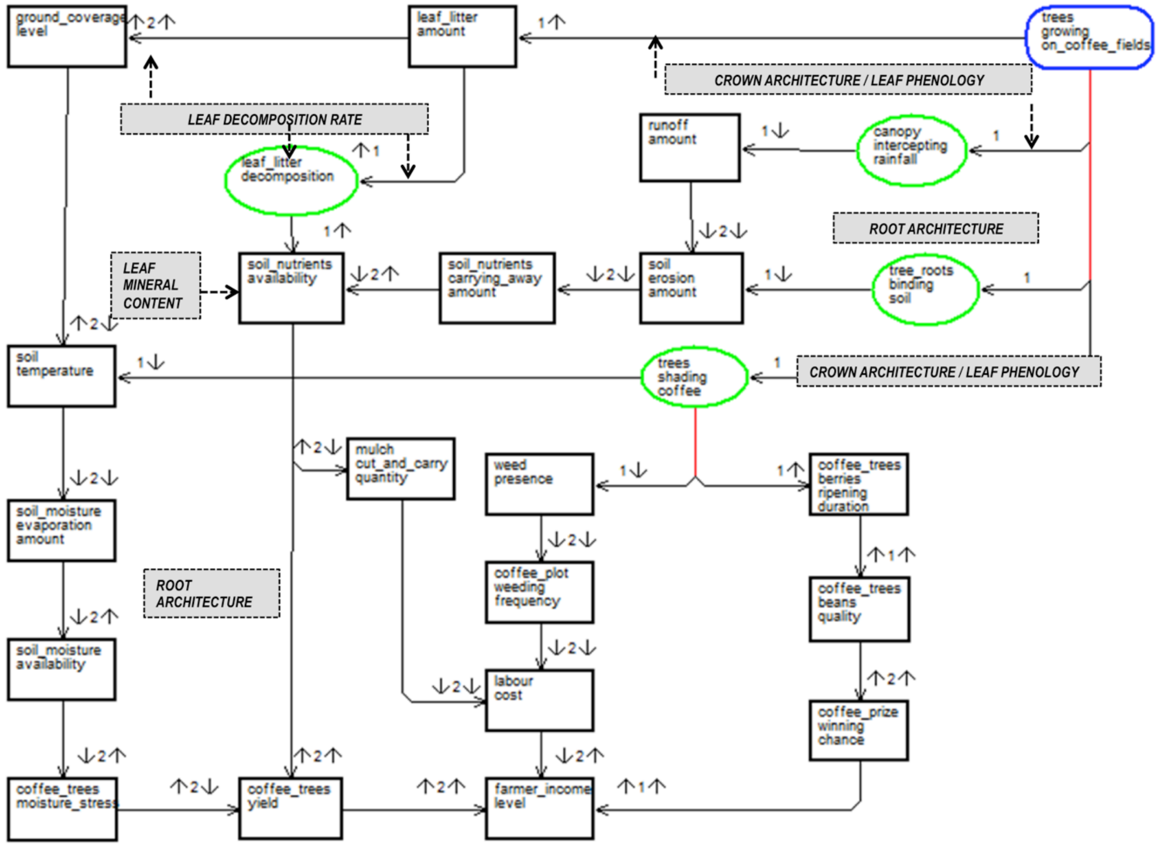

Figure 3.1 Diagram showing farmers' causal knowledge about how trees in coffee fields affect coffee yield and overall income from the coffee plot

Nodes represent human actions (boxes with rounded corners), processes (ovals), or attributes of objects, processes or actions (boxes with straight 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 to the same for 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. Important tree attributes are represented in grey shaded boxes with dotted arrows showing the processes they influence.

Other agronomic services

By increasing ground cover and providing shade, farmers said that trees help reduce soil temperature and evaporation, thereby reducing water stress on coffee plants in the dry season, resulting in positive effects on yield. Weed suppression from shading and mulch was another important service provided by trees in coffee fields compared to full-sun, leading to a reduction in associated labour costs. There was new knowledge that farmers had recently learned from extension workers, relating to shade coffee quality. This was that shade prolonged the duration of coffee berry ripening in turn leading to larger bean weight (an immediate quality measure), as well as enhancing bean quality, giving farmers a higher chance of winning national prizes such as the 'Cup of Excellence'.

Competitiveness

Although farmers mentioned many benefits they also reported some disadvantages of planting trees with coffee, mainly linked to competition for light and water (Figure 3.2). Farmers knew that high shading intensity caused an increase in coffee vegetative growth to the detriment of flowering and fruiting which, in turn, decreased coffee yields. Shading intensity was determined by a combination of ecological attributes of both crown and foliage. Rainfall interception by the tree crown was also seen as negative in the wet season as rainfall would not reach the ground, thus leading to moisture stress and soil compaction which would in turn decrease coffee yields.

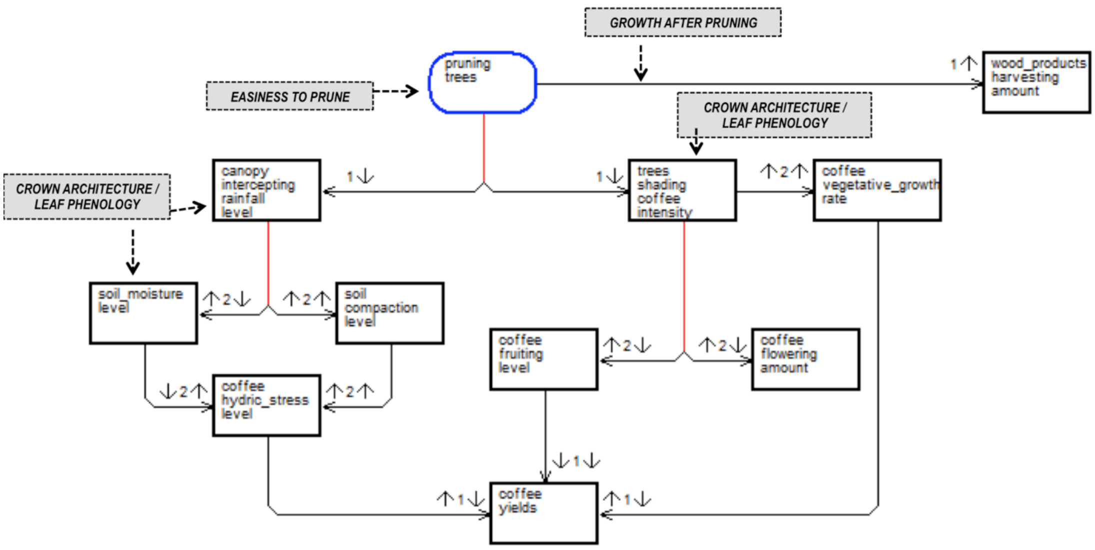

Figure 3.2 Diagram showing farmers' causal knowledge about how tree pruning can reduce the negative influence of shade on coffee yields whilst providing wood products

See Figure 3.1. for explanation of symbols.

Whilst farmers knew that shade management through pruning reduces the negative impact of shade, they did not always act on it and had knowledge gaps about tree species selection, optimal tree density and spatial arrangements that affected both shading and rainfall interception. Crown attributes and ease of pruning were identified as important for management. There was sparse and inconsistent knowledge about the interaction of trees with pests and diseases.

3.3.3. Attribute ranking

Farmers were able to rank trees for the range of attributes they were presented with by comparing individual tree pairs (Figures 3.3. and 3.4.). Less common species such as native forest species (*B. micrantha, M. dura, M. lanceolata*) or newly introduced trees (*I. oerstediana* and *A. acuminata)* were ranked least frequently. The precision of farmers' ranking of trees varied both by attribute as well as tree species. Overall, farmers agreed on which group of trees or which specific tree performed with respect to the expression of a specific attribute, but their ability to further distinguish between certain trees varied from attribute to attribute and this was linked to how the tree was used and how observable the attribute was to farmers.

We define a tree pair to be consistently ranked for a particular attribute if 80% or more of the farmers that compared this pair of trees for the attribute agreed on the order. The majority of tree pairs were consistently ranked for all attributes (the proportion of tree pairs consistently ranked ranged from 60% to 73%, depending on the attribute). The highest consistency was found for ecological attributes that were easily observable, such as growth rate (73%), and crown spread (72%) and density (71%), whereas management and utility attributes, that are more subjectively judged by farmers, such as easiness to prune, growth after pruning, and timber resistance (60% in all three cases), were found to be less consistently ranked.

There were fewer distinctions amongst trees ranked for crown spread than for crown density where clusters of trees represent clear low, medium and high crown density categories (Figures 3.3a and 3.3.b). In terms of root spread and depth, trees at either end of the spectrum were easily identified, but the majority of species were not distinguishable from one another (Figures 3.3c and 3.3d). Farmers consistently ranked trees for growth rate, with species clearly distinguished from one another along the spectrum (Figure 3.3e). Most slow growing species were native whilst fast growing species were mainly recent introductions. Differences for re-growth rate after pruning (Figure 3.3f) could derive from differences in the timing and method of pruning, leading to different re-sprouting responses. Only two farmers ranked *Carica papaya* for pruning.

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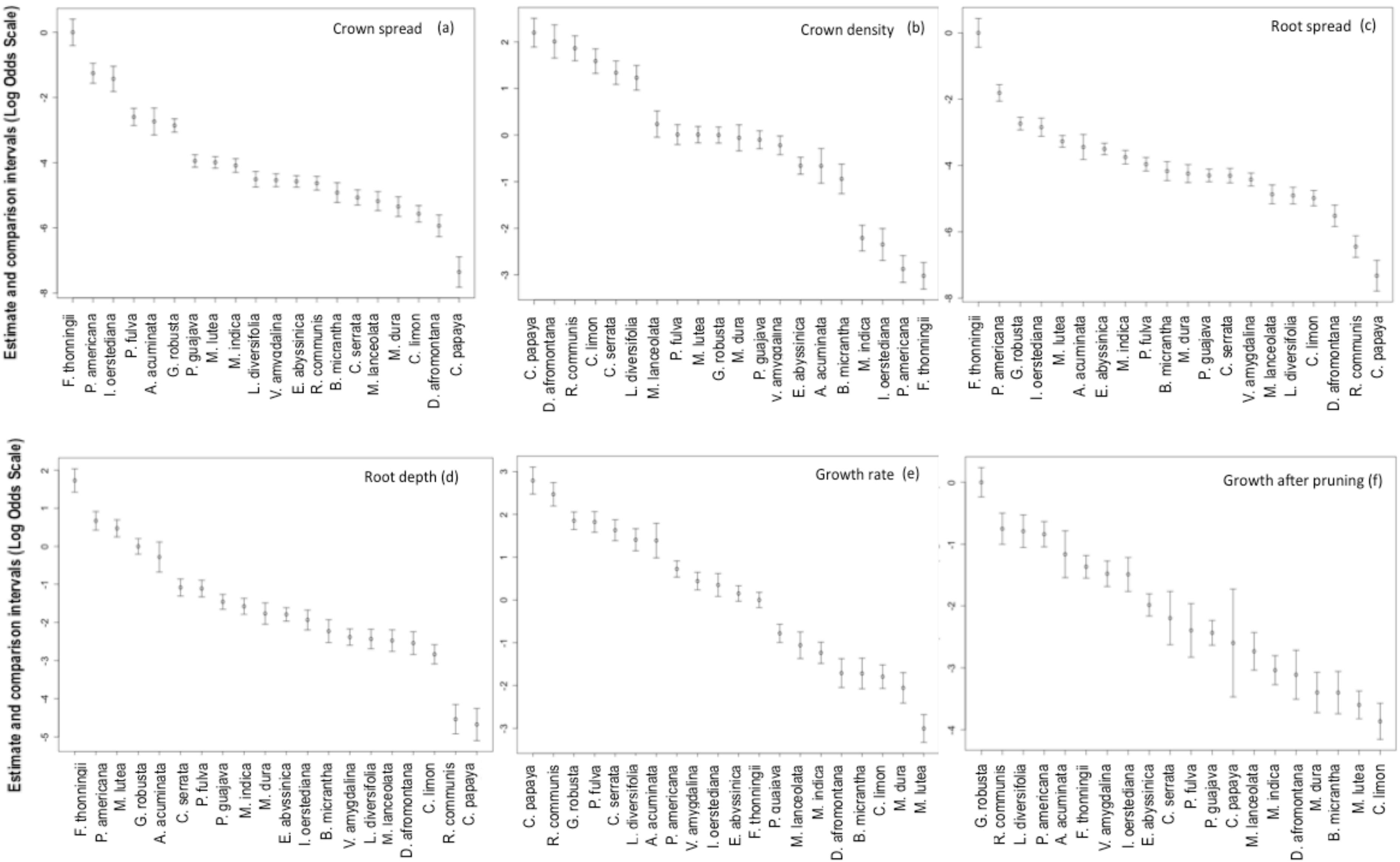


Figure 3.3 Trees ranked by farmers according to different attributes: crown spread (*large to narrow*) (a); crown density (*least dense to most dense*) (b); root spread (*widest to narrowest*) (c), root depth (*deepest to shallowest*) (d); growth rate (*fastest to slowest*) (e) growth after pruning (*fastest to slowest*)

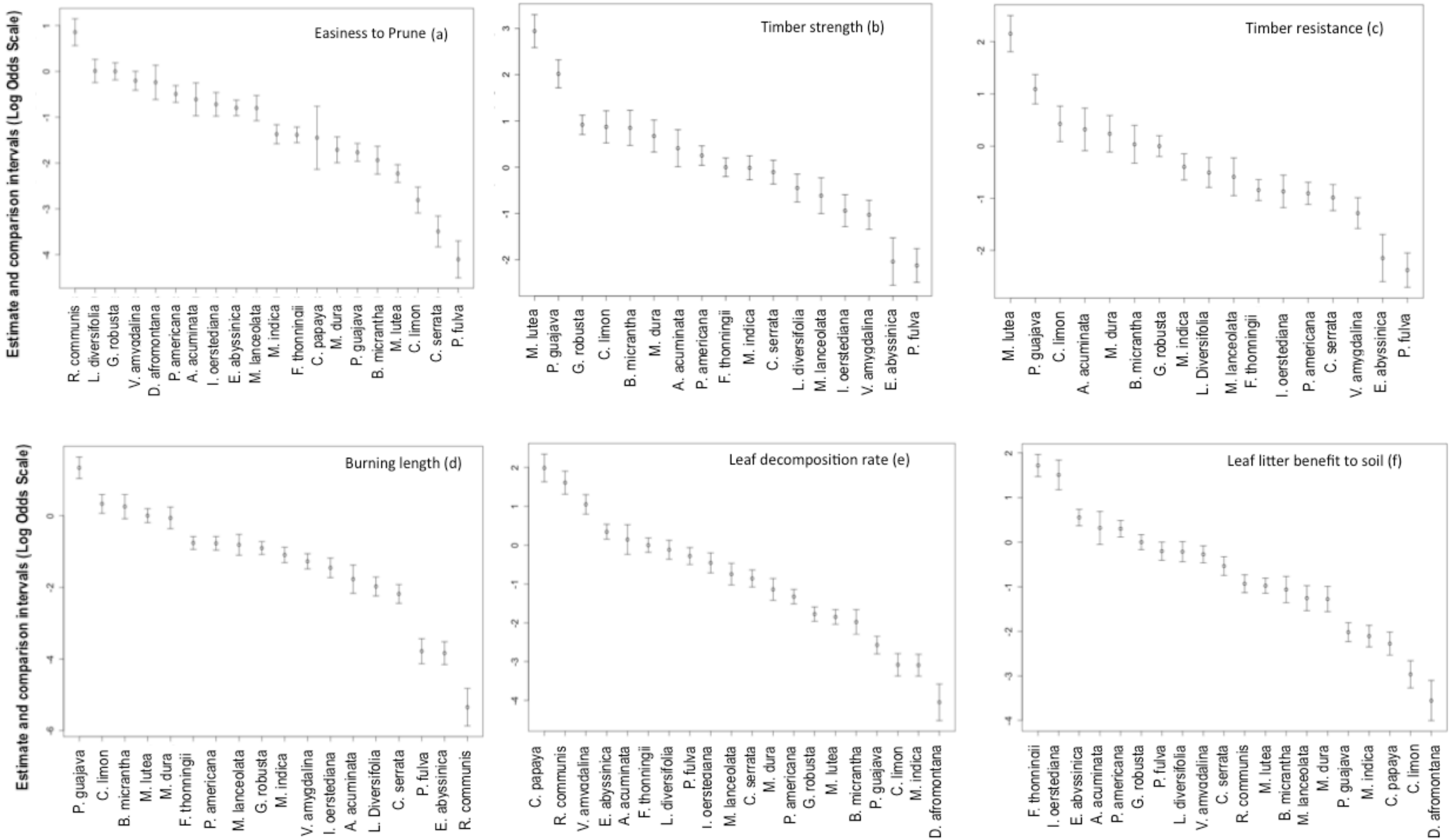


Figure 3.4 Trees ranked by farmers according to different physical attributes: (a); easiness to prune (*easiest to hardest*); (b); timber strength (*strongest to weakest*); (c); timber durability (*most to least durable*); (d) burning length (*longest to shortest*); (e) leaf decomposition rate (*fastest to slowest*) (f), leaf litter benefit to the soil (*most to least*)

For the management attribute 'easiness to prune', trees were less consistently ranked than for other attributes perhaps because different pruning tools and strategies were used and ease of pruning may vary with tree age (Figure 3.4a). For timber attributes, 17 trees were ranked since three were not used for that purpose. The tree ranked highest for timber strength was *M. lutea*, a native species used for wood plank production (Figure 3.4b). Other species with strong timber were trees used for stakes or poles only and not for the sale of planks (*P. guajava* and *C. limon*). There was less consistency in the ranking for timber durability that could be because of gender differences in experience and the variety of uses as planks, poles or stakes (Figure 3.4c). Eighteen trees were ranked for firewood burning length (Figure 3.4d). *C. papaya* and *D. afromontana* were never used for firewood by farmers. *P. guajava* had the longest burning length followed by *C. limon*, though the latter was planted for fruit production and rarely pruned for firewood. Trees less commonly used for firewood included *P. fulva, E. abyssinica* and *R. communis* which had slower burning qualities. Trees were clearly distinguished in terms of leaf decomposition rate with explanation about how texture affected decomposition processes (Figure 3.4e). The amount of mulch generated by trees was linked to foliage density and to deciduousness. *Ficus thonningii, P. americana* and *E. abyssinica* were deciduous trees that provided high leaf biomass and were contributing significantly to soil fertility (Figure 3.4f). *Inga oesterdiana* and *M. lutea* showed progressive shedding of a nutrient-rich leaf litter that was particularly valued by farmers.

3.4. DISCUSSION

3.4.1. Drivers of tree diversity on coffee plots

Despite a history of the Government promoting full-sun coffee in Rwanda (Donovan et al. 2002), most coffee fields (82%) had 10 or more tree species, including a range of native trees. There were four interacting drivers of increasing tree cover on coffee farms: decreasing land availability, resettlement, decreasing availability of forest resources as deforestation progresses, and the promotion of agroforestry by extension services. Farmers explained that increased pressure on land, and the need to optimize space for the simultaneous production of essential goods (fruits, timber, firewood, mulch), made it necessary to integrate trees with coffee. These findings are consistent with trends reported for smallholder coffee farms in Latin America (Mendez et al. 2010). Along with decreasing farm size, farmers' decisions about tree management and positioning on farms was related to the 'Imidugudu' human resettlement policy implemented in Rwanda after 1997. This is a policy that regrouped previously scattered rural homesteads and settlement patterns in new village sites initially set up to assist war-displaced people but also to foster access to services and diversify rural economic opportunities (Isaksson, 2013). In the research site this had caused the abandonment of home gardens and fruit trees could now only be grown in or around coffee fields despite trade-offs from heavy shade. Deforestation in the region had decreased access to firewood, the major source of cooking energy, as well as stakes, widely used for growing climbing beans, a food staple. Similar to other parts of Rwanda, where access to open forest resources has dwindled, farmers were compelled to meet their needs from on-farm trees, triggering an increase in uptake of agroforestry practices (Ndayambaje and Mohren 2011). Farmers had extensive knowledge of vegetative propagation for some native trees and forest species were present on least a quarter of farms, though mainly in the village closest to the Gishwati forest area. This demonstrates the importance of farmers' knowledge for the *in situ* conservation of tree species and genetic diversity (Dawson et al. 2013). External tree planting initiatives, whether for erosion control or more recently for coffee shade management, focused on a few largely exotic species, as a result of limited seed availability and nationally formulated recommendations. This situation is fairly typical of tree planting programs in East Africa where tree seed supply tends to dictate the species that are promoted, often through free seedling distribution, rather than trees being selected based on their agroecological suitability and assessment of community needs, coupled with due consideration of the value of maintaining threshold levels of tree diversity across landscapes (Smith Dumont et al. 2017).

3.4.2. Trade-offs between coffee production and other ecosystem services

Coffee fields were important farm niches for integrating a diversity of trees. In terms of environmental services, farmers were particularly knowledgeable about soil nutrient improvement and erosion control and how these processes affected coffee yields. Soil nutrient deficiencies and erosion problems are common in coffee farms across Rwanda (Nzeyimana et al. 2013) and particularly in the study area (Pinard et al. 2014). As many farmers could not afford fertilizers, soil fertility management was mainly done through mulching and practices had recently shifted towards integrating trees in coffee fields for the production of leaf litter, which reduced labor costs. Our findings show that farmers have sophisticated knowledge about mulching processes, which is consistent with other studies (Soto-Pinto et al. 2007), but provides novel information in the context of Rwanda where previous work on trees and mulch have focused mainly around on-station experiments with a few exotic species (Dusengemungu and Zaonga 2006). Other agronomic benefits of trees in coffee fields frequently mentioned by farmers related to weed suppression and the reduction of water stress during the dry season, which is consistent with the scientific literature (Staver et al. 2001). There were knowledge gaps in terms of the impact of shade on pest and disease interactions and on coffee quality because farmers lacked long-term experience of managing trees in their coffee farms. Despite recognizing the numerous utilities of trees in coffee, farmers were aware that too much shade or too dense a tree canopy was detrimental to coffee yields. As new knowledge is built through the recent experience of managing trees in coffee farms in Rwanda, it will be important to ensure that it can be efficiently and effectively shared amongst farmers (Valencia et al. 2016).

3.4.3. Consistency in ranking tree attributes

Coffee farmers could readily and consistently rank trees against a range of ecological, management and utility attributes. This indicates that farmers' knowledge could be useful in informing the development of agroforestry recommendations. The consistency of ranking varied with the knowledge and experience farmers had, showing greater consistency in their ranking of trees commonly managed on farms but lower consistency for newly introduced species. Ranking was most consistent for ecological attributes that were easily observable, such as those related to leaf litter, crown properties and growth rate which is comparable to tree attribute ranking by farmers in Kenya (Lamond et al. 2016) although the present results indicate higher precision than those achieved in Kenya. This may reflect the use of tighter protocols for conducting the ranking, with explanations elicited from farmers about the reasons for their ranking. Farmers ranked trees less consistently for root attributes such as spread and depth than they did crown attributes. This is likely to be because they are more difficult to observe and root growth is influenced both by pedoclimatic conditions and tree and soil management, with large intra-species variation (Schroth 1995).

Ranking was particularly useful for composite attributes like 'leaf litter benefits to the soil' which combined leaf biomass, deciduousness and speed of decomposition, known to vary widely according to the species' nutrient uptake and litter recycling ability (Montagnini et al. 1993). Farmers ranked trees for 'leaf litter benefits to soil' consistently, corroborating local scientific results showing higher coffee berry production under *P. americana* and *F. thonningii*, as a result of positive effects on soil nutrient content (Pinard et al. 2014). These two species were amongst the most frequent on farms and used for mulch. Leguminous species were ranked highly in terms of soil benefits, including *E. abyssinica* (a locally propagated native species) and *I. oesterdania* (promoted by advisory services) which come from genera that are commonly used for mulch in Central America (Somarriba et al. 2004). Although literature was only available at the genus level, scientifically measured leaf decomposition rates corroborate the farmers' ranking, with *Erythrina* sp. decomposing faster than *Inga* sp. and *P. americana* (Duarte et al. 2013).

While the ranking method enabled us to assess the consistency of knowledge amongst farmers about the magnitude of interactive effects of different species in relation to specific attributes, it does not provide information about trees in absolute terms. Various approaches have been successfully applied to obtain scores rather than ranks from farmers (Franzel et al. 1995), but these have more often related to information about preferences rather than knowledge (Abeyasekera 2001). We used ranking because it is rapid and repeatable. We found that it was clear to both the farmer and researcher what one species being ranked above or below another meant with respect to the attribute in question, and that this is more easily understood by farmers, and is less open to variable interpretation, than scoring methods. The ranking enables qualitative evaluation and discussion of interactions amongst coffee farm system components that determine the magnitude of interactive effects. We have shown that farmers consistently ranked trees in terms of attributes that control interactions, so that different (groups of) tree species can be distinguished in terms of the size of their interactive effects.

We searched available literature (Web of Science) and tree databases (Plant Resources of Tropical Africa; TRY-Global database of plant traits; Biodiversity Heritage Library) to compare farmers' ranking with scientific data but found very few data on the attributes and species that farmers ranked except that on decomposition rates referred to above. Comparisons are complicated by the fact that management and utility attributes often cannot be assessed with single plant trait measurements. Where data are available, comparison amongst species is limited, not only by the lack of standardization in measurement units and protocols but also because of localized variation in tree genetic, environmental and management factors affecting expression of attributes. This makes consistent ranking of attributes by farmers complementary to information that is available scientifically, largely because there are no comparable scientific datasets of relevant attributes for the species that farmers are integrating with coffee. Companion trees directly and indirectly affect coffee production (and other ecosystem services) through a variety of agro-ecological processes and have productive functions in themselves. Farmers' ranking of tree species against attributes enables prediction of the magnitude of interactive effects amongst farming components useful in developing recommendations related to agronomic performance and the reduction of competition with coffee whilst providing livelihood benefits. For example trees with slowly decomposing leaves may be preferred for planting on contours for controlling erosion but those with fast decomposing leaves would be preferred for nutrient cycling in coffee plots. A tree might have a wide and dense crown but the farmer may be able to manipulate the shade if the tree is easy to prune. This information can be integrated in multiple criteria decision-support tools to better inform tree selection and management of companion trees for different farmer circumstances (van der Wolf et al 2016). This can contribute to the promotion of a wider diversity of trees including native species of conservation interest (Smith Dumont et al. 2017)

3.5. CONCLUSION

In many parts of the world, coffee growing has shifted from complex to more simplified agroforestry practices or to unshaded, full-sun systems. In contrast, in the Western Region of Rwanda, farmers are moving away from historically encouraged full-sun coffee, where intercropping was prohibited, to the incorporation of increasing amounts and diversity of tree cover in coffee fields. As farm sizes and access to natural forest resources decrease, farmers' coffee fields are increasingly important farm niches for integrating a diverse mix of tree species, including retention of some native forest species, to obtain products that diversify income and improve soil and water conservation. New knowledge about shade benefits was being disseminated and nurseries set up by government advisory services and cooperative networks, but these focused on a narrow range of mainly exotic species. Farmers had consistent and detailed knowledge of a range of tree attributes and how they influenced tree-coffee interactions determining their suitability for use in specific on-farm niches, but their knowledge was strongly linked to their experience and influenced by their access to rural advisory services. Given the paucity of global scientific data about tree attributes, acquiring farmers' ranking of trees for key ecological, management and utility attributes is a cost-effective way of obtaining information that can be used to build decision-support tools to guide the selection and management of a diversity of companion trees in coffee.

4. INTEGRATING FARMERS' KNOWLEDGE FOR CONTEXT SENSITIVE PARKLAND AGROFORESTRY MANAGEMENT

ABSTRACT

The diversity of trees in the West African agroforestry parklands is known to have essential agro-ecological and livelihood functions but it is increasingly threatened by climate change and land degradation. Scientific knowledge about the management of trees in the parklands remains scarce and this limits the extent to which recommendations can be formulated about how to enhance tree cover and diversity for restoring land and increasing the resilience of communities farming in the region trying to cope with and mitigate climate change. To better understand farmers' knowledge that underpins current and potential tree management options, we conducted an attribute-ranking survey with 120 farmers in the Centre-South Region of Burkina Faso of about 21 useful tree species commonly occurring on farmland. We found that while farmers were able to consistently rank trees for fundamental ecological and economic attributes, there were polarised perceptions on how some trees, in particular the Shea tree (*Vitellaria paradoxa*), affected composite soil fertility, which could be explained by differences in management practices that accelerated leaf decomposition and prevented the negative impact of leaf litter on crop seed germination. In addition to providing new information on a range of parkland trees and on innovative farmer practices of slash and mulch, the collecting and documenting of farmers' knowledge shed light on the complex and highly context-dependent linkages between trees and soil fertility, and the types of benefits derived from a diversity of woody species. We conclude that obtaining and building on such local knowledge is key in informing actions for development, and for future research for co-designing agroforestry options that include a range of trees and management practices tailored to different farmers' needs and conditions.

Key words: Sudanian savannah, West Africa, ranking, trees, soil fertility, leaf litter

4.1. INTRODUCTION

The West African drylands cover an area of over 5.4 million km^2 with a largely agrarian population of about 60 million (Sissoko et al., 2011), considered to be amongst the poorest, most food insecure and vulnerable to climate change in the world (Battisti and Naylor, 2009; Mertz et al., 2011). Agroforestry has been the dominant land use in the region for centuries, where farmers grow crops with valuable native trees and shrubs retained after the fallow cycle, shaping landscapes generically known as parkland systems (Boffa, 1999). In addition to providing products essential to local livelihoods, such as nutritious food, energy, medicine, timber, fodder and income, the woody component in parklands also ensures key regulating and supporting ecosystem services, including maintaining soil health, which is of paramount importance for sustaining food production (Garrity et al., 2010; Bayala et al., 2014). Parklands are heterogeneous systems in their tree composition, land-use intensity and health status (Bayala et al., 2014). Whilst positive trends have been observed with tree cover recovery in some parts of the West African parklands (Reij et al., 2009), there is also evidence of significant decline in terms of tree density and diversity, with an ageing tree population, lack of regeneration and a loss of genetic diversity (Herrman et al., 2005; Kindt et al., 2008). The causes of these changes are diverse and interconnected; they comprise the combined effects of changing climatic conditions with increased aridity, agro-pastoral intensification by a growing population, and over-exploitation of tree resources in an unfavourable institutional and policy environment (Boffa, 1999; Kandji et al., 2006). The associated loss of ecosystem services has alarming consequences for the millions of subsistence farmers that live and depend on natural resources in these landscapes (Gonzalez et al., 2012). Efforts to restore land and enhance livelihood conditions through improved agroforestry or tree-based systems are widespread in the region (Bayala et al., 2011; Place et al., 2016). These range from intensive domestication efforts to improve indigenous fruit germplasm (Kalinganire et al., 2007), to enhancing low-cost farmer-managed natural regeneration practices (Binam et al., 2015). The potential for increasing tree cover and diversity with the intensification of agriculture has been shown to be promising in the drylands (Mortimore and Turner, 2005), but the extent to which any given practices or technology can be scaled up successfully is highly contextual (Coe et al., 2014). Agroforestry may be increasingly viewed as a solution to ensure multiple benefits from landscapes in Africa, but data are scare and many questions remain unanswered about appropriate tree species selection and management practices that can enhance synergies and reduce trade-offs in different sites and for different people (Mbow et al., 2014b).

