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KURZFASSUNG

Der steigende Bedarf an Nahrungsmitteln und Energie aus Holzbrennstoffen stellt für die Wälder in Ghana eine große Bedrohung dar. Um die Abholzung und die Bedrohung wichtiger Ökosysteme zu stoppen, empfehlen Vertreter aus Politik und Wissenschaft integrierte Landnutzungssysteme, die den Nahrungsmittel- und Brennholzbedarf der Haushalte decken können.

Der Anbau von Bambus wird als eine mögliche Lösung des Problems erachtet, da er bereits in Teilen Asiens und in einigen tropischen Regionen erhebliche sozioökonomische und ökologische Vorteile gebracht hat. Es ist jedoch ungewiss, inwieweit die Bauern den Bambusanbau akzeptieren würden und ob bambusbasierte Mischkulturen die Nahrungsmittelproduktion sowie die Energieversorgung der Haushalte decken können. Darüber hinaus sind die Kenntnisse über mögliche ökologische Wechselwirkungen zwischen Bambus-Mischkultursystemen und Ackerkulturen begrenzt. Allerdings wäre dieses Wissen vonnöten, um die Produktivität des Bambusanbaus zu erhöhen.

Die vorliegende Studie untersucht das traditionelle ökologische Wissen und die ökologischen Aspekte des Bambusanbaus anhand von Fragebogeninterviews, Literaturrecherchen und Feldexperimenten. Des Weiteren werden die Potentiale und Implikationen des Bambusanbaus sowie dessen Tauglichkeit als Landnutzungssystem für die Ernährungssicherung und den Brennholzbedarf von Haushalten betrachtet. Die Studie wurde in der sogenannten *Dry Semi-Deciduous Forest Zone (*DSFZ) in Ghana durchgeführt. Zwei exotische Bambusarten wurden für verschiedene Bambus-Mischkulturen und ökologische Versuche verwendet: *Bambusa balcooa* und *Oxytenanthera abyssinica*. Die Studie steht im Einklang mit der Wachstums- und Armutsbekämpfungsstrategie Ghanas und fällt unter das übergeordnete Ziel des Arbeitspakets 4.4 des von der deutschen Regierung geförderten Projekts *BiomassWeb*.

Im ersten Kapitel werden die Grundlagen, der Umfang, die Forschungsfragen und die Ziele dargelegt. Im zweiten Kapitel werden die sozioökonomischen und kulturellen Potentiale des Bambusanbaus auf globaler, regionaler wie lokaler Ebene vorgestellt. Ferner wird ermittelt, welches Forschungsinteresse in Ghana vorhanden ist. Die Forschungsmethodik, das Untersuchungsgebiet und die experimentellen Verfahren werden in Kapitel drei vorgestellt. Die in Kapitel vier ausgewerteten Daten von 200 Landwirten aus der *Dry Semi-Deciduous Zone* in Ghana zeigen, dass das traditionelle Wissen der Landwirte über Bambus, insbesondere seiner Verwendung für die Holzkohle- und Futterproduktion, ein einflussreicher Faktor für die Akzeptanz des Bambusanbaus sind. Zu den wichtigsten Faktoren, welche die Integration von Bambus in traditionelle Anbausysteme beeinflussen, zählen das Alter und Geschlecht der Bauern, die Art des Anbausystems und die regelmäßige Praxis, Bäume auf den Ackerflächen zu lassen.

Im fünften Kapitel wird die Wahrnehmung der Bauern von Bambusstreu als Nutztierfutter, sowie die Qualität des Bambusstreus im Hinblick auf die Ziegenzucht untersucht. Von den Befragten wussten nur 26%, dass Bambusblätter als Futter dienen können. Außerdem stellte sich heraus, dass es bei der Akzeptanz von Bambus als Tierfutter geschlechtsspezifische Unterschiede gibt. 64% der Befragten waren bereit, ihre Tiere mit Bambusblättern zu füttern, sofern diese sich als geeignet erwiesen. Von diesen 64% waren 47% Männer und 17% Frauen.

Die Qualitätsanalyse des Futters ergab, dass die höchste Rohprotein- und In-vitro-Gasproduktion mit *Oxytenanthera abyssinica* stattfindet. Außerdem gab es bei der *O. abyssinica*-Diät den höchsten Tagesgewinn und das niedrigste Verhältnis von Futter zu Gewinn. Der Behandlungseffekt erwies sich als signifikant für die gemessenen Blutvariablen. Das fünfte Kapitel kommt zu dem Ergebnis, dass Bambusblätter ein nützliches Ergänzungsfutter sind, wie ihr

Nährwertprofil und ihr positiver Einfluss auf das Wachstum der Ziegen zeigt, und dass die Bauern bereit sind, Bambusblätter als Futter für die Tierproduktion, insbesondere für Ziegen, zu verwenden.

Im sechsten Kapitel wird das agronomische Potenzial von Bambus untersucht, indem die Wirkung des gemischten Bambusanbaus mit Mais, Augenbohnen sowie Maniok im Vergleich zu Monokulturen dieser Nutzpflanzen und Bambus untersucht wurde. Die Ergebnisse zeigen, dass – unabhängig von der Düngemittelbehandlung – der Bambusanbau und die Monokulturen vergleichbare Auswirkungen auf die Bodeneigenschaften sowie auf die Pflanzenproduktivität hatten. Der Vorteil von Zwischenkulturen im Vergleich zu Monokulturen war offensichtlich für alle Nutzpflanzen mit teilflächen-äquivalenten Verhältnissen für gedüngte und nicht-gedüngte Zwischenkulturen: Für Augenbohnen wurden Werte von 1,37 bzw. 1,54 aufgezeichnet, für Mais 1,38 bzw. 1,36 und für Maniok 1,12 bzw. 1,19.

Im siebten Kapitel werden die Zersetzungs- und Nährstofffreigabeprozesse des Bambus mit fünf anderen, traditionell genutzten Mehrzweckbäumen (MPTs) verglichen. Die Ergebnisse weisen darauf hin, dass Bambus eine sinnvolle Alternative für die Agroforstwirtschaft darstellen könnte.

In den Kapiteln acht und neun werden die sozioökonomischen und ökologischen Potentiale der Bambus-Agroforstwirtschaft sowie mögliche Verbesserungen der Nahrungsmittel- und Energieproduktion kleinbäuerlicher Gemeinschaften diskutiert. Weiterhin wird das Gesamtpotential der Bambus-Agroforstwirtschaft für eine künftige Adoption und Hochskalierung dargestellt. Zudem werden die Grenzen dieser Arbeit sowie weitere Verbesserungsvorschläge aufgezeigt.

Die Studie befasst sich mit den Potentialen des Bambusanbaus. Sie richtet die Aufmerksamkeit des Lesers auf die Befunde, die zeigen wie Kleinbauern ihr Einkommen erhöhen und sozioökonomische Verbesserungen schaffen können, indem sie Bambus anbauen, um produktive Systeme für nachhaltige Agrar-und Brennholzproduktion zu schaffen. Der Nahrungsmittel- und Energiebedarf Ghanas könnte so gesichert werden. Die Ergebnisse dieser Studie können Kleinbauern dazu anregen, den Bambusanbau einzuführen. Der Regierung Ghanas sowie den Entwicklungspartnern im Bereich Bambusanbau wird vorgeschlagen jene politische Maßnahmen zu fördern, die das Land schützen und die Entwicklung vorantreiben. Vor allem können die Ergebnisse dieser Studie lehrreich sein für die Strategie der ghanaischen Politik in Bezug auf die Bioenergieproduktion. Auch für die Regierungskampagne *„planting for food and jobs“* kann diese Studie wertvolle Einsichten liefern, um den Nahrungsmittel- und Energiebedarf zu sichern.

ABSTRACT

In Ghana, the rising need for household energy from wood fuels and food needs is considered a major threat to forest resources conservation. Government and scientists believe that the alarming rate of deforestation and threats to important ecosystem services will not cease unless integrated land-use systems that meet the food and fuelwood demands of households are in place. Bamboo agroforestry is currently considered a possibility in view of the significant socioeconomic and ecological benefits obtained in some parts of Asia and some other tropical regions. Meanwhile, it is unclear whether bamboo would have social acceptability to be planted on farmers' fields and the extent to which bamboo-based intercropping systems will sustain food production and household energy security. In addition, knowledge of possible ecological interactions between mixed bamboo and arable crop systems are limited but would be necessary to inform management decisions applicable to improving the productivity of bamboo agroforestry systems. Using questionnaire interviews, literature review and field experiments, this study explored the traditional ecological knowledge and ecological aspects of bamboo agroforestry and accentuated implications on its adoption potential and suitability as a land-use system for household food security and fuelwood needs. The study was conducted in the Dry Semi-deciduous Forest Zone (DSFZ) of Ghana. Two exotic bamboo species; *Bambusa balcooa* and *Oxytenanthera abyssinica* were used for various bamboo intercropping and ecological trials. The premise of the study fits into Ghana's Growth and Poverty Reduction Strategy and falls within the overarching aim of Work Package 4.4 of the BiomassWeb project sponsored by the German government.

In Chapter one, the rationale, scope, research questions, and objectives are stated. In Chapter two, socioeconomic and cultural potentials of bamboo agroforestry are previewed on global, regional and local scales. Bamboo agroforestry potentials and research needs in Ghana are also established. The research methodology, study area, and field experimentation procedures are presented in Chapter three. Results from data collected from 200 farmers in the dry semi-deciduous forest zone of Ghana in Chapter four show that farmers' traditional knowledge of bamboo, particularly, its use for charcoal production and leaves for fodder are influential determinants of bamboo agroforestry adoption. Also, farmers' age, gender and the regular practice of leaving trees on farmlands and type of cropping system are the most significant predictors influencing bamboo integration into traditional farming systems. In Chapter five, where farmers' perception of bamboo litter for livestock fodder and litter quality trials on goat's production were prospected, only 26% of respondents were aware bamboo leaves could be fed to livestock. It was evident gender may be an influential factor in determining the acceptability of bamboo fodder. Out of the 64% respondents who expressed willingness to feed their animals with bamboo leaves if demonstrated to be suitable, 47% of them were males whilst 17% were females. The fodder quality analysis showed the highest crude protein and *in vitro* gas production occur in *Oxytenanthera abyssinica*. Besides, *O. abyssinica* diets gave the highest daily gain and the lowest feed to gain ratio. The treatment effect was significant on blood variables measured. It is concluded in this Chapter that, bamboo leaves are viable feed supplement for goats as shown by their nutrient profile and positive influence on growth performance of goats and that, farmers are willing to use bamboo leaves as fodder for livestock production, particularly, goats. In Chapter six, agronomic potentials of bamboo were explored by investigating the effect of bamboo agroforestry with maize, cowpea, and cassava as against monocultures of the crops and bamboo. The results show that regardless of fertilizer treatments, bamboo agroforestry and monocropped fields

had comparable effects on soil properties and crop productivity within two years of establishment. Intercropping advantage over monocropping was evident for all crops with partial land equivalent ratios for fertilized and non-fertilized intercropping systems with cowpea recording 1.37 and 1.54, respectively; 1.38 and 1.36, respectively, for maize and 1.12 and 1.19, respectively, for cassava. Decomposition and nutrient release patterns in bamboo were comparable to those from five other traditionally used agroforestry Multipurpose Trees/Shrubs (MPTs) in Ghana in Chapter seven; indicating that bamboo could be a useful alternative agroforestry candidate species.

In Chapters eight and nine, the socioeconomic and environmental potentials of bamboo agroforestry and its consequential potential for improvements in food and energy production for smallholder farming communities are discussed. Also, the overall potential of the bamboo agroforestry for potential adoption and upscaling is presented. The limitation of this thesis is indicated and perceived areas for further improvements are suggested.

By dwelling on the prospects of bamboo, this thesis compels readers to focus attention on the evidence of how smallholder farmers could increase income streams and levels for socio-economic improvements using bamboo agroforestry to maintain productive systems for sustained agricultural and fuelwood production. This could facilitate the attainment of food and energy security in Ghana. With this, the findings of this study may encourage bamboo agroforestry adoption by smallholder farmers. It is suggested that the Government of Ghana and development partners should adopt bamboo agroforestry in land-use conservation and development efforts through policy reviews and invigoration. Particularly, lessons could be drawn from the findings of this study for the Ghana bio-energy production policy and the strategies for the flagship policy of planting for food and jobs, rolled out by the government in the quest to attain food and energy security in Ghana.

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DEDICATION

I dedicate this thesis to the memory of my late senior sister, Mary Akoto. Sister Mary, on my first day at college, looked straight into my face and told me I will one day possess a Ph.D. degree. This was after she sought and gained admission for me to begin my academic work at the second cycle education in 1987(she stood in for our late father). Although she is no more, this foresight she declared to me spurred me on in spite of challenging moments, yet to strife harder to achieve this feat she yearned for. May her gentle soul rest in perfect peace!

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LIST OF ACRONYMS AND ABBREVIATIONS

SSA	-	Sub-Saharan Africa
FAO	-	Food and Agriculture Organization
SDGs	-	Sustainable Development Goals
AFREA	-	Africa Renewable Energy Access Program
GHGs	-	Green House Gases
NEPAD	-	New Partnership for Africa's Development
GDP	-	Gross Domestic Product
IEA	-	International Energy Agency
DSFZ	-	Dry Semi-Deciduous Forest Zone
FSD	-	Forest Services Division
FD	-	Forestry Department
MoFA	-	Ministry of Food and Agriculture
NGOs	-	Non-Governmental Organizations
MPTs	-	Multipurpose Trees and Shrubs
REDD+	-	Reduced Emission from Deforestation and Degradation
MTS	-	Modified Taungya System
FIP	-	Forest Investment Programme
AF	-	Agroforestry
CCFI	-	Collaborative Community Forestry Initiative
GhRRM	-	Ghana Rural Reconstruction Movement
GAP	-	Ghana Primewood Products Limited
GIDA	-	Ghana Irrigation Development Authority
FC	-	Forestry Commission of Ghana
INBAR	-	International Bamboo and Rattan Organization
MAI	-	Mean Annual Increment
BARADEP	-	Bamboo and Rattan Development Programme

IUFRO	-	International Union of Forest Research Organizations
GSGDA	-	Ghana Sacred Growth and Development Agenda
OECD	-	Organization for Economic Co-operation and Development
UNDP	-	United Nations Development Programme
UNECA	-	United Nations Economic Commission for Africa
WB	-	World Bank
DFID	-	Department for International Development
ISSER	-	Institute of Statistical, Social and Economic Research
NTFPs	-	Non- Timber Forest Products
AFU	-	Agriculture and Forestry University
AFOLU	-	Agriculture and Forestry land Use
BARNET	-	Bamboo and Rattan Network of Ghana
KEFRI	-	Kenya Forestry Research Institute
GPRS	-	Ghana Poverty Reduction Strategy
IPCC	-	Intergovernmental Panel on Climate Change
LER	-	Land Equivalent Ratio
DM	-	Dry matter

1. General Introduction: Bamboo agroforestry and research needs in Ghana

1.1. Background

Deforestation emanating from excessive wood extraction for wood fuels, and to allow for agricultural production continues to be a major hindrance against development attempts in Sub-Saharan Africa (SSA) (FAO, 2016a; FAO, 2010). This phenomenon is precarious in most developing countries. With human population rate acceleration cling with the threat of traditional agricultural practices characterized by shifting cultivation and slash and burn agriculture manifest in unsustainable food and energy supply (FAO, 2010; Songsore, 2003; Oldeman et al., 1991). The quest to optimize agricultural production with the intent of real-time access to food has ensured a decline in terrestrial ecosystem structure and function (FAO, 2017). Considering that human populations among forest fringe communities are on the increase, deforestation menace cannot be underestimated. Land-use systems that sustain agricultural productivity and environmental integrity should be a viable option for controlling deforestation. According to Atangana et al. (2013) agroforestry (AF) – intentional management of (shade) trees with crops/or animals, is one of the most promising approaches to reducing deforestation in the tropics while enhancing rural livelihoods.

Bamboo advocacy for biodiversity conservation and reduced pressure on commercial timber through contemporary forest management and sustainable agricultural development has netted endorsement by stakeholders in Ghana (Forestry Commission, 2015). In addition, the Bamboo and Rattan Development Programme (BARADEP) in Ghana has established that bamboo could be a sustainable source of biomass energy. Ghana's government reiterated the commitment for greater bamboo cultivation by introducing 18 exotic species of bamboo from Asia for bioenergy production in 2015 (Forestry Commission, 2016). While bamboo cultivation has several socioeconomic benefits, bamboo monocropping systems could impact adversely food security, considering the pressure on agricultural land. It is therefore imperative to explore possible integration of bamboo into indigenous cropping systems. In Asia, the integration of bamboo within agricultural systems is confirmed as a suitable approach for increased productivity of food crops and non-food biomass (Mailly et al., 1997). However, science-based bamboo agroforestry is yet to be explored in Ghana and available data to prove its suitability is lacking. Besides, there is limited information on social acceptability and knowledge on the ecological interactions between bamboo agroforestry components (bamboo + associated crops) so as to inform how complementarity between components could be improved for increased system productivity and for the adoption of this technology in Ghana. Using questionnaire interviews, literature review and field experiments, this study, explored the social compatibility of bamboo cultivation, evaluated the ecological interactions within an agroforestry system (alley cropping system) and accentuate implications on soil and crop productivity for adoption into farming systems in Dry Semi-deciduous Forest Zone (DSDZ) Ghana. This research was conducted within the purview of work package 4.4 (innovative management and utilization for bamboo biomass in agroforestry systems) for the African BiomassWeb project which was funded by the German Federal Ministry of Education and Research (BMBF) and administered via the International Organization for Bamboo and Rattan (INBAR) in Ghana. Results are expected to directly feed into work package 4.4-: Agroforestry systems for biomass production and food security in Ghana.

1.2. Research scope and rationale

1.2.1. Socioeconomic and cultural aspects of bamboo agroforestry development

According to the technology transfer diffusion theory, as explained by Rogers (2003), land users always consider a combination of social, cultural and economic factors in deciding on introduced innovations. It is, therefore, crucial to assess the socio-economic and cultural aspirations of intended users during or before technology transfer. Considering the dynamic and changing nature of agricultural practices in SSA and Ghana, in particular, understanding the factors that drive changes within the intended locality may also help guide strategies to promote sustainable bamboo agroforestry (Partey et al., 2017a). In Chapters 4 and 5 we explore socioeconomic indicators and farmer perception on bamboo fodder and its potential as supplemental feed for livestock production to address research sub-questions 1 and 2 respectively.

