MSc Thesis

The benefits of woody species for soil quality restoration in farmer fields in West Africa

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940516080010

January 2019

Chair Group:
Forest Ecology and Management

Course Code:
FEM-80436

Supervisors (WUR):
Dr. Madelon Lohbeck
Prof. dr. Frans Bongers

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

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ACKNOWLEDGEMENTS

I would first like to thank my thesis supervisor dr. Madelon Lohbeck of the department of Forest Ecology and Forest Management at Wageningen University and Research, for her patient guidance and useful and constructive feedbacks for this research work. She has been available whenever I had questions about my study or writing.
I would like to thank my second supervisor prof. dr. Frans Bongers of the department of Forest Ecology and Forest Management at Wageningen University and Research, for his valuable comments and support through the writing of this research.
I would also like to thank dr. Emilie Smith-Dumont of The World Agroforestry Center, for welcoming us on our study sites and introducing us to her precious contacts in Burkina Faso. The fieldwork would not have been possible without the tree knowledge and valuable relations with the local farmers of Kipsa Roger Guibre and Salif Kinda. It is thanks to their passionate participation during the data collection that I could carry out this research.
I am grateful to my fellow students, Peggy Albers and Samuel Morel for their close collaboration while working on this thesis.
I would also like to extend my thanks to all the Burkinabe farmers that took part in the interviews and enabled the completion of this study; Aminata Saga, Amadou Bilgo, Pascaline Zoungrana, Mariame Zoungrana, Salamata Bilgo, Saïdou Ouedraogo, Issaka Compaoré, Moussa Tondé, Ami Nikiema, Salamata Simpore, Issaka Bilgo, Etienne Compaoré, Sayouba Zoundi, Oumarou Zoundi, Adjara Compaoré, Alimata Compaoré, Salamata Ouédraogo, Boukaré Zoundi, Issaka Zoundi, Bassibri Zoundi, Amidou Sedeogo, Salamata Ouedraogo, Koudpiga Ouédraogo, Zéma Oueraogo, Maymoma Regtounda, Arigueta Congo, Boukary Sedeogo, Saïdou Tienbego, Moussa Nikiema, Ousmane Tiendrebego, Asseto Dipama, Nana Isseta, Moumouni Sergo, Ousmane Zoungrana, Aminata Ouanga and Salamata Congo.
Finally, I wish to thank my parents for providing me with unfailing support through all my years of study ending with the writing of this thesis and my friends for their priceless encouragements.
Eventually, I would like to thank the different projects and organizations that provided financial support for the completion of this study: 1. Madelon Lohbeck was supported by research programme ALW (863.15.017), financed by the Netherlands Organisation for Scientific Research (NWO), 2. Frans Bongers was supported by 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. financial support was provided by 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), Ouagadougou, Burkina Faso.

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ABSTRACT

Land management has great impact on future food security. Agroforestry, and specifically, the practice of Farmer Managed Natural Regeneration (FMNR), is a way of restorative agriculture for the smallholder farmers in Africa. Trees diversity in West African parklands play an important role on soil health of farmer fields and livelihoods. The objective of this research is to assess how tree diversity on farmer fields influences soil health, as well as to assess how farmers' preferences for certain ecosystem services affect species diversity on the fields. Furthermore, it is determined if the naturally regenerating trees are representative of the standing vegetation.

Data was collected in both Burkina Faso and Ghana. Data from the Land Degradation Surveillance Framework (LDSF) was used, as well as functional traits measurements from focal species of the region and species ecosystem services scoring interviews were carried out with 76 farmers.

Mixed models were used to assess if soil texture, vegetation structure, land management and tree functional properties (community-weighted means and functional diversity) influence soil health (soil organic carbon (SOC), soil nitrogen content (SNC), water infiltration capacity (WIC) and erosion (ER)). In addition, during the interviews, species were scored according to relative contributions to important ecosystem services; economic value, fodder nutritional value for cattle and leaf litter contribution to soil fertility value. An average species score for each service was calculated, across the 76 interviews. Furthermore, based on the woody species inventories made in the farmer fields, an average field score per service was calculated by multiplying the species abundance by the species score per ecosystem service.

Results of the study found that it is mainly soil texture, vegetation structure and land management that exerted a significant influence over soil health. Tree diversity, through the functional properties of the tree communities, had less influence than expected. Also, there is more species diversity in the regeneration community than in the adult community. Farmers tend to select and manage seedlings of species with economic value and weed out species with only high litter value. However, no trade-off between the provisioning services and regulating services were observed at species nor field level. Farmers select multifunctional species on their fields, like the shea tree (*Vitellaria paradoxa*), which has a high economic value but also has high value for soil fertility due to the quality of its litter.

The farmers land and tree management play an essential role in the future of agricultural land in West Africa. Through Farmer Managed Natural Regeneration, smallholder farmers can influence the diversity and density of trees on their fields and manage their land to improve their soil health. There is diversity in the growing natural regeneration, but there are limitations in species of interest that become little present. Farmers value trees, and have a lot of knowledge regarding their uses, but often lack formation on the management of trees and seedlings for sustainable use. This study recommends that FMNR trainings should be supported through the parklands to preserve and increase the present tree diversity.

Keywords : West Africa, Farmer Managed Natural Regeneration, soil quality, ecosystem services

1. Introduction

Land management has great impact on future food security, especially in this sensitive period of climate change (Reij et al, 2009). In Africa, due to the extreme environmental conditions and lack of resources to adapt to climate change, tropical agriculture of smallholder farmers on degraded soils is in increasingly vulnerable position (Verchot et al, 2007).

The integration of tree species into food crop systems has the advantage to maintain a green vegetative cover on the land. Farming with trees has the potential to restore exhausted soils (Garrity et al, 2010). Because local communities need to continue producing food, agroforestry has the potential to be an effective and sustainable way of restorative agriculture (Reij et al, 2009), if appropriate tree species are selected and managed on the field. Agroforestry parklands are traditional land-use systems of intercropping crops with native trees that provide them with supplementary services, and the practice of farming in parkland is a predominant system in West Africa (Nair, 1993; Boffa, 1999). Woody vegetation provides many regulating and provisioning ecosystem services, and different tree species have different benefits at ecological and social level. Indeed, having trees and shrubs on agricultural land has many advantages such as reducing erosion, diminishing water evaporation, facilitating water infiltration and providing the soil with nutrients leading to higher soil fertility. In addition to those regulating services, they also provide the farmers with food, fodder for livestock, as well as fruits, firewood and medicinal products that can either be used for own consumption or cash sales (Chazdon, 2008; Gamfeldt et al, 2013). Nonetheless, tree density of many African countries decreases every year. For example, in Burkina Faso, since only 1990, the percentage of forest area has declined from 25% to 19,5%, while the land devoted to agriculture has increased from 35% to 45% (The World Bank Data). While woody biodiversity and cover gets lost, soil structure and fertility decline too due to exhaustive cropping practices leading to land degradation (Nyberg et al, 2012; Islam & Weil, 2000; Oldeman et al, 1991)

This research is part of the West Africa Forest-Farm Interface Project (WAFFI). It focusses on bringing evidence on the adoption and benefits of farmer-managed natural regeneration (FMNR) applied in Burkina Faso and Ghana, particularly focusing on the benefits for restoring farmland productivity and safeguarding food security. FMNR is a low-cost technique, where no planting is required, to increase local tree density for improving environmental conditions on agricultural lands. Farmers select the trees and shrubs they allow to regenerate naturally on their fields and start managing them through for example pruning (at individual level) and thinning (at population level) (Larwanou et al, 2006; Rinaudo, 2007; WRI, 2008). For FMNR to be practiced nonetheless, natural regeneration of woody species must take place.

To mitigate land degradation there is a need for restoration. A healthy soil forms the basis of farming systems. Soil quality is "the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation" (Karlen et al., 1997). Some agricultural practices based on ecological intensification can improve soil properties (Faucon et al, 2017). This study focusses on soil quality and fertility. The response variables considered in the measurements of soil health are soil organic carbon (SOC), the soil nitrogen content (SNC), water infiltration capacity (WIC) and erosion (ER). An increase in SOC, SNC and WIC positively influences soil health, while an increase in erosion is negatively related to soil health. Other variables, which will influence it, such as soil texture, soil conservation structures, vegetation structure, land management and functional properties are looked at. Intercropping crops with trees or/and shrubs provides a permanent vegetation cover, which may stabilize the soil structure, reduce erosion, and increase the organic matter of the soil (WRI, 2008). This improves soil health by increasing its fertility and raising its moisture retention. It is believed that a healthy soil needs proper land as well as tree management. This is why the impact of various tree and land management techniques such as tree cutting, collecting, agriculture, fire or even grazing are also tested against the soil health. A diversity of tree is economically beneficial for farmers as it provides different products at different periods of the year, and it is also believed to be beneficial for the soil health if the proper species are part of the diversity. Improving the soil quality would increase crop yields and ultimately also the household food security (Yamba & Sambo, 2012).

Research has shown that the tree-soil-crop interaction can be negative, neutral or positive depending on the tree species and crops (Bazié et al, 2012; Sinare & Gordon, 2015). Hence, appropriate tree species must regenerate on the field and must be selected and managed by the farmers to promote soil restoration and optimal growing conditions for the crops. This research focusses on the plant-soil interaction. The functional traits of the woody species will be measured and related to soil properties to assess to what extent seedlings and adults of trees and shrubs on farmer fields affect the soil health. Functional traits are the characteristics of a species and its interaction with their ecosystem (Funk et al., 2017). For example, a species with high leaf dry matter content (LDMC) will decompose slowly but provide mulching for the soil, protecting it from direct exposure and erosion. Species that can fix nitrogen bring additional nutrients to the soil, etc. Plant functional traits are easily measurable indicators of a species ecological contribution to the ecosystem functions. According to a study carried by Faucon *et al* (2017), plant functional traits have regulating effects on soil properties through nutrient cycling, or erosion resistance. Functional traits can be divided into response traits and effect traits. While response traits are about how species respond to the environment, effect traits are about the effect that species can have on their environment (Lavorel & Garnier, 2002). This study focusses on the effect of traits, of Burkinabe and Ghanaian tree species, on soil health. Effect traits of dominant tree species in landscapes influence interactions with the soil and fields productivity (De Deyn et al, 2008). Table 1 summarizes the traits that are included in the research and how they are hypothesized to affect soil properties. After assessment of the species functional traits, the community functional properties are calculated (community weighted mean and functional diversity) and their effect is tested against soil quality parameters (SOC, SNC, WIC and ER).

Table 1: List of measured functional traits with their abbreviations, full name, unit of measurement, acquisitive (A) or conservative (C) strategy and positive effects on soil health. A higher value of the trait relates either to a higher (+) or lower (-) process towards soil health.

Traits abbreviation	Functional traits	Unit	Strategy	Effect on soil health
LA	Leaf area	mm^2	A	Quantity of leaf biomass (+)
SLA	Specific leaf area	mm^2/mg	A	Decomposition rate (+)
LDMC	Leaf dry matter content	mg/g	C	Decomposition rate (-), Mulching (+)
LT	Leaf thickness	mm	C	Quantity of leaf biomass (+), Decomposition rate (-), Mulching (+)
Chl	Chlorophyll content	SPAD-units	A	Nutrient concentration (+)
LP	Leaf phenology deciduous	0/1	C	Litter production (+) Mulching (+)
WD	Wood density	mg/mm^3	C	Decomposition rate (-), Mulching (+)
TDMC	Twig dry matter content	mg/g	C	Decomposition rate (-), mulching (+)
BNF	N-fixing	0/1	A	Fixation of N from the air to the soil (+)

Scientific knowledge on the effect woody species within the practice of FMNR on the soil quality of farmer fields in West Africa is currently lacking. This study evaluates how the soil texture, the vegetation structure, the land management and the functional properties of trees influence the soil health. The objective of this research is to assess the ecological benefits of the tree communities on soil quality. Eventually this study assesses which tree ecosystem services farmers prioritize to select species on their fields. Farmers are the key stakeholders in the adoption of the FMNR practice. They are the actor managing and protecting the natural regeneration of particular species on their lands. It is determined if the naturally regenerating trees are representative of the standing vegetation. The regeneration community enables to predict the potential services the farmer may receive from future trees on his field through managing todays seedlings. Through this research, I hope to provide evidence to support and scale up the adoption of FMNR practices as a restoration technique on the degraded parklands.

1. How does soil texture, vegetation structure, land management and functional properties of trees influence soil health?

I hypothesize that soil texture, vegetation structure, management and functional composition of trees increase or decrease soil health (soil organic carbon, soil nitrogen content, water infiltration capacity and decreases erosion) as specified in table 2.

Table 2: The expected influence of variables (soil texture, vegetation structure, land management and functional properties of trees) on soil health

Variables	Soil health
Soil texture (sand content)	-
Vegetation structure complexity	+
Management	
- Tree cutting	-
- Agriculture	+
- Grazing	-
- Fire	-
- Firewood collection	-
Functional properties of trees	
- Chl CWM	+
- LA CWM	+
- SLA CWM	+
- LDMC CWM	+/-
- TDMC	+/-
- LP CWM	+
- WD CWM	+/-
- BNFCWM	+
- Functional diversity	+

2. How do farmers' preferences for certain ecosystem services affect the woody species community on the fields?

I hypothesize that farmers select trees on their field with higher provisioning services than regulating services. I expect a trade-off on farmer fields between species with high economic and fodder nutritional value and species with high litter contribution value, as well as farmers to have a higher abundance of trees with high provisioning services and low regulating services on their fields

2. Material and Methods

2.1 Study sites

The research was carried in two West African parklands sites, one in central Burkina Faso and one in Upper East Ghana. The two sites are 76,6 km apart (Figure 1).

The Burkinabe site is located around Seloghin, located 100 km south-eastern of the capital Ouagadougou. This southern part of Burkina Faso has a tropical savannah climate (Peel et al, 2007). The mean annual temperature is about 27.8°C. There is one rainy season that stretches from April to October. The mean annual precipitation is around 848mm/year (climate-data.org). The rest of the year is the dry season. Burkina Faso has a relatively flat topography with an average altitude of 400m. The soils have sandy clay textures with low nutrient contents (Jonsson et al., 1999).

The Ghanaian site is located around Navrongo, in Upper East Ghana. The land is also relatively flat. The climate is identical, with rainy summers from April to November and dry winters the rest of the year (Government of Ghana). The average yearly temperature is 28.1°C. The mean annual precipitation is around 940mm/year (climate-data.org). The soils of the region are mainly developed from granite rocks and have low fertility (Government of Ghana).

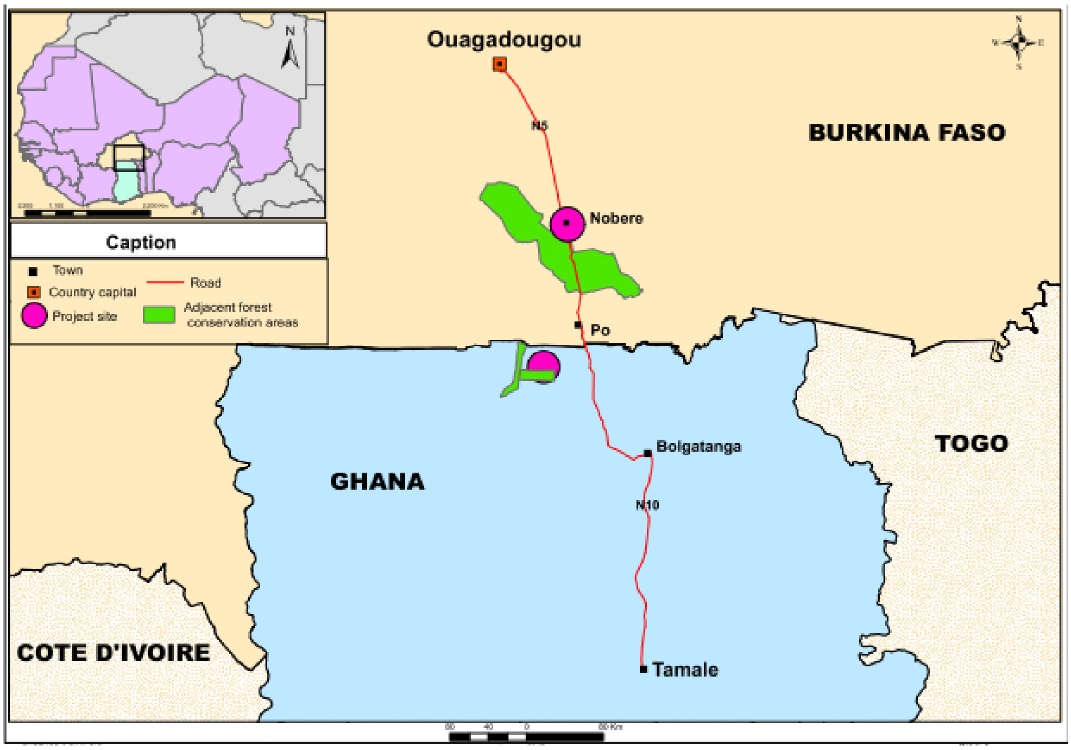

Figure 1: Study sites location in Nobere (Burkina Faso) and Navrongo (Ghana). Both project sites are marked with a pink circle (CIFOR, 2017).

Agroforestry parklands systems are a common land use in both regions, where varieties of trees and shrubs are mixed on land with crops. Most inhabitants rely on subsistence farming, depending on farm products and services provided by trees on the farm. Annual crops such as cotton, sorghum, maize, rice and sesame are cultivated among the scattered trees and shrubs. Some farmers are owners of their field, while others lend it from the chief village.

2.2 The Land Degradation Surveillance Framework and Inventory

A land degradation surveillance framework (LDSF) was carried out in the study sites of Seloghin, Burkina Faso, and Kayoro, Ghana in March 2017. The LDSF is a 100 km^2 (10km by 10km) landscape. It enables to evaluate the land degradation processes and assess the soil and ecosystem health. There are 16 clusters in each site. Each cluster counts 10 plots. This accounts to a total of 320 plots for the study. No convenience sampling occurs due to the randomization of the clusters' centre-points and the plots in the clusters. A plot area is 1000m^2 with four subplots of 100m^2 (Vagen et al, 2015).