The relationship between tree diversity and socio-ecological dynamics is in itself highly context specific and will depend on, among other factors, land users' preferences, natural seed stock and site conditions, as well as tree germplasm delivery mechanisms (Ordonez et al., 2014). In degraded parklands, tree species selection and management may also need to be adjusted to new conditions, including degraded soils and climate change (Kindt et al., 2008; Hänke et al., 2016). Furthermore, in these types of rain-fed mixed farming systems, understanding tree-crop-livestock interactions and competition for scarce resources, such as space, water and nutrients, is very important (Bayala et al., 2015) but also requires significant local knowledge (Reynolds et al., 2007). Farmers make management decisions about trees based on a set of socio-economic, ecological and physical attributes that ultimately determine a species' potential productive function and suitability for different agroforestry practices (Raintree, 1991), as well as the extent to which they can deliver different ecosystem services (Ordonez et al., 2014). Ecological attributes encompass a set of physical and ecological tree characteristics that are often composite in nature, combining morphological, physical and behavioural traits. Their expression is subject to considerable variations that are driven by a combination of environmental conditions, genetic diversity and management practices. Socio-economic attributes are characteristics ascribed to trees by legislation, policy, cultural norms, technology and markets, and these are also contextual. Integrating local knowledge is an essential prerequisite for engaging with local stakeholders and co-design adaptive strategies that capture and take into account the socio-ecological contextual conditions (Sinclair and Joshi 2000; Reynolds et al., 2007; Coe et al., 2014; Smith Dumont et al., 2017).

When it is elicited systematically, farmer's knowledge of tree attributes has been found to be sophisticated and complementary to scientific knowledge on topics such as tree fodder management in Nepal (Thorne et al., 1999), or companion trees' interactions with coffee (Cerdan et al., 2012) or with cocoa (Anglaaere et al., 2011). More recently, novel methods for quantifying probability estimates of tree attributes based on farmers' participatory ranking were tested (Lamond et al., 2016; Gram et al., 2017). The ranking survey method, when applied with a rigorous protocol and the integration of local knowledge, provided a cost-effective way of classifying trees based on ecological (crown, growth, roots), management (easiness to prune, mulch), and utility attributes (firewood burning length; timber strength) (Smith Dumont et al., in press), which can be used in developing customised decision-support tools for integrating companion trees in coffee (van der Wolf et al., 2016).

Numerous ethno-botanical surveys and studies have been conducted in West Africa to assess local perceptions of changes in tree cover and diversity and looked at preference or utility ranking of trees (Lykke et al., 2004; Faye et al., 2011, Sop et al., 2012). However, no study has previously attempted to look at farmers' in-depth knowledge of tree attributes and ecological interactions. We were particularly interested in investigating farmers' knowledge of tree attributes that influence interactions with crops, and doing so for a range of parkland species about which there is a great paucity of scientific knowledge. Our main objective was to assess the consistency of farmers' knowledge of tree attributes and document fine-scale variations that underpin current and potential tree management options in parkland systems. Burkina Faso, a country which scores near the bottom of the United Nation's Human Development Index is landlocked and heavily dependent on farming and forest resources that are mostly located in the drylands, which have varying aridity conditions along a latitudinal gradient. The more productive sub-humid part of the country has been subject to significant land-use changes over the last 40years, driven largely by in-migration from the drier rural parts of the country and the intensification of agriculture for commercial purposes, including for cotton (Pare et al., 2008; Foli and Abdoulaye 2016). By conducting our survey in this dynamic setting our aim was to compare knowledge variations amongst farmers of different origins that are highly dependent on tree resources in an area under high population growth and density (Bouda et al., 2011).

4.2. METHODS

4.2.1. Study site

We conducted our ranking survey in four villages: Cassou, Vrassan, Dao, Kou located in the Ziro Province of Southern Burkina Faso. These villages were selected because they represent a landscape mosaic of community forests and parklands with some of the highest population density of the country (34.7 inhabitants/km2) with a reliance on trees for their livelihoods (Etongo et al., 2015b; Ouedraogo et al., 2015). In terms of phyto-geographical characterisation, they fall under the Sudanian woody savannah vegetation dominated by native edible trees (Fontes and Guinko 1995). The provincial mean annual rainfall for the period 1993– 2011 is 904 mm ± 144 mm falling over a single four to five month rainy season (Dayamba et al., 2016). The villages are located around the edge of a community forest reserve. The native ethnic group are the Nuni (customary land owners) but the majority of the population (over 80%) are migrants, largely from Mossi but also Fulani ethnic groups (Etongo et al., 2015b). The main activities are subsistence and commercial agriculture (sorghum, maize, rice, cotton, sesame) as well as a range of vegetable crops. Non-timber forest products, wood harvesting and extensive livestock production were also a key local income sources (*ibid*).

4.2.2. Sampling

A total of 120 farmers (as individuals or in groups) participated in the survey stratified, equally amongst the four village sites (table 4.1). We further stratified our sample in terms of ethnic origin according to two broad categories of native (Nuni) or migrant (these included Mossi (47) Fulani (16) and Silmi-moega (mixed Mossi and Fulani parents (10). Because we wanted to explore whether farmers coming from outside the community would have different knowledge to those native to the villages we aggregated the data for all migrant farmers. The villages were divided into different neighbourhoods based on ethnicity (ICRAF-INERA, 2013). To select individual farmers, we purposefully went to these different neighbourhoods accompanied by local facilitators and randomly asked farmers if they were willing to participate in the survey. The interview took place either on the spot or at a later time or date based on the preferences of the farmers, was facilitated in the local languages by a local interpreter in Nuni and Moré, and lasted one hour to one and a half hour. We further stratified the sample according to gender - we aggregated the data for interviewees that were conducted either with one or more women (16) or mixed (14) to represent data where women's opinions were voiced and recorded as opposed to male only knowledge acquisition events. In terms of capturing gender differences, it was practically difficult to interview women alone because men were interested in joining exercises if they were present and it was not culturally appropriate to exclude them. It was more difficult to interview native women than migrant women because they were found to be too busy with other domestic activities and less willing to take part in the survey. We therefore adopted a strategy where we tried to include as many women as possible (even if men were also present) to ensure their knowledge was included, while recognising this would compromise the extent to which we would obtain data that would allow us to test differences according to gender.

Table 4.1 Stratified sample for the tree attribute ranking survey according to gender and origin

Village	Gender	Origin: Local	Origin: Migrant	Total
Cassou	men	18	7	***25***
	mixed	1	4	***5***
	total	**19**	**11**	**30**
Dao	men	5	18	***23***
	mixed	3	4	***7***
	total	**8**	**22**	**30**
Kou	men	8	9	***17***
	mixed	4	9	***13***
	total	**12**	**18**	**30**
Vrassan	men	7	18	***25***
	mixed	1	4	***5***
	total	**8**	**22**	**30**
Total		**47**	**73**	**120**
Men (total)		**38**	**52**	**90**
Mixed (total)		**9**	**21**	**30**

4.2.3. Ranking survey and analysis

Twenty-one tree species were selected for the ranking survey based on a participatory rapid appraisal (PRA) study conducted in the four villages (ICRAF-INERA, 2013). Through focus group discussions (FDGs) conducted with two groups of men and women in each village, farmers were first asked to identify the five most important tree functions (food, sales, firewood, medicine, fodder (men only) and tools (women), then list important species for each function and then scored each species for each function based on the frequency of use (on a scale of one to four). The PRA study produced a list of 52 tree species botanically identified (18 species were recorded with vernacular names only). We selected species that were mentioned by farmers in all four villages, with an overall score of at least 5 for their importance by different groups (Appendix 4.1). This process ensured the species selected for ranking would be present in all villages (important for the statistical analysis) and were relevant for people living there. *Saba senegalensis* was excluded because it is a liana and not considered suitable for ranking crown attributes. The ranking survey focused on a selected sample of attributes: 1) economic value (most to least valuable), 2) leaf litter contribution to soil fertility (highest to lowest), 3) crown spread (widest to narrowest), 4) crown density (most to least dense), 5) regrowth after coppicing (fastest to slowest) and 6) competitiveness with crops (most to least competitive). The methodology followed the attribute ranking procedures as laid out in similar work (Lamond et al., 2016, Smith Dumont et al., in press).

Illustrations of the 21 pre-selected species (example Appendix 4.2) represented on illustrated cards were shown to the individual or the group of farmers (when more than one member of the household was present) who identified those that they had direct experience with (species actually occurring in the famers' fields) (Plate 4.1).

Plate 4.1. Testing the ranking attribute survey with Sabine Nadembega and Barry Silimana in Vrassan, Ziro Province, Burkina Faso

If this group of trees exceeded ten species, farmers randomly selected a sample of ten species for ranking each of the six attributes. If the number of trees was smaller than ten, all species mentioned were included in the ranking. Farmers were given the possibility to exclude species from the ranking when they said it did not contribute to a particular attribute (this was the case for economic value and for soil fertility rankings). The final ranking order given by farmers was recorded on data sheets along with the explanatory information they provided for ranking the species in that order. Ranking data was analyzed through an R package 'Rank analyses` fitting the Bradley-Terry model (BTM, Bradley &Terry, 1952) to the data. The BTM model is a latent variable model in which species are placed on a continuous scale such the distances between any pair represent the chance of them being ranked consistently different from each other. For two species i and j, with locations on the scale of s_i and s_j, the probability that i us ranked higher than j is p_{ij} and

$$\log\left(\frac{p_{ij}}{1-p_{ij}}\right) = s_i - s_j \ .$$

Inferences about the overall rankings are then based on the values of si-sj and the statistical properties of the estimates, including tests of which differences are significant. The estimated values of the s_i parameters provide an overall ranking, even though each farmer only ranks a subset of the species. However, the s_i provide more than just an overall ranking as they show which trees are easily separated or consistently ranked differently by participants as they are the ones that are far apart on the s scale.

It thus allows a statistical evaluation of the suitability of local knowledge to be used as a decision aid to select tree species for specific, desirable attributes. It allows the grouping of the trees into functional groups, with respect to the attribute under question. The model also allows investigation of interactions with covariates, by providing and estimates and tests of differences between s_i parameters for different groups of participants.

There was some evidence on 'bipolarity' in rankings of a few species, in with some participants ranking them high and others low. This is not described well with the BT model. We investigated this this defining the relative position of the species i for respondent j as $rp_{ij} = r_{ij}/(n_j+1)$, where r_{ij} is the rank and n_j the number of species ranked by respondent j. Exploratory statistical methods were used to look for patterns in rp_{ij}.

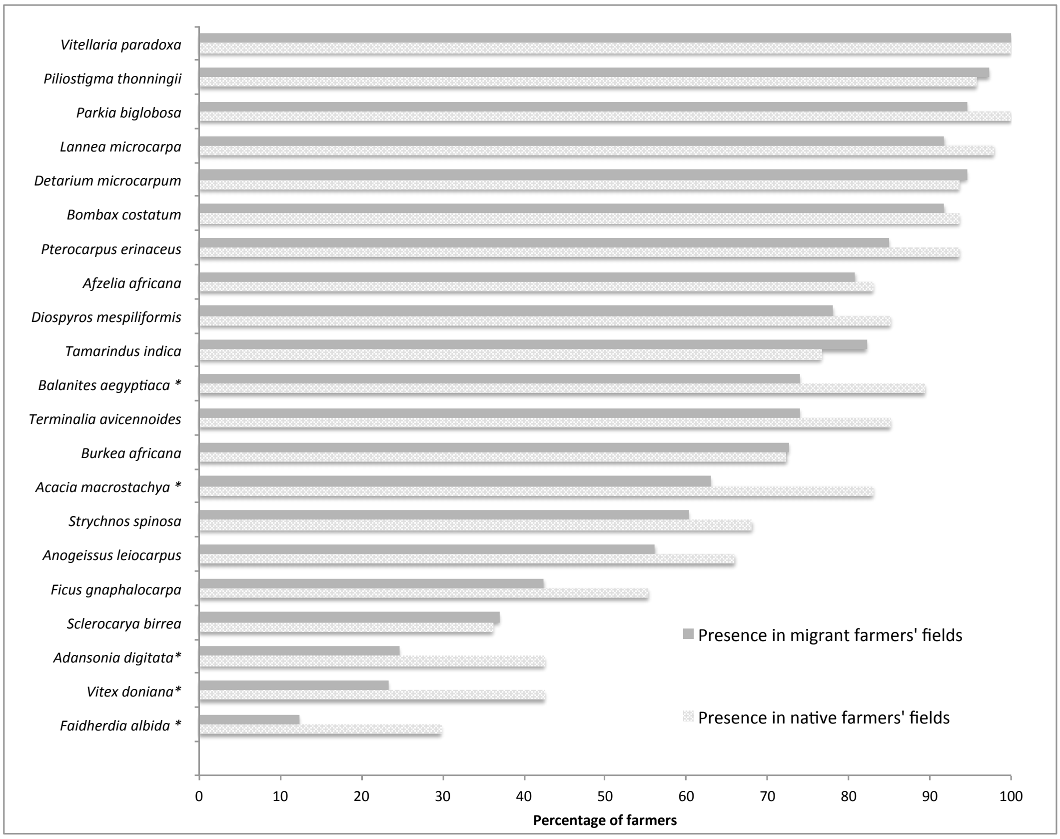
4.2.4 Local knowledge acquisition and contextual farm information

To record and analyse the rich explanatory knowledge informing the ranking survey results, a knowledge base was created using the Agroecological Knowledge Toolkit (AKT5) approach and software (Sinclair and Walker, 1998). The knowledge base captured 545 statements representing farmers' knowledge and qualitative information about tree attributes and interactions underpinning the way trees were ranked by farmers. Analysis of the knowledge base produced causal diagrams representing farmers' causal understanding behind tree attributes and processes. Information relating to each interviewee's context (household composition, landholding size, education level, and farm management practices) was collected separately through a short questionnaire Appendix 4.3)

4.3. RESULTS

4.3.1. Farmers' experience of integrating tree species in crop fields

Native and migrant farmers reported having direct field experience of similar mean numbers of the 21 tree species sampled, 15.9 (SD 3.4) and 14.4 (SD 2.98), respectively but there were differences in how frequently different species were reported by each group. Six species were reported by at least 90% of farmers' as being present on their cropland regardless of their origin (Figure 4.1.), these comprised four fruit trees *Vitellaria paradoxa* (shea tree), *Parkia biglobosa*, *Lannea microcarpa* and *Bombax costatum* as well *Detarium microcarpum*, used principally for fruits and firewood and *Piliostigma thonningii* used principally for fodder and medicine (Appendix 4.4). Other key parkland species important for nutrition and income such as *Tamarindus indica*, *Balanites aegyptiaca* and *Diospyros mespiliformis* were reported as present on 80% or more of farmers' fields regardless of their origin. There was a statistically significant difference between the presence of trees species that grew in specific landscape niches like *Adansonia digitata* (baobab) reported by 42.6% of native farmers but only 24.0% of migrant farmers. Farmers explained that these trees were associated with fields located around old native settlements. This was also the case for *Faidherbia albida* reported by 29.8% of native and 12.3% of migrant farmers and *Vitex doniana* (42.0% of native and 23.3% of migrant farmers) explained by their occurrence along riparian areas that represent high quality croplands allocated primarily to native households.



*next to the species denotes a statistical difference between farmers of different origins (p=<0.05

Figure 4.1 Variations on farmers' direct experience of pre-selected trees according to their origin (native farmers n=47 and migrant farmers n=73) in Ziro province in Burkina Faso, West Africa

4.3.2. Economic value

Ficus gnaphalocarpa was the only tree out of the 21 pre-selected species that no farmer ranked for economic value. Native farmers ranked a similar mean number of species 6.7 (± 1.71) as migrant farmers 5.5 (± 2.4). Ten per cent of farmers only ranked one or two species, which were *Vitellaria paradoxa* followed by *Tamarindus indica* and more rarely *Parkia biglobosa.* On the high end of the economic value spectrum, two species clearly stand out as more valuable than all others, *V. paradoxa* and *P. biglobosa* with little difference between the two species (Figure 4.2). These are followed by another pair *B. costatum* and *T. indica,* which were consistently ranked higher than all other species below them but with little distinction between the two. Lower over of the spectrum, the distinction between groups of species becomes less clear although some species are ranked higher than others (e.g. *A. digitata* higher than all others below itself except *A. macrostachya*).

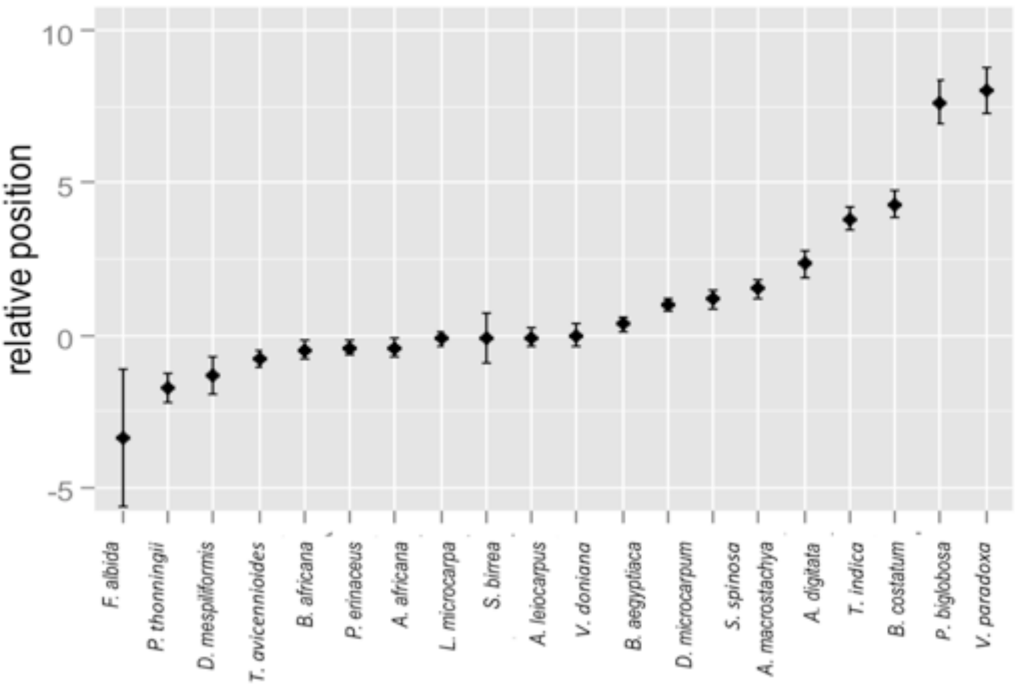


Figure 4.2 Trees ranked by farmers for their economic value (from least to most valuable) in Ziro province in Burkina Faso, West Africa. Vertical scale is the estimated value of s for each species (see methods)

The top four species were ranked similarly by male respondents and by women or mixed gender groups but there were small but significant differences in the ranking of other species (Table 4.2). For example, *S. spinosa*, *B. aegyptiaca* and *A. africana* appeared higher in ranking order for the mixed group than the male group, while *V. doniana*, *A. digitata* and *D. microcarpum* appeared higher in the ranking by men than by the mixed group. There were also gender differences in the overall spread of species, the mixed group of respondents ranked three distinctive pairs of trees on the higher spectrum compared to two pairs for men. The mixed respondents did not rank *S. birrea* and *F. albida* enough times to contribute to the analysis. The origin of farmers also influenced how they ranked species against economic value, whilst *P. biglobosa* was ranked first by native farmers; it was ranked third amongst migrants. *B. aegyptiaca* was also appeared higher in the ranking by migrants than by native farmers.

Table 4.2 Variations in ranking estimates for economic ranking between men only and mixed gender respondents and between farmers of different origins
(native farmers n=47 and migrant farmers n=73; men only n= 90 and women or mixed groups n=30) in Ziro province in Burkina Faso, West Africa (Vitex doniana set as benchmark)

Men only			Mixed group			Native farmers			Migrant farmers		
Rank	Species	Estimates	Rank	Species	Estimates	Rank	Species	Estimates	Rank	Species	Estimates
1	*V. paradoxa*	8.1	1	*V. paradoxa*	9.17	1	*P. biglobosa*	9.38	1	*V. paradoxa*	7.9
2	*P. biglobosa*	7.64	2	*P. biglobosa*	8.94	2	*V. paradoxa*	8.79	2	*B. aegyptiaca*	7.9
3	*B. costatum*	4.11	3	*B. costatum*	6.13	3	*T. indica*	4.35	3	*P. biglobosa*	7.0
4	*T. indica*	3.66	4	*T. indica*	5.66	4	*B. costatum*	3.67	4	*B. costatum*	4.6
5	*A. digitata*	2.12	5	*S. spinosa*	4.79	5	*A. digitata*	2.36	5	*T. indica*	3.4
6	*A. macrostachya*	1.4	6	*A. digitata*	4.47	6	*S. spinosa*	1.78	6	*A. digitata*	2.1
7	*D. microcarpum*	0.85	7	*B. aegyptiaca*	3.27	7	*D. microcarpum*	1.41	7	*A. macrostachya*	1.8
8	*S. spinosa*	0.66	8	*A. macrostachya*	3.08	8	*A. macrostachya*	1.19	8	*D. microcarpum*	1.6
9	*V. doniana*	*0*	9	*D. microcarpum*	2.66	9	*B. aegyptiaca*	0.30	9	*V. doniana*	0.0
10	*B. aegyptiaca*	-0.24	10	*A. leiocarpus*	2.27	10	*P. erinaceus*	0.19	10	*A. africana*	-1.0
11	*S. birrea*	-0.29	11	*A. africana*	1.78	11	*A. leiocarpus*	0.13	11	*S. spinosa*	-1.5
12	*L. microcarpa*	-0.33	12	*L. microcarpa*	1.58	12	*V. doniana*	0.00	12	*B. africana*	-1.6
13	*A. leiocarpus*	-0.37	13	*P. erinaceus*	1.51	13	*B. africana*	-0.18	13	*P. erinaceus*	-1.8
14	*B. africana*	-0.53	14	*T. avicennioides*	1.32	14	*A. africana*	-0.21	14	*L. microcarpa*	-1.9
15	*P. erinaceus*	-0.69	15	*D. mespiliformis*	1.03	15	*L. microcarpa*	-0.29	15	*T. avicennioides*	-2.0
16	*A. africana*	-0.84	16	*B. africana*	0.33	16	*T. avicennioides*	-0.31	16	*D. mespiliformis*	-2.1
17	*T. avicennioides*	-1.1	17	*V. doniana*	*0*	17	*P. thonningii*	-2.68	17	*P. thonningii*	-2.2
18	*D. mespiliformis*	-1.52	18	*P. thonningii*	-1.71	18	*F. albida*	-3.81	18	*F. albida*	-3.2
19	*P. thonningii*	-1.67	19	*F. albida*	NA	19	*D. mespiliformis*	NA	19	*S. birrea*	-9.0
20	*F. albida*	-3.49	20	*S. birrea*	NA	20	*S. birrea*	NA	20	*A. leiocarpus*	-9.1

4.3.3. Contribution of leaf litter to soil fertility

Two farmers stated they believed no tree could contribute to soil fertility and hence provided no ranking information for that attribute, nine farmers ranked five species or less whilst the majority (68%) ranked all ten trees they were presented with. Two species *D. microcarpum* and *F. albida* were ranked higher than all other species except *F. gnaphalocarpa* and *V. paradoxa*, with the latter higher than all others (Figure 4.3). The distribution shows clear distinctions amongst many of the tree species compared with greater separation towards the upper end of the spectrum than the lower end, where *S. spinosa* and *B. aegyptiaca* were nevertheless viewed as lower than almost all other species except *B. africana*. There was little variation in the ranking between farmers of different origins regarding species on the higher end of the spectrum but interesting there were interesting differences for certain species like *T. indica*, ranked fifth by native farmers but perceived as one of the lowest species for contributing to soil fertility by migrant farmers (Table 4.3). There was a similar difference in respect of *Pterocarpus erinaceus*. On the other hand, migrant farmers ranked *B. costatum* comparatively higher than other species, and native farmers ranked *S. spinosa* and *B. aegyptiaca* amongst the lowest species, although they appear in the middle in the ranking by migrants.

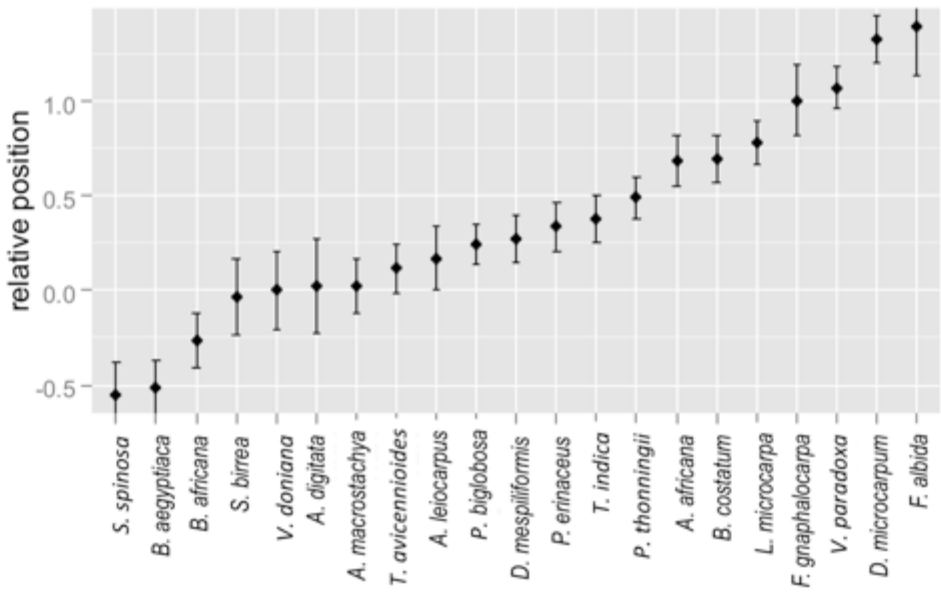


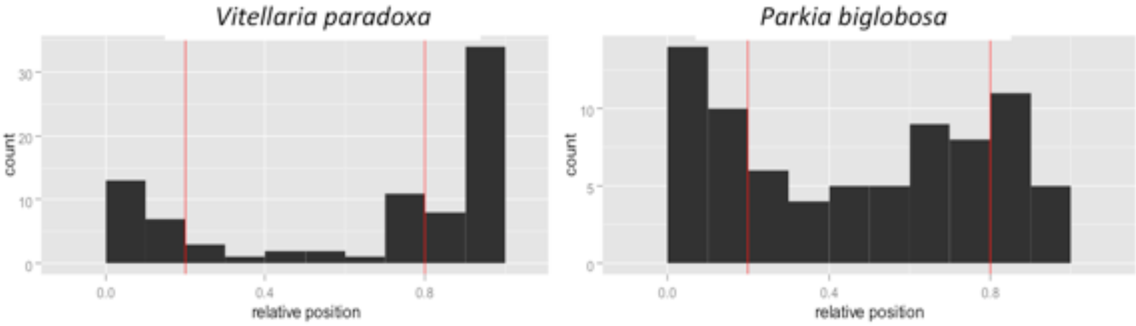
Figure 4.3 Trees ranked against leaf litter benefits to soil fertility (from least to most) in Ziro province in Burkina Faso, West Africa

Table 4.3 Variations in tree ranking against leaf litter benefits to soil fertility between farmers of different origins (native farmers n=47 and migrant farmers n=73) in Ziro province in Burkina Faso, West Africa

Native farmers			Migrant farmers		
Rank	Species	Estimates	Rank	Species	Estimates
1	*F. albida*	1,74	1	*D. microcarpum*	1,05
2	*D. microcarpum*	1,43	2	*F. albida*	0,90
3	*F. gnafalocarpa*	1,23	3	*V. paradoxa*	0,76
4	*V. paradoxa*	1,20	4	*F. gnafalocarpa*	0,63
5	*T. indica*	0,99	5	*L. microcarpa*	0,48
6	*L. microcarpa*	0,91	6	*B. costatum*	0,47
7	*P. erinaceus*	0,88	7	*A. africana*	0,39
8	*A. africana*	0,78	8	*P. thonningii*	0,13
9	*D. mespiliformis*	0,72	9	*B. aegyptiaca*	-0,86
10	*A. leiocarpus*	0,72	10	*S. spinosa*	-0,65
11	*P. thonningii*	0,69	11	*B. africana*	-0,64
12	*B. costatum*	0,69	12	*S. birrea*	-0,57
13	*P. biglobosa*	0,45	13	*A. leiocarpus*	-0,35
14	*S. birrea*	0,36	14	*A. macrostachya*	-0,30
15	*A. macrostachya*	0,20	15	*P. erinaceus*	-0,29
16	*T. avicennioides*	0,10	16	*D. mespiliformis*	-0,24
17	***V. doniana***	**0,00**	17	*T. indica*	-0,24
18	*B. africana*	-0,03	18	*P. biglobosa*	-0,12
19	*A. digitata*	-0,10	19	*T. avicennioides*	-0,09
20	*B. aegyptiaca*	-0,35	20	*A. digitata*	-0,01
21	*S. spinosa*	-0,67	21	***V. doniana***	**0**

4.3.4. Conflicting knowledge on soil fertility

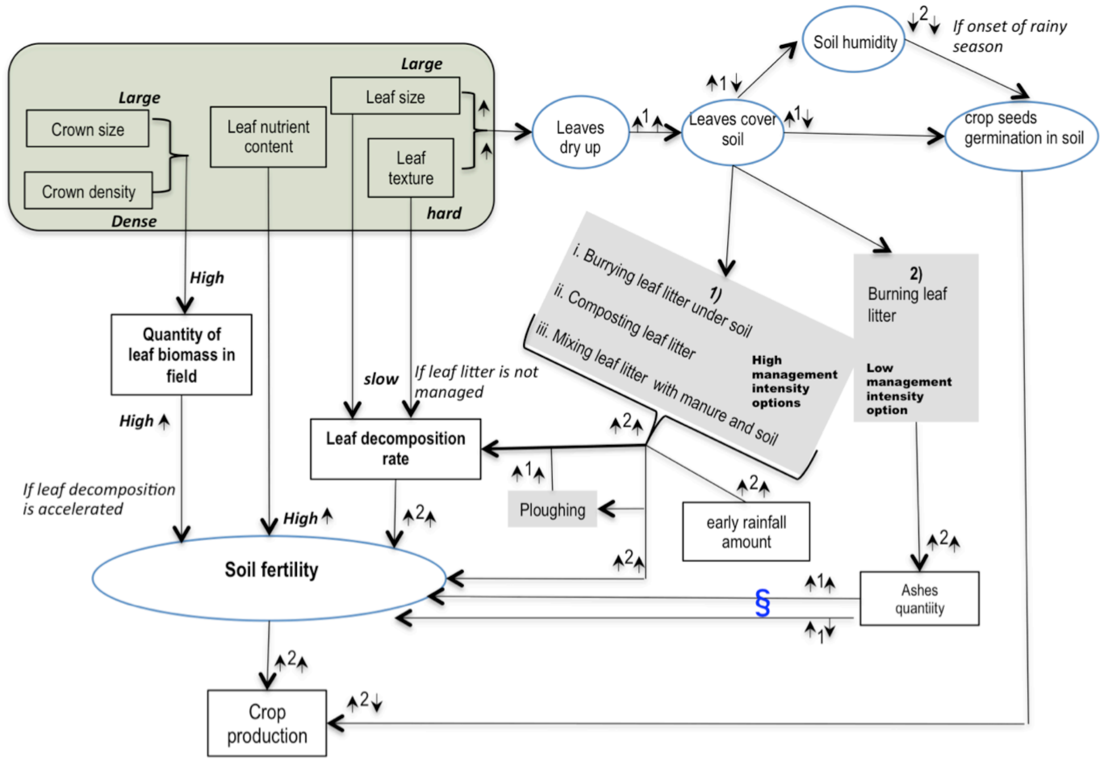
During the ranking survey, the researchers noted polarised ranking of two species *V. paradoxa* and *P. biglobosa* that each appeared to be ranked on both opposite ends of the spectrum by different farmers in respect of the contribution their litter made to soil fertility. This prompted further investigation into the apparent conflict in knowledge about these species. The 'relative position' of *V. paradoxa* and *P. biglobosa* was calculated for farmers who ranked the species against at least five other species in terms of the contribution of their leaf litter made to soil fertility (Figure 4.4). The histograms show evidence of bi-polarity in the relative position of *V. paradoxa* and *P. biglobosa* rankings; that is, that there are some farmers who ranked them high and some who ranked them low but fewer who placed them in the middle).