1.2.2. Ecological interactions in a bamboo-based agroforestry system

The successful integration of bamboo on farmlands would depend on farmer co-operation. According to Ammanor (1996), farmers are most likely to adopt technologies that improve the soil and enhance their crop yields. The evaluation of ecological interactions introduced by bamboo on the crop field is necessary to ascertain the potential of bamboo to improve soil productivity and crop yields. Consequently, crop and soil productivity within bamboo intercropping system is evaluated. Also, litter mass loss and release of nutrients of bamboo leaves are conducted and compared with other traditionally known and used multipurpose trees and shrubs (MPTs) in Chapters 6 and 7 of this thesis respectively, to address sub-questions 3 and 4 of the research respectively.

1.3. Research questions

1.3.1. Main research question

The study broadly sought to answer the main question: Is bamboo agroforestry agronomically and socio-ecologically compatible with crop production systems in Ghana? This is, however, met by splitting into four explicit sub-questions that are precisely addressed with specific objectives.

1.3.2. Sub-research questions

1. What are the socioeconomic indicators (traditional crop production system characteristics, farmer bamboo ethnobotany) for bamboo agroforestry adoption/development in the DSFZ of Ghana? This is addressed by objective 1 in Chapter 4 of this thesis.
2. Could bamboo leaves be considered as fodder for livestock and what is the perception of livestock farmers on bamboo fodder for livestock production? Objective 2 explores the fodder potential of bamboo for livestock production in Chapter 5.
3. What preliminary ecological and economic interactions are induced by a growing bamboo in a bamboo-based alley cropping system and what is the effect of such interactions on crop and soil productivity? In Chapter 6 objective 3 is used to answer this research question.
4. Is bamboo comparable to other traditionally known agroforestry species in ecosystem function potential; how different are the decomposition and nutrient release of bamboo from other traditional multipurpose trees and shrubs (MPTs)? This question was addressed with the help of objective 4 and presented in Chapter 7 of the thesis.

1.4. Objectives

1.4.1. General objective

Generally, the research sought to explore the socio-ecological potential of bamboo for household energy and food production as a basis for the introduction of bamboo agroforestry in the DSFZ of Ghana.

1.4.2. Specific objectives

Specifically, the research sought to:

1. Identify socio-economic indicators of bamboo use for agroforestry development in the DSFZ of Ghana. This objective addressed research sub-question 1 and is presented in Chapter 4.
2. Assess farmer perception and bamboo leaf litter potential for fodder for livestock production in the DSFZ of Ghana. In Chapter 5, this objective was used to answer research sub-question 2.
3. Evaluate crop performance, soil properties and economic impact within bamboo-based agroforestry systems. Chapter 6 prospected the ecological role of bamboo, using objective 3 to provide feedback to research sub-question 3.
4. Determine decomposition and nutrient release of bamboo and compare with other traditional agroforestry MPTs. This ecological potential of bamboo in the agroforestry system was prospected with this objective in Chapter 7 to answer research question 4.

1.5. Limitation of the study

The research was conducted within three years of bamboo establishment and therefore conclusions are based on only findings within three years and not beyond. The study on socioeconomic indicators of bamboo agroforestry could not cover detailed economic analysis because bamboo trade in the study region is relatively new (although farmers consider socio-economic factors in making decisions on the choice farming practices). Economic evaluation is important in wrapping up the understanding of the farmer decision process in this study. The study on the ecological interaction of bamboo and test crops used only one intercropping design as recommended by Nath et al., (2009). Different planting densities with more than the three crops could be explored.

1.6. Structure of the thesis

This thesis is presented in ten (10) Chapters. CHAPTER 1: Chapter one introduces the study with concepts of bamboo agroforestry, rationale, scope and objectives of the study. The relevant literature review is presented in Chapter 2 to provide a theoretical framework on the potentials of bamboo-based agroforestry and research needs in Ghana. CHAPTER 3 gives the study area description, study design and experimental procedures: CHAPTER 4: Chapter four begins the results section and presents general farmer traditional ecological knowledge on bamboo, cropping practices and the socio-economic factors which influence farmer decision on bamboo agroforestry adoption in the study region. CHAPTER 5: Chapter five explores farmers' perception and the potential of bamboo leaf forage for domesticated animal production in the dry semi-deciduous woodland zone of Ghana. CHAPTER 6: In Chapter six, we evaluated the ecological interactions and agronomic effect of bamboo on food crops (maize, cassava, and cowpea as test crops), soil productivity and economic potential of bamboo agroforestry in a bamboo-based agroforestry system. CHAPTER 7: Chapter seven concludes the results section with a comparative study on bamboo leaf litter decomposition and nutrient release with other traditional agroforestry MPTs. CHAPTER 8: A synthesis of key findings from all results sections is presented in Chapter eight as a general conclusion with a general discussion on major findings coming out of the study. CHAPTER 9: In Chapter nine, the outlook of the thesis is presented; areas for further research for bamboo agroforestry development in Ghana, methodological shortfalls and efficiencies; and the general recommendations for policy uptake are outlined for upscaling of bamboo-based agroforestry in Ghana. CHAPTER 10: Chapter ten presents a list of literature cited. Key contributors to the study are also duly acknowledged.

1.7. Research focus and outcomes

Figure 1.1 conceptualizes the research idea with the main aim of exploring socio-ecological and agronomic potentials of bamboo agroforestry in Ghana; split into four thematically focused areas as socio-cultural and traditional ecological knowledge; traditional/cultural farming practices compatibility with bamboo agroforestry; ecological and agronomic potential of bamboo agroforestry; and environmental considerations of bamboo agroforestry in Ghana. These four areas are interconnected, and to the main aim of the research through farmer aspirations and socioeconomic gains. They also drive the focus for field exploration and are underpinned by the information from field experimentation to complete the loop for this bamboo agroforestry development research. Two main outputs could be fashioned out; determination of farmer bamboo ethnobotany and potential adoption of bamboo agroforestry, and ecological and agronomic potential of bamboo within bamboo agroforestry. Subsequently, 2 key outcomes could be framed from the research: A Ph.D. with the philosophy of possible bamboo integration into the agroecological systems in Ghana; and the contribution to the development of protocols for bamboo agroforestry practices in Ghana.

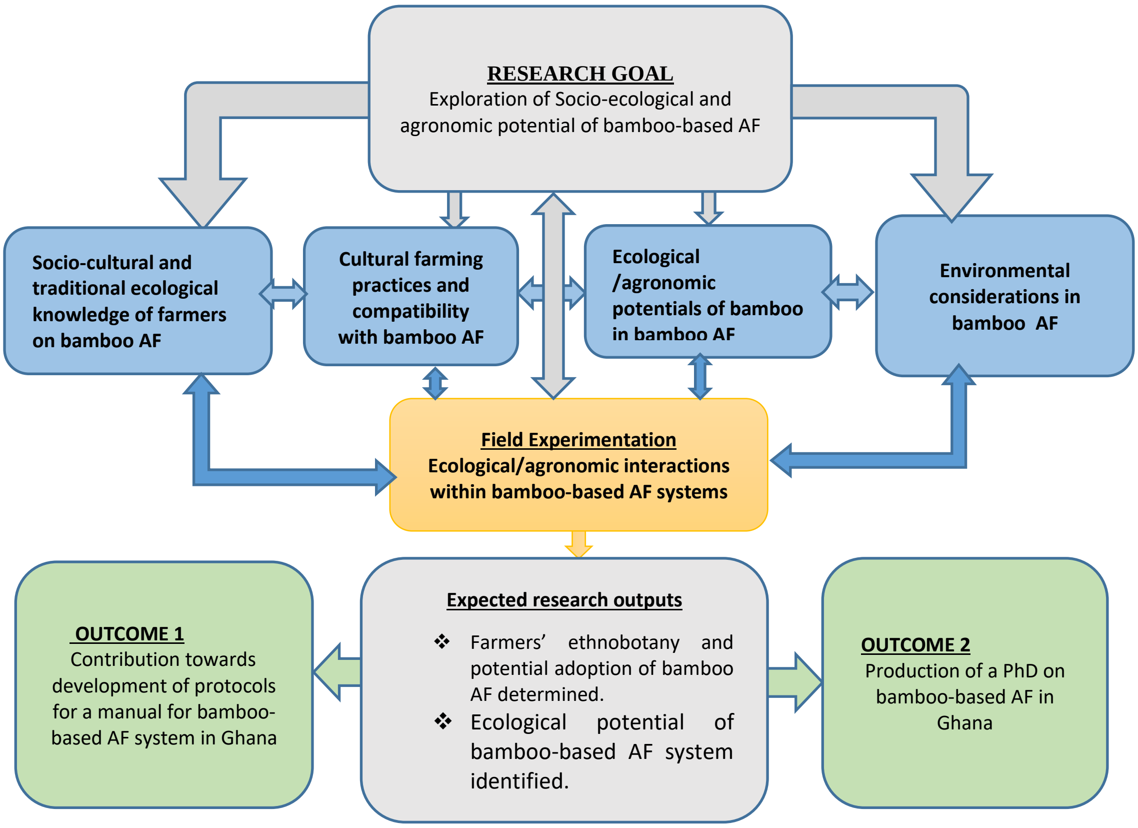

Figure 1.1: Schematic representation of the research focus (Author's construct, 2017)

2. State of-the-art

2.1. Agriculture and fuelwood production

Wood harvesting for wood fuel and agricultural production are the major sources of bio-energy and food production in most developing tropical countries and militate against development by causing forest/land degradation (FAO, 2016a), and at times, deforestation.

Agriculture is the mainstay of most national economies of SSA and its development has significant implications on food security and poverty reduction as highlighted in the United Nation's Sustainable Development Goals (SDGs) (Partey et al., 2017a). Although an economic booster, the traditional methods of agricultural land preparation mostly slash and burn are catalysts of land and environmental degradation (Plate 2.1). Consequently, food production has not to match with the ever-increasing general populace (Partey et al., 2017a). Besides the conversion of forest lands into farmlands, available literature point to fuelwood consumption as one major anthropogenic cause of deforestation in SSA (FAO, 2013). For instance, AFREA (2011) reports that unsustainable wood harvesting and charcoal production influences deforestation and woodland degradation, just as the discharge of ozone-depleting substances (GHGs) influencing global warming. As highlighted in Figure 2.1, fuelwood/charcoal production is among the key forest degradation and deforestation drivers in Africa (FAO, 2017). In developing countries, it appears smaller industries and households largely depend on fuelwood and charcoal for energy. An earlier study indicated that about 2.4 billion people and over representing approximately one-third of the global populace depend on the conventional utilization of wood fuel for food preparation, then several thousands of small enterprises use fuelwood and charcoal as the principal energy sources for baking, tea processing and brickmaking (AFREA, 2011). It is evaluated that about 50% of the wood harvested from forests worldwide goes into fuelwood and charcoal production (FAO, 2017).

A projection of increased degradation of forest resources due to fuelwood consumption and charcoal production is made, and which could have seemingly devastating consequences on many national economies of SSA and forest fringe communities who derive their livelihoods from non-timber forest products (Imo, 2009; Amuah, 2011). For future sustainable development, it would be imperative to resolve these problems, particularly, stabilizing food security and coping with the varying environment (Batish et al., 2008). A land-use system that can provide these basic needs of life and sustain the environment is considered key in the development trajectory. Managing the forest and agriculture trade-offs have the potential to enhance the realization of sustainable development goals (FAO, 2016b). Agroforestry proposes potential answers for the two kinds of issues: they increase farm production simultaneously as fighting ecological debasement (Nair, 1993). They are particularly fit for smallholder farmers in the tropics (FAO, 2006).

Agroforestry can contribute substantially through its multiple benefits and ecosystem services and may provide a means for diversifying production systems and increasing farmers' enthusiasm to continue to sustain production systems (Partey et al., 2017a). Farmers gain the opportunity to diversify farm incomes and stabilize the production system for sustainability by using trees. However, the choice of suitable multipurpose agroforestry tree species is most often a challenge that frequently leads to abandonment of promising agroforestry technologies/interventions (FAO, 2003).

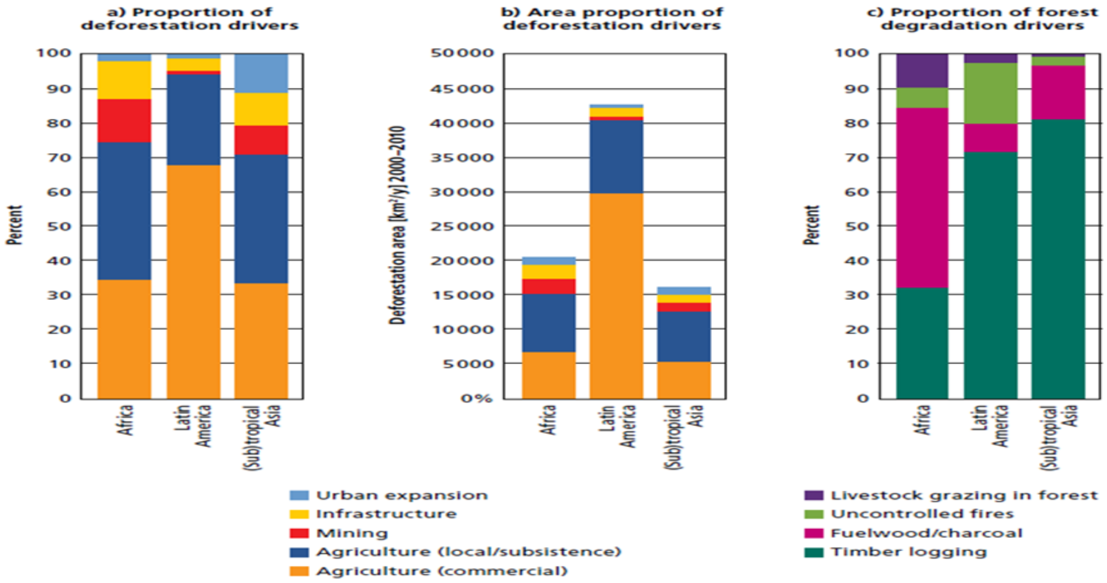

Figure 2.1: Global degradation and deforestation drivers and area proportion in three world regions (Source: FAO, 2016d)

2.2. State of agriculture in Africa

Agriculture is the pillar of the economy of most African States especially those in SSA and plays a major role in their economic growth and development. Agriculture is the division from which the majority of the population draws their employment, and their welfare is attached legitimately to the efficiency of the assets available to them (FAO, 2005). The non-farm populace likewise depends intensely on agriculture, as a greater proportion of their income is spent on food. Agriculture is growing in SSA but the growth is precarious (FAO, 2006). In most countries, it is yet to reach the sustained 6% annual rate estimated by New Partnership for Africa's Development (NEPAD) as necessary to meet the Millennium Development Goal of reducing poverty by 2015. This presents a daunting challenge for

SSA in attempts to achieve goals one (No Poverty) and two (Zero Hunger) of the UN sustainable development agenda.

2.2.1. A new paradigm in agricultural production systems

According to FAO (2011), the focus of sustainable agriculture production has been on sustainable intensification that can close yield and productivity gaps in underperforming systems while lessening the negative and improving the positive environmental impacts of agriculture. Smallholder farmers prevail in an environment of increasing population pressure, food insecurity, exceptionally low (and declining) levels of agricultural profitability and quick natural resource degradation (MoFA, 2011). Building agricultural efficiency and food security will require advance and improved technologies. Explicitly, broad dissemination of recently developed and existing technologies – and agricultural research and innovative work (R&D) institutions are the channels through which this will happen (World Bank, 2003). Potential alternative cropping systems are imperative to improve agricultural productivity. Such land-use systems must sustain agricultural productivity, ensure environmental sustainability, and improve soil conditions and livelihoods of the people (FAO, 2003).

2.3. Agriculture in Ghana

Agriculture remains vital to poverty reduction and economic growth in the 21st century (World Bank, 2008). The sector remains the uppermost contributor to Ghana's Gross Domestic Product (GDP of around 38%), offers employment for the majority of Ghana's population (about 70%) and contributes to about 45% of all export earnings (FAO, 2003). Agrarian make-up plus the district dispersion of farming GDP essentially vary over Ghana's agro-environmental areas (Al-Hassan and Poulton, 2009). On a different tangent, the contribution of agriculture to the overall economic growth is often invisible, which leads to an underestimation of the role of the sector (Diao, 2010). However, evidence from several researchers has established that agriculture affects economic growth. For instance, Tiffin and Irz (2006) found enough evidence that supports the conclusion that agriculture is the main cause of an overall growth rate of an economy. Aryeetey and Fosu (2005) also correlated poverty with growth in agricultural output and found out that at the local level about two-thirds of the reduction in poverty was due to growth in agricultural output. A critique by MoFA (2016) also indicated that crops/livestock productions do not have a significant effect on Ghana's GDP growth. The assertion by Enu is not consistent with Owusu et al. (2017), who reported that cocoa significantly contributes to the economic growth of Ghana.

Despite the support of agriculture to the economy of Ghana, it is reported to be a major driving force of the country's loss of forests. Currently, the deforestation rate in Ghana is estimated at 112.54km^2 per annum and is potentially attributed to poor agricultural practices as mostly reflected by slash and burn systems (Plate 2.1). Banga et al. (2015) reported that Ghana relies heavily on rain-fed agriculture and low input, low-output smallholder systems (less than 2 ha, 90%). This leads to extensive agriculture which results in prevalent deforestation and or land degradation and subsequent reduction in agricultural productivity (FAO, 2010).

In Ghana, agribusiness is dominatingly rehearsed on smallholder, family-worked homesteads utilizing simple innovation (old fashioned-simple tools like the hoe and cutlass) to create about 80% of the all-out yield (Oakley and Garforth, 1985). The greater part of the ranch possessions is under 2 hectares in size despite the fact that there are some huge homesteads and manors especially for elastic, coconut and oil palm, furthermore, on a low degree, rice, maize, and pineapples. There is limited mechanized farming. However, bullock farming is practiced especially in Northern Ghana. Monoculture is mostly associated with commercial or large-scale farms whereas the utmost food crops farms remain intercropped (MoFA, 2011).