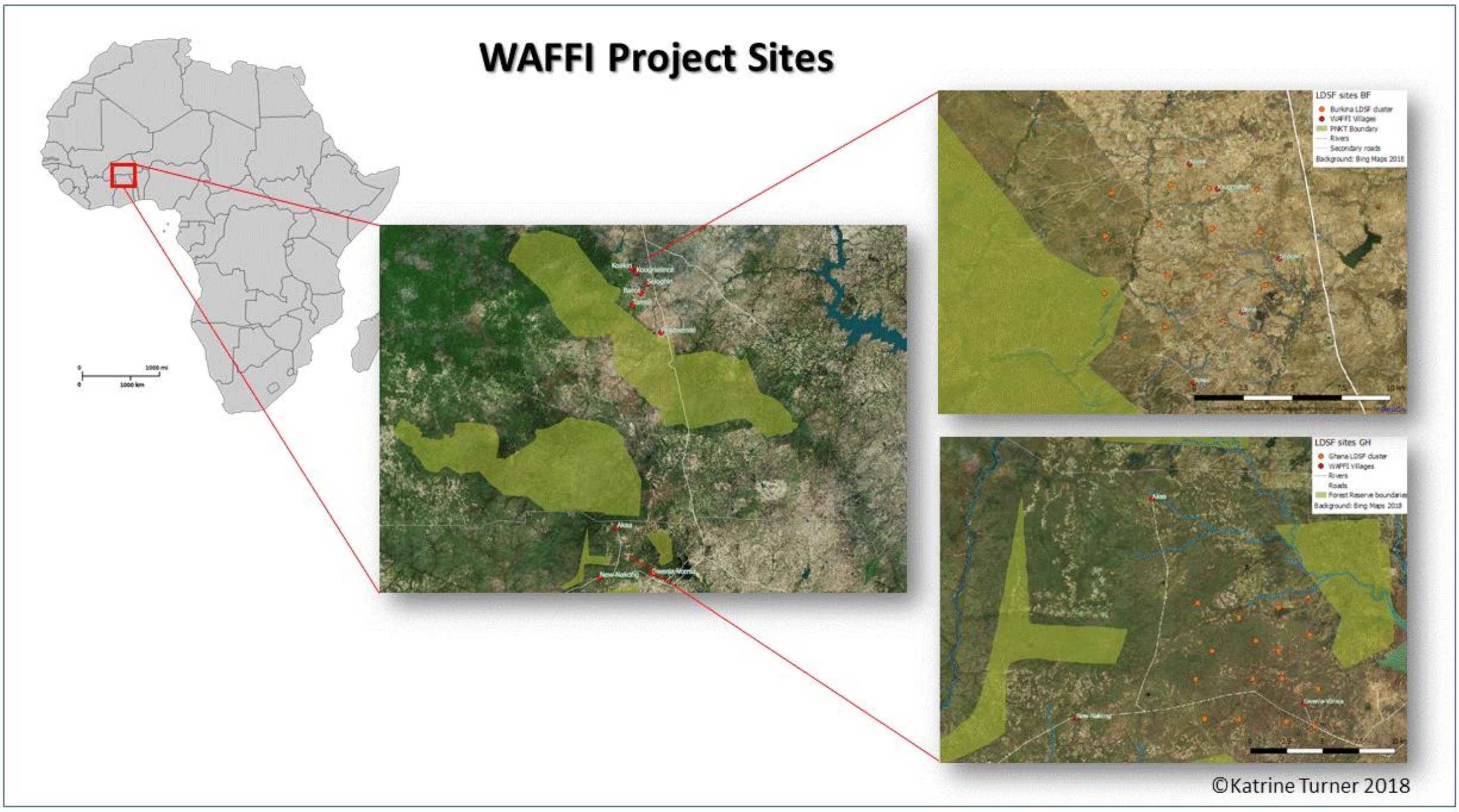

Figure 2: Location of the WAFFI project sites with the LDSF clusters' layout in the landscape (Turner, 2018).

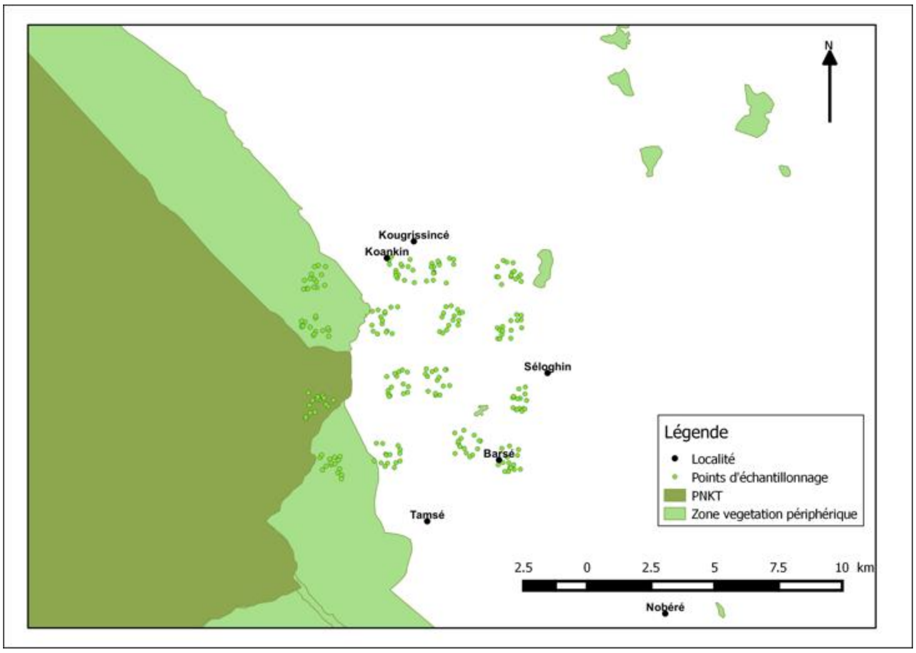

Figure 3: Burkina Faso LDSF layout zoom in of the 10 plots distribution within the 16 clusters distribution.

Soil parameters were recorded at plot and subplot level. Regarding characteristics of the soil surface, signs of erosion prevalence were scored, and the soil cover (woody, herbaceous, rock/stone) was registered. The presence and type of soil conservation structures (none, structural, vegetative) were monitored. Eventually samples from the topsoil (0-20cm) and subsoil (20-50cm) were taken, providing data on the soil depth and texture and the infiltration capacity of the soil was measured using a single-ring infiltration test.

In addition, at the same time and location as the LDSF, an extensive vegetation inventory was made. Adult trees (DBH above 5 cm) were inventoried at the same plot level as the LDSF, and the tree regeneration (DBH of 5 cm or below) only at one smaller central subplot of 20 m^2 (appendix 1). The information on the vegetation included the trees and regeneration species, abundance, health status, height, and DBH (for the adult trees).

In this study, the LDSF and inventory data of 2017 are used to determine the woody vegetation (adults and regeneration) abundance and diversity per plot. SOC, SNC, WIC and ER are used as indicators of soil health. For the SOC and SNC variable we used the carbon content and nitrogen content measured in the top soil, as the study is interested in the benefits of trees on soil on farmers field for the crops and crops are thought to mainly draw nutrients from the top soil. Also, it is thought that the influence of trees on soil organic matter through decomposition of residues, wood and leaves would be more prevalent and direct in the topsoil (Campbell et al., 1994). The carbon and nitrogen analyses were conducted at ICRAF using dry combustion (Winowiecki et al, 2014). The SOC and SNC values were predicted through mid-infrared spectroscopy of all top soil samples collected in each plot (Winowiecki et al, 2016). For the WIC variable, during the LDSF the infiltration rate was measured on a plot for 150 minutes. The WIC was measured on fewer plots (48 out of 160 plots), and only the data measured in Burkina Faso could be used. As the soil becomes saturated over time, the infiltration rate decreases and tends to asymptotically approach the soil infiltration saturation. Consequently, we calculated those asymptotes and used their values for the WIC. For the ER, the signs of visible erosion were recorded at the subplot level. We made the variable binary (0/1), with 0 being the plot not eroded and 1 being plot severely eroded, when two or more of the four subplots were eroded (Lohbeck et al, 2018).

Then, the vegetation structure was categorized as follows: 1=cropland, 2=grassland, 3=shrubland/bushland, 4=wooded grassland, 5=woodland/forest. This ordering is an adapted classification for this study based on the LDSF simplified version of the FAO Land Cover Classification System (LCCS), vegetation classification of White (1983) and impact on habitat from the Royal Botanic Gardens (Vagen et al, 2015). When it comes to the soil conservation structures they were ordered as: 0=none, 1=vegetative structure, such as strips of trees and/or grasses, 2=structural structure, such as terraces or bunds. Finally, the management impacts were scored from 0 to 3 with 0 being no impact on the habitat and 3 being an important impact on the habitat.

All the variables soil texture (soil sand content), vegetation structure, soil conservation structures, impact of management (tree cutting, agriculture, grazing, fire and firewood collection) are used to explain soil quality (SOC, SNC, ER, WIC) across the plots.

2.3 Functional Traits

2.3.1 Focal species selection and sampling

The selection of the focal species representing the community of Burkina Faso and Ghana was done by selecting species for the adults that together cover at least 80% of the basal area of the adult tree communities, and the regeneration that together cover at least 80% of the abundance of the seedling communities (appendix 2). Secondly, species that had an abundance lower than 4 (adult trees and regeneration) in both countries were excluded, as well as *Tectona grandis* that is only present in monoculture plantations and does not regenerate naturally on farmer fields, which is the focus of this study. This process resulted in a list of 44 focal species for which functional trait measurements were taken (appendix 3).

The traits were measured on five individuals per species. The individuals were not imperatively inside the plots but rather selected at random from different sites across habitat range where they could be found (Perez-Harguindeguy et al, 2013). The traits were measured on 195 adult trees or shrubs in southern Burkina Faso, and 25 individuals were measured in Upper East Ghana.

2.3.2 Traits Measurements

The functional traits measurements can be applied on both sites. Functional traits measurements were done using standard protocols (appendix 4) (Cornelissen et al, 2003; Perez-Harguindeguy et al, 2013). Functional traits were selected based on relevance to soil health (see table 1).

For each individual tree, four leaves were selected. As leaf traits may vary within individual plants (plasticity), this number of replicates is required to obtain an accurate indication (Perez-Harguindeguy, 2013). The selected leaves were relatively young, fully expanded and without visible signs of damage. The leaves were taken from the outer canopy where they had sun exposure. For species with simple leaves, the individual leaf lamina was measured. When it comes to compound leaves, the whole leaf area was measured when the size of the leaflets allowed, however when they were too small and numerous an approximation was made; ten leaflets were selected, and the weight and area where then divided by ten and multiplied by the total number of leaflets that were counted. The petiole and rachis were included in leaf trait measurements. In the field the chlorophyll measurement was taken on the leaves using a SPAD. Then, three terminal sun-exposed twigs of 20 to 30 cm long were cut from the tree and stored into a coded plastic bag to protect the twigs and leaves from dehydration.

Once back at field base the twigs, still with the leaves, were cut at the bottom to remain approximately 20 cm long and placed in a bucket in the dark to rehydrate for a minimum of one hour. The fresh leaves and twigs were first weighted on an accurate balance (TM electronic scale). Then, the leaf thickness was measured with a digital calliper in the middle of the leaf on the blade. Next, a photograph of the leaf was taken on a white surface next to a ruler, after which leaf area was calculated with the pixel counting software

ImageJ (Schneider, Rasband & Eliceiri, 2012). Afterwards the four leaves and three twigs were stored in a coded envelope and hang on a line to dry in a well-ventilated room until constant weight (between 1 and 4 weeks). After this the dry weight of the leaf and twig samples was measured on the balance.

Based on the above measurements, the following functional traits were derived:

- The relative leaf chlorophyll content (Chl) indicates the light capture efficiency and nutrient concentration of leaves, especially N (Rozendaal et al. 2006). The nutrient concentration of leaves is an important factor to consider as it brings nutrient to the soil through its cycle. A high N concentration in leaves means they are more nutritious, which will also make the soil more fertile.
- The leaf thickness (LT) (mm) indicates how thick a leaf is. A thicker leaf will decompose more slowly but will provide mulching.
- The leaf area (LA) is the one-sided area of a leaf (mm^2). The leaf size provides information about the quantity of leaf biomass. A larger leaf brings more nutrients and protect the soil.
- The specific leaf area (SLA) is a key leaf characteristic in the study of traits. In order to measure the SLA, the leaf area (mm^2) is divided by the leaf's dry mass (mg). The SLA amount indicates the decomposition rate of the leaves, as well as their net mineralisation (Lohbeck et al, 2012).
- The leaf dry matter content (LDMC) gives information on the structure of the leaf tissue. The leaf's dry mass (mg) is divided by its fresh mass (g). The amount of dry matter content indicates the decomposition rate of the leaves. So a leave with more dry mass will have a slower decomposition rate. (Lohbeck et al, 2012). A higher leaf tissue leads to slower decomposition. Leaves with lower LDMC bring quickly nutrients to the soil, while those with higher LDMC provide mulching. The LDMC therefor influences the litter quality, which improves the soil's health.
- The twig dry matter content (TDMC) is complementary to the literature research of wood density. The results provide information on the species wood, and the trait was measured in the field. The TDMC (mg/g) is the oven-dry mass of a terminal twig, divided by its water-saturated fresh mass (Pérez-Harguindeguy et al., 2013).

Additional functional traits were derived from the literature and local knowledge:

- The leaf phenology (LP), also known as deciduousness (De), is the ability (binary 0/1) of a plant species to lose its leaves for a period of time during the year (Cornelissen et al, 2003). Defoliating trees bring nutrients back to the soil, enhancing its fertility. Deciduous trees increase nutrient cycling (Ambus & Zechmeister-Boltenstern, 2007). This information was retrieved from the research carried by Seghieri, Do, Devineau, & Fournier (2012) on the phenology of woody species in West tropical Africa as phenology varies according to the region. The global leaf phenology database from Zanne et al. (2009; 2013) was used to complete the missing species. In addition, the information collected on the 22 species used in the interviews was correlated with the literature research. If farmers have different answers, we took the majority score.

- The wood density (WD) gives information on the accumulation of standing biomass (Lohbeck et al, 2012). It is the oven-dry mass of a section of the main stem of a plant divided by the volume of the same section, when still fresh (mg/mm^3) (Cornelissen et al., 2003). In order to avoid damaging the farmers trees, this information is based on the global wood density database from Zanne et al. (2009; 2013). If the species was not part of the database, an average of the WD was taken from the species with the same genus and located in Africa or, if this last one was not available either, from the tropics. Eventually if no species of the same genus was part of the database, an average was taken from the family located in Africa. WD provides information on wood decomposition rate and consequently carbon-cycling effect traits. A high wood density leads to slow wood decomposition, which provides mulching, while lower wood density decomposes faster providing nutrients to the soil.
- Biological N-fixing (BNF) ability (binary 0/1) focuses on the trees having the ability to make nodules and fix nitrogen biologically from the atmosphere (Giller, 2003; Cornelissen et al, 2003)). The N-fixing species bring more nitrogen into the nutrient cycles, and thus into the soil. This information is retrieved from the ICRAF agroforestree (AFT) 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 where genera were categorised as making nodules and not making nodules. The plant genera absent from the databases are considered unable to fix nitrogen.

2.4 Scaling up from species-level functional traits to plot-level Functional Properties

Community-weighted mean (CWM) trait values and functional diversity (FD) were calculated per plot for the overall community in Burkina Faso and Ghana by combining the species contribution per plot (inventory made with LDSF in 2017) with the species traits measurements. The CWM and FD were calculated with the "FD package".

The CWM is a formula that calculates the aggregated trait value, while including the relative contribution of each species to the community (Garnier et al, 2004):

$$\text{trait}_{\text{agg}} = \sum_{i=1}^{n} p_i \times \text{trait}_i$$

In this formula, p_i is the relative contribution of species i to the community, and trait_i is the trait value of species i. The relative contribution of species is the relative basal area for trees and relative abundance for seedlings. With the CWM we can test whether the dominant species of the community affect the ecosystem processes (Damour et al, 2018). With FD we can test whether species functional complementarity affects ecosystem processes (Damour et al, 2018) and ecosystem services (Diaz et al, 2007). The FD can be measured by several indices (Laliberté et al, 2010). For this research the functional dispersion (FDis) was chosen as it had the least missing values (NA) compared to functional evenness (FEve) and functional divergence (FDiv), as well as the strongest effect on the soil variables compared to Rao's quadratic entropy (Rao's Q). FDis makes use of all traits simultaneously. This measure is the mean distance of each individual species to the centroid of all the species of the community, considering the species relative contribution (Laliberté et al, 2010):

$$\text{FDis} = \frac{\sum a_j z_j}{\sum a_j}$$

In this formula, a_j is the contribution of species j and z_j is the distance of species j to the weighted centroid. The relative contribution is the relative abundance for seedlings and relative basal area for adults. This formula requires quantitative traits. This research focusses on how functional diversity contributes to soil health, through different species providing the soil with complementary assistances (cover, nutrients, etc.) Because diverse communities can make optimal use of the resources, they can also increase the ecosystem process rates. This is known as niche complementarity effect (Tilman et al. 1997).

Regarding the CWM, the plots without trees were assigned a missing value (NA). For the functional diversity zeros were added to the plots without trees. This means that both plot with only one tree species and plots with no tree species have a functional diversity of zero.

2.5 Farmers preferences and knowledge of the benefits

2.5.1 Interviews setup

The social part of the study was conducted in villages that are part of the WAFFI project. Three villages within the LDSF study site were selected for Burkina Faso: Barsé, Koankin and Kougrissincé, within the villages the selection criteria of the respondents were based on gender and FMNR training. Four villages closest by the LDSF study site were selected for Ghana: Gwenia, Wombio, Akaa and Adabania. Individual interviews were realized with a total of thirty-six farmers in Burkina Faso and forty in Ghana, accounting to a total of seventy-six farmers. In Burkina Faso, twelve farmers were interviewed per village, from which half were women and half men and for each gender half had received a training and half did not. In Ghana, ten farmers were interviewed per village, the majority of the respondents were men and none of the farmers had received an FMNR training.