A relative position of near 1 means it is ranked near the top of those species compared. A relative position of near zero means it is ranked near the bottom

Figure 4.4 Histograms of the relative positions of *Vitellaria paradoxa* and *Parkia biglobosa* in farmers' ranking for soil fertility contribution in Ziro province in Burkina Faso, West Africa

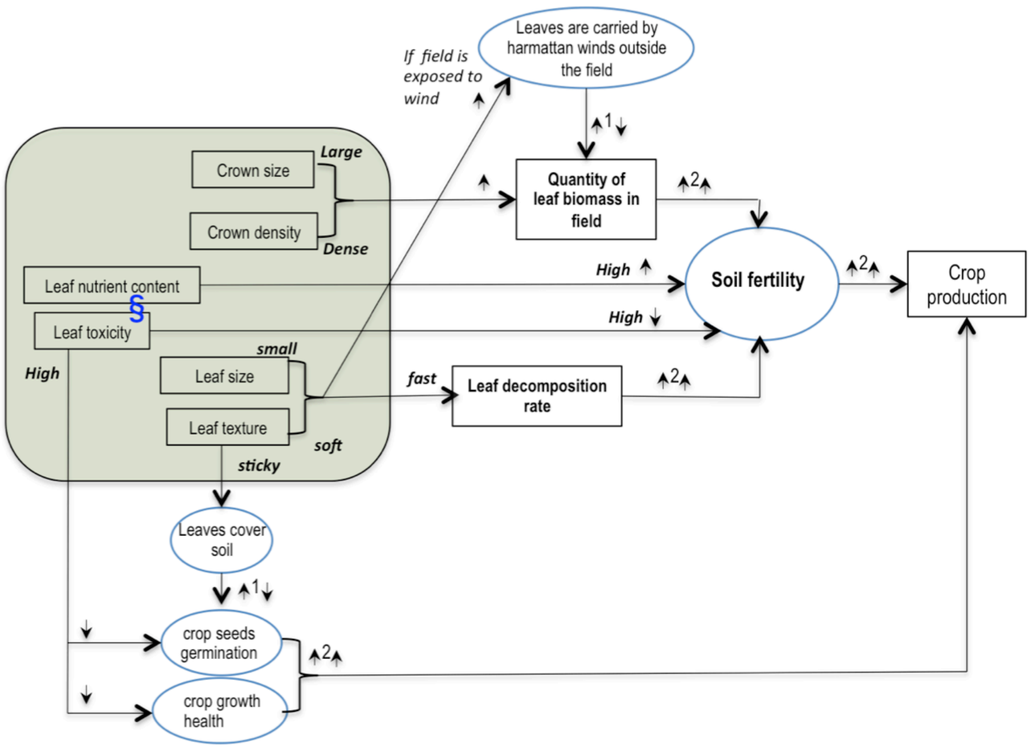
Local explanatory knowledge elicited around *V. paradoxa* shows that farmers agreed on the expression of specific tree attributes that influenced how leaf litter contributed to soil fertility, such as the abundance of leaf biomass it generated and the nutrient quality of its leaves (Figure 4.5). There was also a consensus that leaves were both large in size and hard in texture and hence slow at decomposing (taking often more than a year). In the absence of deliberate management, leaf litter could have a negative impact on crop production because it might inhibit crop seed germination either by not allowing rainwater to reach the soil at the onset of the rainy season or by physically obstructing seeds. Farmers who ranked the species high against other trees also mentioned that they used management options to accelerate the decomposition of its leaf litter, either by burying leaf litter, mixing it with soil and manure or by adding it to compost pits. Some farmers considered burning to be the most effective way of managing it, but there were differences in opinions on the impacts of burning on soil fertility, which some farmers said led to soil degradation. So the negative impact of untreated litter on crop production appears to be the major reason for the polarity in ranking with people not managing litter considering *V. paradoxa* of low value to soil fertility but those who used management practices to accelerate decomposition considering it to have a high value.



Nodes represent human actions (grey boxes), natural processes (ovals), or attributes of objects, processes or actions (boxes with straight 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 to the same for 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. (see Walker and Sinclair, 1998 for an explanation of diagrammatic syntax and it's relation to knowledge representation). Conditions are expressed in italics, § denotes conflicting knowledge on a causal effect. Specific tree attributes are highlighted in the green-shaded box.

Figure 4.5 Diagrammatic representation of farmers' causal knowledge about the effect of Vitellaria paradoxa leaf litter on soil fertility and crop production in Ziro province in Burkina Faso, West Africa.

In contrast, local knowledge about *P. biglobosa* showed stronger differences amongst farmers with regards to leaf nutrient content and toxicity than found with *V. paradoxa* (Figure 4.6). Thirteen farmers mentioned that the leaf litter was poisonous and inhibited seed germination and healthy crop growth, whilst a similar number of others considered the leaf litter to be highly enriching (14 farmers). Five farmers mentioned the leaf litter was so sticky it prevented seed germination. Other factors influencing differences in farmers perceptions were the quantity of leaf biomass available with five farmers mentioned it was blown by the harmattan wind outside their field and they didn't benefit from its fertilising effect, and this effect was enhanced by environmental factors such as the level of exposure to wind, which they said was related to tree cover in the vicinity.



See figure 4.5 for legend

Figure 4.6 Diagrammatic representation of farmers' causal knowledge about the effect of *Parkia biglobosa's* leaf litter on soil fertility and crop production in Ziro province in Burkina Faso, West Africa

4.3.5. Farmers' knowledge of factors influencing tree species' contribution to soil fertility

Explanatory information underpinning farmers' overall ranking of all species shows that the extent to which different species contributed to soil fertility was influenced by three key attributes: leaf nutrient quality, quantity of leaf biomass and rate of leaf decomposition (Figure 4.7). Whilst the first related to a fundamental leaf physical property, the other two were composite attributes and related to the outcome of a combination of crown (e.g. spread and density) and leaf related physical attributes (e.g. size and texture), heavily influenced by contextual variables such as human actions and environmental conditions. There was a consensus amongst farmers that over half of the species ranked (13) and in particular *F. albida*, *D. microcarpum, A. africana, B. costatum, L. microcarpa* and *A. digitata* had leaves that were highly rich in nutrients (Table 4.4.). There were differences in opinions regarding four species. Thirteen farmers described *P. biglobosa* 's litter as allelopathic (i.e. poisonous) and five described *T.*

indica and *A. leiocarpus* as having acidic litter or a high content in potassium and three farmers mentioned having observed this negative litter with *V. doniana*.

The quantity of leaf litter available was said to depend not only on the crown size and density about which there was a consensus amongst farmers (Appendix 4.5) but also on leaf phenology and leaf use as food or feed. Trees like *B. costatum*, *L. microcarpa* and A. *macrostachya* loose most of their leaves before January (start of the intense harmattan wind period) and have their leaf litter carried away from their field especially when these are particularly exposed to wind (little tree cover).

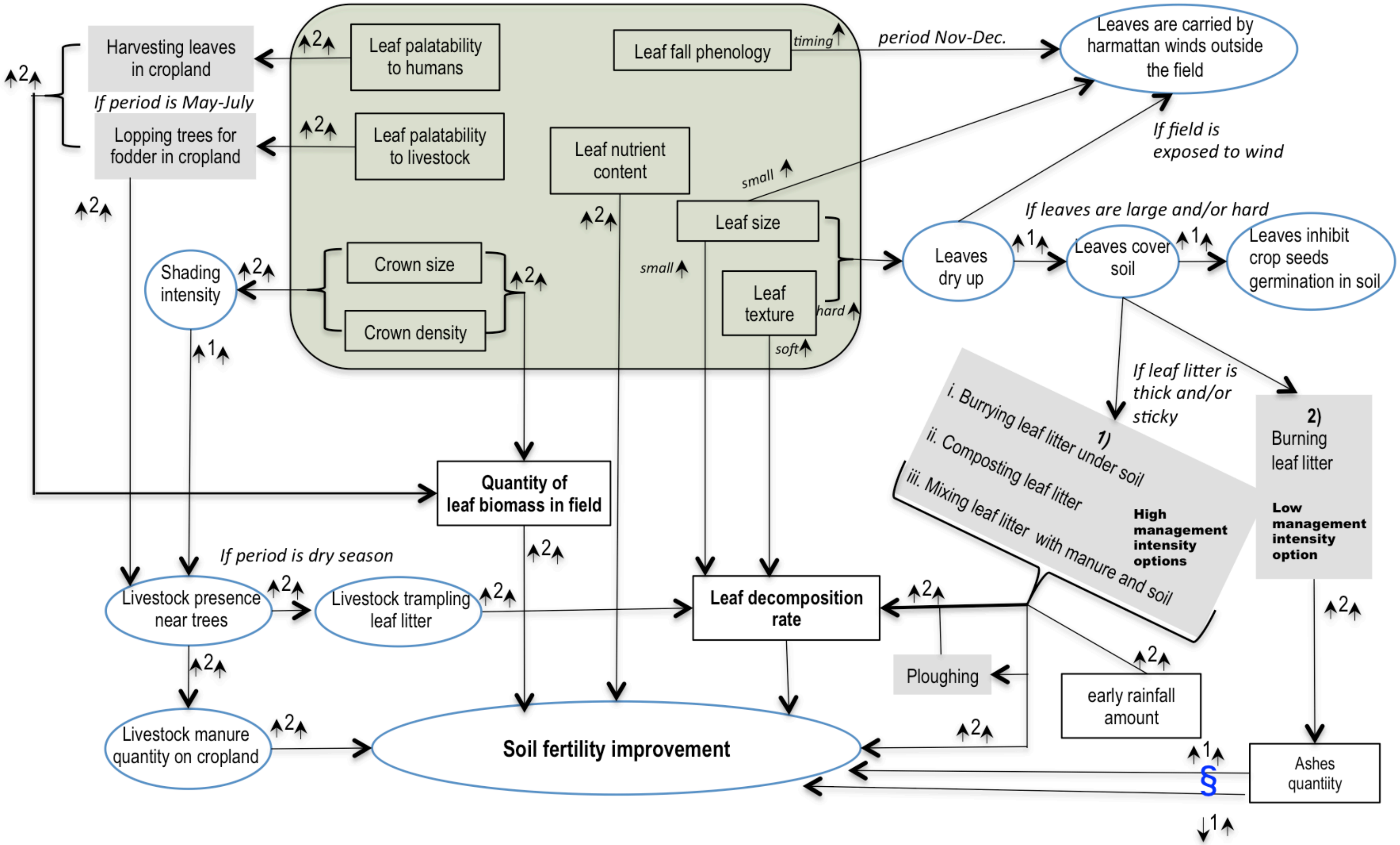


Figure 4.7. Diagrammatic representation of farmers' causal knowledge about the factors influencing the contribution of trees to soil fertility in Ziro province in Burkina Faso, West Africa

Table 4.4 Farmers' classification of tree attributes influencing leaf litter contribution to soil fertility in Ziro province in Burkina Faso, West Africa **Farmers' classification of tree attributes influencing leaf litter contribution to soil fertility in Ziro province in Burkina Faso, West Africa**

Scientific name	Categories of tree attributes described by farmers							
	Leaf litter quality		**Decomposition speed**		**Biomass quantity**			
	High leaf nutrient content	Allelopathy	Small and/or soft leaves	Large and/or hard leaves	Large and dense crowns	Removal of foliage for food or fodder	Biomass provided by natural regeneration	Early leaf fall
Acacia macrostachya	x		x					x
Adansonia digitata	x		x		x	x		
Afzelia africana	x		x		x	x		
Anogeissus leiocarpus		x	x					
Balanites aegyptiaca			x			x		
Bombax costatum	x		x					x
Burkea africana			x					x
Detarium microcarpum	x		x				x	
Diospyros mespiliformis	x			x				
Faidherdia albida	x		x			x		
Ficus gnaphalocarpa				x	x			
Lannea microcarpa	x		x		x			x
Parkia biglobosa	x	x	x		x			
Piliostigma thonningii	x			x			x	
Pterocarpus erinaceus	x		x			x		
Sclerocarya birrea			x					
Strychnos spinosa			x			x		
Tamarindus indica		x	x		x	x		x
Terminalia avicennioides				x				
Vitellaria paradoxa	x			x	x			
Vitex doniana	x	x	x			x		

Farmers explained that both leaf texture and size determine their decomposition rate and grouped trees into two categories 1) those with soft and/or small leaves decomposing fast, typically leguminous species but also *S. birrea, S. spinosa* as well as *A. digitata* and *B. costatum* and 2) those with large and/or hard leaves that take a long time (often more than a season) to decompose like *V. paradoxa, Terminalia avicennoides, F. gnaphalocarpa* and *P. thonningii.* There was a consensus that trees with large and /or hard leaves, as described above for *V. paradoxa* required some form of purposive management to avoid the litter sticking to the soil thus preventing crop seeds from germinating either because of lack of water permeating the soil or because of the thick layer of litter prevented seedling emergence. Management options aim at accelerating leaf decomposition rate and ensuring faster return of nutrients for better crop production. An indirect but important effect of trees mentioned by farmers was linked to the presence of livestock in fields either because of the shade intensity or because they were palatable trees that were lopped and fed to livestock *in situ*. The added manure and trampling of leaf litter were said to be beneficial to soil fertility and this influenced the ranking provided by farmers. There was no significant different between the management practices farmers of different origins were using in their fields with the exception of chemical fertiliser used by 91% of native farmers and 72% of migrants and over 85% had access to ploughing (Appendix 4.6). Roughly 65% of farmers were burning some residues when preparing their fields. Over a third of farmers (regardless of their origin) were not practicing any burning and were only burying crop residues and tree litter, compost pits were present on about 40% of farms.

4.4. DISCUSSION

4.4.1. Species diversity fosters inclusive options for farmers

Despite increasing degradation of tree resources in the Cassou and Gao districts of the Ziro Province in centre-west Burkina Faso (Etongo et al., 2015b; Ouedraogo et al., 2015), and the low species richness now present in cropland (Dayamba et al., 2015), where *Vitellaria paradoxa* largely dominates (Valbuena et al., 2016), farmers across the study area were managing a diversity of multi-purpose indigenous trees about which they had detailed knowledge, regardless of whether they were native or migrant farmers. The present research focussed on 21 native tree species, which, while far from exhaustive in terms of trees utilised across the landscape, is sufficient to provide key insights about local knowledge and its link to farmer practices. Farmers were actively managing from 7 to all of the 21 species, with a mean of 14.95. Four fruit tree species (*V. paradoxa, Parkia biglobosa, Tamarindus indica and Bombax costatum)* were considered more economically valuable than others, regardless of farmer gender or origin and these trees were present on at least 80% of farms. This is consistent with previous reports of parkland management that cite a few valuable species being retained on cropland when fallow plots are cleared (Boffa 1999; Augusseau 2006). A complementary finding of the present research is that there was a wider range of tree species providing income to different stakeholders at different times of the year, thereby contributing to the stability and resilience of livelihoods. Women, for example, were involved in the sale of tree leaves for human consumption at the onset of the rainy season from *A. africana, Adansonia digitata, Balanites aegeptiaca* and *Strychnos spinosa*. Sales of firewood from *B africana, Detarium microcarpum* and *A. leiocarpus* found on-farm and in the community forests provided dry season income for both men and women. Migrant women were involved in processing *B. aegeptiaca* nuts into soap and hence ranked the species as comparatively higher in economic value than did other people, whilst native farmers ranked *S. spinosa* higher than did non-native farmers because they were involved in the sale of its fresh leaves. This indicates that a diversity of species may be associated with meeting the diverse needs of a diversity of people, who have different knowledge, opportunities and constraints in using tree resources.

It is clear that the use of trees in the area reflects a tight coupling of social and ecological factors. Tree resources found in parklands (whether used for timber or non-timber products) often act as safety nets against food shortages, especially for women, and their coping strategies depend on their access to resources, which is mediated by the structure of the landscape (Koffi et al., 2016; Ouédraogo et al., 2017). Migrant farmers considered *P. biglobosa* high in economic value, but ranked it lower than they did some other species because they had limited access rights to trees on cropland, as these are granted instead to spouses of native landowners. Efforts to plant or assist the regeneration of *P. biglobosa* were hindered by insecure tenure (Etongo et al., 2015a). Fruits and leaves of *A. digitata* were considered a highly valuable income source (ranked fifth overall), but it was only growing in a third of farmer's fields, which may explain the particular interest in planting the species (*ibid*). Several farmers said that they had tried to plant *A. digitata* seedlings but none had survived because of water stress or bushfires. In addition to provisioning services (food, fodder, energy, medicine and timber), trees also contribute to important regulating functions, such as enhancing and maintaining soil fertility through nutrient cycling via their leaf litter (Bayala et al., 2014), and this was recognised locally by the majority of farmers we interviewed. A comparison of the ranking of trees for economic value and for soil fertility benefits reveals clear differences between those trees considered of high economic value because of their products, and those that contributed most to soil fertility. However, local knowledge acquisition was key to understanding the clear connections between local practices (e.g. harvesting foliage and thus reducing biomass quantity available for mulching), and prioritisation of leaf biomass for other purposes, which would influence how the tree was ultimately perceived to contribute to soil fertility. The understanding of the socio-ecological context elicited from farmers suggests that pathways to simultaneously enhance complementary livelihood and environmental functions from a range of trees can translate into distinct opportunities for managing different species, which match with the different landscape conditions and farmers' needs.

4.4.2. Conflicting, complementary and new knowledge about impacts of trees on soil fertility

Whilst farmers found it easy to rank trees according to economic value, and generally agreed about the relative positions of different species, asking farmers to evaluate soil fertility benefits of different tree species triggered very animated and rich discussion. There was consensus about the top two species *Faidherbia albida* and *D. microcarpum,* but divergence in the assessment of the relative contribution many of the other species made to soil fertility.

4.4.2.1. Consensus about highly ranked species

That *F. albida* is highly ranked by farmers is consistent with it being a Nitrogen-fixing tree with reverse phenology, which results in it having few or no leaves when herbaceous crops are at key growth stages (Boffa, 1999). But only a small proportion of farmers, less than 20%, had it in their fields and reported that it was mostly found in riparian areas near ‘old fields’ and around native farmers’ settlements, with no regeneration elsewhere. Considerable enthusiasm has been generated around the potential for *F. albida* to enhance soil fertility as a component of conservation agriculture or farmer-managed natural regeneration (FMNR) (Garrity et al., 2010). However, in addition to its slow growth (15 to 30 years to obtain full benefits), *F. albida* appears to occupy an ecological niche specialised around riparian areas, the presence of groundwater and/or alluvial soils (Wood, 1992; Boffa, 1999), and this limits the extent to which it can be successfully promoted at scale across different contexts (Umar et al., 2013). The fact that *D. microcarpum* was ranked consistently very highly compared with all other species is much more of a surprise because little information is available on this tree. It was one of the species found most commonly regenerating in fields from rootstock, and farmers ranked it as having the fastest growth rates after coppicing compared with others. Alongside *P. thoninghii*, which exhibited similar regeneration patterns, it was the only species purposefully managed for mulch, albeit by a minority of farmers. This was done by annually coppicing the regenerating branches and leaving twigs and leaves on the soil to decompose and thus enhance soil fertility. This innovative ‘slash and mulch’ practice has been recently documented elsewhere in Burkina Faso, where findings confirm that the annual coppicing of shrubby vegetation for mulching can have a significant and positive impact on cereal production (Yélémou et al., 2013; Felix et al., 2015). FMNR is generally considered to involve ‘protecting and nurturing wildlings to maturity’ (Reij & Garrity, 2016), but perceptions of competition of mature trees with crops, especially for species that are not economically valued, may limit adoption (Binam et al., 2015). In contrast, managing shrubs for mulch offers significant opportunities for restoring land by utilising rootstock available in the soil and perhaps deserves more attention with respect to scaling-up adoption. Including *D. microcarpum* in eco-physiological research to expand the knowledge underpinning slash and mulch practices that has been so far been largely confined to *Piliostigma* spp. and *Guiera senegalensis (*Dossa et al., 2013). *Detarium microcarpum* has a wide ecological spread and well-known socio-economic importance across the Sudanian parklands (Wiersum and Sinlerland 1997) so understanding its potential for contributing to soil fertility maintenance and improvement would be important and merited.

4.4.2.2. Conflicting knowledge reveals context dependence of soil fertility benefits from some species

Farmers in the tropical highlands of Rwanda, who all practiced mulching their coffee with tree leaf litter, consistently agreed on the respective contribution that different species made to soil fertility (Smith Dumont et al, in press). On the contrary, there were polarised assessments about the contribution that some common trees made to soil fertility amongst the parkland farmers in Burkina Faso in the present research, particularly notable for *V. paradoxa and P. biglobosa* with some farmers ranking them highly and others putting them towards the bottom of the list. ‘Soil fertility benefit’ is a composite attribute that combines leaf nutrient content, the quantity of leaf biomass produced and leaf decomposition rates. The Burkinabe farmers agreed on the ranking of tree species for these fundamental attributes, which correspond to plant traits, but there were large differences in how they ranked the composite soil fertility attribute. Looking at the two species for which there were polarized perceptions we found that it for *V. paradoxa* management practices only used by some farmers that accelerated leaf decomposition positively influenced their perceptions and for *P. biglobosa* it could be related to phenotypic differences in chemical composition of leaves. Farmers’ opinions are in agreement with available scientific knowledge. The two species have different crown shapes and leaf types (Hall et al., 1996, 1997). The composite type of the leaves of *P. biglobosa* and their higher content in nitrogen lead to an evenly spread of the small leaflets under the tree and to a faster decomposition of its litter litter. In turn, the upright canopy shape allows wind to carry away the broad leaves of *V. paradoxa* and accumulate them in heaps in the Western direction and their lower content in nitrogen is associated with slower decomposition rate (Bayala et al., 2003, 2005). It is therefore understandable that farmers seek for ways either thermal (burning) or non-thermal (burying or composting) for the broad-leaved litter of *V. paradoxa*. In a decomposing experiment, Bayala et al., (2005) found that burying accelerated the decomposition rate for this species. In turn, small-leafed mulch of *P. biglobosa* decomposed faster even without being buried in the soil (though practicing the latter was also found to speed the decomposition). Because both species were found to have limited contribution to soil nitrogen content within a single cropping season (Bayala et al., 2003, Gnankambary et al., 2008), the only chemical benefit that can be expected is through their contribution in carbon content (Bayala et al., 2006). Burning practices have been shown in some cases to increase the immediate nutrient availability to plants and reduce litter shading in the short term but generally lead to soil nutrient depletion and land degradation in the long term (Breman & Kessler, 2012). Furthermore burning the *V. paradoxa* litter is a waste of biomass capital compared to the benefits that can be gained by farmers using non-thermal practices in increasing their soil carbon content and soil biota (Barrios et al. 2012). Moreover, incorporating tree litter into the soil enables its transformation into soil carbon that is critical for the environment (less CO_2 emitted in the atmosphere) and the sustainability of the cropping systems particularly in region like our study area with kaolinite as the main type of clay in the soils (Bayala et al., 2006).

The difference between farmers' perceptions about the soil nutrient versus toxic content of *P. biglobosa* 's leaf litter remains harder to elucidate and requires further investigation. The potential allelopathy associated with *P. biglobosa* mentioned by the farmers was investigated by Bayala et al., (2003) in a laboratory experiment, where germination of sorghum seeds were treated with leaf leachate but the results were not conclusive. Such results might due to the fact allelopathy is mediated by soil in the real world (Inderjit & Keating 1999) but also a confusion with the shade depressive effect on crops under *P. biglobosa* (Bayala et al., 2013, 2015). Another major contextual factor influencing perceptions of different species was farmers' prioritisation of leaves for livestock or human consumption most often harvested at the onset of the rainy season thereby reducing the quantity of leaf biomass available. So if farmers once again agreed on fundamental traits (related to leaf and crown), foliage harvesting practices influenced the perception of the tree's overall contribution to soil fertility explaining why *A. digitata*, *S. spinosa* and *B. ageptiaca* would be ranked lower than other species since a large part of their leaf biomass is harvested. *A. digitiata* has been generally considered to contribute to soil fertility (Rhoades 1996; Faye et al.,

2011) including in the Ziro province (Etongo et al., 2015a) and farmers agreed that the leaf quality was high (and so were the decomposing fibre of branches) but ranked it low since its leaves are intensively lopped. Little scientific information is available on both other species but farmers' negative perception could also be compounded by the small size of both trees and the thorns they bear mentioned during interviews. It should also highlighted that tree contribution to soil fertility is not only from leaf litter but also from other parts of the tree such as fruits and fine root decay as well as through the transfer of fertility through livestock visiting fodder species (Bayala et al., 2014). Other contextual factors, such as tree genetic diversity, soil types and soil biota as well as land use history were not covered in this study but could also explain differences in farmers' perceptions (Bayala et al., 2011).

4.4.3. Implications for parkland management

Analysis of land cover change over the last fifteen years in the Cassou and Gao district shows that gallery forest and wood savannah are highly exposed to the transition to shrub savannah in a context where availability of cropland is saturated and land degradation is increasing (Ouedraogo et al., 2015). This supports the case that tree improvement options and the development of specialized agroforestry niches need to be tailored to the shift towards permanent and intensified agroforestry systems in Sudanian parklands (Augusseau et al., 2006). Governmental and non-governmental institutions had been promoting tree planting in our research area with a handful of species, mostly exotic and with limited uptake as a result of "mismatch between species promoted by projects and those preferred by farmers" (Etongo et al., 2015a). But farmers' knowledge confirms that there are distinct opportunities for different types of farmers and in different parts of the landscape (e.g. native farmers on riparian land and migrant farmers on degraded shrubland). So in order to move beyond silver-bullet prescriptions based on prioritisation, which continue to dominate the tree planting or agroforestry development and research agenda in West Africa (Faye et al., 2011), we can build on local knowledge to recommend set of species and management options fit to different farmers' preferences, resource endowment and agro-ecological conditions. Maximising soil fertility and economic returns from *V. paradoxa* and other fruit trees could entail promoting leaf litter management recommendations combined with improved tree management techniques such as pruning to reduce competition with crops and grafting and ensure better returns from products (Bayala et al., 2014). The differences in knowledge between farmers on these practices could be used to enhance farmer-to-farmer learning through exchange field visits. By demonstrating non-thermal ways to accelerate leaf litter (and crop residues) decomposition farmers could be offered alternative options to stop burning potentially useful biomass whilst minimising negative interference with tillage and planting operations (Diedhiou et al., 2009). Capturing the benefits of regenerating shrubs through slash and mulch techniques could be another important strategy for improving soil health and will be based on the available regeneration rootstock but requires more knowledge dissemination of new knowledge and scientific knowledge (Sanou et al., 2017).

4.4.4. The utility of farmer ranking

Using ranking to collect farmers' knowledge of tree attributes and functions has been shown to be an effective and fast way to collect information about a range of trees managed by coffee farmers in tropical highlands and this was particularly valuable because there is little scientific information available on most species (Lamond et al 2016; Gram et al., 2017). Here we tested this method in the West African parklands, a very different agro-ecological context than intensive cash crop coffee farming in tropical highlands. We found that while Burkinabe farmers were also able to consistently rank trees for fundamental ecological and economic attributes, there was polarisation in ranking of some composite attributes that affect the utility of tree. It is important to be able to identify this polarity, which is not immediately apparent from summarised results (such as Figure 4.3.). Thus it needs to be tested for which can be done by simply looking at distributions of rank positions (as shown in Figure 4.5.). Where there is consistent polarisation, it is then productive to look at whether contextual factors associated with different farmers can explain consistent differences in their assessment of attributes for particular species. In our study we found conflicting knowledge to be linked to the conditionality of the environment as well as management practices for composite attributes important in agroforestry like soil fertility benefit of leaf litter. The subjectivity around composite attributes in agroforestry management has been already highlighted in the ranking done with Rwandese coffee farmers (Smith Dumont et al., in press). We were able to tease out some of the fine scale contextual elements underpinning differences in perceptions because the researchers who conducted the survey were experienced in systematic local knowledge acquisition and combined ranking with the compilation of agro-ecological knowledge bases (Sinclair & Walker, 1999). While ranking produced results that are more complex to numerically analyse, we find it an easier and more consistent way to collect information from farmers than scoring which tends to be idiosyncratic as there is less ambiguity about putting things in order of magnitude than giving them relative scores. The co-variation analysis that was included in this study is an important development to the method that makes it possible to test differences amongst stakeholders and will add significant depth to the understanding of contextual variations amongst stakeholders, locations or practices.

4.5. CONCLUSION

Our findings confirm that using a participatory ranking survey that focuses on tree attributes enables the quick collection of valuable knowledge about a range of woody parkland species, which is complementary to available scientific information. This is particularly important because knowledge of the interactions of trees with crops in parkland systems is scant and difficult to extrapolate from when developing recommendations for improving tree-based systems (Bayala et al, 2015). The Burkinabe farmers agreed on the ranking of tree species for fundamental attributes, which correspond to plant traits, but there were large differences in how they ranked the attribute of composite soil fertility. Their decisions were influenced by either prioritisation in the uses of leaves for household needs reducing available biomass, or by how they actively managed leaf litter to accelerate decomposition rates and thus prevented negative interactions with crop seed germination, in the case of broad-leaved species. The contextual influence on species variations in leaf biomass quantity and leaf decomposition rate have been highlighted before, but our study provides new information about a suite of trees and suggests ways that their management can be improved to enhance soil fertility benefits. The spatial variations in species' occurrence in the landscape and in their uses by different people showed a tight coupling of socio-ecological factors, which can be translated into distinct opportunities for adapting and improving the delivery of products and services from a diversity of trees. We found the acquisition of local knowledge to be a robust starting point for informing actions for development and for future research for co-designing agroforestry options that are context sensitive because they are tailored to different farmers' specific needs and conditions. The next steps would be to involve stakeholders in further testing and evaluating options to facilitate agroforestry projects/programmes, which would be accompanied by the dissemination of context-appropriate knowledge that builds on local and scientific knowledge. This could involve the use of on-farm trials through planned comparisons, which would be embedded in participatory action research processes that build evidence and refine tree-based options, as we gain a more solid understanding of the heterogeneity in the effects of different management practices for trees in parkland systems.

5. STRUCTURED STAKEHOLDER ENGAGEMENT LEADS TO DEVELOPMENT OF MORE DIVERSE AND INCLUSIVE AGROFORESTRY OPTIONS

ABSTRACT

There is a lot of interest in the contribution that agroforestry can make to reverse land degradation and create resilient multifunctional landscapes that provide a range of socio-economic benefits. The agroforestry research agenda has been characterized by approaches that promote a few priority tree species, within a restricted set of technological packages. These have often not spread widely beyond project sites because they fail to take account of fine scale variation in farmer circumstances. New methods are needed to generate diverse sets of agroforestry options that can reconcile production and conservation objectives and embrace varying local conditions across large scaling domains. Here, we document a novel approach that couples local knowledge acquisition with structured stakeholder engagement to build an inclusive way of designing agroforestry options. We applied this approach in the eastern part of the Democratic Republic of Congo (DRC) where armed conflict, erratic governance and poverty have resulted in severe pressure on forests in the Virunga National Park, a global biodiversity hotspot. Around the park, natural resources and land are severely degraded whilst most reforestation interventions have consisted of exotic monocultures dominated by *Eucalyptus* species grown as energy or timber woodlots mainly by male farmers with sufficient land to allocate some exclusively to trees. We found that structured stakeholder engagement led to a quick identification of a much greater diversity of trees (more than 70 species) to be recommended for use within varied field, farm and landscape niches, serving the interests of a much greater diversity of people, including women and marginalized groups. The process also identified key interventions to improve the enabling environment required to scale up adoption of agroforestry. These included improving access to quality tree planting material, capacity strengthening within the largely non-governmental extension system, and collective action to support value capture from agroforestry products, through processing and market interventions. Integrating local and global scientific knowledge, coupled with facilitating broad-based stakeholder participation, resulted in shifting from reliance on a few priority tree species to promoting tree diversity across the Virunga landscape, that could underpin more productive and resilient livelihoods. The approach is relevant for scaling up agroforestry more generally.