Plate 2.1: Slash and burn method of land preparation for farming in Ghana (Source: field data, 2015)

2.3.1. Deforestation, land degradation and sustainable agriculture in Ghana

Population growth, coupled with economic pressures and illegitimate timber harvesting has increased the rate of deforestation of Ghana's natural forests (Misana et al., 2012). A satellite image analysis (Figure 2.2) shows a sharp decline of green cover to large degraded and built-up areas from 1999 to 2010 (FAO, 2010). Deforestation has likewise been on the expansion from anthropogenic stressors of expanding interest for fuelwood, tree grub, timber, shafts and rural land (Misana et al., 2012). Soil erosion, deficiency of fuelwood, land debasement, siltation of water bodies and bringing down of horticultural generation as a rule result from deforestation (Misana et al., 2012). Over-cropping by ranchers has additionally brought about lost vegetation, which takes into account simple soil disintegration with its subsequent exhaustion of soil ripeness (Misana et al., 2012). One critical factor to land degradation is soil erosion which is the most visible and extensive form of soil degradation, with a serious negative consequence on economic development in Ghana depends heavily on the environment (land, forests, and water) for agricultural and rural development (Diao and Sarpong, 2007). Ghana has a relatively substantial size of arable land per capita; nevertheless, most lands are characterized by poor fertility and are subject to degradation (Diao and Sarpong, 2011). To support crop yield increment and guarantee sustenance security, soil nutrient and water assets should be fittingly foreseen and moderated (Quansah, 1996). As per reports by the Environmental Protection Agency (EPA) of Ghana (EPA, 2002), seasonal variability in rainfall, and varied fluxes in spatial distribution ensued over years and decades, resulting in frequent droughts. The major droughts of 1968–73, 1982–85, and 1990–92 with severe hydrological imbalances adversely affected land resources, essentially, freshwater supplies and soil quality in Ghana (EPA, 2002). Evidence of climate change induced-erosion in the coastal areas of the country has also been reported (EPA, 2002). Diao and Sarpong (2007) identified many long-term factors driving vegetation and soil degradation, comprising population pressure, increased urbanization, and climatic changes in Ghana. The noted elements are reflected in agricultural, mining and other production practices that have occasioned soil nutrient depletion through soil erosion, overgrazing, pollution and groundwater depletion. The peripheral effect of the erodibility of soil on yield decline or loss is equivalent to 14 kg/ha for maize in Ghana when Stocking and Peake (1986) coefficient for cowpeas in an exponential equation is adopted, the peripheral yield loss was 3.86 kg/ha for cowpeas. Grounded on the results of Thao (2001), the marginal yield loss is 39.8 kg/ha in the case of cassava. Tully et al. (2015) emphasized that in an agricultural system, it is imperative to consider the biomass generated in both the deliberate and unintended species present.

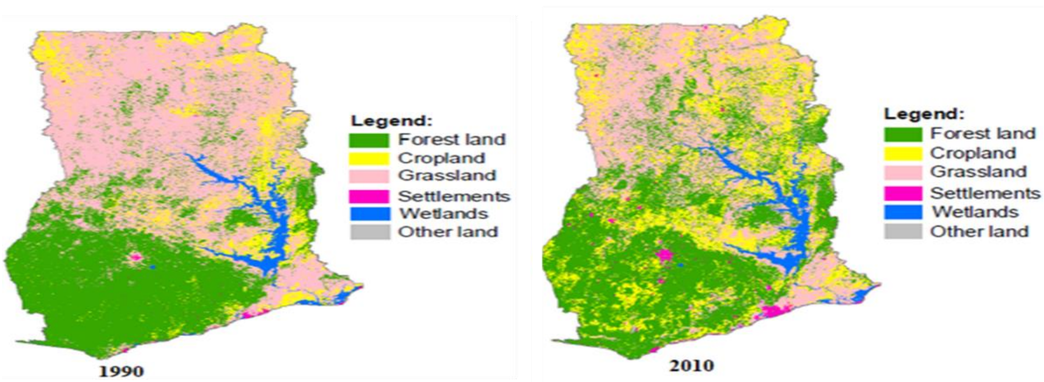

Figure 2.2: Forest vegetation loss in Ghana from 1999-2010 (Forestry Commission, 2016)

2.4. Global bio-energy production and utilization

The continuous accessibility of energy sources at an affordable price is a prime aim for most national energy security sectors. Wood fuel has extensive returns, including large distribution coverage and local abundance; low investment costs and affordability; high potential for renewability and conversion to cleaner fuels, less difficult transportation requirement and storage as a commodity. It is therefore imperative as it constitutes a key component of national energy security, particularly for billions of people with less access to contemporary and commercial energy services and the millions of people challenged with natural or humanitarian crises. However, a significant paradigm shift (2-billion) in demand from the traditional energy source to fossil fuel in recent times may cause pressure

on supply dynamics and the risk of supply interruptions (Mohammed et al., 2014). Wood energy could, therefore, present a strategic option for countries to improve energy security (Mohammed et al., 2014). Wood fuel production is particularly prevalent in most tropical countries which provides a ready source to other parts of the world.

2.5. Bio-energy harvesting, use and impact in Ghana

According to the Ghana Population and Housing Census (Afrane, 2012), about 73% of rural households and 48% of urban households depend on firewood and charcoal, respectively, for cooking, warmth provision and industrial utilization. Charcoal supply predominantly comes from fragile savanna zones, and with lesser amounts from deciduous and rain-forests. Charcoal production is the next most dependent livelihood option after farming especially for inhabitants of the dry semi-deciduous forest zone (DSFZ) (Benhin and Barbier, 2001). Farmers engage in charcoal production during the lean farming season to support income from farming activities (Partey et al., 2017a, c). Utilizing fossil fuels have disadvantages such as; non-renewability of resources and as major drivers of climate change. Policymakers are therefore committed to the search for other forms of alternative energy sources with an emphasis on renewable energy. Ghana is rated among the top one percent of West African countries (FAO, 2016a) with high consumption and demand for wood, and it is reported that the country may lose a gross revenue of US$133.65 million equivalent to 2.6% of its 2008 agricultural sector Gross Domestic Product due to forest loss (Dumenu and Obeng, 2016).

Although a major livelihood source, fuelwood production is a major cause of forest degradation in Ghana. Fuelwood as dominant energy is still widely used among all classes of people in Ghana (Amuah, 2011). As a renewable form of energy, it has been significantly harvested and used in Ghana due to its open-source nature. Fuelwood commercialization is connected to people who do not require an extensive and longer period of training and experience because harvesting requires simple tools and implements (Arnold et al., 2003). The 2010 Ghana Statistical Service (GSS) report highlighted an increase in the country's fuelwood consumption for both rural and urban populations and the statistics have invariably motivated several people to engage in the commercial harvest of fuelwood (GSS, 2010). Gathering and collecting fuelwood alongside farming activities in rural areas involves walking long distances and this impact negatively on production time (Sesabo and Tol, 2005) and its relation to poverty reduction and land degradation (Sunderlin et al., 2005).

2.5.1. Government of Ghana's intervention on vegetation loss

Over the last century, the government of Ghana has been using several approaches in managing forest resources, particularly in dealing with wood use and wood scarcity (Ammanor, 1996). Most popular ones include forest plantation schemes using agroforestry technologies as in the Taungya System, the Modified Taungya System (MTS), National Plantation Program, New National Plantation Program (NNPP), The Ghana Highly Indebted Poor Country (HIPC) Plantation program and, lately, the Forest Investment Programs (FIP) (Forestry Commission, 2015). In the agricultural sector, there has been an encouragement of the use of trees on farms and improvements in tree nursery development schemes (Wireko, 2011). Recent intervention for increased interest in tree planting and agroforestry has been the engagement of experts, researchers, NGOs, students and other development agents for research, training, and exploration of potential multipurpose tree species (MPTs) and technologies to facilitate tree growth, recover vegetation loss and to provide for wood needs and other socio-economic benefits to society (Forestry Commission, 2015; Asare, 2004).

2.5.2. The recognition of agroforestry as an intervention for vegetation loss in Ghana

Agriculture is the predominant livelihood source in the forest zone of Ghana and several forms of farming innovations have evolved over the years (Asare, 2004; Ammanor, 1996). Over the period, woody perennials have been incorporated in the farming systems unconsciously for soil productivity maintenance and to ameliorate microclimate conditions in cropping systems (Ammanor, 1996). Nevertheless, the growing demand for timber, fodder, and fuelwood has greatly reduced the practice of keeping trees on farms. Trees are harvested to make way for more space for farming purposes (Asare, 1999). An interest in and recognition of agroforestry as a suitable land-use intervention has, therefore, become essential to encourage sedentary agriculture and rejuvenate over-burden soils. The potential of nitrogen-fixing trees for improving soil fertility in crop farms and pasture is important.

Again, the prevalence of some trees to harsh conditions such as drought and, the role of windbreaks in protecting cropland and pasture are important factors to consider. It is crucial to identify the contribution of high protein tree fodder to livestock production and the commercial potential of several kinds of tree crops (Ammanor, 1996). In addition to these various paybacks, agroforestry practices are apposite for a wide variety of places within the landscape, not just for cropland or pasture.

2.6. Agroforestry as a land-use system and relevance

Agroforestry as a land-use system has become very relevant in land use management discourse because of the recent spate of land degradation resulting from indiscriminate destruction of vegetation for the production of food and non-food biomass (FAO, 2016c). Socioeconomic as well as environmental particularly, climate change-related problems are being ameliorated through agroforestry practices in several regions of the world (Verchot et al., 2007). Agroforestry's potential to resolve these environmental problems has already been proven (Partey et al., 2017a).

2.6.1. Agroforestry status and challenges in Ghana

In Ghana, agroforestry is a significant land-use system that has been practiced, particularly by rural communities (Terakawa, 2002). Examples of such practices include improved tree fallows, home gardens, alley cropping, taungya system, silvipastoral and hedgerow intercropping. However, damage of agricultural crops due to tree harvesting, insecure tree tenure, longer rotation periods of most tree species, risk and uncertainty, inadequate knowledge of the agroforestry technology were some of the hindrances to the widespread practice or adoption of the agroforestry technology in Ghana (Wireko, 2011; Rasul and Thapa, 2006). The lack of attention given to tree products and services in data collection, coupled with the lack of information on the value of agroforestry trees in supporting food and nutritional security represents an integral constraint to the agroforestry concept (FAO, 2013). In Ghana, factors that hinder farmers' engagement in agroforestry practices span through environmental and socioeconomics (Asare, 2005; 2004). For example, environmental issues such as rapid regeneration by prolific woody perennials could displace food crops and take over entire fields. Also, the potential of trees to serve as hosts to disease-causing insect pests that are harmful to food crops makes it problematic (Ammanor, 1996). Farmers are also adamant to adopt several agroforestry systems due to a possible tree-crop competition for sunlight, space, moisture, and nutrients which may reduce crop yield (Ammanor, 1996). Dealing with the socio-economic aspects and requirements for more labor inputs may cause scarcity in other farm activities (Asare, 2004). Similarly, lower composite yields than from sole crops which are mostly caused by competition between food and tree crops, are a highly limiting factor (Wireko, 2011). The longer rotation period of trees has a strong influence on the potential economic value to be realized and thereby threatening the practice of an agroforestry technology (Asare, 2004). Resistance by farmers to practice land-sharing using food crops and trees, especially where there is land scarcity and the view that agroforestry could be relatively more complex, less well comprehended and a little more seemingly difficult to apply, hinder people to involve and develop agroforestry systems (Ammanor, 1996).

2.6.2. Agroforestry adoption in Ghana

Ghana developed her national agroforestry policy in 1986 in the quest to sustain land-use (Terakawa, 2002) and factors including socioeconomic and ecological (food security, income, fuelwood, fodder, mulch, soil fertility, and poles) gains from the system have led farmers at Asunafo South District in the Brong- Ahafo to practice agroforestry (Wireko, 2011). However, several diverging factors that influence the choice to practice agroforestry across different geographical areas have been studied. A study done in Cameroon by Adesina et al. (2000) recounted that farmers with higher education are more likely to adopt new technologies compared to farmers with less educational background. This was supported by Traoré et al. (1998), who highlighted that agroforestry technologies are knowledge-intensive and consequently require high levels of education. This assertion is inconsistent with the study by Wireko (2011) who found the adoption of Agroforestry in Ghana and, level of education and age to be insignificant. However, the study showed that occupation and religion influenced the adoption of the technology. Tree crop interaction is key in agroforestry systems and therefore farmers must have adequate knowledge on the best multipurpose tree to be used. In the Western Region of Ghana, some trees were found to be associated with cocoa (*Theobroma cacao*) as a shade tree. These include *Cola nitida*, *Persea americana* and *Petersianthus marcocarpus* (Ammanor, 1996). However, *Cola nitida* was regarded as harmful as it attracts mistletoe (Chauvette et al., 2015). Trees such as *Albizia*, *Senna*, *Leucaena* and *Gliricidia* species within agroforestry systems in Ghana have been reported by Vanhie et al. (2015) and Partey et al. (2011). Report on long rotations and invasiveness of some plant species like *Leucaena leucocephala* has been recounted (Partey et al., 2011). However, several species of bamboo such as *Bambusa bluemeana* were considered and integrated into an agroforestry system in several Asian and some tropical countries like Dong Cao in northern Vietnam serving as a sustainable land use option (Nguyen, 2004).

2.6.3. Agroforestry potentials in Ghana

The main aim of prominent agroforestry projects in Ghana in the late 1980s focused on providing readily available seedlings to farmers who were prepared to take up the agroforestry technology by raising tree seed nurseries (Asare, 2016). This underpinned the National Agroforestry Policy objectives, targeted at raising and maintaining 350 attained trial centers, 400 nurseries and 30,000 hectares of agroforestry systems throughout the country (Asare, 2016). By the end of 1992, 119 demonstration sites, 131 nurseries, and 1,642 hectares of agroforestry systems were raised; attaining 34%, 33%, and 5% respectively (Anim-Kwapong, 2004). Farming practices comprise the use of trees either sequentially or simultaneously with crops and animals and is, therefore, agroforestry by definition (Swallow et al., 2007). Cocoa agroforestry integrated with *Persea americana*, *Petersianthus marcocarpus* among others is well known in the country (Ammanor, 1996). The most common agroforestry technologies in the DSFZ are: scattered *Anogeisus* species on farmlands, cocoa agroforestry, cashew agroforestry and *Dalbergia afzeliana* ('dawadawa')/shea butter/locust trees agroforestry. The result from a study by Negash et al. (2012) asserted that, after four years of woody perennials' integration, food crop yield increased significantly in an agroforestry system in a typical agroforestry system in Ghana. One possible reason might be that woody perennials in agroforestry systems encourage plants' physiology through the shade, as in the case of cocoa (Jagoret et al., 2018). The needs of rural communities in Ghana are diverse and Appiah-Kubi et al. (2014) recounted that farmers grow woody perennials such as *Eucalyptus grandis*, *Tectona grandis,* etc. together with their understorey crops in farms to produce timber, poles, fuelwood and fiber product. In rural communities, several people depend on charcoal and firewood for daily activities (FAO, 2016a). FAO (2008) stated that firewood and charcoal from woody perennials are crucial for the survival and well-being of about two billion people in the world. For this purpose, the woody perennials in agroforestry systems may offer locally available, renewable and affordable fuel. Kamp et al. (2016) showed that fuel production from agroforestry was a more attractive alternative intervention in terms of soil fertility, net soil carbon emission, labor requirement, resource use efficiency, and global renewability compared to other two-biogas-based technologies in Ghana. Successful integration of nitrogen-fixing tree species like *Leucaena leucocephala*, *Gliricidia sepium, Senna siamea,* and *Albizia lebbeck* in agroforestry systems has been reported (Partey et al., 2011; Poudyal and Hodges, 2009). All these point to a strong indication of the potential of agroforestry for agroecology development in Ghana.

2.6.4. Policy action on agroforestry in Ghana

Strong economies are built on well-outlined policies and according to Asare (2004), in Ghana, agricultural policies and practices have evolved to encompass the introduction and intensification of recent agroforestry approaches as a component in the National Agroforestry Policy of 1986. The foremost goal of the policy is to promote agroforestry practices for sustainable land-use (Kang and Akinnifesi, 2000). Nevertheless, there is still a recognizable gap between provisions in the national policy and the actual practice in the field, which explains the level of policy impacts, either expected or not (Anim-Kwapong, 2004). To achieve effective policy implementation and monitoring, three main stratified institutions were established. These involved the National Agroforestry Committee, Agroforestry Technical Sub-Committee and, Regional and District Agroforestry Committees (Asare, 2004). The policy also explicitly indicated research as a central component.

2.6.5. Exploration and introduction of more suitable agroforestry multipurpose trees/shrubs

Within the forestry and agricultural sectors, the government of Ghana partnered with all stakeholders in the exploration of more woody species to close the wood deficit gap and to increase socioeconomic and environmental benefits (Ammanor, 1996). Over decades, species such as *Tectona grandis, Eucalyptus candambai, Cassia siamea, Cedrela odorata,* and *Gmelina arborea* have been introduced and used in most forest plantation schemes, whiles other indigenous but underutilized and lesser-known species in the scarlet star ecological guild-class are being piloted in experiments to be used in the forestry sector (Ammanor, 1996). In the agricultural sector, tree species such as *Azadirachta indica*, *Gliricidia sepium, Acacia mangium, Albizia lebbeck*, etc. have been tried on farmlands in feasible agroforestry interventions for improved crop yields and productivity (Asare, 2005; 2004). Since 2012, the government, scientists and development agents in Ghana have advocated the use of bamboo as a potential woody species for bioenergy production by drawing lessons from Asia and other sub-tropical countries where the species is widely used in agroforestry systems for socio-economic development (Forestry Commission, 2015). Several studies (but mostly social and mechanical aspects) have been conducted for acquiring the necessary information on bamboo use (Forestry Commission, 2015). For instance, the Government through the Forestry Commission of Ghana introduced 18 foreign species of bamboo from Asia into the country for wood fuel plantation development trials. These included: *G. albociliata*, *B. edulis*, *D. brandisii*, *B. oldhanmii*, *D. asper*, *G. angustifolia*, *D. strictus*, *G. chacoensis*, *D. membrenaceus*, *T. siamensis*, *D. latiflorus*, *B. textilis*, *B. ventricosa and B. burmanica* (Forestry Commission, 2016).

