Linking household strategies to natural regeneration in West African parklands

Farmer managed natural regeneration as a restoration practice

MSc Thesis

Peggy Albers

Thesis report, January 2019

Linking household strategies to natural regeneration in West African parklands

Farmer managed natural regeneration as a restoration practice

Peggy Albers (911031009070)

Chair Group: Forest Ecology and Management

Course code: FEM-80436

Supervisors (Wageningen University and Research - WUR):
Dr. Madelon Lohbeck
Prof. dr. Frans Bongers

External supervisor (World Agroforestry Centre - ICRAF):
Dr. Emilie Smith-Dumont

Abstract

Aim: The West African Parklands are under growing threat from increased human populations and climatic change. This leads to degradation, loss of productivity and loss of biodiversity. Farmer managed natural regeneration (FMNR) might be a solution, as it has shown to improve livelihoods and to re-green the Sahel, but evidence on the human drivers of FMNR is limited. The aim of this study was to provide evidence for FMNR as a restoration practice, with a focus on human drivers:

- RQ1: How do community and household characteristics affect the adoption and intensity of FMNR?
- RQ2: How do the human drivers influence abundance, diversity and functional traits of regeneration and trees on farmers' fields?
- RQ3: How do species functional traits reflect the economic, fodder and litter values attributed by farmers?

Location: Smallholder agroforestry farming systems in the parklands of West Africa, Upper East Ghana and Southern Burkina Faso.

Methods: We surveyed 40 households and their fields, across four communities and having different wealth status (poor or comfortable). First, we modelled FMNR adoption (binary) and intensity (4 levels) as a response to community and household characteristics. Second, we investigated farmers tree species perceptions, knowledge and management. Third, we modelled tree regeneration and adult tree abundance, diversity (taxonomic & functional diversity) in response to household characteristics and household management strategy. Finally, we assessed the relation between farmers knowledge on species and scientific knowledge from functional traits measured.

Results:
The main driver of FMNR adoption is plot tenure and for FMNR intensity it is community wealth: farmers who own their plot are more likely to adopt, and poor communities' practice more intense FMNR. Farmers have knowledge and manage many different species (50 species across all 40 households), in different ways, and thereby influence abundance & diversity. Farmers knowledge of species positive aspects of reproduction habits and competition with crops reflects species abundance for adults, but less for regeneration. For diversity of woody regeneration, the main driver is tenure, where farmers that have tenure over their plot tend to have a lower diversity. For adult trees the main driver is distance to market: the greater the distance the higher the density but the lower the diversity. Farmers value multipurpose tree species: species that farmers value for economic purpose, they also value for fodder and leaf litter and vice versa. Farmers' attribute scores are linked to maximum plant height, seed mass and specific leaf area.

Main conclusions:
FMNR is widely practiced across the study area (65%), be it at different levels of intensity. Human drivers influence abundance, diversity and functional traits of the regeneration trees and adult trees on farmers' fields. Management is of great influence on the adult tree community of the parklands, but less to the regeneration. There is room for improving the farmers' FMNR practices. But under the current situation FMNR is already combating land degradation, by enhancing the tree abundance.

Table of Content

List of figures

List of tables

Acknowledgements

I am grateful to my supervisors Madelon Lohbeck and Frans Bongers, from Wageningen University and Research, Forest Ecology and Management Chair group. Their guidance, support, expertise and encouragements helped me to conclude this thesis process successfully. I am grateful to my external supervisor Emilie Smith-Dumont from the world agroforestry center (ICRAF). She helped us get familiar with our new surroundings and introduced us to the people, she made us feel welcome. Without her help and contacts my fieldwork would not have been possible. I would like to thank Thomas Addoah and Gloria Adeyiga, for helping me set up my field work and for making me feel at home in Ghana. Without their help my time in Africa would have been very complicated. They introduced me to the facilitators and assisted in my field work. I owe many thanks to the local facilitators: Baazebakewora Baani-Ayere Nelson, Hanson Abaloori, Abdul-Aziz Batogikune Ayaga and Adayira Stephen, they located the participants and translated for me. Without them my research would not have been possible. I also want to thank all the farmers that participated in my research, their kindness, enthusiasm and friendliness warmed my heart and I wish them all the best. I would like to thank my fellow students Sam Morel and Laetitia Boels. The close collaboration during our whole thesis process was very useful, helpful and fun. Furthermore, I want to thank my friends and family for the moral support and encouragement during the whole adventure.

Finally, I want to gratefully acknowledge the different projects and organizations who provided financial support: 1. Research program ALW (863.15.017), financed by the Netherlands Organization for Scientific Research (NWO), 2. EU funded LEAP-AGRI (A Long-term EU- Africa research and innovation Partnership on food and nutrition security and sustainable Agriculture) project Roles of Agroforestry in sustainable intensification of small farms and food Security for Societies in West Africa (RAMSESII), and 3. The project STRENGTHENING SMALLHOLDER FOOD SECURITY, INCOME, AND GENDER EQUITY WITHIN WEST AFRICA'S FOREST-FARM INTERFACE (WAFFI) funded by IFAD through the World Agroforestry Centre (ICRAF).

1. Introduction

All over the world people manage their land, providing them with food as well as a range of other ecosystem services. People depend on these natural resources to sustain their livelihood, especially in developing countries where people rely on subsistence farming. An example of such a system is the parklands of Sahelian Africa, where 40-50 million people practice subsistence farming (Birch et al. 2015). The parklands are traditional land use systems where crops and trees are grown together: agroforestry (Boffa 2000). The traditional agroforestry systems of the parklands are undergoing changes due to increased human populations and climatic change (Ræbild, 2012). Declining agricultural productivity, land clearance and climate change are exacerbating the vulnerability of already marginal rural population in West Africa (Weston et al 2015). Due to the people's dependence on natural resources and climate sensitive livelihoods (Binam et al 2015), the parklands and the people depending on the parklands, are especially vulnerable to climate hazards, such as: droughts, dust storms, flash floods, wildfire, heavy rainfall events and heat waves (Middleton & Sternberg 2013). Moreover, across the parklands there are worrying signs, such as widespread reports of disappearing tree species (Gonzalez, 2001; Hall et al. 1997; Maranz, 2009; Ouédraogo, 1995; Ræbild, 2012; Sina, 2006; Wezel &Lykke, 2006), and the ageing of the tree species in the parklands - in the Sahel referred to as 'le vieillissement des parcs' (Maranz, 2009; Sina, 2006). Some tree species respond immediately to changes, while others have a delayed response, extinction debt: the species will go extinct when the remaining individuals die (Lindorg & Eriksson, 2004). The current tree community contains species whose populations cannot be sustained in the long term (Kuussaari et al., 2009; Tilman, May, Lehman, & Nowak, 1994). A lack of regeneration results in an ageing tree population and loss of genetic diversity, leading to a decline in forest cover and biodiversity (Herrmann, Anyamba, and Tucker 2005; Smith-Dumont n.d.; Sop and Oldeland 2013). Consequently, the parkland livelihoods risk land degradation which will affect all aspects of daily life, such as nutrition, medicine, firewood, construction, fodder and tools (Gonzalez, 2001).

Global concerns about the effects of degradation have led to ecological restoration becoming a priority issue. Ecological restoration is the process of restoring one or more valued processes or attributes of a landscape (Davis & Slobodkin 2004). When restoring a landscape, it is important to first define the restoration goal (Davis & Slobodkin 2004). A goal can be to restore ecosystem services through restoring vegetation cover or diversity. Restoring woody vegetation cover is often done via afforestation; planting trees. In the drylands, many of these projects fail because of the very harsh conditions for the planted seedlings: scarce rainfall, extreme temperatures and poor soil quality (Chirino et al. 2009). A more promising way to restore vegetation cover and soil fertility is through Farmer Managed Natural Regeneration (FMNR): actively managing and protecting naturally regenerating trees and shrubs to get more woody vegetation on farm fields (Birch et al. 2015; Haglund et al. 2011). Nowadays, FMNR is promoted as a simple, affordable, fast and effective method to restore large areas of degraded landscapes and at the same time provide many environmental and especially socio-economic benefits (Bayala et al. 2011; Birch et al. 2015; Cunningham et al. 2005; Francis and Weston 2015; Haglund et al. 2011; Reij 2009). Some of the benefits of FMNR in Upper East Ghana are for example: increased soil fertility, increased income from firewood and increased biodiversity (Weston et al. 2015). With this thesis research I investigate FMNR and its human drivers: I determine what human drivers influence FMNR adoption and evaluate their influence in restoring landscapes.

In this study natural regeneration or regeneration refers to the process where trees start growing naturally, either from arriving seeds or from the 'underground forest' (Birch et al. 2015): living tree stumps, roots and seeds. Natural regeneration is influenced by biophysical factors (ecological drivers) and socioeconomic factors (human drivers), which together determine the potential possibilities within which the individual households finally select and manage the tree community on their fields. Trees first depend on the ecological drivers (for instance; soil quality, water, dispersers, forest remains), then on farmer management (household strategy). Ultimately it is the farmers who decides what species they allow to regenerate on their fields; farmers decide on the final abundance, diversity and functional properties of the adult tree and regenerating tree community, as shown in the conceptual model (Figure 1).

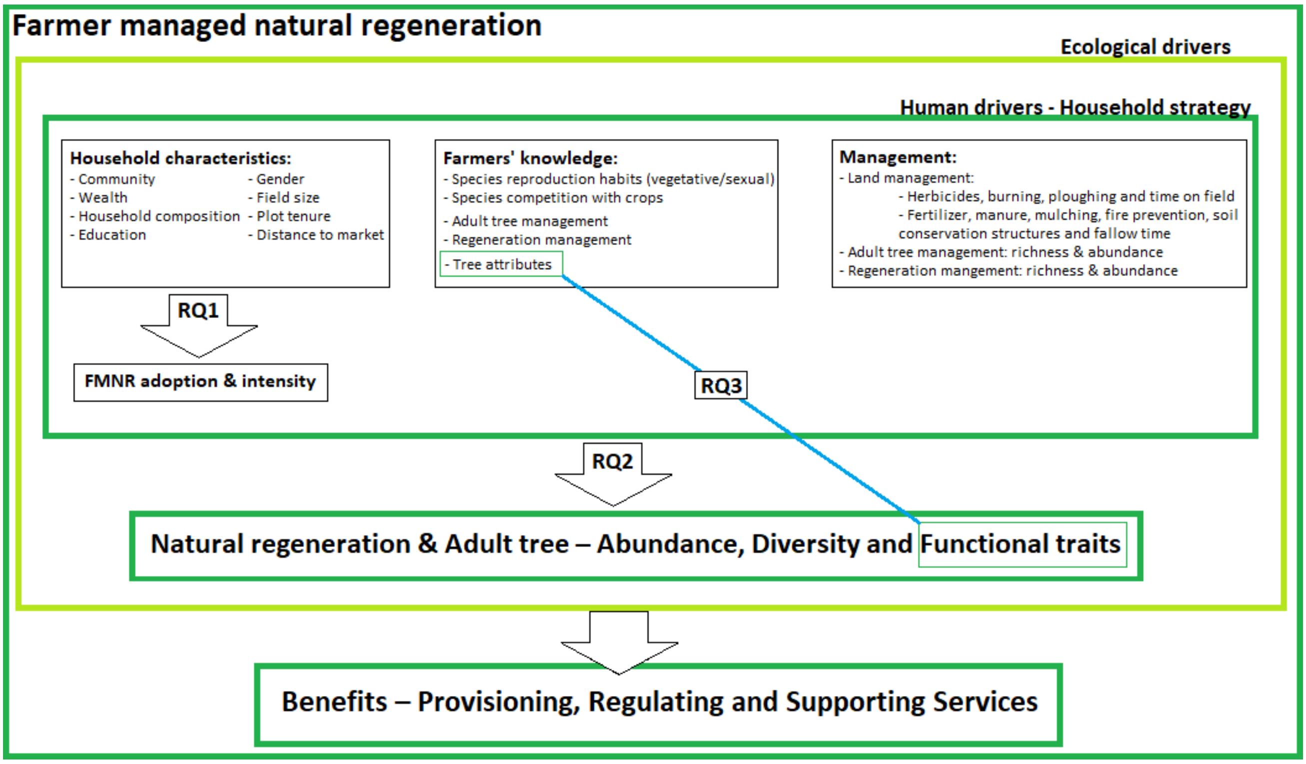

Figure 1; Conceptual model showing the different components of Farmer Managed Natural Regeneration (FMNR) included in this research. The main drivers of FMNR are ecological (biophysical, e.g. climate, soil type, parent trees) and human (socioeconomic, e.g. wealth, distance to market, tenure). The ecological drivers form the potential possibilities within which the human drivers determine the final tree community. The human drivers or the household strategy is made up of three parts: first the household characteristics, second the farmers' knowledge and third management. The three parts of the household strategy work together to determine what natural regeneration and adult trees are present on the farmers' fields. The abundance, diversity and functional traits of trees and regeneration on farmers' fields will influence the benefits of FMNR.

FMNR adoption has been widely researched, but we know little about the different practices within FMNR and their effects on the benefits that farmers get from it. Some farmers are more active in managing regeneration than others, therefore I studied different levels of intensity, and expect that intensity and adoption are driven by biophysical (e.g. climate, soil quality) and socioeconomic (e.g. tenure, distance to market, wealth, education, household composition, and land size) aspects (Barranche et al. 2006; Binam et al 2015; Elias 2013; FAO 2013; Hugland et al. 2011; Iiyama et al. 2017; Nagendra 2007; Mikulcak 2011; Ndegwa et al 2017). The focus of this thesis research is on the human drivers (socioeconomic factors), see Figure 1 conceptual model RQ1. Socioeconomic factors play a fundamental role in households' choice of agroforestry adoption and particular management system (Ndegwa et al 2017). To begin, the majority of studies reported in the literature found land tenure to influence the willingness to engage in long-term investments like trees

(Barranche et al. 2006; Elias 2013; FAO 2013; Ndegwa 2017). However, tenure is not as simple as it may sound, there is tenure of land but also of trees. Land can be owned, borrowed or leased. Trees are often owned by the government and managed by the state forestry service, with consequences for farmers managing trees on their fields. For instance, in most Sahelian countries (Burkina Faso, Mali, Niger, Senegal and Ghana), farmers are allowed to exploit and also cut the trees they have planted, but if they have protected and managed natural regeneration they need a permit from the forestry service in order to manage, prune or harvest the trees (Reij & Garrity, 2016). In Ghana, these laws are not enforced, and farmers can freely decide to cut or prune without consequences (T. Addoah, CIFOR, personal communication, 17 November 2018). Nevertheless, these laws may inhibit FMNR adoption. Second, distance to market influences adoption: it is a matter of comparing incentives and disincentives for instance, when living closer to the market, transaction costs are reduced, meanwhile the risk of theft and browsing by animals increases (Hugland et al. 2011). Subsequently, there is a lack of empirical investigations into the influence of economic on traditional agroforestry practices such as FMNR (Sood 2006). It is expected that poorer farmers have limited resources and risk aversion (Sabastian et al. 2014), but a higher incentive to adopt FMNR, as FMNR is low risk, low cost, fast and simple and is expected to restore degraded landscapes and increase and diversify income (Bayala et al. 2011; Birch et al. 2015; Cunningham et al. 2005; Francis and Weston 2015; Haglund et al. 2011; Reij 2009).

The focus of this study will be the effect of human drivers of regeneration as it is the household strategy that shapes the environment and the natural regeneration on the fields (within the ecological boundaries) (Wallace, 2002). I define household strategy as a meaningful activity, embedded in social relationships and encompassing a range of activities. A household strategy consists of management, household characteristics and farmers' species knowledge and aspirations (hopes/ambitions) for their fields (Figure 1, conceptual model RQ2). First, the household characteristics are the community, plot tenure (ownership of plot), distance to market, wealth, household composition, education and gender. All these variables influence the household strategy (and FMNR adoption). Second, the household strategy for managing natural regeneration is based on the farmers' aspirations (hopes/ambition) of their fields and their knowledge of tree species (including reproductive mode, competition with crops and management) and their benefits (tree attributes). Whether a species is viewed as useful will define whether a seedling is kept or removed. Having both trees and crops can help fulfill households' subsistence and consumption needs (e.g. food, feed, medicine) (Bayala et al 2014). Trees can contribute to specific benefits, which can be classified into provisioning, regulating and supporting services (Binam et al 2015). Trees can provide a regular cash income (provisioning services) and can also function as a financial safety net in times of crises (Binam et al 2015). Trees can benefit micro-climate, ground water and prevent erosion and therefore also improve crop growth (regulating services). For example, trees reduce run-off, increase infiltration and decrease flooding, also, trees reduce soil temperature and wind speed and retain soil moisture (Bayala et al 2014). Further having trees on farmland benefits soil carbon, nutrient cycling and reduces greenhouse gas emissions (supporting services) (Bayala et al 2014). For instance, trees contribute to the reduction of carbon in the atmosphere by accumulating biomass via photosynthesis. Tree attributes are the benefits farmers expect to derive from having that tree species on their field (Smith-Dumont, in press). Tree attributes are for instance: economic value, fodder nutritional value for cattle and leaf litter values for fertility. The household will aim to include some species based on tree attributes, for instance to increase income or soil fertility, and remove species that do not have the desired benefits. Final and third, management is divided into land management, adult tree management and regeneration management. Land management includes the application and intensity of: fertilizer, manure, mulching, fire prevention, soil conservation structures, fallow time, herbicides, burning, ploughing and time on field. Adult tree and regeneration management consist of how species are managed, converted into management richness (the number of different practices performed per household) and management abundance (the total number of management practices or activities performed per household, to indicate the total time invested in managing the plot). All these variables (Household characteristics + Farmers knowledge + Management) work together to create the household strategy and the household strategy will impact the species present on a farmers' field. Farmers' fields are the fields where farmers practice agriculture, it can include crops and trees, but can also be without trees, and farmers can have multiple fields.

The tree species on the farmers' field are the species with valued attributes, and these are also likely to relate to functional trait values. Similarly, the farmers select specific functional traits, belonging to specific tree attributes. Plant functional traits are species characteristics measurable at the individual level, that impact fitness indirectly via their effects on growth, reproduction and survival (Violle et al. 2007; Faucon, Houben & Lambers. 2017). There are two types of functional traits: response and effect traits (Funk et al., 2017). Response traits are the traits that respond to the environment (resources and disturbances), they determine a species' success to thrive in an ecosystem (Garnier et al. 2015). Effect traits determine the effect plants have on ecosystem functioning or how they contribute to ecosystem processes (e.g. nutrient cycling) (Lavorel and Garnier 2002; Lohbeck 2014). For instance, a species' effect on the soil fertility: scientists would look at functional traits like nitrogen, phosphor, carbon and chlorophyll content, specific leaf area or leaf dry matter content, while the farmers would look for easily decomposing leaves, leaf size or the trees' effect on the crops. By linking functional traits to tree attributes I hope to bridge the gap between farmers and ecologists/scientists (Isaac et al. 2018) (Figure 1 conceptual model RQ3).

There are many functional traits, I selected traits that could be important for farmers: maximum plant height (PH), spinescence (S), leaf phenology/deciduousness (LP), leaf compoundness (LC), chlorophyll content (Chl), leaf area (LA), leaf thickness (LT), specific leaf area (SLA), leaf density (LD), leaf dry matter content (LDMC), twig dry matter content (TDMC), wood density (WD), resprouting ability (R), seed mass (SM) and nitrogen fixing (NF). Appendix 1 - **Fout! Verwijzingsbron niet gevonden.** shows an overview of the traits and how human drivers and ecological drivers affect their prevalence through natural regeneration. Or in other words: why would farmers promote higher values of the trait, what environmental conditions promote higher values of the trait and what is the ecosystem functioning consequence of higher values in this trait? For instance, spinescence: species with spines can serve as live fencing (human driver), have protected themselves from herbivory (ecological driver) and serve as protection against herbivores (ecosystem service). Another example is a species' ability to regrow: regrowth after coppicing makes it possible to harvest stems and come back next year and harvest it again (human driver), have protected themselves against disturbances like fire or herbivory (ecological driver), and resilience and persistence after environmental disturbances (ecosystem service).

There remain knowledge gaps in understanding tree regeneration and their human drivers in the West African Parklands (Smith-Dumont in press.; Sop and Oldeland, 2013). There is little evidence as to the extent to which FMNR is being practiced and how FMNR is being practiced (including management, intensity of management and regeneration nurturing practices). Likewise, the consequences for the abundance, diversity and functional traits of the natural regeneration on farmers' fields and how they may vary across the landscape is unknown. Subsequently, little research has been done as to what extent tree attributes can be linked with functional traits.

Research for my MSc thesis is part of the West Africa Forest-Farm Interface Project (WAFFI), a project led by Center for International Forestry Research (CIFOR), in collaboration with World Agroforestry Centre (ICRAF) and TreeAid and supported by funding from International Fund for Agricultural Development (IFAD). WAFFI aims to generate evidence to illustrate the effectiveness of integrated management systems to ensure robust and resilient food and energy supplies and increase income from forest and agricultural value chains (CIFOR, IFAD, TreeAid & ICRAF, 2017). Within the WAFFI project research has been ongoing, I built on to previously collected data from a Land Degradation Surveillance Framework (a method for systematic landscape-level assessment of soil and ecosystem health, including a tree and regeneration inventory (Vågen et al. 2013)) and a Forest poverty toolkit survey (including classification of households into wealth categories) that were carried out in 2017 (WAFFI, 2017). The poverty toolkit survey looked at household's wealth indicators to classify them into wealth categories based on indicators: livestock, housing, food production, education, number of dependents, remittances, clothing, means of farm production (e.g. bullock, money for fertilizer), transport, electricity, electronics, diversification of income, non-cash income from crops, forest products and livestock. Households were then classified as poor or comfortable.

Aim: This MSc thesis research investigates the role of human drivers in FMNR. Thereby, it contributes evidence that is needed to scale up the adoption and practice of FMNR and helps to understand the benefits of FMNR in restoring degraded landscapes in the West African parklands.

Research questions:

1. How do community and household characteristics affect the adoption and intensity of FMNR?
2. How do the human drivers of FMNR influence abundance and diversity of regeneration and trees on farmers' fields?
3. How do species functional traits reflect the economic, fodder and litter values farmers attribute to species?

Hypotheses:

RQ1
Tenure has a positive effect on FMNR adoption and intensity. Wealth & distance to market have a negative effect on FMNR adoption and intensity.

RQ2
Farmers select preferred species, species that are valued high for certain attributes, therefore more intense practice of FMNR increases abundance of highly valued species but decreases diversity of tree species. Farmers select species that can regrow after cutting or other disturbances, so species that resprout have a larger abundance. Farmers select species that do not compete with the crops, so crop-friendly species are more abundant. Farmers who own their plot are more likely to invest in trees, therefore more likely to practice FMNR, which increases abundance and decreases diversity. Wealthy communities have many trees, to make a lot of money from them, but they will focus on a few cash tree species and not on many different ones. Distance to market will have the opposite effect, further from market less intensive FMNR is being practiced. Farmers focus more on subsistence farming and local market, and less on producing tree products for more national or international market, they will have more different species to use and sell locally. While at the same time they cultivate crops for subsistence and local market, and crops will be instead of trees.

RQ3

I divided the traits according to their strategy in acquisitive, conservative and reproductive traits (Table 1). Acquisitive species invest in growth whereas conservative species invest in survival (Lohbeck et al 2015). Conservative leaf traits will have a mostly negative effect on the three attributes, because these are slow growing, long lived, tough and resistant leaves (Wright et al. 2004). Acquisitive traits, on the other side, have a more positive effect on the attributes, as they are cheap, short-lived leaves with high assimilation rates (Wright et al. 2004), but are also nitrogen fixing species, and they bring nutrients into the system. Conservative stem traits like wood density and twig dry matter content are good for economic value, but no effect on litter and fodder is expected. Reproductive traits can have a positive or a negative effect on the attributes.