Key words: tree selection, local knowledge, stakeholders, tree diversity, participatory methods

5.1. INTRODUCTION

The current global environmental crisis is leading to calls for new strategies to sustainably manage agricultural landscapes so that they can provide a more balanced set of provisioning, regulating, supporting and cultural ecosystem services (MA, 2005). Land use systems that promote multi-functionality, such as agroforestry, are seen as potential vehicles to deliver resilience at landscape scale, and play an important role in the ecological restoration of degraded land (Mbow et al., 2014a). Farmers make decisions about land use change locally and the factors influencing their decisions are largely context specific, determined by a complex mix of biophysical and socio-ecological conditions, as well as by the enabling policy and institutional environment (Coe et al., 2014). Most agroforestry development and research projects have, in the past, focused on promoting prescriptive technology packages, such as improved fallows, alley cropping or fodder banks (Pollini, 2009) whilst tree selection has been largely based on prioritization of a few selected species for domestication or promotion (Franzel, 1996). Despite the promise of agroforestry technologies, reviews of adoption have highlighted their often-limited spread beyond project sites (Meijer et al., 2015). Where adoption has been widespread, it has often been restricted to a narrow group of stakeholders, such as those with higher resource endowment and secure land tenure. Women, for example, have frequently been less likely to utilize agroforestry technologies, limiting the socio-economic benefits that are realised (Kiptot & Franzel, 2012). A separate but related issue is that agroforestry and reforestation projects in Africa have often led to the promotion of a few largely exotic tree species (Ashley et al., 2006). This can have detrimental impacts on biodiversity and contributes to ever more simplified agroecosystems (Harvey et al., 2011). This is especially critical in areas around protected tropical forest (DeFries et al., 2007).

There are now calls for different approaches to agroforestry promotion that go beyond prescriptive ‘one size fits all’ agroforestry technology designs, that promote only a few iconic agroforestry tree species (Coe et al., 2014). It is argued that more diverse and adaptable technology options will be adopted by more people and deliver greater benefits both to smallholder livelihoods and to ecosystem health (Franzel et al. 2001). Tree management options that can be locally adapted to fine scale variation in both ecological and socio-economic context are likely to spread further and faster than less flexible prescriptions. The contextual variables that condition suitability of agroforestry options depend on which factors are important for a particular innovation to be adopted, and how much these factors vary across the geography of interest. Common ecological contextual variables that need to be considered include various soil parameters, altitude, climate and water availability while variations in socio-economic context such as, ethnic differences, gender roles, assets and access to markets are often important (Rubens et al., 2011; Coe et al., 2014). There is scope for new approaches to promoting agroforestry, that look at farming systems and landscapes more holistically than previously, in order to analyze variations in context and offer farmers a broader menu of agroforestry options suited to their different sets of needs and circumstances (Franzel et al 2001, German et al., 2006).

The objectives of the research reported here were to explore the extent to which greater involvement of stakeholders and their knowledge in designing agroforestry interventions would lead to more diverse and inclusive options being identified for promotion, together with developing an understanding of how the resulting options could be tailored to local context. We tried out this structured stakeholder engagement in the challenging context of the landscape around the Virunga National Park in the East of the Democratic Republic of Congo (DRC). This is a global biodiversity hotspot that has been subject to prolonged environmental degradation and conflict. Over the last three decades, there have been various reforestation initiatives attempting to promote tree planting to reduce the pressure on natural forests. These have focused on the promotion of energy woodlots, using a few fast growing exotic species, managed mostly by men who have large enough holdings to devote some land exclusively to trees (Lejeune et al., 2013). We adopted a participatory action research approach (Chevalier and Buckles, 2013), working closely with development and conservation partners, in particular the World Wide Fund for Nature (WWF), a key regional actor involved in promoting energy woodlots on farms since 1987.

5.2. METHODOLOGY

5.2.1. Site description

The Virunga National Park is located in North Kivu province in the East of the Democratic Republic of Congo stretching along the Ugandan and Rwandese borders at the heart of the Great lakes. It embraces a land area of 59 483 km^{-2} with a population estimated in 2015 as 6.655 million and belongs to the biodiversity hotspot of the Albertine rift (INS, 2015). The region is ecologically diverse, with altitude varying from 800 m in the equatorial forests and river plains to 2500 m in the

Afromontane forest zone with summits peaking above 5000 m in the Rwenzori glaciers with sharp gradients that have given rise to a wide range of habitat types including savannas as well as equatorial lowland and Afromontane forests (Plumptre et al., 2007). The province in general is endowed with fertile volcanic soils and a favorable tropical climate but with more pronounced ecological variation in the northern part of the province. Agriculture used to be the engine of a thriving economy with dynamic domestic and international trade in a range of food and industrial crops. This collapsed in the 1990s with the proliferation of local-level rebellions and international armed conflict causing a prolonged humanitarian and environmental crisis. In this densely populated part of the world, with an overall provincial average of 112 people km^{-2}, conflict has caused an increase in urbanization and markedly unequal access to farmland (INS, 2015; Jayne et al., 2014). The main land use around the park continues to be agriculture, involving annual and perennial crops as well as large cattle ranches. Current trends are towards increasing reliance on subsistence rather than commercial farming, loss of soil fertility and decreasing crop yields.

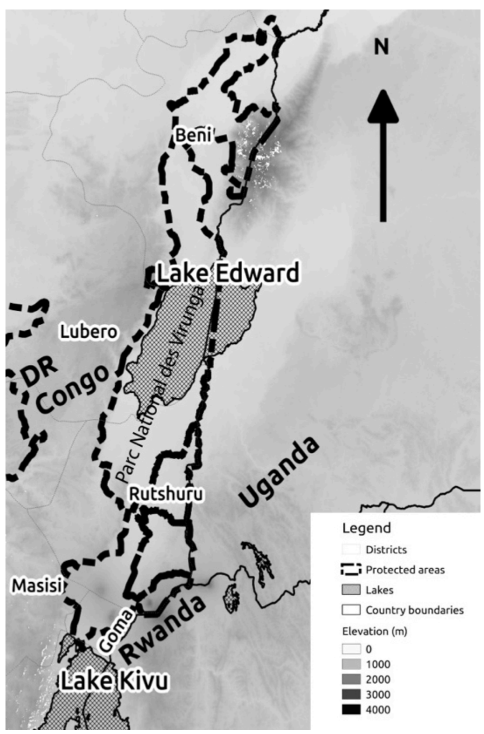


Figure 5.1 Map of the Virunga landscape in North-Kivu, Eastern DRC with elevation information and the Parc National des Virunga boundaries (map by B. Onkware

There are ethnic differences between the northern and southern parts of the study area. The Nande are the predominant ethnic group in the northern part around Beni and Lubero, whereas the southern part is more ethnically diverse and subject to severe civil conflicts between Hunde, Tembo and Nyanga communities and a large migrant population of Banyarwanda. Indigenous Batwa people have been displaced from protected forest areas, including the Virunga National Park and are a particularly marginalised group (Gilbert, 2013). Most communities are reliant for their survival on natural resources and especially protected forests, which are now under severe pressure because of illegal charcoal production (Lejeune et al., 2013). The baseline in terms of agroforestry development in the region, was a focus on promoting fast growing exotic tree species for the production of charcoal or timber in woodlots, largely dominated by the *Eucalyptus* genus but also including *Acacia mearnsii* and *Senna siamea* and to a lesser extent *Grevillea robusta* (LeJeune et al 2013), with a main aim of reducing pressure on resources from the Park. Our key conservation and development partner in the research was WWF who had been implementing the ECOmakala project that focused on woodlot promotion, for 7 years before the present research began

5.2.2. Local knowledge acquisition

Decision making about agroforestry at landscape scale in North-Kivu Province is hampered by sparse literature and data available about local agricultural and land use practices. In order to capture information about prevailing livelihood systems, tree management in various farm and landscape niches and farmers' knowledge and preferences relating to trees, two participatory scoping studies were conducted in the Lubero district in the north and the Masisi district in the south (Figure 5.1.). The aim was to elicit local knowledge about drivers of land use and land cover change as well as about agroforestry practices and the present and potential roles of trees in supporting people's livelihoods. Semi-structured interviews were conducted with 60 individual farmers (of which 22 were women) complemented by 10 focus group discussions with farmer association members and forestry technicians involving a further 85 people (25 of them women). These field studies were instrumental in enabling the facilitation of stakeholder workshops by researchers, because they provided a collective understanding of the prevailing land use and livelihood systems in the area and helped to build trust between researchers and other local stakeholders. Where appropriate, information from the scoping study was used to set up and structure discussion sessions in the subsequent multi-stakeholder design workshops.

Plate 5.1 Moise and Jean-Claude interviewing Batwa bee keepers, Nyaragongo, North-Kivu, DRC (E.smith)

5.2.3. Structured multi-stakeholder workshops

Two multi-stakeholder design workshops were organized, one in Goma (Plate 5.2.) covering the three districts in the southern part of the province (Masisi, Rutshuru and Nyaragongo) and the other in Butembo covering two districts in the northern part (Lubero and Beni) in October 2014. Participants were selected on the basis of their involvement and interest in tree planting in the region and included a diversity of interest groups with different types of knowledge (practical, technical and scientific). Many of the participants were drawn from those who had taken part in the earlier scoping studies. There were 25 participants in the Goma workshop (five of them women) and 38 in Butembo (eight of them women). They included technical staff and members of farmers' tree planting associations involved in the ECOmakala project, government extension agents, representatives of different farmers groups (herders, coffee growers, bee keepers) and women's community based organisations, and lecturers in local technical colleges and universities.

Plate 1.9 Gender discussion group developing agroforestry options during the multiple stakeholder workshop in Goma, DRC (E.Smith)

The objective of the workshop sessions was to explore agroforestry options potentially suitable for the different contexts found across the province. This was achieved by addressing four themes that each constituted a working group: 1) trees and crops, 2) trees and livestock, 3) trees and income and 4) trees and gender (which involved all the women participants). The main steps followed during the workshop were: i) an introduction led by the workshop facilitators which covered agroforestry practices around the world and presented results from the local knowledge acquisition activity in North Kivu; ii) identification by participants of a list of generic agroforestry practices with supplementary details of tree species, farm niche locations and spatial arrangements potentially involved in different locations; iii) assessment of opportunities and constraints to the adoption of these practices; and, iv) definition of actions to promote agroforestry locally and address barriers to adoption. Following this, we systematized and represented the contextual information affecting adoption of agroforestry practices including requirements for interventions to create a conducive enabling environment (Coe et al., 2014). Priority actions to address barriers to the adoption of promising agroforestry practices were then identified by participants.

5.2.4. Training and reflection

A technical manual incorporating agroforestry options suitable for different contexts across North Kivu was developed, incorporating findings from the design workshops, together with scientific knowledge about the tree species and agroforestry practices involved (Smith Dumont et al. 2015). This manual was used in training, involving 2 events with 58 participants (, that included WWF forestry outreach staff, technical staff from community-based organisations, governmental agents and local researchers over an 18 month period following the design workshops and culminating in a reflection workshop that sought to collate and reflect upon experiences of participants who had taken part in the structured stakeholder engagement. The workshop was held in Goma between the 21 and 23rd March 2016 March and brought together 46 people from the southern and northern parts of the province

5.3. RESULTS

5.3.1. Generic agroforestry practices

Three major types of land with different prospects for agroforestry were identified during the scoping as separate land use categories (Sinclair, 1999), within which trees may be integrated. These were cropland, pastures and homesteads, and they were used as an organising framework for discussing integration of trees in fields, on farms and across landscapes in the scoping study and stakeholder workshops. Fifteen generic types of agroforestry practice relevant to these different land use categories were identified during the workshops (Table 5.1). This variety reflects the diversity of needs and opportunities across North Kivu province. These practices were generic (in that they describe primarily the desired function). In our experience local actors will customise these agroforestry systems (by using different mixtures of trees) to better suit the ecological requirements of their location, embracing the altitudinal gradient across the province, as well as farmers' individual needs, endowments and preferences.

Table 5.1 Generic agroforestry practices identified in the two stakeholder workshops in North Kivu province

Generic agroforestry practice	Land use category	Remarks
Woodlot	cropland*, pastures, homestead	For timber, energy, bee keeping, medicine, and mushrooms. May be zoned (a separate larger area of woodlot >0.25 ha) or clumped (groups of trees <025 ha)
Live-fence	cropland, pastures, homestead	Generally multipurpose tree species.
Boundary planting of high value trees	cropland, pastures, homestead	
Fodder bank	cropland, pastures, homestead	May be clumped, on boundaries or along contours
Trees for veterinary or biopesticides	cropland, pastures, homestead	Only in the northern part of the province.
Scattered high value trees	cropland, pastures	Mainly for timber and fruit.
Improved fallow	cropland, pastures	
Trees for erosion control on slopes	cropland, pastures	In degraded zones and along contours or on terraces.
Trees for river bank stabilisation	cropland, pastures	
Scattered shade trees	cropland, pastures	On perennial cropland where the crop is coffee, cocoa or banana) may also be along boundaries
Trees for soil improvement	cropland, pastures	Generally multipurpose tree species. May be on bou or scattered / intercropped.
Windbreak	pastures	
Orchard	cropland	Mainly fruit trees with bee keeping.
Trees for condiments and food	homestead	Especially *Laurus nobilis* and *Moringa oleifera*
Medicinal trees	homestead	

**cropland includes both annual and perennial crops*

5.3.2. Tree species

During the workshops, stakeholders detailed 15 agroforestry technology options. Participants were able to associate a range of tree species with these agroforestry practices across a range of farm and landscape niches. These niches were more detailed than the land use categories described in Table 1 and provided more precise detail on the location of practices within farms. During the workshops 71 species of trees, shrubs and liana (Appendix 4.1) were identified as suitable for use in at least one of the generic agroforestry practices. Forty-four species were discussed during the South Virunga workshop and 57 in the Butembo workshop with 34 species common to both. Five of the 15 options developed by stakeholders illustrate not only the potential diversity of native and exotic trees they considered appropriate for each option, but also the range of farm niches and potential spatial arrangements, corresponding to different farm conditions and people's needs

(Table 5.2). Planting high value fruit trees, for example, is a key option to improve nutrition and income, and these can be integrated in several landscape and farm niches. Other options were more niche specific, such as integrating shade trees in coffee systems.

5.3.3. Options by context matrices

To understand contextual variables influencing adoption and scaling up of agroforestry options across the province, we compiled information relating to opportunities and constraints associated with the different options identified by participants into two matrices covering farm level (Table 5.3) and enabling environment (Table 5.4) contextual requirements, respectively. We present details for three of the five agroforestry options outlined in Table 5.2 to illustrate the results obtained when participants were asked to discuss the contextual relevance of different options. Workshop participants identified 13 contextual factors that were important in determining suitability of different options. These were classified by researchers into those operating at farm level (6), and those relating to the enabling environment, within which farms operate (7). These categories were found useful for structuring discussion but are to some extent subjective, and there are interactions amongst them. Land tenure for example is seen here to operate at a farm level, in as much as the tenure status of land affects what options farmers are prepared to practice on it, but tenure may also be affected by both formal (policy and institutions) and less formal (cultural) aspects of the enabling environment. Gender influences other contextual factors because of differential access to resources amongst men and women, but also directly influences choices of tree species and agroforestry options.

Table 5.2 Five locally specified agroforestry technology options for North Kivu province

Agroforestry option	Potential tree species	Generic agroforestry practices	Position in landscape
High value fruit trees to improve nutrition and income	NATIVE: *Annona senegalensis; Cola nitida; Syzigium spp.; Myrianthus* spp.- EXOTIC: *Averrhoa carambola; Carica papaya; Citrus spp.; Cyphomandra betacea; Eriobotrya japonica; Mangifeira indica; Morus alba; Passiflora spp.; Persea americana; Psidium guajava; Syzygium malaccen*se	Orchard Scattered high value trees Boundary planting of high value trees	Annual cropland Pastures Riverbanks Homestead Perennial cropland
Trees for soil fertility improvements and erosion control	NATIVE: *Albizia gummifera; Cordia abyssinica; Croton megalocarpus; Erythrina abyssinica; Ficus spp.; Maesopsis eminii; Maesa lanceolata; Markhamia lutea; Sesbania sesban; Spathodea campanulata; Tephrosia vogelii* - *Tetradenia riparia* EXOTIC: *Acacia mearnsii; Acrocarpus fraxinifolius; Cajanus cajan; Calliandra calothyrsus; Casuarina equisetifolia; Cedrela spp; Flemingia macrophylla; Gliricidia sepium; Leucaena leucocephala; Grevillea robusta; Moringa oleifera ;Morus alba; Senna siamea; Senna spectabilis; Tithonia diversifolia*	Trees for erosion control on slopes (contours, and degraded zones). Trees for soil improvement (boundary, intercropped).	Annual cropland (maize, cassava, beans, sweet potatoes, Irish potatoes)
Fodder banks	*NATIVE: Albizia gummifera; Ficus spp.; Erythrina abyssinica; Maesa lanceolata; Myrianthus arboreus; Sesbania sesban; Sinarundanaria alpina; Tephrosia vogelii; EXOTIC: Acacia mearnsii; Cajanus cajan; Calliandra calothyrsus; Leucaena leucocephala; Persea americana; Moringa oleifera; Tithonia diversifolia*	Fodder bank (clumped or along boundaries, or contours)	Pastures Homestead Cropland
Coffee agroforestry	*NATIVE: Albizzia gummifera; Cordia abyssinica; Erythrina abyssinica; Ficus thonningii; Ficus vallis choudae; Kigelia africana; Maesopsis eminii; Markhamia lutea; Sesbania sesban; Spathodea campanulata; Terminalia superba- EXOTIC: Acacia mearnsii; Cedrela spp.; Leucaena leucocephala; Grevillea robusta; Persea americana*	Scattered shade trees (intercropped or on boundaries)	Perennial cropland (coffee fields).
Woodlots	*NATIVE: Cordia abyssinica; Entandrophragma excelsum; Maesopsis eminii; Markhamia lutea; Podocapus falcatus; Prunus africana EXOTIC: Acacia mearnsii; Eucalyptus spp.; Grevillea robusta; Cedrela spp.; Senna siamea; Terminalia superba*	Woodlots (zoned or clumped)	Cropland (particularly upper slope, degraded land and riverbanks)

Table 5.3 Farm level contextual factors and requirements for three agroforestry options documented from stakeholder engagement for the Virunga landscape

AGROFORESTRY OPTION	Farm level contextual requirements					
	Ecology	**Availability of germplasm**	**Farm size and location**	**Labour availability**	**Land tenure**	**Gender**
High value fruit trees to improve nutrition and income LOCAL RELEVANCE Fruit trees have largely disappeared as a result of conflict and insecurity aggravating problems with food and nutritional security	Regional climate overall favourable to a diversity of species- but some species better suited to particular elevations e.g. *Mangifeira indica, Carica papaya* and *Citrus* spp at lower altitude and *Cyphomandra betacea at higher altitude*	Improved germplasm is not widely available. And grafting is not a widely held skill, There is potential to use existing nursery network to develop fruit tree seedling market. Mother trees are present in the landscape	Along field boundaries on small farms (<1 ha) - in orchards on larger holdings. Only viable where distance from field or pastures to homestead is close enough to mitigate threat of fruit theft. Bush fire is a threat in lowlands.	Intensive labour requirement especially for weeding during tree establishment. Understanding about labour availability was limited but there were many women headed households with few family members active in agriculture.	Land security is a prerequisite and women have restricted access to land. Early maturing trees preferable for households with lower security of tenure. Potential for community orchards on land given to community associations.	Women control income from fruit sales. Orchards can provide benefits to men and women through integration of bee keeping where men control income from honey production.
Fodder banks LOCAL RELEVANCE Diversify feed sources especially in dry season for specialist dairy and mixed livestock farmers Trees can be multi-purpose and so also help to improve soil fertility and provide other products.	Many leguminous species adaptable to most altitudes in the landscape but some have specific altitudinal ranges (e.g., *Calliandra calothyrsus* < *1800m; Maesa lanceolate* < *1500m; Dombeya* spp 1800- 3000masl; *Sinarundinaria alpina 2300-3300 masl*	Lack of seedling availability through nurseries. Native fodder species are not domesticated. Some native species can be propagated from cuttings.	Zoned configuration makes it suitable for small farms and homesteads even in urban areas where may be very small constituting a live-fence. Less suitable in large pastures with large conflicts in Masisi.	Labour required for establishment and protection against browsing especially in juvenile phase.	Land tenure is a restricting factor, more severely the longer the rotation length. There is scope for developing agreements for ownership of fast growing species on rented land.	Men usually responsible for dairy production especially in Masisi/Rutshuru. Women for small ruminants. Women can benefit from stakes and firewood by-products

AGROFORESTRY OPTION	Farm level contextual requirements					
	Ecology	**Availability of germplasm**	**Farm size and location**	**Labour availability**	**Land tenure**	**Gender**
Woodlots LOCAL RELEVANCE Income possible for men from important markets for timber, charcoal and fibre (*Acacia mearnsii*), medicine (*Prunus Africana*) and honey if bees are integrated.	Exotic species adapted to most parts of the landscape. High value native species have altitudinal requirements (e.g *Podocarpus falcatus* and *Prunus africana* at higher altitude and *Milicia excelsa* or *Khaya anthoteca* at lower altitudes.	Some exotic species (especially eucalypts) are widely available. Seed and seedling systems not developed for native species but native mother trees present.	Large farm sizes required restricted to wealthier men. There may be potential to plant on degraded land although eucalypts may cause degradation if planted on fertile land.	Labour for sowing and weeding required.	Land tenure is a restricting factor, more severely the longer the rotation length.	Men are generally the main beneficiaries.

Workshop participants indicated that the ecological conditions across the province of North-Kivu were highly variable and hence suitable for a wide range of trees but that altitude was a major factor determining the performance and suitability of individual species in particular locations (Table 5.3). Access to quality germplasm was a constraining factor for establishment of all three options, with the exception of *Eucalyptus* seeds for establishing woodlots, which were widely available. Sourcing seed or seedlings of native species was difficult, and although parent trees were often present in the landscape, they were seldom used to produce propagation material because of lack of knowledge and skills to do so (see human capital in Table 5.4). Farm size influenced how much space could be used for establishing orchards or woodlots, but there were also specific planting arrangements tailored to small holdings such as boundary planting, live fences and scattered trees in fields. Labour availability constrained establishment of trees, especially in female-headed households with few family members active in agriculture. Land tenure was a particularly restricting factor for tree establishment because many small farmers did not have secure land titles, although farmers who rented land could grow fast growing tree species where agreement could be reached with landlords. There were clear gender differences in benefits accruing from different practices; women were primary beneficiaries of high value fruit trees whilst men were usually in control of woodlots. Men were also in charge of fodder banks for dairy farms, although women responsible for small ruminants could also benefit from on farm tree fodder availability, while women were often responsible for fruit tree orchards that could be utilised by men for bee-keeping.

Table 5.4 Enabling environment contextual factors for three agroforestry options documented from stakeholder engagement for the Virunga landscape

AGROFORESTRY OPTION	Enabling environment contextual requirements						
	Financial capital	**Infrastructure**	**Social capital**	**Human capital**	**Access to markets**	**Policy/Institutions**	**Culture**
High value fruit trees to improve nutrition and income	Cash required to purchase inputs (pesticides, processing equipment) often not available to women who often lack capital to invest aggravated by low access to micro-credit.	Lack of infrastructure and equipment for conditioning/storing or processing fruits. Poor state of roads and agricultural paths make transportation access to markets for perishable goods difficult. Lack of fruit selling points.	Presence of women's groups/ associations in villages. Presence of civil and religious associations.	Widespread knowledge of a variety of species. Women lack technical skills to improve fruit tree production - they are entrepreneurs but lack management and accounting skills; extension network exists but lacks qualified technical staff	Local markets for fresh fruits and for processed products far from saturation but better prices possible where product bulked and transported to urban markets though collective marketing rare. . Factories for processing guava and tree tomatoes are located in cities like Beni and Goma.	National program of agricultural intensification with a fruit tree component. No fruit tree seed regulation. Pluralistic legal rules have caused mass land grabbing and conversion to pastures reducing availability of agricultural land.	Some fruit trees associated with taboos in certain localities. Sensitisation campaigns about family nutrition and fruits are changing perceptions. Fruit theft is a threat and not considered a punishable crime in villages. Bush fires are culturally acceptable but need to be controlled for tree establishment to viable in many contexts.
Fodder banks	Not mentioned	Not mentioned	Local farmers' institutions organisations . Technical institutes. Women's associations. Herder's associations must be targeted directly.	Widespread knowledge available about native and exotic fodder trees Knowledge gaps about nutritive value (fodder quantity, quality, timing, diet formulation). Lack of techniques and knowledge about cut and carry, zero grazing systems and conservation/storage of fodder.	Currently the market for tree fodder is not developed but there is a potential for development especially in peri-urban areas.	Lack of capacity of state extension services in livestock production could be addressed through addressing lack of policy related to improved pasture management and animal nutrition.	Lopping trees for fodder is common but fodder trees are not well integrated in farming practice. Herders not commonly involved in tree planting programs. Zero grazing is uncommon. There are negative perceptions of trees competing for space with pasture grasses and crops.

AGROFORESTRY OPTION	Enabling environment contextual requirements						
	Financial capital	**Infrastructure**	**Social capital**	**Human capital**	**Access to markets**	**Policy/Institutions**	**Culture**
Woodlots	Land set aside with delayed production benefits may constrain investment.	Poor state of roads and agricultural paths make transportation difficult and expensive.	Active tree planting associations with seedling networks present across most of the districts	Widespread technical knowledge about woodlots. Lack of knowledge about integrating bee keeping with woodlots. Gaps in knowledge about propagating native trees and in skills for managing multiple species woodlots.	Farmers are poorly integrated in value chains (honey, charcoal, timber). There is a lack of collective action for transportation of products and low bargaining power since farm gate prices are low.	Land use plans needed to identify land for food crops and for reforestation. Heavy taxation (informal and formal) creates disincentives for tree planting.	Woodlots are common features but dominated by a few exotic species. Slow growth rate of native species is often a constraint to establishing diversity.

Financial capital restrictions were particularly important for women, who did not have the formal means to invest in tree seedlings and inputs for improving fruit production (Table 5.4). The lack of road infrastructure was a constraint, especially for transporting and marketing fresh perishable fruits, timber, charcoal and honey. In terms of social capital, there were several local community based organisations and tree planting associations. In terms of human capital, farmers and extension workers had knowledge about a wide range of trees and their suitability for different locations but lacked skills in propagating most native species. Women also lacked fruit tree management and propagation skills and there were no trained extension staff specialised in horticulture to support them in this respect. Herders lacked knowledge about the nutritional value of fodder species and the conservation, management and handling of fodder from trees. Despite the market potential, notably to supply urban areas, lack of collective action around wood and non-wood products was limiting value capture and hence profit. Women were particularly interested in value addition, including processing of fruits into juices or jams but lacked access to micro-finance to enable them to engage in these opportunities. There were cross cutting policy issues that related mainly to pluralistic land tenure laws and customary rules that have allowed widespread alienation of land held under custom (Vlassenroot & Huggins 2005), aggravated by lack of government support in agricultural services and in land use planning. There were also cultural norms that affected use of some tree species and the adoption or management of some practices. These included taboos around fruit trees as well as a lack of awareness that fruit consumption could improve nutrition, and ethnic and gender specificity in preferences for some tree species and practices, such as Batwa men favouring meliferous tree species to enhance bee-keeping.

5.3.4. Delivery mechanisms for promoting agroforestry options

Amongst solutions and contextual prerequisites for scaling up the three agroforestry practices documented in Tables 5.3 and 5.4, local stakeholders highlighted a series of complementary interventions required, that relate to improvements in delivery mechanisms and the enabling environment (Table 5.5). Increasing the quality and diversity of germplasm for native and exotic species was an important intervention across the three practices, that stakeholders indicated could be achieved through expanding and strengthening existing community based networks. Researchers also thought that development of seed orchards and seed banks would reduce the reliance on external sourcing of germplasm that is often driven by projects. This was a concept well received by local stakeholders. Sensitisation/awareness-raising activities were considered important for all three practices, to target not only beneficiaries, but also opinion leaders and customary chiefs. Capacity development, through increasing knowledge and technical skills, was also considered important, targeting specific interest groups but also extension services in general, who has received little agroforestry training and lacked expertise in collecting and handling native seeds. To scale up women's involvement in fruit tree production, training in fruit tree management and pest and disease control were identified as important, together with training in accounting and management skills that could underpin development of collective action for enabling value addition. Expanding and strengthening collective action for improving the value chain, and thereby increasing returns, was important not only for fruits but also for wood and honey from woodlots. Common enabling environment interventions revolved around the creation of a platform for sharing agroforestry knowledge and experience, for accessing credits and inputs, as well as for collective market action. Improving the very poor road infrastructure was also raised as an important factor to facilitate transport and market access. In the sphere of policy and institutional change, the major obstacles to adoption of agroforestry were identified as those related to tenure. Unclear and overlapping formal and customary land tenure and property rights, indicated that stronger agrarian legislation and land use planning would be required to foster cross-sectoral integration, enabling larger investments in agroforestry

Table 5.5 Interventions for improving the delivery mechanisms and enabling environment to scale up three agroforestry practices in the North-Kivu Province ***(bold X denote the interventions that apply to all three options)***

Intervention components	Delivery mechanisms and enabling environment	Fruit trees	Fodder banks	Woodlots
GERMPLASM	Increase quality and diversity of seeds and seedlings	**X**	**X**	**X**
	Initiate domestication of native species	**X**	**X**	**X**
	Establish local seed banks	**X**	**X**	**X**
	Establish seed orchards for local production	**X**	**X**	**X**
	Promote grafting reproduction methods	X		
	Promote alternative propagation (direct seeding, cuttings)		X	X
SENSITISATION - AWARENESS RAISING	Establish demonstration farms and experimental fields	**X**	**X**	**X**
	Extension material in local languages	**X**	**X**	**X**
	Farmer organisations on land tenure rules and rights	**X**	**X**	**X**
	Religious confessions/opinion leaders on agroforestry planning	**X**	**X**	**X**
	Local customary chiefs - on agroforestry planning	**X**	**X**	**X**
	Herder groups agroforestry on zero-grazing systems		X	
	Nutrition (schools, market, radio theatre)	X		X
CAPACITY BUILDING/ KNOWLEDGE	Extension staff and farmer groups in seed collection of native species	**X**	**X**	**X**
	Extension staff and farmer groups in seed handling and conservation	**X**	**X**	**X**
	Local extension staff in fruit tree management	X		
	Women in fruit tree propagation and management	X		
	Women in fruit tree pest and disease control	X		
	Local extension staff in improved tree fodder management		X	
	Herders in improved tree fodder management (types, quantity, timing)		X	
	Bee keepers (Batwa included) in improved apiculture techniques	X		X
	Women in fruit transformation techniques	X		
	Women in accounting and management skills	X		
MARKET	Support collective action for improving access to markets	**X**	**X**	**X**
	Market information systems	**X**	**X**	**X**
	Developing efficient value chain for honey, fruits, timber, charcoal, fodder	**X**	**X**	**X**
	Improve market value of fruits through transformation	X		
	Developing efficient value chain for honey, fruits, timber, charcoal, fodder	X		X
	Link farmers to markets and businesses through fairs and market days	X	X	X
NETWORKS - PLATFORMS	Create a multi-stakeholders agroforestry platform	**X**	**X**	**X**
	Support access to credit schemes	**X**	**X**	**X**
	Create groups for collective action based on selected commodities	**X**	**X**	**X**
Intervention components	**Delivery mechanisms and enabling environment**	**Fruit trees**	**Fodder banks**	**Woodlots**
INFRASTRUCTURE	Build fruit selling points for collective sales	X		
	Road network	X		X
POLICIES - LAWS - RULES	Reform of agrarian legislation	**X**	**X**	**X**
	Reform of land tenure policy	**X**	**X**	**X**
	Investment in agroforestry research	**X**	**X**	**X**
	Investment in the rehabilitation of road network	X		X
	Support for botanical gardens development and maintenance	**X**	**X**	**X**
	Develop and implement a national seed policy	X	X	
	Cross sectoral programs should include agroforestry	X	X	X
	Taxation policy on charcoal			X

5.4. DISCUSSION

5.4.1. Tree diversity and social inclusion

The dominant agroforestry interventions in the region had previously focused on promoting fast growing exotic species for the production of energy or timber in woodlots, largely dominated by the *Eucalyptus* genus but also including *Acacia mearnsii* and *Senna siamea* (both of which have the potential to be invasive) and to a lesser extent *Grevillea robusta* (LeJeune et al 2013). The process of engaging with a range of local stakeholders, using a holistic landscape and farming systems approach (Sinclair, 1999), led to a rapid identification of a diverse set of locally relevant agroforestry practices, in various farm and landscape niches, and a list of more than 70 species, including 30 native trees not previously part of formal tree promotion efforts in the region, but locally known as useful for different contexts. This list was complemented by local knowledge acquisition, information from natural vegetation maps and market studies, leading to the development of a technical extension manual and a series of training materials covering 120 species (Smith Dumont et al. 2015).