2.7. Global bamboo resource and distribution

Bamboo is a quickly developing species, inexhaustible, broad, low recovery cost, condition upgrading asset with incredible potential to reduce neediness and improve natural protection (Xuhe, 2003). Globally, the market for bamboo products is high, amounting approximately to USD 7 billion which was expected to triple by the year 2017 (Smith and Marsh, 2005). Various bamboo species cover a total area of about 31.5 million hectares globally, accounting for about 0.8% of the world's total forest area in 2010 (FAO, 2012). Ethiopia took first place in bamboo potential exploration in Africa; containing about 67 percent of the continent's bamboo forest area (Bessie et al., 2016). Beyond traditional handicrafts and furniture, the weaving of mat boards from bamboo has industrial uses demonstrating a strong promising venture for household income generation (INBAR, 2006b). Bamboo use has extensively been (about 1500 documented uses) investigated worldwide (INBAR, 2006b). With huge and dynamic uses in Southeast Asia, the extent of bamboo utilization in Ghana and other African countries is relatively low. It is believed that lack of technical knowledge on the characteristics of native bamboo species and poor processing techniques may be accounting for this (INBAR, 2006a; UNIDO, 2001).

2.7.1. Bamboo ecology, growth, and physiological characteristics

Bamboos are noted for their simple spread, woody culms, complex fanning, hearty rhizome framework, inconsistent flowering and high profitability (Akoto et al., 2017; Nath et al., 2009; Scurlock et al., 2000). Bamboos mostly grow in the tropics and subtropics in mixed forests or as pure stands in plantations, on homesteads and farms (INBAR, 2014). Usually, the stand matures within 2-4 years (Nath et al., 2009). Based on the physiological and anatomical properties of bamboo, it is considered as a multipurpose tree (Chaubey et al., 2013; Scurlock et al., 2000). Basic wood density, girth, moisture content, culm height, internode length and diameter, the number of internodes per culm and culm thickness of bamboo differ per location and are crucial in determining bamboo suitability (Scurlock et al., 2000).

Several bamboo species are known to be invasive especially the monopodial type, whereas, most sympodial bamboos like *Bambusa balcooa, Oxytenanthera abyssinica* and *Bambusa multiplex* are not invasive (Buckingham et al., 2011). Song et al. (2011) elaborated that in recent decades, most bamboos have been invading other forest types and gradually displacing native pioneer tree species at the higher altitudes and latitudes. According to Pande et al. (2012), it is necessary as much as possible, to select non-invasive bamboo species for agroforestry systems. Nevertheless, invasiveness from monopodial bamboos could be controlled through the regular stem and root reduction.

2.7.2. Bioenergy properties/potentials of bamboo

Bamboo can be processed in many ways to produce different energy products such as syngas, biofuels, and charcoal (Truong and Le, 2014). According to Scurlock et al. (2000), bamboo has several appropriate fuel characteristics such as low ash content and alkali index. The authors further stated that it has higher heat value and lower moisture content (8-23%) compared to several agricultural residues.

2.7.3. Nutritional and fodder value of bamboo

Bamboo is multipurpose and its use is extensive ranging from fodder for livestock, shelter provision to erosion control (Bhandari et al., 2015). Bamboo's foliage biomass is nutrient-rich and has enormous potential to provide quality fodder for livestock. Therefore, bamboo leaves are important components of ruminant food and maybe planted on marginal lands which would improve soil fertility and produce evergreen biomass round the year (Bhandari et al., 2015; Kumbhare and Bhargava, 2007). For instance, bamboo shoots are profoundly wealthy in proteins, amino acids, starches, numerous significant minerals and nutrients and consequently are indispensable for human wellbeing (Fu, 2018). (Xia, 1989; Visuphaka, 1985). There is a rich amount of amino acids in bamboo shoot-based diets with 8 out of 17 amino acids reported to be essential for the human body (Nongdam and Tikendra, 2014). Bamboo shoots are good sources of protein; with protein content ranging between 1.49 g/100 g and 4.04 g/100 g fresh weight in fresh bamboo shoots (Chongtham et al., 2011; Sundriyal and Sundriyal, 2001). They are endowed with rich quantities of beneficial minerals such as magnesium, iron, potassium, sodium, calcium, and phosphorus which are required for the proper functioning of several useful metabolic activities of the human body. For carbohydrates, the amount present in bamboo shoots is high and significant in the edible shoots of *Bambusa nutans* (3.3%), *Bambusa vulgaris* (3.4%), *Dendrocalamus strictus* (0.6%), *and Dendrocalamus asper* (2.9%) (Kumbhare and Bhargava, 2007). However, the amount of fats in bamboo shoots is less and makes it an ideal option for providing healthy nutrition to diabetic people and for the treatment of cardiothoracic diseases (Kumbhare and Bhargava, 2007). The dietary fibers possess many health benefits as they control blood pressure, hypertension, and obesity (Nongdam and Tikendra, 2014). Other significant uses of bamboo include papermaking, handicraft industry, house and furniture construction, and household storage items (Vatsala, 2003).

2.7.4. Characteristics of bamboo as a candidate agroforestry species

Bamboo has been identified as an excellent multipurpose woody perennial because of its numerous socio-ecological benefits and characteristics particularly; fast growth and soil stabilization effects (FAO, 2003). The strength of bamboo culms, their straightness, lightness, combined with extraordinary hardness, flexibility, range in sizes, hollowness, long fiber, its abundance, ease of handling, ease of propagation and working qualities make them suitable for a variety of end-uses and thus, provide numerous opportunities for their users (Jayanetti, 2001; Gaur, 1987). Generally, most bamboos reach structural maturity within three years and the mean annual increment (MAI) of medium or large-sized bamboos is as high as or higher than that of many other fast-growing tree species (Amneth, 1996). Bamboo generates plenty of oxygen, low light intensity and protects against ultraviolet rays and is also considered to be an atmospheric and soil purifier. Furthermore, it conserves water and greatly reduces soil erosion (Amneth, 1996). Integrating bamboo into the farm ecology may enhance soil moisture condition and physical properties and hence could improve entire cropping system productivity (Amneth, 1996).

2.8. Bamboo resources in Ghana

Bamboos grow predominantly in areas of heavy rainfall in Ghana (Forestry Commission, 2011). Such growing areas in the country are Central, Brong-Ahafo, Ashanti, Volta, and Eastern Regions (Figure 2.3).

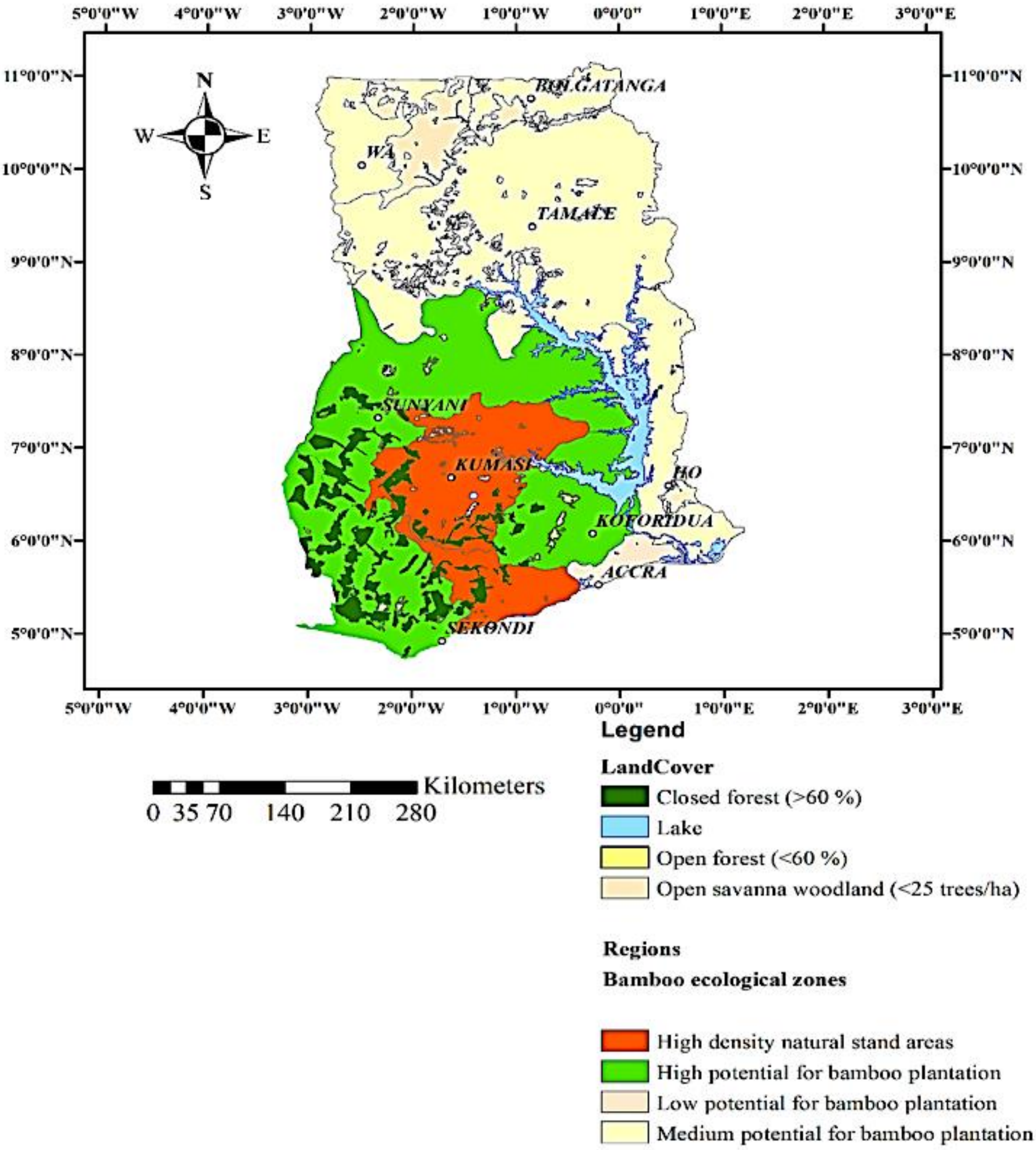

Figure 2.3: Bamboo area distribution in Ghana (study area-shaded green, has high potential for bamboo plantations) (Source: Forestry Commission, 2011)

The seven (7) main bamboo species found in Ghana are *Bambusa arundinacea*, *Bambusa bambos*, *Bambusa multiplex*, *Bambusa pervariabilis*, *Bambusa vulgaris*, *Bambusa var. vitata*, and *Dendrocalamus strictus* (Forestry Commission, 2015). Other species are *Bambusa burmanica, Bambusa edulis, Bambusa oldhamii, Bambusa textilis, Dendrocalamus asper, Dendrocalamus* *latiflorus, Dendrocalamus membranaceus, Guanochlor albociliata,* and *Thyrsostachys siamensis*, *Bambusa hetrostachya* and *Dendrocalamus barbatus* (Forestry Commission, 2016; Peprah et al., 2014). However, only *Bambusa vulgaris* is indigenous to Ghana and the others were introduced into the country from Asia (Akoto et al., 2017; Baah, 2001). *Bambusa vulgaris* is yellowish and green, with an average height growth of 2400cm and about 12mm in stem diameter. It has a high nutrient level and that makes it susceptible to worm destruction (Boateng et al., 2013).

Bambusa vulgaris var. vitata (yellow bamboo) is also common in Ghana and can be easily propagated. This species is known to have low protection from organic falling apart operators or irritation and growths (Pretty, 1999). *Bambusa vulgaris var. vitata* has inside its structure starch, wax, gum, and lignin which offer solidarity to the material. The high sugar substance makes the material susceptible to bug attack (Boateng et al., 2013). *Bambusa bambos* or *Bambusa aroundinacea* is viewed as one of the bamboos that have some degree of protection from bug assault (Nath et al., 2009). Studies have additionally demonstrated that this assortment displays high stem quality (straightness) and broadly utilized by skilled workers in the creation of ancient rarities (Akinlabi et al., 2017). They are generally found around water bodies. *Bambusa bambos* has a large culm size and low sugar content, thereby favoring its use for lamination into paneling boards and other constructional activities. *Dendrocalamus strictus* is another species found in Ghana. It grows to about 80-100 feet high (Boateng et al., 2013). According to Obiri and Oteng-Amoako (2007), *Bambusa aroundinacea* thrives well on Ghanaian soil. The species grows to a considerable height of 72 feet to 900 feet (Obiri and Oteng-Amoako, 2007). The internodes or culms measure 30cm to 46cm with a diameter of 3cm to 8cm. Boateng et al., (2013) mentioned two species found in Ghana as well as China and Japan; *Bambusa guadua* and *Bambusa striata* (*Bamboo cramineae*). They are erect, a strong standing plant that grows to a height of 450cm with yellow and green pendulous stem and are highly crowded.

2.8.1. Recent interest and focus on bamboo in Ghana

There has been less interest in bamboo use in Ghana in the past due to sufficient quantities of forest and wood resources (INBAR, 2006a). The 1984 forest inventory data indicated that Ghana has 126 species of trees but considered only 50 as merchantable with 23 as most preferred timber species (Forestry Commission, 2016). This gave Ghana 90 million m^3 of wood per annum (Forestry Commission, 2016). Accordingly, it was usual to overlook such supposedly-less-valuable-woody resource like bamboo (Forestry Commission, 2015). Also, the indigenous bamboos in Ghana have hollow stems with very thin woody cover and thus, were considered inferior and their use reserved for fencing, firewood, and mounting of television antennae poles. Again, there was limited research conducted in Ghana to unearth the other potential uses of bamboo (Forestry Commission, 2011). With the current threat of a dwindling state of the nations' forest and wood resources, it has become necessary to explore for more underutilized or new alternatives to supplement the loss. Currently, the annual allowable cut (available and permissible volume of wood to be removed from Ghana's forest) is a little less than 1.2 million m^3 (Forestry Commission, 2015). The need for shorter rotational tree crops for woodlots for fuelwood provision has increased recently in the developing world (FAO, 2016a). With this trend, the government of Ghana has therefore fallen on bamboo to meet such need (Forestry Commission, 2016).

2.8.2. Recent bamboo resources development and use in Ghana

Since 2012, the Government of Ghana and most forest sector development partners have expressed keen interest in the cultivation and management of bamboo resources. This is to reduce the over-dependence on the dwindling natural timber and wood resources. The aim has been to optimally produce bamboo materials for agricultural uses such as fencing, tools, rafts, trellises, water pipes, and forest and for protected area conservation (Forestry Commission, 2015). Bamboo stands are also managed for stream and riverbank stabilization, scarp embankment (side protection), as ornamental plants in the landscape and as cut foliage. Some bamboo products are used for industrial housing purposes and as light and strong materials for crafts, handicrafts, and furniture (Akoto et al., 2017; INBAR, 2012). Ghana appears to have good initiative for bamboo resources development in both plantations and processing centers and the establishment and operation of the sub-regional office of the International Bamboo and Rattan Organization (INBAR) in Kumasi, is steadily facilitating the cultivation and use of bamboo in Ghana. Also, the Government and INBAR have collaboratively established the Bamboo and Rattan Development Programme (BARADEP). Ghana has several sustainable development and natural resources sector commitments in which bamboo and rattan have vital roles to play. These commitments include (1) support for the establishment 1,000 hectares of bamboo and rattan plantations annually; (2) agenda to plant 50,000 hectares of bamboo and rattan plantations over the next 25 years as indicated in the 2016-2040 National Plantation Development Strategy of Ghana; (3) development of Ghana's bioenergy sector, including bamboo biomass, to ensure sustainability of biomass energy in Ghana (Ghana Bioenergy Policy initiative); (4) reduction of Ghana's greenhouse gas emissions, including reduced emissions from deforestation and forest degradations (REDD)(Intended Nationally Determined Contributions to UNFCCC); and (5) development of Ghana's bamboo and rattan sector for job creation, income generation and environmental protection under the framework of BARADEP.

2.9. Bamboo-based agroforestry

Bamboos occupy the same ecological niche as traditional trees and are well suited for agroforestry interventions (Netondo et al., 2008). For instance, the rural indigenous Apatani farmers in Ziro Valley of Arunachal Pradesh, India, have developed an integrated "bamboo + pine homestead agroforestry system" where the bamboo is inter-planted with pine trees (Netondo et al., 2008). The pine + bamboo agroforestry could provide ecosystem services such as carbon sequestration optimization, bioturbation, diagenesis, control of soil erosion and other natural flood control, enhancement of water use and storage efficiency (Tangjang and Nair, 2016; Indrawana et al., 2014; Netondo et al., 2008). Somewhere else, *Bambusa tulda* and *Bambusa balcooa* were intercropped with paddy, groundnut, pigeon pea, turmeric, elephant foot yam, and cocoyam; *Pseudo-Oxytenanthera* were also intercropped with sweet potato and cowpea in India (Pattanaik and Hall, 2011). Bamboo has proven to be suitable for the following technologies; Bamboo + conifer + broadleaf timber trees, Bamboos + tea model, Bamboo as windbreak, Bamboo + Medicinal Plants, Bamboo + crops + fish ponds, Bamboo + edible fungi and Bamboo + poultry/dairy farm (GBPUAT, 2010; Banik et al., 2008). In Kenya, successful intercropping of bamboo and tobacco has been reported (Kibwage et al., 2014). As likewise in India, agroforestry systems with sympodial bamboo species have been successful (Netondo et al., 2008). Sustainable production of firewood and charcoal has been reported to be associated with bamboo-based agroforestry systems with species such as *B. multiplex, B. vulgaris* (the green type), *B. bambos, B. pervariabilis, B. vulgaris var. vitata* and *O. abyssinica or D. strictus* (Partey et al., 2017a). Agroforestry systems adoption and designs are coordinated to the type of ecosystems and farmers' requirements with an emphasis on the associated non-woody component (Banik et al., 2008).