Table 1, relationship between tree functional trait values and farmers' value for services. Table shows the functional trait and its unit, the trait strategy that high values of this trait refer to (A = acquisitive, C = conservative, R = reproductive effort) (Lohbeck et al 2015), the three tree attributes and the expected effect of the traits on the attributes.

Functional trait	**Strategy**	**Economic value**	**Leaf litter contribution to soil fertility**	**Fodder nutritional value for cattle**
Maximum plant height (cm)	A	+/-	+/-	+/-
Spinescence (binary)	C	+/-	-	-
Leaf phenology/ deciduousness (binary)	C	+/-	+	+
Leaf compoundness (binary)	C	+/-	+/-	+/-
Chlorophyll content (SPAD-units)	A	+	+	+
Leaf area (mm^2)	A	+/-	+	+/-
Leaf thickness (mm)	C	-	-	-
Specific leaf area (m^2/kg)	A	+	+	+
Leaf density (g/cm^3)	C	-	-	-
Leaf dry matter content (g/g)	C	-	+/-	-
Twig dry matter content (g/g)	C	+	+/-	+/-
Wood density (mg/mm^3)	C	+	+/-	+/-
Resprouting ability (binary)	R	+/-	+/-	+/-
Seed mass (g/1000 seeds)	R	+/-	+/-	+/-
Nitrogen fixing (binary)	A	+	+	+

2. Methodology

2.1 Study site

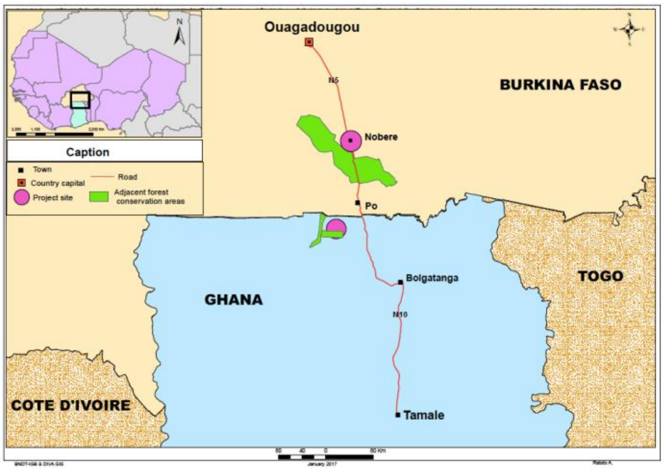

Figure 2, The two landscape sites in the West Africa Forest Farm Interface project in Burkina Faso and Ghana.

Research is part of the WAFFI-project and it covers two landscape sites; one in South-Centre Burkina Faso (Nobere, Seloghin) and another in Upper East Ghana (Navrongo, Kayoro), both landscapes include six villages on the margin of protected forest areas (Figure 2). This study focused on Kayoro, located in the Sudanian ecological zone, originally characterized by short, fire resistant deciduous trees of open canopy with shrubs and grass undergrowth (Taylor, 1952). Nowadays, extensive farmland with significant tree densities are more common (Asiamah et al. 1997). The landscape is commonly called "parklands" across West Africa. Asiamah et al (1997) reported the following important tree species; the baobab (*Adansonia digitata*), neem (*Azadirachta indica*), sheanut (*Vitellaria paradoxa*), Dawadawa (*Parkia clappertonniana*), mango (*Mangifera indica*) and *Acacia albida*. Currently, the landscape is largely dominated by Shea trees (LDSF, 2017). The main ethnic group in the area is Kassem, they are subsistence farmers, with some animal husbandry. The main crops are millet, sorghum, groundnut and rice. A large part of the area is underlain by a wide range of rock types (Asiamah et al. 1997). Both sites have a tropical savanna climate, with dry winters (Nov-April) and wet summers (April/June-Nov). During winter months a strong hot wind called the Harmattan blows and brings dust from the Sahara (Government of Ghana. 2018). In Kayoro the average temperature is 28.1 °C, with April the highest (31.4°C) and August the lowest (25.8°C). Rainfall average is 940mm/year, with the highest precipitation in August (Climate-data.org. 2018b). Often the rain occurs as thunderstorms and the intensity exceeds the soil infiltration rates causing surface runoff, giving the water no chance to infiltrate into the soil (Liebe et al 2005).

2.2 Study design

Different methods of data collection were used to answer my three research questions. The study has two separate parts: a household survey and a functional trait assessment.

The household survey took place on the farmers' field and consisted of: 1. an interview (Appendix 2) to determine the household characteristics and household strategy (RQ1 & RQ2), 2. an inventory to determine the present regeneration and adult tree species (RQ2), and 3. a tree attribute scoring to understand farmers' species knowledge and values (RQ3). The household survey is to determine and understand the household strategy and its influence on the abundance, diversity and functional traits of regeneration and trees on farmers' fields (RQ2). Additionally, the household survey serves as a means to find out if farmers indeed practice FMNR and what influences the adoption of FMNR (RQ1).

The second part consists of functional trait measurements. Functional trait values can inform about plant functional strategies and effects on ecosystem functioning. By matching functional trait values to tree attribute scoring scientific knowledge (or ecosystem functioning) is linked to the farmers' knowledge (RQ3).

2.3 Household survey

2.3.1 Household selection

Four communities were selected from the WAFFI project: the two poorest (Akaa and Gwenia) and two most comfortable (Wombio and Adabania) (determined from previous research within the WAFFI project, using the poverty toolkit survey. Comfortable communities are more prosperous or less poor). Household selection was stratified random, 20 poor and 20 comfortable, 40 households in total, 10 in each community, see Table 2. Selection was stratified random because the member of the population was first categorized into subpopulations (poor or comfortable) and then randomly selected (by writing the names of the households on cards, shuffling them and randomly picking 5, plus one for backup). The survey took place at the farmers' field, after free prior informed consent was obtained (United Nations 2005).

Table 2. Household survey sampling, showing the four communities selected based on community wealth, the community, the selection of female and male for both poor and comfortable households, the number of famers interviewed per community and the total.

Community		Poor		Comfortable		total
		Female	Male	Female	Male	
Comfortable	Adabania	2	3	0	5	10
	Wombio	1	4	2	3	10
Poor	Akaa	0	5	1	4	10
	Gwenia	0	5	1	4	10
Total		3	17	4	16	40

2.3.2 Semi-structured interviews

To be able to answer the first and second research question a semi-structured interview was done. The line of questioning followed a general script and covered a list of topics, but was open to adjustments (Russel 2015), see Appendix 2. I asked each farmer to show me their field (only one field was included per farmer/household) and explain their decisions for tree and field management. Each community within the WAFFI-project has a local facilitator, they assisted me in finding the households and farmers' fields, and they translated for me. T. Addoah (from CIFOR, works within the WAFFI project area) assisted and translated for the first interviews in each community. When we were confident the local facilitators understood the procedure, the local facilitators would start translating for me.

To evaluate the adoption of FMNR (RQ1) and the abundance, diversity and functional traits of regeneration and adult trees on farmers' fields (RQ2), the household characteristics, the land management activities, adult tree management activities and regeneration management activities were defined from the information collected with the interviews. During the interviews, first the farmers' household characteristics (Appendix 4.1, Table 13) and land management activities (Appendix 4.2, Table 14) were asked, then the farmers were asked about the species present on their field. Thus, one household explained for their field, per species, therefore there are more responses than there are households, but each species is only mentioned once by each farmer. Species information included: the origin of the regeneration (Appendix 4.3, Table 15a), if a species was friendly or disturbing to the crops and why (Appendix 4.3, Table 15bc), the management activities for regenerations as well as for adults (Appendix 4.3, Table 15de). The tables in the appendices show each of the categories named by the farmers and their description.

A species is defined as being friendly when it has no influence, good spacing, good growth, adds fertility, has other benefits (for instance, harvest leaves and give income). Farmers said species that are disturbing have; bad growth, bad spacing (for instance, when they grow too crowded), have a direct negative effect on crops or attract animals that eat the crops. The category friend or foe, with the most responses became the final category of the species. Some species had the same number of responses in friend as in foe, those species were categorized as both friendly and disturbing. Adult tree management has seven categories; use, protect, promote, manage competition, kill, do nothing, and other. The management of the regeneration has 9 categories; promote & protect, promote1, promote2, protect1, protect2, manage competition (protect this one and cut the rest around it), kill and do nothing. For the regeneration management promote and protect are both divided in two subgroups because the farmers' responses differed in their intensity, where the second category is more intense. For instance; a farmer would promote growth by pruning, but another farmer would also go and water the regeneration, the latter having a higher intensity of seedling promotion and would be given promote2. The farmers were also asked about the origin of the regeneration; seed, regrowth or planted. Seed is when the regeneration arrives naturally from seed, regrowth is when the regeneration originates from root or stumps and when the regeneration is planted it can either be from seed or transplanting.

The different categories of management (for adult tree and regeneration) were used to determine the households' management richness and abundance (separately for trees and regeneration). The richness was determined by counting the different management practices per household, the abundance by counting all the adult tree (and separately all the regeneration) management activities a farmer practiced, see Appendix 4.3, Table 16.

Next the households' adoption of FMNR was determined through the interview. I followed the definition of Hugland et al (2011): a farmer has adopted FMNR when he is actively managing and protecting non-planted trees and shrubs. Therefore, when a farmer said to encourage the growth of trees on their farmland (i) by pruning and (ii) by protecting young trees, this farmer has adopted FMNR. FMNR has different intensities, therefore, in addition, I created 4 categories of practicing FMNR: 1. No FMNR, when regenerations are not managed, 2. Minor FMNR when the farmer mentions two different activities for managing regeneration, 3. Medium FMNR when the farmer mentions three different activities, and 4. FMNR when the farmer mentions more than 3.

2.3.3 Adult tree and regeneration inventory

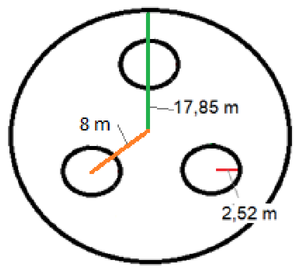

Figure 3, Schematic overview of plot and subplots used for the tree and regeneration inventory

An adult tree and regeneration inventory took place together with the household survey. This way it is possible to directly link the household strategy to the abundance, diversity and functional traits of the regeneration and trees (RQ2). Regeneration is defined as individuals (tree/shrub species) with a diameter of up to 5 centimeters, thereafter it is classified as a tree. The plots were located in the middle of the farmers' field (a farmers' field is defined as the field the farmers showed me and where he cultivates this year), within each plot there were three subplots (Figure 3). The location of the subplots was determined using the following procedure; the first one was defined by standing in the middle of the plot and looking at my watch, the direction the second-hand aims at is the direction of the first subplot, 8 meters from the center. The other two subplots are about 120 degrees apart, each subplot had a radius of 2,52 m which is 20m2 and the plot had a radius of 17,85 making it 1000m2.

Adult tree (plots) and regeneration (sub-plots) species identification, height and DBH (only for trees) were recorded and measured. DBH was measured at 1.3 meters above ground. If the tree branched below this level, I measured the main trunk or all the branches with DBH >10cm at 1.3 meters above ground and average them (Vågen et al 2013). The height for the regenerations and adult trees was measured. The regeneration inventory also noted if the regeneration regenerated from seed or root stock. The farmer was asked if the individual was root or seed stock, additionally I determined this by feeling the thickness of the plant material just below the surface. If the regeneration regenerated from seed stock this plant material was small and fragile, whereas from coppice the base was much bigger. Sometimes this was easy to feel, but sometimes it was not, with the roots much deeper. If this was the case I could feel it by pulling: the regeneration originating from root stock don't come out if you pull hard, whereas regeneration from seed do. Every time the farmer and I agreed on the origin.

The farmers identified the species for me giving their local name, later, together with a local facilitator (Abdul-Aziz Batogikune Ayaga) the scientific name of each species was defined. Not for all species' local names a scientific name could be identified, therefore 11 species were excluded from the analysis. *Acacia sieberiana, Acacia dudgeoni* and *Acacia gourmaensis* were taken together, because they were sometimes hard to identify.

The inventory data was used to calculate the households' abundance and diversity. The households' abundance was calculated via density, number of individuals per hectare, separately for adult trees and regeneration. For taxonomic diversity we took species richness, separately for adult trees and regeneration. We calculated the rarefied species richness, using the vegan-package in R (Oksanen et al. 2018), because of the limited sample size. For adult trees we did it with 2 and for regeneration with 10, because that best represented the data. The functional diversity was calculated using FD-package in R, see chapter 2.5.1.

2.3.4 Tree species attribute scoring

To answer research question 3, we used tree attributes; the farmers' tree species knowledge and perceptions of values for different services. Methods are based on previous work by E. Smith-Dumont (Smith-Dumont, in press). In this study a pre-selected species list of 22 species was used. Appendix 5 Table 17 for the steps taken to get to the tree species list, Table 18 for the species and Table 19 explains the scoring values.

The 22 tree species were represented on illustrated cards (including code and local name) to facilitate communication and discussion. First, I showed the 22 illustrated cards and asked the farmers to select the species they had direct experience with (species the farmer manages). If this list exceeded ten, farmers randomly selected a sample of ten species for ranking and scoring (the illustrated card are turned upside-down and they selected ten). If the number was smaller than ten, farmers scored and ranked all selected species. Tree attribute ranking, and scoring is time consuming, therefore, the sample had a maximum of ten species. Second, the farmer scored the selected species four times, based on their ability to provide the following benefits: economic value, leaf litter contribution to soil fertility and fodder nutritional value for cattle.

Figure 4; attribute scoring, a farmer in Gwenia scoring the selected species.

Per attribute the farmer scored the sample of tree species (between 1 and 10), scoring was done from 0 to 5, zero to high value (with stones) (Figure 4). Then to validate the scores, I ranked the tree species according to their score values and asked the farmers if anything should change and why. With an equal score the species were ranked as a tie. The final scoring value and ranking order and all the explanatory information was recorded (by making notes).

2.4 Functional trait assessment

2.4.1 Focal species selection and sampling

To evaluate the functional traits of regeneration and adult trees on farmers' fields (RQ2), a functional traits assessment was done. Focal species were selected using species abundance: regeneration species that cover 80% of the abundance of regeneration across all plots, and tree species that make up 80% of the basal area across all plots (Garnier et al. 2004; Pakeman and Quested 2007; Pérez-Harguindeguy et al. 2013). Species abundance was determined from the woody vegetation inventory carried out in 2017 within the land degradation surveillance framework (LDSF) (LDSF March 2017, Appendix 6). We further narrowed the list, by excluding the species with an abundance (number of individuals totally measured) of lower than 4, as well as the *Tectona grandis* (only present at plantations). Resulting in a list of 44 focal species, across both sites (Appendix 6, Table 20). 5 individuals of each focal species were collected outside of the plots, across sites and habitat range (Garnier et al. 2007; Pérez-Harguindeguy et al. 2013): 195 individuals in Burkina Faso and 25 in Ghana.

2.4.2 Functional trait measurement

Appendix 1 shows which traits were measured and why they are important for this research. To answer research question 3 the species functional trait values will be determined. For plant functional trait measurements we made use of the 'New Handbook for standardized measurement of plant functional traits worldwide' by Pérez-Harguindeguy et al. (2013). Measurement of the traits in the field followed a standard protocol (Appendix 6) (Cornelissen et al. 2003; Pérez-Harguindeguy et al. 2013). The functional traits were determined using different approaches, see Table 3 for all the functional traits, the definitions and methods used to obtain the values.

Table 3. Functional traits and their method of measurement.

Functional trait	Method of measurement
	Whole plant traits
PH	The maximum plant height (PH) was calculated using the LDSF inventory (2017) by taking the average of the three tallest trees per species across both sites.
S	Spinescence (S) was determined during the field measurements.
	Leaf traits
LP	Leaf phenology (LP) or deciduousness was determined from literature: research done by Seghieri, Do, Devineau and Fournier (2012) and the global leaf phenology database of Zanne et al (2013). First, the research report was used (Seghieri et al 2012), if some species were lacking, the database was used (Zanne 2013). Thereafter, still three species were missing, local knowledge collected during the household survey was used to determine the LP of these species. Seghieri et al (2012) divided the leaf phenology into many categories, if a species has the ability to loose it's leaves completely it is decidious (Cornelissen et al 2003).
LC	Leaf compoundness (LC) was determined during the field measurements, and from 'the guide d'identification des arbres du Burkina Faso' (Sacande et al 2012).

Chl	Leaf chlorophyll content (Chl) was measured on four different leaves per individual using a leaf chlorophyll meter (SPAD), the Chl value was averaged per individual and later per species.
LA	Leaf area (LA) was measured on four leaves per individual. The leaves were photographed on a white surface with a ruler next to it and the LA was calculated using pixel counting software ImageJ (Schneider, Rasband & Eliceiri, 2012). For woody species with simple leaves, the individual leaf lamina was measured. For compounded leafs the whole leaf area was measured, however when the leaflets were too small and numerous we made an approximation. All leaflets were counted, from only ten leaflets the measurements were done, to be able to make the approximation. The petiole and rachis were included in the measurements.
LT	Leaf thickness (LT) was measured with a digital caliper in the middle of the leaf, without including any nerves
LD	LD was calculated as leaf dry mass divided by leaf volume (LA * LT) (Lohbeck et al. 2013)
SLA	Specific leaf area (SLA) SLA was calculated by dividing the LA by the leaf's dry mass.
LDMC	Leaf dry matter content (LDMC) was calculated by dividing the leaves dry weight by the leaf's fresh weight.
Stem traits	
TDMC	Twig dry matter content (TDMC) is the oven-dry mass of a terminal twig, divided by its water-saturated fresh mass, expressed in g g^{-1} (Pérez-Harguindeguy et al., 2013). In the field, three terminal (highest ramification-order; smallest diameter-class), sun-exposed twig of 20-30 cm long were collected and stored in plastic bags. Rehydration and dry mass weighting procedures were the same as previously explained for leaves. (Pérez-Harguindeguy et al., 2013)
WD	Wood density (WD) was defined from the wood density database of Zanne et al (2009). Only species that occur in the region Africa (tropical) and Africa (extratropical) were considered. If a species was present in this database, all individuals were averaged, f it was not: all species of that genus were averaged, if there were no species of the same genus present an average of the family was taken.
Regenerative traits	
R	Resprouting ability (R) was determined from the household surveys and/or from the assessment of regeneration in the field
SM	Seed mass (SM) is the oven-dry mass of an average seed of a species, expressed in mg, and was defined from a seed database (Royal Botanic Gardens Kew 2018).
Belowground traits	
NF	The ability of a species to fix nitrogen (NF), was determined from literature: from the ICRAF agroforestree database (2009) and the global database of plants with root-symbiotic nitrogen fixation: NodDB (2018) regrouping meta-studies and databases of plant roots that nodule or not at genus level. For the binary trait-based study, the species were categorized as nodulating and non-nodulating. The plant genera absent from the databases are considered as lacking the nodulating capacity.

2.5 Statistical analysis

2.5.1 Functional diversity

To answer research question 2 the functional diversity (FD) was determined. To upscale the plant functional traits from species level to plot level, the species functional trait values were linked to the adult tree and regeneration/regeneration inventory I performed on the farmers' fields. FD describes the functional structure of the community (Damour, Navas, and Garnier 2018), and was calculated using the FD package (Laliberté & Legendre 2010; Laliberté, Legendre, and Shipley 2014; Lavorel et al 2008).

The functional traits were collected on the focal species from the LDSF inventory, not from my own inventory. Therefore, I checked if for my own inventory I achieve the 80% abundance (of the individuals for regeneration and of the basal area for adult trees). In most plots the 80% was achieved (35 out of 40 for regeneration and 37 out of 40 for adult trees). The 80% adult tree abundance was not achieved for households/plot number: 4 (36%), 6 (42%) and 16 (0%). The 80% regeneration abundance was not achieved for households/plot number: 8 (50%), 10 (33,33%), 17 (75%), 25 (40%), and 30 (77%).

I used an FD index, called functional dispersion (FDis). FDis is the mean distance in multidimensional trait space of individual species to the centroid of all species; it can account for species abundances by shifting the position of the centroid toward the more abundant species and weighting distances of individual species by their relative abundances (Laliberté & Legendre 2010). *FDis*, is the weighted mean distance to the weighted centroid, and computed with following formula: $FDis = \frac{\sum ajzj}{\sum aj}$ where aj is the abundance of species (the relative abundance of regeneration and the relative basal area of adult trees) j and zj is the distance of species j to the weighted centroid. When communities only have one species the *FDis* is 0 (Laliberté & Legendre 2010).

5.5.2 FAMD – Land management variables

The land management activities taken into account in this study are listed in appendix 3.2, Table 14. The land management variables were explored using Factor Analysis for Mixed Data (FAMD). With FAMD the differences and similarities between sites and land management strategies were explored. Analysis was done using the R-packages: FactoMineR (Le, Josse, and Husson 2008) and factoextra (Kassambara & Mundt 2017). FAMD (instead of Multiple Correspondence Analysis (MCA) or Principle Component Analysis (PCA)) was used because the land management variables are both qualitative (MCA) and quantitative (PCA) variables. The input for the FAMD consist out of 40 households/farmers' fields and their land management activities (eight qualitative variables consisting of 28 categories and two quantitative continuous variables, together creating 30 land management variables). The FAMD results in reduced dimensions/components (from 30 variables to two dimensions), which were used for further analysis. The two created dimensions form the axis on which the variables and sites are projected, the distance between points indicates the differences between them. Therefore, FAMD converts the observed possible correlation between variables into linear variables, the dimensions.

5.5.3 Mixed effect models

To answer research question 1 & 2, mixed effect models were constructed, using the lmer function from the lme4 package (Bates et al 2015). The households/farmers' fields were used as the unit of replication, there were 40 in total. Community was taken as a random factor to account for the nested structure of the data. Separate models were constructed for each of the eight response variables: FMNR adoption, FMNR intensity, regeneration density/abundance, adult tree density/abundance, regeneration species richness/taxonomic diversity, adults species richness/taxonomic diversity, adult functional diversity and regeneration functional diversity. Each dependent variable used a series of alternative models of increasing complexity (Table 4).

The models for FMNR adoption and intensity only included alternative model 1 to 3, and the models for abundance and diversity included all the alternative models 1-7, Table 4. The effect of community and household characteristics on FMNR adoption and intensity was tested. In alternative model 3, the household characteristics were systematically replaced, both FMNR adoption and intensity had 14 alternative models in total. The effect of community, household characteristics, land management practices, adult tree management abundance and diversity and regeneration management abundance and diversity on the regeneration and adult tree abundance and diversity was tested. All seven alternative models (Table 4) are included, including the six additional alternatives of model 3 and the two additional alternatives of model 5, 6 and 7, resulting in 98 alternative models per dependent variable.

For each dependent variable, the 14 (FMNR adoption & intensity) or 98 (abundance & diversity) alternative models were compared. The alternative model with the lowest Akaike Information Criterions (AIC) and highest adj. R2 was selected as the optimal model. Lower AIC values and higher R2 mean a better fit of the model. AIC values were seen as different when Δ AIC was >2. The models R2 was calculated, using the MuMIn package (Barton 2018). The residuals of the optimal models were tested for normal distribution and transformed where needed.

Table 4, alternative models of increasing complexity, to test the effect of human drivers on FMNR adoption, intensity, abundance and diversity of the regeneration and adult trees on farmers' fields. For each of the dependent variables these alternative models are constructed. FMNR adoption and intensity only use alternative model 1-3.