The discussions of species suitability for different farm and landscape niches during knowledge acquisition and at the design workshops, led to elicitation of a rich set of information about how to manage trees and their interactions with crops, livestock and human needs. This knowledge embraced the range of conditions across the province, rendered diverse because of altitudinal variation and varied social and economic context. These result in fine scale variation in agroecosystems, based around annual and perennial crops, mixed farming and dairy production. Key gaps in local knowledge were also identified, especially relating to tree propagation, consistent with findings more broadly (Lillesø et al., 2011).

Conventional approaches to tree promotion have focused on identifying a few, usually exotic, tree species through rapid participatory appraisal and ranking, aiming at consensus on priorities (Franzel 1996), rather than embracing the diversity of needs and conditions that farmers experience (German et al., 2006). A potential drawback with promoting only a few species is that if this is successful it may result in reducing the biodiversity of landscapes and hence their resilience (Harvey et al., 2011). A number of recent studies in East Africa have shown that farmers, when deciding on tree retention and planting on their farms in less disrupted landscapes than those of North Kivu, have tended to embrace a diversity of species that contribute to landscape and livelihood resilience (Nyaga et al., 2015; Iiyama et al., 2016). Where tree planting is aiming to contribute to landscape restoration around protected areas, as is the case around the Virunga National Park, it is particularly important to promote a diversity of tree species that can contribute to biodiversity conservation at the same time as productivity and profitability of farming (Ashley et al., 2006).

This diversity of agroforestry options generated from stakeholder engagement, included species and practices that could benefit a much greater diversity of people than were previously reached by woodlots of exotic species, that tended to be adopted by male farmers with sufficiently large land holdings to be able to devote land exclusively to timber or charcoal production (LeJeune et al., 2013). Options identified during the stakeholder engagement process in Eastern DRC, included early maturing fruit tree species, with options to add value through processing into juice or jam, as well as fertilizer trees to improve soil fertility, favoured by women. Men from the indigenous Batwa community were interested in meliferous trees to support honey production from their bee-keeping enterprises. Tree species suitable for both windbreaks and fodder production were identified by livestock keepers as important for the extensive areas of pasture in the landscape and to support dairy production. The identification of options for a broader range of stakeholders derives specifically from the strategy of knowledge acquisition from different stakeholder groups, coupled with workshop sessions deliberately organised to give voice to otherwise marginalized people, who often lack agency in multi-stakeholder fora (Chomba et al., 2015). This was particularly effective in addressing issues important for women through having workshop groups focusing specifically on trees and gender, comprising all of the female participants. Greater inclusiveness in agroforestry options identified and promoted in an area is likely to lead to more effective scaling up because the range of options addresses needs of a higher proportion of the people living there (Franzel et al., 2001; Coe et al., 2014).

5.4.2. Seed and seedling supply mechanisms

Access to quality tree planting material for a diverse range of species was identified as a major barrier to the adoption of many of the agroforestry options considered relevant in North-Kivu, a situation mirrored in many places across Africa (Nyoka et al., 2015). Despite recent efforts to develop locally sustainable tree seed and seedling supply systems, it remains common in Africa for the availability of tree planting material to be largely determined by government institutions and NGOs continuing to freely distribute a limited number of often exotic species, that can be quickly accessed in large quantities by tree promotion initiatives (Brandi-Hanson et al., 2007). A major issue is that the same traits that make species good candidates for mass seed production, also make them more susceptible to being invasive or aggressive, potentially posing threats to biodiversity (Ashley et al., 2006). Most donor driven tree planting projects are governed by short term targets specifying how many trees are to be planted, often with little consideration of which species these are, the quality of germplasm used, or its relevance to local conditions (Nyoka et al., 2015). The stakeholders involved in the design workshops underlined the relevance of a wide range of species, they also stressed the need to move away from sole reliance on sourcing germplasm through external projects, to develop locally owned seed orchards for native and exotic species, to domesticate native species and promote alternative modes of propagation (natural regeneration or vegetative propagation methods). They also identified key knowledge and skill gaps in propagation of native tree species amongst both farmers and extension staff. This corroborates recent global reviews that have highlighted the importance of developing local sourcing of tree germplasm coupled with market development, to ensure supply of quality tree seeds and seedlings, through fostering the growth of small seed and seedling production and distribution enterprises (Lillesø et al., 2011)

5.4.3. Enabling environment: markets and the policy environment

Despite the existence of important markets for numerous wood and non-wood products in North-Kivu, a good understanding of how these markets operate is lacking and market development is heavily constrained by political uncertainty and weak governance (O'Donnell et al., 2015). It has been suggested that scaling up adoption of agroforestry practices requires strategies for promoting tree planting to be connected to interventions aiming to expand market opportunities for farmers, around diversified portfolios of high value products (Russel & Franzel 2004). Increasing the knowledge of farmers, technicians and rural advisory agents in processing of tree products was identified as an important capacity strengthening activity, required to foster value chain development for agroforestry products in North Kivu, with women specifically interested in processing fruit but constrained by lack of access to micro-finance. A key realization from the stakeholder engagement process was that extension approaches would need to be tailored to different stakeholder groups, with a focus on gender and socioeconomic differences, that determine gaps in knowledge and skills (Franzel et al., 2001). Combining market information with value chain interventions in production, harvest and post-harvest stages with institutional support for collective action, has been found critical for supporting enterprise development and commercialisation of agroforestry elsewhere in Africa (Gyau et al., 2014)

North Kivu faces particularly daunting challenges with respect to governance issues, that for most agroforestry initiatives represent context, rather than presenting an opportunity to intervene. Depending on the size and scope of interventions possible, policy and institutional reform may either be an option, or represent context within which other technology, extension system and market options have to work (Coe et al., 2014). In North Kivu, weak and pluralistic governance mechanisms in a politically unstable region, prone to ethnic conflict, have been associated with land grabbing, a low level of public investment in infrastructure, and burdening taxation in an often corrupt environment, all of which hinder agricultural development and natural resources management (Vlassenroot & Huggins 2005). Resulting lack of security in land tenure deters many farmers from investing in trees. While this constrains what can be done to improve the enabling environment for agroforestry interventions, stakeholders identified possibilities to expand and strengthen farmer networks associated with sourcing germplasm, as well as collective processing and marketing of agroforestry products. They also highlighted areas where the extension system could be improved through capacity strengthening as discussed above.

5.4.4. Lessons from the structured stakeholder engagement process

The structured stakeholder engagement has resulted in recommending a far more diverse set of options than were considered previously or that prioritization and ranking methods, that deliberately seek consensus on a few priority species, would be likely to elicit (Franzel et al., 1996). Prioritization, although also participatory, typically results in identifying fewer than ten tree species at regional or even national levels, appropriate for focusing tree domestication efforts (Dawson et al., 2012) but not necessarily for identifying what trees and agroforestry practices to promote to farmers in any particular locality (Coe et al., 2014). There has been a long history of researcher-led participatory diagnosis and design in agroforestry (Raintree, 1987), but this has tended to lead to rich diversity of diagnoses but only a very restricted set of suggested interventions (Sinclair and Walker, 1999). The co-learning process of involving stakeholders in conceptualizing tree planting through the identification of field, farm and landscape niches for different tree species and functions used here, resulted in a much wider diversity of agroforestry options than where researchers fit, a usually limited set of prescribed interventions to match a diagnosis. We found that the initial knowledge acquisition phase was critical for informing and enabling researchers to facilitate the stakeholder workshops. This was because talking with farmers and other stakeholders on their own turf, where they were more confident, enabled an understanding of what different stakeholders knew about trees and agroforestry to emerge (Sinclair & Walker 1999), as well as their preferences and the constraints that they faced. By deliberately consulting different stakeholders, encompassing explicit consideration of gender, ethnicity, wealth and the different roles people played in the agricultural system (such as farmers, extension staff, development professionals, researchers and community leaders), a range of distinct perspectives were gathered that researchers used to structure the workshop sessions, for example, by including a group focusing on trees and gender that included all of the female participants, enhancing their agency and the importance accorded to their perspectives in the agroforestry options that emerged from the stakeholder engagement process.

So, the initial knowledge acquisition enabled researchers to set up effective stakeholder dialogue because many key issues were identified before the workshops, and the workshop sessions were then deliberately structured to address them. On reflection, we found evidence of changes in the knowledge and attitudes of stakeholders. One farmer indicated when evaluating the Goma workshop that he had been empowered through realizing that he knew as much about local agroforestry practices and requirements as researchers, and the head of a local NGO remarked at the Butembo workshop that ‘this was the first meeting where scientists and farmers could interact, the approach was rich in learning and in giving and receiving’. The forest manager with the WWF ECOmakala project said after the Goma workshop that ‘it had opened up our perspectives on tree planting, we realize we need to do things differently and adapt our approach to promote agroforestry and different species’ while an extension agent for a local farmers’ association remarked that ‘I was not aware there were so many important native species we could promote and that agroforestry was about so many different practices’. Similarly at the Butembo workshop a coordinator of an NGO said that ‘I have been planting trees with ECOmakala since 2006 and wondering how we could develop agroforestry, now we know how to give better advice to our farmers’.

The combination of structured stakeholder engagement to design agroforestry options with the subsequent technical training that integrated local knowledge with global scientific expertise resulted in changes in knowledge and attitudes about tree planting amongst stakeholders including farmers, researchers, extension staff and development agencies.

This is evidenced by the reflection workshop, which took place a year and a half after the stakeholder design workshops. Several local community based organisations and regional NGOs currently working in partnership with WWF presented some of their achievements since the design workshops. They indicated changes in their practice, including promoting a broader range of tree species as detailed in the technical manual, including native species not previously promoted by either government extension systems or non-governmental organisations (NGOs) in the region. They also indicated that they were recommending a more diverse range of ways in which these tree species could be incorporated within fields and farming landscapes rather than focusing on woodlots (Smith Dumont and Bonhomme 2016). The extent to which this results in changes in farmer behavior and more diverse tree cover across the landscape is a key priority for subsequent impact evaluation. Experience from the Lake Tanganyika catchment, where similar approaches to engaging stakeholders in agroforestry design were followed in a development initiative, led to over 2 million trees being locally raised and planted in 2012, including 16 native species not previously promoted in the region (Marijnissen, 2013).

5.5. CONCLUSION

Our results demonstrate that consulting a broad range of stakeholders and sharing knowledge amongst them through facilitated workshops, resulted in a shift from promotion of a handful of exotic tree species in woodlots, largely benefiting wealthier men, to recommendations for over 70 species, 30 of them native, across a wide range of field, farm and landscape niches. These options addressed the needs of women, various ethnic groups and different types of farmers, including those producing annual crops, perennial crops and livestock. Whilst the use of multiple stakeholder engagement and participatory processes are generally known to be effective bottom up approaches that increase learning, local ownership and adoption of new technologies (Franzel et al., 2006; Akpo et al., 2014), the novel aspect of this method stems from building on explicit acquisition of local knowledge, which was then used to facilitate a systematic consideration of trees at field, farm and landscape scales. This outlook on agroforestry resulted from the structuring of information around consideration of different options (technologies, market interventions and institutional reform), and the contexts for which they were relevant (covering ecological, economic, social and cultural factors). The options that were identified related as much to addressing key constraints to scaling up agroforestry in the enabling environment, including market, extension system and institutional interventions, as to technology options at field, farm and landscape scales.

6. SYNTHESIS AND CONCLUSIONS

6.1. Building on local knowledge to promote on-farm tree diversity

The agro-ecological zones and rural contexts in Africa, where we have interviewed in depth over 700 farmers about their knowledge of trees, represent contrasting farming systems subject to different drivers of land use change. But across these studies we found that farmers had a much wider knowledge of a range and number of species than was available to scientific knowledge or extension advice This rich and complementary knowledge points to wider opportunities for improving tree management that can reconcile production and conservation objectives in degraded landscapes.

6.1.1. Diversity of native and exotic trees for multiple functions

In the Southwest of Cote d'Ivoire, despite the large-scale deforestation associated with the expansion of cocoa and other tree crop plantations that occurred over the last fifty years (Oszwald, 2005), smallholders described a rich diversity of over 100 different tree species growing in their cocoa fields. This included 74 species that could be botanically identified, 63 of which were native forest species (ten species on the IUCN red list of threatened species) thus showing that cocoa farms still contained a reservoir of native forest species. In our survey involving 355 cocoa farmers, we found that regardless of their origin or eco-certification status, 95 % of farmers wanted to grow more trees. These findings diverge with the prevailing view within the cocoa industry in West Africa that farmers will progressively reduce and ultimately eliminate shade in their cocoa fields where newly introduced hybrids would strive better under full sun (Ruf, 2011). In the densely populated and degraded tropical highlands of the Western Region of Rwanda (Karamage et al., 2016), we found that as farm sizes and access to natural forest resources decreased, coffee fields became increasingly important farm niches for integrating a diverse mix of tree species, including retention of some native forest species, to obtain products that diversify nutrition, provide income and improve soil and water conservation. A review of shade coffee tree management in Central America also highlighted a similar trend amongst farmers (Mendez et al., 2010). Thirty-five species, either intercropped or grown on boundaries of coffee fields, were discussed with farmers; planted fruit trees had some of the highest on-farm frequencies. Both cocoa and coffee farmers valued a range of companion trees for products (fruits, firewood, timber, medicine) and environmental services. In Cote d'Ivoire, cocoa farmers described trees as increasingly important in the adaptation to changing climatic conditions; shade is necessary to buffer against heat and water stress during an increasingly long dry season (*cf.* Brou, 2010) and decreasing soil fertility, a particular challenge given the poor soil health of the Nawa region (Koko, 2009). In Rwanda, farmers had sophisticated knowledge about tree-leaf litter management for mulching coffee fields to improve soil fertility, and about the role of trees in controlling soil erosion which is a major concern on the steep slopes of the landscape (Karamage et al., 2016). This echoes general findings that tree diversity in shaded cocoa or coffee systems is important for reducing the vulnerability and risks faced by smallholder farmers (Duguma et al., 2001; Tscharntke et al. 2011).

6.1.2. Contrast between rural advisors' and farmers' knowledge

In the past, research and extension recommendations for cocoa production in the West Africa region have often served as a barrier to farmer innovation. At best they have led to the promotion of a few key species rather than increasing tree diversity (Asare, 2005). In Cote d'Ivoire, extension services have traditionally not only encouraged full-sun cocoa but also specifically advised farmers to remove forest tree species from cocoa fields: several lists covering over 50 species have been disseminated (SATMACI, 1984; FIRCA, 2008; CNRA, 2011). In Rwanda, farmers were moving away from historically encouraged full-sun coffee, where intercropping was prohibited, to increasing tree cover and diversity in coffee fields. We found both coffee and cocoa farmers' engagement with eco-certified cooperatives to be an important source of new advice about shade trees in the two case studies. Advice provided had a clear influence on preferences shared by eco-certified farmers but was concentrated on a limited list of eight species, whilst farmers, on the other hand, expressed the desire to use a broader diversity of trees to meet their needs for numerous tree products and services. In Rwanda, government advisory services and cooperative networks had set up tree nurseries for promoting shade trees but species diversity was limited by seed availability and nationally formulated recommendations; this resulted in the propagation and distribution of only five species for a regional shade program that involved 8000 coffee farmers and a million seedlings. In addition they focused on a narrow range of mainly exotic species, which we found was again limited compared to the diversity managed by farmers for different benefits and with distinct management practices.

This difference between rural advisory recommendations and farmers' knowledge and management of trees was not limited to coffee and cocoa systems that were shifting from full sun to shade management as a result of eco-certification; We also found a marked contrast between the nature of current reforestation programs in the heterogeneous landscape around the Virunga National Park in Eastern Congo. This is part of the Albertine Rift global biodiversity hotspot, with the potential for a much wider diversity of species and tree management options tailored to the diversity of socio-ecological conditions and farmers' needs. However, most reforestation interventions have consisted of exotic monocultures dominated by Eucalyptus species grown as energy or timber woodlots mainly by male farmers with sufficient land to allocate exclusively to trees (LeJeune et al., 2013). We found that structured stakeholder engagement building on local knowledge led to a quick identification of a much greater diversity of trees (more than 70 species) and customised tree management to distinct field, farm and landscape niches. These have the potential to serve the interests of a much greater diversity of people, including women and marginalized groups than current interventions focusing on a limited set of species grown in woodlots.

6.1.3. Opportunities for reconciling biodiversity conservation and food security

Whether tree based interventions are aiming to contribute to landscape restoration around protected areas, as in the case around the Virunga National Park, or to sustainable shade coffee or cocoa production systems or to parklands in the semi-arid zone of West Africa, there is a strong potential in promoting a diversity of tree species that can contribute to biodiversity conservation whilst enhancing productivity and resilience of farming systems (McNeely, 2004; Ashley et al., 2006; Harvey et al., 2011, Faye et al., 2011). A number of recent studies in East Africa have shown that farmers, when deciding on nurturing regeneration or planting trees have tended to embrace a diversity of species that contribute to landscape and livelihood resilience (Nyaga et al., 2015; Iiyama et al., 2016). The existence of native forest species across the different farming systems confirms the importance of local knowledge for the in situ conservation of tree species (Dawson et al., 2013) and the potential to better integrate them in different agroforestry practices (McNeely, 2004). Alongside the conservation interests in tree diversity, there is also growing evidence of the importance played by trees in improving smallholder food security (Icowitz et al., 2014). A wide range of species in agroforestry landscapes are known to be contributing directly to food production (Jamnadass et al., 2011), either through the direct consumption of fruit/edible parts of trees (Leakey & Tchoundjeu, 2001) or through diversification of income sources that can enable food purchases (Sonwa et al. 2007; Cerda et al. 2014; Ouedraogo, 2017). Across all four sub-Saharan studies documented here, farmers had a marked interest in exotic and native fruit species. In certain contexts, the market potential may determine farmers' desire to intensify certain species, however integrating a diversity of fruit trees is very important to provide an all-year-round portfolio of species that can also provide households' nutritious food including micronutrients (Jamnadass et al., 2011). This is especially relevant in the context of sub-Saharan Africa where we observe the highest prevalence of severe food insecurity in the world estimated to affect 26 per cent of the population above the age of 15 whilst one in three children under the age of five is affected by stunting (FAO, 2017). Thus, in addition to understanding the overall smallholder system potential for nutrition at landscape level, efforts could be channelled to build on farmers' practices and enhance both quantity and quality of fruit tree products. This could be through domestication or dissemination of improved cultivars and on promoting best management practices, such as those associated with pest and disease control (Jamnadass et al., 2011).

6.2. Operating in data sparse environment: The importance of local knowledge in understanding complex system interactions in agroforestry

6.2.1. Acquiring local knowledge about complex agro ecological interactions

Tree-crop interactions and the biophysical and socio-economic factors influencing farmers' decision-making about trees are complex and context-specific but fine scale data relating to them are rarely available. In fact, very little information exists on tropical or subtropical native species and their current or potential contributions to different ecosystem functions. As Ordonez et al. (2013) highlight from analysing the global plant trait database (TRY), out of 30,000 tree species: almost half do not have trait information, a third had information on less than 5 functional traits and only about 3% (mostly temperate species) have very detailed functional characterization. Because agroforestry can involve spatial or temporal associations of different trees with a range of crops (annual and perennial) and grasses and spatial configurations, it is complicated to make predictions on how different trees can contribute to different sets of ecosystem services and agronomic interactions. This difficulty is compounded by the fact that the expressions of attributes that will ultimately determine the outcome of complex processes such as how trees contribute to soil nutrient enrichment or how much shade competes with neighbouring crops are themselves affected by their genetic, environmental and management factors. We found that systematic local knowledge acquisition and representation using AKT (Walker and Sinclair 1998) added significant depth to the understanding we have of the contextual variations and the causality in the interactions between a wide range of trees and other farm system components articulated by farmers.

Coffee farmers in Rwanda for example had detailed knowledge about soil and water conservation processes associated with trees and about the trade-offs against perceived competition for light, water and nutrients with coffee. The services or disservices (competitiveness) of trees to coffee was influenced by combinations of attributes related to: crown architecture, foliage properties and growth patterns; as well as how trees responded to management, and, their overall utility. Farmers also detailed and sophisticated explanatory knowledge about mulching processes, which is consistent with other studies (Soto-Pinto et al. 2007), but provides novel information in a range of contexts where previous work on trees and mulch have focused mainly around on-station experiments with a few exotic species (Dusengemungu and Zaonga 2006). In Burkina Faso, farmers also had sophisticated causal knowledge about the interconnected factors influencing the contribution of trees to soil fertility including how different leaf attributes: leaf nutrient quality, quantity of leaf biomass and rate of leaf decomposition of different species were influenced by contextual variables such as human actions (such as harvesting leaves or treating leaf litter for speeding decomposition) and environmental conditions (e.g. field exposure to wind). The contextual influence of species variations in leaf biomass quantity and leaf decomposition rate have been highlighted before but our study in the Sudanian parklands of Burkina Faso also provided novel information about a suite of trees and suggests ways of building on farmers' knowledge to promote locally adapted non-thermal ways to accelerate leaf litter decomposition.

6.2.2. Using tree attribute ranking surveys to complement available scientific knowledge

Similarly to findings of local knowledge studies on shade tree management (Angalaare 2011, Cerdan et al. 2012), farmers in Western Rwanda recognised clear tree attributes in their direct or indirect influence on coffee production and other ecosystem services that determined their suitability for intercropping. These were classified as relating to i) utility (e.g. length of burn of firewood or economic value), ii) ecology (e.g. speed of decomposition of litter) or iii) management (e.g. easiness of pruning; contribution of mulch to soil fertility).

Building on this qualitative assessment, we sought to quantify the magnitude of the interactive effects for the range of species that farmers were intercropping with coffee. We therefore combined a participatory survey of tree attribute ranking with statistical analysis probability estimates of tree attributes. Participatory ranking and scoring methods have both been used successfully in the past, particularly to assess stakeholder preferences or uses (Franzel et al. 1995; Abeyasekera, 2001, Coe, 2010). But our objective was different in that we wanted to assess farmers' knowledge on the expression of a range of specific tree attributes that they had identified as determining different interactions. We therefore preferred ranking over scoring, because it is both rapid and more reliable, being less subjective to the interpretations different farmers may have of scoring values (i.e. farmers understand unambiguously the meaning of placing different species below or above another with respect to a specific attribute).

Our findings show that farmers were able to consistently rank trees in terms of attributes that control interactions, so that different tree species can be distinguished in terms of the magnitude of their effect on interactions. Previously, the use of farmer ranking of tree fodder quality in Nepal (Thapa et al., 1997; Thorne et al., 1999; Walker et al., 1999) was used to develop an equivalence between indigenous descriptors of fodder quality (*posilopan* and *obanopan*) and scientifically derived fodder quality measures (corresponding broadly to protein supply and digestibility). The information was then used to calibrate simulation models of livestock nutrition and develop a decision support tool to provide useful advice about the likely effect of feeding different fodder combinations on animal productivity. The research focused on two attributes and a total of eight species with simpler interactions to consider than the complexity of causal-effects between companion trees with coffee, or parkland trees and cereal crops where a larger number of tree species were managed by farmers. Through the complex data set we were able to generate in the two ranking surveys (twenty species against twelve attributes in Rwanda and twenty one species against eight attributes in Burkina Faso) and the statistical analysis we developed, we demonstrate that consistent data on a range of attributes affecting interactions can be derived from farmers' knowledge. This knowledge we found to be largely complementary to science – and constitutes a potential source of reliable and quantitative knowledge about how a diverse range of tree species, largely unknown to agroforestry science but important in farmers' practice, might be expected to affect production and other ecosystem services.

Important attributes identified by farmers are composite in nature, for example 'mulch benefits to soil', combines leaf biomass quantity, phenology and leaf decomposition rate. Species ranked high in Rwanda corroborated results from eco-physiological experiments in the same research sites that show increased coffee berry production under *Persea americana* and *Ficus thonningii* as a result of positive effects on soil nutrient content (Pinard et al., 2014) while leguminous species including *Erythrina abyssinica* and *Inga oesterdania*, which come from genera that are commonly used for mulch in Central America were also ranked highly (Somarriba et al., 2004). In semi-arid Burkina Faso, farmers agreed on the ranking of tree species for fundamental attributes, which correspond to plant traits and there was some agreement about certain species but also large differences in how farmers ranked the composite soil fertility attribute. There was a consensus about *Faidherbia albida* in line with scientific knowledge (Garrity et al., 2010) and new information about *Detarium microcarpum*, which merits further investigation especially because it was being used as part of innovative slash and mulch practices. However there were also differences in how farmers ranked a number of species because their decisions were influenced either by leaf prioritisation for household needs or by the different ways farmers actively managed leaf litter to accelerate decomposition rates and prevent negative interactions with crop seed germination in the case of broad-leaved species (Bayala et al., 2005).

6.2.3. Development of decision-support tools integrating local and scientific knowledge

In Eastern DRC, the results of the participatory research on agroforestry were integrated with scientific knowledge to produce customized recommandations for rural advisory actors. This included a technical agroforestry manual for North-Kivu[1] with detailed information on vernacular names (the first in region) tailored meets the needs and conditions of local communities around Virunga National Park. The manual covered key knowledge gaps about many native species and their propagation, agroforestry

[1] Smith Dumont, E., Bonhomme S., Sinclair, F.L. (2015) Guide technique d'agroforesterie pour la sélection et la gestion des arbres au Nord-Kivu, RDC, World Agroforestry Centre, Nairobi, Kenya 130p. http://www.worldagroforestry.org/sites/default/files/Manuel_%20Agroforesterie_RDC_Nord_kivu_ICRAF.pdf

management practices, and the potential to integrate trees on farm highlighted during the local knowledge studies and subsequent agroforestry design workshops in the region (Smith Dumont et al., 2015). A simple excel tool covering 120 species "Useful trees of North-Kivu" was also designed to guide species selection based on a series of multiple criteria (using filter fonctions around ecological, utility and management attributes).

Plate 6.1. Extension agents and farmer groups representatives with the agroforestry manual that builds on local knowledge and scientific knowledge after a training in agroforestry in Butembo, North-Kivu DRC

Knowledge derived from tree attribute ranking has been recently used in customised decision support tools for integrating a diversity of trees for multiple ecosystem services in coffee systems (van der Wolf et al., 2016). It would be useful to expend this work to compare attribute ranking estimates with quantitative ecological proxies such as functional traits for example on tree phenology, leaf decomposition rates and N-mineralization from litter of a broad range of tree species (Barrios et al. 2012). Many of the tree attributes mentioned by farmers may be quantifiable (e.g. wood burning length) and may correspond to a particular plant trait (e.g. speed of leaf litter decomposition) but they are difficult to measure scientifically, across the range of species and contexts relevant to farmers' decision-making. The comparability of local with scientific knowledge about attributes and ecological processes opens up new opportunities to integrate elements of functional ecological theory regarding the plant traits that determine the potential impact of vegetation on ecosystem services such as biomass production, soil erosion control or regulation of air temperature (Díaz et al., 2007; Kattge et al. 2011).

This could allow us to take a step further in the quantification of interactive effects between trees and other system components (e.g. crop, livestock, tree crop) that could then be used in simulation modelling to better inform species selection and management options and to develop context sensitive guidelines for their development.

6.3. The science of scaling: knowledge intensive framework for sustainable interventions

6.3.1. How to move beyond silver-bullets

There is a growing recognition that increasing tree species choice is critical to foster tree diversity and increase the resilience of local socio-ecological systems (Ashley et al. 2006, Coe et al., 2014). More recently, agroforestry decision-support tools have been developed to help select “the right tree for the right place”, based on coarse scale natural vegetation prediction maps that are innovative and useful for identifying the potential of native species based on their ecological suitability and promoting biodiversity conservation (van Breugel et al., 2015). However, these do not take into account exotic and naturalized species nor the specific landscape niches where distinct species might behave differently or management practices that are likely to be different based on farm conditions (Sinclair, 1999). Furthermore, there are also difficulties in defining species’ agro-ecological ranges and natural distribution, with systematic research on biophysical limits largely missing for many species, and existing literature sources often providing dissimilar information (Kindt et al,. 2008; Reubens et al., 2011).

Conventional approaches to tree promotion have focused on identifying a few, usually exotic, tree species through rapid participatory appraisal and ranking, aiming at consensus on priorities (Franzel, 1996), rather than embracing the diversity of needs and conditions that farmers experience (German et al., 2006). Prioritization, although also participatory, typically results in identifying fewer than ten tree species at regional or even national levels, appropriate for focusing tree domestication efforts (Dawson et al., 2012; Faye et al. 2011) but not necessarily for identifying what suite of trees and management practices to promote to farmers in different contexts (Coe et al., 2014). In our experience local actors will customise agroforestry practices (by using different mixtures of trees and spatial configurations) to better suit the ecological requirements of their location, embracing the altitudinal gradient across the province, as well individual needs, endowments and preferences (Sinclair &Joshi, 2000; German et al., 2006).

The co-learning process of involving stakeholders in conceptualizing tree planting and management through the identification of field, farm and landscape niches for different tree species and functions used around the Virunga national park in Eastern DRC, resulted in a much wider diversity of agroforestry options than where researchers fit a usually limited set of prescribed interventions to match a diagnosis. Around the Virunga National Park, the initial knowledge acquisition phase was critical for informing and enabling researchers to facilitate the stakeholder engagement process. What enabled new understandings and perspectives on trees and agroforestry to emerge was the deliberate consultation of different stakeholders, encompassing explicit consideration of gender, ethnicity, wealth and the different roles people played in the agricultural system (such as farmers, extension staff, development professionals, researchers and community leaders), and the knowledge sharing amongst them through facilitated workshops. The combination of structured stakeholder engagement to design agroforestry options with the subsequent technical training that integrated local knowledge with global scientific expertise, resulted in knowledge and attitude changes about tree planting amongst stakeholders including farmers, researchers, extension staff and development agencies. This resulted in a shift from the promotion of a handful of exotic tree species in woodlots, largely benefiting wealthier men, to recommendations for over 70 species, 30 of them native, across a wide range of field, farm and landscape niches. These options addressed the needs of women, various ethnic groups and different types of farmers, including those producing annual crops, perennial crops and livestock. The use of multiple stakeholder engagement and participatory processes are generally known to be effective bottom up approaches that increase learning, local ownership and adoption of new technologies (Franzel et al., 2006; Akpo et al., 2014), however the novel aspect of this method stems from building on explicit acquisition of local knowledge, which was then used to facilitate a systematic consideration of trees at field, farm and landscape scales. This outlook on agroforestry resulted from the structuring of information around consideration of different options (technologies, market interventions and institutional reform), and the contexts for which they were relevant (covering ecological, economic, social and cultural factors). The options that were identified related as much to addressing key constraints to scaling up agroforestry in the enabling environment, including market, extension system and institutional interventions, as to technology options at field, farm and landscape scales. These included improving access to quality tree planting material for a diverse range of species, which is still considered a major barrier to the adoption of many of the agroforestry options considered relevant in North-Kivu, a situation mirrored in many places across Africa (Nyoka et al., 2015). Hence efforts should instead aim to develop local sustainable tree seed and seedling supply systems, to domesticate native species and promote alternative modes of propagation (natural regeneration or vegetative propagation methods (Lillesø et al., 2011). Scaling up also requires strategies for connected tree planting-value chain interventions aiming to expand market opportunities for farmers. These should be around diversified portfolios of high value products (Russel & Franzel, 2004) with institutional support for collective action for supporting enterprise development and commercialisation of agroforestry (Gyau et al., 2014). Certification schemes and better integration of producers in value chains to ensure higher economic returns to tree products whether from tree crops or companion trees can also become an important incentive to adopt new practices (Tscharntke et al., 2011). Despite the existence of important markets for numerous wood and non-wood products for example in North-Kivu in DRC, a good understanding of how these markets operate is lacking and market development is heavily constrained by political uncertainty and weak governance (O'Donnell et al., 2015). Similarly, the exclusion of farmers from the timber market is an important constraint to managing timber trees on cocoa farms in Côte d'Ivoire (Anglaaere et al., 2011; Ruf, 2011) and this was often the reason why farmers were felling or burning high value timber trees in their cocoa plots (Ruf et al., 2006) instead of incorporating them in the production system. In addition to market access, a favourable policy environment that includes security of land and tree tenure for farmers determined whether a farmer will be willing to invest in trees.