At the start of the interview, respondents were shown a list of twenty-two tree species (appendix 5). The aim of the species preselection was to show the farmers species they know best because they are commonly found on the fields and expected to be valuable for the farmers. The preselected species accounted to thirty, thirteen common to both sites, and nine to Burkina Faso and nine to Ghana. In order to make the list, first focal species based on 80% of abundance of regeneration and adult individuals that cover 80% of basal area across all LDSF plots in Burkina Faso or Ghana were selected. This was based on the inventory made in March 2017. Second, for Burkina Faso, species present only in the Kaboré Tambi National Park (PNKT) and the park buffer zone were excluded, as these are not on the farmer fields. Third, from the remaining species of step one and two, a selection of the highest abundance of trees and regeneration was made to reach a list of the most present species on fields for both different countries. To simplify the process *Combretum* species were merged together because their values to the farmers (economic, litter and fodder) are similar. After discussion with the local interview facilitator and translator the *Acacia* species (*Acacia gourmaensis and Acacia seyal*) were taken out of the preselected species list in Burkina Faso because they have no value to the farmers, who consequently do not keep them in their fields after fallows. Due to a mistake, the *Anogeissus leiocarpus* was not part of the preselected species list.

2.5.2 Survey methodology of ecosystem services scoring

The survey was carried out through individual interviews. It started with gathering general information on the farmer (village, gender, training, field cultivation time). Pictures of the preselected species were presented to the farmer on cards, after which the farmer was asked to select the ones he/she had direct experience with on his/her field. For each of these selected species we asked if he/she chose to keep it on his/her field, and if through FMNR, or if the species was already present on his/her field.

If the number of species selected by the farmer was inferior to ten, all the selected species were included for the scoring. If the farmer species selection exceeded ten species, we chose randomly only ten species among those presents on his field in order to keep the interviews in a reasonable duration. The farmer assigned a score to each tree species based on three ecosystem services (1) economic value, (2) leaf litter contribution to soil fertility, (3) fodder nutritional value for cattle. The score ranged from 0 to 5, with 0 being of no value and 5 being of high value (appendix 8). The scoring allowed to order the species from best to worst according to each of the three ecosystem services per farmer. Farmers were asked to explain each score to make sure the respondents reflected on their personal experience in their local context (such as the availability and abundance on its field). In addition, we asked information regarding the leaf shedding phenology of each species (categorized into early, mid, late or continuous shedders). This information was correlated with the literature research for LP functional trait.

By the end of the interview, the farmer was asked the constraints he/she faced in managing trees on his/her field, and if there would be no constraints, which tree species and how many he/she wished to have.

2.5.3 Inventory on farmer fields

Inventories were made on farmer's field after the interviews to relate the data directly. Following the inventory framework made with the LDSF, the trees abundance was done at plot scale (1000m^2) in the centre of the field. The farmer would accompany and show us where the middle of his fields was. The DBH of each individual was taken. In addition, the regeneration abundance was done at sublot level (20m^2). Three sublots were measured at 8 meters from the centre with their centre-points separated by angles of 120°.

2.6 Data analyses

To evaluate whether tree diversity increases soil health I carried out a series of generalized linear models, in which SOC, SNC, WIC and ER were the response variables, and I analyzed the influence of soil texture, vegetation structure, land management and the functional properties of the communities on soil health across the plots.

SOC, SNC and WIC were $\log_{10}$ transformed to be close to be normally distributed and to be able to use parametric statistical methods (family=gaussian). Erosion is a binary variable (0=no erosion, 1=severely eroded), and therefore nonparametric statistical tests were applied (family=binomial).

Different models were created for each soil variable. Firstly, the models were carried out for Burkina Faso and for Ghana separately to enable comparisons between sites. Secondly site was included as a random factor in the same model through generalized linear mixed models. A general structure of increasingly complex alternative models with the relevant independent variables categories was set up, and a forward selection followed to get the optimal model (table 3). It was decided to retrieve the soil conservation structures from the model general structure because they had no significant influence on any of the soil health variables. The management and functional properties are both independent variables with categories consisting of respectively five and ten variables. Thus, the five types of managements were tested separately in each alternative model, as well as the ten functional properties. This ended up in a total of fifty-seven alternative models per soil variable to obtain its optimal model. Based on the Akaike information criterion (AIC) the model with the best fit was selected for each soil variable. If the lowest AIC had the same value (difference lower than 2) for multiple models, the model with the highest r-square was selected. Statistical tests were carried using statistical program R version 3.3.3 (R core team, 2017).

Table 3: The alternative models tested in the study to explain the soil variables

1. Soil variable ~ (site) + sand content
2. Soil variable ~ (site) + sand content + vegetation structure
3. Soil variable ~ (site) + sand content + vegetation structure + *management**

*a. tree cutting
b. agriculture
c. grazing
d. fire
e. firewood collection

4. Soil variable ~ (site) + sand content + vegetation structure + *management* + *functional properties**

*a. Chl CWM
b. LA CWM
c. SLA CWM
d. LDMC CWM
e. TDMC CWM
f. LP CWM
g. WD CWM
h. BNF CWM
i. Functional Diversity

To test whether farmers select tree species for provisioning services or for regulating services, an average score for each tree species was made per ecosystem service (economic value, fodder nutritional value for cattle, leaf litter contribution to soil fertility) according to the scores attributed to each species by interviewed farmers. Kruskal-Wallis Tests were conducted to examine if there were difference in the scores given by the two countries, by the different villages, by the farmers that received an FMNR training or not and by men or women. Respectively of the different countries, the species scores were subsequently multiplied by the species adult abundance inventoried on each individual farmer field to get a field score per farmer (combining thus the species scores with all the species present on the farmer's field). The same multiplication of the species score by the regeneration abundance was done to evaluate how the future tree composition on the farmer field may provide the farmer and regulate the soil. This resulted in a field score for each ecosystem service per farmer, for the adult trees composition and regeneration composition on his field. Eventually, the species average scores were tested against each other to see if there are trade-offs between ecosystem services at species level, and similarly at field level.

3. Results

3.1 Optimal models for soil variability

In Burkina Faso, the optimal model for soil organic carbon (SOC) includes sand content and vegetation structure. The model explains 56 percent of the variance of the SOC. Sand content is significant and negatively associated with the SOC, while vegetation structure is positively associated.

For Ghana, the optimal model explaining the soil organic carbon is only composed of the sand content. The model explains 59 percent of the SOC variability. Sand content is significant and negatively associated with the SOC.

For both sites combined (site as random factor in the model), sand content, vegetation structure and impact of agriculture are part of the optimal model explaining the soil organic carbon. In contrast to the expectation the functional properties (FD and CWM) of the community had no effect on soil organic carbon. The model explains 59 percent of the SOC variability. Sand content is significant and negatively associated with the SOC vegetation structure and agriculture are significant and positively associated with the SOC (appendix 9).

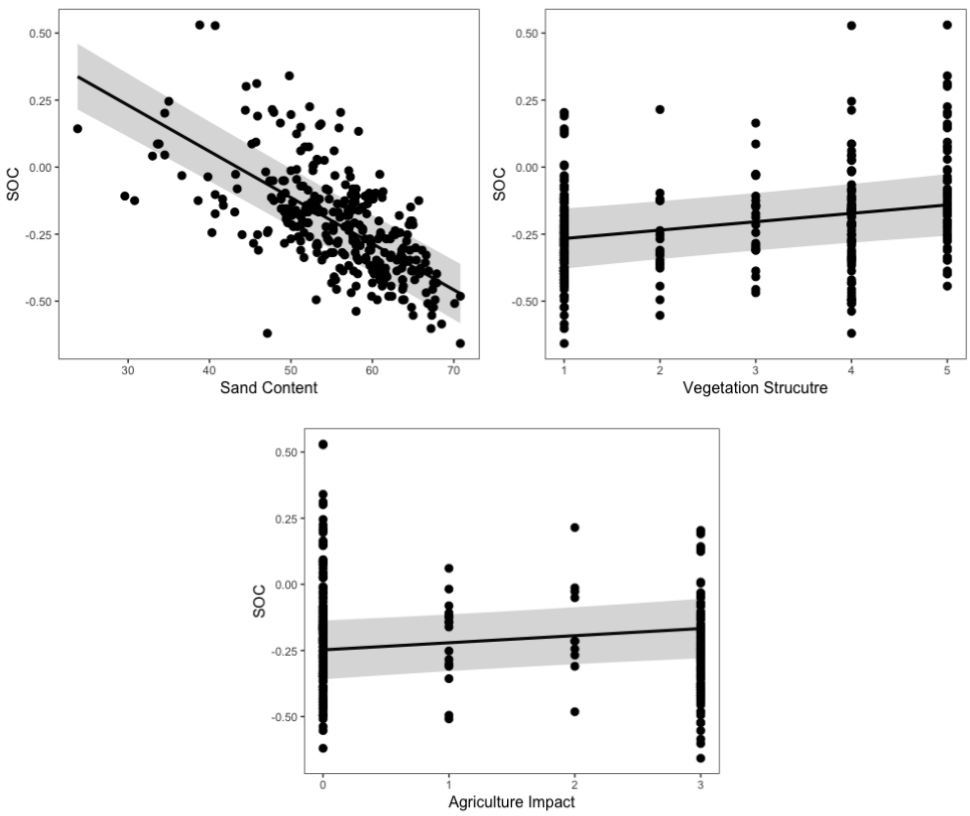

Figure 4: The effect of the optimal model independent variables on SOC in Burkina Faso and Ghana

In Burkina Faso, the optimal model for soil nitrogen content (SNC) includes sand content, vegetation structure, impact of tree cutting and functional diversity. The model explains 50 percent of the variability in SNC. Sand content and vegetation structure are significant and negatively associated with SNC. The other variables, tree cutting and FD, are positively associated with SNC.
In Ghana the optimal model for soil nitrogen content only includes sand content. This is similar to its optimal model for SOC. In addition, the model also explains 59 percent of the variability in SNC and sand content is significant and negatively associated with SNC. When both Burkina Faso and Ghana are analysed together, the optimal model for nitrogen content is similarly to the optimal model of only Ghana. The optimal model is composed of the single sand content variable. Against expectation, the functional properties (FD and CWM) of the community had no effect on nitrogen content. The model explains 56 percent of the variability in SNC and sand content is significant and negatively associated with SNC (appendix 9).

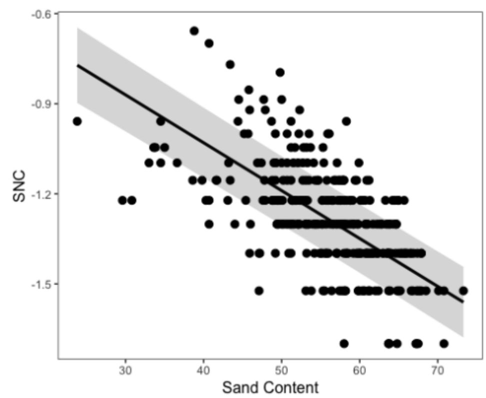

Figure 5: The effect of the optimal model independent variables on SNC in Burkina Faso and Ghana

When it comes to the optimal model for the water infiltration capacity (WIC), sand content, vegetation structure, impact of grazing and SLA CWM have an influence. The optimal model could only be done with data of Burkina Faso. The model explains 51 percent of the variability of WIC. Only SLA CWM is significant in the model, and negatively related with WIC. Sand content, grazing and vegetation structure are positively associated with WIC (appendix 9).

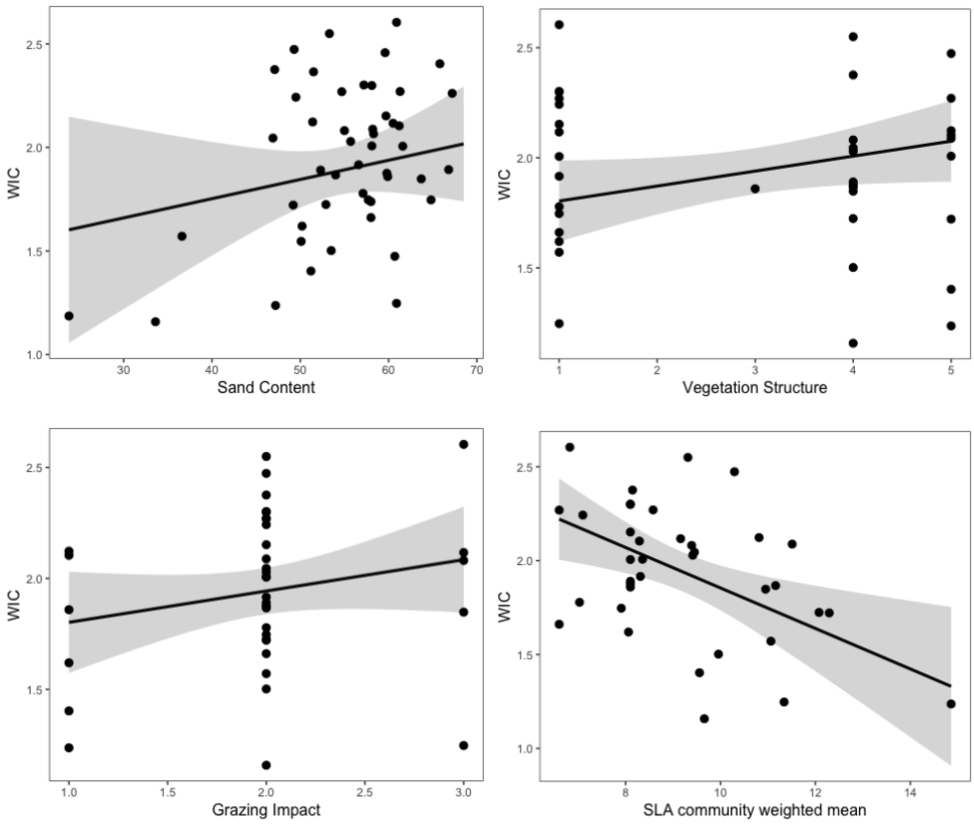

Figure 6: The effect of the optimal model independent variables on WIC in Burkina Faso

Eventually, in Burkina Faso, the optimal model for the erosion (ER) is composed of sand content, vegetation structure, impact of tree cutting and TDMC CWM. The model explains 45 percent of the variance of the ER. Tree cutting is significant and positively associated to ER, and sand content is also positively associated to ER. Vegetation structure and TDMC CWM are negatively associated.

In Ghana, the erosion is according to the optimal model influenced by sand content, vegetation structure, impact of grazing and Chl CWM. The model explains 42 percent of the variance of the ER. Grazing is significant and positively associated with ER, sand content and vegetation structure are also positively related to ER, while Chl CWM has a negative correlation.

When both sites are tested jointly, the optimal model for erosion includes sand content, vegetation structure, impact of grazing and LT CWM. The model explains 40 percent of the variance of the ER. Vegetation structure and grazing are significant and positively related to ER, LT CWM is also positively associated while the sand content is negatively related to ER (appendix 9).

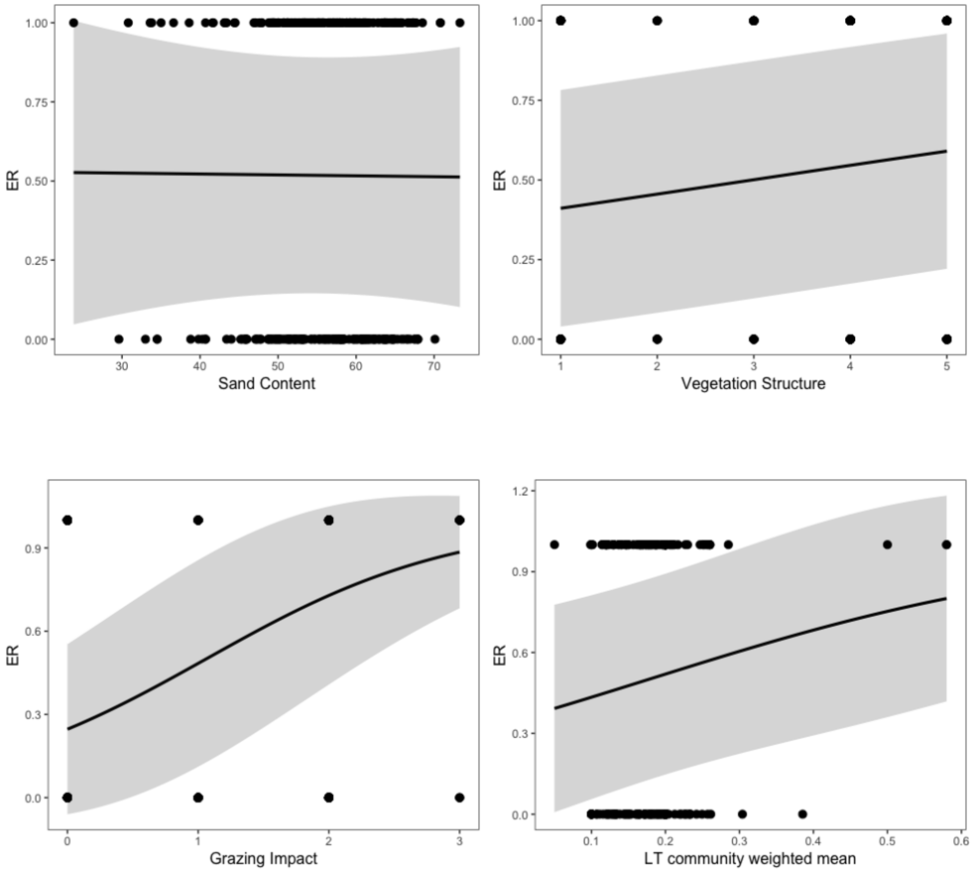

Figure 7: The effect of the optimal model independent variables on ER in Burkina Faso and Ghana

Table 4: Summary of the independent variables included in each optimal model for the four soil health dependent variables, with their significance (Significance codes: ***<0,001, **<0.01, *<0,05) and negative or positive standardized estimate sign between brackets.