#	**Alternative Models**
1	Dependent variable ~ random effect community
2	Dependent variable ~ random effect community + community wealth
3	Dependent variable ~ random effect community + community wealth + household characteristic
3a-f	HH characteristics options are: a. household wealth, b. field size, c. household composition, d. education, e. gender or f. plot tenure
4	Dependent variable ~ random effect community + community wealth + household characteristic + Distance to market
5	Dependent variable ~ random effect community + community wealth + household characteristic + Distance to market + Land management practices
5a-b	Land management practices: a. dimension 1 or b. dimension 2
6	Dependent variable ~ random effect community + community wealth + household characteristic + Distance to market + Land management practices + Adult tree management practices
6a-b	Adult tree management practices: a. abundance or b. diversity
7	Dependent variable ~ random effect community + community wealth + household characteristic + Distance to market + Land management practices + Adult tree management practices + Regeneration management practices
7a-b	Regeneration management practices: a. abundance or b. diversity

5.5.4 Linking tree attribute scores and functional trait values

Farmers knowledge was linked to ecosystem functioning; using the species attributes scores and the species functional trait values. The analyses included; the three tree attributes; Economic value, Leaf litter contribution to soil fertility and Leaf nutritional value for cattle (fodder), and 13 measured functional traits (see appendix 2, Table 12). The relationship between the average scores of tree attributes and species functional trait values was tested using a correlation matrix, and significant results were visualized using Lm in R. All variables were first tested for normal distribution, if not normal they were transformed.

Table 5 gives an overview/summary of the research questions and how they were answered. All statistical analyses were carried out using R version 3.3.3 (R Core Team, 2014).

Table 5; overview of the study, showing the research questions and their dependent variables, what they entail and how the data was analysed or how the research questions were answered.

RQ	Description	How
RQ1		
FMNR adoption	Number of households that adopted FMNR (promote and protect trees)	lmer Household characteristics
FMNR intensity	Number of households practicing FMNR per level of intensity (non, minor, medium, FMNR)	lmer Household characteristics
RQ2		
Abundance & Diversity	Inventory species	Excel/ Inventory Farmers knowledge
Abundance	Density per hectare	lmer Household characteristics & management
Diversity	Rarefied species richness	lmer Household characteristics & management
	Functional diversity	lmer Household characteristics & management
RQ3		
Link farmers knowledge & scientific knowledge	Functional trait values & Farmers average tree attribute scores	Correlation & Lm

3. Results

3.1 FMNR in the study site

The household survey resulted in a total of 69 species, composed of both inventory and interviews (Appendix 7, Table 21). During the interview farmers named 58 species, while the inventory resulted in 49 species, 44 species overlap, nine are only found in the inventory and 14 only from the interview. 11 species were excluded in further analysis because no scientific name was found. The interviews had a total of 315 responses, of which 138 responses for both regeneration and adults, 230 for only regeneration and 223 for only adults. With the inventory 624 individuals were measured: 384 regeneration, and 213 adult trees. Across the 40 households only two inventory plots did not include any adult trees, and five did not include any regeneration, in the interviews all but one farmer said to have trees and regeneration on their field. Out of the 40 households surveyed, 26 have adopted FMNR (65%), there is no difference in adoption between the four communities (Table 6). When we look at FMNR intensity, there is a difference: more households in Gwenia and Akaa (both poor communities) practice FMNR more intensely (Table 6 and Figure 5).

Table 6; FMNR adoption and intensity across the four communities, showing the number of households (#hh) that have adopted FMNR or practice FMNR at some level of intensity, per community and the total number of households practicing. Also the number of households per level of intensity is shown per community and total.

	Gwenia	Wombio	Akaa	Adabania	Total
Adoption (# hh)	7	6	7	6	26
Intensity total (# hh)	10	7	10	9	36
Intensity elaborated:					
non (# hh)	0	3	0	1	4
minor (# hh)	2	5	0	3	10
medium (# hh)	2	2	3	4	11
FMNR (# hh)	6	0	7	2	15

Figure 5 shows the differences in management strategy between the communities. The responses from all communities show that they all remove a lot of the regeneration (Kill), especially in Wombio (62%) and Adabania (48%). Farmers across all communities select some individuals to protect, promote and manage competition, the most in Akaa (80%) and Gwenia (70%). Akaa and Gwenia are the poorest communities. Akaa (the poorest community) promotes and protects regeneration the most, additionally they keep most or all of their regeneration.

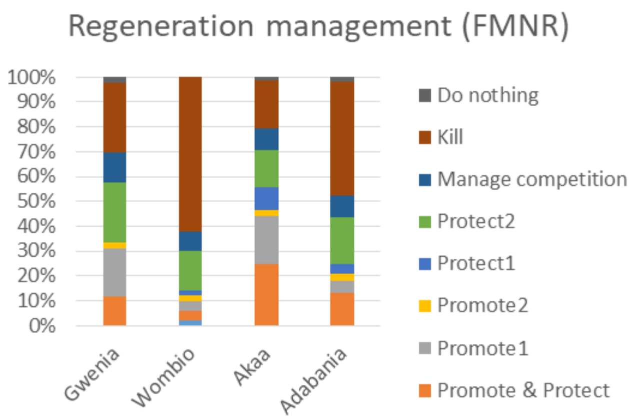

Figure 5, FMNR (regeneration management) in the study site: per community the percentage of responses per management category. (Appendix 3.3 table 15d for the explanation of categories)

The optimal models explained 42% of the variance in FMNR adoption and 69% of the variance in FMNR intensity. Most household characteristics were not retained in the optimal models (Table 7). I found no significant effect of distance to market on the adoption or intensity of FMNR. Plot tenure had a positive effect on FMNR adoption, education on FMNR intensity and community wealth had a negative effect on FMNR intensity (full model output: Appendix 9, Table 22).

Table 7. Overview of the models for FMNR adoption and FMNR intensity. Models included the household characteristics: community wealth, household wealth, household composition, education, gender, plot tenure and distance to market. (Left out of the table are: community (included as random factor), household wealth, household composition and gender because they were not included in the models) . The 'blank' cells indicate the variable was not included in the model. The table shows which variables were found significant for each model. Significance is highlighted in grey and the strength indicated with codes, the +/- indicates whether the effect was positive or negative, and the R indicates the fit of the model.

Model	**COMw**	**EDU**	**Plot tenure**	**Dist. market**	**R2**	**Adj.R2**
FMNR adoption	ns		**+	ns	0.32	0.42
FMNR intensity	*-	med **+ non *+		ns	0.66	0.69
*Signif. codes: '***' < 0.001, '**' <0.01, '*'<0.05', 'ns' >0.05, 'Blank cell' variable was not included in the model*						

3.2 Human drivers & abundance and diversity

3.2.1 Farmers' knowledge & management of tree species

Figure 6 shows an overview of the farmers species knowledge and management, the figure summarizes the information obtained from the interviews.

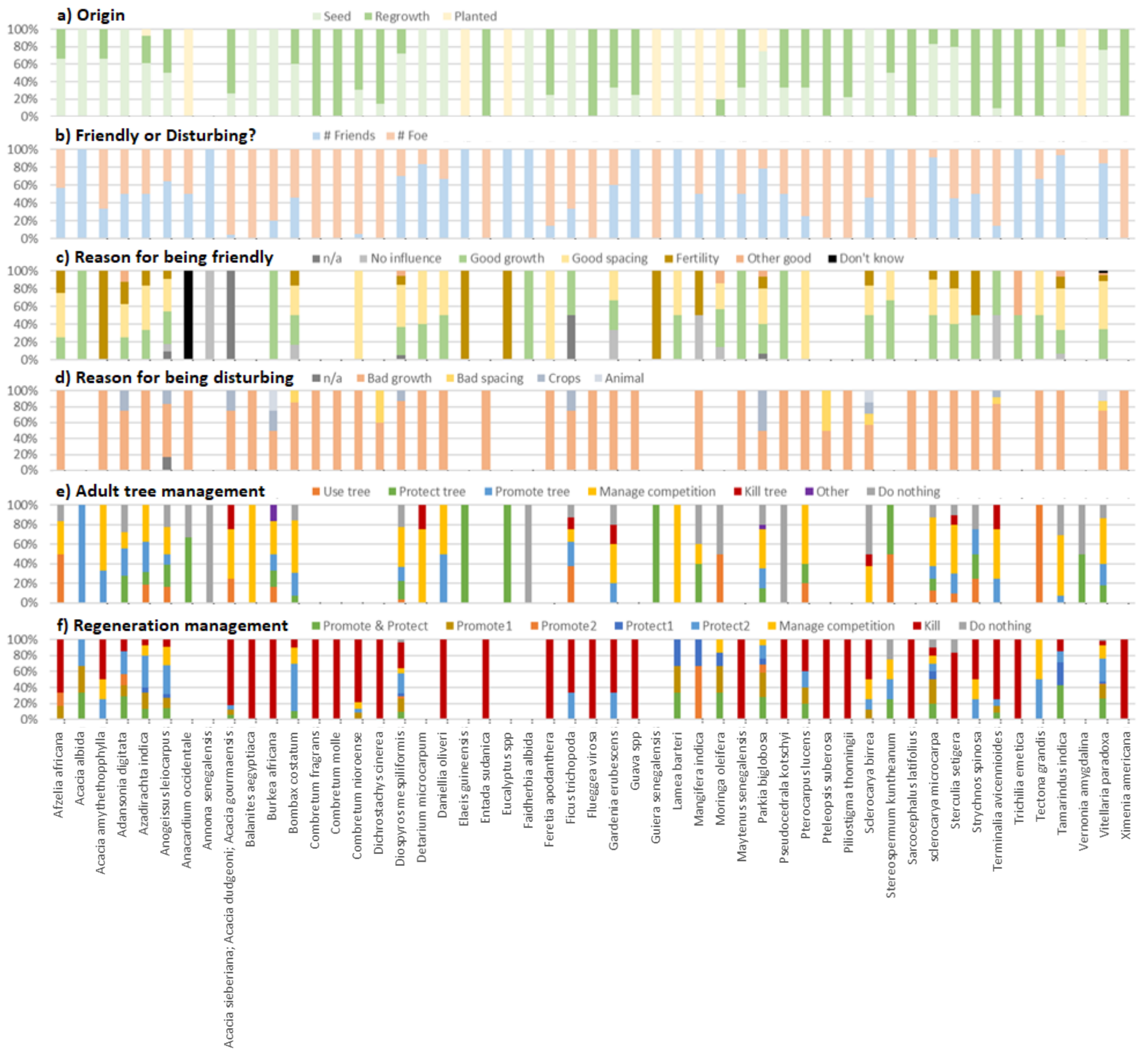

Figure 6; Overview of Farmers tree species knowledge and management: all 51 species and a) their origin, b) if the species are considered friendly or disturbing to the crops, c) the reason for being a friendly species, d) the reason for being a disturbing species, e) adult tree management and f) regeneration management. Figure shows the species ordered alphabetically from left to right and its percentage of responses in each category.

a) <u>Origin</u>

First farmer knowledge on species reproduction habits (vegetative or sexual) was explored. Unit of replication is the regeneration species mentioned by the farmers during the interviews. Each farmer could respond with multiple species, and different farmers mentioned the same and different species, therefore the 40 households resulted in 297 responses and 50 species. In appendix 4.3, Table 15a, the categories of reproduction are explained. Figure 6a, shows all species and their origin and Figure 7a, shows an overview of farmers' knowledge on tree species origin. Results show what farmers reported; most individuals and most species reproduce by seed and regrowth; few species are planted.

20 species reproduce on farmers' fields via both seed and regrowth, for example *A. africana or A. amythethopphylla* (Figure 6a), only *M. oleifera* reproduces via regrowth and planting, *P. biglobosa* is planted and regenerates through seed, and *A. indica* regenerates through regrowth, seed and planting. Only 10 out of the 50 species are planted, of which 6 are solely planted (*A. occidentale, E. guineensis, Eucalyptus spp, G. senegalensis, M. indica and V. amygdalina)*. 12 species reproduce only via seed (for example; *B. africana* and *S. birrea*) and 12 other species reproduce only through regrowth (for example; *C. fragrans and T. grandis*).

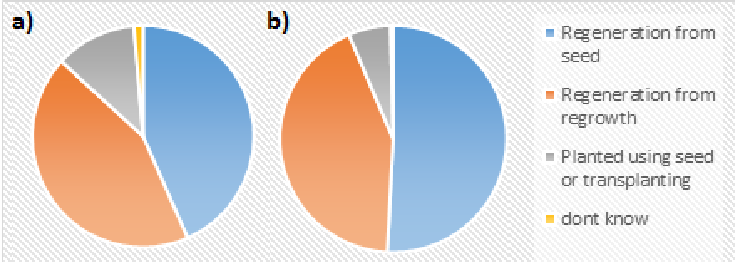

Figure 7; species origin, overview of farmers knowledge on species origin: a) number of species per category, b) number of responses per category. See Appendix 10, Table 23a.

b) <u>Friend or Foe?</u>

The second human driver of abundance, diversity and functional traits of regeneration and adult trees on farmers' fields is the farmers' perception of species competition with crops. Unit of replication is regeneration species and adult tree species mentioned by the farmers during the interviews: 305 individuals and 50 species. Farmers mentioned 153 friendly individuals containing 39 species and 128 disturbing individuals with 40 species. Figure 6b, shows most species to be both friendly and disturbing to the crops (e.g. *B. costatum* and *V. paradoxa*), 14 species are seen only as disturbing (e.g. *C. fragrans* and *P. thonningii*), and 13 only as friendly (e.g. *A. senegalensis* and *Eucalyptus spp*).

Farmers gave 180 responses for why the 128 disturbing individuals are bad, and 198 responses for why the 153 friendly individuals are good. The reasons farmers gave for species being disturbing or friendly can be found in Appendix 4.3, Table 15bc.

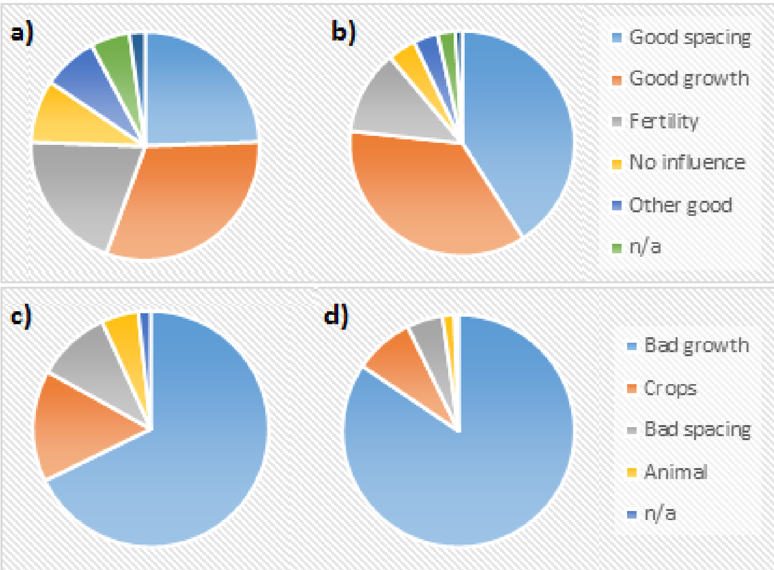

Figure 8, overview of friendly species (a, b) & disturbing species (c, d): showing percentage of species (a, c) and responses (b, d) per category. See Appendix 10, Table 23bc.

Figure 8ac show that the different categories contain a different number of species. For friendly species the category good spacing includes most responses (where the species grow at a good distance from each other, and are not crowded), followed by good growth. Good growth has the most different species, followed by good spacing. For disturbing species, bad growth has by far the most responses: all the disturbing tree species farmers named belong (among others) to this category.

Figure 6bcd shows species occur in multiple categories, for example: farmers say *A. digitata* is friendly because it has good growth, good spacing, adds fertility to the soil, and provides other goods (easily decompose, gives income), at the same time it is disturbing because it has bad growth and is bad for the crops (competition for light and water.

c) <u>Valued tree species</u>

Farmers value for species (attributes) influences the abundance and diversity of the farmers' fields. The unit of replication was again the 40 households, this time the attribute scoring done for the 22 preselected species. **Fout! Verwijzingsbron niet gevonden.** shows most species have some value, most obvious are the *V. paradoxa*, *P. biglobosa, A. digitata* and *T. indica*. *A. digitata* is valued for all three attributes, *V. paradoxa*, *P. biglobosa* and *T. indica* only for economic and litter. If we look at **Fout! Verwijzingsbron niet gevonden.**, we see that there is a positive trend when we plot abundance against species attribute scores: species that are valued high are more abundant. The trend is strongest for litter value, especially for adult trees. For regeneration fodder value the trend is almost horizontal.

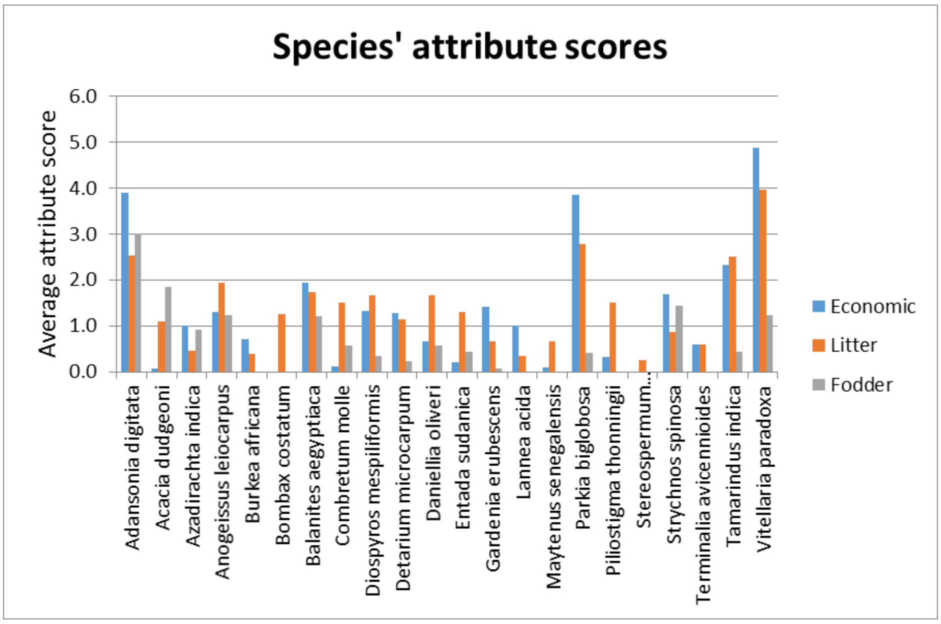

Figure 9, farmers' species value, showing average species' attribute scores, for economic value, leaf litter contribution to soil fertility and fodder nutritious value for cattle.

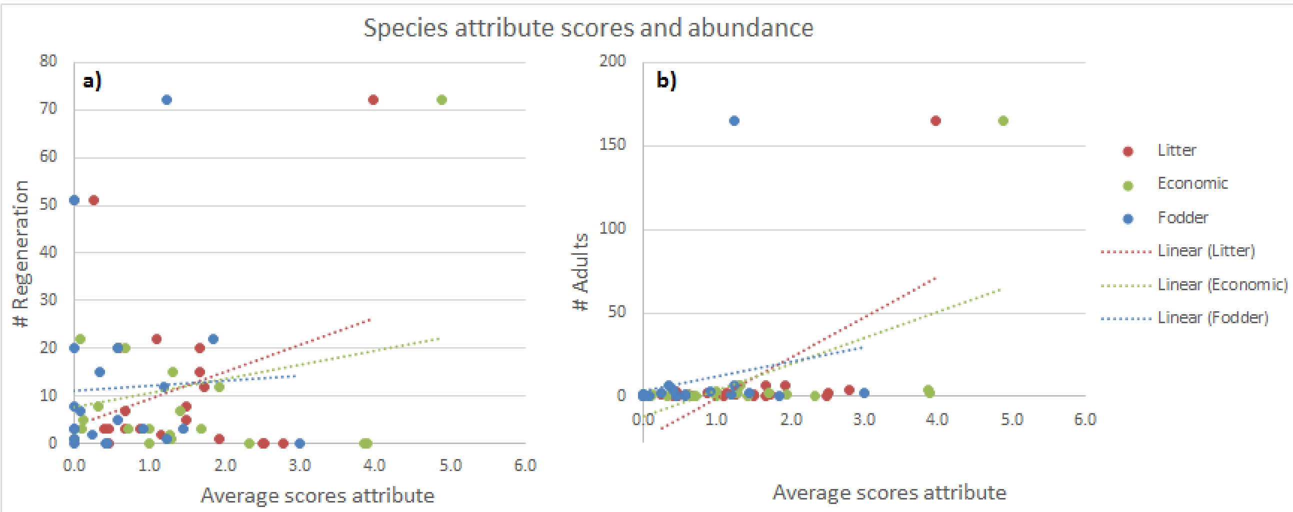

Figure 10, species abundance and attribute scores, regeneration (a) and adult tree (b) abundance from the woody inventory, species average attribute scores and the linear trend lines, showing the more abundant species are valued higher.

d) Adult tree management

The unit of replication is the adult tree species mentioned by the 40 farmers during the interviews. Each farmer mentioned present adult trees, the species and the management they apply to it, this resulted in 272 responses: 216 individuals and 37 species, categorized into 7 categories, see Appendix 4.3, Table 15e for explanation of each category.

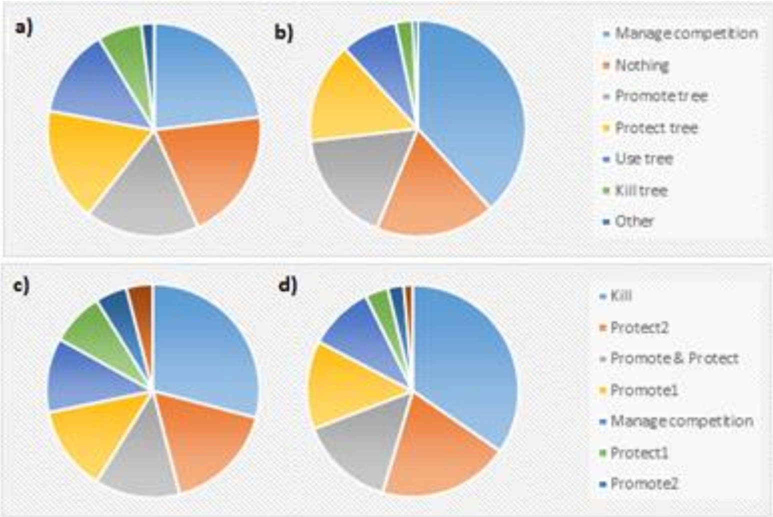

Figure 11; overview of tree management, for adult trees (ab) and regeneration (cd): showing percentage of species (ac) and responses (bd) per category, see also Appendix 10, Table 23de.

Figure 11ab, shows an overview of the number of species (a) and the number of responses (b) per category, and Figure 6e shows all the adult tree species and their management. Results show all categories have multiple species and species can belong to multiple categories. Almost all species are managed for competition (only 14 are not). Many responses were to do nothing, for three it was even the only category (*A. senegalensis, F. albida,* and *P. kotschyi*). Next many individuals are promoted, especially *A. albida*, and *D. oliveri*. Three species are said to be solely protected: *E. guineensis*, *Eucalyptus spp* and *Guava spp*. 14 species are said to be used, especially *T. grandis, M. oleifera, A. africana* and *F. trichopoda*. Not many species are said to be killed, and for none it is the only management category.

e) Regeneration management

The unit of replication is the regeneration species obtained from the farmers' interviews. Similar to the adult tree management, farmers mentioned which species they had, and how they managed them. This resulted in 370 responses: 236 individuals and 43 species, categorized into 8 categories, see Appendix 3.3, Table 15d for explanation of each category.