2.9.1. Bamboo-based agroforestry in Ghana

Bamboo-based agroforestry is quite a new concept in Ghana. In SSA and Ghana, in particular, most of the available bamboo species are sympodial and are highly concentrated in the forest agro-ecological zones. Agroforestry systems with sympodial bamboo species have been successfully developed in India (Hiwale, 2015). The development of any agroforestry systems with bamboo species such as *B. multiplex*, *B. vulgaris (the green type)*, *B. bambos*, *B. pervariabilis*, *B. vulgaris var. vitata*, *O. abyssinica* or *D. strictus* could be an opportunity to develop a sustainable bamboo biomass resource base for firewood and charcoal production in Ghana (Partey et al., 2017b). The bamboo species in Ghana might be appropriate for the following agroforestry technologies; planted as fallows on overburden land, windbreak, boundary planting, and as shelterbelts to prevent the risk of crop failure due to their sympodial characteristics (Partey et al., 2017a; Hiwale, 2015).

2.9.2. Key researches/studies related to bamboo (agroforestry) development in Ghana

With bamboo agroforestry being new in Ghana, there is a paucity of information that suggests its feasibility or suitability in the socioecological setting. Although there have been some studies from which lessons could be drawn for possible bamboo agroforestry development, most of them focus on the physiological, morphological and physical properties (mostly for engineering purposes) of bamboo and some few socioeconomic aspects. Only a few reports on the ecological potentials of bamboo. For instance, Obiri and Oteng-Amoako (2007) explored bamboo resource availability and assessed their technical characteristics for future manufacturing and green building in Ghana. They revealed the establishment of 18 exotic species of bamboo with varied physiological, morphological and mechanical characteristics that influence their uses. For instance, *Bambusa vulgaris* and *Bambusa bambos* were identified as suitable for the housing and construction industry in Ghana and; they further recommended the use of the underutilized abundant bamboo species for a greener future. Good quality laminated bamboo panel doors are produced and are subsequently recommended bamboo for door manufacturing (Khalil et al., 2015). In a current study in Ghana, Appiah-Kubi and others tested the bending strength (MOR), Modulus of Elasticity (MOE) and compressive strength of laminated boards produced from three plantations managed bamboo species of *Bambusa vulgaris, Dendrocalamus brandisii* and *Guadua chacoensis* (Appiah-Kubi et al., 2014). They concluded that laminated boards from these three bamboo species are appropriate to be used as boards for the housing industry. Reviewing the bamboo resources in Ghana, the potential of bamboo is not adequately utilized considering their uses elsewhere, for instance, in Asia. Research and development efforts on bamboo in Ghana have focused on theoretical use as well as on the natural stocking (Essien et al., 2011; Tekpetey, 2011; Oteng-Amoako et al., 2005). Ghana abounds in adequate bamboo resources which presents lots of potential for different dimensions of socioeconomic development and therefore should be explored through more adaptive research (Tekpetey et al., 2015; Essien et al., 2011).

On ecological study of bamboos in Ghana, Peprah et al. (2014) explored the potential of bamboo for accelerated reclamation of mined over-burden sites and found that *Dendrocalamus membranaceus*, *Oxytenanthera abyssinica* and *Bambusa vulgaris* var. *vitata* could be used for reclamation of mined sites as they performed well in terms of foliage accumulation, early growth, and establishment. In a study of trade and innovation in the bamboo and rattan furniture industry in Ghana, Tekpetey and others evaluated how artisans increase products' value with innovative designs in the Kumasi metropolis. It was discovered that product innovation was almost non-existent in all the groups and there were low product diversification and limited value addition in the industry. They recommended that efforts by NGOs and government agencies should be geared towards improving design and innovation as well as training of artisans to manufacture products that meet international standards (Tekpetey et al., 2015). In the last decade, a nationwide survey towards sustainable development of the bamboo industry in Ghana indicated that bamboos could be planted almost in all the ten (now sixteen (16) regions; and there was the readiness of the Ghanaian community to accept and use bamboo products (Obiri and Oteng-Amoako, 2007). The report recommended an improvement in the extension of bamboo marketing networks and also a need to increase the production of bamboo through cultivation to supplement the demand for wood from timber (Obiri and Oteng-Amoako, 2007). Another nationwide survey on the general socioeconomic perspective on bamboo concluded that Ghana has the potential to use bamboo for socioeconomic gains but would require a national effort and assessment of regional and local socioeconomic potentials for the use and development of the bamboo sector (Ebanyele and Oteng-Amoako, 2007). According to Akoto et al. (2017), estate developers are optimistic about the sustainable use of bamboo in the housing industry whereas a greater majority of the end-users are skeptical about the quality and duration of bamboo-based housing units. The authors recommended further research to help increase the durability of bamboo in use in the housing industry and more sensitization for users to patronize the bamboo-based housing units. Obiri et al. (2014) carried out an analysis of constraints in the bamboo production to consumption system in Ghana and concluded that the natural stocking of bamboo is woefully insufficient to meet the demand of the emerging bamboo economy in Ghana and hence, required a stronger and a more sustainable production system. Consequently, they recommended the inclusion of farmers and other private sectors to increase bamboo production, and to take advantage of the emerging bamboo economy which has greater prospects. The potential co-operation of farmers in bamboo production is a strong incentive to advocate for and emphasize for bamboo agroforestry adoption.

Currently, a study on bamboo agroforestry in Ghana is yet to suffice. The only related output is a presentation given during the Ghana Bio-energy Policy Forum on 15th of December, 2017; where the potentials of the bamboo resources of Ghana were suggested for bamboo-agroforestry development and subsequently, in-depth reference made to the INBAR/BiomassWeb-led bamboo agroforestry research at Jeduako in the Sekyere-Central District of the Ashanti Region of Ghana.

3. Study area and research design

3.1. Study area description

This research was conducted in the Ashanti Mampong, Ejura-Sekyedumase Municipals and Sekyere Central, Kumawu-Sekyere and Sekyere-Afram Plains Districts of Ghana (Figure 3.1). These areas are located within the dry semi-deciduous forest zone of Ghana (DSFZ), with a characterized bimodal rainfall pattern (with an average annual rainfall of 1270 mm). The major rainy season starts in March and peaks in May (Tom-Dery et al., 2014). There is a minor dint in July and a peak in August, ending in November. December to February is the drier season, which is warm and dusty (in the driest period). The mean annual temperature is 27 °C with variations in mean monthly temperature ranging between 22 °C and 30 °C throughout the year. The vegetation of the study zone is predominantly savannah. It lies within the Forest and Savannah agro-ecological zone and has a mixture of forest and guinea savannah; composed of short deciduous fire-resistant/tolerant trees like *Lophira laceolata, Anogeisus leiocarpus and Triplochiton scleroxylon* (see Appendix 12 for authors). The soil type of the study site is sandy loam (Ejura—Denteso Association) and classified as ferric acrisol (Tom-Dery et al., 2014). This area falls within the zone, considered as the major food basket of Ghana and has the highest production of charcoal and fuelwood from natural sources. Subsistence agriculture employs about 65% of the population as it is the major economic activity. The bulk of agricultural production is from smallholder (manually cultivated) and rain-fed crops. Major crops include maize, cowpea, cassava, yam, and plantain. The DSFZ was chosen because of its unique characteristic features which combine those of the forest and savanna zones.

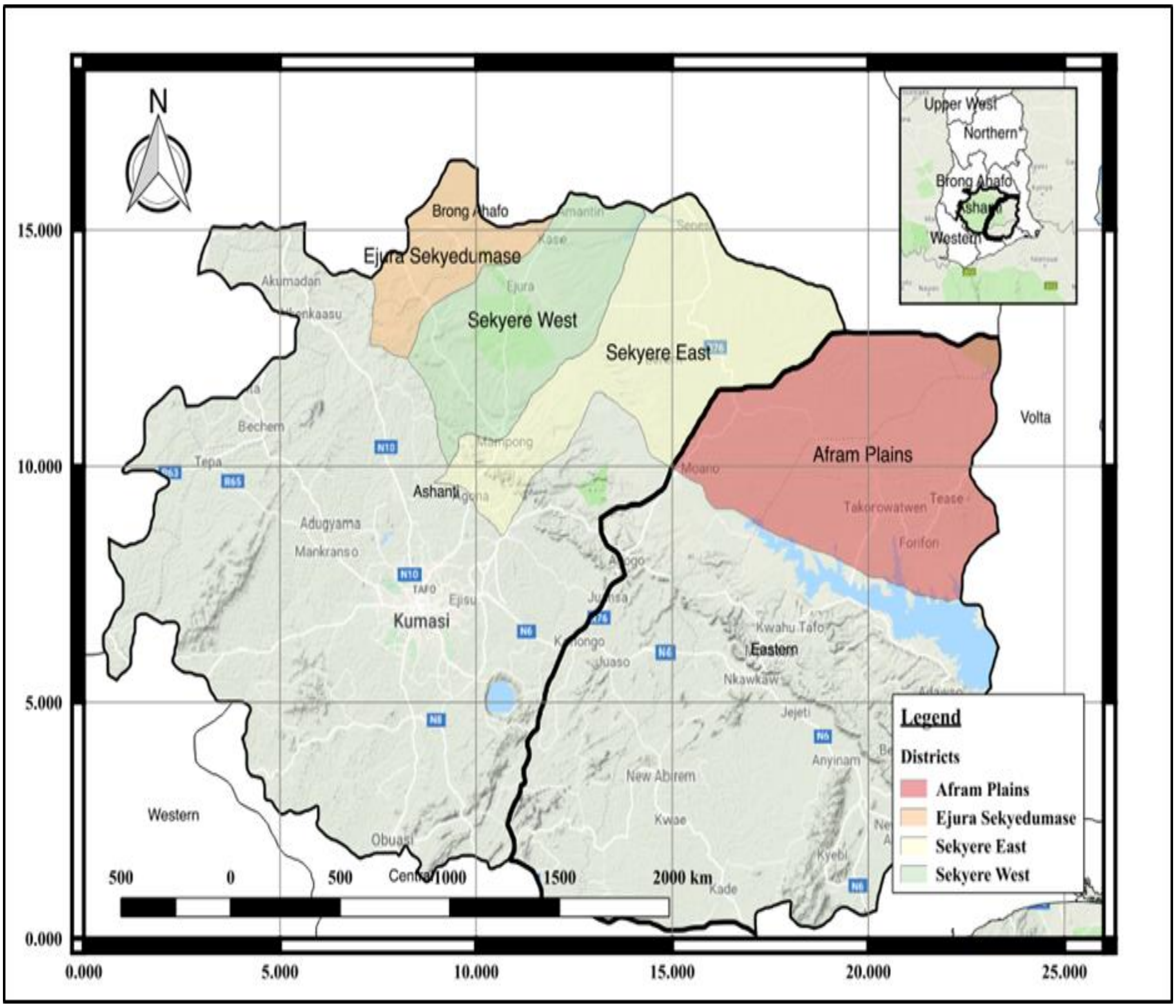

Figure 3.1: District map of Ghana showing the study sites in the Dry Semi-deciduous Forest Zone (Akoto et al., 2018).
(Map Overlaid in Google Satellite Scene (2018) of Ghana)

3.2. Research designs and methods

3.2.1. Socio-economic survey

3.2.1.1. Socio-economic analysis

Socioeconomic status (SES) as defined by Rogers, (2003) is a composite measure of an individual's economic and sociological standing. It is measured in a variety of ways with indicators of a person's work experience, economic and social position relative to others, based on revenue, education, and occupation. It has been propounded that household socio-economic factors (income, household size, and gender) have a positive influence on the adoption of agroforestry (Baffoe-Asare et al., 2013). Having secondary occupation, level of education, age and ethnicity have a negative influence on the adoption of agroforestry (Baffoe-Asare et al., 2013). For the determination of the socioeconomic indicators of bamboo use for agroforestry development study in Chapter 4, a systematic purposive (farmers were the main targets) sampling method was adopted to select 200 household heads with farming as their primary occupation. Information from the semi-structured questionnaire was obtained on the socioeconomic variables with potential to influence adoption of bamboo agroforestry.

3.2.2. Perception of farmers on bamboo litter as fodder for livestock and bamboo litter quality assessment

For the bamboo fodder quality analysis and farmer perception on bamboo fodder for livestock study in Chapter 5, a combination of focus group discussions (involving 10 household heads – 5 males and 5 females) and questionnaire (Appendix 9) interviews were used to: characterize livestock production systems, assess local knowledge and perception of bamboo leaf use as forage for livestock and for a field fodder quality experimentation using twenty Djallonké kids (juvenile goats- about 3 months old) with mean initial weight of 13.77 ±1.16 kg for the trial. Serum test and feed conversion ratio (FCR) were used to assess fodder quality with bamboo as supplemental feed.

3.2.3. Evaluation of soil and crop productivity and economic viability of bamboo agroforestry

3.2.3.1. Field establishment and experimental procedure

Soil and crop productivity and economic viability within the bamboo-intercropping system with maize, cowpea and cassava crops were evaluated using a split-plot design with four replicates. It was designed and established with modification from the design recommended by Nath et al. (2009).

3.2.3.2. Bamboo litterfall collection

Bamboo litter was collected weekly for both dry and wet seasons (Breda, 2003) to inform on aspects of the ecological contribution of bamboo to the intercropping system. Total litter biomass was determined by drying litter in an oven at 65^{o}C for 72 hours.

3.2.3.3. An economic evaluation of bamboo agroforestry

Net present value – investment in trees, annual crop revenues, the harvest of trees

Net present value (NPV) is mostly used for agroforestry analysis (Atangana et al., 2014; Palma et al., 2007; Dyack et al., 1999). An NPV ranking provides a guideline criterion for comparing the economic returns from alternative farming systems over time (Nelson and Cramb, 1998). The net present value is the difference between the present value of cash inflows and cash outflows. For economic analysis, NPV compares the value of an amount today to the value of that same amount in the future, taking inflation, risk, and returns into account. If the NPV of a prospective project is positive, it is financially feasible (Harrison, 2010).

Benefit-Cost analysis

The benefit-cost ratio (BCR) is an econometric indicator, used to evaluate the overall value for money of a project or proposal. In agroforestry systems, BCR is widely used to compare the discounted benefits to discounted costs of each land-use system (Momen et al., 2006).

Land equivalent ratio (LER)

Land equivalent ratio (LER) is expressed as the relative land area required for a sole crop to produce the same yields as that of intercrops (Mead and Willey, 1980; Andrews and Kassam, 1976). For each crop used in the trials, a ratio is calculated to determine the partial LER for that crop, the partial LERs are summed to give the total LER for the intercrop (Darish et al., 2006). An LER value of 1.0 recommends no difference in yield between the intercrop and the monocultures whereas any value larger than 1.0 indicates a yield advantage for intercrop (Mazaheri and Oveysi, 2004). According to Mead and Willey (1980), the advantage of LER is that it provides a standardized basis so that crops can be added to form combined yield. Partial land equivalent ratio (LER) was used to determine intercropping advantage over monocropping using the relation by Darish et al. (2006) for agricultural crops. This ratio was used, because the focus of the experiments was on the effect of bamboo on the associated crops, and therefore, only agricultural crop yields in the intercropped and monocropped fields were compared.

Comparative financial cost-benefit analysis

The Financial Cost-Benefit Analysis (FCBA) methodology adopted from Gittinger (1982) was used for the comparative economic valuation of the bamboo agroforestry system and monocrop food production in this study.

3.2.4. Decomposition and nutrient release patterns of bamboo and other traditional agroforestry species

The litter bag approach was used to determine the decomposition of the leaf litters and laboratory analysis to evaluate the nutrient release patterns of *Oxytenathera abyssinica*, *Bambusa balcooa*, *Bambusa vulgaris, Albizia lebbeck*, *Senna siamea*, *Gliricidia sepium*, *Leucaena leucocephala,* and *Eucalyptus grandis* (see Appendix 12 for authors) for eight months (June 2016 to January 2017) under field conditions, following Partey et al. (2011) in Chapter 7 of this thesis. The litter bag method remains the most commonly and widely used technique for examining litter decomposition in terrestrial ecosystems despite several drawbacks (Moore et al., 2017; Sun et al., 2017).

3.3. Research approach

The research workflow took iterative steps at different stages of the thesis from the project proposal stage, fieldwork, thesis writing to defense. The research began with an extensive literature review of scientific information and ideas in the four key areas (presented as four results Chapters in this thesis) of the study subject. Some of the subject topics the literature review covered were, the national energy sector and outlook, the proposal and need for bioenergy policy in Ghana, research studies on bamboo in Ghana, contemporary forestry management and issues in Ghana, national forest policies, national agricultural policies, national agroforestry policy, national REDD+ policies, soil fertility, carbon stocks, biodiversity, and agroforestry systems. The literature review helped to identify the key research gap for the development of the bamboo economy in Ghana and based on that, the rationale and objectives of the research were duly defined and formulated. This was followed by the selection of the study area. The initial findings from the literature review facilitated the design of the research proposal, work plan and budget for approval. Oral presentation of the research proposal, work plan, and budget were made to the academic staff of the Department of Ecology and Natural Resources Management - Center for Development Research, University of Bonn, before undertaking the fieldwork in 2015.

Logistics for the fieldwork included linear tapes, electronic diameter, GPS, prismatic compasses, diameter tapes, soil augur, etc. The socioeconomic and energy needs data collection was conducted in five of the seven Districts which lie in the transition between the dry-semi deciduous forest zone and the forest savannah of Ghana for 12 months between May 2015 and April 2016. The biophysical data collection within the bamboo-based intercropping/alley cropping system was done on a 5-ha pilot plot at Sekyere-Central in the Ashanti region of Ghana –also in the dry semi-deciduous forest zone. After the fieldwork, socioeconomic, laboratory and statistical analyses were performed to achieve the specific objectives. Results from the data analyses informed the preparation of four manuscripts for journal publication. The four manuscripts are compiled into thesis Chapters for the thesis defense in fulfillment of the Ph.D. graduation requirements.