6.3.2. Framework for developing context sensitive matrices of options to scale up agroforestry

Coe et al. (2014) propose a co-learning paradigm for scaling agroforestry to test and refine matrices of agroforestry options that match sites and people's needs and circumstances through planned comparisons. Building from this first application of the options by context approach in DRC and the broader evidence and experience acquired in the body of applied agroforestry research presented for this doctoral thesis, I propose a 'knowledge intensive framework for agroforestry' to support the promotion of locally adapted diversified tree-based options that aim to deliver both environmental and socio-economic benefits (Figure 6.1.). The framework looks at integrating multiple knowledge systems within a structured stakeholder engagement process that can foster co-learning at multiple scales and enable a holistic and socially inclusive reading of the landscape dynamics. The two pillars of knowledge stem from scientific inquiry and participatory research into local knowledge to identify prevailing land use and livelihood system dynamics for different stakeholders in the landscape, especially into the drivers of changes, and defining current/potential role of trees and their management in supporting different people's livelihoods. Available scientific information (e.g. natural vegetation maps, remotely sensed erosion hotspots, tree inventories, value chain analyses) is integrated with local knowledge and fed into a 'structured stakeholder engagement' process involving a socially inclusive representation of farmers, rural advisory services, scientists and decision-makers through participatory workshops.

The first step is to foster collective reflections around the identification of locally relevant generic agroforestry practices (e.g. woodlots, improved fallow, fodder banks, windbreaks) for distinct land uses (e.g. homestead, cropland, pasture) and landscape niches (e.g. degraded slopes, riparian buffers) with respective specifications about potential woody species and spatial arrangements. The next step is to elicit the contextual elements that condition the adoption of different options by different stakeholders (i.e. constraints and opportunities stemming from biophysical, economic, social, cultural and institutional conditions). These results can then be systematically structured in the form of binary matrices of agroforestry options with details of their contextual suitability at farm and landscape scale and their necessary interventions in the delivery mechanisms (e.g. seed and seedling systems, market access, infrastructure) and in the institutional/policy environment (e.g. land tenure, gender and social equity rights, governance) as we have done in the case of the Virunga landscape. Another extremely important output of the process is that it enables to tease out gaps in knowledge domains that can be addressed either through training farmers and/or extension agents (e.g. grafting, pruning, propagation of native species) and the design of simple decision support tools. The process of co-learning is not only key to design context sensitive options but also to evaluate and refine the options that can then reduce the risks and maximize benefits for smallholder farmers and for development organisations and donor funded programs. The development of knowledge about managing trees could be supported through long-term trials designed with farmers to measure the impact of various technologies and other ecosystem services across the range of contexts (Coe et al., 2014).

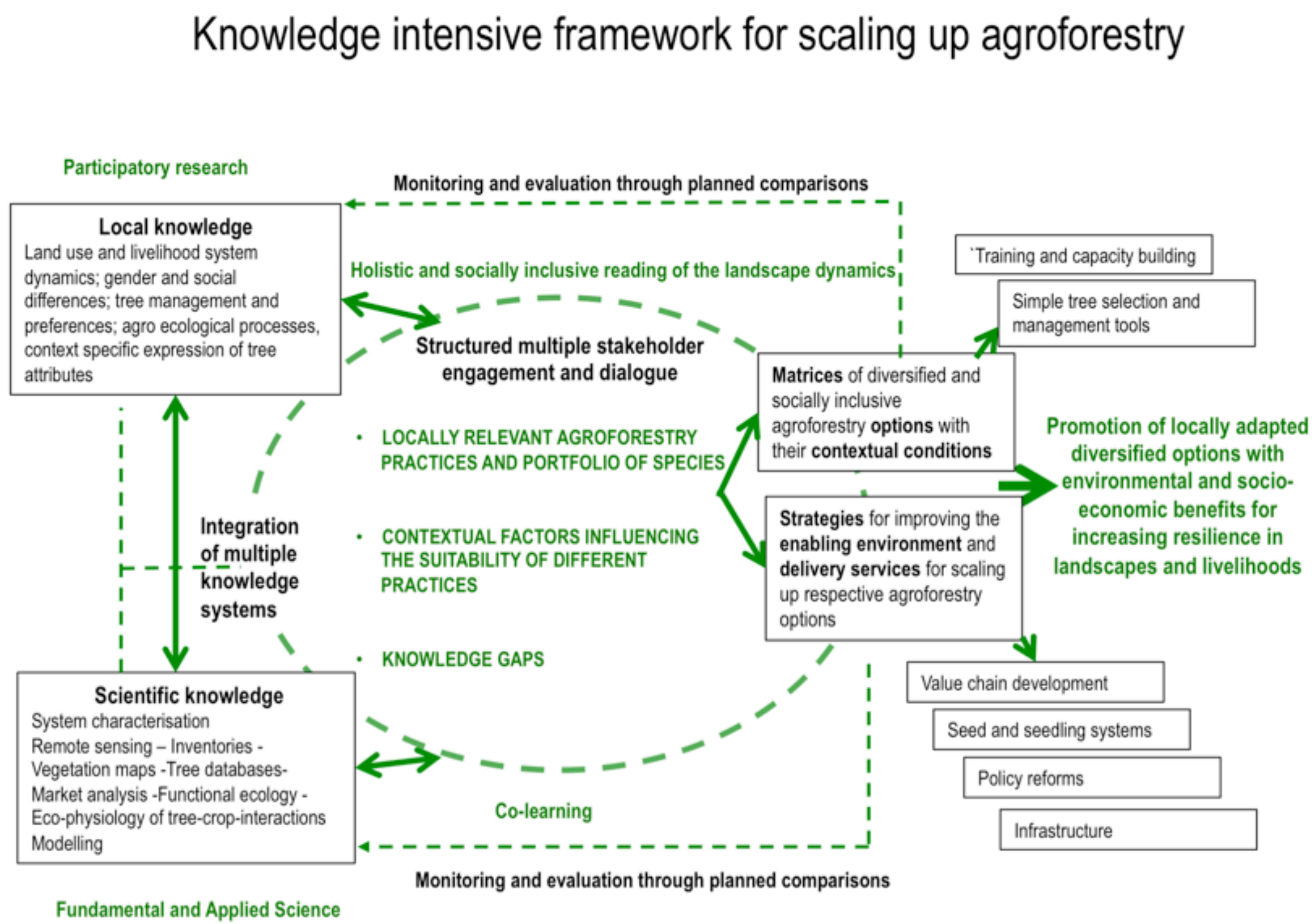


Figure 6.1. Knowledge intensive framework for scaling up agroforestry

As new knowledge is built through the experience of managing trees in different field or landscape niches, it will be important to ensure that it can be efficiently and effectively shared amongst farmers (Valencia et al., 2016; Raymond et al., 2010) and that extension approaches are tailored to different stakeholder groups, with a focus on gender and socioeconomic differences that determine gaps in knowledge and skills (Franzel et al., 2001).

Integrating a 'knowledge intensive' framework in development or conservation based projects is challenging and ambitious because most donor driven tree planting projects are governed by short term numerical targets often with little consideration of species, the quality of germplasm used, or its relevance to local conditions (Nyoka et al., 2015). It remains common in Africa that it is driven by the availability of tree planting material largely determined by government institutions and NGOs continuing to freely distribute a limited number of often exotic species that can be quickly accessed in large quantities (Brandi-Hanson et al., 2007). A major issue of concern is that the same traits that make species good candidates for mass seed production also make them more susceptible to being invasive or aggressive, potentially posing threats to biodiversity (Ashley et al., 2006). So the next step would be to test whether the active engagement and participation of intended project beneficiaries in designing agroforestry interventions secures ownership of activities that will ensure the sustainability of interventions (i.e. more people will look after trees which they have selected to meet their needs and conditions hence raising survival rates). It would thus be useful to investigate the extent to which different intensity of knowledge and stakeholder engagement methods are effective and cost effective in scaling up agroforestry adoption that can reconcile landscape restoration objectives with livelihood improvements. This would involve in particular, testing the effectiveness of investing in more knowledge intensive approaches versus rapid appraisal or prioritisation processes in designing tree planting options and planning for germplasm needs. This would hold important lessons relevant to donors, decision-makers and implementers globally on suitable methods, level of resources and time needed to be invested upstream of tree planting investments to foster social learning and inclusion, local ownership, and behavioural change; i.e. the planting and sustainable management of more diverse and contextually appropriate portfolios of trees matched to the diversity of farmers (gender, age, ethnicity) and landscape niches (fields, pastures, homestead, communal land, degraded slopes, river banks). In parallel, a meta-analysis of tree planting investments and success rates, especially for large scale tree-planting programs would be of great value to compare the cost effectiveness of using a more knowledge intensive approach to tree planting in general and advocate the need for long-term trials and impact evaluations.

6.4. CONCLUSIONS

Through the four papers of contrasting agroforestry systems presented in this thesis, I demonstrate that farmers' knowledge about agroecological interactions is rich and complementary to science and can be articulated both qualitatively and quantitatively. It can thus be explicitly integrated in tree planting or agroforestry development initiatives to make more objective assessments about how a diverse range of tree species, largely unknown to science but important in farmers' practice, might be expected to affect farm production and other ecosystem services. In both the tropical highland context in Rwanda and in the semi-arid Sudanian parklands in Burkina Faso, we found the novel tree attribute ranking and the explicit probability model to be a practical route to predict effects of agroecological interactions about which ranking estimates were consistent and agree with scientific assessments when they can be compared. Given the paucity of global information about tree traits, the ranking method, when applied with a rigorous protocol and the integration of local knowledge, provided a cost-effective way of classifying trees based on ecological, management and utility attributes. The findings provide new information about a range of native and exotic trees and their management that can be used in developing customised decision support tools for integrating a diversity of trees for multiple ecosystem services in different contexts. We also demonstrate that taking an 'options by context' approach that builds on local and scientific knowledge is a solid basis for structuring engagement with local stakeholders to co-design more inclusive agroforestry options. In DRC, this led to a change in the attitudes and knowledge around tree planting by stakeholders with a shift from the promotion of a handful of exotic tree species in woodlots, largely benefiting wealthier men, to recommendations for over 70 species, 30 of them native, across a wide range of field, farm and landscape niches that addressed the needs of women, various ethnic groups and different types of farmers, including those producing annual crops, perennial crops and livestock. The process was also useful in structuring the information necessary to address key constraints for scaling up agroforestry by systematically considering different options (technologies, market interventions and institutional reform), against the contexts for which they were relevant (covering ecological, economic, social and cultural factors). The next step would be to test how greater inclusiveness in agroforestry options identified and promoted in an area through a more knowledge intensive approach leads to more effective scaling up because the range of options are sensitive to the needs and conditions of a higher proportion of the people living there.

REFERENCES

Abeyasekera, S. (2001). Analysis approaches in participatory work involving ranks or scores. DFID Theme Paper (revised). UK: Statistical Services Centre, University of Reading. 17p.

Akpo, E., Crane, T.A., Vissoh, P.V. & Tossou, R.C. (2014). Co-production of Knowledge in Multi-stakeholder Processes: Analyzing Joint Experimentation as Social Learning. Journal of Agricultural Education and Extension: 1-20. http://dx.doi.org/10.1080/1389224X.2014.939201

Anglaaere L.C.N., Cobbina J., Sinclair, F.L. & McDonald M.A. (2011). The effect of land use systems on tree diversity: farmer preference and species composition of cocoa-based agroecosystems in Ghana. Agroforestry Systems 81 (3): 249–265.

Ashley, R., Russell, D., & Swallow, B. (2006). The policy terrain in protected area landscapes: challenges for agroforestry in integrated landscape conservation, Biodiversity & Conservation, 15(2): 663-689.

Anim-Kwapong, G.J. & Osei-Bonsu, K. (2009). Potential of natural and improved fallow using indigenous trees to facilitate cacao replanting in Ghana. Agroforestry systems 76(3): 533-542

Asare, R. (2005). Cocoa agroforests in West Africa: a look at activities on preferred trees in the farming systems. Forest and Landscape Denmark (FLD) 77p

Asare, R. (2006). Learning about neighbour trees in cocoa growing systems: a manual for farmer trainers. Forest and Landscape Development and Environment Series 4-2006 80p

Assiri, A., Yoro, G., Deheuvels, O., Kebe, B.I., Keli, Z.J., Adiko, A. & Assa, A. (2009). Les caractéristiques agronomiques des vergers de cacaoyer (*Theobroma cacao* L.) en Côte d'Ivoire. Journal of Animal and Plant Sciences 2(1): 55-66.

Augusseau, X., Nikiéma, P., & Torquebiau, E. (2006). Tree biodiversity, land dynamics and farmers' strategies on the agricultural frontier of south-western Burkina Faso. Biodiversity & Conservation, 15(2), 613-630.

Barnes, R., & Fagg, C. W. (2003). *Faidherbia albida* monograph and annotated bibliography. Tropical Forestry Papers No 41, Oxford Forestry Institute, Oxford, UK. 281 p

Barrios, E., Sileshi, G., Shepherd, K. & Sinclair, F.L. (2012). Agroforestry and soil health: Linking trees, soil biota and ecosystem services. Soil Ecology and Ecosystem Services:315-330.

Battisti, D. S., & Naylor, R. L. (2009). Historical warnings of future food insecurity with unprecedented seasonal heat. Science (New York, N.Y.), 323(5911), 240-244. doi:10.1126/science.1164363 [doi]

Bayala, J., Mando, A., Ouedraogo, S., & Teklehaimanot, Z. (2003). Managing *Parkia biglobosa* and *Vitellaria* paradoxa prunings for crop production and improved soil properties in the sub-sudanian zone of Burkina Faso. Arid Land Research and Management, 17(3):283-296.

Bayala, J., Mando, A., Teklehaimanot, Z., & Ouedraogo, S. (2005). Nutrient release from decomposing leaf mulches of karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) under semi-arid conditions in Burkina Faso, West Africa. Soil Biology and Biochemistry, 37(3): 533-539.

Bayala, J., Balesdent, J., Marol, C., Zapata, F., Teklehaimanot, Z., & Ouedraogo, S. (2006). Relative contribution of trees and crops to soil carbon content in a parkland system in Burkina Faso using variations in natural 13C abundance. Nutrient Cycling in Agroecosystems, 76(2-3): 193-201.

Bayala, J., Kalinganire, A., Tchoundjeu, Z., Sinclair, F., & Garrity, D. (2011). Conservation agriculture with trees in the West African Sahel–a review. ICRAF Occasional Paper, 14 p

Bayala, J., Bazié, H.R., Sanou, J. (2013). Competition and facilitation-related factors impacts on crop performance in an agroforestry parkland system in Burkina Faso. African Journal of Agricultural Research 8(43): 5303-5310.

Bayala, J., Sanou, J., Teklehaimanot, Z., Kalinganire, A., & Ouédraogo, S. (2014). Parklands for buffering climate risk and sustaining agricultural production in the Sahel of West Africa doi:http://dx.doi.org/10.1016/j.cosust.2013.10.004

Bayala, J., Sanou, J., Teklehaimanot, Z., Ouedraogo, S. J., Kalinganire, A., Coe, R., & Noordwijk, M. v. (2015). Advances in knowledge of processes in soil–tree–crop interactions in parkland systems in the West African Sahel: A review doi:http://dx.doi.org/10.1016/j.agee.2015.02.018

Berkes, F. (1993) Traditional ecological knowledge in perspective in Inglis, J.T (Ed.), Traditional Ecological Knowledge, Concepts and Cases, Canadian Museum of Nature/International Development Research Centre, Ottawa: 1-9

Berkes, F., & Turner, N. J. (2006). Knowledge, learning and the evolution of conservation practice for social-ecological system resilience. Human Ecology, 34(4): 479

Binam, J. N., Place, F., Kalinganire, A., Hamade, S., Boureima, M., Tougiani, A., Badji, M. (2015). Effects of farmer managed natural regeneration on livelihoods in semi-arid West Africa. Environmental Economics and Policy Studies, 17(4):543-575.

Bisseleua, D.H.B., Missoup, A.D. & Vidal, S. (2009). Biodiversity conservation, ecosystem functioning, and economic incentives under cocoa agroforestry intensification. Conservation Biology 23(5): 1176-1184

Boffa, J. (1999). Agroforestry parklands in Sub-Saharan Africa (No. FAO CG-34 FAO, Roma (Italia). 233 p

Bos, M.M., Steffan-Dewenter, I. & Tscharntke, T. (2007). The contribution of cacao agroforests to the conservation of lower canopy ant and beetle diversity in Indonesia. Biodiversity & Conservation 16(8): 2429-2444

Bouda, H., Savadogo, P., Tiveau, D., & Ouedraogo, B. (2011). State, forest and community: Challenges of democratically decentralizing forest management in the Centre‐West region of Burkina Faso. Sustainable Development, 19(4): 275-288.

Bradley, R.A. & Terry, M.E. (1952). Rank analysis of incomplete block designs: I. The method of paired comparisons. Biometrika, *39*(3/4): 324-345.

Brandi, E., Lillesø, J-P. B., Moestrup, S., & Kisera, H. K, (2007). Do organisations provide quality seed to smallholders?: a study on tree planting in Uganda, by NGOs and CBOs. Development and Environment, No 8- Hørsholm: Center for Skov, Landskabog Planlægning/Københavns Universitet, Denmark, 68p.

Breman, H., & Kessler, J. (2012). Woody plants in agro-ecosystems of semi-arid regions: With an emphasis on the Sahelian countries Advance series in agricultural sciences 23, Springer Verlag Berlin. 34 p

Brou T. (2010). Variabilité climatique, déforestation et dynamique agrodémographique en Côte d'Ivoire. Science et changements planétaires/Sécheresse 21(4): 327-329

Cerda, R., Deheuvels, O., Calvache D., Niehaus, L., Saenz, Y., Kent, J., Vilchez, S., Villota, A., Martinez, C., & Somarriba E. (2014). Contribution of cocoa agroforestry systems to family income and domestic consumption: looking toward intensification. Agroforestry systems 88(6): 957-981.

Cerdan, C.R., Rebolledo, M.C., Soto-Pinto, G., Rapidel, B. & Sinclair, F.L. (2012). Local knowledge of impacts of tree cover on ecosystem services in smallholder coffee production systems. Agricultural Systems 110: 119-130.

Chambers, R. (1997). Whose reality counts (Vol. 25). London: Intermediate technology publications.

Chomba, S. W., Nathan, I., Minang, P.A. & Sinclair, F. (2015). Illusions of empowerment? Questioning policy and practice of community forestry in Kenya, Ecology and Society 20(3): 2. http://dx.doi.org/10.5751/ES-07741-200302

Clough, Y., Faust, H. & Tscharntke, T. (2009). Cacao boom and bust: sustainability of agroforests and opportunities for biodiversity conservation. Conservation Letters 2 (5): 197-205.

Coe R. (2010). Analysing ranking and rating data from participatory on-farm trials. African Statistics Journal,10 :14-53

Coe, R., Sinclair, F. & Barrios, E. (2014). Scaling up agroforestry requires research 'in'rather than 'for'development, Current Opinion in Environmental Sustainability, (6):73-77.

CNRA (2011). Guide de la lutte contre la maladie du swollen shoot du cacaoyer en Cote d'Ivoire, Première edition. Centre National de Recherche Agronomique/Programme Cacao. 39pp

De Foresta, H, Somarriba, E, Temu, A, Boulanger, D, Feuilly, H, Gauthier ,M. (2013). Towards the assessment of trees outside forests. Resources Assessment Working Paper 183. Rome: Food and Agriculture Organization of the United Nations

Dawson I., Harwood C., Jamnadass R. & Beniest J. (eds.) (2012). Agroforestry tree domestication: a primer, The World Agroforestry Centre, Nairobi, Kenya. 148 p.

Dawson I. K., Guariguata M. R., Loo J., Weber J. C., Lengkeek A., Bush D., Cornelius J., Guarino L., Kindt R., Orwa C., & Russell J. (2013). What is the relevance of smallholders' agroforestry systems for conserving tropical tree species and genetic diversity in circa situm, in situ and ex situ settings? A review. Biodiversity & Conservation, 22(2): 301-324.

Dayamba, S. D., Djoudi, H., Zida, M., Sawadogo, L., & Verchot, L. (2016). Biodiversity and carbon stocks in different land use types in the Sudanian zone of Burkina Faso, West Africa. Agriculture, Ecosystems & Environment, 216: 61-72.

DeFries, R., Hansen, A., Turner, B., Reid, R. & Liu, J. (2007). Land use change around protected areas: management to balance human needs and ecological function. Ecological Applications, 17(4): 1031-1038.

Deheuvels, O., Avelino, J., Somarriba, E. and Malezieux, E. (2012). Vegetation structure and productivity in cocoa-based agroforestry systems in Talamanca, Costa Rica. Agriculture, Ecosystems & the Environment 149: 181-188

Díaz, S., Lavorel, S., de Bello, F., Quétier, F., Grigulis, K., & Robson, T. M. (2007).

Incorporating plant functional diversity effects in ecosystem service assessments. Proceedings of the National Academy of Sciences, 104(52): 20684-20689.

Diedhiou, S., Dossa, E.L., Badiane, A.N., Diedhiou, I., Sene, M., Dick, R.P., (2009). Decomposition and spatial microbial heterogeneity associated with native shrubs in soils of agroecosystems in semi-arid Senegal., Pedobiologia 52: 273-286.

Donovan C., Mpyisi E. and Loveridge S. (2002). Forces Driving Change in Rwandan Smallholder Agriculture 1990-2001. Ministry of Agriculture (MINAGRI) research report (unpublished).

Dossa, E. L., Diedhiou, I., Khouma, M., Sene, M., Badiane, A. N., Samba, N., Lufafa, A. (2013). Crop productivity and nutrient dynamics in a shrub-based farming system of the Sahel. Agronomy Journal, 105(4):1237-1246.

Duarte, E. M., Cardoso, I. M., Stijnen, T., Mendonça, M. A. F., Coelho, M. S., Cantarutti, R. B. & Mendonça, E. S. (2013). Decomposition and nutrient release in leaves of Atlantic Rainforest tree species used in agroforestry systems. Agroforestry systems, *87* (4) : 835-847.

Duguma, B., Gockowski, J. and Bakala, J. (2001). Smallholder cacao (*Theobroma cacao* Linn.) cultivation in agroforestry systems of West and Central Africa: challenges and opportunities. Agroforestry systems 51(3): 177-188

Dusengemungu L. & Zaongo C. (2006). Etat de la recherche agroforestière au Rwanda, étude bibliographique, période : 1987–2003. ICRAF Working Paper (30). Nairobi, World Agroforestry Centre. [2]

Etongo, D., Djenontin, I. N. S., Kanninen, M., & Fobissie, K. (2015a). Smallholders' tree planting activity in the Ziro province, southern Burkina Faso: Impacts on livelihood and policy implications. Forests, 6(8): 2655-2677.

Etongo, D., Djenontin, I. N. S., Kanninen, M., Fobissie, K., Korhonen-Kurki, K., & Djoudi, H. (2015b). Land tenure, asset heterogeneity and deforestation in southern Burkina Faso doi: http://dx.doi.org/10.1016/j.forpol.2015.08.006

FAO. 2013. Advancing Agroforestry on the Policy Agenda: A guide for decision-makers, by G. Buttoud, in collaboration with O. Ajayi, G. Detlefsen, F. Place & E. Torquebiau. Agroforestry Working Paper no. 1. Food and Agriculture Organization of the United Nations. FAO, Rome. 37 pp.

FAO. (2017). Regional Overview of Food Security and Nutrition in Africa 2016. The challenges of building resilience to shocks and stresses. Accra. Ghana 40p

Faye, M. D., Weber, J. C., Abasse, T. A., Boureima, M., Larwanou, M., Bationo, A. B., Samaké, O. (2011). Farmers'preferences for tree functions and species in the West African Sahel. Forests, Trees and Livelihoods, 20(2-3):113-136.

Félix, G. F., Douzet, J., Ouédraogo, M., Belliard, P., Lahmar, R., Clermont-Dauphin, C., Cournac, L. (2015). Ecosystem services for West African farming families: The role of woody shrub mulch. 5th International Symposium for Farming Systems Design, Montpellier, France. http://www.wassa-eu.org/wp-content/uploads/2013/09/FSD5_Félix-et-al-2015_v2.pdf

FIRCA (2008). Guide la régénération des vergers de cacaoyer ou de caféier en Côte d'Ivoire. Le Fonds Interprofessionnel pour la Recherche et le Conseil Agricole. République de Côte d'Ivoire. 39 p

Foli, S., & Abdoulaye, R. (2016). Drivers and outcomes of changing land use in parkland agroforestry systems of central Burkina Faso. In Deakin, L., Kshatriya, M. & Sunderland T. (eds) Agrarian Change in Tropical Landscapes, Bogor Indonesia, CIFOR :269-301

Fontès, J., & Guinko, S. (1995). Carte de la végétation et de l'occupation du sol du Burkina Faso: Notice explicative. Toulouse: Ministère De La Coopération Française 66p

Franzel, S., Hitimana, L., & Akyeampong, E. (1995). Farmer Participation in On-Station Tree Species Selection for Agroforestry: a Case Study from Burundi. Experimental Agriculture 31: 27-38.

Franzel, S., Jaenicke, H., & Janssen, W. (1996). Choosing the right trees: setting priorities for multipurpose tree improvement, The Hague, The Netherlands: ISNAR, 81p.

Franzel, S., Coe, R., Cooper, P., Place, F., & Scherr, S. J. (2001). Assessing the adoption potential of agroforestry practices in sub-Saharan Africa Agricultural systems, 69(1): 37-62.

Franzen, M. & Mulder, M.B. (2007). Ecological, economic and social perspectives on cocoa production worldwide. Biodiversity & Conservation 16(13): 3835-3849

Garcia, C.A., Bhagwat S.A., Ghazoul J., Nath C. D., Nanaya K. M., Kushalappa C.G. and Vaast P. (2010). Biodiversity conservation in agricultural landscapes: challenges and opportunities of coffee agroforests in the Western Ghats, India. Conservation Biology, 24(2):479-488.

Garrity, D. P., Akinnifesi, F. K., Ajayi, O. C., Weldesemayat, S. G., Mowo, J. G., Kalinganire, A., Bayala, J. (2010). Evergreen agriculture: A robust approach to sustainable food security in Africa. Food Security, 2(3): 197-214.

Gausset, Q. (2004). Ranking local tree needs and priorities through an interdisciplinary action research approach. The Journal of Transdisciplinary Environmental Studies 3: 1-17.

German, L.A., Kidane, B. & Shemdoe, R. (2006). Social and environmental trade-tree species selection: a methodology for identifying niche incompatibilities in agroforestry, Environment, Development and Sustainability, 8 (4): 535-552.

Gnankambary, Z., Bayala, J., Malmer, A., Nyberg, G., & Hien, V. (2008). Decomposition and nutrient release from mixed plant litters of contrasting quality in an agroforestry parkland in the south-sudanese zone of West Africa. Nutrient Cycling in Agroecosystems, 82(1):1-13.

Gockowski, J., Weise, S., Sonwa, D., Tchatat, M. & Ngobo, M. (2004). Conservation because it pays: shaded cocoa agroforests in West Africa. National Academy of Sciences in Washington DC on February 10. 2004. (http://www.icraf.com/treesandmarkets/inaforesta/documents/shaded_cocoa_agroforests_in_w_africa.pdf)

Gockowski, J. & Sonwa, D. (2011). Cocoa intensification scenarios and their predicted impact on CO2 emissions, biodiversity conservation, and rural livelihoods in the Guinea rain forest of West Africa. Environmental Management 48 (2): 307-321.

Gonzalez, P., Tucker, C. J., & Sy, H. (2012). Tree density and species decline in the African Sahel attributable to climate. Journal of Arid Environments, 78, 55-64.

Gram, G., Vaast, P., van der Wolf, J., & Jassogne, L. (2017). Local tree knowledge can fast-track agroforestry recommendations for coffee smallholders along a climate gradient in mount Elgon, Uganda. Agroforestry Systems, 1-14.

Gyau, A., Franzel, S., Chiatoh, M., Nimino, G. & Owusu, K. (2014). Collective action to improve market access for smallholder producers of agroforestry products: key lessons learned with insights from Cameroon's experience, Current Opinion in Environmental Sustainability, 6: 68-72.

Hall, J., Tomlinson, H., Oni, P., Buchy, M., & Aebischer, D. (1997). *Parkia biglobosa*: A monograph. A monograph, School of Agricultural and Forest Sciences, University of Wales Bangor, UK, 105 p.

Hall, J. B., Aebischer, D. P., Tomlinson, H. F., Osei-Amaning, E., & Hindle, J. (1996). *Vitellaria paradoxa*: A monograph, School of Agricultural and Forest Sciences, University of Wales Bangor, UK, 105 p.

Hänke, H., Börjeson, L., Hylander, K., & Enfors-Kautsky, E. (2016). Drought tolerant species dominate as rainfall and tree cover returns in the West African Sahel. Land use Policy, 59: 111-120.

Harvey, C.A., Villanueva, C., Esquivel, H., Gómez, R., Ibrahim, M., Lopez, M., Martinez, J., Muñoz, D., Restrepo, C., Saénz, J.C., Villacís, J. & Sinclair, F.L. (2011). Conservation value of dispersed tree cover threatened by pasture management. Forest Ecology and Management 261: 1664-1674.

Herrmann, S. M., Anyamba, A., & Tucker, C. J. (2005). Recent trends in vegetation dynamics in the african sahel and their relationship to climate. Global Environmental Change, 15(4): 394-404.

Herzog F (1994). Multipurpose shade trees in coffee and cocoa plantations in Côte d'Ivoire. Agroforestry systems 27: 259-267 .

Holmes KA, Evans HC, Wayne S and Smith, J (2003) *Irvingia*, a forest host of the cocoa black-pod pathogen, *Phytophthora megakarya*, in Cameroon. Plant Pathology 52(4): 486-490

ICRAF-INERA (2013). Etude exploratoire et prioritisation des espèces agroforestières dans les villages pilotes du projet Biocarbone et Développement Rurale en Afrique de l'Ouest (BIODEV) au Burkina Faso. 94 p

ICRAF (2011). Presentation Synoptique du Departement de Soubré. World Agroforestry Centre Vision for Change Project, Internal Document. Cote d'Ivoire

Inderjit, K., & Keating, L. (1999). Allelopathy: Principal and practice. promises for biological control in: Advance in agronomy,(eds). John Sparks dl. Academic Press, 67: 141-231.

Iiyama, M., Derero, A., Kelemu, K., Muthuri, C.W. , Kinuthia, R., Ayenkulu, E., Kiptot, E., Hadgu, K., Mowo, .J, Sinclair, F.L. (2016). Understanding patterns of tree adoption on farms in semi-arid and sub-humid Ethiopia, Agroforestry Systems http://link.springer.com/article/10.1007/s10457-016-9926-y

Ickowitz, A., Powell, B., Salim, M. A., & Sunderland, T. C. (2014). Dietary quality and tree cover in Africa. Global Environmental Change, 24:287-294.

Institut National de la Statistique INS (2015). Annuaire statistique 2014, Ministère du Plan et Révolution de la Modernité, République Démocratique du Congo, 560p.

Isaac, M.E., Timmer, V.R. & Quashie-Sam S.J. (2007). Shade tree effects in an 8-year-old cocoa agroforestry system: biomass and nutrient diagnosis of *Theobroma cacao* by vector analysis. Nutrient Cycling in Agroecosystems 78(2): 155-165

Jagoret, P., Kwesseu, J., Messie, C. , Michel-Dounias, I. & Malezieux, E. (2014). Farmers' assessment of the use value of agrobiodiversity in multispecies systems. An application to cocoa agroforests in central Cameroon. Agroforestry systems,88 (6): 983-1000.