Figure 11cd, shows an overview of the number of species (a) and the number of responses (b) per category, and Figure 6f shows all regeneration species and their management. Again, results show that most categories contain multiple species, and different species can belong to different and/or multiple categories For example: *A. digitata* is part of Promote & Protect, Promote1, Promote2, Protect1 and kill. For almost all species individuals are killed, and for 17 species all individuals are killed (See Figure 6f). Only a few are not killed at all (*A. albida, L. barteri, M. indica, M. oleifera, P. biglobosa, S. kuntheanum and T. grandis*). For many species selection takes place (Protect2) and often the same species are also promoted and protected by weeding around to prevent fire (Promote & Protect) and promoted by pruning (Promote1). Competition is managed for many species, especially *T. grandis*. Not many species show in the remaining categories. Only a few farmers keep all the regeneration: few species show in this category (e.g. *M. oleifera* and *M. indica*). *M. indica* is actively promoted by watering the plants (Promote2), indicating that the farmer puts a lot of effort into growing *M. indica*.

3.2.2 Human drivers & abundance

The relative abundance of all 50 species was calculated, across the 40 inventoried plots, see Appendix 11, Table 24. Table 8 shows the top 10 most abundant species from the woody vegetation inventory performed on the 40 farmers' fields (Table 8a for the regeneration and Table 8b for the adults). Many (14 out of 21) of the most abundant regeneration species reproduce with both seed and regrowth, among others; *V. paradoxa, S. kuntheanum, D. mespiliformis,* and *A. leiocarpus*. Results between adults and regeneration are similar, althought with different species. Additionally, there are planted species among the most abundant adult trees: *P. biglobosa, M. indica* and *A. indica*. The most abundant adult tree species are mostly friendly to the crops (6 out of 11). Similar for regeneration the top two species *Vitellaria paradoxa* and *Stereospermum kuntheanum* (which make up 33.6% of the total regeneration abundance) are friendly, but many species are also seen as disturbing to the crops (6 out of 10, 37.7% of the total abundance). The regeneration management can either be positive where the regeneration is promoted and/or protected, or negative where regeneration is removed. The management is in line with the farmers perception of species competition with crops: friendly species are positively managed and disturbing species are negatively managed.

Table 8, farmers knowledge & abundance: species scientific name, farmers perception of species competition, farmer regeneration management (positive or negative), farmers knowledge on origin and relative abundance (from woody vegetation inventory performed on the 40 farmers' fields).

Scientific name	Competition with crops	Regeneration management	Origin	Relative abundance (%)
a) Regeneration				
Vitellaria paradoxa	Friend	+	SR	19.7
Stereospermum kuntheanum	Friend	+	SR	13.9
Combretum nioroense	Foe	-	SR	11.2
Dichrostachys cinerea	Foe	-	SR	6.8
Acacia sieberiana; Acacia dudgeoni; Acacia gourmaensis	Foe	-	SR	6.0
Daniellia oliveri	Friend	-	S	5.5
Terminalia avicennioides	Foe	-	SR	5.5
Pteleopsis suberosa	Foe	-	R	4.9
Diospyros mespiliformis	Friend	+	SR	4.1
Bombax costatum	Foe	+	SR	3.3
b) Adult tree				
Vitellaria paradoxa	Friend	+	SR	77.8
Diospyros mespiliformis	Friend	+	SR	3.3
Anogeissus leiocarpus	Friend	+	SR	3.3
Sclerocarya microcarpa	Friend	+	SR	1.9
Mangifera indica	Friend/Foe	+	P	1.9
Parkia biglobosa	Friend	+	SP	1.9
Azadirachta indica	Friend/Foe	+	SRP	1.4
Sclerocarya birrea	Foe	+/-	S	0.9
Strychnos spinosa	Friend/Foe	+/-	R	0.9
Detarium microcarpum	Friend	n/a	S	0.9
Adansonia digitata	Friend/Foe	+	S	0.9

3.2.3 Household land management

To explore patterns in land management activities or in other words to find farmers' land management strategy, all the land management activities (Appendix 4.2, Table 14) applied by the 40 households were analyzed using a Factor Analysis for Mixed Data (FAMD). The unit of replication is the 40 households' fields. The FAMD resulted into multiple dimensions. Often 10% is the (arbitrary) threshold for retaining or discarding a dimension, so only the first two were retained, explaining: 12.8% (dimension 1) and 11.3% (dimension 2) of variation in land management activities.

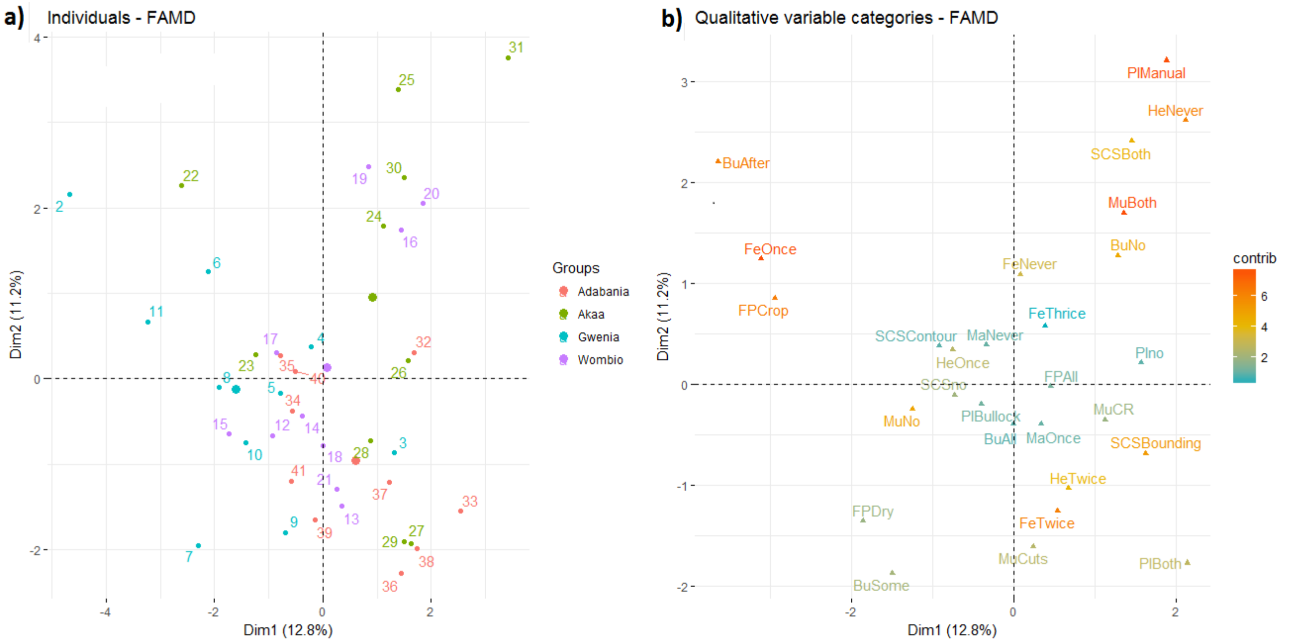

Figure 12. FAMD: a) the location of the households/fields (shown as dots with corresponding household numbers) plotted on the first two dimensions, Dim1 explaining 12.8% and Dim2 explaining 11.2% of the variation. Coloring shows to which of the four communities the sites belong; b) the qualitative variables (triangles), coloring indicates their contribution to the dimensions.

1. Figure 12 shows the FAMD, it shows the distribution of the sites (a) when separated based on land management practices; both categorical (b) and continuous management practices (Appendix 12, Figure 12c). Figure 12a show that the households are scattered, with no clear distinction between the communities. Although, Akaa is spread out most and Adabania least, and Wombio and Akaa are scattered in the same direction, as well as Adabania and Gwenia are. Appendix 12, Appendix – Farmers' species knowledge and the species' relative abundance

Table 24, farmers' species knowledge and species relative abundance: the 50 species named during the interviews by the farmers, their scientific name, the species competition with the crops (friendly, disturbing (foe) or both), the regeneration management (positive (protect/promote) or negative (kill)), the origin (seed, regrowth, planted), and the species' relative abundance (species' total number of individuals measured across the 40 farmers fields' during the inventory divided by the total number of individuals measured times 100) separate for regeneration and adult trees. The table is ordered alphabetically. Inventory of farmers' field: the adult trees were measured in a plot of 1000m2, within the regeneration was measured in three subplots of each 20m2. Total number of individuals: 366 regeneration and 212 adult trees, across 40 farmers' fields.

ID	Scientific name	Competition with crops	Regeneration management	Origin	Regeneration Abundance (%)	Adult tree abundance (%)
1	*Acacia albida*	Friend	+	S	0,0	0,0
2	*Acacia amythethopphylla*	Foe	=	SR	0,3	0,5
3	*Acacia sieberiana; Acacia dudgeoni; Acacia gourmaensis*	Foe	-	SR	6,0	0,0
4	*Adansonia digitata*	Same	+	S	0,0	0,9
5	*Afzelia africana*	Friend	-	SR	0,0	0,0
6	*Anacardium occidentale*	Same	n/a	P	0,0	0,5
7	*Anogeissus leiocarpus*	Friend	+	SR	0,3	3,3
8	*Azadirachta indica*	Same	+	SRP	0,8	1,4
9	*Balanites aegyptiaca*	Foe	-	S	0,8	0,0
10	*Bombax costatum*	Foe	+	SR	3,3	0,5
11	*Burkea africana*	Foe	-	S	0,3	0,5
12	*Combretum fragrans*	Foe	-	R	1,4	0,0
13	*Combretum molle*	Foe	-	R	1,4	0,5
14	*Combretum nioroense*	Foe	-	SR	11,2	0,5
15	*Daniellia oliveri*	Friend	-	S	5,5	0,0
16	*Detarium microcarpum*	Friend	n/a	S	0,5	0,9
17	*Dichrostachys cinerea*	Foe	-	SR	6,8	0,0
18	*Diospyros mespiliformis*	Friend	+	SR	4,1	3,3
19	*Elaeis guineensis*	Friend	n/a	P	0,0	0,0
20	*Entada sudanica*	Foe	-	R	0,0	0,5
21	*Eucalyptus spp*	Friend	n/a	P	0,0	0,0
22	*Faidherbia albida*	Friend	n/a	S	0,0	0,0
23	*Feretia apodanthera*	Foe	-	SR	2,2	0,0
24	*Ficus trichopoda*	Foe	-	S	0,0	0,0
25	*Flueggea virosa*	Foe	-	R	0,3	0,0

26	*Gardenia erubescens*	Friend	-	SR	1,9	0,0
27	*Guava spp*	Friend	n/a	P	0,0	0,0
28	*Guiera senegalensis*	Foe	-	SR	0,0	0,0
29	*Lamea barteri*	Foe	+	S	0,0	0,0
30	*Mangifera indica*	Same	+	P	0,0	1,9
31	*Maytenus senegalensis*	Same	-	SR	0,8	0,0
32	*Moringa oleifera*	Friend	+	RP	0,0	0,5
33	*Parkia biglobosa*	Friend	+	SP	0,0	1,9
34	*Piliostigma thonningii*	Foe	-	SR	2,2	0,0
35	*Pseudocedrala kotschyi*	Same	-	SR	1,1	0,0
36	*Pteleopsis suberosa*	Foe	-	R	4,9	0,0
37	*Pterocarpus lucens*	Foe	+	SR	0,5	0,0
38	*Sarcocephalus latifolius*	Foe	-	R	0,0	0,0
39	*Sclerocarya birrea*	Foe	=	S	1,6	0,9
40	*sclerocarya microcarpa*	Friend	+	SR	1,9	1,9
41	*Sterculia setigera*	Foe	-	SR	0,0	0,0
42	*Stereospermum kuntheanum*	Friend	+	SR	13,9	0,5
43	*Strychnos spinosa*	Same	=	R	0,8	0,9
44	*Tamarindus indica*	Friend	+	SR	0,0	0,0
45	*Tectona grandis*	Friend	+	R	0,0	0,0
46	*Terminalia avicennioides*	Foe	-	SR	5,5	0,5
47	*Trichilia emetica*	Friend	-	R	0,0	0,0
48	*Vernonia amygdalina*	dk	n/a	P	0,0	0,0
49	*Vitellaria paradoxa*	Friend	+	SR	19,7	77,8
50	*Ximenia americana*	Foe	-	R	0,0	0,0

Appendix – shows the same figure twice, once with ellipses around the communities, showing the slight clustering (Figure 18a, Appendix 11), and the other has different coloring showing the contribution of the sites to the dimension's variation (Figure 18b, Appendix 11). Figure 12b, shows the distribution of the categories of land management activities (It is the MCA part of the FAMD). This figure matches figure 12a in showing how the categorical variables underlie the separation in sites. Variables that are close together in this graph are correlated. For example, the households in the top right: practice manual ploughing, never use herbicides, have both soil conservation structures and don't burn their field. Another example is to the left of the graph: households that burn after the cropping season, apply fertilizer once and prevent fire during the cropping season. Appendix 12, Figure 12c shows the continuous land management activities underlying the separation in sites (the PCA part of the FAMD).

All land management activities contribute differently to the dimensions. Table 9, shows the top 5 and their percentage of contribution to dimension 1 and 2. With the use of dimension 1 and dimension 2 land management strategies are seen. The two dimensions shown here, were used as input for further analysis, to see how land management influences species abundance, diversity and functional traits.

Cat. Code	Description	Dim.1 (%)	Dim.2 (%)
Mu	Mulching	17.19	16.67
SCS	Soil conservation structures	15.22	
PF	Prevention of fire	15.22	
Fe	Fertilizer	13.99	21.49
Bu	Burning	13.85	13.92
He	Herbicides		15.88
Pl	Ploughing		15.72

Table 9. FAMD top 5 land management categories that contribute above average to the 1st and 2nd dimension. Table shows the category code, description and their contribution to the dimensions, colouring indicates the variables contribution (light to dark).

3.2.4 Human drivers and abundance, diversity and functional traits

Appendix 13, Table 25 & 26, show the descriptive statistics of the household characteristics, abundance, diversity, management (adult and regeneration management abundance and diversity), total and per community. Table 10**Fout! Verwijzingsbron niet gevonden.** shows the optimal models and their results; where the dependent variables (density, diversity and functional diversity) could be explained by the independent variables (Community, household characteristic, land management strategy, adult tree and regeneration management practices) included in this study.

The optimal model for regeneration abundance explained 30% of the density of regeneration although none of the variables had a significant effect. The optimal model for adult tree density explains 50% of the total variance of adult tree density. Only distance to market and regeneration management abundance have a significant and positive effect.

The optimal model for regeneration species richness explains 47% of the variances. Plot tenure has a significant negative effect on the regeneration species richness. Land management dimension 2 and regeneration management abundance both have a significant positive effect. For adult tree species richness, the optimal model explained 63% of the total variance. Both community wealth and distance to market show a negative significant effect, while gender shows a positive significant effect.

The optimal model for regeneration functional diversity explained 48% of the total variance of the regeneration FD. Plot tenure shows a significant negative effect, while community wealth, land management dimension 2 and regeneration management abundance show significant positive effects. The optimal model for adult tree functional diversity explained 63% of the total variance. Land management dimension 1, adult tree management abundance and regeneration management abundance, have a positive significant effect.

Table 10. Overview of the models showing significant effect for regeneration (a) and adults (b). Models included household characteristics (Community wealth, household wealth, household composition, education, gender, plot tenure, distance to market), land management (dimension 1 & 2), adult tree and regeneration management abundance and diversity. The table shows which variables were found significant for each of the dependent variables. Significance is highlighted in grey and the strength indicated with codes, the +/- indicates whether the effect was positive or negative, and the R indicates the fit of the model. Because of the way we selected the optimal models (selecting the alternative model with the lowest AIC), they include 'ns' variables.

Dependent variable	Community wealth	Household wealth	Household composition	Education	Gender	Field size	Plot tenure	Distance market	Dim 1	Dim 2	Adults management abundance	Adult management diversity	Regeneration management abundance	Regeneration management diversity	R2	Adj. R2
a) Regeneration models																
Density	ns				ns			ns							0.28	0.30
Diversity	ns						*-	ns		*+	ns		*+		0.45	0.47
Functional diversity	ns						*-	ns		*+	ns		*+		0.46	0.48
b) Tree models																
Density	ns		ns					*+		ns		ns	**+		0.48	0.50
Diversity	ns				*+			***-	ns						0.60	0.63
Functional diversity	ns					ns		ns	ns		**+			*+	0.60	0.63

*Signif. codes: '***' < 0.001, '**' <0.01, '*'<0.05', 'ns' >0.05, 'blank cells' variable not included in model;*
[a] means the distribution of the models' residuals was not normal but close to normal

3.3 RQ3 – How do species functional traits reflect the ecosystem service values that farmers attribute to species?

A Pearson correlation table was created to see which attributes and functional traits are correlated (**Fout! Verwijzingsbron niet gevonden.**). The attributes are all positively correlated to each other and to maximum plant height (PH), litter and economic value to seed mass (SM) and fodder value to specific leaf area (SLA). The variables where a correlation was found (shown in grey) were further tested for linearity.

To begin, linearity was found between all attributes (see Appendix 14, Figure 19). The species that farmers value for economic purpose, they also value for fodder and leaf litter and vice versa. Second, the relationship between the attributes and the functional trait values (only for PH, SLA and SM) were tested and found linear (see Figure 13**Fout! Verwijzingsbron niet gevonden.**). Subsequently, the attribute litter contribution to soil fertility; a linear relationship was found with maximum plant height (Figure 13a) and seed mass (Figure 13b). Similarly, the attribute fodder nutritional value for cattle has a linear relation with both maximum plant height (Figure 13c) and SLA (Figure 13d). Moreover, the economic value of species has a linear relation with maximum plant height (Figure 13e), and seed mass (Figure 13f).

Table 11, correlation matrix, showing the correlation coefficients between the different attributes and functional traits. The variables showing correlation are shown in grey. Where a correlation between the three attributes (litter, fodder and economic value) and the functional traits was found, a linear regression was made, to visualize the relationship. (Appendix 14, Table 28 full output

	Litter	*Fodder*	*Economic*
Litter	1		
Fodder	0.53	1	
Economic	0.72	0.54	1
PH	0.59	0.51	0.62
Chl	-0.09	-0.13	0.16
LT	-0.19	-0.40	-0.16
LA	0.09	-0.16	0.05
SLA	-0.04	0.56	-0.15
LDMC	0.07	-0.14	-0.08
TDMC	0.06	-0.13	-0.27
WD	-0.07	-0.09	-0.28
LD	0.16	-0.09	0.20
SM	0.46	0.19	0.49
S	-0.28	0.13	-0.17
LP	0.16	0.25	0.20
LC	-0.13	0.19	0.09

Abbreviations: Litter; average score for leaf litter contribution to soil fertility, Fodder; square root of average score for leaf nutritional value for cattle, economic; log of average score of economic value of trees, PH; maximum plant height, Chl; log of leaf chlorophyll content, LT; log of leaf thickness, LA; log of leaf area, SLA; log of specific leaf area, LDMC; leaf dry matter content, TDMC; twig dry matter content, WD; wood density, LD; leaf density, SM; log of seed mass, S; spinescense, LP; deciduousness, LC; leaf compoundness.

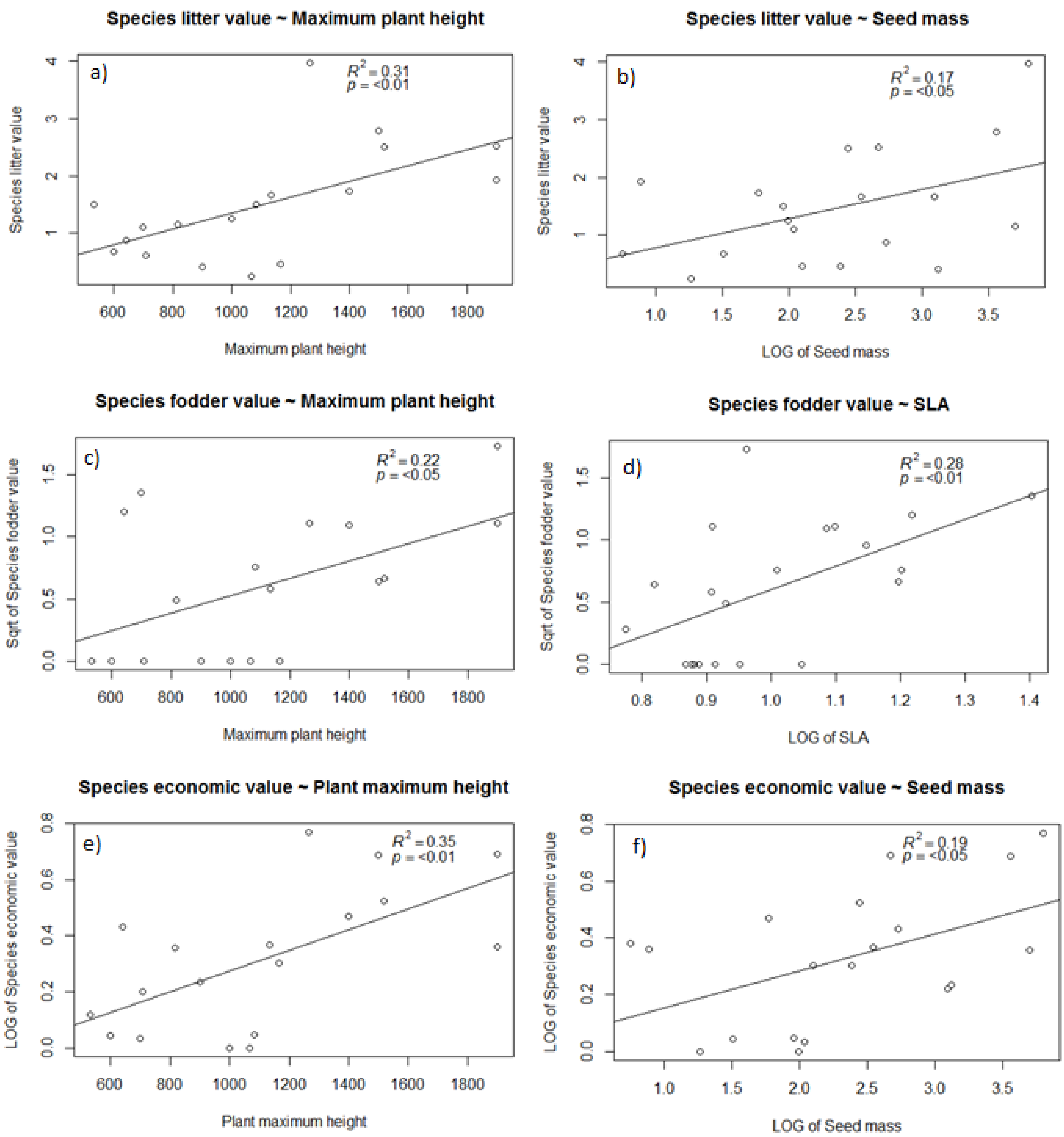

Figure 13. tree species attribute values & functional trait values: a) maximum plant height and litter value, b) seed mass and litter value, c) maximum plant height and fodder value, d) SLA and fodder value, e) maximum plant height and economic value and f) seed mass and economic value. Graphs show the adj. R2 and p significance for linearity.

Discussion

I looked at FMNR in the study area. I found FMNR is being practiced widely in the study area at different intensities. Next, I investigated how human drivers of FMNR influence abundance, diversity and functional traits of regeneration and trees on farmers' fields. I found the human drivers to be of great influence, although less on regeneration than on adult trees. Finally, I tried to link farmers' knowledge (tree attributes) and scientific knowledge (functional traits) on trees but found that few attributes and traits were linked.

RQ 1 – FMNR in the study site/area

From the 40 households surveyed, none of the farmers had heard of the term FMNR. Nevertheless, they do practice FMNR, be it at different levels of intensity, for them managing natural regeneration on their fields is just tradition. I hypothesized that FMNR adoption and intensity increase with tenure and decrease with wealth and distance to market. Indeed, plot tenure had a positive effect on FMNR adoption, and community wealth had a negative effect on FMNR intensity, but I found no significant effect of distance to market.