4. Socioeconomic indicators of bamboo use for agroforestry development in the dry semi-deciduous forest zone of Ghana

This Chapter has been published as Akoto, S. D., Denich, M., Partey, S.T., Frith, O., Kwaku, M., Mensah, A. and Borgemeister, C., 2018. Socioeconomic Indicators of Bamboo Use for Agroforestry Development in the Dry Semi-Deciduous Forest Zone of Ghana. *Sustainability*, *10*(7):.2324.

http://www.mdpi.com/2071-1050/10/7/2324

4.1. Abstract

Bamboo agroforestry is currently being promoted in Ghana as a viable land-use option to reduce dependence on natural forests for wood fuels. To align the design and introduction of bamboo agroforestry to the needs of farmers, information on the determinants of bamboo acceptability and adoption is necessary. It is, therefore, the aim of this study to determine how socioeconomic factors, local farming practices and local knowledge on bamboo may influence its acceptability and adoption as a component of local farming systems. Data were collected from 200 farmers in the dry semi-deciduous forest zone of Ghana using semi-structured questionnaire interviews. The results show that farmers' traditional knowledge of bamboo including its use for charcoal production and leaves for fodder are influential determinants of bamboo adoption. Among the demographic characteristics of farmers, age and gender are the most significant predictors. It is also evident that the regular practice of leaving trees on farmlands and the type of cropping system may influence bamboo integration into traditional farming systems.

4.2. Introduction

Deforestation emanating from excessive wood extraction for wood fuels continues to be a major agent of land degradation. The rate of deforestation in Ghana stands at 112.54 km^2 per annum, largely attributed to the expansion of agriculture (FAO, 2010; Oldeman et al., 1991). According to Afrane (2012), about 73% of rural and 48% of urban households in Ghana depend on firewood and charcoal, respectively, for domestic and industrial use. Charcoal supply predominantly comes from savanna zones, and with a lesser amount from deciduous and rainforests. Charcoal production is the next most dependent livelihood of the dry semi-deciduous forest zone (DSFZ) after farming and used as a secondary activity to support income from farming activities (Benhin and Barbier, 2001).

Owing to the increased sourcing of wood biomass from primary forests for charcoal production, government and scientists are advocating for the production and use of bamboo to reduce pressure on the major commercial timber species sourced as fuelwood. Due to development initiatives, such as the Bamboo and Rattan Development Programme (BARADEP), bamboo plantation establishment has increased in Ghana. This notwithstanding, monoculture bamboo plantations on agricultural lands may impact adversely on food security unless integrated systems with arable crops and/or livestock are given due consideration. In many parts of Asia, the integration of bamboo on croplands is confirmed as a suitable approach for increased productivity of food crops and non-food biomass (Mailly et al., 1997). In Ghana, science-based bamboo agroforestry systems are limited and data to prove their suitability are lacking.

Currently, the International Bamboo and Rattan Organization (INBAR) is piloting a bamboo agroforestry system as a land-use option for food security and renewable energy production in the DSFZ of Ghana. As an innovative development-oriented project, filling knowledge gaps on the determinants of bamboo use and adoption as a component of traditional farming systems is imperative to achieve large scale landscape adoption. In addition, knowledge of adoption determinants of bamboo will help in designing a bamboo-based agroforestry system that is tailored to the needs of farming communities. It was, therefore, the aim of this study to determine how socioeconomic factors, local farming practices and local knowledge on bamboo may influence its acceptability and adoption as a component of local farming systems.

4.2.1. Conceptual framework of the study

Several analytical frameworks have been used for the analysis of the adoption of agroforestry technologies. Biot et al. (1995) grouped these approaches into three major types: top-down interventions, populist or farmer-first, and neoliberal approaches. Stemming from the concept of farmer-first and sustainable livelihood principles, Van Ginkel et al. (2013) developed a wider conceptual framework for analyzing factors stimulating the successful adoption and adaptation of smallholder technologies. Given the focus of this study, the conceptual framework developed by Mercer (2004) and modified by Zerihun et al. (2014) is considered appropriate. The framework focuses on the adoption of already existing agroforestry technologies. However, this framework could be seen as very broad and complex to analyze the adoption rate and institutional setup of agroforestry technologies synchronously because institutional arrangements other than farmers were not directly evaluated to see their impact on adoption. Again, this study explored the willingness of farmers to accept bamboo agroforestry in the face of current wood energy needs and diversified income expectations of farmers in the DSFZ. Specifically, we modeled the interaction of explanatory variables, such as farmer characteristics, cropping systems, farming practices, bamboo ethnobotany, to predict the potential adoption of bamboo agroforestry in the DSFZ (Figure 4.1). These interactions facilitate farmer decision making processes and culminate in either adoption or non-adoption of technologies.

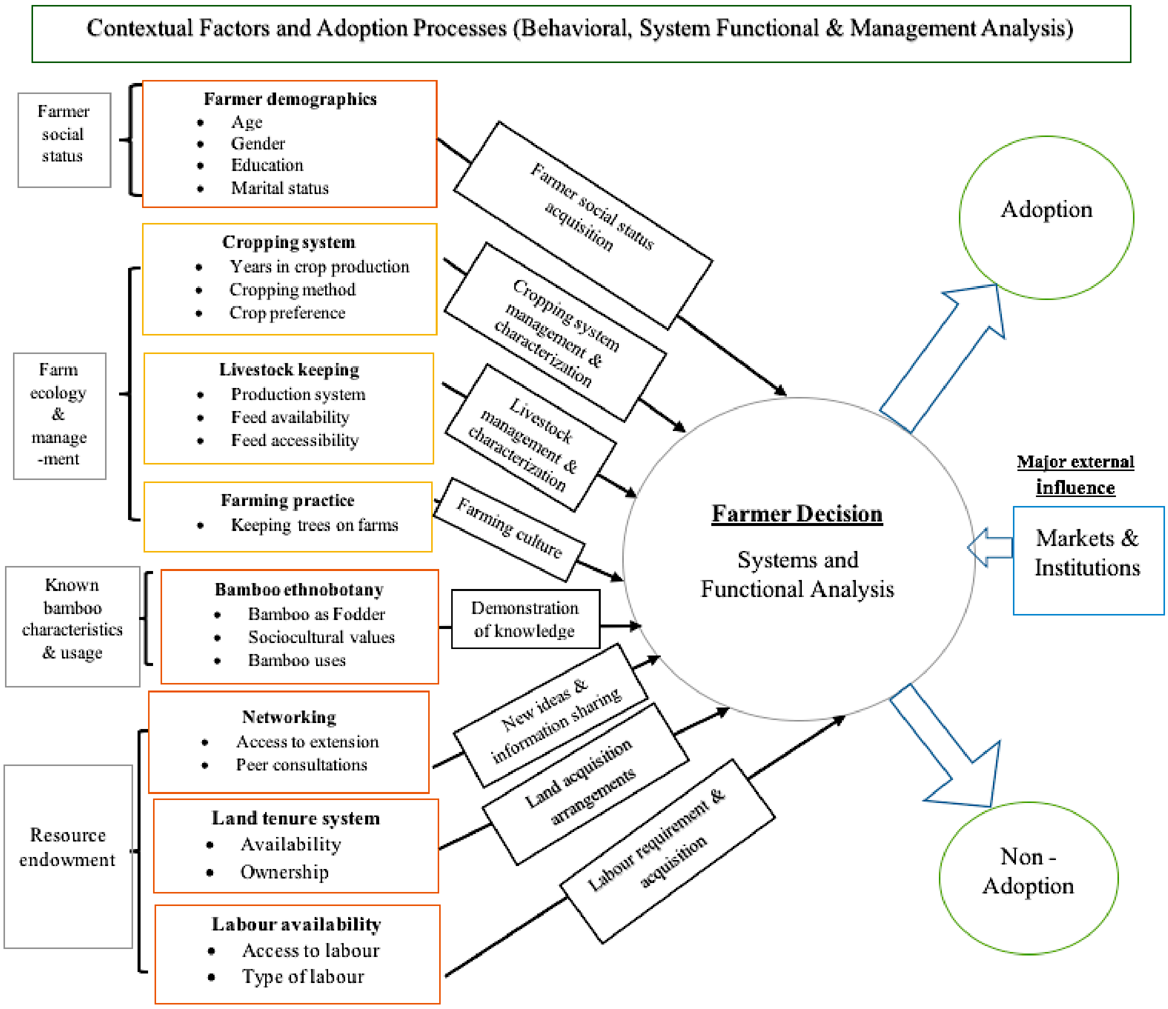

Figure 4.1: Analytical framework for modeling adoption potential of bamboo agroforestry

Source: Adapted from Zerihun et al. (2014).

4.3. Materials and methods

4.3.1. Study area description

4.4. Study area description

This research was conducted in the Ashanti Mampong, Ejura-Sekyedumase Municipals and Sekyere Central, Kumawu-Sekyere and Sekyere-Afram Plains Districts of Ghana (Figure 4.2). These areas are located within the dry semi-deciduous forest zone of Ghana (DSFZ), with a characterized bimodal rainfall pattern (with an average annual rainfall of 1270 mm). The major rainy season starts in March and peaks in May (Tom-Dery et al., 2014). There is a minor dint in July and a peak in August, ending in November. December to February is the drier season, which is warm and dusty (in the driest period). The mean annual temperature is 27 °C with variations in mean monthly temperature ranging between 22 °C and 30 °C throughout the year. The vegetation of the study zone is predominantly savannah. It lies within the Forest and Savannah agro-ecological zone and has a mixture of forest and guinea savannah; composed of short deciduous fire-resistant/tolerant trees like *Lophira laceolata, Anogeisus leiocarpus and Triplochiton scleroxylon* (see Appendix 12 for authors). The soil type of the study site is sandy loam (Ejura—Denteso Association) and classified as ferric acrisol (Tom-Dery et al., 2014). This area falls within the zone, considered as the major food basket of Ghana and has the highest production of charcoal and fuelwood from natural sources. Subsistence agriculture employs about 65% of the population as it is the major economic activity. The bulk of agricultural production is from smallholder (manually cultivated) and rain-fed crops. Major crops include maize, cowpea, cassava, yam, and plantain. The DSFZ was chosen because of its unique characteristic features which combine those of the forest and savanna zones.

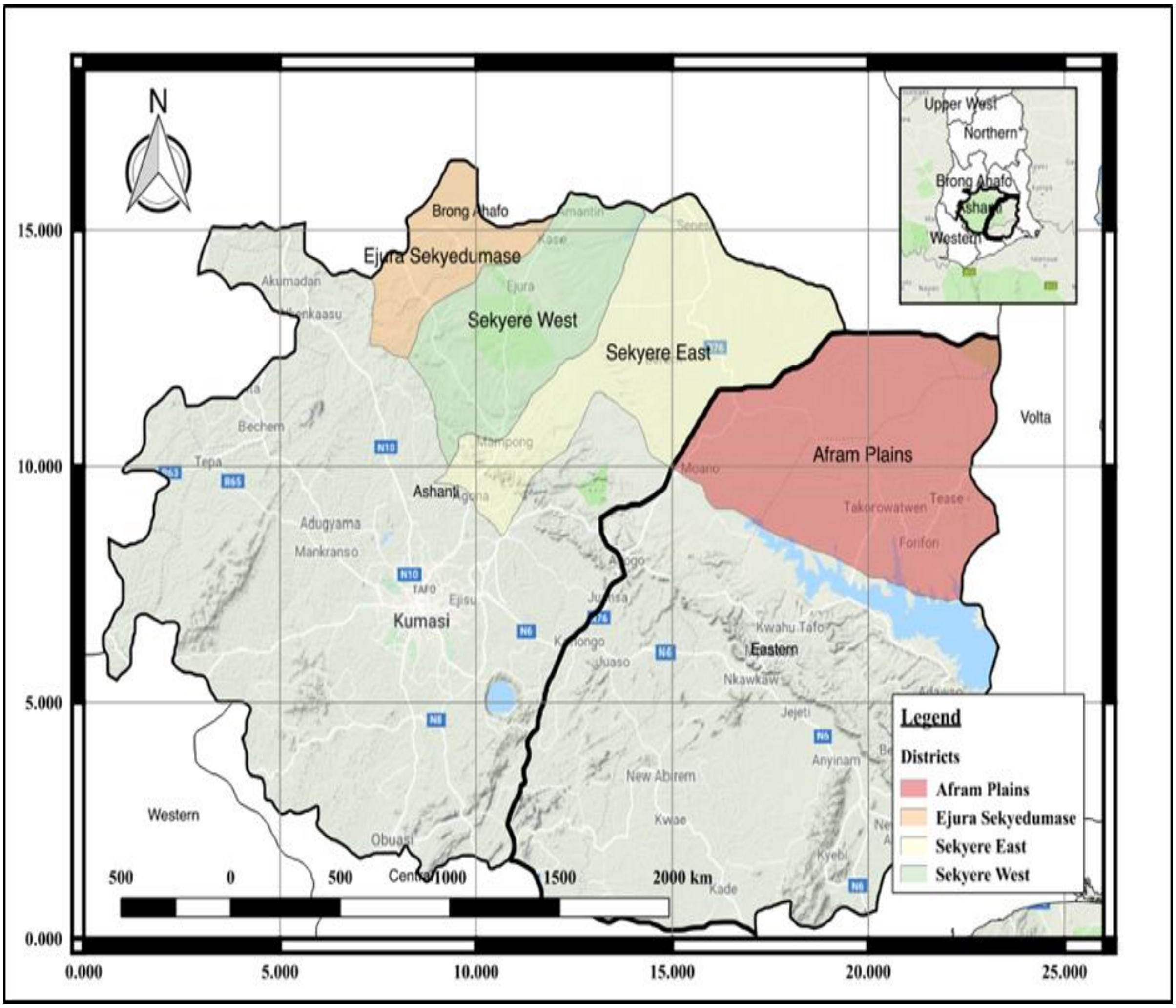

Figure 4.2: District map of Ghana showing the study sites in the Dry Semi-deciduous Forest Zone (Akoto et al., 2018).
(Map Overlaid in Google Satellite Scene (2018) of Ghana)

4.4.1. Data collection, sampling procedure, and analysis

With a purposive sampling method 200 household heads with farming as their primary occupation, were selected. Farmers (specifically, vegetable, yam, cowpea, maize, and cassava farmers) from 20 communities of five districts (four from each district) were selected for a household survey. The number of households interviewed in each community was estimated according to the recommendations by Edriss (2006):

$$n = \frac{N}{1+N\,(e)^2} \qquad \text{………………. (Equation 4.1)}$$

where '*n*' is the sample size, '*N*' is the population size, and '*e*' is the level of precision equal to 0.05 at 95% confidence level.

A semi-structured questionnaire was administered during the household survey to obtain information on the socio-economic variables that are likely to influence the adoption of bamboo agroforestry (see Appendices 3 to 7). We modeled the potential adoption of bamboo agroforestry by designating a value of '1' if the farmer is willing to plant bamboo on his/her farmland (potential adopter) and '0' if the farmer is unwilling to plant bamboo on his/her farmland (potential non-adopter). Primary data collected were analyzed using binary logistic regression as recommended by Masangano (1996) to model potential adoption of bamboo agroforestry on a set of predictive variables from farmer characteristics (age, education level, gender, marital status), bamboo ethnobotany (knowledge and use), and agronomic practices (cropping system patterns, farming practices) at a 5% probability level using Statistical Package for Social Sciences (SPSS ver. 20.0). The best set of model predictors were evaluated using the log-likelihood criterion, significance of the Chi-square test statistic and the overall model performance adjudged by the stronger power of coefficient of determination (R^2). Therefore, the interpretation of results focused on statistical significance, the direction of the regression coefficients (either positive or negative), and the odds-ratio [Exp (β)]. Cross-tab analyses were also conducted to estimate the proportion of potential adopters and non-adopters of bamboo agroforestry.

The main limitation of the survey was that it could not acquire all information needed for the pragmatic diagnosis of bamboo integrated farming system problems, because bamboo agroforestry is yet to be practiced; with no field demonstrations existing in all sampled communities. As a result, detailed information on traditional farming practices adopted by farmers and their bamboo ethnobotany, energy (fuelwood) needs and crisis, soil fertility and management, and crop yield trends were collected through focus group discussions with farmers to validate the answers in the questionnaires.

4.5. Results

4.5.1. Farmers' characteristics/demographics as an indicator for adoption

Table 4.1 summarizes the model results on using farmer characteristics as predictive variables for agroforestry adoption. The best set of model predictors are statistically significant ($p < 0.001$) with 87% correct prediction at a 5% significance level. The results show that the gender and age of farmers can significantly predict the potential adoption of bamboo agroforestry. The odds ratio for age is 1.092 with a positive coefficient of 0.088 signifying that adults have a higher potential to adopt bamboo agroforestry than the youth. The odds ratio also for gender is 1.002 with a positive coeffiecient of 0.002 also implying that gender has inflence on the adoption potential of bamboo agroforestry- men having higher potential.

Table 4.1: Parameter estimates of modeling farmers' characteristics for predicting bamboo agroforestry adoption.

Variables [1]	Coefficients	Std. Error	*p*-Value	Exp (β)
Age	0.088	0.065	0.000	1.092
Gender	0.002	0.028	0.030	1.002
Education level	−0.853	0.090	0.059	0.426
Marital status	0.006	0.041	0.102	1.006
Constant	−1.889	0.210	0.000	0.151

[1] The best set of model predictors (−2 Log-likelihood = 95.9) was significant (Chi-square test value = 58.04, $p < 0.001$) and overall model predictions on adoption of 87.4%. Std. error is the standard error and Exp (β) is the odds-ratio representing the likelihood of adoption.

4.5.2. Farming practices as an indicator for the adoption of bamboo agroforestry

Farming practices such as keeping trees on farms had a significant effect and explained 79.2% of the adoption potential of bamboo agroforestry (Table 4.2).

Table 4.2: Farming practices to predict bamboo agroforestry adoption in the DSFZ.

Variables [1]	Coefficients	Std. Error	*p*-Value	Exp (β)
Keeping trees on farms	1.866	0.010	0.001	0.155
Type/preferred tree species	−1.021	0.020	0.04	1.200
Constant	−1.889	0.210	0.000	0.151

[1] The best set of model predictors (−2 Log-likelihood = 158.4) was significant (Chi-square test value = 116.09, $p < 0.05$) and overall model predictions on adoption of 79.2%. Std. error is the standard error and Exp (β) is the odds-ratio representing the likelihood of adoption.