Jagoret, P., Michel-Dounias, I., and Malézieux, E. (2011). Long-term dynamics of cocoa agroforests: a case study in central Cameroon. Agroforestry systems 81(3): 267-278.

Jamnadass, R. H., Dawson, I. K., Franzel, S., Leakey, R. R. B., Mithöfer, D., Akinnifesi, F. K., & Tchoundjeu, Z. (2011). Improving livelihoods and nutrition in sub-Saharan Africa through the promotion of indigenous and exotic fruit production in smallholders' agroforestry systems: a review. International Forestry Review, 13(3): 338-354.

Jayne, T.S., Chamberlain, J & Headey, D.D. (2014). Land pressures, the evolution of farming systems, and development strategies in Africa: A synthesis. Food Policy 48: 1-17

Jha, S., Bacon, C. M., Philpott, S. M., Méndez, V. E., Läderach, P. & Rice, R. A. (2014). Shade coffee: update on a disappearing refuge for biodiversity. BioScience, 64(5): 416-428.

Jose, S. (2009). Agroforestry for ecosystem services and environmental benefits: an overview. Agroforestry systems, 76(1), 1-10.

Kalinganire, A., Weber, J., Uwamariya, A., & Kone, B. (2007). Improving rural livelihoods through domestication of indigenous fruit trees in the parklands of the Sahel in Akinnifesi F.K., Leakey R.R.B., Ajayi O.C., Sileshi G., Tchoundjeu Z., Matakala P., Kwesiga F.R. (eds) Indigenous fruit trees in the tropics: domestication, utilization and commercialization. CAB International, Wallingford 186-203.

Kandji, S. T., Verchot, L., & Mackensen, J. (2006). Climate change and variability in the Sahel region: Impacts and adaptation strategies in the agricultural sector United Nations Environment Programme World Agroforestry Centre Nairobi. Kenya, 36p

Karamage, F., Zhang, C., Ndayisaba, F., Shao, H., Kayiranga, A., Fang, X., & Tian, G. (2016). Extent of cropland and related soil erosion risk in Rwanda. Sustainability, 8(7):609.

Kattge, J., Diaz, S., Lavorel, S., Prentice, I. C., Leadley, P., Bönisch, G., & Cornelissen, J. H. C. (2011). TRY–a global database of plant traits. Global change biology, 17(9), 2905-2935.

Kindt, R., Kalinganire, A., Larwanou, M., Belem, M., Dakouo, J. M., Bayala, J., & Kairé, M. (2008). Species accumulation within land use and tree diameter categories in Burkina Faso, Mali, Niger and Senegal., Biodiversity and Conservation, 17(8), 1883-1905.

Kiptot, E. & Franzel, S. (2012). Gender and agroforestry in Africa: a review of women's participation, Agroforestry Systems, 84(1):35-58.

Koffi, C. K., Djoudi, H., & Gautier, D. (2016). Landscape diversity and associated coping strategies during food shortage periods: Evidence from the Sudano-sahelian region of Burkina Faso. Regional Environmental Change, 1-12.

Koko, L.K., Snoeck, D., Lekadou, T.T. & Assiri, A.A. (2013). Cacao-fruit tree intercropping effects on cocoa yield, plant vigour and light interception in Côte d'Ivoire. Agroforestry systems, 87(5), 1043-1052.

Koko, L.K., Kassin, K.E., Yoro, G., NGoran, K. & Yao-Kouamé, A. (2009). Corrélations entre le vieillissement précoce des cacaoyers et les caractéristiques morphopédologiques dans le sud-ouest de la Côte d'Ivoire. Journal of Applied Biosciences 24:1508-1519

Kwesiga, F., F. K. Akinnifesi, P. L. Mafongoya, M. H. McDermott, and A. Agumya. (2003) Agroforestry research and development in southern Africa during the 1990s: review and challenges ahead. Agroforestry systems 59 (3): 173-186.

Lamond, G., Sandbrook, L., Gassner, A. and Sinclair F.L. (2016) Local knowledge of tree attributes underpins species selection on coffee farms. Experimental Agriculture http://dx.doi.org/10.1017/S0014479716000168 [2]

Leakey, R.R.B. and Tchoundjeu, Z. (2001). Diversification of tree crops: domestication of companion crops for poverty reduction and environmental services. Experimental Agriculture 37: 279–296.

Lejeune, G., Ansay, F., Van Geit, M. & Lusenge, T. (2013). ECOmakala : répondre à la demande énergétique pour protéger les forêts du Parc National des Virunga au Nord-Kivu (RDC) et lutter contre la pauvreté, WWF Belgium, 36 p

Léonard, E. and Ibo, J.G. (1994). Appropriation et gestion de la rente forestière en Côte-d'Ivoire: La nature et l'homme en Afrique. Politique africaine 53: 25-36

Lillesø, J., Graudal, L., Moestrup, S., Kjær, E.D., Kindt, R., Mbora, A., Dawson, I., Muriuki, J., Ræbild, A. & Jamnadass, R. (2011). Innovation in input supply systems in smallholder agroforestry: seed sources, supply chains and support systems. Agroforestry Systems, 83(3):347-359.

Lykke, A., Kristensen, M., & Ganaba, S. (2004). Valuation of local use and dynamics of 56 woody species in the sahel. Biodiversity and Conservation, 13(10): 1961-1990.

Mbow, C., Van Noordwijk, M., Luedeling, E., Neufeldt, H., Minang, P. A., & Kowero, G. (2014a). Agroforestry solutions to address food security and climate change challenges in Africa. Current Opinion in Environmental Sustainability, 6: 61-67

Mbow, C., van Noordwijk, M., Prabhu, R. & Simons, T. (2014b). Knowledge gaps and research needs concerning agroforestry's contribution to sustainable development goals in Africa. Current Opinion in Environmental Sustainability, 6: 162-170.

Meijer, S.S., Catacutan, D., Ajayi, O.C., Sileshi, G.W. & Nieuwenhuis, M. (2015). The role of knowledge, attitudes and perceptions in the uptake of agricultural and agroforestry innovations among smallholder farmers in sub-Saharan Africa. International Journal of Agricultural Sustainability, 13(1): 40-54.

Méndez, V. E, Bacon, C.M., Olson, M., Morris, K. S. & Shattuck A. (2010). Agrobiodiversity and Shade Coffee Smallholder Livelihoods: A Review and Synthesis of Ten Years of Research in Central America. The Professional Geographer 62 (3): 357- 376

Mercer, D. E. (2004). Adoption of agroforestry innovations in the tropics: a review. Agroforestry systems, 61(1): 311-328.

Mertz, O., Mbow, C., Reenberg, A., Genesio, L., Lambin, E. F., D'haen, S., Barbier, B. (2011). Adaptation strategies and climate vulnerability in the Sudano-Sahelian region of West Africa. Atmospheric Science Letters, 12(1):104-108.

Mission économique, MINEFI-DGTPE (2005). Le Cacao en Côte d'Ivoire. Fiche de synthèse, Ambassade de France en Côte d'Ivoire. 3 p.

Montagnini, F., Ramstad, K. & Sancho, F. (1993). Litterfall, litter decomposition and the use of mulch of four indigenous tree species in the Atlantic lowlands of Costa Rica. Agroforestry Systems, 23(1): 39-61

Mortimore, M., & Turner, B. (2005). Does the Sahelian smallholder's management of woodland, farm trees, rangeland support the hypothesis of human-induced desertification? Journal of Arid Environments, 63(3): 567-595.

National Institute of Statistics of Rwanda (NISR), Ministry of Finance and Economic Planning (2012). Rwanda Fourth Population and Housing Census, Thematic Report: Population size, structure and distribution, Rwanda.

Nair, P.K.R (1993). An introduction to agroforestry. Springer Science & Business Media, 1993.

Ndayambaje, J.D. & Mohren, G.M.J. (2011). Fuelwood demand and supply in Rwanda and the role of agroforestry. Agroforestry systems, 83(3): 303-320.

Neef, A. & Neubert, D. (2011). Stakeholder participation in agricultural research projects: a conceptual framework for reflection and decision-making. Agriculture and Human Values, 28(2):179-194.

Nomo B., Madong B.A. & Sinclair F.L/ (2008). Status of non-cocoa tree species in cocoa multistrata systems of Southern Cameroon. International Journal of Biological and Chemical Sciences, 2(2): 207-215.

Nyaga, J., Barrios, E., Muthuri, C.W., Öborn, I., Matiru, V. & Sinclair, F.L. (2015). Evaluating factors influencing heterogeneity in agroforestry adoption and practices within smallholder farms in Rift Valley, Kenya. Agriculture, Ecosystems & Environment, 212: 106-118.

Nyoka, B.I., Mng'omba, S.A., Akinnifesi, F.K., Ajayi, O.C., Sileshi, G. & Jamnadass, R. 2011, Agroforestry tree seed production and supply systems in Malawi, Small-Scale Forestry,10(4): 419-434.

Nzeyimana I., Hartemink A. E. & de Graaff J. (2013). Coffee farming and soil management in Rwanda. Outlook on Agriculture, 42(1): 47-52.

N'Goran, K. (1998) Reflections on a durable cacao production: the situation in the Ivory Coast, Africa. Paper presented at a workshop held in Panama, 3/30-4/2, 1998. Smithsonian Institution, Washington, D.C.

Obiri, B.D., Bright, G.A., McDonald, M.A., Anglaaere, L.C. & Cobbina J (2007). Financial analysis of shaded cocoa in Ghana. Agroforestry systems 71(2): 139-149

Oke, D.O. & Odebiyi K.A. (2007). Traditional cocoa-based agroforestry and forest species conservation in Ondo State, Nigeria. Agriculture, Ecosystems and the Environment 122(3): 305-311

Olsson, P., & Folke, C. (2001). Local ecological knowledge and institutional dynamics for ecosystem management: a study of Lake Racken watershed, Sweden. Ecosystems, 4(2), 85-104.

OIPR, GTZ (2000). Flore du Parc national de Tai (Côte d'Ivoire). Manuel de reconnaissance des principales plantes. Office Ivoirien des Parcs et Réserves. Ed. Kasparek Verlag 320pp

Ordonez, J. C., Luedeling, E., Kindt, R., Tata, H. L., Harja, D., Jamnadass, R., & van Noordwijk, M. (2014). Constraints and opportunities for tree diversity management along the forest transition curve to achieve multifunctional agriculture. Current Opinion in Environmental Sustainability, 6: 54-60.

Opoku, I.Y., Akrofi, A.Y. & Appiah, A.A. (2002). Shade trees are alternative hosts of the cocoa pathogen *Phytophthora megakarya*. Crop Protection 21(8): 629-634

Orwa, C., Mutua, A., Kindt, R., Jamnadass, R. & Simons, A. (2009). Agroforestree database: a tree reference and selection guide version 4.0.

Oszwald, J. (2005). Dynamique des formations agroforestières en Côte d'Ivoire (depuis les années 1980 aux années 2000): suivi par télédétection et développement d'une approche cartographique. 2005. PhD Thesis. Université de Lille, France

O'Donnell, M., Cook, A & Magistro, J. (2015). Assessment of the DRC's agricultural market systems: value chains in the North & South Kivu and Katanga provinces. LEO Report #16, USAID, Washington 192p

O'Farrell, P. J., & Anderson, P. M. (2010). Sustainable multifunctional landscapes: a review to implementation. Current Opinion in Environmental Sustainability, 2(1): 59-65.

Ouédraogo, I., Mbow, C., Balinga, M., & Neufeldt, H. (2015). Transitions in land use architecture under multiple human driving forces in a semi-arid zone. Land, 4(3): 560-577.

Ouédraogo, P., Bationo, B. A., Sanou, J., Traoré, S., Barry, S., Dayamba, S. D., . Thiombiano, A. (2017). Uses and vulnerability of ligneous species exploited by local population of northern Burkina faro in their adaptation strategies to changing environments. Agriculture & Food Security, 6(1):15.

Padi, B. and Owusu, G.K. (2003). Towards an Integrated Pest Management for Sustainable Cocoa Production in Ghana. Paper from workshop held in Panama, 3/30-4/2, 1998. Smithsonian institution. Washington, D.C.

Palla, F. (2005) *Alstonia boonei* De Wild. [Internet] Record from PROTA4U. Louppe, D., Oteng-Amoako, A.A. and Brink, M. (Editors). PROTA (Plant Resources of Tropical Africa / Ressources végétales de l'Afrique tropicale), Wageningen, Netherlands.

Paré, S., Söderberg, U., Sandewall, M., & Ouadba, J. M. (2008). Land use analysis from spatial and field data capture in southern Burkina Faso, West Africa. Agriculture, Ecosystems & Environment, 127(3): 277-285.

Parfitt, Julian. (1997). Questionnaire design and sampling in Flowerdew, R. & Martin, D.M. (Eds) Methods in human geography: A guide for students doing a research project 76-109. 2nd Edition, Routledge

Pattanayak, S. K., Mercer, D. E., Sills, E., & Yang, J. C. (2003). Taking stock of agroforestry adoption studies. Agroforestry systems, 57(3): 173-186.

Patton, M.Q. (2005). Qualitative research. Encyclopedia of Statistics in Behavioral Science. John Wiley & Sons, Ltd. DOI: 10.1002/0470013192.bsa514

Phillips, E.J. (1977). Mistletoe on cocoa in Ghana. Ghana Journal of Agriculture Sciences 10: 137-143.

Philpott, S.M. & Dietsch, T. (2003). Coffee and conservation: a global context and the value of farmer involvement. Conservation Biology 17: 1844–1846.

Pinard, F., Boffa, J.M. & Rwakagara E. (2014). Scattered shade trees improve low-input smallholder arabica coffee productivity in the northern Lake Kivu region of Rwanda. Agroforestry Systems, 88(4): 707-718

Place, F., Garrity, D., Mohan, S., & Agostini, P. (2016). Tree-based production systems for Africa's drylands World Bank Publications. doi: 10.1596/978-1-4648-0828-9. License: Creative Commons Attribution CC BY 3.0 IGO 93p

Plumptre, A. J., Davenport, T. R., Behangana, M., Kityo, R., Eilu, G., Ssegawa, P., & Moyer, D. (2007). The biodiversity of the Albertine Rift. Biological Conservation, 134(2): 178-194.

Pollini, J. (2009). Agroforestry and the search for alternatives to slash-and-burn cultivation: From technological optimism to a political economy of deforestation. Agriculture, Ecosystems & Environment, 133(1): 48-60.

Pretty, J. N. (1997).The sustainable intensification of agriculture. In Natural resources forum , 21, (4). 247-256). Blackwell Publishing Ltd.

Raintree, J. (1987) The state of the art of agroforestry diagnosis and design. Agroforestry Systems, 5: 219-250

Raymond, C. M., Fazey, I., Reed, M. S., Stringer, L. C., Robinson, G. M., & Evely, A. C. (2010). Integrating local and scientific knowledge for environmental management. Journal of environmental management, 91(8):1766-1777.

Reij, C., Tappan, G., & Smale, M. (2009). Agroenvironmental transformation in the Sahel: Another kind of" green revolution" IFPRI Discussion Paper 00914. Washington DC: International Food Policy Research Institute.

Reij, C., & Garrity, D. (2016). Scaling up farmer-managed natural regeneration in Africa to restore degraded landscapes. Biotropica, 48(6): 834-843. doi:10.1111/btp.12390

Reynolds, J. F., Smith, D. M., Lambin, E. F., Turner, B. L., Mortimore, M., Batterbury, S. P., Walker, B. (2007). Global desertification: Building a science for dryland development. Science (New York, N.Y.), 316(5826): 847-851. doi:316/5826/847 [pii]

Rice, R.A. & Greenberg, R. (2000). Cacao cultivation and the conservation of biological diversity. AMBIO: A Journal of the Human Environment 29(3): 167-173

Richardson, D. M., & Rejmánek, M. (2011). Trees and shrubs as invasive alien species–a global review. Diversity and Distributions, 17(5): 788-809.

Robiglio, V. & Sinclair, F.L. (2011). Maintaining the conservation value of shifting cultivation landscapes requires spatially explicit interventions. Environmental Management 48: 289-306

Rousseau, G. X., Deheuvels, O., Rodriguez Arias, I., & Somarriba, E. (2012). Indicating soil quality in cacao-based agroforestry systems and old-growth forests: The potential of soil macrofauna assemblage. Ecological Indicators 23: 535-543

Reubens, B., Moeremans, C., Poesen, J., Nyssen, J., Tewoldeberhan, S., Franzel, S., Deckers, J., Orwa, C. and Muys, B. (2011). Tree species selection for land rehabilitation in Ethiopia: from fragmented knowledge to an integrated multi-criteria decision approach. Agroforestry Systems, 82(3) :303-330.

Ruf, F. & Zadi, H. (1998). Cocoa: from deforestation to reforestation. Paper from workshop on Shade Grown Cocoa held in Panama, 3/30-4/2, 1998. Smithsonian institution. Washington, D.C.

Ruf, F. & Konan, A. (2001). Replanting difficulties: what future for cocoa in Côte d'Ivoire? Oléagineux Corps Gras Lipides 8:593-598

Ruf, F., Deheuvels, O. & Sarpong, D. (2006). Intensification in cocoa cropping systems: Is Agroforestry a solution for sustainability? The case of Manso Amenfi, Western Region, Ghana. In 15th International conference on cocoa research (1): 355-364

Ruf, F. (2011). The myth of complex cocoa agroforests: the case of Ghana. Human Ecology 39(3): 373-388

Russell, D. & Franzel, S. (2004). Trees of prosperity: agroforestry, markets and the African smallholder in New Vistas in Agroforestry, Springer : 345-355.

Ryan, D., Bright, G.A., & Somarriba, E. (2009). Damage and yield change in cocoa crops due to harvesting of timber shade trees in Talamanca, Costa Rica. Agroforestry systems 77:97-106

Saj, S., Jagoret, P. & Ngogue, H.T. (2013). Carbon storage and density dynamics of associated trees in three contrasting *Theobroma cacao* agroforests of Central Cameroon. Agroforestry systems 87(6):1309-1320.

SAN (Sustainable Agricultural Network) (2009) Interpretation guidelines – indicators for sustainable cocoa production in Ivory Coast, Sustainable Agriculture Program Rainforest Alliance, Costa Rica

SATMACI (1984) Manuel de cacaoculture. Societe d'Assistance Technique la Modernisation Agricole de la Côte d'Ivoire. Ministere de l'Agriculture. Abidjan, Avril 1984

Sayer, J., & Campbell, B. (2004) The Science of Sustainable Development Local livelihoods and the Global Environment Cambridge University Press

Sayer, J., Sunderland, T., Ghazoul, J., Pfund, J. L., Sheil, D., Meijaard, E., ... & van Oosten, C. (2013). Ten principles for a landscape approach to reconciling agriculture, conservation, and other competing land uses. Proceedings of the national academy of sciences, 110(21): 8349-8356.

Schroth, G. (1995). Tree root characteristics as criteria for species selection and systems design in agroforestry, in Sinclair, F. L. (Ed.) Agroforestry: Science, Policy and Practice, Kluwer Academic Publishers, Netherlands: 125–144.

Schroth, G., Krauss, U., Gasparotto, L., Aguilar, J.D. & Vohland, K. (2000) Pests ad diseases in agroforestry systems of the humid tropics. Agroforestry systems 50(3): 199-241.

Schroth, G. & Harvey, C.A. (2007) Biodiversity conservation in cocoa production landscapes: an overview. Biodiversity & Conservation 16(8): 2237-2244.

Sillitoe, P. (1998). The development of indigenous knowledge: a new applied anthropology. Current anthropology, 39(2): 223-252.

Sinclair, F.L. & Walker, D.H. (1998). Acquiring qualitative knowledge about complex agroecosystems. Part 1: a natural language approach to representation. Agricultural Systems, 56(3): 341-363.

Sinclair, F.L. (1999). A general classification of agroforestry practice, Agroforestry Systems, . 46, (2): 161-180.

Sinclair, F.L. & Walker, D.H., (1999). A utilitarian approach to the incorporation of local knowledge in agroforestry research and extension In: L.E. Buck, J.P. Lassoie and E.C.M. Fernandes (eds). Agroforestry in Sustainable Agricultural Systems, Lewis Publishers, New York: 245-275

Sinclair, F. L., & Joshi, L. (2000). Taking local knowledge about trees seriously. Forestry Forest Users and Research: New Ways of Learning.Edited by Lawrence A.European Tropical Research Network (ETFRN), 45-58.

Sinclair, F. L. (2017). Systems science at the scale of impact. Sustainable Intensification in Smallholder Agriculture in (Eds) An Integrated Systems Research Approach, (3) 43.

Sissoko, K., van Keulen, H., Verhagen, J., Tekken, V., & Battaglini, A. (2011). Agriculture, livelihoods and climate change in the West African Sahel. Regional Environmental Change, 11(1), 119-125.

Smith Dumont, E., Bonhomme S., Sinclair, F.L. (2015) Guide technique d'agroforesterie pour la sélection et la gestion des arbres au Nord-Kivu, RDC, World Agroforestry Centre, Nairobi, Kenya 130p.

Smith Dumont, E., Bonhomme, S., Pagella, T. and Sinclair, F.L. (2017). Structured stakeholder engagement leads to development of more diverse and inclusive agroforestry options. Experimental Agriculture. DOI: https://doi.org/10.1017/S0014479716000788

Smith-Dumont, E., Lamond, G., Nansamba, R., Gassner, A., & Sinclair, F. (in review) The utility of farmer ranking of tree attributes for selecting companion trees in coffee production systems. Agroforestry Systems

Somarriba, E., Cerda, R., Orozco, L., Deheuvels, O., Cifuentes, M., Dávila, H., Espin, T., Mavisoy, H., Ávila, G., Alvarado, E., Poveda, V., Astorga, C., & Say, E. (2013). Carbon stocks in agroforestry systems with cocoa (*Theobroma cacao* L.) in Central America. Agriculture, Ecosystems and the Environment 173:46-57.

Somarriba, E., Harvey, C.A., Samper M., Anthony F., González J., Staver C. & Rice R.A. (2004). Biodiversity conservation in neotropical coffee (*Coffea arabica*) plantations. Agroforestry and Biodiversity Conservation in Tropical Landscapes. Island Press, Washington, DC: 198-226.

Sonwa, D.J., Nkongmeneck, B.A., Weise, S.F., Tchatat, M., Adesina, A.A. & Janssens, M.J. (2007). Diversity of plants in cocoa agroforests in the humid forest zone of Southern Cameroon. Biodiversity & Conservation 16(8):2385-2400.

Sonwa, D. J., Weise, S. F., Schroth, G., Janssens, M. J., & Shapiro, H. Y. (2014). Plant diversity management in cocoa agroforestry systems in West and Central Africa—effects of markets and household needs. Agroforestry systems, 88(6): 1021-1034.

Sop, T. K., Oldeland, J., Bognounou, F., Schmiedel, U., & Thiombiano, A. (2012). Ethnobotanical knowledge and valuation of woody plants species: A comparative analysis of three ethnic groups from the sub-Sahel of Burkina Faso. Environment, Development and Sustainability, 14(5), 627-649.

Soto-Pinto, L., Villavaza-López, V., Jiménez-Ferrer, G., Ramírez-Marcial, N., Montoya, G. and Sinclair, F.L. (2007) The role of local knowledge in determining shade composition of multistrata coffee systems in Chiapas, Mexico. Biodiversity & Conservation, 16: 419-436.

Soto-Pinto, L., Villalvazo-López, V., Jiménez-Ferrer, G., Ramírez-Marcial, N., Montoya, G. & Sinclair, F.L. (2007). The role of local knowledge in determining shade composition of multistrata coffee systems in Chiapas, Mexico. Biodiversity and Conservation 16(2): 419-436.

Staver, C., Guhuray, F., Monterroso, D., & Muschler R. (2001). Designing pest-suppressive multistrata perennial crop systems: shade grown coffee in Central America. Agroforestry Systems 53: 151-170

Tchoundjeu, Z. & Atangana, A.R. (2007). *Ricinodendron heudelotii* (Baill.) Pierre ex Heckel. [Internet] Record from PROTA4U. van der Vossen, H.A.M. and Mkamilo, G.S. (Editors). PROTA (Plant Resources of Tropical Africa / Ressources végétales de l'Afrique tropicale), Wageningen, Netherlands.

Thorne, P., Subba, D., Walker, D., Thapa, B., Wood, C., & Sinclair, F.L. (1999). The basis of indigenous knowledge of tree fodder quality and its implications for improving the use of tree fodder in developing countries. Animal Feed Science and Technology, 81(1): 119-131.

Tscharntke, T., Clough, Y., Bhagwat, S.A., Buchori D., Faust, H., Hertel, D. & Wanger, T.C. (2011). Multifunctional shade-tree management in tropical agroforestry landscapes–a review. Journal of Applied Ecology 48(3):619-629.

Umar, B. B., Aune, J. B., & Lungu, O. I. (2013). Effects of *Faidherbia albida* on the fertility of soil in smallholder conservation agriculture systems in eastern and southern Zambia. African Journal of Agricultural Research, 8(2): 173-183.

Vaast, P., Kanten, R.V., Siles, P., Dzib, B., Franck, N., Harmand, J-M. & Genard M. (2005). Shade: a key factor for coffee sustainability and quality. In: ASIC 2004. 20th International Conference on Coffee Science, Bangalore, India, 11-15 October 2004: 887-896.

Vaast P., Beer J., Harvey C., and Harmand, J-M. (2005). Environmental services of coffee agroforestry systems in Central America: a promising potential to improve the livelihoods of coffee farmers' communities. In: Integrated Management of Environmental Services in Human-Dominated Tropical Landscapes. CATIE, IV Henri A. Wallace Inter-American Scientific Conference Series, Turrialba, Costa Rica: 35–39.

Valbuena, R., Heiskanen, J., Aynekulu, E., Pitkänen, S., & Packalen, P. (2016). Sensitivity of above-ground biomass estimates to height-diameter modelling in mixed-species West African woodlands. PloS One, 11(7), e0158198.

Valencia, V., West, P., Sterling, E. J., García-Barrios, L., and Naeem, S. (2015). The use of farmers' knowledge in coffee agroforestry management: implications for the conservation of tree biodiversity. Ecosphere, 6(7): 1-17

Van Oijen, M., Dauzat, J., Harmand, J-M., Lawson, G. and Vaast, P. (2010). Coffee agroforestry systems in Central America: I. A review of quantitative information on physiological and ecological processes. Agroforestry Systems 80: 341-359.

van Breugel, P., Kindt, R., Lillesø, J. P. B., Bingham, M., Demissew, S., Dudley, C., ... & Moshi, H. N. (2015). Potential Natural Vegetation Map of Eastern Africa (Burundi, Ethiopia, Kenya Malawi, Rwanda, Tanzania, Uganda and Zambia). Version 2.0.

van der Wolf, J, Jassogne, L., Gram, G., & Vaast, P. (2016) .Turning local knowledge on agroforestry into an online decision-support tool for tree selection in smallholders' farms, Experimental agriculture DOI: http://dx.doi.org/10.1017/S001447971600017X .

Vlassenroot, K. & Huggins, C. (2005). Land, migration and conflict in eastern DRC. In Huggins, C. & Clover, J. in Eds. From the Ground Up: Land Rights, Conflict and Peace in Sub- Saharan Africa. Nairobi/Pretoria: African Centre for Technology Studies Press/Institute for Security Studies:115–194

Walker, D.H. & Sinclair, F.L. (1998) Acquiring qualitative knowledge about complex agroecosystems. Part 2: formal representation. Agricultural Systems, *56*(3):365-386.

Walker, D.H., Thorne, P.J., Sinclair, F.L., Thapa, B., Wood, C.D. and Subba, D.B. (1999). A systems approach to comparing indigenous and scientific knowledge: consistency and discriminatory power of indigenous and laboratory assessment of the nutritive value of tree fodder. Agricultural Systems 62: 87-103.

Warren, D. M., & LJ Brokensha, D. (1995). The cultural dimension of development; indigenous knowledge systems (No. 581.63 C968).

Wiersum, K., & Slingerland, M. (1997). Use and management of two multipurpose tree species (*Parkia biglobosa* and *Detarium microcarpum*) in agrosilvopastoral land-use systems in Burkina Faso. Programme de recherche SPS Aménagement et Gestion de l'Espace Sylvo-Pastoral au Sahel.129 p

Wiggins, S. and Cromwell, E. (1995). NGOs and seed provision to smallholders in developing countries. World Development 23: 413-422

Wessel, M., & Quist-Wessel, P. F. (2015). Cocoa production in West Africa, a review and analyss of recent developments. NJAS-Wageningen Journal of Life Sciences, 74:1-7.

Wilkie, P. & Saridan, A. (1999). The limitations of vernacular names in an inventory study, Central Kalimantan, Indonesia. Biodiversity & Conservation 8(11): 1457-1467

Wood, P. (1992). The botany and distribution of *Faidherbia albida*. Faidherbia Albida in the West African Semi-Arid Tropics': Workshop Proceedings ICRISAT Niamey Niger, 9-17.

World Cocoa Foundation (2012). Cocoa market update accessed online 6th January 2014 http://worldcocoafoundation.org/wp-content/uploads/Cocoa-Market-Update-as-of-3.20.2012.pdf[1]

Yélémou, B., Dayamba, S. D., Bambara, D., Yaméogo, G., & Assimi, S. (2013). Soil carbon and nitrogen dynamics linked to *Piliostigma* species in ferugino-tropical soils in the Sudano-sahelian zone of Burkina Faso, west africa. Journal of Forestry Research, 24(1), 99-108.

Appendix 2.1. Survey tool used in the cocoa survey conducted in the South West of Cote d'Ivoire

NUMERO L'ENQUETEUR: 00	**DATE:**

SECTION A : INFORMATION DE BASE

Nom et Prénom:						
Village / Campement:			**Sous-préfecture**			
Age:			**HOMME**			**FEMME**
Nationalité:			**Ethnie:**			
1. Depuis quelle année vivez vous dans le village?						
2. Etes vous membre d'une coopérative?			**OUI**			**NON**
3. Si 2=OUI quel est le nom de la coopérative:						
4. Avez vous un role dans la cooperative ? Si OUI lequel?						

SECTION B INFORMATION GENERALE SUR LA PLANTATION:

B1. Combien de champs de cacaoyers différents avez-vous? …………

B2. Quelle est la superficie de votre plantation de cacaoyers dans cette localité? *Noter la superficie HECTARES*

B3. Cultivez vous d'autres champs que les champs de cacaoyers dans cette localité ?

	CULTURES	SUPERFICIE
Champ 1		
Champ 2		
Champ 3		
Champ 4		
Champ 5		

B4 Informations sur le(s) champ(s) de cacaoyers dans la localité

Pour chaque champ dans la localité noter dans les cases correspondantes du tableau :

1 En quelle année les cacaoyers ont-t-ils été planté ?
2. Quelle est la superficie de ce champ (partie cacao) en hectares?
3. Quel est le statut foncier du champ? (remplir en utilisant la légende)
4. Depuis quand le planteur cultive-t-il lui meme ce champ?
5. Il y a t-il des cultures associées (caféiers, bananes, cultures vivrières) ?

SECTION C INFORMATION GENERALE SUR LES ARBRES DANS LA PLANTATION :

ETAPE NO 1 : Etablir les listes des arbres plantés et sauvages dans la plantation de cacaoyers. Consulter la liste de référence et l'aide visuelle avec le planteur et confirmer bien lesquels parmi les arbres listés il possède dans ses champs de cacaoyers. Cochez la case grise si l'arbre est listé dans la liste de référence.

LISTES DU PLANTEUR

Liste des arbres qui ont ete **plantés** dans les champs de cacaoyers

	NOMS DE L'ARBRE	CHAMPS NO:	Liste de reference
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			

Liste des arbres **sauvages** presents dans les champs de cacaoyers

	NOMS DE L'ARBRE	CHAMPS NO:	Liste de reference
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			

Appendix 2.1. Survey tool used in the cocoa survey conducted in the South West of Cote d'Ivoire

ETAPE NO 2

Les fiches d'information doivent maintenant être remplies pour 10 espèces présentes dans les champs de cacao avec - maximum de 10 arbres.