Previous research shows tenure to be essential in understanding forest-cover change, and households that own their land are more likely to be motivated to engage in long term investments like trees (Binam et al 2015; Barranche et al. 2006; Elias 2013; FAO 2013; Nagendra 2007; Ndegwa 2017), although, not all studies agree (Iiyama et al 2017; Mikulcak 2011). Farmers who own their land are willing to invest in trees, but other factors influence the intensity. Literature states, market access influences FMNR adoption (Hugland 2011). Market access was included in both models, but not found significant. Research has shown a positive relationship between income and adoption (Hugland et al 2011; Pattanayak et al. 2003), this is not the case in my study: wealth did not have a significant influence on adoption. On FMNR intensity results were like I hypothesized: FMNR intensity decreases with wealth or in other words poorer communities (Akaa and Gwenia) practice more FMNR (Chapter 3.1 Table 6 and Figure 5). It could be that more comfortable communities rely less on agroforestry and more on other sources of income (Pattanayak et al. 2003; WAFFI 2017). Also, FMNR is used for subsistence products and environmental services (Ndegwa 2017), hence poorer households (who cannot afford e.g. fertilizer, livestock) have more to gain from adopting FMNR. Additionally, FMNR is cheap and does not need much input (Birch et al. 2015).

RQ 2 – Human drivers & abundance, diversity and functional traits

I hypothesized farmers would select preferred species, which can resprout, are crop-friendly, and valued high for attributes. More intense FMNR thus increases abundance but decreases diversity and plot ownership has the same effect, as it increases the willingness to invest in trees. Wealthy communities have a high abundance and low diversity, whereas poor communities have a low abundance and high diversity. Finally, distance to market will decrease FMNR intensity and abundance, but increase diversity.

Abundance

Unlike expected, I found no significant effect of any of the variables on regeneration density. The woody vegetation inventory was performed partly before the start of the planting season and before land preparation. During land preparation farmers clear weeds and regeneration, they do not want. A lot of the regeneration inventoried was small and not more than one year. It is likely, the farmers did not yet manage the regeneration considered in this study. Therefore, the abundance of regeneration is influenced more by other (biophysical) factors, or a combination of factors, that were not included in this study. For instance: soil type or climate conditions, but also producing parent trees, site characteristics and seed characteristics (Brissette 1996).

On the other hand, for adult tree density, I indeed found an increase with regeneration management. The increases in adult tree density can be explained because more management (e.g. protect & promote instead of just killing) of the regeneration eventually results in more adult trees. The management can change from regeneration to adult trees (Figure 6ef). For a lot of species all regeneration is killed, and no adult trees remain, but there are also species that do have adult trees and regeneration. Chapter 3.2.1, Figure 6ef, *Afzelia africana*: most of the regeneration is killed and some is promoted, and adults are mostly cut for use and competition is managed. Some of the individuals that are regenerating are protected to grow into trees to later harvest for use. Other species are managed in a similar way. The regeneration of *Tamarindus indica* is promoted and protected, and also removed, but for adult's competition is managed and the tree is a bit promoted, or nothing is done.

Figure 14; Shea trees and the rocky soil of Akaa

Contrary to what I hypothesized distance to market showed a positive effect on adult tree density. A meta-analysis (Pattanayak et al 2003) showed FMNR adoption (and thereby also the tree density) to be negatively correlated with distance to market, possibly as a result of the price effect (distance increases similarly transport price increases). There is also evidence of a positive effect of distance to market (Pattanayak et al 2003; Iiyama et al 2017). In the study site in Ghana, the positive effect of distance to market can be assigned to the high density of shea trees in the community of Akaa (furthest away from the market, see appendix 13, Table 26). A part of the area, especially in Akaa, was very rocky and unproductive (crops yields were low and the land difficult to cultivate) but was full of shea trees (Figure 14).

Like hypothesized, reproduction habits do influence abundance (Appendix 11, Table 24): the most abundant species, according to the farmers, use both sexual and vegetative reproduction. Being able to regrow after a disturbance is a good trait to have in the West African Parklands (both for the tree and for the farmers) and most of the inventoried species can (66% of the 50 species). There is a lot of disturbance; fire, livestock, and agriculture, and if a species can regrow from its roots or stem they are more likely to persevere. Research has shown that vegetative reproduction is much more successful than sexual reproduction under high disturbance (e.g. fire) frequency in neotropical savanna (Hoffmann 1998). Furthermore, the root system is already in place to support the growth and protect the individual: offering access to deep soil moisture and nutrients, plus to stored energy (Birch et al. 2016). Seeds can lie dormant for a long time, waiting for the right time to germinate. Farmers said that soon after the first rain, all the seeds germinate, giving them the change to select the ones they want to protect or transplant. Additionally, two planted species are among the most abundant adult trees: *A. indica* (the Neem tree) and *S. spinosa*. Planted species are species farmers really want, but most of the species farmers named to plant were not found in the inventory on farmer fields. Both species are used: the neem tree to treat malaria and the *S. spinosa* as fodder and food.

Like expected species that are valued high for income, fodder and/or litter are more abundant. Especially for litter because species valued for litter are good for the crops, therefore more of them can grow and still have a positive effect on crop production.

Similarly, I expected friendly species to be more abundant, but results are unclear. Farmers' species perception and management depends on different aspects. Many species are both friendly and disturbing, for instance the *Acacia amythethopphylla,* Chapter 3.2.1, Figure 6bcd: 33% of the farmers responses were friendly and 67% disturbing. Farmers said the *Acacia amythethopphylla* adds fertility and provides mulching that keeps the soil moist, but it can also be disturbing because it is too shady. Management plays an important role in defining a species' competition with crops. The categories with reasons for why a species is disturbing or friendly (Appendix 4.3, Table 15bc) are not always species characteristics, but rather how to manage for less competition. For instance: good growth, meaning the species grows high up, has few leaves and/or is not too shady. These properties can be species characteristics, but can also be managed, a thin line which is hard to define. Some species do have the tendency to have a straight stem and grow high fast, while others have many stems and grow wide (which is defined as bad growth). But if there are too many stems, leaves or when they grow too close together, pruning and selection is done to manage competition. Take for instance the shea tree (*Vitellaria paradoxa,* Figure 15) seen as (mostly) friendly (Chapter 3.2.1, Figure 6bc), although it does give a lot of shade, and competes with the crops. Most farmers said it is friendly because it has good spacing. Farmers only keep the individuals that come up in the right place and only a few farmers said they would transplant. Therefore, because the regeneration comes up in the right place (species characteristic/biophysical) the farmer can manage the regeneration to become a tree which has good spacing. Farmers also gave good growth as a reason for why the shea tree is friendly. Farmers told me the shea tree has multiple ways of growing, and they try to select the ones that have one straight stem. In addition, many farmers said to prune the tree to manage the shade. Some farmers said they prefer the yield from the shea to the yield of the crops that could otherwise grow below: the species is so important that negative effects on the crops are not important. Two farmers said they plant shade tolerant crops below trees and said all trees are friendly. Other research (Smith-Dumont in press) also found management to be of great influence in a farmers' species perception. They found that, for instance, by ploughing the leaves of the shea into the soil the decomposition was increased, and thereby the effect on soil fertility. Therefore, I conclude that some species are clearly friendly or disturbing, but for many it is a combination of management and species characteristics that define its competition with the crops.

Figure 15; Vitellaria paradoxa, the shea tree, showing its wide and dense crown.

Most of the farmers responses for why a species is disturbing to the crops is bad growth (too shady, roots and branches spread wide, spines, slow decomposition, bad juice, competition) (Chapter 3.2.1, Figure 8d & Figure 6d). In addition, these species reproduce mostly by regrowth (a), are seen as disturbing to the crops (b) and are also often killed as regeneration (f) and have no adult trees (e). These species (e.g. *Combretum glutinosum* and *Guiera senegalensis*) are like weeds, they have no benefits (in terms of fruit production) but provide firewood and play a crucial role in regeneration of the vegetation (thus of soil fertility) (Gijsbers, Kessler & Knevel 1994). Managing these species to prevent competition with the crops take a lot of effort, therefore, farmers do not keep them and after field preparation, they will mostly be gone.

Management matches the farmers perception of the species competition with the crops, this can be seen in Table 8 (Chapter 3.2.2) and Table 24 (Appendix 11). The tables show most of the 26 species that are seen as disturbing are killed, only two are positively managed (protected/promoted) and two are equally killed as promoted/protected. For the 16 friendly species, only four are killed and one is equally killed as promoted/protected, the rest (11) is positively managed. The most abundant adult species are friendly with on top the shea tree (78%), but for regeneration many disturbing species are abundant. This suggests that the friendly species are abundant because the farmers want them there, keep the regeneration, manage the trees, and the disturbing species are species that are not wanted, and continuously killed but that are not easy to get rid of.

Diversity – Taxonomic & Functional

<u>Regeneration</u>

In contrast to what hypothesized, land ownership decreases regeneration diversity (both taxonomic & functional). Tenure is often associated with long term family owned land, this land has been managed for a long time, and with increasing anthropogenic activities the species diversity often decreases (Mwase et al 2007). Ownership of land and resources is often essential in creating incentives for sustainable management and conservation of diversity of tree and shrub species (Binam et al 2015; Barranche et al. 2006; Elias 2013; FAO 2013; Mwase et al 2007; Nagendra 2007; Ndegwa 2017). However, land ownership does not necessarily lead to more diversity. Farmers can decide to only keep a few economically valuable species, thus decreasing the species richness. Subsequently, economically valuable species will have similar trait values, for instance higher nutritional value. By only keeping those few adult trees, the regeneration will be less diverse too, as the diversity of seed sources declines.

With increased land management intensity, the land is likely more intensely farmed and there will be less space for regeneration. Contrary, I found land management dimension 2 increases regeneration diversity (both taxonomic & functional). Land management dimension 2 consists of fertilizer and mulching (Chapter 3.2.3, Table 9), these practices improve the soil quality and microclimate, therefore growing conditions for regeneration is improved (Gupta 1991) and diversity increases.

I hypothesized, that more intense FMNR (more management) would decrease the diversity but found an increase in diversity with regeneration management abundance. The more a farmer promotes, protects, managed competition, the more different species and traits are selected, resulting in more diversity.

<u>Adult trees</u>

Taxonomic adult tree diversity is driven by distance to market. I expected, distance to market to increase taxonomic diversity. Wealthy households and households with good access to market invest more in commercial oriented agroforestry (Abebe et al 2013; Gibreel 2013; Ndegwa et al 2017), meaning lower diversity. Whereas farmers with poor accessibility to market prefer to adopt trees mostly for locally used products, thus engaging in protection of the well understood regenerating indigenous trees (FMNR) (Ndegwa et al 2017; Winterbottom and Hazlewood 1987), thus a higher diversity. Contrary, I found the reverse: farmers further from the market have a lower diversity and farmers closer to the market have more different species. Adult tree abundance was discussed in the previous section, where a high density of the shea trees in Akaa explained the positive effect of distance to market (Appendix 13, Table 25 & Table 26). Looking at the results on adult tree density and diversity: farmers further from the market have a higher adult tree density but lower adult tree diversity. The density is higher, but the focus is only on a few species, therefore the diversity is lower.

My results are contradicting with other literature (Abebe et al 2013; Gibreel 2013; Ndegwa et al 2017; Winterbottom and Hazlewood 1987). A possibly explanation is again Akaa, where because of the fields' low crop yield, more trees are kept, and to make as much money as possible the most valued trees are only kept.

In addition, I found gender to increase tree diversity. Different literature states FMNR empowers women and improves their lives (Francis et al 2015; Garrity et al 2010; Hugland et al 2011; Weston et al 2015), but no direct link to diversity was made. In the study area men headed households have on average more tree species than female headed households. While I was interviewing one of the female farmers, she did not want to answer all my questions because she said it was a men's job. Possibly, female headed households have a lower diversity, because culturally they are not supposed to know about tree management, they will focus on producing staple food, not on managing trees. On the other hand, another woman I interviewed was clearly practicing FMNR; she had selected one stem per group of regenerating stems and pruned them to grow high (Figure 16). She said she had learned it from her father, and it would benefit the soil. All individuals were of the same species (because that was the only species regenerating), therefore also this woman had a low species richness. Admitting, only seven (out of the 40 sampled households, Appendix 12, Table 25) were female headed households, and most of them were widows, so no valid comparison can be made.

Figure 16; FMNR in Gwenia, regeneration of *Combretum nioroense* is protected and pruned to grow into trees (each bush has one stem remaining), in the back ground there are adult shea trees.

For adult tree functional diversity, unlike expected, I found an increase with adult tree management abundance and regeneration management diversity. Both variables were calculated from the abundance and diversity in the plots, therefore it could be that the found positive relation is an artifact of the calculations. Nevertheless, more adult tree management is related to more trees, and that in turn could lead to more diverse trait values. Farmers select species for instance for; firewood, building material, chewing stick, medicine or fodder, and all these species will have different trait values. Similarly, regeneration management diversity; the more effort (different management) a farmer puts into managing regeneration, the more different adult species this will result into (if regeneration management is constant over time). Therefore, farmers practicing more different regeneration management will have a more functional diverse field.

I expected a decrease in diversity due to the selection of species for their ability to regrow and their friendliness to crops, but this was not found. Results show that most species can reproduce via seed and regrowth and only few are planted. In addition, there are many different friendly species, and it is often management that determines if a species is friendly or disturbing to the crops (Smith-Dumont in press). Farmers management shows they manage many different species, in different and in the same way, and thereby influence diversity.

RQ3 – Linking tree attribute scores and functional trait values

I hypothesized there would be a link between farmers knowledge (species attributes) and scientific-ecological knowledge (functional trait values). I indeed found such a link, but only for a few traits and attributes: maximum plant height was positively linked to all three attributes (economic, fodder, litter), seed mass to litter and economic value and specific leaf area to fodder.

Maximum plant height was calculated using the LDSF woody vegetation inventory, thus indicates the average maximum height of the species in the study site. Species that are not valued are not kept, hence their maximum plant height is lower. Species that are preferred for either one of the attributes (or another attributes) will be protected and promoted to grow into adults, therefore have a higher maximum plant height, explaining the positive relation between the three attributes and height. Additionally, from talking with the farmers I understood that when a tree was high it is not competing with the crops (see appendix 4.3, Table 15b, friendly species; Good growth), and when they are not competing with the crops they are good for the soil. Similarly, the effect of tree canopy cover on soil fertility was studied in a Nigerian savanna and found trees above seven meters to have more influence on soil properties than smaller trees (Isichei & Muoghalu 1992). Hence, farmers would value higher trees more for leaf litter contribution to soil fertility.

V. paradoxa, P. biglobosa, A. digitata and T. indica are valued high for economic and litter. These species are all tall trees (PH is 1267, 1500, 1900 and 1517 cm) and they give fruits that serve as income, while at the same time the fruits are good for the soil. Hence, the link between litter value and seed mass, and economic value and seed mass. Species with highest seed mass are *Vitellaria paradoxa, Detarium microcarpum and Parkia biglobosa*. These species are valued for their fruit, which the farmers can eat, sell or leave for the soil. Large seeds provide advantage for seedlings establishing in low soil moisture conditions (Leishman & Westoby 1994). Consequently, the farmers might select/prefer species with larger seeds because they have a higher survival rate through the dry season.

Fodder has other species which scored highest, two of them are *Acacia dudgeoni* and *Strychnos spinosa*, both species do not have a high maximum plant height (700 and 640 cm), but the remaining species did cause the linearity, although the relation is less strong than for litter and economic value. Fodder is also linearly linked to specific leaf area, species with a higher specific leaf area score higher for fodder (except for *Adansonia digitata,* which was scored high because cattle love the sugary fruit, hence leaf traits do not explain that). The positive relation can be explained because species with low SLA values are associated with low leaf nutrient concentrations and slower rates of litter decomposition (Laughlin 2014). Thus, farmers would score species with leaves with high nutrient concentrations and easier to digest (and higher SLA) higher for fodder. Expected was that species with higher SLA would also be valued for litter, but no such relation was found, which could be explained by the fact that good litter is achieved through different complementary mechanisms (e.g. decomposition and mulching). Litter quality is influenced by C-to-N ratio and lignin-to-N ratio (Satti et al 2003). Higher concentrations of lignin and tannins cause slower decomposition, at the same time slowly decomposing leaf tissues serve as mulching.

Contrary to what was expected, most functional traits could not be linked to the attributes. The reason might be that if the species gives the farmers income they also see the benefits for the soil, hence the high scoring for both economic and litter. On the other hand, for fodder, farmers did not keep those species on their fields. Mostly, they would collect fodder in the bush, and not on their fields, therefore they did not know the effect on the soil.

Another reason for why we could not find a link for most of the attributes and trait, might be in the choice of traits and attributes: the selected traits might not sufficiently reflect the attributes. All included traits can be influenced by the farmers and the traits can influence the environment. But maybe some important traits were not included. Ordoñez et al. (2009), looked at specific leaf area, phosphor, carbon and nitrogen content for soil fertility, I only looked at SLA and did not find a link.

Topps (1992) states fodder quality is determined by dry matter content, chemical composition, digestibility, protein and fiber. I included, among other, dry matter content, nitrogen fixing and chlorophyll content, and I found a link between specific leaf area and fodder. But for the farmers the link between protein or fiber to fodder might have been easier to make.

What is striking about the results of the tree attributes is, the same species are valued for each attribute. Indicating there is no trade-off: farmers value multipurpose tree species that benefit soil fertility, give income and serve as fodder.

Limitations

A translator is needed when there is a language barrier. Great care should be taken when finding a translator. They need to be trustworthy because the results of the research depend on how the translator asks your questions to the participants and on how the translator then translates the answers to you. Best is to have one translator during the whole survey, to be sure the questions are asked in the same way. First, T. Addoah from CIFOR translated for me. He is trusted in the communities and experienced in interviewing the local people. Unfortunately, he did not have time to translate during all my household surveys. Therefore, we tried to find another translator, who could join me for the complete survey. We found another researcher who had experience in doing surveys in the communities, but unfortunately, he turned out to be influencing the farmers' responses, therefor I had to let him go and redo the surveys I did with him. Thereafter, the local facilitators (every WAFFI community has multiple facilitators, who are trained and work with the project) translated for me. To prevent differences in the translation between each facilitator, T. Addoah would join in the first surveys, to show them how to do it.

Another limitation was the timing of the inventory. The household surveys started at the end of dry season just before the rains started, and finished when the rainy season had really started, and planting had begun. Therefore, a lot of the regeneration present in the final plots had not yet come up in the first plots. Subsequently, that could have influenced the regeneration abundance and diversity of the different communities. I started the surveys in Gwenia, followed by Wombio, next came Akaa and last I did Adabania. When we look at the density and species richness (Appendix 8, Table 25 & 26), we cannot clearly see the influence of the timing, but still it might be there.

The next limitation is related to the location of the farmers' fields included in the study. The included fields all had a different distance to the farmers' home, some close, others quite far. Therefore, some were closer to the bush and had more trees, while the fields closer to the communities had less trees. Still most fields had trees and regeneration and FMNR was widely practiced.

The last limitation is related to the focal species selection. We used the inventory of the LDSF to select the species for which functional traits were to be measured. Therefore, when I later used my own inventory data to determine the functional diversity, the 80% was not met in all plots, meaning the results for functional diversity are not representative.

Conclusion

FMNR is widely practiced (65%) at different intensity, even though farmers do not know the term FMNR. Land ownership decreases the diversity of the regeneration but increases the farmers' willingness to have trees on their fields, thus increases FMNR adoption. Wealth then influences the amount of time farmers invest or the level of intensity in managing the natural regeneration. The biophysical environment mainly influences what regenerates and the farmers influence what stays: regeneration is influenced less than adults. Preferred species are friendly species and are abundant because the farmers want them there, keep the regeneration, manage the trees, and the disturbing species are species that are not wanted, and continuously killed but that are not easy to get rid of. Distance to market increase adult tree abundance and decreases adult tree diversity. Poor households are more active in FMNR possibly because they have more to gain.

Now, there is regeneration present and farmers practice FMNR. Farmers only want/keep species that give them benefits, like food, fodder and prefer multipurpose trees. Still there are many different species (50 named in total). The most abundant regenerating species are species the farmers do not want (disturbing species) but can still improve the soil health.

The effect of FMNR can be increased. An excellent example was this one lady who was managing the only species that did regenerate on her field close to her home. Even though, the species' only benefit would be, on the long run, for the soil. I believe that is where FMNR has the most to gain/ can improve the most. A great opportunity lies in these unwanted resilient species. Some of these species have benefits (e.g. for the soil fertility, fodder or firewood). If farmers are made aware of the benefits, they will keep them, resulting in the rapid increase in tree cover. An increase in tree cover will combat land degradation and by careful management of the competition it will benefit crop yield too. Eventually, other species will be able to grow again because of the improved microclimate. Farmers said often planted seedlings die, when the tree cover is increased the seedlings have a better chance of surviving.

I conclude, FMNR helps to increase forest cover and thereby combat land degradation. Although diversity is left behind in favor of a few multipurpose trees.

Recommendations

FMNR in the study site is of yet unknown to the farmers, therefore there is an opportunity to improve the farmers traditional way of tree management, and to show them the benefits of trees. Several farmers per community should be trained to get familiar with the term and practice of FMNR. In their turn these farmers will teach the other households within the community and FMNR will spread throughout the region.

The training should include the importance of diversity and increase awareness of different benefits. Currently, only a few multipurpose tree species are kept on their fields, but there are many species that could be included. Many of the preferred species do not regeneration abundantly, and mostly only under the mother trees. In addition, a lot of the regeneration dies during the dry season. Therefore, I recommend teaching farmers methods to improve seedling survival in the dry season.

Land and tree ownership need to be established. Enabling policies should be created, where farmers own their trees and can decide on how to manage them.

Bibliography

Abebe T, Sterck FJ, Wiersum KF, Bongers F (2013) Diversity, composition and density of trees and shrubs in agroforestry homegardens in Southern Ethiopia. Agrofor Syst 87:1283–1293

Anthony, M.J., Verboom, G., Rebelo, A.G., Cramer, M.D. (2010). Ecophysiological significance of leaf size variation in Proteaceae from the Cape Floristic Region. *Functional Ecology 24: 485–492*

Arbonnier, M. (2004). *Trees, shrubs and lianas of West African dry zones*. Editions Quae.

Asiamah, R.D., J.K. Senayah, T. Adjei-Gyapong, and C. Spaargagen. (1997). 'Ethno-Pedology Surveys in the Semi-Arid Savanna Zone of Northern Ghana'. : 46.

Barton, K. (2018). MuMIn: Multi-Model Inference. R package version 1.42.1. https://CRAN.R-project.org/package=MuMIn

Bates, D., Maechler, M., Bolker, B., Walker, S. (2015). Fitting Linear Mixed-Effects Models Using lme4. Journal of Statistical Software, 67(1), 1-48. doi:10.18637/jss.v067.i01.

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.*

Bayala, J., Sanou, J., Teklehaimanot, Z., Kalinganire, A., & Ouédraogo, S. J. (2014). Parklands for buffering climate risk and sustaining agricultural production in the Sahel of West Africa. *Current Opinion in Environmental Sustainability, 6, 28-34.*

Birch, Julia, Peter Weston, Tony Rinaudo, and Rob Francis. (2015). Land Restoration: Reclaiming Landscapes for a Sustainable Future Releasing the Underground Forest: Case Studies and Preconditions for Human Movements That Restore Land with the Farmer-Managed Natural Regeneration (FMNR) Method. Elsevier Inc. http://dx.doi.org/10.1016/B978-0-12-801231-4.00016-1.

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

Bonkoungou, E. G. (2002). The shea tree (Vitellaria paradoxa) and the African shea parklands. *CFC Techincal Paper, (21), 51-59.*

Boffa, J. M. (2000). West African agroforestry parklands: keys to conservation and sustainable management. *UNASYLVA-FAO-*, 11-17.