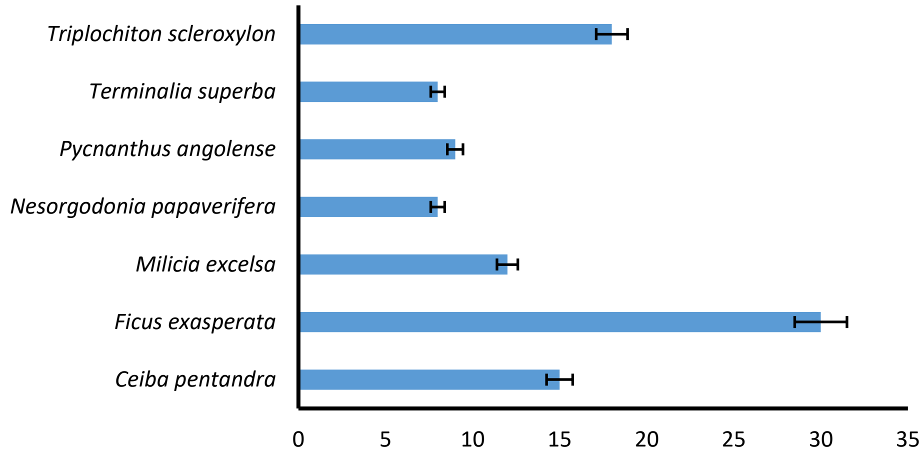

Figure 4.2: Preferred tree species left on farms by respondents.
Error bars show a percentage (5%) deviation of sampled respondents.

Figure 4.2 gives the most common species farmers prefer to keep on farm. *Ficus exasperata* was observed as the most highly preferred with *Nesorgodinia papaverifera* being the least preferred by farmers to be kept on farm.

4.5.3. Characterizing farmers' cropping systems as a predictor for adoption

The set of predictors such as crop production objective, meeting crop production target, crop preference and cropping method which characterize cropping systems in the study area were found to be significant ($p < 0.001$) determinants of bamboo agroforestry adoption (Table 4.3).

Table 4.3: Parameter estimation of farmers' cropping system in predicting bamboo agroforestry adoption.

Variables [1]	Coefficients	Std. Error	*p*-value	Exp (β)
Number of years in crop production	−0.273	0.047	0.961	0.761
Primary objective for growing crops	17.368	0.049	0.02	0.031
Crop preference	1.357	0.110	0.01	3.886
Regular cropping method	−1.537	0.106	0.03	0.754
Meeting crop production target	1.637	0.031	0.02	5.142
Challenges with soil fertility	1.959	0.031	0.084	7.091
Access to fertilizer	−0.708	0.033	0.490	0.493
Constant	−25.382	0.024	0.998	0.000

[1] The best set of model predictors (−2 Log-likelihood = 118.8) was significant (Chi-square test value = 35.22, $p < 0.001$) and overall model predictions on adoption of 86.9%. Std. error is the standard error and Exp (β) is the odds-ratio representing the likelihood of adoption.

4.5.4. Bamboo ethnobotany as a predictive variable for the adoption of bamboo agroforestry

From the study, local knowledge on bamboo characteristics and usage record a strong prediction (88.9%) to the model of potential adoption. Farmers' readiness to try bamboo fodder on their livestock, readiness to incorporate bamboo cultivation on farms for fodder, the visibility of bamboo by farmers, personal planting of bamboo, bamboo use, and farmers' readiness to produce bamboo charcoal are statistically significant to the model (Table 4.4).

Table 4.4: Model estimates of farmers' bamboo ethnobotany to predict bamboo agroforestry adoption.

Variables [1]	Coefficients	Std. Error	*p*-Value	Exp (β)
Knowledge on bamboo leaves used as fodder	−0.769	0.026	0.067	0.463
Livestock fed with bamboo leaves before	−20.505	0.018	0.098	0.000
Readiness to try bamboo fodder	−1.840	0.033	0.000	0.159
Readiness to incorporate bamboo cultivation on farm as fodder	−1.040	0.035	0.005	0.219
Seen/heard of bamboo before	3.727	0.017	0.033	1.316
Personally planted bamboo before	2.321	0.011	0.040	8.364
Taboos/beliefs associated with the use or planting of bamboo	−0.603	0.017	0.471	0.547
Knowledge on bamboo charcoal	−0.006	0.023	0.836	0.994
Production of bamboo charcoal before	1.243	0.000	0.060	1.222
Readiness to produce bamboo charcoal	1.456	0.011	0.001	4.562
Personally used/seen someone using bamboo	2.343	0.028	0.004	3.561
Constant	−12.382	0.024	0.998	0.000

[1] The best set of model predictors (−2 Log-likelihood = 11.9) was significant (Chi-square test value = 12.93, $p < 0.001$) and overall model predictions on adoption of 88.9%. Std. error is the standard error and Exp (β) is the odds-ratio representing the likelihood of adoption.

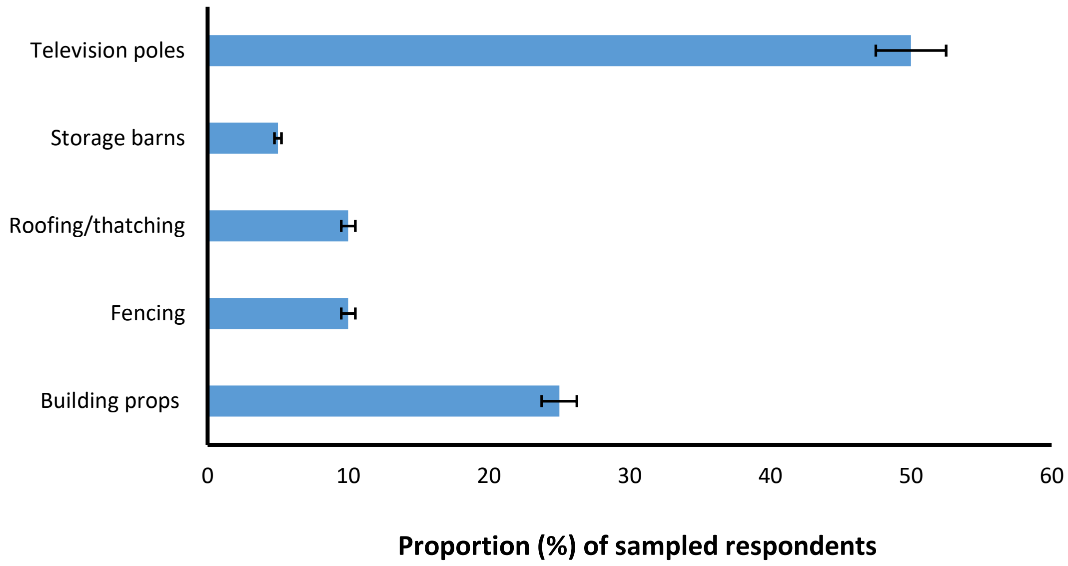

Figure 4.3: Predominant uses of bamboo known to sampled respondents in the DSFZ.

Error bars show a percentage (5%) deviation of sampled respondents.

4.6. Discussion

4.6.1. Farmers' characteristics/demographics as an indicator for adoption

The study found the majority of respondents within the ages of 31–45 years (40%). Within the ages of 31–45 (27%) are potential adopters whilst 24 (12%) are potential non-adopters. This age-influenced adoption trend could be attributed to the perception of young farmers; most of them see farming as a secondary occupation and use it to supplement their monetary income relative to older farmers whose major source of livelihood is farming and thus have a stronger likelihood to accept new farming technologies. This finding is inconsistent with reports by Ajayi et al. (2007) and Keil et al. (2005), which highlight a decreasing potential of agroforestry technology adoption with increasing age. The effect of age on technology adoption has been well studied and reported to be context-specific. For instance, while Kassie et al. (2013) and Ajayi et al. (2007) found age could influence agricultural technology adoption, Njuguna et al. (2015) and Ndiema (2002) found no relationship between age and technology adoption. On the other hand, other researchers have found age to be positively correlated with technology adoption (Okuthe et al., 2013; Atibioke et al., 2012; Wasula, 2000; Aboud, 1997; Ragland and Lal, 1993), citing people between the ages of 18-43 as more active and ready to take risks by adopting new technologies. This is crucial information in deciding the age group as a focus for the bamboo agroforestry introduction.

Gender analysis is also significant to the adoption model with men found to be more likely to adopt bamboo agroforestry than women. The majority of the farmers are males, 160 (80%) of which potential adopters are 136 (68%) and 24 (12%) estimated as potential non-adopters. Female farmers numbered 40 with 38 (19%) characterized as potential adopters whilst only 2 (1%) were non-adopters. Although the female respondents constitute a smaller percentage of respondents, the majority of them show a keen interest in adopting bamboo agroforestry. Nevertheless, the decisions on the choice of new technologies by women farmers are strongly dependent on their husbands as male household heads tend to have more access to land. This agrees with Scherr (1995) who found in her studies on economic factors influencing farmer adoption of agroforestry that females are not permitted to make decisions to adopt agroforestry technologies without consulting the family head (mostly males). This adds to the growing concern of gender inequalities on household decisions and access to farm resources. The lower proportion of sampled women-farmers in the study area could be linked to situations where women do not have headship to land and tree tenure due to the largely patrilineal inheritance systems (Nyaga et al., 2015). Issues of gender in agricultural technology adoption have been explored over the years, and studies report mixed evidence concerning the different roles females and males play in the adoption of technology (Bonabana-Wabbi, 2002). In comparing these facts, Morris and Doss (1999) report no significant relationship between gender and probability to adopt improved maize in Ghana. Conversely, other studies have shown differences in gender norms and culture play significant roles in technology adoption (Mignouna et al., 2011; Mesfin, 2005). In Nigeria, Obisesan (2014) found gender to be a significant determinant of the adoption of improved cassava production approaches. Similarly, Lavison (2013) also reports male farmers are more likely to adopt organic fertilizer as compared to their female colleagues.

Unlike age and gender, the study shows that the level of education and marital status are not significant determinants of bamboo agroforestry adoption. Although this contradicts the assertion that education (formal and informal) or training increases the rate of technology adoption (Venkatesh et al., 2000), it may be context-specific. Other studies, such as Ndiema (2002) and Amudavi (1993), also found that the educational status of a farmer was not a significant indicator of technology adoption. The results of the current study suggest that, in the study region, the kind of education or training that can facilitate the adoption of an innovation might be the education on the innovation itself and how well farmers are exposed to the innovation; and not necessarily academic education (Ntshangase et al., 2018; Tegegne, 2017; Wafuke, 2012; Kafle and Shah, 2012; Thangata and Alavalapati, 2003).

Many new practices stemming from a top-down approach and overlooking socio-economic realities often produce disappointing results for implementing agencies (Buck et al., 1998). However, understanding the prevailing social values can positively influence the adaptation and commitment to both existing and introduced technologies (Pattanayak et al., 2003). In addition, studies on agroforestry adoption are becoming increasingly important to researchers. It is therefore essential to monitor socio-economic concepts in agroforestry to delineate strengths and weaknesses in the current state of knowledge and to foster guidance for further investigation and optimal decision making through productive feedback loops between researchers and farmers (Rule et al., 2000).

4.6.2. Farming practices as an indicator for the adoption of bamboo agroforestry

For the 194 farmers who kept trees on their farms, 168 (85%) were potential adopters and 26 (13%) were potential non-adopters. However, all the farmers (4) who do not leave trees on their farms were potential adopters (2%). Figure 4.3 shows the preferred trees left on farmlands for economic and environmental benefits. The farmers report several reasons for leaving trees on farms such as economic gains, shade, soil and water conservation, fodder, and fuelwood provision. This implies that farmers would most assuredly accept to plant any woody perennial on their farm if they knew the ecological and economic functions of such woody perennial. It could be further deduced that farmers' decision for keeping trees on their farmlands have ecological justifications and importance since trees maintain and improve soil fertility through processes of nitrogen fixation and nutrient uptake from deep soil horizons (Nair et al., 2007). Furthermore, trees improve the structural properties of the soil with their rooting systems by reducing soil erosion and increasing soil water infiltration (Ayres et al., 2009**)**. Alavalapati et al. (2001) recounted that farmers mostly implement agroforestry systems to provide household needs such as food, fodder, and fuelwood. This system may not be imperative to the conventional 'agroforester' such as social benefits or community acceptability of the system (Kurtz, 2000; Buck et al., 1998). Technology adoption has many policy implications on agricultural and agroforestry development and technology-specific attributes have been shown in the past to significantly determine farmers' decision to adopt a technology (Idrisa et al., 2010). The economic value of woody perennials is a key factor in farmers' adoption of technology (Scherr, 1995). Furthermore, according to Glover et al. (2013), the environmental or ecological potential of a woody perennial also is critical in influencing an adoption decision.

4.6.3. Characteristics of farmers' cropping systems as a predictor for adoption

It was observed that most (67%) of the sampled respondents were farmers who grow crops mainly for commercial purposes. Out of this, 61% were potential adopters and 6% were potential non-adopters. With recent climate change and land degradation impacts on crop yields and poverty trends especially in sub-Saharan Africa (SSA), most farmers are shifting from the traditional subsistence farming to become more commercially-oriented. Such farmers are keener to explore innovations that seek to increase production and farm incomes (Castle et al., 2016; Lavison, 2013). Other findings have also supported the assertion that the capital or economic situation of a farmer influences technology adoption (Girmay et al., 2016; Caswell et al., 2001; Venkatesh et al., 2000). In SSA, bamboo-based agroforestry systems are now developing, but literature on their economic feasibilities is limited. However, with livelihoods in SSA mostly tied to agriculture and forestry, investments in bamboo-based agroforestry systems may contribute to rural poverty reduction and improved livelihoods in the region (FAO, 2010). Like most agroforestry systems, bamboo-based agroforestry systems are expected to open new income streams by diversifying agroecosystems and offering multiple economic benefits from the sale of grains and vegetables from short-duration crops (integrated with bamboo), supply of fodder for livestock, and the sale of processed bamboo culms as fuelwoods, charcoal, timber or industrial raw materials (Babulo et al., 2008). In most of SSA, it is common for rural households to diversify income streams as a pathway to reduce vulnerability to the failure of their primary income-generating activities (Castle et al., 2016; Alobo-Loison, 2015).

Although bamboo raw materials have no guaranteed prices in Ghana, potential bamboo farmers have the advantage of benefiting from the emergent and growing bamboo economy and industry in the country. Ghana seems to be on a pathway to advancing bamboo resource development following the increasing market for bamboo products and the presence of the West Africa sub-regional office of INBAR in Kumasi. The Government of Ghana and INBAR have collaborated in establishing the Bamboo and Rattan Development Programme (BARADEP). Aside the small-scale traditional bamboo basketry/craft shops and the famous Bamboo Bicycle Producing Company at Toase-Nkawie in Kumasi, several other private bamboo initiatives. Comprising small cottage to large-scale enterprises, Global Bamboo Products in Anyinam, KWAMOKWA bamboo plantations all in Kumasi, Greater Accra Bamboo, and Rattan Handicrafts Association**,** Brotherhood Cane/Rattan Weavers Association., Links Handicrafts Association, New Vision Handicrafts Association, Pioneer Bamboo Manufacturing Co. Ltd. (Accra, Ghana), Assin Fosu and T-Tom Bamboo Toothpick Processing Company, Tandan are some of few. Similarly, foreign investors have taken advantage of this initiative owing to a sound political environment and favorable climatic conditions for bamboo development. These cut across a dozen of large-scale plantations and processing centers in Ghana. One of the most successful of such initiatives is the EcoPlanet Bamboo project, with its vision as a bamboo plantation and processing company that focuses on the provision of a secure and certified source of fiber for timber manufacturing industries and markets on a global scale. Darlow Enterprises is another bamboo company of importance which is also resident in Ghana. With headquarters in Belize and the Philippines. Darlow Enterprise focuses on bamboo charcoal production. All these enterprises present a great market channel for bamboo trade from which potential bamboo farmers could link up and benefit financially through the trading of bamboo products.

4.6.4. Bamboo ethnobotany as a predictive variable for the adoption of bamboo agroforestry

Ethnobotany focuses on how plants have been or are used, managed and perceived in human societies, and it expresses how plants are used for various needs (clothing, conservation techniques, shelter, food, medicine, hunting, magico-religious concepts) as well as their general economic, and sociological importance in societies (Wanzala et al., 2005).

Out of the 186 farmers who appeared to possess some level of knowledge on bamboos, 164 (88%) were potential adopters and 22 (12%) were potential non-adopters. Bamboo use in Ghana is tied to fencing, use as television poles, roofing, etc. (Figure 4.4). Cross-tab analysis also showed that 124 (78%) farmers are ready to try bamboo fodder, whilst 36 (22%) preferred otherwise. It is argued that new or existing interventions to encourage tree planting on farmlands need to be centered or realigned on farmers' comprehension of tree management in the domains of household livelihood schemes, such as fodder needs, energy needs and supplement of income, stressing that information about farmers' perceptions of the significance of trees and the constrictions they face in increasing tree resources are rare (Atangana et al., 2014; Hogarth and Belcher, 2013; Wang et al., 2008). In the DSFZ, livestock is mostly kept on free-range systems where prolonged drought limit access to nutritive food materials (Satya et al., 2010). As bamboos are drought-tolerant and produce relatively high nutritive fodder, their integration into farming systems can supply supplementary feed materials for livestock (Partey et al., 2017a). While the increased knowledge and use of bamboo have the potential to support its integration into traditional farming systems, issues of land tenure, labor availability and economic importance have to be critically assessed.

4.7. Conclusion

The study identifies the socioeconomic factors and farming practices that influence the adoption of bamboo agroforestry in the dry semi-deciduous forest zone of Ghana. Factors found to be statistically significant were: age, gender, cropping method, crop preferences, the primary objective for growing crops such as market availability and early maturity, role of bamboo as a fodder plant, uses and benefits of bamboo, cropping system and farming practice. The present study provides key contributions for future bamboo-based agroforestry design and some directions for agricultural development policies. The key influential socioeconomic indicators identified in the study may provide a guide for rolling local farmers into 2016–2040 National Forest Plantation Development Strategy of Ghana which seeks to establish 1,000 hectares of bamboo plantations annually; culminating into the agenda to plant 50,000 hectares of bamboo plantations over the next 25 years by employing agroforestry principles. In the quest to develop Ghana’s bioenergy sector, bamboo biomass has been included to ensure the sustainability of the Ghana Bioenergy Policy initiative. The Government of Ghana may benefit essentially by using this study as a basis for further studies in developing a comprehensive national database to offer more insight into bamboo-socioeconomic implications to enhance the achievement of this goal. There is also the opportunity for Ghana to revitalize the almost ‘defunct’ national agroforestry policy by drawing lessons from this study; by critically considering those socioeconomic indicators identified.