Explained Variables	Predictor variables		
	Burkina Faso	**Ghana**	**Burkina Faso & Ghana**
SOC	Sand content*** (-)	Sand content*** (-)	Sand content*** (-)
	Vegetation structure (+)		Vegetation structure** (+)
			Impact of agriculture* (+)
SNC	Sand content*** (-)	Sand content*** (-)	Sand content*** (-)
	Vegetation structure* (-)		
	Impact of tree cutting (+)		
	FD (+)		
WIC	Sand content (+)	Not tested	Not tested
	Vegetation structure (+)		
	Impact of grazing (+)		
	SLA CWM** (-)		

ER	Sand content (+)	Sand content (+)	Sand content (-)
	Vegetation structure (-)	Vegetation structure (+)	Vegetation structure* (+)
	Impact of tree cutting*** (+)	Impact of grazing* (+)	Impact of grazing** (+)
	TDMC CWM (-)	Chl CWM (-)	LT CWM (+)

3.2 Farmer's species knowledge and management

3.2.1 Species' scores per ecosystem service

The farmers scored the species they kept on their field for three ecosystem services (economic value, fodder nutritional value for cattle, leaf litter contribution to soil fertility). Table 5 gives an overview of the species average scores per ecosystem service in Burkina Faso and in Ghana. There is nevertheless quite some difference in the scoring among the farmers as can be observed from the standard deviations (appendix 10). No significant differences in scoring were found among any of the groups and subgroups, which are the Burkinabe and Ghanaian sites, the three Burkinabe communities, the four Ghanaian communities, the Burkinabe farmers with and without training, the Burkinabe farmers gender (appendix 11).

Table 5: The tree species average scores (0-5) per ecosystem service in Burkina Faso and in Ghana.

Species in Burkina Faso	Economic ecosystem service	Fodder ecosystem service	Litter ecosystem service
Afzelia Africana (AAF)	2.17	4.5	0
Annona senegalensis (ASE)	0	0.38	0.25
Balanites aegyptiaca (BAE)	1.25	4.38	0.13
Bombax costatum (BCO)	3.67	3.86	2.71
Combretum species (COM spp)	0	0.50	0.33
Detarium microcarpum (DMI)	1.84	0.04	1.24
Dichrostachys cinerea (DCI)	0	0.33	0
Diospyros mespiliformis (DME)	0.15	0	1.05
Flueggea virosa (FVI)	0.20	0	0
Gardenia erubescens (GER)	0	1.60	0
Guierra senegalensis (GSE)	0	1.25	0.25
Lannea acida (LAC)	0	0	1.40
Lannea microcarpa (LMI)	0.38	0.26	1.59
Mitragyna inermis (MIN)	0	2.33	0
Parkia biglobosa (PBI)	3.88	0.21	1.29
Piliostigma thonningii (PTH)	0.10	3.15	3.75
Pterocarpus erinaceus (PER)	0	5	0
Sclerocarya birrea (SBI)	0.64	1.36	0.27

Strychnos spinosa (SSP)	NA	NA	NA
Tamarindus indica (TIN)	2.95	0	0.53
Terminalia avicennioides (TAV)	0	0.27	2
Vitellaria paradoxa (VPA)	4.85	1.24	4.85
Species in Ghana			
Adansonia digitata (ADI)	3.90	3.00	2.52
Acacia dudgeoni (ADU)	0.08	1.85	1.10
Azadirachta indica (AIN)	1.00	0.92	0.45
Anogeissus leiocarpus (ALE)	1.29	1.23	1.93
Balanites aegyptiaca (BAE)	0.71	0.00	0.40
Burkea africana (BAF)	0.00	0.00	1.25
Bombax costatum (BCO)	1.94	1.20	1.73
Combretum spp (COM spp)	0.11	0.57	1.50
Diospyros mespiliformis (DME)	1.32	0.33	1.67
Detarium microcarpum (DMI)	1.28	0.24	1.14
Daniellia oliveri (DOL)	0.67	0.57	1.67
Gardenia erubecens (GER)	1.41	0.08	0.67
Lannea acida (LAC)	1.00	0.00	0.46
Maytenus senegalensis (MSE)	0.10	0.00	0.67
Parkia biglobosa (PBI)	3.86	0.41	2.79
Piliostigma thonningii (PTH)	0.32	0.00	1.50
Stereospermum kunthianum (SKU)	0.00	0.00	0.25
Strychnos spinosa (SSP)	1.70	1.44	0.87
Terminalia avicennioides (TAV)	0.58	0.00	0.60
Tamarindus indica (TIN)	2.33	0.44	2.50
Vitellaria paradoxa (VPA)	4.88	1.24	3.97

In Burkina Faso, the average scores of each species show that the *Vitellaria paradoxa* (shea tree), has the highest value for the economic ecosystem service (4,85) and litter ecosystem service (4,85). Secondly, for the economic ecosystem service, it is the *Parkia biglobosa* (3,88), with much lower scores for the fodder and litter ecosystem services. Thirdly, the *Bombax costatum* (3,67), which was quite highly scored for the three ecosystem services; fodder ecosystem service (3,86) and litter ecosystem service (2,71).

The species that have the highest value for the fodder ecosystem service, *Pterocarpus erinaceus* (5), *Afzelia Africana* (4,5) and *Balanites aegyptiaca* (4,38), are poorly scored for the two other ecosystem services. The *Piliostigma thonningii* was the second highest score for the litter ecosystem service (3,75), also quite highly scored for the fodder ecosystem service (3,15).

In Ghana, the average scores per species show similarly to Burkina Faso that the *Vitellaria paradoxa*, has the highest score for the economic ecosystem service (4,88) and litter ecosystem service (3,97). Second for the economic ecosystem service, it is the *Adansonia digitata* (3,90), which is also the highest scored for the fodder ecosystem service. Third, the *Parkia biglobosa* (3,86), with much lower scores for the fodder and litter ecosystem services like in Burkina Faso. However, in contrast to Burkina Faso the *Bombax costatum* and *Piliostigma thonningii* are rather poorly scored for the three ecosystem services. Farmers were asked to explain each score to make sure the respondents reflected on their personal experience in their local context (table 6).

Table 6: Farmers' personal experience with the most valued tree species, according to the scores given for the economic ecosystem service, fodder ecosystem service and litter ecosystem service in Burkina Faso and Ghana.

Valued species	Economic ecosystem service	Fodder ecosystem service	Litter ecosystem service
Vitellaria paradoxa	**Burkina Faso & Ghana** - High demand for products, particularly the nuts - Variety of uses of products - High price for products	**Burkina Faso & Ghana** - Young leaves only, during hunger gap	**Burkina Faso & Ghana** - Leaves are thick, broad and nutrient rich - Slow decomposition. Farmers create mounds covering the leaves for faster decomposition - Some farmers make compost with leaves
Piliostigma thonningii	**Burkina Faso & Ghana** - Almost none - Some farmers sell green manure made from the fruit	**Burkina Faso** - Young leaves - Fruit, very nutritious	**Burkina Faso** - Leaves are thick, broad, heavy and nutrient rich -Higher nutrient content than *Vitellaria paradoxa* - Slow decomposition. Farmers create mounds covering the leaves for faster decomposition
		Ghana - Young leaves	**Ghana** - None
Bombax costatum	**Burkina Faso** - High demand for products - Flowers can be dried and sold during hunger gap - High price for products because species only present in South and West of country	**Burkina Faso** - Young and old leaves, very nutritious and appreciated by livestock - present during hunger gap, creating high demand	**Burkina Faso & Ghana** - Leaves are broad but light, decompose fast - Depending on farmers experience, low or high nutrient content. If taken into mounds great contribution, otherwise blown away by wind
	Ghana - Flowers are sold by some farmers but for lower price than in Burkina Faso because more common in country	**Ghana** - Flowers, in low abundance - Leaves are not very appreciated by livestock	

Adansonia digitata	**Ghana** - High demand for multiple products	**Ghana** **-** Young and old leaves, very nutritious and appreciated by livestock - Fruit, very nutritious	**Ghana** **-** Leaves decompose fast and nutrient rich
Parkia biglobosa	**Burkina Faso & Ghana** - High demand for multiple products ***- Particularity in Burkina Faso:*** *Tree sometimes belongs to village chief, rather than to farmer*		**Burkina Faso & Ghana** - Leaves are nutrient rich but small and light - Depending on farmers experience, low or high nutrient content. If taken into mounds great contribution, otherwise blown away by wind
Tamarindus indica	**Burkina Faso & Ghana** - High demand for multiple products - Low price because of abundance of products		**Burkina Faso** - Almost none. All leaves collected for human consumption
			Ghana - Leaves decompose fast but tiny and light. If taken into mounds great contribution, otherwise blown away by wind
Pterocarpus erinaceus		**Burkina Faso** - Young and old leaves, very nutritious and appreciated by livestock	
Afzelia Africana	**Burkina Faso** - Leaves are sold for good price	**Burkina Faso** - Young and old leaves, very nutritious and appreciated by livestock	
Mitragyna inermis		**Burkina Faso** -Young and old leaves, nutritious and available during hunger gap	
Balanites aegyptiaca	**Burkina Faso** - Leaves are part of the human diet	**Burkina Faso** - Young and old leaves, nutritious	
	Ghana - None	**Ghana** - None	**Ghana** - None
Terminalia avicennioides			**Burkina Faso** - Leaves are large, thick and heavy, but decompose slowly if they are not taken into mounds. Keep soil moisture.
			Ghana - None, unless leaves are burned

3.2.2 Field scores per ecosystem service

According to the species scores per ecosystem service, field scores were calculated for each ecosystem service by multiplying species scores with their abundance in the field. In Burkina Faso, the adult tree compositions tend to have higher or equal field score for the litter ecosystem service and for the economic ecosystem service, compared to the field score for the fodder ecosystem service, which is much lower. In contrast, in the regeneration compositions the field score for the economic ecosystem service is lower. It is again the litter ecosystem service that is the highest scored, followed by the fodder ecosystem service (figure 8). The Burkinabe farmers have thus a higher field score in average for the litter ecosystem service in the adult and regeneration composition. The most abundant species, influencing the most the field scores, are the *Vitellaria paradoxa, Terminalia avicennioides*, *Piliostigma thonningii*, *Combretum species*, as well as *Detarium microcarpum and Annona senegalensis* (appendix 7).

In Ghana, the adult tree compositions tend to have higher field scores for the economic ecosystem service, followed by the litter ecosystem service. The field score for the fodder ecosystem service is again much lower. In contrast, in the regeneration compositions the field score for the economic ecosystem service is almost equal to the litter ecosystem service, followed by the fodder ecosystem service (figure 8). The Ghanaian farmers have thus a higher field score average for the economic ecosystem service in the adult and regeneration composition than in Burkina Faso. The most abundant species, influencing the most the field scores, is the *Vitellaria paradoxa,* as well as the *Stereospermum kunthianum* for the regeneration (appendix 7).

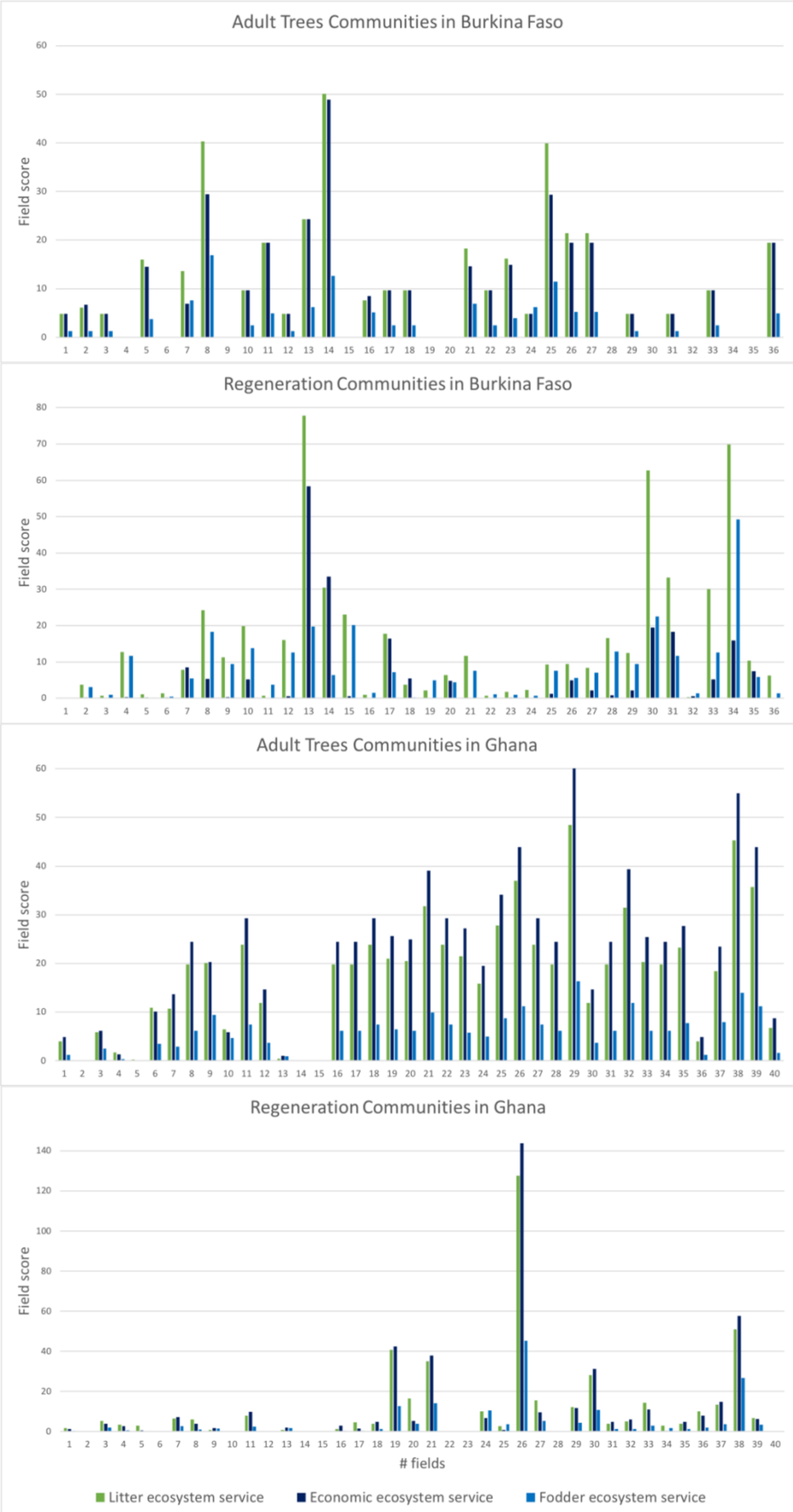

Figure 8: The field scores per ecosystem service (litter, economic and fodder) inventoried on the 36 fields in Burkina Faso, first the adult trees' communities and then the regeneration, and similarly for the 40 fields in Ghana

3.2.3 The trade-off between species on fields

Based on the average species scores and the field scores, the economic and fodder ecosystem services scores could be tested against the litter ecosystem service scores to see whether there is a trade-off for the farmers between the provisioning services and regulating services.

Figure 9 shows that unlike expected, there is no trade-off at species level, but on the contrary a positive trendline between the economic ecosystem service and the litter ecosystem service. Species such as the *Vitellaria paradoxa* (VPA) and *Bombax costatum* (BCO) in Burkina Faso, and *Vitellaria paradoxa (*VPA), *Adansonia digitata* (ADI) and *Parkia biglobosa* (PBI) in Ghana tend to have multiple uses, and a synergism can be observed rather than a trade-off of ecosystem services. When a species' score for its economic ecosystem service increases, its score for the litter ecosystem service increases too. The trendline is nevertheless not a 1:1 relationship. The trendline increases more slowly for the economic ecosystem service than for the litter ecosystem service.

A small trade-off is visible for the fodder value against the litter value for *Afzelia Africana* (AAF), *Pterocarpus erinaceus* (PER), *Balanites aegyptiaca* (BAE) in Burkina Faso, although in both countries the majority of the species have a low score for both fodder ecosystem service and litter ecosystem service.

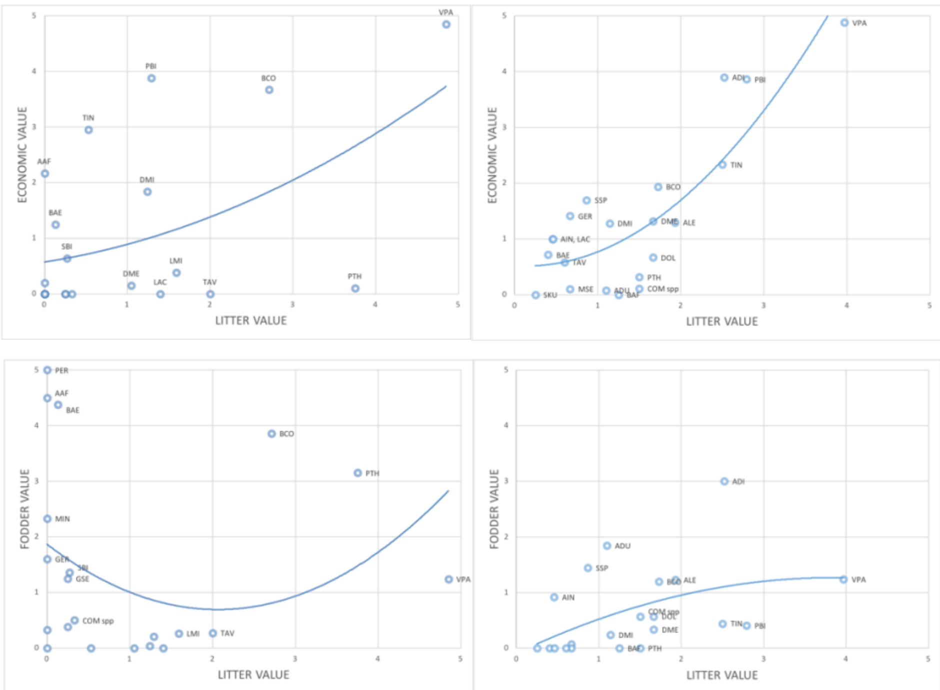

Figure 9: Relationship between the economic and litter ecosystem services and the fodder and litter ecosystem services at species level in Burkina Faso (left) and Ghana (right).