Botta-Dukát, Z. (2005). Rao's quadratic entropy as a measure of functional diversity based on multiple traits. Journal of vegetation science, 16(5), 533-540.

Brissette, J. C. (1996). Effects of intensity and frequency of harvesting on abundance, stocking and composition of natural regeneration in the Acadian forest of eastern North America.

Cadotte, M. W., Carscadden, K., & Mirotchnick, N. (2011). Beyond species: Functional diversity and the maintenance of ecological processes and services. Journal of Applied Ecology, 48, 1079–1087

Chirino, E., Vilagrosa, A., Cortina, J., Valdecantos, A., Fuentes, D., Trubat, R., ... & Peñuelas, J. L. (2009). Ecological restoration in degraded drylands: the need to improve the seedling quality and site conditions in the field. *Forest management. Nova Publisher, New York*, 85-158.

CIFOR, IFAD, TreeAid & ICRAF (2017). 'The West Africa Forest-Farm Interface Project (WAFFI). Strengthening smallholder food security, income and gender equity within West Africa's forest-farm interface.' Blog.cifor.org

Climate-data.org. (2018a). Climate Basgana. Retrieved on March 19, from: https://fr.climate-data.org/location/52629/

Climate-data.org. (2018b). Climate Navrongo. Retrieved on March 23, from: https://en.climate-data.org/location/44657/

Cornelissen, J. H. C., Lavorel, S., Garnier, E., Diaz, S., Buchmann, N., Gurvich, D. E., ... & Pausas, J. G. (2003). A handbook of protocols for standardised and easy measurement of plant functional traits worldwide. Australian journal of Botany, 51(4), 335-380.

Cunningham, P. J., & Abasse, T. (2005). Reforesting the Sahel: farmer managed natural regeneration. Domestications des especes agroforestieres au sahel: situation actuelle et perspectives. ICRAF Working Paper, 5, 75-80.

Díaz, S., Lavorel, S., de Bello, F., Quetier, F., Grigulis, K., & Robson, T. M. (2007). Incorporating plant functional diversity effects in ecosystem service assessments. Proceedings of the National Academy of Sciences of the United States of America, 104, 20684–20689.

Damour, Gaëlle, Marie L. Navas, and Eric Garnier. (2018). 'A Revised Trait-Based Framework for Agroecosystems Including Decision Rules'. Journal of Applied Ecology 55(1): 12–24.

Davis, M. A., & Slobodkin, L. B. (2004). The science and values of restoration ecology. *Restoration Ecology*, 12(1), 1-3.

Faucon, M. P., Houben, D., & Lambers, H. (2017). Plant functional traits: soil and ecosystem services. *Trends in plant science*, 22(5), 385-394.

Francis, R., Weston, P., & Birch, J. (2015). The social, environmental and economic benefits of Farmer Managed Natural Regeneration. *World Vision Australia*.

Funk, J. L., Larson, J. E., Ames, G. M., Butterfield, B. J., Cavender-Bares, J., Firn, J., Laughlin, D. C., Sutton-Grier, A. E., Williams, L., and Wright, J. (2017). Revisiting the Holy Grail: using plant functional traits to understand ecological processes. Biological Reviews, 92(2), 1156-1173.

Garnier, E., Cortez, J., Billès, G., Navas, M. L., Roumet, C., Debussche, M., ... & Neill, C. (2004). Plant functional markers capture ecosystem properties during secondary succession. Ecology, 85(9), 2630-2637.

Garnier, E., Lavorel, S., Ansquer, P., Castro, H., Cruz, P., Dolezal, J., ... & Grigulis, K. (2006). Assessing the effects of land-use change on plant traits, communities and ecosystem functioning in grasslands: a standardized methodology and lessons from an application to 11 European sites. Annals of botany, 99(5), 967-985.

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

Gibreel TM (2013) Crop commercialization and adoption of gum-arabic agroforestry and their effect on farming system in western Sudan. Agrofor Syst 87:311–318

Gijsbers, H. J. M., Kessler, J. J., & Knevel, M. K. (1994). Dynamics and natural regeneration of woody species in farmed parklands in the Sahel region (Province of Passore, Burkina Faso). *Forest Ecology and Management*, 64(1), 1-12.

Government of Ghana. (2018). Upper East, Background and Location. Retrieved on March 23, from: http://ghana.gov.gh/index.php/about-ghana/regions/upper-east

Gupta, G. N. (1991). Effects of mulching and fertilizer application on initial development of some tree species. *Forest Ecology and Management*, 44(2-4), 211-221.

Haglund, Eric, Jupiter Ndjeunga, Laura Snook, and Dov Pasternak. 2011. ‘Dry Land Tree Management for Improved Household Livelihoods: Farmer Managed Natural Regeneration in Niger’. *Journal of Environmental Management* 92(7): 1696–1705. http://dx.doi.org/10.1016/j.jenvman.2011.01.027.

Hall JB, Tomlinson HF, Oni PI, Buchy M, Aebischer DP (1997) Parkia biglobosa: a monograph. School of agricultural and forest sciences. *University of Wales*, Bangor.

Herrmann, Stefanie M., Assaf Anyamba, and Compton J. Tucker. (2005). ‘Recent Trends in Vegetation Dynamics in the African Sahel and Their Relationship to Climate’. *Global Environmental Change* 15(4): 394–404.

Hoffmann, W. A. (1998). Post-burn reproduction of woody plants in a neotropical savanna: the relative importance of sexual and vegetative reproduction. *Journal of Applied Ecology*, *35*(3), 422-433.

Iiyama, M., Derero, A., Kelemu, K., Muthuri, C., Kinuthia, R., Ayenkulu, E., Kiptot, E., Hadgu, K., Mowo, J. & Sinclair, F. L. (2017). Understanding patterns of tree adoption on farms in semi-arid and sub-humid Ethiopia. *Agroforestry systems*, 91(2), 271-293.

Isaac, M. E., Cerda, R., Rapidel, B., Martin, A. R., Dickinson, A. K., & Sibelet, N. (2018). Farmer perception and utilization of leaf functional traits in managing agroecosystems. *Journal of Applied Ecology*, 55(1), 69-80.

Isichei, A. O., & Muoghalu, J. I. (1992). The effects of tree canopy cover on soil fertility in a Nigerian savanna. *Journal of Tropical Ecology*, 8(3), 329-338.

Kassambara, A. & Mundt, F. (2017). factoextra: Extract and Visualize the Results of Multivariate Data Analyses. R package version 1.0.5. https://CRAN.R-project.org/package=factoextra

Kuussaari, M., Bommarco, R., Heikkinen, R. K., Helm, A., Krauss, J., Lindborg, R., … Steffan-Dewenter, I. (2009). Extinction debt: A challenge for biodiversity conservation. *Trends in Ecology and Evolution*, 24, 564–571. https://doi.org/10.1016/j.tree.2009.04.011

Laliberté, E., and Legendre, P. (2010) A distance-based framework for measuring functional diversity from multiple traits. *Ecology* 91:299-305.

Laliberté, E., Legendre, P., and Shipley, B. (2014). FD: measuring functional diversity from multiple traits, and other tools for functional ecology. R package version 1.0-12.

Laughlin, D. C. (2014). Applying trait-based models to achieve functional targets for theory-driven ecological restoration. *Ecology letters*, *17*(7), 771-784.

Lavorel, S, and E Garnier. (2002). ‘Predicting Changes in Community Composition and Ecosystem Functioning from Plant Traits: Revisting the Holy Grail’. *Functional Ecology* 16(Essay Review): 545–56.

Le, S., Josse, J., Husson, F. (2008). FactoMineR: An R Package for Multivariate Analysis. *Journal of Statistical Software*, 25(1), 1-18. 10.18637/jss.v025.i01

Leishman, M. R., & Westoby, M. (1994). The role of seed size in seedling establishment in dry soil conditions--experimental evidence from semi-arid species. *Journal of Ecology*, 249-258.

Liebe, J., Van De Giesen, N., & Andreini, M. (2005). Estimation of small reservoir storage capacities in a semi-arid environment: A case study in the Upper East Region of Ghana. *Physics and Chemistry of the Earth, Parts A/B/C*, 30(6-7), 448-454

Lindborg, R., & Eriksson, O. (2004). Historical landscape connectivity affects present plant species diversity. *Ecology*, 85, 1840–1845. https://doi.org/10.1890/04-0367

Lohbeck, M., Poorter, L., Paz, H., Pla, L., van Breugel, M., Martínez-Ramos, M., & Bongers, F. (2012). Functional diversity changes during tropical forest succession. Perspectives in Plant Ecology, *Evolution and Systematics*, 14(2), 89-96. http://dx.doi.org/10.1016/j.ppees.2011.10.002.

Lohbeck, M., Poorter, L., Lebrija-Trejos, E., Martínez-Ramos, M., Meave, J. A., Paz, H., ... & Bongers, F. (2013). Successional changes in functional composition contrast for dry and wet tropical forest. Ecology, 94(6), 1211-1216.———. 2014. *Functional Ecology of Tropical Forest Recovery*.

Lohbeck, M., Lebrija-Trejos, E., Martínez-Ramos, M., Meave, J. A., Poorter, L., & Bongers, F. (2015). Functional trait strategies of trees in dry and wet tropical forests are similar but differ in their consequences for succession. *PloS one*, 10(4), e0123741.

Maranz, S. (2009). Tree mortality in the African Sahel indicates an anthropogenic ecosystem displaced by climate change. *Journal of Biogeography*, *36*(6), 1181-1193.

McGillivray, C.W. & Grime, J.P. (1995) Genome size predicts frost resistance in British herbaceous plants: implication for rates of vegetation response to global warming. *Functional Ecology 9, 320–325. McIntyre*

Middleton, N. J., & Sternberg, T. (2013). Climate hazards in drylands: A review. *Earth-Science Reviews*, *126*, 48-57.

Mikulcak F (2011) The Implications of Formal and Informal Institutions on the Conservation of On-farm Trees: An analysis from the Department of Mirriah, Republic of Niger. *Master thesis in geography, Department of Human Geography, Stockholm University, p 80*

Mwase, W. F., Bjørnstad, Å., Bokosi, J. M., Kwapata, M. B., & Stedje, B. (2007). The role of land tenure in conservation of tree and shrub species diversity in miombo woodlands of southern Malawi. *New Forests*, 33(3), 297-307.

Nagendra, H. (2007). Drivers of reforestation in human-dominated forests. *Proceedings of the National Academy of Sciences*, *104*(39), 15218-15223.

Ndegwa, G., Iiyama, M., Anhuf, D., Nehren, U., & Schlüter, S. (2017). Tree establishment and management on farms in the drylands: evaluation of different systems adopted by small-scale farmers in Mutomo District, Kenya. *Agroforestry Systems*, 91(6), 1043-1055.

Oksanen, J., Guillaume Blanchet, F., Friendly, M., Kindt, R., Legendre, P., McGlinn, D., Minchin, P. R., O'Hara, B., Simpson, G. L., Solymos, P., Henry M., Stevens, H., Szoecs E. and Wagner, H. (2018). *vegan: Community Ecology Package*. R package version 2.5-2. https://CRAN.R-project.org/package=vegan

Ordoñez, J. C., Van Bodegom, P. M., Witte, J. P. M., Wright, I. J., Reich, P. B., & Aerts, R. (2009). A global study of relationships between leaf traits, climate and soil measures of nutrient fertility. *Global Ecology and Biogeography*, 18(2), 137-149.

Orwa C, Mutua A, Kindt R, Jamnadass R, Simons A. (2009). Agroforestree Database: a tree reference and selection guide version 4.0. *World Agroforestry Centre, Kenya*.

Pakeman, R.J., Quested, H.M. (2007) Sampling plant functional traits: what proportion of the species need to be measured? *Applied Vegetation Science* 10,91–96. doi:10.1111/j.1654109X.2007.tb00507.x

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

Pérez-Harguindeguy, N. et al. (2013). 'New Handbook for Standardized Measurment of Plant Functional Traits Worldwide'. *Australian Journal of Botany* 61(34): 167–234. http://www.uv.es/jgpausas/papers/PerezHarguindeguy-2013-AJB_traits-handbook2.pdf.

Petchey, Owen L., and Kevin J. Gaston. (2002). 'Functional Diversity (FD), Species Richness and Community Composition'. *Ecology Letters* 5(3): 402–11.

Petchey, O. L., & Gaston, K. J. (2006). Functional diversity: back to basics and looking forward. *Ecology letters*, 9(6), 741-758.

R Core Team (2014). *R: A Language and Environment for Statistical Computing*. Vienna, Austria: R Foundation for Statistical Computing. URL http://www.R-project.org/.

Reij, Chris. (2009). 'Agroenvironmental Transformation in the Sahel'. Food Policy (November): 52. http://www.ifpri.org/sites/default/files/publications/ifpridp00914.pdf.

Royal Botanic Gardens Kew. (2018) Seed Information Database (SID). Version 7.1. Available from: http://data.kew.org/sid/ (March 2018)

Rozendaal, D. M. A., Hurtado, V. H., & Poorter, L. (2006). Plasticity in leaf traits of 38 tropical tree species in response to light; relationships with light demand and adult stature. *Functional Ecology*, 20(2), pp. 207-216.

Russel, Bernard. (2015). The effects of brief mindfulness intervention on acute pain experience: An examination of individual difference Research Methods in Anthropology: Qualitative and Quantitative Approaches.

Sacande, M., Sanou, L., & Beentje, H. (2012). *Guide d'identification des arbres du Burkina Faso*. Royal Botanic Gardens.

Sandel, B., Corbin, J. D., & Krupa, M. (2011). Using plant functional traits to guide restoration: A case study in California coastal grassland. *Ecosphere*, 2, art23.

Schneider, C. A.; Rasband, W. S. & Eliceiri, K. W. (2012), "NIH Image to ImageJ: 25 years of image analysis", Nature methods 9(7): 671-67

Sabastian, G., Kanowski, P., Race, D., Williams, E., & Roshetko, J. M. (2014). Household and farm attributes affecting adoption of smallholder timber management practices by tree growers in Gunungkidul region, Indonesia. *Agroforestry systems*, *88*(2), 257-268.

Satti, P., Mazzarino, M. J., Gobbi, M., Funes, F., Roselli, L., & Fernandez, H. (2003). Soil N dynamics in relation to leaf litter quality and soil fertility in north-western Patagonian forests. *Journal of Ecology*, 91(2), 173-181.

Seghieri, J., Do, F. C., Devineau, J. L., & Fournier, A. (2012). Phenology of woody species along the climatic gradient in west tropical Africa. In *Phenology and climate change*. InTech.

Smith-Dumont, E. (in press) 'Integrating Farmers' Knowledge for Context Sensitive Parkland Agroforestry Management'.

Sood, K. K. (2006). The influence of household economics and farming aspects on adoption of traditional agroforestry in Western Himalaya. *Mountain Research and Development*, 26(2), 124-130.

Sop, Tene, and Jens Oldeland. (2013). 'Local Perceptions of Woody Vegetation Dynamics in the Context of a "Greening Sahel": A Case Study from Burkina Faso.' *Land Degradation & Development* 24(6): 511–27. citeulike-article-id:9790121%5Cnhttp://onlinelibrary.wiley.com/doi/10.1002/ldr.1144/pdf.

Taylor C. Y. (1952). The vegetation zones of the Gold Coast. For. Dept. Bull. no. 4

Tedersoo, L., Laanisto, L., Rahimlou, S., Toussaint, A., Hallikma, T., & Pärtel, M. (2018). Global database of plants with root-symbiotic nitrogen fixation: Nod DB. *Journal of Vegetation Science*.

Tilman, D., May, R. M., Lehman, C. L., & Nowak, M. A. (1994). Habitat destruction and the extinction debt. *Nature*, 371, 65–66. https://doi.org/10.1038/371065a0

Topps, J. H. (1992). Potential, composition and use of legume shrubs and trees as fodders for livestock in the tropics. *The Journal of Agricultural Science*, *118*(1), 1-8.

United Nations. (2005). 'Economic and Social Council - Report of the International Workshop on Methodologies Regarding Free, Prior and Informed Consent and Indigenous Peoples'. 24326(February): 1–27. Retrieved on April 11, from: https://undocs.org/E/C.19/2005/3

Vågen, Tor Gunnar, Leigh Winowiecki, Jerome E. Tondoh, and Lulseged Tamene Desta. (2015). ‘LDSF - Field Guide’. Wikipedia: 1–3

Violle, C., Navas, M. L., Vile, D., Kazakou, E., Fortunel, C., Hummel, I., & Garnier, E. (2007). Let the concept of trait be functional!. Oikos, 116(5), 882-892.

WAFFI. (2017). Poverty toolkit analysis, unpublished results.

Walker, D. H., and F. L. Sinclair. (1998). ‘Acquiring Qualitative Knowledge about Complex Agroecosystems. Part 1: Representation as Natural Language’. Agricultural Systems 56(3): 365–86.

Wallace, C. (2002). Household strategies: their conceptual relevance and analytical scope in social research. *Sociology, 36*(2), 275-292.

Weston, Peter, Reaksmey Hong, Carolyn Kaboré, and Christian A. Kull. (2015). ‘Farmer-Managed Natural Regeneration Enhances Rural Livelihoods in Dryland West Africa’. *Environmental Management* 55(6): 1402–17.

Winterbottom R, Hazlewood PT (1987) Agroforestry and sustainable development: making the connection. Ambio 16(2/3):100–110

Wright, I. J., P. B. Reich, M. Westoby, D. D. Ackerly, Z. Baruch, F. Bongers, J. Cavender-Bares, T. Chapin, J. H. C. Cornelissen, M. Diemer, J. Flexas, E. Garnier, et al. 2004. The worldwide leaf economics spectrum. *Nature* 428:821-827.

Zanne, A. E., Lopez-Gonzalez, G., Coomes, D. A., Ilic, J., Jansen, S., Lewis, S. L., ...Chave, J. (2009) Data from: Towards a worldwide wood economics spectrum. *Dryad Data Repository*. doi: 10.5061/dryad.234

Zanne, A. E., Tank, D. C., Cornwell, W. K., Eastman, J. M., Smith, S. A., FitzJohn, R. G., ...Ordonez, A. (2013) Data from: Three keys to the radiation of angiosperms into freezing environments. *Dryad Digital Repository*. doi: 10.5061/dryad.63q27.2

2. Appendix – PLANT FUNCTIONAL TRAITS, THEIR DRIVERS AND ECOSYSTEM FUNCTIONING

Table 12, plant functional traits, their human and ecological drivers and the ecosystem functioning consequences

Plant Functional Trait	**Unit**	**Human driver (what reasons could people have to promote higher values of this trait?)**	**Ecological driver (what environmental conditions would promote higher values of this trait?)**	**Ecosystem functioning consequences (what ecosystem functions would be promoted by higher values of this trait?)**
		Whole plant traits		
Max. plant height; PH	cm	More products; more money	Good soil quality	Soil quality, shade, wind protection, erosion prevention
Spinescence; S	Binary	Spinescence plants can serve as live fencing	Herbivory	Protection against herbivores
		Leaf traits		
Leaf Phenology; LP	Binary	Competition with crops	Drought	Nutrient cycling, drought avoidance
Leaf compoundness; LC	Binary	More resilient to heat stress	Heat	Drought avoidance and resistance
Leaf chlorophyll content; Chl	SPAD-units	More nutritious	Good soil quality	Higher photosynthetic rate, nutrient concentration
Leaf area; LA	mm2	Competition with crops for light; increased biomass (fodder, food, or soil)	Good soil quality, herbivory, competition	Drought and heat resistance
Leaf thickness; LT	mm	More resilient to heat and herbivores; bad for soil	Heat, herbivory	Lower decomposition rate; self-shading

Specific leaf area; SLA	m2/kg	Relative growth rate	Good soil quality, competition	Higher decomposition rate
Leaf density; LD	g/cm3	Quality for fodder, food, or soil	Heat, herbivory, soil quality	Lower decomposition rate; biomass quantity
Leaf dry matter content; LDMC	g/g	More resilient to damage; bad for soil; slow growing trees	Heat, herbivory	Lower decomposition rate
		Stem traits		
Twig dry matter content; TDMC	g/g	Slow growing trees; good firewood	Good soil quality, competition	Drought resistance
Wood density; WD	mg/mm3	Slow growing trees; good firewood or building material	Good soil quality, competition	Drought resistance
		Regenerative traits		
Resprouting ability; R	Binary	Regrowth after coppicing	Fire disturbances	Disturbance recovery; resilience and persistence after environmental disturbances
Seed mass; SM	g per 1000 seeds	Some seeds can be used (food/fodder/other)	Competition in germination stage	Less seeds, smaller dispersal range, increased survival and germination success
		Belowground traits		
N-fixing; NF	Binary	Food, fodder and soil quality	Poor soil quality	Increased soil quality

3. Appendix – SEMI-STRUCTURED INTERVIEW

The interview questions I asked the participating farmers during the household survey. Not all information collected during the interviews was used in the analysis.

Farmers' gender: F/M and age
HH composition: F/M kids/ number you feed
Education: Non – Medium (Primary 1 & 2) – High (Secondary)
Farm size: Number of bags of ground nut

Land management

1. Do you have ownership of this land?
2. How long have you cropped this field?
3. What are the crops you plant?
4. What do you do to improve your soil quality/yield?
5. How do you improve your soil fertility? how often do you do this?
   A) External input: fertilizer, herbicides, composting, manure, mulching, other
   B) Conservation: zai pits, conservation structures, other
   C) Other: fallow, livestock, ploughing, burning, suppression of bushfires

Tree management

6. Do you know about the technique called FMNR? Have you come into contact with FMNR information or training?
7. Do you own the trees on your field?
8. Do you have user right; Do you own the tree and products on the field?
9. Which tree species do you have on your field? – ask per tree:
   - Where did this species come from?
     - Was this species already here when you started cultivating (adult individuals/previous generation)
     - Did you allow this species to regenerate?
     - Did it originate from seed or root stock, plant or transplant?
   - Is this species a friends/disturbing to your crops?
     - Why?
     - Is this an undesirable species?
   - Do you manage this species?
     - What, when, how often, why?
     - Is there a difference in management for trees and regeneration?
   - What do you do to the regeneration of this species?
     - Do you protect/ nurture regeneration?
     - What, when, how often, why?
   - How many regenerations do you keep on your field? And why?
10. Do many trees regenerate on your field?
    - How come? (probe into level/nature of nurturing/proactive management)
11. Do you do anything to promote regeneration on your field? / Proactive management?
    A) Direct regeneration planting B) Direct seed planting
    C) Tending regeneration D) Coppice management
12. Do you want more trees?
    A) Yes B) No
13. What species would you want more off?
    - Why?
    - Where?
14. What are the constraints to having more trees?

4. Appendix – Variables included in the study

4.1 Household characteristics

Table 13; household characteristics, variable codes, description and unit

Variable code	Description	Unit
COM	Community, the community the household belongs to.	Adabania, Akaa, Gweni and Wombio
COMw	Community wealth, the wealth of the community the household belongs to.	Poor, Comfortable
HHw	Household wealth, the wealth of the household.	Poor, Comfortable
HHcomp	The number of people in the household.	Continuous
EDU	The education level of the farmer.	Non, Medium, High
Gender	The gender of the farmer.	Male, Female
Fsize	A proxy of the farmers' field size. Used was the amount of groundnut bags they could produce on their field. For one community the size was measured in hectare. Both these field sizes were rescaled (into 0-1)	Continuous (0-1)
PlotTenure	Complete ownership of the plot: farmers decides what happens to their plot.	Binary
DisPath	Distance to market, following the roads.	Meters

4.2 Land management activities

Table 14, Land management variables, their codes and description

Variable Code	**Description**
Fe	The application of fertilizer on the farmers' field, in one year.
FeNever	When fertilizer is never applied.
FeOnce	When fertilizer is applied sometimes or once.
FeTwice	When fertilizer is applied twice.
FeThrice	When fertilizer is applied thrice.
He	The application of herbicides on the farmers' field, in one year.
HeNever	When herbicides are never applied.
HeOnce	When herbicides are applied sometimes or once.
HeTwice	When herbicides are applied twice.
Ma	The application of manure (cow dung) on the farmers' field, in one year.
MaNever	When no manure is applied.
MaOnce	When manure is applied sometimes or once.
Mu	The practice of mulching on the farmers' field, in one year.
MuNo	When no mulching is applied.
MuCR	When the crop residue is kept on the soil.
MuCuts	When the cuts of the regeneration and weeds is left on the soil.
MuBoth	When both the crop residue and cuts are left on the soil.
Bu	The practice of burning the field, to get rid of vegetation and add fertility to the soil.
BuNo	When no burning is practised.