SUR LES LISTES DU PLANTEUR :

Commencer par sélectionner en priorité les arbres QUI SONT REPRESENTES DANS LA LISTE DE REFERENCE (ceux dont les cases sont cochées)

Si le planteur possède plus de 10 espèces présentes sur la liste de référencer il faudra choisir d'abord les espèces les moins fréquentes ou sélectionner les espèces que le planteur connaît le mieux.

Si le planteur possède moins des 10 espèces présente sur la liste de référence il faudra compléter avec LES ARBRES QUI NE SONT PAS REPRESENTES DANS LA LISTE DE REFERENCE.

Si le planteur possède plus d'espèces que le nombre manquant pour obtenir 10 fiches d'information il faudra sélectionner sur les LISTES DU PLANTEUR le 1er parmi les arbres plantés et le 2ème parmi les arbres sauvages, le 3ème parmi les arbres plantés, le 4ème parmi les arbres sauvages, le 5ème parmi les arbres plantés, 6ème parmi les arbres sauvages et ainsi de suite.

FICHE D'INFORMATION SUR LES ARBRES PRESENTS DANS LES CHAMPS DE CACAOYERS (1/10)

Arbre no: **NOM DE L'ARBRE:**					
UTILITES		Fruits (alim)		Feuilles (alim)
		Graines/noix (alim)		Médicament
		Fourrage		Bois d'œuvre
		Bois de chauffe		Charbon
		Fertilite		Ombrage
		Ornemental		Culturel/Religieux
		Revenu *Préciser le produit vendu*		
		Autre utilité *Préciser*		
NOMBRE		**Arbre + de 3 ans**		
		Arbre jeune - de 3 ans		
ORIGINE		Planté		Sauvage

QUESTIONS	Un peu	Moyen	Beaucoup	Non	Ne sait pas
1. L'ombrage de cet arbre est il gênant pour les cacaoyers					
2. Cet arbre favorise-t-il la pourriture brune?					
3. Cet arbre favorise-t-il la maladie du swollen shoot?					
4. Cet arbre attire-t-il les mirides?					
5. Cet arbre attire-t-il les foreurs de tronc?					
6. Cet arbre attire-t-il les rongeurs (ecureuils, rats)?					
7. Cet arbre favorise-t-il le loranthus (plante parasite)?					
8. Cet arbre cause-t-il des degats physiques?					
7. Cet arbre est-t-il bon pour la fertilité du sol?					
SI 7=NON Cet arbre est-t-il gourmand en fertilité du sol?					
8. Le sol est-t-il sec autour de cet arbre?					
9. Dans l'ensemble pensez vous que cet arbre est bon a planter avec le cacaoyer?		OUI		NON	
10. Voudriez vous avoir plus de cet arbre dans vos champs?		OUI		NON	
11. SI 10=OUI Combien de pieds souhaitez vous?					

SECTION E: AUTRES ARBRES SOUHAITES

E1. Il y a-t-il d'autres arbres que vous aimeriez planter dans vos champs de cacaoyers?

	OUI		NON

Si E1=OUI noter les arbres, le nombre souhaité par le planteur et ses raisons dans le tableau suivant:

	Nom de l'arbre	Nombre /ha souhaité	Raison
1			
2			
3			
4			
5			

E2 Il y a t'il d'autres arbres que vous aimeriez planter ailleurs sur vos terres dans cette localité?

	OUI		NON

E2 Si OUI noter les arbres, le nombre souhaité par le planteur et ses raisons:

	Nom de l'arbre	**Nombre souhaité**	**Raison**	**Ou?**
1				
2				
3				
4				
5				

SECTION F L’OPINION GENERALE DES ARBRES D’OMBRAGES DANS LES CHAMPS DE CACAOYERS

F1 **En général pensez vous que les arbres d’ombrage sont favorables pour les cacaoyers**

	OUI		NON

F2. LES BENEFICES ET LES INCONVENIANTS

Quels sont les 3 benefices les plus importants d’avoir des arbres d’ombrage dans les champs de cacaoyers ?

1……………………………………..……………………… ………………

2………………………………….…………………………… ………………

3………………………………….…………………………… ………………

Quels sont les 3 problèmes les plus importants d'avoir des arbres d'ombrage dans les champs de cacaoyers ?

1……………………………………..……………………… ………………

2…………………………………..…………………………… ………………

3…………………………………..…………………………… ………………

F3 En général pensez vous qu'il faut couper tous les arbres pour faire une plantation de cacaoyers

	OUI		**NON**

SI F3= OUI Pourquoi ?

Appendix 2.2. List of tree species and vernacular names recorded during the survey of cocoa farms in the South West of Cote d'Ivoire

Noms scientifiques	Familles	Noms pilotes	Bakoué	Bété	Baoulé	Sénoufo/Dioula	Koulango	(Mossi)
Antiaris toxicaria	Moracées	Ako	Gôlè	Guèdè	Ofi/Ofing	Fouyiri		
Celtis zankeri	Ulmacées	Assan	Klôh	Kohi	Assan			
Beilschmiedia manii	Lauracées	Attiokouo	Bilè/bitehi	Bitéhi/bitéssou				
Nauclea diderichii	Rubiacées	Badi	Tougbeglé	Guiédré	Bonou-tolè			
Irvingia gabonensis	Irvingiacées	Boborou	Sapêtou/Betou	Siôkô	Kaklou			
Cordia platythyrsa	Borraginacées	Bon		Pri/prihi	Ahouné			
Artocarpus altilis	Moracées	Chataignier/arbre à pain	Bablou-tou	Bôdo	Blofoè Ngatè	Tigayiri/kouyiri		
Piptadeniastrum africanum	Mimosacées	Dabema	Galo	Garo/gobo	Akassanoum ou (agni)		Nanhi	
Rauwolfia vomitoria	Apocynacée	Déchavi		Trokpéhi	Ngnawi			
Ficus exasperata	Moracées	Dèdè	Dèhè/Gnossi	Gnagnoui	Yinglè	Trogbègnan	Issayo	Kakanga
Ricinodendron heudelotii	Euphorbiacées	Eho	Kofo-tou	Kohi/Kolo (Kouzié)	Akpi		Api	

Noms scientifiques	Familles	Noms pilotes	Bakoué	Bété	Baoulé	Sénoufo/Dioula	Koulango	(Mossi)
Alstonia bonei	Apocynacées	Emien	Nètou	Kahi/Nohi	Emien	Soumayayiri	Lorowi	
Tetrapleura tetraptera	Mimosacées	Essé essé		Fikifiki/Koussèkèssèkè				
Nauclea sp	Rubiacées	Faux badi	Sra-tou		Trèlè	Batou (Djimini)		
Ficus sur	Moracées	Ficus	Bègrou/Dèh	Bagossou	Alloman		Hindjo	
Ficus sp	Moracées	Ficus étrangleur	Dèh	Didoko	Django	Djatiguifaga		
Terminalia superba	Combrétacées	Fraké	Saro	Solo/Soloui	Fla/ Fla-ouffoué			
Terminalia ivorensis	Combrétacées	Framiré	Broutou	Saroui	Fla/Fla oklohè			
Ceiba pentendra	Bombacacées	Fromager	Foteu	Gôh	Ngnin	Bana-yiri	Tonhonko	Gonga
Pycnanthus angolensis	Myristicacées	Ilomba	Têpê-tou	Doudoui	Adrin			
Milicia excelsa	Méliacées	Iroko	Djèdjè/Guègue	Djédjé	Ela / Alla	Silly (Malinké)		
Bombax buonopense	Bombacacées	Kapokier	Yuayua-fotê/Dofolou	Djoh/Kpaoléssou	Kpouka		Adingré	Vaga
Nesogordonia papaverifera	Sterculiacées	Kotibé	Kakê	Digbehi/dibehi	Eyà			
Pterygota macrocarpa	Sterculiacées	Koto	Bèrèfolou	Pohouro	Walè		Wogolidjo	

Noms scientifiques	Familles	Noms pilotes	Bakoué	Bété	Baoulé	Sénoufo/Dioula	Koulango	(Mossi)
Parkia bicolor	Mimosacées	Loh	Takê tou	Dogbogla-sou	Kpalè			
Tieghemela heckelii	Sapotacées	Makoré	Boutoutou	Guéri-sou	Dimori (agni)			
Spondias monbin	Anacardiacées	Monbin		Tétéhi/titi	Troman			
Monodora myristica	Annonacées	Moué						
Albizia adianthifolia	Mimosacées	Ouochi		Galo	Kpangba			
Musanga cecropioides	Moracées	Parasolier	Wossou	Kodo	Adjuin		Egoui	
Sterculia tragacantha	Sterculiacées	Poré Poré	Toutui	Oupoui/Zègrèpoutoui	Kotoki		Orohi	Kondélé
Triplochiton scleroxylon	Sterculiacées	Samba	Sogolou	Gligbèhi/Doh	Kpatabouè			
Entandrophragma utile	Méliacées	Sipo		Zizé	Loukrou			
Erythrophleum ivorense	Caesalpiniacées	Tali/Poison de vérité		Gôpô	Allui	Tali		
Trema guinensis	Ulmacées	Trema			Ahissian	Sodé		
Spathodea campanulata	Bignoniacées	Tulipier Du Gabon	Babloutou	Zibliyi	Abiésrinlin			

Noms scientifiques	**Familles**	**Noms pilotes**	**Bakoué**	**Bété**	**Baoulé**	**Sénoufo/Dioula**	**Koulango**	**(Mossi)**
Dacryodes klaineana	Burséracées	Safoutier/Adjouaba	Weri?					
Coula edulis	Olacacées	Attia						
Entandrophragma angolense	Méliacées	Tiama		Zizezara	Tiama (agni)			
Xylopia aethiopica	Annonacées	Poivrier d'Afrique/Fondè		Lilossou/lilo	Sindion		Sokodjo	
Cola nitida	Sterculiacées	Colatier	Gôtou	Gouéléssou/Gouélé	Wèssè	Woro-yiri	Pèssè	
Bombax brevicuspe	Bombacacées	Kondroti			Kouhobéné (Agni)			
Holarrhena floribunda	Apocynacées	Hévéa sauvage/Sohuié		Worobassou	Pohè		Manguibè	

Appendix 3.1. List of tree names and recording sheets for the tree attribute ranking survey in Western Rwanda

Farm number:
Factory:
Location:
Date:
Name of fieldworker:
Name of person(s) who took part in the exercise:
Number of men: Number of women:
GPS of farm:
For each tree note in the relevant column if the farmer has had direct experience with the tree and note those selected for ranking (no more than 10 trees?)

Scientific Name	**Local Name**	**Direct experience Y/N**	**Ranked Y/N**
Alnus acuminata	Arinusi		
Bridelia micrantha	Imigimbo		
Carica papaya	Papayi		
Cedrela serrata	Sederela		
Citrus limon	Indimu		
Erythrina abyssinica	Umuko		
Ficus thoningii	Umuvumu		
Grevillea robusta	Geleveriya		
Inga oerstediana	Paypay		
Leucaena diversifolia	Lisena		
Maesa lanceolata	Umuhanga		
Mangifera indica	Umuhembe		
Markhamia lutea	Umusave		
Millettia dura	Umuyogoro		
Persea americana	Avoka		
Polyscias fulva	Umwungo		
Psidium guajava	Amapera		
Ricinus communis	Umubonobono		
Vernonia amygdalina	Umubirizi		
Dracaena afromontana	Umuhondogoro		

Appendix 3.2. Example tree information card used during attribute ranking in Western Rwanda

UMUKO

Scientific name:
Erythrina abyssinica

Other common or local names:
Erythrina, Lucky bean tree

Appendix 3.3. Example data sheet for recording trees ranked for general attributes in the ranking survey conducted in Western Rwanda

Farm number:						
Factory:						
Date:						
Trees ranked in order for each general attribute						
Crown spread	Crown density	Easiness to prune	Growth after pruning	Rooting depth	Rooting spread	Growth rate
Widest	Most dense	Easiest	Fastest	Deepest	Widest	Fastest
Narrowest	Least dense	Hardest	Slowest	Least deep	Narrowest	Slowest
Comments and farmers' answers to questions to be recorded here:						

Appendix 4.1 Species selected from analysing the participatory rapid appraisal data that scored tree species based on their importance for different functions by different gender groups and in the four villages of Ziro province in Burkina Faso, West Africa

Species with overall scores of at least five based on the addition of individual scores for all five functions by focus groups in the four villages

Tree species	Vrassan women	Vrassan men	Kou women	Kou men	Dao women	Dao men	Cassou women	Cassou men	**TOTAL**
Adansonia digitata	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**8**
Afzelia africana	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**8**
Balanites aegyptiaca	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**8**
Bombax costatum	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**8**
Detarium microcarpum	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**8**
Parkia biglobosa	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**8**
Pterocarpus erinaceus	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**8**
Strychnos spinosa	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**8**
Tamarindus indica	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**8**
Vitellaria paradoxa	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**8**
Vitex doniana	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**8**
Piliostigma thonnigii		**1**	**1**	**1**	**1**	**1**	**1**	**1**	**7**
Acacia macrostachya	**1**		**1**	**1**	**1**	**1**	**1**	**1**	**7**
Anogeissus leiocarpus	**1**		**1**	**1**	**1**	**1**	**1**	**1**	**7**
Burkea africana		**1**	**1**	**1**	**1**		**1**	**1**	**6**
Ficus gnaphalocarpa		**1**		**1**	**1**	**1**	**1**	**1**	**6**
Lannea microcarpa		**1**	**1**	**1**	**1**		**1**	**1**	**6**
Diospyros mespiliformis		**1**			**1**	**1**	**1**	**1**	**5**
Faidherdia albida		**1**		**1**	**1**	**1**	**1**	**1**	**6**
Sclerocarya birrea	**1**	**1**	**1**	**1**	**1**			**1**	**6**
Terminalia avicennoides		**1**		**1**	**1**	**1**		**1**	**5**
Saba senegalensis (liana)		1	1	1	1	1	1	1	**7**
Capparis corymbosa	1					1	1	1	**4**

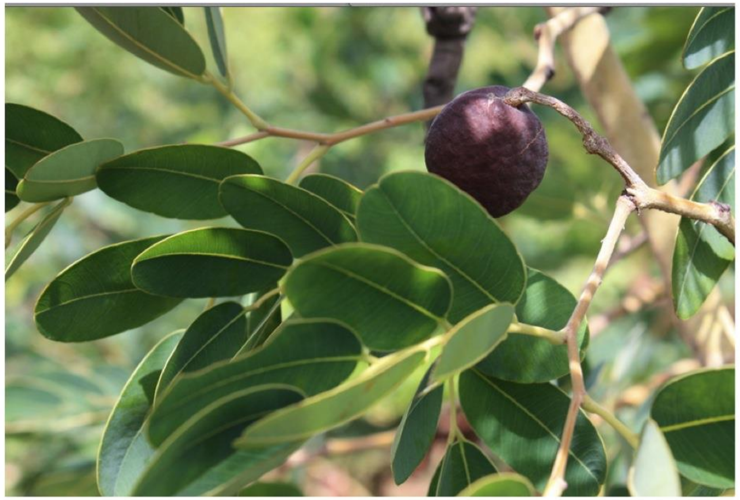
Species with overall scores of at least five based on the addition of individual scores for all five functions by focus groups in the four villages

Tree species	Vrassan women	Vrassan men	Kou women	Kou men	Dao women	Dao men	Cassou women	Cassou men	**TOTAL**
Crossopterix febrifuga	1			1	1		1		**4**
Annona senegalensis		1			1		1	1	**4**
Cassia spp		1			1		1	1	**4**
Dichrostachys glomerata		1		1	1			1	**4**
Kaya senegalensis		1		1		1		1	**4**
Pericopsis laxiflora		1		1	1			1	**4**
Pteleopsis suberosa		1		1		1		1	**4**
Acacia nilotica				1			1	1	**3**
Acacia seyal		1		1				1	**3**
Acacia siberiana		1		1				1	**3**
Calotropis procera		1	1			1			**3**
Gardenia erubescens		1				1		1	**3**
Lannea acida		1	1		1				**3**
Parinari curatellifolia		1		1				1	**3**
Pseudocedrela kotschyi		1			1			1	**3**
Securida longepedunculata		1			1	1			**3**
Daniellia oliveri		1						1	**2**
Mitrigina inermis		1		1					**2**
Terminalia spp	1						1		**2**
Cadaba farinosa								1	**1**
Eucalyptus camaldulensis			1						**1**
Ficus capensis		1							**1**
Grevia bicolor				1					**1**
Guiera senegalensis								1	**1**
Mangifera indica			1						**1**

Species with overall scores of at least five based on the addition of individual scores for all five functions by focus groups in the four villages									
Tree species	Vrassan women	Vrassan men	Kou women	Kou men	Dao women	Dao men	Cassou women	Cassou men	**TOTAL**
Nauclea latifolia		1							**1**
Ostryoderis sthulmanii							1		**1**
Ziziphus mauritiana						1			**1**
Unidentified									
Nessabaoh		1		1			1		3
Yeni			1		1				2
Bonavaoh		1							1
Koala					1				1
Tiassopoura		1							1
Tiassouga					1				1
Nithilson					1				1
Badanapené					1				1
Kolchonon					1				1
Appolonan							1		1
Barafairi			1						1
Croa				1					1
Kapronwian							1		1
Kétielou							1		1
Teyevo				1					1
Tiapian			1						1
Tounapou							1		1
Yansouasin			1						1

(Original data source ICRAF, 2013)

Appendix 4.2 Example tree information card to be used during attribute ranking in Western Rwanda

Konou	Dankola
Toêêga	Kagadga
ADA	DET
	

Appendix 4.3. Short questionnaire used with the ranking survey in the Ziro Province

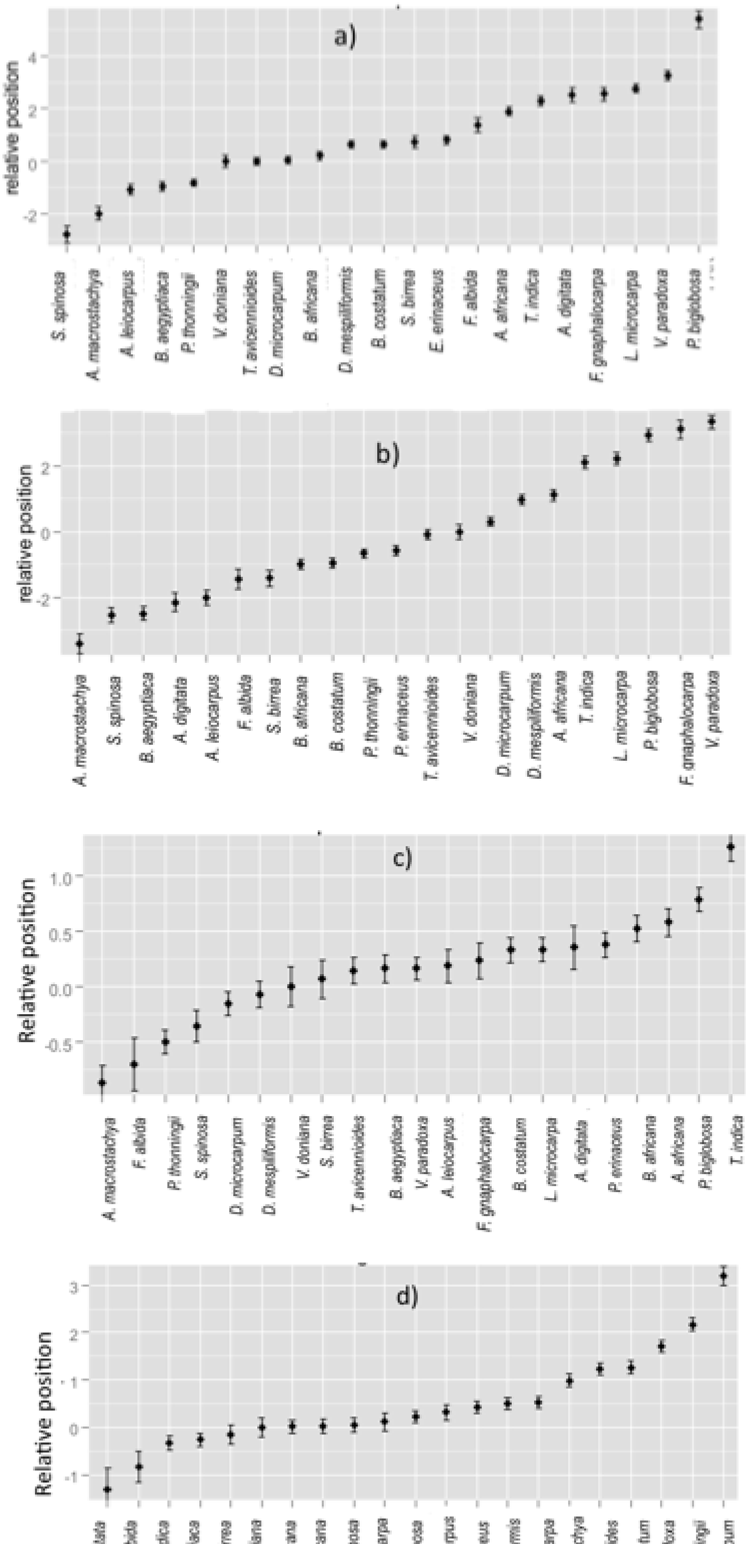
VILLAGE:		
NOM ET PRENOM:		
AGE DU CHEF DE FAMILLE:		
TAILLE DU MENAGE:		
NOMBRE D'ACTIFS:		
ALPHABETISATION (oui ou non)		
A-T'IL DEJA VOYAGE EN COTE D'IVOIRE? (oui ou non)		
SI LE CHEF DE MENAGE EST UN MIGRANT:		
Est-il né au village? oui ou non		
Si non depuis combien d'année est-il au village?		
INFORMATIONS SUR LES CHAMPS		
NOMBRE DE CHAMPS		
CHAMP 1		
AGE ET DIMENSION	**TYPE DE SOL**	**TOPOGRAPHIE**
CULTURES PRINCIPALES		
CHAMP 2		
AGE ET DIMENSION	**TYPE DE SOL**	**TOPOGRAPHIE**
CULTURES PRINCIPALES		
CHAMP 3		
AGE ET DIMENSION	**TYPE DE SOL**	**TOPOGRAPHIE**
CULTURES PRINCIPALES		
GESTION GENERALE DES CHAMPS si oui dans quel(s) champ(s)?		
Apport fumier ménager		
Fosse fumière		
Engrais chimique		
Brule les résidus des arbres		
Enfouis les résidus des arbres		
Utilise des herbicides		
Rotation des cultures		
Cordons pierreux		
Possede une charrue		
Possede une charette		

Appendix 4.4: Details of tree species selected for the ranking survey with their vernacular names, key products harvested and their periods of harvest in Ziro province in Burkina Faso, West Africa

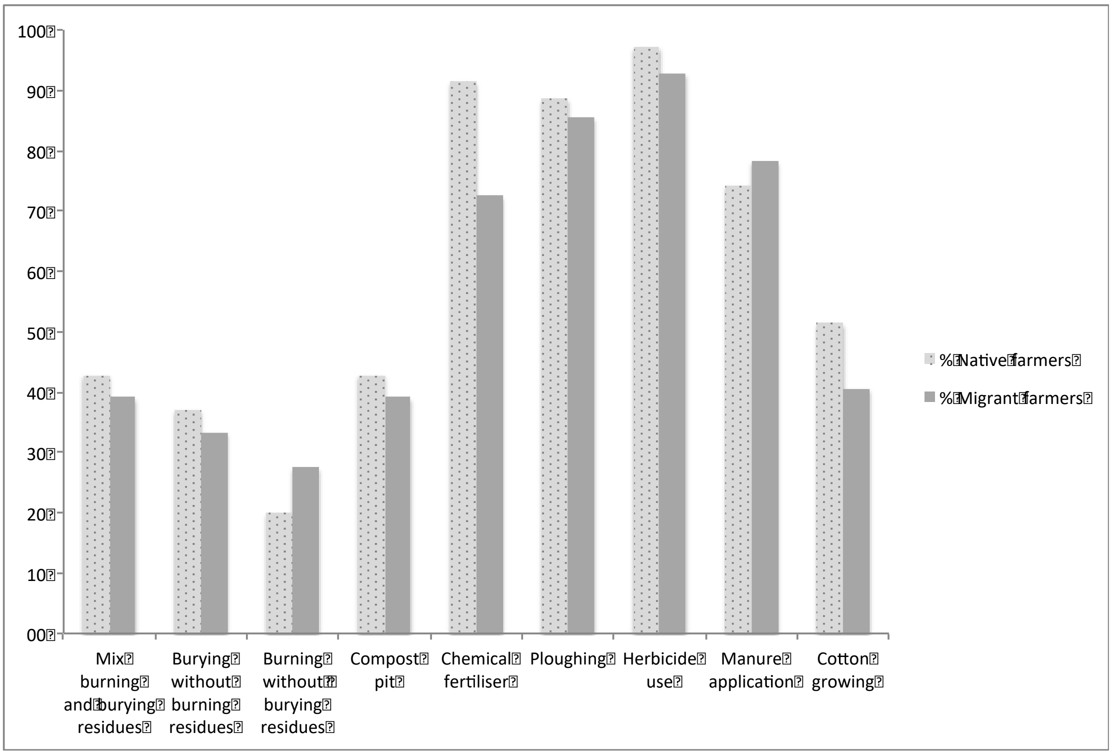
Scientific name	Name in More	Name in Nuni	Family	Key products	Harvesting period
Acacia macrostachya	Zamné	**Sankayolo**	*Fabaceae*	Food (seeds); Fodder (leaves; pods); Firewood; Medicinal; Income (seeds)	Fruits: Nov-Jan
Adansonia digitata	Toêêga	**Konou**	*Malvaceae*	Food (fruit pulp, leaves); Income (leaves, fruit pulp, fruits); Fodder; Medicinal	Fruits: Jan-June Leaves: April-Oct
Afzelia africana	Kahkalga	**Kolou**	*Fabaceae*	Food (leaves); Fodder (leaves); Income (leaves); Medicinal; Timber ; Firewood	Food: March-May; Fodder April-June
Anogeissus leiocarpus	Siiga	**Loan**	*Combretaceae*	Medicinal; Timber, Firewood Income (timber, firewood)	Dry season
Balanites aegyptiaca	Kieglega	**Sao**	*Zygophyllaceae*	Food (leaves, fruits); Fodder (leaves); Income (leaves; soap); Medicinal	Fruits: Nov-June Leaves: March-May
Bombax costatum	Voaka	**Ofo**	*Malvaceae*	Food (flowers, fruits); Income (flowers) ,Timber (craft)	Flowers: Dec-Feb; Fruits: March-April
Burkea africana	Seingah	**Tagnah**	*Fabaceae*	Medicinal; Firewood; Income (firewood), Timber (craft)	Dry season
Detarium microcarpum	Kagadga	**Dankola**	*Fabaceae*	Food (fruits); Fodder (leaves); Firewood; Income (fruits; firewood); Medicinal	Fruits: Jan-Aug; Wood: dry season
Diospyros mespiliformis	Ganka	**Kaanon**	*Ebenaneceae*	Food (fruits); Medicina, Timber (craft)l	Fruits: Dec-Feb
Faidherdia albida	Zaanga	**Nessanon**	*Fabaceae*	Fodder (leaves and pods); Medicinal	Pods: Jan-February
Ficus gnaphalocarpa	Kahkanga	**Kaproh**	*Moraceae*	Food (fruits); Medicina, Timber (craft)l	Fruits (2 periods - April-Dec)
Lannea microcarpa	Sanbga	**Katcho**	*Anacardiaceae*	Food (fruits); Income (fruits); Medicinal, Timber (craft)	Fruits: April-July
Parkia biglobosa	Roanga	**Souan**	*Fabaceae*	Food (pulp, seeds); Fodder (pods); Medicinal; Income (pulp flour, pods, soumbala)	Pods: March-June;
Piliostigma thonningii	Bagande Yaanga	**Vagnanon**	*Fabaceae*	Fodder (pods, leaves); Medicinal, Timber (craft)	Pods: Dec-March; Leaves: April-June
Pterocarpus erinaceus	Noega	**Taan**	*Fabaceae*	Medicinal; Firewood; Fodder (leaves); Timber; Income (timber; firewood)	Dry season
Sclerocarya birrea	Nogba	**Mooloh**	*Anacardiaceae*	Food (fruits); Fodder (leaves); Income (fruits); Medicinal	Fruits: April-June
Strychnos spinosa	Katre-fannga	**Poa**	*Loganiaceae*	Food (leaves, fruits); Fodder (leaves); Income (leaves); Medicinal	Fruits: Feb-April; Leaves: March-May
Tamarindus indica	Pousga	**Sonou**	*Fabaceae*	Food (leaves, fruits); Income (leaves, fruits); Medicinal; Timber	Fruits: Oct-Feb; Leaves: April-Aug
Terminalia avicennoides	Kondré	**Kow**	*Combretaceae*	Medicinal;Firewood; Timber; Income (firewood)	Dry season
Vitellaria paradoxa	Taaga	**Soan**	*Sapotaceae*	Food (fruits, nuts); Medicinal;Veterinary; Income (fruits,nuts,*butter*); firewood	Fruits: May-Sept
Vitex doniana	Laihga	**Felenou**	*Verbenacae*	Food (leaves, fruits); Fodder (leaves); Income (leaves); Medicinal	Fruits: Aug-Oct Leaves: March-May

Appendix 4.5. Ranking results of ecological attributes of tree species in Ziro province in Burkina Faso, West Africa

a) Crown spread (narrowest to largest, b) crown density (least to most dense), c) competition with crops for water (least to most), d) regrowth after coppicing (least to most)



Appendix 4.6. Variations in farmers' filed preparation and management practices according to their origin (native farmers n=35 and migrant farmers n=69) in Ziro province in Burkina Faso, West Africa (only chemical fertiliser was found statistically different (p=<0.05))



Variations in farmers' filed preparation and management practices according to their origin (native farmers n=35 and migrant farmers n=69) in Ziro province in Burkina Faso, West Africa (only chemical fertiliser was found statistically different (p=<0.05))

Appendix 5.1. List of the 71 species identified during the participatory agroforestry workshops in North Kivu, DRC

(e=exotic; n=native)

Botanical name	origin	Botanical name	origin
Acacia mearnsii	e	*Maesa lanceolata*	n
Acrocarpus fraxinifolius	e	*Maesopsis eminii*	n
Albizia gummifera	n	*Mangifera indica*	e
Annona muricata	e	*Markhamia lutea*	n
Averrhoa carambola	e	*Milicia excelsa*	n
Azadirachta indica	e	*Morus alba*	n
Bambusa vulgaris	e	*Coccinia grandis*	n
Cajanus cajan	e	*Moringa oleifera*	e
Calliandra calothyrsus	e	*Myrianthus arboreus*	n
Carica papaya	e	*Olea africana*	n
Casuarina equisetifolia	e	*Passiflora edulis*	e
Cedrela serrulata	e	*Passiflora*	e
Citrus reticulata	e	*Pennisetum spp*	n
Citrus limon	e	*Persea americana*	e
Citrus sinensis	e	*Piper guineense*	e
Coffea arabica	e	*Podocarpus falcatus*	n
Cola nitida	n	*Malus domestica*	e
Cordia abyssinica	n	*Prunus africana*	n
Croton megalocarpus	n	*Psidium guajava*	e
Cupressus lusitanica	e	*Ricinus communis*	n
Cyphomandra betacea	e	*Senna siamea*	e
Datura arborea	e	*Senna spectabilis*	e
Dracaena cf. arborea	n	*Sesbania sesban*	n
Entandrophragma	n	*Sinarundanaria*	n
Eriobotrya japonica	e	*Spathodea*	n
Erythrina abyssinica	n	*Syzygium guineense*	n
Eucalyptus citriodora	e	*Syzygium*	e
Eucalyptus grandis	e	*Tephrosia vogelii*	e
Ficus thonningii	n	*Terminalia superba*	e
Ficus vallis-choudae	n	*Tetradenia riparia*	n
Flemingia macrophylla	e	*Tithonia diversifolia*	e
Gliricidia sepium	e	*Urena lobata*	n
Grevillea robusta	e	*Vernonia amygdalina*	n
Jatropha curcas	e		
Eremospatha	n		
Kigelia africana	n		
Laurus nobilis	e		
Leucaena leucocephala	e		