The field being an aggregate of the species, nor was there a trade-off between the provisioning and regulating services at field level. In both countries, for the adult compositions, fields with a higher score for the economic ecosystem service tend to have a higher score for the litter ecosystem service too, while all the scores for the fodder ecosystem service remain very low.

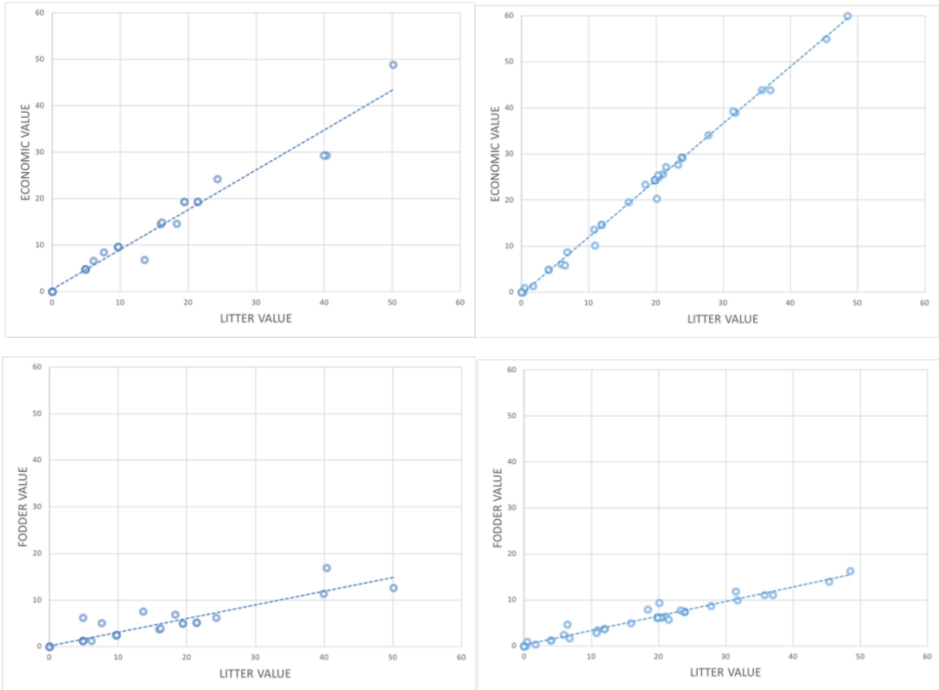

Figure 10: Relationship between the economic and litter ecosystem services and the fodder and litter ecosystem services at field level for adult trees in Burkina Faso (left) and Ghana (right).

Similarly, for the regeneration compositions, synergism rather than trade-offs can be observed. In Burkina Faso fields with very low score for the economic ecosystem service, have a higher score for the litter ecosystem service. In Ghana the score for the economic ecosystem service and litter ecosystem service tend to be more equivalent for each field. This accounts as well, in both countries, for the score for the fodder ecosystem service and litter ecosystem service, which seem to be synergistic.

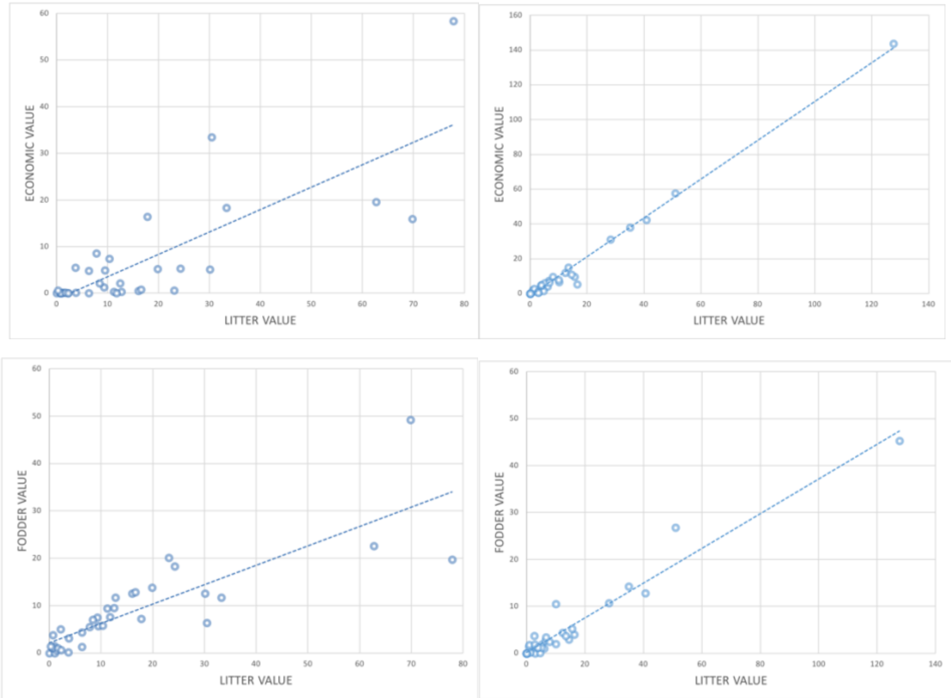

Figure 11: Relationship between the economic and litter ecosystem services and the fodder and litter ecosystem services at field level for regeneration in Burkina Faso (left) and Ghana (right)

4. Discussion

The soil quality is influenced by ecological as well as social factors, which is why Farmer Managed Natural Regeneration is a holistic land management practice for restorative agriculture. In this research we focused on the effect of the soil texture, the vegetation structure, the land management and the functional properties on soil health.

The results showed that the functional properties of tree communities had less influence on soil health than expected. The sand content is highly associated with soil health, primarily in relation to the carbon and nitrogen content. It is mainly a high vegetation structure and good land management practices that increase soil health. Through FMNR smallholder farmers can influence the diversity and density of trees on their fields, in addition to managing their land to improve their soil health.

It was expected that the farmer would prioritize species on their fields with high value for economic or fodder ecosystem services above species with high value for litter ecosystem services. The results showed that there is no trade-off in ecosystem services between the tree species, neither at field-level, indicating that farmers manage trees for multiple benefits. In the second section of the discussion, at species level, the four most valued species by the farmers are detailed, followed by the other key species for each of the three ecosystem services. Eventually, at field level, the adult diversity is dominated by the *Vitellaria paradoxa,* which has high value score for provisioning as well as regulating services. The regeneration species composition is more diverse than the adult species composition, implying that farmers select species with multiple purposes, and weed out the ones with only high value for litter ecosystem services. The adult and regeneration field compositions are further discussed in the third and last section of the discussion.

4.1 The soil health variability

The soil organic carbon (SOC), soil nitrogen content (SNC), water infiltration capacity (WIC) and erosion (ER), are influenced by different predictor variables (table 4). An increase in SOC, SNC and WIC relates positively with soil health, while an increase in erosion negatively.

4.1.1 The effect of the soil texture

The sand content is a main factor of soil health. It represents the soil physical texture together with the silt and clay content. A high sand content limits the soil capacity to store nutrients (Winowiecki et al, 2016), and is therefore significantly negatively associated with

SOC and SNC. A lack of nutrients is bad for soil health. Furthermore, the sand content also contributes to explain the WIC and ER. The WIC is positively related to sand content, meaning that higher percentage of sand in the soil leads to a faster infiltration. Indeed, soils containing much sand drain well because they have relatively large pores. The fact that soil texture contributes to the soil infiltration capacity has already been much studied (Wischmeier et al, 1969). A high sand content leads to high-infiltrability, which is positive for the soil health in the dry lands because of the erratic rains during the rainy season that otherwise start surface runoff and provoke erosion (Panagos et al, 2017). Indeed, runoff occurs when the soil becomes saturated because the rainfall intensity exceeds the infiltration rate. Well drained soils do not become saturated, this reduction of risk of water runoff explains thus also why a higher sand content reduces erosion.

4.1.2 The effect of the vegetation structure

The vegetation structure is another main influence on soil health. The West African parklands are dominated by crops, grasses, shrubs and/or trees, which all influence the soil quality differently. Lands composed of woodland and forests have a higher SOC concentration than croplands or grasslands. In drylands, the larger root systems and the litter inputs from the trees enriches the soils beneath the tree canopies of organic matter content (Bayala et al., 2006). The improved soil structure is directly linked with the water infiltrability that also increases with the vegetation structure. In the croplands and grasslands, the water infiltration capacity is lower than in the shrubland and woodland.

Other studies in the drylands have similarly shown that trees have a positive impact on soil hydraulic properties (Bargués Tobella et al, 2014; Wilcox et al, 2003; Wainwright, 2002; Dunkerley, 2000; Belsky et al, 1993). In addition, the soil beneath tree canopies is protected from raindrop impact, which reduces the crust formation that would decrease the WIC, and thus the soil health (Bochet, 1998; Hoogmoed and Stroosnijder, 1984).

The vegetation structure then also influences the erosion resistance (Zuazo et al, 2009). There is a positive association between erosion and the vegetation structure complexity. This can be explained when an increase in vegetation structure means more woody cover but less nonwoody ground cover. Overall, the vegetation fixes the soil with its roots (Baets et al, 2007; Gyssels et al, 2005) and reduce water runoff by improving WIC (Puigdefabregas, 2005), particularly the herbaceous layer provides a precious year-round ground cover reducing sediment flow, through wind and water erosion, at soil surface

(Lohbeck et al, 2018; Zuazo et al, 2009; Raya et al, 2006; Lee et al, 2000; Van Dijk, 1996). To mitigate this effect, farmers could protect the bare soil in high vegetation structure complexity with mulch as ground cover.

4.1.3 The effect of land management

The various forms of land management critically influence the soil health. Farmers therefore are key players in the preservation of their field soils. The stronger the impact of agriculture on a field, the more SOC there will be. Indeed, many management practices increase SOC, which is the basis of soil fertility and soil health. A few examples are the proper crop rotation, cover crops, fallows, conservation tillage, leaving crop residues on the field for mulching, or the addition of organic materials such as compost or manure (Lungu, 2015; Shrestha et al, 2015; Batjes, 2014; Sampson et al, 2000). As well as keeping trees on the field as developed above. During the interviews carried with the famers, some explained that to improve the soil fertility they would create mounts during the field labouring, covering the leaves shed by the trees on their fields so that they would decompose faster and enhance the soil organic matter. Farmers are thus aware of the importance of keeping a fertile soil and have local means to effectively increase soil fertility.

In addition, grazing also plays a role in soil health. During the dry season, the domestic livestock roams freely in the fallows and in the cultivated plots once they have been harvested. While it decreases soil health, according to the famers, those free foraging animals are also an important constraint to FMNR because they eat or break the re-sprouts. With their hooves, the cattle herds disrupt the surface layers of the soil (Dunne et al, 2011) and create soil compaction. The trampling consequently enhances the erosion process by increased runoff (Shah et al, 2017). The grazing is however positively associated with water infiltrability. This association is probably due to the fact that where there is grazing it means that there is vegetation and as developed above, vegetation enhances infiltrability. To avoid a reduction of plant cover, and specifically natural regeneration, the grazing must be controlled to sustainable levels (Batjes, 2004; Rietkerk et al, 2000).

4.1.4 The effect of the functional properties

The functional properties of the tree communities present on farmer fields have little influence on soil health, unlike expected. The relationships of the community-weighted means seem to be more a response from soil health than an effect on soil health.

Of the variables tested, we found a significant negative association between the acquisitive trait SLA and the WIC, which entails that a high abundance of trees in a community with high SLA values relate to a slower infiltration rate. While usually smaller specific leaf areas are considered as an adaptation to drought stress, a research from Aspelmeier et al (2006) on *Betula pendula* has shown increasing specific leaf area values for trees under water limitation. Soil with a low water infiltration capacity do not let enough water enter the soil and make their vegetation vulnerable to drought stress which result in an increase of specific leaf area values of the tree community. Moreover, there is a positive relation between the conservative trait leaf thickness and erosion. The species with thick leaves (Piliostigma spp, Terminalia spp, Combretum spp) are also the ones that are most abundant in the regeneration community on farmer fields. An explanation to this positive correlation could thus be that the trees with a high leaf thickness are more tough, growing back even on eroded soils. In addition, the young leaves are then attractive for the cattle roaming freely in area, which will provoke more soil compaction where the regeneration is, enhancing the erosion as developed above.

4.2 The farmers preferences

4.2.1 The species importance to selected ecosystem services

Some tree species have multiple functions and are highly rated for several services, such as the *Vitellaria paradoxa,* or *Piliostigma thonningii* and the *Bombax costatum* in Burkina Faso and *Adansonia digitata* in Ghana*,* while others like *Afzelia Africana* and *Pterocarpus erinaceus* are kept by the farmers mainly for fodder, and *Parkia biglobosa* for its economic ecosystem service. The species that were highly rated for the litter ecosystem service, were generally highly rated for the economic ecosystem service or fodder ecosystem service too.

Some species scored zero, indicating that the species was useless for the selected ecosystem service. This score was most common, and there was usually a strong consensus among the farmers for the zero value, contrarily to the higher values which varied more among the respondents. The farmers were more consistent regarding the low fodder value of species than regarding the economic value of species (appendix 10). The least consistency of scores was regarding the value of the litter ecosystem service, indicating that possibly farmers manage the trees and litter differently on their field. This result entails that farmers could teach each other how to manage the tree species with litter of high quality to reach higher litter scores among all farmers. As mentioned above, some practices agriculture, such as covering leaves under mounts for faster decomposition, positively influences the SOC and consequently the soil health (table 4 and 6).

The *Vitellaria paradoxa,* commonly known as shea tree, is by far the most abundant tree species in the area, with an abundance of 78% for the adult communities in Burkina Faso and 83% in Ghana (appendix 6 and 7). Farmers like to have many individuals of the species on their fields as there is a high demand for the nuts in the whole country as well as from larger companies abroad, and the products are sold for a high price (table 6). The high score for the economic ecosystem service of the tree is the only high score that was constant among all the farmers in both countries (appendix 10). There is a variety of uses of the products, and the farmer can sell the fruits, the nuts or sell transformed products such as shea butter, soap, etc. Due to the high abundance of the *Vitellaria paradoxa* on the fields, lots of leaves are shed contributing greatly to the soil fertility. The leaves are thick, broad and nutrient rich (table 6). In order for the leaves to decompose faster, the majority of the farmers cover them with soil by putting them into mounds during ploughing. Some farmers would take the leaves to compost pits with animal manure, straw and cereals and bring the mix back to the field later. When it comes to the fodder ecosystem service, only the young leaves are eaten by animals during the hunger gap (table 6), which is a period of a couple of months from when the food from the previous growing season is finishing up until when new crops are ready to be harvested.

The *Piliostigma thonningii,* is abundant in Burkina Faso (with an abundance of 7% for the adult communities, and 18% for the regeneration communities) while its economic ecosystem service is almost none (table 6). Its dried fruit can be transformed into potash, which is powder used as fertilizer, and sold as green manure. However most of the farmers keep the *Piliostigma thonningii* on their field mainly for its high litter quality. The *Piliostigma thonningii* has broad, thick and heavy leaves with a high nutrient content (table 6). While the abundance of *Piliostigma thonningii* is lower on the fields than *Vitellaria paradoxa*, its leaves nutrient content is higher than *Vitellaria paradoxa*. Farmers observe that crops grow much better where *Piliostigma thonningii* leaves have decomposed. All the leaves of *Piliostigma thonningii* remain on the field, on some fields they are put into mounds to decompose faster (table 6). In addition, *Piliostigma thonningii* also scores highly for the fodder ecosystem service. Some farmers give young leaves to their animals, but it is mainly the fruit that are eaten during the hunger gap, and which are very nutritious (table 6). On the contrary in Ghana, the species is much less common (appendix 6 and 7) and poorly rated for the three ecosystem services (table 5 and 6). Ghanaian farmers do not see their usefulness and because the leaves tend to decompose slowly, they explained during the interviews that they weed out the regeneration of the trees. To maximize and expand the potential of the *Piliostigma thonningii* to soil fertility, measures should be taken so that the Burkinabe farmers could share their knowledge of the tree management with Ghanaian farmers.

The *Bombax costatum* is present in both sites. In Burkina Faso it has a high value for the economic ecosystem service for its flowers that are eaten. There is a high demand for this product, and has a high price, because the species is not available everywhere in Burkina Faso (only in the South and the West). Moreover, the flowers can be dried and sold during the hunger gap (table 6). The *Bombax costatum* leaves however are of no use for human consumption. According to some farmers the leaves have low nutrient content, while for other farmers the nutrient content is similar to *Vitellaria paradoxa* and *Piliostigma thonningii* and thus high. The farmers that scored *Bombax costatum* lower for its litter ecosystem service was either because they prioritized the leaves for fodder or because although the leaves are broad they are light and blown away by the wind, consequently not fertilizing their field. Nevertheless, the majority said the remaining leaves that had the time to decompose on their field contributed greatly to soil fertility. Whenever the leaves were taken into the mounds that the famers create during ploughing, those farmers would score the species very high for the litter ecosystem service similarly to *Vitellaria paradoxa* (table 6). Eventually, for the fodder ecosystem service the *Bombax costatum* was highly scored as its leaves (young and old) are considered to be very nutritious and appreciated by the animals. The leaves are present on the trees during the hunger gap, which creates a high demand (table 6). On the contrary in Ghana the Bombax costatum is poorly rated for the three ecosystem services. Some farmers sell the flower, but the price is not as high as in Burkina Faso, while others do not sell anything from the tree (table 6). The species is indeed more common in Ghana, decreasing the price at the local market. The farmers argue that the leaves decompose fast but are not shed at once and the leaves that are not taken into mounds during the ploughing are blown away contributing thus poorly to the soil fertility of their field. For the fodder, the flowers are fed to the animals but not in abundance and contrarily to what the Burkinabe farmers claimed, in Ghanaian farmers maintained that the leaves are not very appreciated by their livestock (table 6). In Ghana the farmers feed their livestock mainly with *Adansonia digitata*, which is more abundant in the region and some other tree species like the *Acacia dudgeoni.*

The *Adansonia digitata*, commonly known as the baobab, is present in both countries but more frequent in Ghana, and therefore was only evaluated in this site (appendix 1). According to the Ghanaian farmers, the species provides many benefits to the farmer, it has high values for the economic, fodder and litter ecosystem services. Multiple products from tree can be sold at the market (powder, seeds, leaves and fruit) generating good income (table 6). Because the trees become very big, not everything is picked for human consumption or sale. The leaves that remain on the decompose fast and improve the soil fertility (table 6). In addition, livestock eat the leaves as well as the fruits, which are both very nutritious (table 6). Nevertheless, although the species is highly valued by the farmers the species population is decreasing dramatically because of its inability to regenerate naturally, due to environmental factors as well as increased human pressure (Mukhtar et al, 2016). Only two adult baobab trees were inventoried on farmer fields in Ghana, and no regeneration. None were inventoried in Burkina Faso (appendix 6).