BuSome	When the farmer gathers most ((s)he leaves some) sticks, leaves and cuts, to burn them during land preparation, before planting.
BuAll	When the farmer gathers all sticks, leaves and cuts, to burn them during land preparation, before planting.
BuAfter	When the farmer gathers all sticks, leaves and cuts, to burn them after the cropping season.
FP	The practice of preventing fire by making a fire belt around the field. A fire belt is a strip of land that is cleared of all vegetation, to prevent bush fires from entering the farmers' field.
FPCrop	When the farmer makes a fire belt during the cropping season.
FPDry	When the farmer makes a fire belt during the dry season.
FPAll	When the farmer always has a fire belt around the field.
Pl	The practice of ploughing the farmers' field.
Plno	When the field is not ploughed.
PlManual	When ploughing is done manually.
PlBullock	When ploughing is done with a bullock.
PlBoth	When ploughing is done both manually and with bullock.
SCS	The practise where soil conservation structures are made to prevent erosion.
SCSno	When no SCS are made.
SCSContour	When the farmer practises contour ploughing. Contour ploughing is a practise where the farmer follows the contours of elevation during ploughing, to prevent water from flowing freely downhill and forming gullies, thereby preventing erosion.
SCSBounding	When the farmer practises bounding. Bounding is a practise where the farmer makes a boundary structure along the borders of the field, to prevent erosion and keep water in the field: either a stone structure or a mound of earth.
SCSBoth	When both bounding and contour ploughing are practised.
T.Field	The number of years the farmer has practised agriculture on this field.
T.Fallow	The length of a fallow in number of years. Fallow means the farmer leaves the field uncultivated or unplanted for a time period, to improve the soil quality and fertility.

4.3 Farmers knowledge & management

Table 15; Farmer species knowledge variables, the categories farmers used to define a) species origin, to explain why a tree species is b) friendly or c) disturbing the crops, d) regeneration management, e) adult tree management, and the explanation for what belongs in each category.

Category	**Explanation of the categories**
a) <u>Origin</u>	
Seed	Regeneration from naturally arriving seeds.
Regrowth	Regeneration either from root stock or stumps.
Planted	Regeneration that the farmer planted. The farmers planted from mostly from seed, but some farmers said they transplanted individual sometimes.
b) <u>Friendly species</u>	
No influence	When the farmer says the species has no negative or positive influence on the crops. Meaning: this species does not influence the crops, this species only occurs in the bush, and/or this individual is too young to have influence.

Good growth	When the farmer says the species has a good growth, and therefore does not impact the crops negatively. meaning: the species grows up, has few leaves, and/or is not shady.
Good spacing	When the farmer says the species has good spacing, and therefore does not impact the crops negatively. Meaning: the species is not too crowded, they are scattered, or not too close. And/or there are just a few or only one and/or not too many. (Farmers each have their own good spacing, but most say about 3 meters between trees.)
Fertility	When the farmer says the species adds fertility to the soil. Meaning: add fertility, good for soil fertility, and/or makes soil loose.
Other good	When the farmers answer did not fit in any of the other categories. Meaning: harvest leaves so no shade, trade-off (crops vs income), and/or where there is trees there are no crops but trees give income.
Non-applicable	When there was no explanation given.
Do not know	When the farmer said (s)he did not know.
c) <u>Disturbing species</u>	
Bad growth	When the farmer says the species has a bad growth, and thereby impact the crops negatively. Meaning: too shady, roots/branches are spread wide, spines, slow decomposition, competition (for light, water, nutrients) and/or, bad juice/taste.
Bad spacing	When the farmer says the species has bad spacing. Meaning: grows overcrowded, with too many and/or too close to each other.
Crops	When the species is bad for the crops. Meaning: bad for crops, no crops below, plant other crop and/or bad for farmer (and indirectly bad for crops).
Animal	When the farmer says the species attracts animals who damage the crops. Meaning: species attracts monkeys, birds come in and eat the crops.
Non-applicable	When there was no explanation given.
d) <u>Farmers regeneration management</u>	
Promote & Protect	When the farmer either promotes or protects a regeneration. Meaning: clear/weed around, protect from fire, farm around the regeneration.
Promote1	When a farmer promotes a regeneration. Meaning: prune to grow well, add up (an activity where soil is put up around the regeneration stem to keep it more stable), and add fertility (by leaving leafs in the soil).
Promote2	When the farmer actively promotes the growth of regeneration. Meaning: watering, transplanting, spreading seeds (in an area where they want that species).
Protect 1	When a farmer keeps all or most of the regeneration that is coming up. Meaning: keep all or keep most.
Protect 2	When the farmer selects some regeneration to protect and promote to become a tree. Meaning: keep youngsters after fallow, select if in good place where there is space, select for use (building material, fruit), and select if regeneration has good shape.
Manage Competition	When the farmer manages competition with crop, and other regeneration. Meaning: cut others, or prune to avoid shade.
Kill	When the farmer clears or cuts them all.
Do nothing	When a farmer does not do anything to the regeneration. Meaning: nothing, or no time.
n/a	When there are no regeneration present.

e) **Farmers Adult tree management**	
Use Tree	When the farmer protects or keeps a tree for use. And/or when the farmer prunes or cuts a tree for use. Meaning; medicine, fodder/ animal feed, fruit/ human food, bark, building material, and firewood.
Protect Tree	When the farmer actively protects the tree. Meaning: prevent cutting, prevent fire (by clearing/weeding around the tree), and protect it from birds.
Promote Tree	When the farmer prunes/trims the tree to promote growth. When the farmer weeds/clears around the tree to promote growth, fruiting or seed production/viability. Meaning: prune to grow up, prune to grow well, weed around to get healthier and more seeds, and weed around to promote fruiting.
Manage Competition	When the farmer manages competition with crop, and other trees. Meaning: Trim/prune during field preparation to keep it small, prune to prevent competition with crops, plant crops far from trees, trim/cut when there are too many, cut old ones to give young ones a chance.
Kill	When the farmer kills the tree, or when (s)he cuts them all.
Other	This category includes: 'clear around to sit', 'big tree died because of insect'.
Do nothing	When the farmer does not do anything to the trees.

Table 16, Regeneration/regeneration & adult tree management diversity and abundance calculated per household. Table shows the abbreviation used during analysis and the description of the variable.

Variable code	Description
Smdiv	Regeneration management diversity. The total different regeneration/regeneration management practices per household.
Smabun	Regeneration management abundance. The total regeneration/regeneration management practices the household practices.
Tmdiv	Tree management diversity. The total different adult tree management practices per household.
Tmabun	Tree management abundance. The total adult tree management practices per household.

5. Appendix – TREE ATTRIBUTE RANKING & SCORING

Table 17, steps followed to get to the pre-selected species list for Ghana

	Steps taken to get the preselected species list that was used during the tree attribute scoring in Ghana
1.	Make the focal species list based on 80% abundance, across tree and regeneration inventory Ghana and Burkina Faso (from previous research done within WAFFI project)
2.	Species that occur less than 5 times across both sites were excluded. In addition, *Tectonis grandis* (Teak) was excluded, because it only occurs on plantations.
3.	The 13 most abundant tree and 13 most abundant regeneration species, resulting in a list of 20 species (5 species selected as both regeneration and tree showed in red)
4.	Check if species need to be excluded species because they do not occur on farmers' fields.
5.	Check if species should be added because they have high value to farmers. (*Tamarindus indica* was added, resulting in final list of 21 species)
6.	Prepare and print illustrated cards (including code and local name)

Table 18, preselected species list for the attribute ranking Ghana; shows scientific name, local name and the code

ID	Scientific	Local	Code
1	*Acacia dudgeoni*	Saborasina	ADU
2	*Adansonia digitata*	Tiu	ADI
3	*Anogeissus leiocarpus*	Lua	ALE
4	*Azadirachta indica*	Feilateo	AIN
5	*Balanites aegyptiaca*	Sisaa - Kangogu	BEA
6	*Bombax costatum*	Kafuru	BCO
7	*Burkea africana*	Tanyono	BAF
8	*Combretum molle*	Vorsanga	CMO
9	*Daniellia oliveri*	Kachelo	DOL
10	*Detarium microcarpum*	Kalankolo	DMI
11	*Diospyros mespiliformis*	Kokunu	DME
12	*Gardenia erubescens*	Kantongo	GER
13	*Lannea acida*	Nyaburu	LAC
14	*Maytenus senegalensis*	Loo	MSE
15	*Parkia biglobosa*	Sunu	PBI
16	*Piliostigma thonningii*	Pelavoo - Kavayono	PTH
17	*Stereospermum kuntheanum*	Giling giling punga	SKU
18	*Strychnos spinosa*	Kampoa	SSP
19	*Tamarindus indica*	Sana	TIN
20	*Terminalia avicennioides*	Kogo	TAV
21	*Vitellaria paradoxa*	Songo	VPA

Table 19, Tree attribute scoring values explained. Table shows the different tree attributes, the scores and related meaning.

Economic value	
Score	**Explanation**
5	Essential for livelihood
4	Significant for livelihood
3	Moderate value to livelihood
2	Minor value to livelihood
1	Very minor value to livelihood
0	no income from this tree
Leaf litter contribution to soil fertility (observable benefits of leaf litter on soil)	
Score	**Explanation**
5	Exceptional contribution/pro-active management of leaf litter for soil recovery
4	Very good contribution to soil fertility
3	Moderate contribution
2	Minor contribution
1	Very minor contribution
0	No observable contribution
Fodder nutritional value for cattle (trees that are lopped to feed cattle)	
Score	**Explanation**
5	Extremely nutritious (farmers first preference for feeding cattle)
4	Very nutritious (farmers second preferences)
3	Moderately nutritious
2	Low nutritious
1	Very poor nutrition (only when there is nothing else to feed)
0	No value

6. Appendix – Land degradation surveillance framework & inventory of woody vegetation

The Land Degradation Surveillance Framework (LDSF) was performed in both study: Kayoro, Ghana and Seloghin, Burkina Faso. The LDSF is a method for systematic landscape-level assessment of soil and ecosystem health (Vågen et al. 2013). The LDSF described by Vågen et al. (2013), is built up of a hierarchical field survey and sampling protocol, using sites of a 100 km2 (10 by 10 km). This 100 km2 is divided into 16 tiles (2.5 x 2.5 km), in each tile a cluster center-point is randomly placed, around which 10 plots are randomized. Each plot is 0.1 ha (1000 m2) and has four subplots of 0.01 ha each. That means 160 plots were measured in Ghana and 160 plots measured in Burkina Faso. The LDSF is a method for systematic landscape-level assessment of soil and ecosystem health. Using the randomized sampling design minimizes the local biases that may arise from convenience sampling. The LDSF measurement have multiple scales; first there are the two sites Kayoro in Ghana and Seloghin in Burkina Faso, they each have 16 clusters of 10 plots each and each plot has four subplots. In the plot level basic site characteristic are described and recorded, including vegetation cover, land-use, landowner and current use. At sub-plot level the soil surface characteristics, vegetation measurements and soil sampling take place. The vegetation measurements included adult tree and regeneration/seedling species, density, height and DBH (only for trees). The impact on habitat was also noted consisting of; the impact of tree cutting, agriculture, grazing, fire, urban activities, industrial activities, erosion, alien vegetation and firewood collection.

The woody vegetation inventory was performed in 160 plots in Ghana and 160 plots in Burkina Faso, a total of 84 species were identified and 1866 individuals were measured. From this list the focal species were selected: regeneration species that cover 80% of the abundance of regeneration across all plots, and tree species that make up 80% of the basal area across all plots (Garnier et al. 2004; Pakeman and Quested 2007; Pérez-Harguindeguy et al. 2013) (Table 20).

Table 20, Focal species based on the tree and regeneration inventory of Burkina Faso and Ghana (LDSF). On these species the functional traits were measured. The total number of individuals shows the abundance of the species across the 320 LDSF plots; 160 in Ghana and 160 in Burkina Faso.

ID	Scientific name	Burkina Faso		Ghana		Total individual
		Regeneration	Trees	Regeneration	Trees	
1	*Acacia dudgeoni*	4	0	2	34	40
2	*Acacia gourmaensis*	11	8	0	1	20
3	*Acacia seyal*	13	2	0	0	15
4	*Acacia sieberiana*	0	5	0	5	10
5	*Adansonia digitata*	0	4	0	11	15
6	*Afzelia africana*	0	6	0	1	7
7	*Annona senegalensis*	35	0	0	0	35
8	*Anogeissus leiocarpus*	34	83	0	36	153
9	*Azadirachta indica*	0	0	1	35	36
10	*Balanites aegyptiaca*	7	23	1	2	33
11	*Bombax costatum*	0	8	0	16	24
12	*Burkea africana*	0	1	2	16	19
13	*Combretum fragrans*	6	8	0	0	14
14	*Combretum glutinosum*	80	0	0	0	80
15	*Combretum molle*	8	8	11	4	31

16	*Combretum nigricans*	55	20	0	0	75
17	*Crossopterix febrifuga*	0	7	3	0	10
18	*Daniellia oliveri*	1	0	1	3	5
19	*Detarium microcarpum*	19	32	0	6	57
20	*Dichrostachys cinerea*	21	0	0	0	21
21	*Diospyros mespiliformis*	13	21	3	38	75
22	*Entada sudanica*	0	0	0	6	6
23	*Feretia apodanthera*	8	0	0	0	8
24	*Flueggea virosa*	16	0	0	0	16
25	*Gardenia erubescens*	11	0	3	0	14
26	*Gardenia ternifolia*	0	7	0	0	7
27	*Guierra senegalensis*	50	0	0	0	50
28	*Lannea acida*	2	15	0	20	37
29	*Lannea microcarpa*	2	40	0	0	42
30	*Maytenus senegalensis*	8	1	1	2	12
31	*Mitragyna inermis*	0	6	0	0	6
32	*Parkia biglobosa*	0	18	0	2	20
33	*Piliostigma thonningii*	76	12	1	2	91
34	*Pterocarpus erinaceus*	2	6	0	2	10
35	*Sclerocarya birrea*	3	10	0	2	15
36	*Sterculia setigera*	0	3	0	5	8
37	*Stereospermum kuntheanum*	0	0	0	6	6
38	*Strychnos spinosa*	9	0	6	1	16
39	*Tamarindus indica*	0	7	0	6	13
40	*Terminalia avicennioides*	16	14	4	3	37
41	*Terminalia laxiflora*	0	6	0	0	6
42	*Terminalia macroptera*	1	5	0	1	7
43	*Vitellaria paradoxa*	73	202	12	266	553
44	*Ximenia americana*	0	11	0	0	11

7. Appendix – FUNCTIONAL TRAIT MEASUREMENT PROTOCOL

FUNCTIONAL TRAIT MEASUREMENT PROTOCOL

In the field:

1. Find reproductively mature and healthy-looking individuals: leafs fully expanded, sun-exposed, no damage
2. Check spinescence (S)
3. Check leaf compoundness (LC)
4. Chlorophyll measurement using a SPAD on 4 leaves per individual. (Chl)
5. Terminal sun-exposed twigs (2 or 3) of 20 cm long will be cut from the tree and stored into coded plastic bag.

Once back at field base:

6. Twigs will be rehydrated in a bucket in the dark for at least 1 hours (the bottom part of the twig will be cut to enable better water sucking).
7. Measure leaf instantaneous chlorophyll fluorescence with a Fluor pen. (LICF)
8. Remove all leaves from twig.
9. Weight 4 fresh leaves per individual on a, balance (TM electronic scale)
10. Weight 3 fresh twigs per individual on a balance (TM electronic scale)
11. Measure the leaf thickness of 4 leaves per individual with a digital caliper in the middle of the leaf. (LT)
12. Photograph 4 leaves per individual on a white surface next to a ruler. (LA)
13. Store 4 leaves per individual in paper bags and hang on a line to dry (in a well-ventilated room).
14. Hang 2/3 twigs on a line to dry (in a well-ventilated room).
15. Weight the leaf's dry mass a week later on a balance. (LDMC, SLA, LD)
16. Weight the twigs dry mass a week later on a balance. (TDMC)
17. Repeat weighing the leaves and twigs until the dry weight is constant (this took 1 week to 4 weeks).

Figure 17, Functional trait measurement protocol; steps to be followed when measuring the functional traits of the focal species

8. Appendix – Identified tree species

Table 21. Tree species identified during the household survey, performed on 40 households/ farmers' fields. Table shows the scientific name, local name and the species identified through the inventory and through the interviews. Inventory of farmers' field: the adult trees were measured in a plot of 1000m2, within the regeneration was measured in three subplots of each 20m2. Interview: the farmers' responses for a species being present on their field that were counted: the number of farmers who mentioned the species for regeneration, the number of farmers who mentioned the species for adult trees, and the total. The 11 species of which no scientific name could be identified, were excluded from any analysis.

ID	Scientific name	Local name	Inventory Regeneration	Inventory adults	Total inventory	Interview HH Regeneration	Interview HH adults	Interview total HH
1	*Acacia albida*	Sinzuna - kasinzono	0	0	0	1	1	1
2	*Acacia amythethopphylla*	Busungu	1	1	2	3	2	3
3	*Acacia sieberiana; Acacia dudgeoni; Acacia gourmaensis*	Saborapuna; Saborasina; Saborazuna	22	0	22	15	4	15
4	*Acacia tortitis*	Kaporilia	2	0	2	0	0	0
5	*Adansonia digitata*	Tiu	0	2	2	4	13	13
6	*Afzelia africana*	Kolo	0	0	0	5	6	6
7	*Anacardium occidentale*	Cashew - Atia	0	1	1	0	2	2
8	*Annona senegalensis*	Kawolo	1	0	1	0	1	1
9	*Anogeissus leiocarpus*	Lua	1	7	8	10	14	14
10	*Azadirachta indica*	Feilateo	3	3	6	9	10	11
11	*Balanites aegyptiaca*	Sisaa	3	0	3	1	1	1
12	*Bombax costatum*	Kafuru	12	1	13	5	11	11
13	*Burkea africana*	Tanyono	1	1	2	1	3	3
14	*Combretum fragrans*	Kamolo	5	0	5	2	0	2
15	*Combretum glutinosum*	Kamolesinga	1	0	1	0	0	0
16	*Combretum molle*	Vorsanga	5	1	6	1	0	1
17	*Combretum nioroense*	Vopong - Lampooni	41	1	42	20	1	20
18	*Crossopterys febrifuga*	Labadiu	1	0	1	0	0	0
19	*Daniellia oliveri*	Kachelo	20	0	20	1	2	2
20	*Detarium microcarpum*	Kalankolo	2	2	4	0	4	4
21	*Dichrostachys cinerea*	Chao	25	0	25	6	0	6
22	*Diospyros mespiliformis*	Kokunu	15	7	22	20	21	22
23	*Elaeis guineensis*	Oil Palm	0	0	0	0	1	1
24	*Entada sudanica*	Kaynansono	0	1	1	2	1	2
25	*Eucalyptus spp*	Eucalyptus	0	0	0	0	0	1
26	*Faidherbia albida*	Faidherbia	0	0	0	0	1	1
27	*Feretia apodanthera*	Chilachiga	8	0	8	7	5	7
28	*Ficus trichopoda*	Kapurikangogo - Kapira - Kapuru	0	0	0	3	0	5

		kayono - Kangagu						
29	*Flueggea virosa*	Lulua	1	0	1	1	0	1
30	*Gardenia erubescens*	Kantongo	7	0	7	2	4	4
31	*Guava spp*	Guava	0	0	0	0	1	1
32	*Guiera senegalensis*	Chiralua - Piolua	0	0	0	3	0	3
33	*Lamea barteri*	Kachulanboo	0	0	0	1	1	1
34	*Lannea acida*	Nyaburu	0	1	1	0	0	0
35	*Lonchocarpus laxiflorus*	Naadindelem	5	0	5	0	0	0
36	*Mangifera indica*	Mango	0	4	4	1	3	4
37	*Maytenus senegalensis*	Loo	3	0	3	2	0	2
38	*Moringa oleifera*	Marenga - Felajamasuni	0	1	1	3	2	5
39	*Parkia biglobosa*	Sunu	0	4	4	9	15	16
40	*Piliostigma thonningii*	Pelavoo - Kavayono	8	0	8	8	0	8
41	*Pseudocedrala kotschyi*	Nyabori	4	0	4	2	1	2
42	*Pteleopsis suberosa*	Lansoa	18	0	18	1	0	1
43	*Pterocarpus lucens*	Tintanga	2	0	2	3	4	4
44	*Sarcocephalus latifolius*	Kelagongo	0	0	0	2	0	2
45	*Sclerocarya birrea*	Kansola	6	2	8	5	8	8
46	*sclerocarya microcarpa*	Kachugu	7	4	11	5	7	7
47	*Sterculia setigera*	Kampolo	0	0	0	4	8	9
48	*Stereospermum kuntheanum*	Giling giling punga	51	1	52	2	1	2
49	*Strychnos innocua*	Kampo-bia	6	0	6	0	0	0
50	*Strychnos spinosa*	Kampoa	3	2	5	3	3	4
51	*Tamarindus indica*	Sana	0	0	0	4	12	12
52	*Tectona grandis*	Teak	0	0	0	1	2	2
53	*Terminalia avicennioides*	Kogo	20	1	21	10	3	11
54	*Trichilia emetica*	Viyaa nadua	0	0	0	1	0	1
55	*Vernonia amygdalina*	Siwaga	0	0	0	0	1	1
56	*Vitellaria paradoxa*	Songo	72	165	237	33	37	37
57	*Ximenia americana*	Miu	0	0	0	1	0	1
58	*Ziziphus mauritiana*	Saboralanguo	2	0	2	0	0	0
59	N/A	Bamilim - Nomelem - Namelimi	4	0	4	1	0	1
60	N/A	Breluga	1	0	1	0	0	0
61	N/A	Chakura (akaa) - Chikura	0	0	0	1	2	2
62	N/A	Dimvanbaro	1	0	1	0	0	0
63	N/A	Foro	8	0	8	0	0	0
64	N/A	Galeseh	0	0	0	0	1	1
65	N/A	Kanyelega - kanyelegu	0	0	0	1	1	1
66	N/A	Langogno	2	0	2	1	0	1
67	N/A	Lukong - Logkono	1	0	1	0	0	0
68	N/A	Tamolo	7	0	7	3	0	3
69	N/A	Tolo - Kaporo	3	0	3	0	2	2
		Total	**411**	**213**	**624**	**230**	**223**	**315**

9. Appendix – FMNR adoption and level of intensity mixed effect models output

Table 22. Optimal model output FMNR adoption (a) and level of intensity (b): showing the variables included in the model, their estimated coefficients (Estimate β), standard error (Std. Error), degrees of freedom (df), t-value, p-value for the t-test (Pr(>|t|)), and significance coding.