Two additional species are kept on the fields by the farmers mainly for the economic ecosystem service in both Burkina Faso and Ghana, namely the *Parkia biglobosa* (also known as Néré) and the *Tamarindus indica* (also known as Tamarind). The *Parkia biglobosa* has a high value for the economic ecosystem service. There is a high demand for the seeds and the flesh, which are essential ingredients in local cooking (table 6). The particularity of the *Parkia biglobosa* in Burkina Faso is that it is the only species from which the trees on the farmer's fields sometimes belong to the village chief, who gets all the economic benefits derived from it. When it comes to the *Tamarindus indica,* the leaves are collected for human consumption, either personal or to sell, and fruit is used to make juices. There is a high demand for *Tamarindus indica* leaves because of its large consumption in every household. Nevertheless, the price at the market is relatively low because of the abundance of the product (table 6). The value of *Parkia biglobosa* in the extent to which its litter contributes to the soil fertility varied widely among the farmers (appendix 10). The leaves are rich in nutrients, but some scored them 0 because they were small and blown away by the wind, while others scored them 4 because they would prune the trees before ploughing, take the leaves into mounds and see a clear difference of fertility under the tree crown. However, for the *Tamarindus indica* the litter contribution is very low in Burkina Faso because all the leaves are collected for human consumption. This is not the case in Ghana were the leaves contribute to fertilizing the soil mainly when taken into mounds because there are many leaves that decompose fast, but they are light and tiny (table 6).

Some tree species are mainly kept by the farmers for the fodder ecosystem service. The *Pterocarpus erinaceus* and *Afzelia Africana* are well known for their very nutritious and appreciated leaves for animal food (table 6), as has been confirmed by the study of Ouédraogo-Koné et al. (2008) about the browse species in West Africa. In addition, the *Afzelia Africana* leaves are also a little used in typical Burkinabe meals. The overharvesting of the species has however reduced the species ability to regenerate, which could affect the long-term viability of the species (Delvaux et al., 2009). *Afzelia Africana* is classified "Vulnerable" in the IUCN red list, and *Pterocarpus erinaceus* "Endangered" (The IUCN Red List of Threatened Species). None of both species were inventoried on farmer fields, neither as adult trees, nor as regeneration (appendix 6). *Afzelia Africana* is rarer in Burkina Faso and its leaves are sold for a good price, raising the value of the economic ecosystem service (table 6). Because all the leaves are collected, none remain to fertilize the soil and the litter ecosystem service is thus scored 0. Some species like the *Mitragyna inermis*, are nutritious and present during the hunger gap, but remain however a second choice for the farmers to feed their cattle (table 6). The leaves of the *Balanites aegyptiaca* are nutritious, and all the leaves are collected and most of the time kept by the farmers for personal consumption, or to feed their livestock. However, this does not apply to Ghana, were the farmers said the *Balanites aegyptiaca* had no economic ecosystem service, no effect on soil and was not even eaten by the animals because of its bad taste (table 6). Except for a few species, the value for the fodder ecosystem service tend to be low (table 5). This could be explained by the fact that not all farmers have animals, therefore not prioritizing this ecosystem service from the uses that can be made from the tree species.

The species that had a high score for the litter ecosystem service often also had a high score for the economic or fodder ecosystem service like *Vitellaria paradoxa, Piliostigma thonningii Bombax costatum* and *Adansonia digitata.* In addition, species like *Terminalia avicennioides* have large leaves that contribute also to the soil fertility because they stay on the field (table 6). Their leaves keep the soil moisture, but they are thick and decompose slowly if they are not taken into mounds. While they were scored by some farmers in Burkina Faso, their value was much less recognized in Ghana where they are also less present on the fields (appendix 6 and 7). The Ghanaian farmers said they had no effect on soil fertility unless they would burn them (table 6). A main reason for a couple of species to be poorly scored for the litter contribution to soil fertility by the farmers was that they had small and light leaves that would be blown away by the wind or taken away with water and would therefore not fertilize the farmer's field soil, unless taken into mounts.

It should be noted that some tree species are kept on the fields by the farmers while scored poorly for all three ecosystem services (table 5). In most cases they are either used by the farmer for traditional medicine or wood which were not part of the interview questions for this study. The farmers said during the interviews that all the species kept on their fields had a useful purpose.

4.2.2 TREE COMPOSITION ON FARMER FIELDS

In Burkina Faso the field scores for the adult tree compositions was almost equal for the litter ecosystem service and economic ecosystem service, although some fields had a higher score for the litter ecosystem service. In Ghana, on the contrary, the field score for the adult tree compositions was higher for the economic ecosystem service, followed closely by the litter ecosystem service. When looking at the species abundance and diversity on the fields, it can be observed that the *Vitellaria paradoxa* dominates (appendix 6). The species is indeed controlling the agroforestry parklands of the region (Valbuena et al., 2016; Lovett, 2000; Boffa, 1999). The field score differences can consequently be explained by the different average scores given to the *Vitellaria paradoxa* for each ecosystem service in the two countries. In Burkina Faso the economic ecosystem service and litter ecosystem service were given the same average score of 4.85 out of 5, while in Ghana the economic ecosystem service was scored 4.88 and the litter ecosystem service 3.97. Thus, the scores for the economic ecosystem service are consistent among the Ghanaian and Burkinabe farmers, but the score for the litter ecosystem service is lower in Ghana. If the leaves are not worked into the soil, they may cover the ground and inhibit crop germination. The agricultural practice of ploughing in order to enhance leaf litter contribution to soil fertility (table 4), in addition to preparing the soil for sowing, should be further encouraged in Ghana. In Burkina Faso and Ghana, the scores for the litter and economic ecosystem services were much higher than for the fodder ecosystem service. Indeed, farmers in both countries were consistent in the low value scoring (1.24 out of 5). The abundance of *Vitellaria paradoxa* is nevertheless higher in Ghana, which explains the overall higher field scores in Ghana (figure 8 and 12).

When it comes to the trees' regeneration on the farmers' fields, a higher species diversity of the regenerating community is observed compared to the adult community (appendix 7). Regeneration re-sprouts from remaining rootstock or grows from seeds dispersed by adult trees in the surroundings. The regeneration may be representative of the future composition of on-farm trees. The regeneration community enables to predict the potential services the farmer may receive from future trees on his field through managing todays seedlings. In Burkina Faso, the field score for the litter ecosystem service is the highest, followed by the field score for the fodder ecosystem service and the field score for the economic ecosystem service is the lowest. The most abundant seedling species influencing those field scores are the *Terminalia avicennioides*, *Piliostigma thonningii* and the *Combretum species* (appendix 7). There were very few *Vitellaria paradoxa* seedling inventoried (26 seedling over the 36 fields). The regeneration composition on the farmers' fields thus tends to have a higher average field score for the litter ecosystem service than the adult composition. The farmers seem to choose to manage the seedlings of species with high scores for the economic ecosystem service, such as *Vitellaria paradoxa* and weed out species with only a high score for the litter ecosystem service such as the *Piliostigma thonningii* or *Terminalia avicennioides,* which is in line with what Lovett (2000) found in her study about shea trees. The *Terminalia avicennioides, Piliostigma thonningii* and *Combretum species* also are species that re-sprout easily from perennial rootstock even though the individuals are entirely chopped down by the farmers every year during field clearing (Jurisch et al, 2012; Arbonnier, 2009). In Ghana, field score for the litter ecosystem service and the field score for the economic ecosystem service are almost equal for the regeneration composition, the field score for the fodder ecosystem service is the lowest. Contrarily to Burkina Faso, the most abundant seedling species influencing the field scores are the *Vitellaria paradoxa* and *Stereospermum kunthianum* (appendix 7). The *Vitellaria paradoxa* tend to be kept and managed by the farmers because of the high benefits of the trees. The species also has a good regeneration capacity (Hall et al, 1996). *Stereospermum kunthianum* on the contrary is very tough species to get rid of. The farmers said the species had no value during the interviews, and few adult trees of the species were inventoried on the fields, but the species re-sprouts every year from root stock (appendix 7). It can be established that the farmers tend to keep and manage the species with a high value for the economic ecosystem service and remove the seedlings of the species with no value or only high scores for the litter ecosystem service. In both countries, the adult composition had a higher average field score for economic ecosystem service than the regeneration composition, which would entail that the species with a higher value for the economic ecosystem service (like the *Vitellaria paradoxa*) are selected by the farmers to practice FMNR.

There are limitations in the tree species farmers can choose to select on their fields through FMNR. Some species that are highly valued by the farmers for their ecosystem services were not present on the farmers' fields, as adults nor regeneration. This was the case for the *Tamarindus indica,* and *Parkia biglobosa* in Burkina Faso, as well as mainly species that are highly valued for fodder; *Afzelia Africana* and *Pterocarpus erinaceus* and *Balanites aegyptiaca* are absent from the fields, and only two regeneration of *Mitragyna inermis* were found (appendix 6). The reason might be that those species are heavily pruned for livestock feeding, which may lead to difficulties in regenerating, or the young seedlings eaten by the roaming animals. Such species may consequently rarefy, and the farmers may no longer be able to benefit from their presence. In addition, while the *Adansonia digitata* is much valued by the farmers, its regeneration is very limited. Two *Adansonia digitata* adult trees were inventoried, and no seedlings (appendix 6). Furthermore, the *Piliostigma thonningii* is highly valued for its litter contribution to soil fertility in Burkina Faso, and their tree management could be extended to Ghana to increase the litter field scores except that the *Piliostigma thonningii* abundance is much lower in Ghana (appendix 1 and 6). Consequently, sustainable management options in the area should be considered to reduce overharvesting and allow seedlings of those highly valued species to germinate and grow in the area.

It should nevertheless be noted that the field inventories have been carried out from April to June. During this time lapse the rainy season started, changing the field compositions. While at the end of the dry season fields were full of regeneration, once the farmers ploughed their fields and started sowing only very few were kept. This influenced the regeneration abundance inventoried on the fields throughout the period, which would have been more constant if the whole year would be inventoried.

Contrarily to what was expected, there was no trade-off observable already at species level between the economic or fodder ecosystem services against the litter ecosystem service, but rather a synergism. Species, such as the *Vitellaria paradoxa* tend to have multiple uses (figure 9). The field being an aggregate of the species, nor was there a trade-off between the provisioning and regulating services at field level in the species composition selected and managed by the farmer, similarly to what was found at species level. This shows the multifunctionality of species, and the overall benefit of the trees selected by the farmers on their fields

Farmers keep trees on their fields for various benefits, the regulating services on soil quality as well as the provisioning services such as monetary benefits and fodder. While it was hypothesized that farmers select the trees on their fields giving more importance to provisioning services than to regulating services the results showed a different outcome (figure 8). Nevertheless, the farmers field inventories were made in a plot of 1000m2 in the centre of the farmers' fields. A full inventory of the field would have been more representative.

Keeping trees on farmer fields also involves constraints to the farmers. It is labour intensive as the farmer needs to prune them to reduce the light competition with crops, and the tree parasites (*Tapinanthus* spp) must be removed, all of which is manual labour. Many farmers said they lacked formation for the sustainable maintenance of trees and seedlings. Without those constraints all farmers mentioned they wanted to have more tree species on their fields.

5. Conclusions

The farmers land and tree management play an essential role in the future of agricultural land in West Africa. Based on the results obtained the diversity of tree communities had less influence on soil health than expected. It is rather a low sand content, high vegetation structure and good land management that increase soil health. Through Farmer Managed

Natural Regeneration, smallholder farmers can influence the diversity and density of trees on their fields and manage their land to improve their soil health.

We stressed that tree species have various benefits for the local farmers. Farmers tend to select and manage seedlings of species with high value for the economic ecosystem service and weed out species with only high value for the litter ecosystem service. This is noticeable by the higher species diversity in the seedlings than in the adult community. Farmers chose to nurture multifunctional species on their fields, like the shea tree (*Vitellaria paradoxa*), which has a high economic value but also has high value for soil fertility due to the quality of its litter. No trade-off was thus found between ecosystem services of trees, at species nor field level, but rather that farmer prefer species with multiple uses. This affects the species diversity on the fields, with the shea tree being the dominant species of the parklands by 78% in Burkina Faso and 83% in Ghana.

While there is diversity in the natural regeneration, there is a lack of regeneration by species of interest, like the *Tamarindus indica, Parkia biglobosa, Afzelia Africana*, *Pterocarpus erinaceus* and *Adansonia digitata*. Further researches could focus on the environmental and human drivers of natural regeneration to assist the species that are rarefying to increase again in the parklands. Farmers value trees, and have a lot of knowledge regarding their uses, but often lack formation on the management of trees and seedlings for sustainable use. The management by famers of the natural regeneration with multiple uses will help restore the soil quality in farmer fields.

6. Recommendations

The practice of FMNR should be scaled up in the parklands for smallholder farmers in West Africa that want to restore their soil quality, and in order to preserve and increase the present tree diversity. Farmers need to adapt their management practices and are eager to learn. They could add compost and manure for soil nutrients, protect bare soil with mulch against erosion, control grazing against erosion or till soil surface to increase water infiltration capacity. Therefore, skills trainings should be enhanced by projects like WAFFI or by World Vision to smallholders and afterwards spread from farmer to farmer through the parklands according to their personal experiences. Additionally, teachings could already start in school curriculums since children, from a young age, start helping their parents on the fields.

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APPENDIX 1: TOTAL SPECIES INVENTORIED IN 2017

Table 7: Total number of trees and seedlings species inventoried in Burkina Faso (BF) and Ghana (Gh) in the inventory made in 2017

ID	Scientific name	Total nb trees BF	Total nb seedlings BF	Total nb trees Gh	Total nb seedlings Gh
1	*Acacia dudgeoni*	4	4	34	2
2	*Acacia gourmaensis*	11	8	1	1
3	*Acacia macrostachya*	2	4	0	0
4	*Acacia nilotica*	2	0	0	0
5	*Acacia pennata*	0	1	0	0
6	*Acacia senegal*	0	1	0	0
7	*Acacia seyal*	13	2	0	0
8	*Acacia sieberiana*	5	0	5	0
9	*Acacia tortilis*	0	0	0	2
10	*Adansonia digitata*	4	0	11	0
11	*Afromosia laxiflora*	0	3	0	0
12	*Afzelia africana*	6	0	1	0
13	*Annona senegalensis*	0	35	0	0
14	*Anogeissus leiocarpus*	83	34	36	0
15	*Azadirachta indica*	0	0	36	1
16	*Balanites aegyptiaca*	23	7	2	1
17	*Bauhinia spp*	0	0	3	0
18	*Bombax costatum*	8	0	16	0
19	*Burkea africana*	1	0	16	2
20	*Bridelia ferriginea*	0	2	0	0
21	*Combretum collinum*	0	0	0	2
22	*Combretum fragrans*	6	8	0	0
23	*Combretum ghasalense*	0	0	2	0
24	*Combretum glutinosum*	2	80	0	0
25	*Combretum molle*	8	8	4	11
26	*Combretum nigricans*	20	55	0	0
27	*Crossopteryx febrifuga*	2	7	3	0
28	*Daniellia oliveri*	0	1	3	1
29	*Detarium microcarpum*	32	19	6	0
30	*Dichrostachys cinerea*	0	21	0	0
31	*Diospyros mespiliformis*	21	13	38	3
32	*Elaeis guineensis*	0	0	1	0
33	*Entada abyssinica*	1	0	0	0
34	*Entada africana*	2	0	6	0
35	*Erythrina senegalensis*	1	0	0	0

36	*Faidherbia albida*	0	0	3	0
37	*Feretia apodanthera*	1	8	0	0
38	*Ficus gnaphalocarpa*	0	0	2	0
39	*Ficus ingens*	1	0	0	0
40	*Ficus platyphylla*	1	0	1	0
41	*Ficus sycomorus*	3	0	0	0
42	*Flueggea virosa*	0	16	0	0
43	*Gardenia aqualla*	0	1	0	0
44	*Gardenia erubecens*	0	11	0	3
45	*Gardenia ternifolia*	0	7	0	0
46	*Grewia bicolor*	1	1	0	0
47	*Guava*	0	0	1	0
48	*Guierra senegalensis*	0	50	0	0
49	*Karpolo*	0	0	1	0
50	*Lannea acida*	45	2	20	0
51	*Lannea microcarpa*	40	2	0	0
52	*Lannea velutina*	1	0	0	0
53	*Magifera indica*	0	0	1	0
54	*Maytenus senegalensis*	1	8	2	1
55	*Mitragyna inermis*	6	0	0	0
56	*Moringa oleifera*	0	0	2	0
57	*Parinari curatellifolia*	0	0	1	0
58	*Parkia biglobosa*	18	0	2	0
59	*Piliostigma reticulatum*	1	2	0	0
60	*Piliostigma thonningii*	12	76	2	1
61	*Poupartia birrea*	0	0	4	0
62	*Prosopis africana*	2	0	1	0
63	*Pseudocedrala kotschyi*	0	0	0	1
64	*Pteleopsis suberosa*	0	1	0	1
65	*Pterocarpus erinaceus*	6	2	2	0
66	*Saba senegalensis*	1	1	0	0
67	*Sclerocarya birrea*	10	3	2	0
68	*Sterculia cinerea*	0	0	3	0
69	*Sterculia setigera*	3	0	5	0
70	*Stereospermum kunthianum*	3	0	6	0
71	*Strychnos spinosa*	1	9	4	6
72	*Tamarindus indica*	7	0	6	0
73	*Tectona grandis*	0	0	14	0
74	*Terminalia avicennioides*	14	16	3	4
75	*Terminalia laxiflora*	5	6	0	0
76	*Terminalia macroptera*	0	1	1	0

77	*Terminalia microcarpus*	0	0	1	0
78	*Vitelaria paradoxa*	202	73	266	12
79	*Vitex doniana*	0	0	1	0
80	*Ximenia americana*	1	11	0	0
81	*Ziziphus mauritiana*	0	1	0	1
	TOTAL	**643**	**621**	**581**	**56**

Appendix 2: Species representing 80% of the community in Burkina Faso and Ghana

Table 8: Selection of the species representing 80% of the abundance of seedling community and 80% of the basal area of the adult tree community, over the 160 plots in Burkina Faso

ID	80% focal species Burkina Faso	Total nb trees	Total nb seedlings
1	*Acacia dudgeoni*	0	4
2	*Acacia gourmaensis*	11	8
3	*Acacia macrostachya*	0	4
4	*Acacia seyal*	13	2
5	*Acacia sieberiana*	5	0
6	*Adansonia digitata*	4	0
7	*Afromosia laxiflora*	0	3
8	*Afzelia africana*	6	0
9	*Annona senegalensis*	0	35
10	*Anogeissus leiocarpus*	83	34
11	*Balanites aegyptiaca*	23	7
12	*Bombax costatum*	8	0
13	*Burkea africana*	1	0
14	*Combretum fragrans*	6	8
15	*Combretum glutinosum*	0	80
16	*Combretum molle*	8	8
17	*Combretum nigricans*	20	55
18	*Crossopteryx febrifuga*	0	7
19	*Daniellia oliveri*	0	1
20	*Detarium microcarpum*	32	19
21	*Dichrostachys cinerea*	0	21
22	*Diospyros mespiliformis*	21	13
23	*Entada abyssinica*	1	0
24	*Erythrina senegalensis*	1	0
25	*Feretia apodanthera*	0	8
26	*Ficus sycomorus*	3	0
27	*Ficus platyphylla*	1	0
28	*Flueggea virosa*	0	16
29	*Gardenia erubescens*	0	11
30	*Gardenia ternifolia*	0	7
31	*Guierra senegalensis*	0	50
32	*Lannea acida*	15	2
33	*Lannea microcarpa*	40	2
34	*Lannea velutina*	1	0
35	*Maytenus senegalensis*	1	8

36	*Mitragyna inermis*	6	0
37	*Parkia biglobosa*	18	0
38	*Piliostigma reticulatum*	0	2
39	*Piliostigma thonningii*	12	76
40	*Prosopis africana*	2	0
41	*Pteleopsis suberosa*	0	1
42	*Pterocarpus erinaceus*	6	2
43	*Sclerocarya birrea*	10	3
44	*Sterculia setigera*	3	0
45	*Strychnos spinosa*	0	9
46	*Tamarindus indica*	7	0
47	*Terminalia avicennioides*	14	16
48	*Terminalia laxiflora*	0	6
49	*Terminalia macroptera*	5	1
50	*Vitellaria paradoxa*	202	73
51	*Ximenia americana*	0	11
52	*Ziziphus mauritiana*	0	1

Table 9: Selection of the species representing 80% of the abundance of seedling community and 80% of the basal area of the adult tree community, over the 160 plots in Ghana

ID	80% Focal Species Ghana	Total nb trees	Total nb seedlings
1	*Acacia dudgeoni*	34	2
2	*Acacia gourmaensis*	0	1
3	*Acacia sieberiana*	5	0
4	*Acacia tortilis*	0	2
5	*Adansonia digitata*	11	0
6	*Afzelia africana*	1	0
7	*Anogeissus leiocarpus*	36	0
8	*Azadirachta indica*	35	1
9	*Balanites aegyptiaca*	2	1
10	*Bauhinia spp*	3	0
11	*Bombax costatum*	16	0
12	*Burkea africana*	16	2
13	*Combretum collinum*	0	2
14	*Combretum ghasalense*	2	0
15	*Combretum molle*	4	11
16	*Crosopterix febrifuga*	3	0
17	*Daniella oliveri*	3	1
18	*Detarium microcarpum*	6	0
19	*Diospyros mespiliformis*	38	3
20	*Elaeis guineensis*	1	0

21	*Entada africana*	6	0
22	*Faidherbia albida*	3	0
23	*Ficus gnaphalocarpa*	2	0
24	*Gardenia erubescens*	0	3
25	*Lannea acida*	20	0
26	*Magifera indica*	1	0
27	*Maytenus senegalensis*	2	1
28	*Parkia biglobosa*	2	0
29	*Piliostigma thonningii*	2	1
30	*Poupartia birrea*	4	0
31	*Prosopis africana*	1	0
32	*Pseudocedrala kotschyi*	0	1
33	*Pterocarpus erinaceus*	2	0
34	*Pteleopsis suberosa*	0	1
35	*Sclerocarya birrea*	2	0
36	*Sterculia cinerea*	3	0
37	*Sterculia setigera*	5	0
38	*Stereospermum kuntheanum*	6	0
39	*Strychnos spinosa*	1	6
40	*Tamarindus indica*	6	0
41	*Tectona grandis*	14	0
42	*Terminalia avicennioides*	3	4
43	*Terminalia macroptera*	1	0
44	*Terminalia microcarpus*	1	0
45	*Vitellaria paradoxa*	266	12
46	*Ziziphus mauritiana*	0	1

APPENDIX 3: FUNCTIONAL TRAITS FOCAL SPECIES

Table 10: Focal species on which functional traits were measured for Burkina Faso (BF) and Ghana (Gh). The number of trees and seedlings show the abundance of each species in the 160 LDSF plots in each country.

ID	Scientific name	Total nb trees BF	Total nb seedlings BF	TOTAL BF	Total nb trees Gh	Total nb seedlings Gh	TOTAL Gh
1	*Acacia dudgeoni*	0	4	4	34	2	**36**
2	*Acacia gourmaensis*	11	8	**19**	0	1	1
3	*Acacia seyal*	13	2	**15**	0	0	0
4	*Acacia sieberiana*	5	0	**5**	5	0	**5**
5	*Adansonia digitata*	4	0	4	11	0	**11**
6	*Afzelia africana*	6	0	**6**	1	0	1
7	*Annona senegalensis*	0	35	**35**	0	0	0
8	*Anogeissus leiocarpus*	83	34	**117**	36	0	**36**
9	*Azadirachta indica*	0	0	0	35	1	**36**
10	*Balanites aegyptiaca*	23	7	**30**	2	1	3
11	*Bombax costatum*	8	0	**8**	16	0	**16**
12	*Burkea africana*	1	0	1	16	2	**18**
13	*Combretum fragrans*	6	8	**14**	0	0	0
14	*Combretum glutinosum*	0	80	**80**	0	0	0
15	*Combretum molle*	8	8	**16**	4	11	**15**
16	*Combretum nigricans*	20	55	**75**	0	0	0
17	*Crossopterix febrifuga*	0	7	**7**	3	0	3
18	*Daniellia oliveri*	0	1	1	3	1	4
19	*Detarium microcarpum*	32	19	**51**	6	0	**6**
20	*Dichrostachys cinerea*	0	21	**21**	0	0	0
21	*Diospyros mespiliformis*	21	13	**34**	38	3	**41**
22	*Entada africana*	0	0	0	6	0	**6**
23	*Feretia apodanthera*	0	8	**8**	0	0	0
24	*Flueggea virosa*	0	16	**16**	0	0	0

25	*Gardenia erubescens*	0	11	**11**	0	3	3
26	*Gardenia ternifolia*	0	7	**7**	0	0	0
27	*Guierra senegalensis*	0	50	**50**	0	0	0
28	*Lannea acida*	15	2	**17**	20	0	**20**
29	*Lannea microcarpa*	40	2	**42**	0	0	0
30	*Maytenus senegalensis*	1	8	**9**	2	1	3
31	*Mitragyna inermis*	6	0	**6**	0	0	0
32	*Parkia biglobosa*	18	0	**18**	2	0	2
33	*Piliostigma thonningii*	12	76	**88**	2	1	3
34	*Pterocarpus erinaceus*	6	2	**8**	2	0	2
35	*Sclerocarya birrea*	10	3	**13**	2	0	2
36	*Sterculia setigera*	3	0	3	5	0	**5**
37	*Stereospermum kuntheanum*	0	0	0	6	0	**6**
38	*Strychnos spinosa*	0	9	**9**	1	6	**7**
39	*Tamarindus indica*	7	0	**7**	6	0	**6**
40	*Terminalia avicennioides*	14	16	**30**	3	4	**7**
41	*Terminalia laxiflora*	0	6	**6**	0	0	**0**
42	*Terminalia macroptera*	5	1	**6**	1	0	1
43	*Vitellaria paradoxa*	202	73	**275**	266	12	**278**
44	*Ximenia americana*	0	11	**11**	0	0	0

APPENDIX 4: STEP BY STEP PROTOCOL FOR TRAITS MEASUREMENTS

1. Discuss with local people when traits can be measured for each species (depending on when leaves are present on trees).
2. Ask local people about resprouting capacity of species *(R.CAP)*, deciduousness of species *(LP).*

<u>In the field:</u>

3. Check spinescence of the species *(S)*
4. Check leaf compoundness of the species *(LC)*
5. Measure the chlorophyll content using a SPAD on four leaves per individual *(CHL)*
6. Cut and collect three terminal sun-exposed twigs of 20 to 30 cm long with healthy leaves from the individual and store them into coded plastic bag

<u>At field base:</u>

7. Cut bottom part of twigs to enable better water sucking and put them in a bucket in the dark to rehydrate for a minimum of one hour
8. Measure leaf instantaneous chlorophyll fluorescence with a fluorpen *(LICF)*
9. Remove all leaves from twig
10. Select and weight 4 fresh leaves per individual on a balance
11. Weight the 3 fresh twigs per individual on a balance
12. Measure the leaf thickness of the 4 leaves per individual with a digital calliper in the middle of the leaf *(LT)*
13. Photograph the 4 leaves per individual on a white surface next to a ruler *(LA)*
14. Store the 4 leaves and 3 twigs per individual in paper bags and hang on a line to dry.
15. Weight the leaf's dry mass a couple of days later on a balance *(LDMC, SLA, LD)*
16. Weight the twigs dry mass a couple of days later on a balance *(TDMC)*

APPENDIX 5: PRESELECTED SPECIES LIST FOR INTERVIEWS

Table 11: Concise preselected species list for interviews based on abundance of trees and seedlings on fields in the region surrounding the study site in Burkina Faso

Scientific name	Total nb trees	Total nb seedlings
Acacia gourmaensis	11	8
Acacia seyal	13	2
Afzelia africana	6	0
Annona senegalensis	0	35
Anogeissus leiocarpus	83	34
Balanites aegyptiaca	23	0
Bombax costatum	8	0
Combretum glutinosum	0	80
Combretum molle	8	0
Combretum nigricans	20	55
Detarium microcarpum	32	19
Dichrostachys cinerea	0	21
Diospyros mespiliformis	21	13
Flueggea virosa	0	16
Gardenia erubescens	0	11
Guierra senegalensis	0	50
Lannea acida	15	0
Lannea microcarpa	40	0
Mitragyna inermis	6	0
Parkia biglobosa	18	0
Piliostigma thonningii	12	76
Pterocarpus erinaceus	6	2
Sclerocarya birrea	10	0
Strychnos spinosa	0	9
Tamarindus indica	7	0
Terminalia avicennioides	14	16
Vitellaria paradoxa	202	73

Table 12: Concise preselected species list for interviews based on abundance of trees and seedlings on fields in the region surrounding the study site in Ghana

Scientific name	Total nb trees	Total nb seedlings
Acacia dudgeoni	34	2
Adansonia digitata	11	0
Anogeissus leiocarpus	36	0
Azadirachta indica	35	1
Balanites aegyptiaca	2	1
Bombax costatum	16	0
Burkea africana	16	2
Combretum spp	4	11
Daniellia oliveri	3	1
Detarium microcarpum	6	0
Diospyros mespiliformis	38	3
Entada africana	6	0
Gardenia erubescens	0	3
Lannea acida	20	0
Maytenus senegalensis	2	1
Parkia biglobosa	2	0
Piliostigma thonningii	2	1
Stereospermum kuntheanum	6	0
Strychnos spinosa	1	5
Tamarindus indica	6	0
Terminalia avicennioides	3	4
Vitellaria paradoxa	266	12

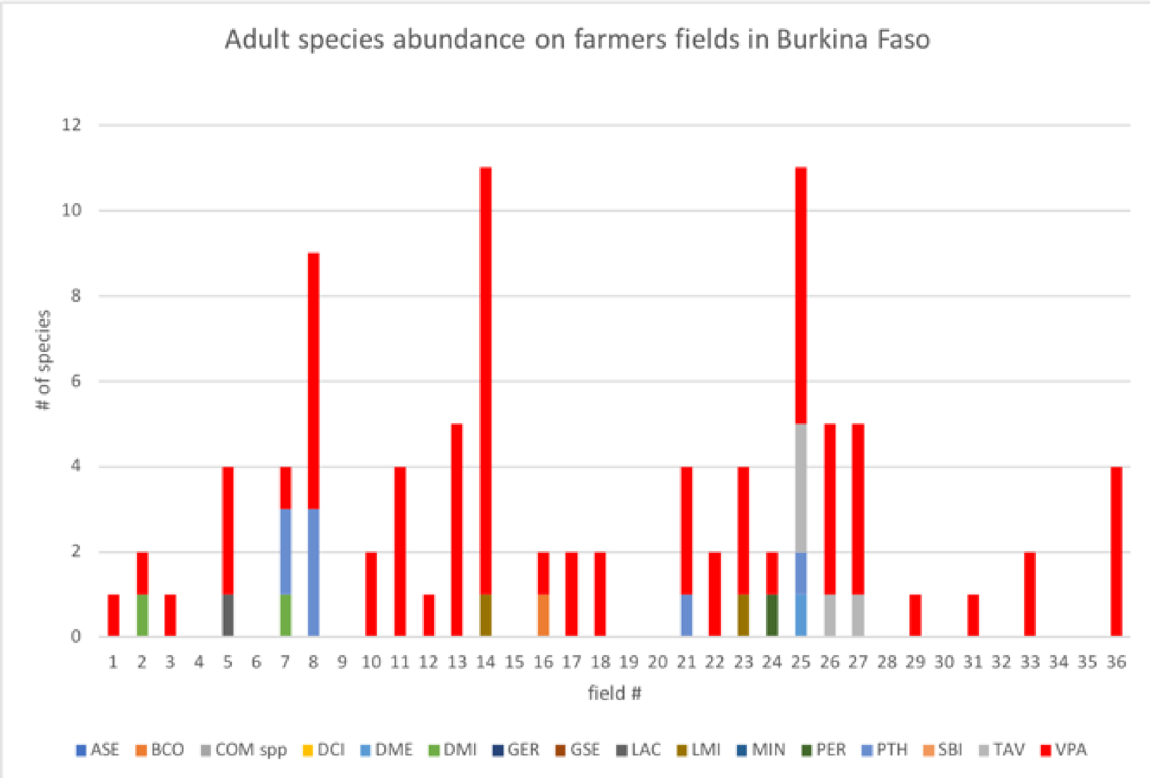
APPENDIX 6: TOTAL SPECIES INVENTORIED ON FARMERS' FIELDS

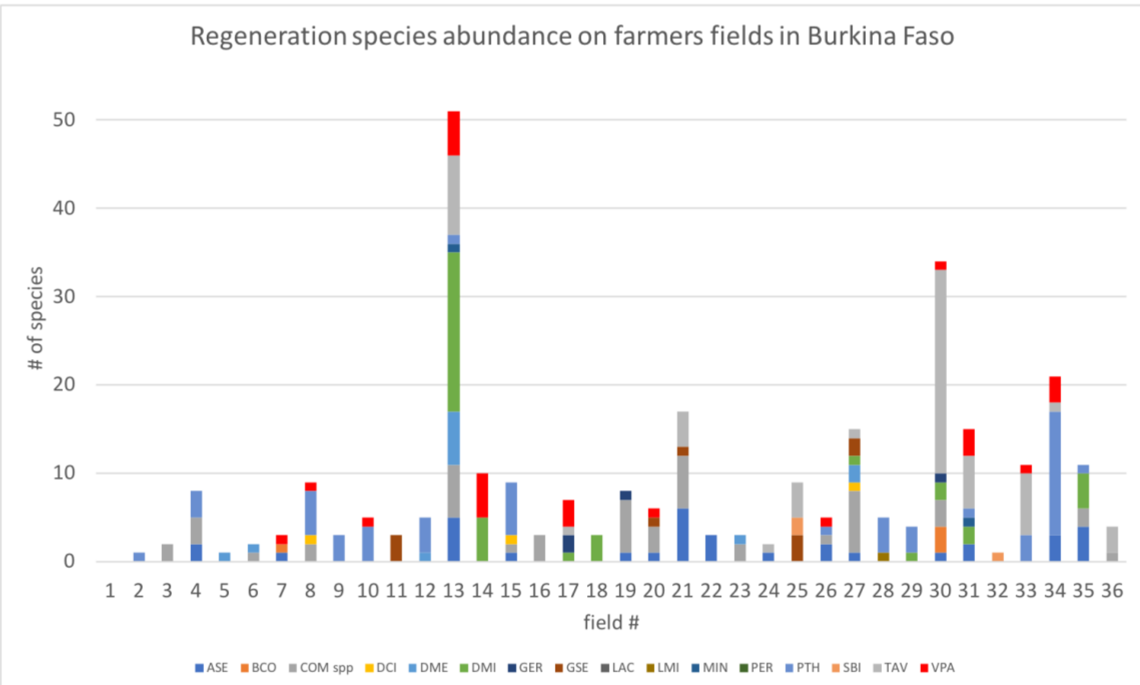
Table 13: Total number of trees and seedlings species inventoried in Burkina Faso (BF) and Ghana (Gh) during the inventories on famers fields