Variables	Estimate β	Std. Error	df	t-value	Pr(>|t|)	Significance
a) <u>FMNR adoption</u>						
(Intercept)	0.581639	0.123301	37	4.71721	3.37E-05	***
Community wealth	-0.27609	0.144985	37	-1.90428	0.064671	ns
Plot tenure	0.409145	0.143182	37	2.857529	0.006969	**
Distance to market	-0.03482	0.071664	37	-0.48581	0.629964	ns
b) <u>FMNR intensity adoption</u>						
(Intercept)	3.016103	0.35222	16.1511	8.563125	2.11E-07	***
Community wealth	-1.18612	0.343107	4.600121	-3.45699	0.020694	*
EDUmed	0.911013	0.330534	34.53679	2.756185	0.009274	**
EDUnon	0.614824	0.287321	35.05717	2.139849	0.039405	*
Distance to market	-0.11221	0.164185	4.876475	-0.68346	0.525429	ns
*Signif. codes: '***' < 0.001, '**' <0.01, '*'<0.05', 'ns' >0.05*						

10. Appendix – Farmer species knowledge and management

Table 23, overview of famers responses: a) origin, b) friendly and c) disturbing species. Table shows the different categories, the number of species per category, the percentage of the total number of species, the number of responses per category and the percentage of the total.

Category	# species	% of total*	# responses	% of total**
a) <u>Origin</u>				
Regeneration from seed	33	66	151	51
Regeneration from regrowth	33	66	127	43
Planted using seed or transplanting	9	18	18	6
Do not know	1	2	1	0
b) <u>Friendly</u>				
Good spacing	22	56	81	41
Good growth	28	72	71	36
Adds fertility	18	46	24	12
No influence	8	21	8	4
Other good	7	18	7	4
n/a	5	13	5	3
Do not know	2	5	2	1
c) <u>Disturbing</u>				
Bad growth	40	100	152	84
Crops	9	23	15	8
Bad spacing	6	15	9	5
Animal	3	8	3	2
n/a	1	3	1	1
d) Regeneration management				
Kill	36	84	128	35
Protect2	21	49	74	20
Promote & Protect	16	37	54	15
Promote1	16	37	50	14
Manage competition	14	33	37	10
Protect1	10	23	13	4
Promote2	6	14	9	2
Do nothing	5	12	5	1
e) Adult tree management				
Manage competition	24	65	104	38
Do nothing	21	57	49	18
Promote tree	18	49	46	17
Protect tree	18	49	41	15
Use tree	14	38	23	8
Kill tree	7	19	7	3
Other	2	5	2	1

** total number of species (a: 50, b: 39, c: 40, d: 43, e: 37);*
*** total number of responses (a: 297, b: 198, c: 180, d:370, e: 272)*

11. Appendix – Farmers' species knowledge and the species' relative abundance

Table 24, farmers' species knowledge and species relative abundance: the 50 species named during the interviews by the farmers, their scientific name, the species competition with the crops (friendly, disturbing (foe) or both), the regeneration management (positive (protect/promote) or negative (kill)), the origin (seed, regrowth, planted), and the species' relative abundance (species' total number of individuals measured across the 40 farmers fields' during the inventory divided by the total number of individuals measured times 100) separate for regeneration and adult trees. The table is ordered alphabetically. Inventory of farmers' field: the adult trees were measured in a plot of 1000m2, within the regeneration was measured in three subplots of each 20m2. Total number of individuals: 366 regeneration and 212 adult trees, across 40 farmers' fields.

ID	Scientific name	Competition with crops	Regeneration management	Origin	Regeneration Abundance (%)	Adult tree abundance (%)
1	*Acacia albida*	Friend	+	S	0,0	0,0
2	*Acacia amythethopphylla*	Foe	=	SR	0,3	0,5
3	*Acacia sieberiana; Acacia dudgeoni; Acacia gourmaensis*	Foe	-	SR	6,0	0,0
4	*Adansonia digitata*	Same	+	S	0,0	0,9
5	*Afzelia africana*	Friend	-	SR	0,0	0,0
6	*Anacardium occidentale*	Same	n/a	P	0,0	0,5
7	*Anogeissus leiocarpus*	Friend	+	SR	0,3	3,3
8	*Azadirachta indica*	Same	+	SRP	0,8	1,4
9	*Balanites aegyptiaca*	Foe	-	S	0,8	0,0
10	*Bombax costatum*	Foe	+	SR	3,3	0,5
11	*Burkea africana*	Foe	-	S	0,3	0,5
12	*Combretum fragrans*	Foe	-	R	1,4	0,0
13	*Combretum molle*	Foe	-	R	1,4	0,5
14	*Combretum nioroense*	Foe	-	SR	11,2	0,5
15	*Daniellia oliveri*	Friend	-	S	5,5	0,0
16	*Detarium microcarpum*	Friend	n/a	S	0,5	0,9
17	*Dichrostachys cinerea*	Foe	-	SR	6,8	0,0
18	*Diospyros mespiliformis*	Friend	+	SR	4,1	3,3
19	*Elaeis guineensis*	Friend	n/a	P	0,0	0,0
20	*Entada sudanica*	Foe	-	R	0,0	0,5
21	*Eucalyptus spp*	Friend	n/a	P	0,0	0,0
22	*Faidherbia albida*	Friend	n/a	S	0,0	0,0
23	*Feretia apodanthera*	Foe	-	SR	2,2	0,0
24	*Ficus trichopoda*	Foe	-	S	0,0	0,0
25	*Flueggea virosa*	Foe	-	R	0,3	0,0
26	*Gardenia erubescens*	Friend	-	SR	1,9	0,0
27	*Guava spp*	Friend	n/a	P	0,0	0,0
28	*Guiera senegalensis*	Foe	-	SR	0,0	0,0
29	*Lamea barteri*	Foe	+	S	0,0	0,0
30	*Mangifera indica*	Same	+	P	0,0	1,9
31	*Maytenus senegalensis*	Same	-	SR	0,8	0,0
32	*Moringa oleifera*	Friend	+	RP	0,0	0,5
33	*Parkia biglobosa*	Friend	+	SP	0,0	1,9
34	*Piliostigma thonningii*	Foe	-	SR	2,2	0,0

35	*Pseudocedrala kotschyi*	Same	-	SR	1,1	0,0
36	*Pteleopsis suberosa*	Foe	-	R	4,9	0,0
37	*Pterocarpus lucens*	Foe	+	SR	0,5	0,0
38	*Sarcocephalus latifolius*	Foe	-	R	0,0	0,0
39	*Sclerocarya birrea*	Foe	=	S	1,6	0,9
40	*sclerocarya microcarpa*	Friend	+	SR	1,9	1,9
41	*Sterculia setigera*	Foe	-	SR	0,0	0,0
42	*Stereospermum kuntheanum*	Friend	+	SR	13,9	0,5
43	*Strychnos spinosa*	Same	=	R	0,8	0,9
44	*Tamarindus indica*	Friend	+	SR	0,0	0,0
45	*Tectona grandis*	Friend	+	R	0,0	0,0
46	*Terminalia avicennioides*	Foe	-	SR	5,5	0,5
47	*Trichilia emetica*	Friend	-	R	0,0	0,0
48	*Vernonia amygdalina*	dk	n/a	P	0,0	0,0
49	*Vitellaria paradoxa*	Friend	+	SR	19,7	77,8
50	*Ximenia americana*	Foe	-	R	0,0	0,0

12. Appendix – FAMD

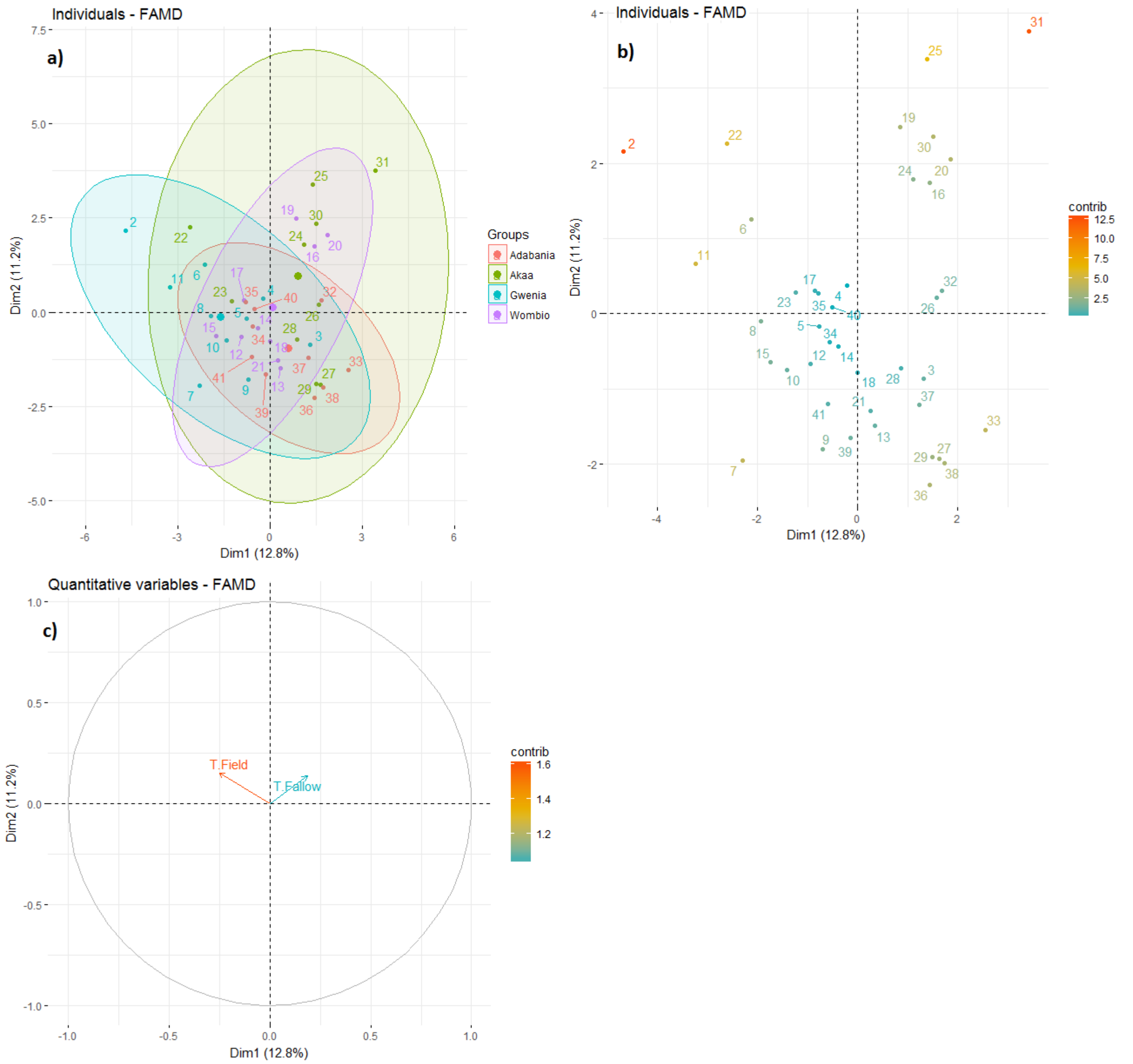

Figure 18: FAMD: a) the location of the households/fields (shown as dots with corresponding household numbers) plotted on the first two dimensions, Dim1 explaining 12.8% and Dim2 explaining 11.2% of the variation. Coloring shows to which of the four communities the sites belong. The ellipses show the clustering of the sites and communities. Results show that Adabania is very similar to all other communities, but mostly to Gwenia. Wombio is quite different from Gwenia, showing a different direction. Akaa has a wide range of variances overlapping with all other communities. b) shows the sites contribution to the dimensions. c) Correlation circle of the quantitative variables (arrows) of the FAMD, coloring indicates the variables' contribution to the dimensions. Arrows close together are correlated and arrows opposite each other are negatively correlated. The length of the arrows indicates the strength of the correlation between variables, farther away from the center/ closer to the circle variables have a high cos2 (good representation of variable on dimension). And arrows close to the axis are strongly correlated with that axis or dimension. Only time on field and fallow time are part of the continuous land management activities. They are not correlated, and time on field has a higher contribution to the dimensions than fallow time does.

13. Appendix – Descriptive statistics

Table 25; overview household characteristics, each of the included household characteristics and the average or the number of households for the total sample and per community

Household characteristics	Sample	Gwenia	Wombio	Akaa	Adabania
Number of households in comfortable Community	20	0	10	0	10
Number of households in poor Community	20	10	0	10	0
Number of households with Poor wealth	20	5	5	5	5
Number of households with comfortable wealth	20	5	5	5	5
*Average household composition**	7,0	9,2	6,3	7,4	5,2
Number of households without education	21	5	7	6	3
Number of households with medium education	10	4	1	3	2
Number of households with high education	9	1	2	1	5
Number of female-headed households	7	1	2	1	3
Number of male-headed households	33	9	8	9	7
*Average field size (scaled)***	2,3	3,4	1,2	1,9	2,6
Number of households that own the plot (Tenure)	25	7	8	4	6
*Average distance to market (km)***	17,1	7,9	20,6	27,2	9,8

**** S.D.: Sample 3.5; Gwenia 3.5; Wombio 4.1; Akaa 2.6; Adabania 1.7***
***** S.D.: Sample 2.4; Gwenia 3.0; Wombio 0.7; Akaa 1.9; Adabania 2.8***
****** S.D.: Sample 7.96; Gwenia 1.3; Wombio 1.7; Akaa 27.2; Adabania 0.4***

Table 26; descriptive statistics: overview a) abundance, b) diversity and c) management across the four communities, table shows each variables community average for regeneration (R) and adults (A) separately.

		Sample (N = 40)		Gwenia (N = 10)		Wombio (N = 10)		Akaa (N = 10)		Adabania (N = 10)	
		Mean	*S.D.*	*Mean*	*S.D.*	*Mean*	*S.D.*	*Mean*	*S.D.*	*Mean*	*S.D.*
a) Abundance											
Density	R	1712,50	1833,71	1167,00	1080,12	1333,00	1686,55	2617,00	2429,05	1733,00	1509,60
	A	53,25	30,20	39,00	28,09	43,00	21,00	69,00	27,73	62,00	31,87
b) Diversity											
Richness (Srar10 & Trar2)	R	2,97	1,93	2,88	2,05	1,87	1,53	3,43	2,06	3,71	1,47
	A	1,20	0,41	1,36	0,58	1,01	0,37	1,12	0,17	1,30	0,32
Functional diversity (Fdis)	R	0,083	0,070	0,076	0,080	0,044	0,054	0,090	0,064	0,121	0,054
	A	0,034	0,056	0,056	0,055	0,005	0,011	0,015	0,029	0,061	0,077
c) Management											
Management richness (Smdiv & Tmdiv)	R	3,88	1,49	4,20	1,17	2,40	1,28	4,90	1,14	4,00	1,10
	A	2,63	1,32	3,70	1,27	2,60	1,50	1,90	0,83	2,30	0,78
Management abundance (Smab & Tmabun)	R	9,43	5,80	13,50	7,79	4,90	3,21	8,80	2,32	10,50	4,41
	A	7,05	3,78	9,20	3,89	5,80	2,64	4,80	1,47	8,40	4,45

14. Appendix – Tree attributes & Functional traits

Table 27; species' attribute scores, scientific name of the species, the number of times each species was scored by a farmer (N), the mean and standard deviation (S.D.) per attribute (economic, litter and fodder).

		Economic		Litter		Fodder	
Scientific	**N**	**Mean**	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**
Adansonia digitata	29	3,9	1,1	2,5	1,8	3,0	2,0
Acacia dudgeoni	13	0,1	0,3	1,1	1,6	1,8	1,7
Azadirachta indica	14	1,0	1,4	0,5	0,8	0,9	1,3
Anogeissus leiocarpus	17	1,3	1,1	1,9	1,5	1,2	1,2
Burkea africana	7	0,7	0,9	0,4	0,5	0,0	0,0
Bombax costatum	5	0,0	0,0	1,3	0,4	0,0	0,0
Balanites aegyptiaca	16	1,9	1,1	1,7	1,0	1,2	1,2
Combretum molle	9	0,1	0,3	1,5	1,9	0,6	1,0
Diospyros mespiliformis	28	1,3	1,4	1,7	1,2	0,3	0,7
Detarium microcarpum	25	1,3	1,0	1,1	1,2	0,2	0,5
Daniellia oliveri	9	0,7	0,9	1,7	1,6	0,6	0,7
Entada sudanica	10	0,2	0,6	1,3	1,6	0,4	1,0
Gardenia erubescens	17	1,4	1,1	0,7	0,7	0,1	0,3
Lannea acida	12	1,0	1,2	0,3	0,5	0,0	0,0
Maytenus senegalensis	10	0,1	0,3	0,7	0,9	0,0	0,0
Parkia biglobosa	29	3,9	1,0	2,8	1,4	0,4	1,0
Piliostigma thonningii	19	0,3	0,8	1,5	1,1	0,0	0,0
Stereospermum kuntheanum	4	0,0	0,0	0,3	0,4	0,0	0,0
Strychnos spinosa	23	1,7	1,3	0,9	0,9	1,4	1,9
Terminalia avicennioides	12	0,6	1,0	0,6	0,9	0,0	0,0
Tamarindus indica	21	2,3	1,1	2,5	1,3	0,4	1,0
Vitellaria paradoxa	33	4,9	0,3	4,0	1,3	1,2	1,7
Eindtotaal	**362**	**1,9**	**1,8**	**1,8**	**1,6**	**0,8**	**1,5**

Table 28; correlation matrix, showing the correlation coefficients between the different attributes and functional traits. The variables showing correlation are shown in grey. Where correlation between the three attributes (litter, fodder and economic value) and the functional traits was found, a linear regression was made, to visualize the relationship.

	Litter	*Fodder*	*Economic*	*PH*	*Chl*	*LT*	*LA*	*SLA*	*LDMC*	*TDMC*	*WD*	*LD*	*SM*	*S*	*LP*	*LC*
Litter	1															
Fodder	0.53	1														
Economic	0.72	0.54	1													
PH	0.59	0.51	0.62	1												
Chl	-0.09	-0.13	0.16	-0.12	1											
LT	-0.19	-0.40	-0.16	-0.46	-0.03	1										
LA	0.09	-0.16	0.05	0.10	0.12	-0.03	1									
SLA	-0.04	0.56	-0.15	0.03	-0.37	-0.49	-0.34	1								
LDMC	0.07	-0.14	-0.08	0.13	0.41	-0.28	-0.07	-0.20	1							
TDMC	0.06	-0.13	-0.27	-	0.00	-	-	0.18	0.61	1						

				0.07		0.08	0.44									
WD	-0.07	-0.09	-0.28	-0.21	0.00	-0.16	-0.68	0.34	0.32	0.71	1					
LD	0.16	-0.09	0.20	0.48	0.23	-0.69	0.28	-0.19	0.57	0.06	-0.03	1				
SM	0.46	0.19	0.49	-0.09	0.21	-0.01	0.29	-0.13	-0.08	-0.12	-0.22	-0.06	1			
S	-0.28	0.13	-0.17	-0.39	-0.07	-0.10	-0.44	0.33	-0.42	-0.15	0.06	-0.28	-0.07	1		
LP	0.16	0.25	0.20	0.25	-0.49	-0.04	0.14	0.26	-0.23	-0.14	-0.05	-0.11	-0.14	-0.30	1	
LC	-0.13	0.19	0.09	0.14	-0.10	-0.51	0.39	0.32	-0.33	-0.33	-0.27	0.21	0.33	0.21	0.12	1

Abbreviations: Litter; average score for leaf litter contribution to soil fertility, Fodder; square root of average score for leaf nutritional value for cattle, economic; log of average score of economic value of trees, PH; maximum plant height, Chl; log of leaf chlorophyll content, LT; log of leaf thickness, LA; log of leaf area, SLA; log of specific leaf area, LDMC; leaf dry matter content, TDMC; twig dry matter content, WD; wood density, LD; leaf density, SM; log of seed mass, S; spinescense, LP; deciduousness, LC; leaf compoundness.

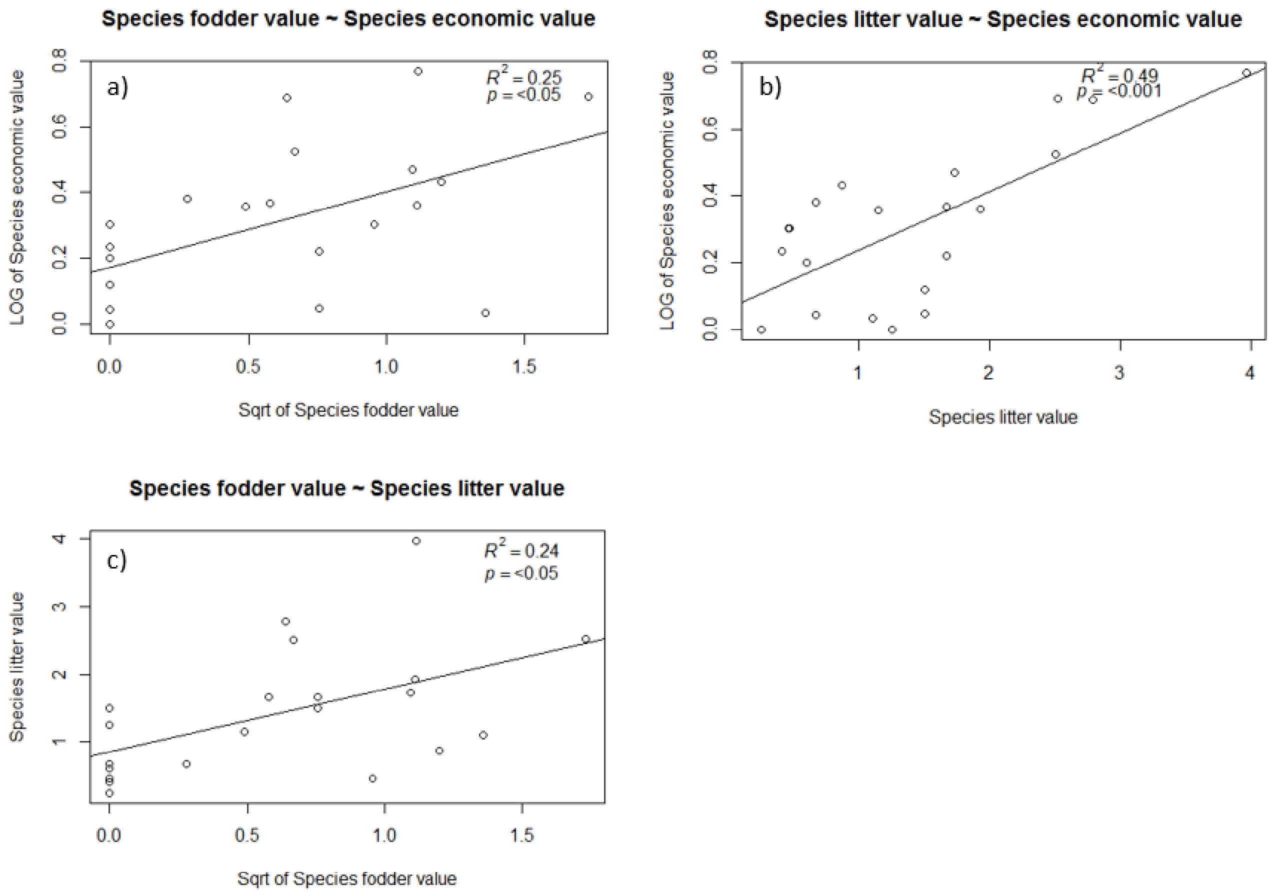

Figure 19, relationship between farmers species values and functional trait values. Linear regressions between the species average attribute score and trait values. a) Positive linear relationship between tree species economic value and tree species fodder nutritional value for cattle, b) Positive linear relationship between tree species economic value and tree species litter contribution to soil fertility, and c) positive linear relationship between tree species litter contribution to soil fertility and tree species fodder nutritional value for cattle. Graphs show the adj. r2 and p significance of linearity.