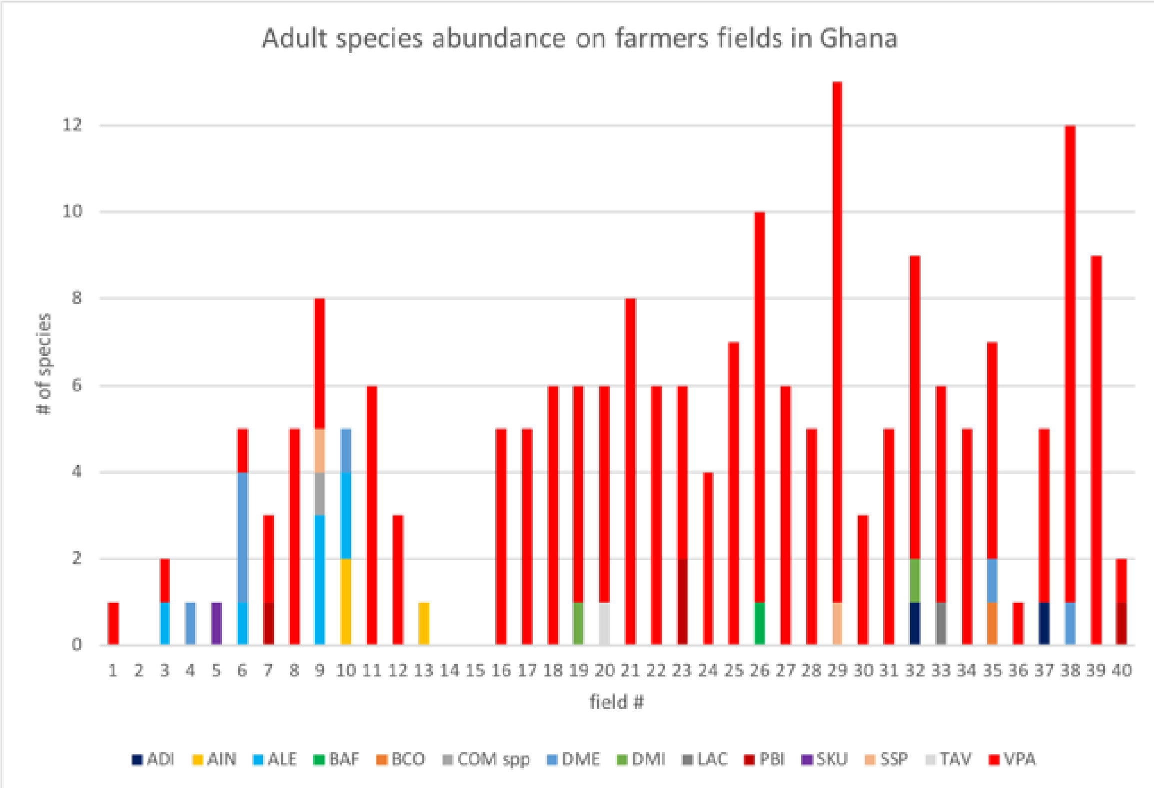
ID	Scientific name	Total nb trees BF	Total nb seedlings BF	TOTAL BF	Total nb trees Gh	Total nb seedlings Gh	TOTAL Gh
1	*Acacia dudgeoni*	0	0	0	0	20	20
2	*Adansonia digitata*	0	0	0	2	0	2
3	*Annona senegalensis*	0	31	31	0	0	0
5	*Anogeissus leiocarpus*	0	0	0	7	1	8
4	*Azadirachta indica*	0	0	0	3	3	6
7	*Balanites aegyptiaca*	0	0	0	0	3	3
8	*Bombax costatum*	1	4	5	1	12	13
6	*Burkea africana*	0	0	0	1	1	2
9	*Combretum spp*	0	50	50	1	5	6
13	*Daniellia oliveri*	0	0	0	0	20	20
12	*Detarium microcarpum*	2	37	39	2	2	4
10	*Dichrostachys cinerea*	0	3	3	0	0	0
11	*Diospyros mespiliformis*	1	15	16	7	15	22
14	*Gardenia erubescens*	0	4	4	0	6	6
15	*Guierra senegalensis*	0	14	14	0	0	0
16	*Lannea acida*	1	0	1	1	0	1
17	*Lannea microcarpa*	2	1	3	0	0	0
19	*Maytenus senegalensis*	0	0	0	0	3	3
18	*Mitragyna inermis*	0	2	2	0	0	0
20	*Parkia biglobosa*	0	0	0	4	7	11

22	*Piliostigma thonningii*	7	54	61	0	0	0
21	*Pterocarpus erinaceus*	1	0	1	0	0	0
24	*Sclerocarya birrea*	0	3	3	0	0	0
23	*Stereospermum kuntheanum*	0	0	0	1	51	52
25	*Strychnos spinosa*	0	0	0	2	3	5
26	*Terminalia avicennioides*	5	60	65	1	19	20
27	*Vitellaria paradoxa*	71	26	97	165	72	237

Appendix 7: Visualization of the tree species abundance for the adult community and regeneration community on the fields in Burkina Faso and in Ghana







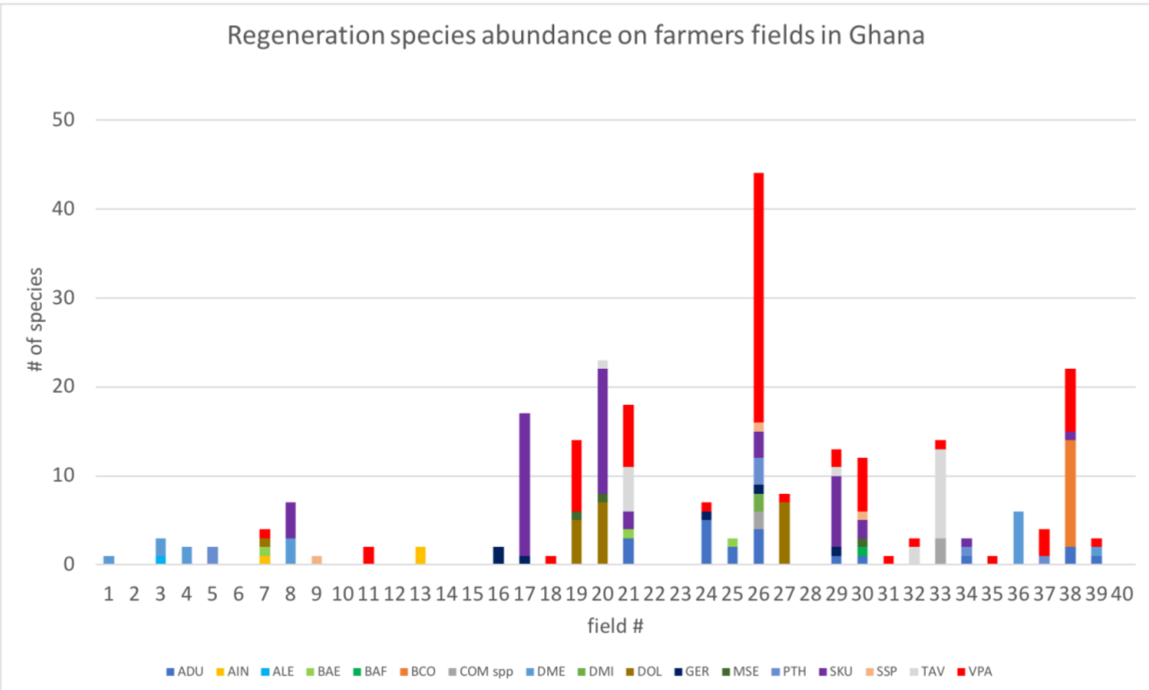


Figure 12: Visualization of the tree species diversity for the adult community and regeneration community on the fields in Burkina Faso and in Ghana

APPENDIX 8: INTERVIEWS' SCORES VALUES

Table 14: Score range for the economic ecosystem service

Score	Economic value: the amount of money generated from tree products
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

Table 15: Score range for the leaf litter contribution to soil fertility ecosystem service

Score	Leaf litter contribution to soil fertility (litter value): observable benefits of leaf litter on soil
5	Exceptional contribution
4	Very good contribution to soil fertility
3	Moderate contribution
2	Minor contribution
1	Very minor contribution
0	No observable contribution

Table 16: Score range for the fodder nutritional value for cattle ecosystem service

Score	Fodder nutritional value for cattle (fodder value): trees that are lopped to feed cattle
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

APPENDIX 9: OPTIMAL MODELS OUTCOMES

Table 17: Optimal model output for soil health variables (SOC, SNC, WIC, ER), showing the variables included in the model, their estimated coefficient (Estimate β), standard error (Std. Error), degrees of freedom (df), t-value or z-value, p-value for the t-test or Z-test (Pr(>|z|) or Pr(>|z|), and significance coding.

<table>
<tr><th>SOC</th><th>Variables</th><th>Estimate β</th><th>Std. Error</th><th>df</th><th>t-value</th><th>Pr(>|t|)</th><th>significance</th></tr>
<tr><td>Lmer*</td><td>(intercept)</td><td>6.24E-01</td><td>8.84E-02</td><td>1.37E+01</td><td>7.053</td><td>6.44E-06</td><td>***</td></tr>
<tr><td></td><td>Sand content</td><td>-1.72E-02</td><td>9.54E-04</td><td>3.11E+02</td><td>-18.054</td><td>< 2e-16</td><td>***</td></tr>
<tr><td></td><td>Vegetation structure</td><td>3.13E-02</td><td>9.67E-03</td><td>3.10E+02</td><td>3.238</td><td>0.00133</td><td>**</td></tr>
<tr><td></td><td>Impact of agriculture</td><td>2.68E-02</td><td>1.11E-02</td><td>3.10E+02</td><td>2.422</td><td>0.016</td><td>*</td></tr>
<tr><td>SNC</td><td>Variables</td><td>Estimate β</td><td>Std. Error</td><td>df</td><td>t-value</td><td>Pr(>|t|)</td><td>significance</td></tr>
<tr><td>Lmer*</td><td>(intercept)</td><td>-3.92E-01</td><td>7.46E-02</td><td>5.50E+00</td><td>-5.263</td><td>2.49E-03</td><td>**</td></tr>
<tr><td></td><td>Sand content</td><td>-1.59E-02</td><td>8.44E-04</td><td>3.16E+02</td><td>-18.891</td><td>< 2e-16</td><td>***</td></tr>
<tr><td>WIC</td><td>Variables</td><td>Estimate β</td><td>Std. Error</td><td>df</td><td>t-value</td><td>Pr(>|t|)</td><td>significance</td></tr>
<tr><td>Glm*</td><td>(intercept)</td><td>1.945139</td><td>0.611636</td><td></td><td>3.18</td><td>0.00326</td><td>**</td></tr>
<tr><td></td><td>Sand content</td><td>0.009279</td><td>0.00863</td><td></td><td>1.075</td><td>0.29033</td><td></td></tr>
<tr><td></td><td>Vegetation structure</td><td>0.067897</td><td>0.037136</td><td></td><td>1.828</td><td>0.07684</td><td></td></tr>
<tr><td></td><td>Impact of grazing</td><td>0.141154</td><td>0.102321</td><td></td><td>1.38</td><td>0.1773</td><td></td></tr>
<tr><td></td><td>SLA CWM</td><td>-0.107798</td><td>0.03557</td><td></td><td>-3.031</td><td>0.0048</td><td>**</td></tr>
<tr><td>ER</td><td>Variables</td><td>Estimate β</td><td>Std. Error</td><td>df</td><td>z-value</td><td>Pr(>|z|)</td><td>significance</td></tr>
<tr><td>Glmer*</td><td>(intercept)</td><td>-2.249157</td><td>1.449787</td><td></td><td>-1.551</td><td>0.12081</td><td></td></tr>
<tr><td></td><td>Sand content</td><td>-0.001144</td><td>0.01953</td><td></td><td>-0.059</td><td>0.95331</td><td></td></tr>
<tr><td></td><td>Vegetation structure</td><td>0.181341</td><td>0.088199</td><td></td><td>2.056</td><td>0.03978</td><td>*</td></tr>
<tr><td></td><td>Impact of grazing</td><td>1.051954</td><td>0.341784</td><td></td><td>3.078</td><td>0.00209</td><td>**</td></tr>
<tr><td></td><td>LT CWM</td><td>3.443901</td><td>2.380002</td><td></td><td>1.447</td><td>0.14789</td><td></td></tr>
</table>

*Lmer/glmer were carried when both Burkina Faso and Ghana were included in the model, and the site was included as random factor. A glm was carried for WIC because only data from Burkina Faso was used.

** A general structure of increasingly complex alternative models with the relevant independent variables categories was set up, and a forward selection followed to get the optimal model (table 3). The optimal models were selected based on the lowest AIC. If the lowest AIC had the same value (difference lower than 2) for multiple models, the model with the highest r-square was selected

Appendix 10: Visualization of the tree species average scores per ecosystem service in Burkina Faso and in Ghana

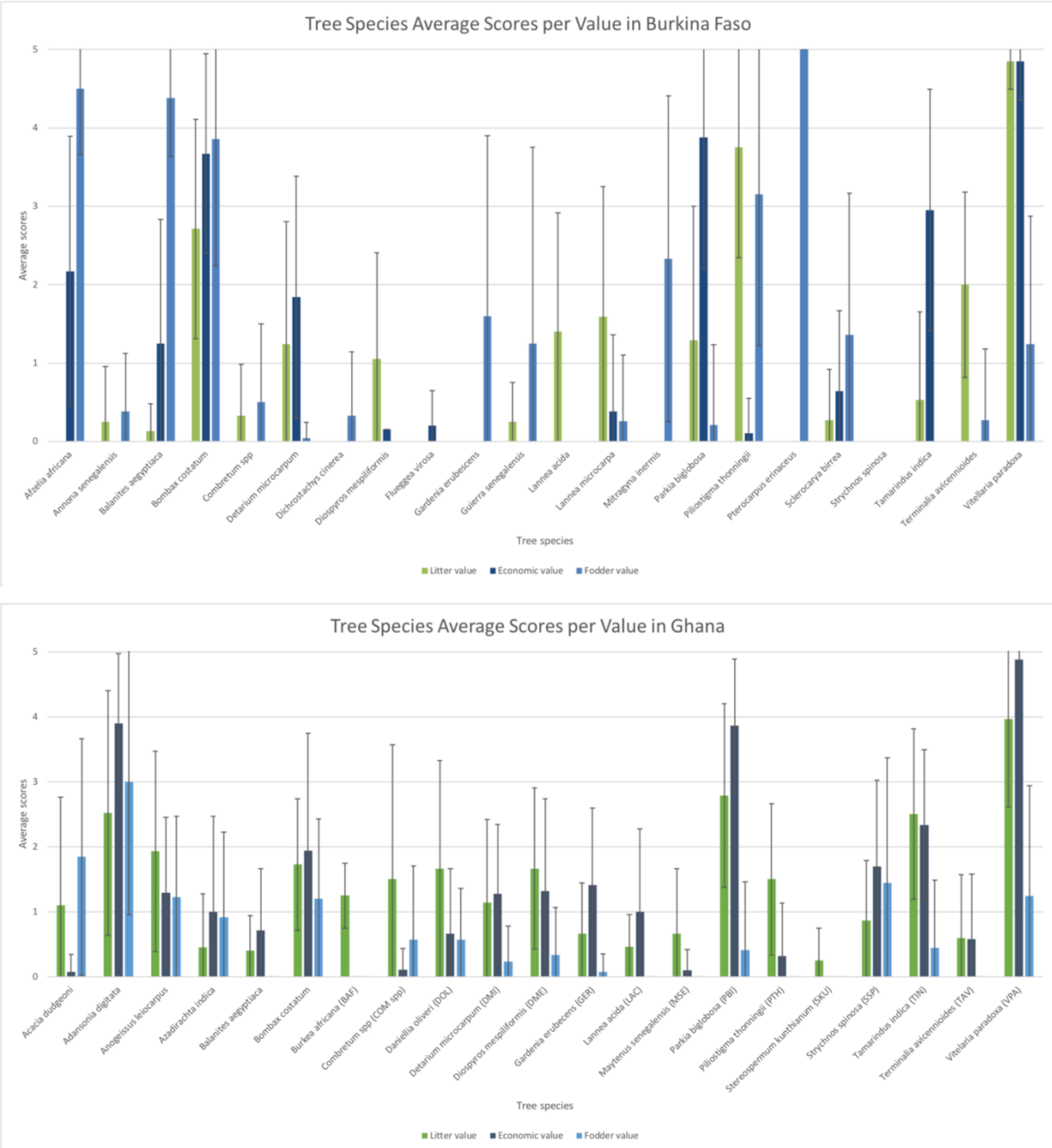


Figure 13: Visualization of the tree species average scores (out of 5, being the highest) per ecosystem service with the standard deviations in Burkina Faso and in Ghana.

Appendix 11: Value scores differentiation among groups

Table 18: Kruskal-Wallis rank sum test to check for a difference in economic value and litter value scoring between the Burkinabe and Ghanaian sites, the three Burkinabe communities, the four Ghanaian communities, the Burkinabe farmers with and without training, the Burkinabe farmers gender.

Sites	chi-squared	df	p-value
Economic value	0.8583	1	0.3542
Litter value	0.1451	1	0.7033
Communities BF	chi-squared	df	p-value
Economic value	2.2073	2	0.3317
Litter value	3.4383	2	0.1792
Communities Gh	chi-squared	df	p-value
Economic value	2.799	3	0.4236
Litter value	5.6973	3	0.1273
Training	chi-squared	df	p-value
Economic value	0.0046	1	0.9458
Litter value	0.5199	1	0.4709
Gender	chi-squared	df	p-value
Economic value	0.0002	1	0.9892
Litter value	0.0803	1	0.7769