4.8. Acknowledgments

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5. Farmer perception and potential of bamboo leaf as fodder for livestock production in the dry semi-deciduous forest zone of Ghana

5.1. Abstract

With limited access to fodder with fair nutritive characteristics during dry periods, it is envisaged that evergreen bamboo, which produces year-round litter production and has relatively high nutritive characteristics, may provide a valuable supplementary source of feed. In Ghana, bamboo use as fodder is largely unknown and efforts to promote its use will require an understanding of local knowledge and perception as an entry point to disseminating viable positive results on bamboo fodder use for livestock. Using a case study of Jeduako in the dry semi-deciduous zone of Ghana where a bamboo-based agroforestry model is being piloted by the International Bamboo and Rattan Organization (INBAR), a combination of focus group discussions (involving 10 household heads – 5 males and 5 females) and questionnaire interviews were used to - (1) characterize livestock production systems and (2) assess local knowledge and perception of bamboo leaf use as fodder for livestock and (3) for a field fodder quality experimentation using twenty Djallonké kids (juvenile goats) of 1-year-old with mean initial weight of 13.77 ±1.16 kg for the trial and allotted to four dietary treatments in completely randomized block design with five replicates per treatment to assess the effect of leaves of two bamboo species (*Oxytenanthera abyssinica* and *Bambusa balcooa*) as a feed supplement to goats fed on basal diets of *Pennisetum purpureum* and *Brachiaria decumbens*. The study revealed farmers reared goats, sheep, and cattle but goat production is a priority for most households particularly women household heads. Livestock is mostly kept under semi-intensive conditions mainly to meet the local market and generate income for household welfare needs. With a dominating semi-intensive production system, farmers source fodder from managed and planted trees and shrubs, crop residues, grasses and forbs available on their homesteads or home gardens. While bamboo is a useful woody perennial for various household needs, only 26% of respondents were aware bamboo leaves could be fed to livestock. Respondents had learned of this by seeing someone feed goats with it, personally fed goats with it or heard someone talked about it. Moreover, 64% of the respondents expressed willingness to feed their animals with bamboo leaves if shown to be suitable. These findings suggest that bamboo could be a preferred feed source for livestock if demonstrated through participatory action research. However, the results showed gender may be an influential factor in determining the acceptability of bamboo fodder for livestock. The results indicated about 91.6% higher probability of men farmers accepting bamboo leaf fodder as livestock feed than women. This gives an indication of how gender should be mainstreamed in the introduction of bamboo fodder to farmers. The fodder quality results indicated that nutrient composition and *in vitro* gas production of the treatments varied significantly among the grasses and the bamboo supplement. The highest crude protein and *in vitro* gas production was observed in *O. abyssinica*. Besides, *O. abyssinica* diets recorded the highest daily gain and the lowest feed to gain ratio. The treatment effect was significant on blood variables measured. Bamboo leaves are viable feed supplement for goats as shown by their nutrient profile and positive influence on the growth performance of goats. Leaves of any of the bamboo species could be used as supplemental feed for goats, however, we recommend the choice of the leaves of *O. abyssinica* for goat production in Ghana. The 'Rearing for Food/meat and Jobs Programme, a flagship policy initiative of the government of Ghana, may introduce bamboo leaves as additional supplemental feed for livestock production in Ghana.

5.2. Introduction

Livestock production remains a major livelihood activity for most of Ghana’s agrarian communities Laube et al. (2012) reported that making an investment in this industry is crucial for alleviating poverty and enhancing food security. Among other factors, the Ministry of Food and Agriculture (MoFA) reports access to sustainable feed supply as a constraint to the livestock industry (MoFA, 2011). As most livestock are kept on a free-range system, forage of good nutritive value is normally scarce in the dry season resulting from recurrent droughts, continuous over-grazing and lack of range improvement interventions. Livestock is kept on a free-range system where they move around for long distances for feed, where in most cases; available feeds have low nutritive value and are normally scarce in the dry season. As a result, the productivity of ruminant livestock is compromised. The problem is further exacerbated by the inability of most farmers to provide supplementary feed sources for their livestock (MoFA, 2011). In the drier forest transitional zones in Ghana (study region) the highly palatable and productive perennial grasses, legumes and herbaceous species have declined and increasingly giving way to unpalatable, low quality annual species, with an associated loss of soil fertility through excessive livestock overgrazing and climate variability effects (MoFA, 2011). Leng and Fujita (1997) reported that dietary supplements are required in order to attain adequate levels of glucose and glycogenic compounds to support high ruminant productivity from low-quality tropical forage. The nutritive estimation of the remaining predominant pasture species is extremely poor with a normal crude protein (CP) content of less than 7%, and the grazing livestock are deficient in about 50% of their required CP intake (Khan and Habib, 2012). Established research findings reported that supplementation of CP, minerals, and vitality feeds optimizes microbial fermentation of low-quality fibrous feeds in the rumen that in turn expands total dry matter (DM) consumption and improves animal productivity (Patra, 2010; Khan et al., 2009). Notwithstanding, in the predominant small scale, subsistence farming systems in Ghana’s pastoral communities, a large portion of the farmers cannot afford a nonstop supplementation of concentrate feeds to their animals. Cost consideration of conventional animal feeds (i.e. cereal and protein-based diets – maize and wheat bran, fish meal and soybean meal) that ensure high productivity may limit their use as a supplement. Besides, they are also in short supply during certain times in the year owing to their high demand for human consumption.

With increasing consumption and demand for livestock products, as a result of growing economies, rising incomes and changes in lifestyle, urbanization and the associated shrinking land area, future hopes of feeding the ever-increasing Ghanaian population and ensuring food security will depend on the better utilization of non-conventional feed resources. Current research is, therefore, focusing and directed towards on an exploration of an affordable and abundant, alternate CP and energy-rich feeds. In such a manner, tree leaves have received considerable attention, because of several points of interest, for example, a supply of good quality green fodder during the dry periods, and high CP and mineral contents (Waghorn, 2008; Devendra and Sevilla, 2002). Recent discoveries demonstrate that tree leaves can be efficiently utilized as a low-cost CP and minerals supplement to the low-quality fibrous diets in the tropics, particularly during the prolonged feed scarcity periods (Salem and Smith, 2008) Considering this need, the International Bamboo and Rattan Organization (INBAR) is steering a bamboo-based agroforestry model in the dry semi-deciduous forest zone of Ghana to promote the integration of bamboo into indigenous cropping systems to advance the reconciliation of socioeconomic needs and give satisfactory feed for livestock.

It is envisaged that evergreen bamboo, which produces year-round litter and has relatively high nutritive characteristics, may provide a valuable supplementary source of feed. In India, bamboo leaves are already used as fodder for ruminants, particularly when there is a scarcity of pasture. In Himachal Pradesh and Uttarakhand during winter months, bamboo (*Dendrocalamus hamiltonii*) and dwarf bamboo leaves are extensively used as green fodder. All species of bamboos used as fodder have shown positive effects on cattle, particularly young calves, and reportedly increased milk production (Toth and Dou, 2016). Furthermore, leaves of 27 species of bamboo analyzed for their nutrient content were found to be rich in crude protein (9-19%) and low in crude fiber (18-34%) (Partey et al., 2017b). In Ghana, bamboo use as fodder is largely unknown and efforts to promote its use will require an understanding of local knowledge, perception and leaf fodder quality on bamboos as an entry point to disseminating viable positive results on bamboo fodder use for livestock. It was, therefore, the objective of this study to: - (1) characterize livestock production systems (2) assess local knowledge and perception of bamboo leaf use as fodder for livestock, (3) determine the nutritional profile of bamboo species (*Oxytenanthera abyssinica and Bambusa balcooa*) and compare with commonly used grass species (*Pennisetum purpureum* and *Brachiaria decumbens*), (4) determine the effect of bamboo leaves on the intake and growth of goats fed a basal diet of *Pennisetum purpureum* and *Brachiaria decumbens* and, (5) assess the effect of bamboo leaves supplementation on the blood profile of goats.

It is hypothesized that feeding bamboo leaves as supplement to common grasses such as *Brachiaria sp.* and *Pennisetum sp.* to goats, will enhance their feed intake, improve growth performance and blood profile; and the knowledge of farmers on the use of bamboo leaves as fodder could facilitate the adoption process and strategies of integrating bamboo into farmland ecology in Ghana.

5.3. Materials and methods

5.3.1. Study site

The study was carried out at Jeduako in the Sekyere Central District of Ghana; located within Lat. $06^{o}55^{1}$ and $07^{o}30^{1}$N and Long. $05^{o}00^{1}$ W (Figure 5.1). The District covers a total land area of 1564 km^2 and has 150 settlements with 70% being rural. The research area falls within the Dry Semi-Deciduous Forest Zone of Ghana. It is characterized by a bimodal rainfall pattern with an average annual rainfall of 1270 mm. The major rainy season starts in March with a major peak in May. There is a slight dip in July and a peak in August, tapering off in November. December to February is a very long season, which is warm and dusty (the driest period). The area has a mean annual temperature of $27^{o}C$, with variations in mean monthly temperature ranging between $22^{o}C$ and $30^{o}C$ throughout the year. The soil type of the study site is sandy loam (Ejura – Denteso Association). Subsistence agriculture is the main economic activity engaging about 65% of the population. The majority of agricultural production is from manually cultivated rain-fed crops. The intercropped range of rain-fed crops differs with greater potentials for maize, plantain, beans, cassava, and yam. This agroecological zone was chosen because of its unique characteristic features which combine those of the forest and savanna zones. The grassland/ rangeland vegetation in this zone favors livestock production; but this is currently being challenged by excessive anthropogenic activities like overgrazing, harvesting of wood for fuelwood and agricultural 'extensification'. This has reduced fodder availability for livestock (especially goats-which is predominant in this area) production and therefore the need to explore alternative fodder sources is paramount. It is the zone where the Forestry Commission of Ghana has proposed and earmarked for massive community tree (including bamboo) planting for fuelwood production (Forestry Commission, 2015). Therefore, bamboo fodder could probably be a suitable and readily available future fodder source if proven to be of the required quality and acceptable to the community.

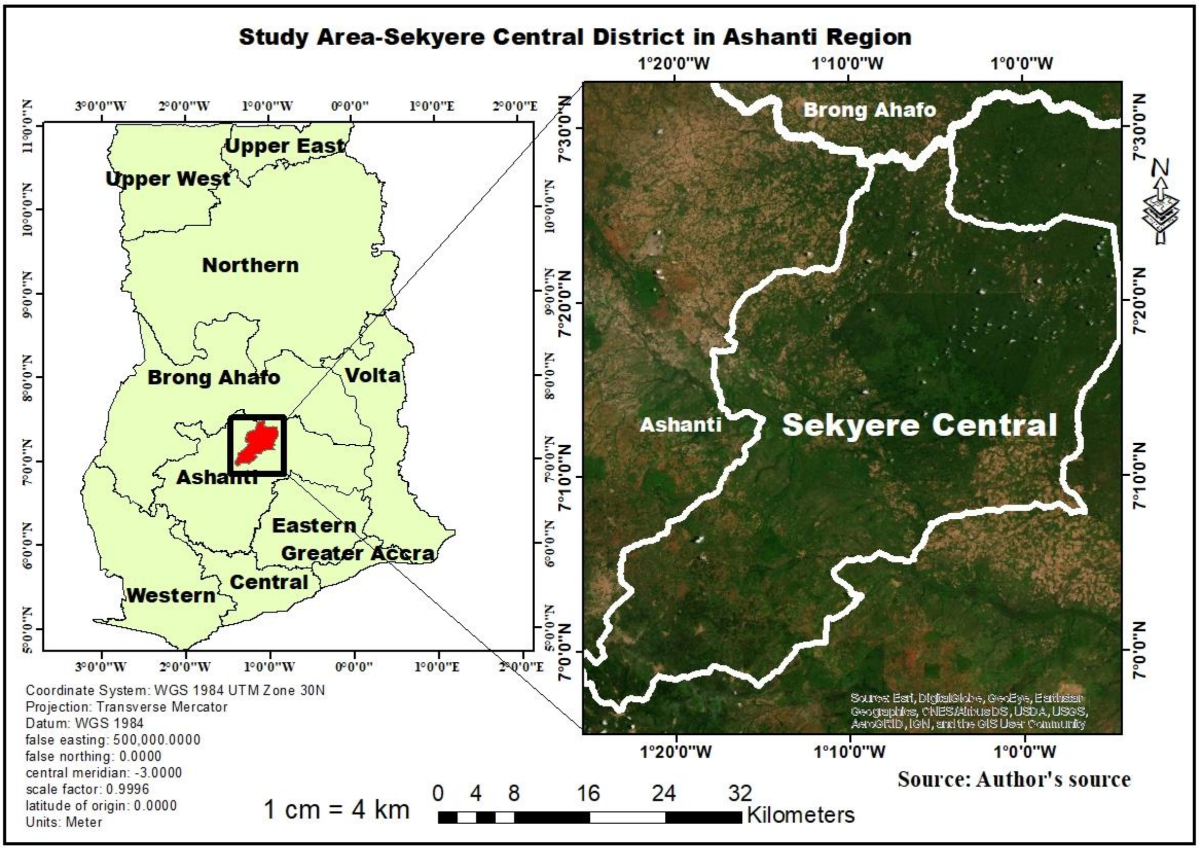

Figure 5.1: Map of Ghana showing the Sekyere Central District where study was carried out

5.3.2. Data collection and analysis for farmer perception

Data were collected using focus group discussions and semi-structured questionnaire interviews (See Appendix 9). The focus group involved 10 household heads – 5 males and 5 females. The participants were engaged from the farming population of the study area based on recommendations from opinion leaders. The focus group was conducted with three research team members; one played the role of a moderator, whilst two members recorded the information and supported with follow-up questions to probe issues to details. The focus group was conducted in a local dialect (Asante Twi) translated, transcribed, and analyzed in English. Issues discussed in the focus group bordered on – (1) livestock preference, (2) benefits and feeding challenges, (3) perception of bamboo use as fodder, and (4) willingness to integrate bamboo into cropping systems or as a component of a land management unit for food production. Semi-structured questionnaires were also administered to 100 respondents (farmers) to complement the qualitative information from the focus group discussions. The 100 farmers (involving 47% females and 53% male household heads) were purposively selected from the study area based on their involvement in livestock production either as a sole pastoral system or in integration with crops.

The number of respondents was computed from the relation below by Edriss (2006):

$$n = \frac{N}{1+N\,(e)^2}$$ ………………………………………………….. (**Equation 5.1**)

Where n is the sample size, N is the population size, and e is the level of precision equal to 0.05 at a 95% confidence level.

A combination of closed and open-ended questions (Appendix 8) was used to generate data on farmers' demography, farm production systems, livestock nutrition, and feeding challenges, alternative livelihood activities, perception of bamboo use as fodder, and farmers' willingness to integrate bamboo into indigenous cropping systems. A combination of descriptive and inference statistical approaches such as chi-square and logit models were used to analyze data collected where applicable. Chi-square tests were employed in cross-tabulations between variables whereas logit models were used to analyze the relationship between a binary dependent variable and a set of independent variables, whether binary or continuous. The logistic model for 'k' independent variables (X_i, X_2, X_3… X_k) is given by:

$$\text{Logit P (X)} = \alpha + \sum_{i=1}^{k} \beta_i\, x_i$$ ……………………………….. (**Equation 5.2**)

Where Exp (β_i) indicates the odds ratio for a person having characteristics *i* versus not having *i*, while β_i is the regression coefficient, and α is a constant

5.3.3. Location and source of materials for fodder quality trial

The study on the effect of bamboo fodder as supplement feed for goats was conducted at the Department of Animal Science, Kwame Nkrumah University of Science and Technology (KNUST). *Pennisetum purpureum*, *Brachiaria decumbens* and the bamboo leaves needed for the study were obtained from the International Bamboo and Rattan Organization (INBAR) project site at Jeduako in the Sekyere Central District of Ashanti Region, Ghana and the surrounding communities. Twenty Djallonké kids (juvenile goats of an average age of 1 year in age) with a mean initial weight of 13.77 ±1.16 kg was obtained from the Ejura Goat Breeding Station of MoFA and transported to the Department. They were tagged, dewormed and put on antibiotics and multivitamin injection. They were allowed to open-graze before confining them in the goat barn for the trial. The choice of goats for this fodder quality trial was because goat production was seen from the focus group discussions and the initial farmer perception study as the most preferred livestock in the study region.

5.3.4. Preparation of the goat barn

Thirty (30) barns measuring 4x7ft were renovated by cementing the floor, changing the slabs and the wire mesh.

5.3.5. Carting of fodder and sample preparation

The grasses and the bamboo leaves were baled with a box baler and carted respectively from the surrounding communities, and from Jeduako in the Sekyere Central District of Ashanti Region to the Department. Representative samples were obtained from the bale and milled through a 2mm screen for chemical analysis and *in vitro* gas production.

5.3.6. Chemical analysis

The chemical analysis adopted the procedures of AOAC (2002) using 2.0g triplicate samples and the 0.5g triplicate sample were used for the neutral detergent and acid detergent fibers (NDF and ADF) respectively, adopting the Ankom Daisy technique.

5.3.7. In vitro gas production assays

Approximately 200 mg triplicate samples of the dry matter (DM) of each sample were placed in a 100 ml graduated glass syringe filled with 10mL of rumen fluid, and 20mL of buffer (Oni et al., 2011). Pistons were lubricated with Vaseline[i] and inserted into the syringes. The rumen fluids were sampled from rumens of goats with permanent rumen fistula. Rumen digesta was squeezed through four (4) layers of cheesecloth, homogenized and kept at 39^{0}C in a water bath under continuous flushing with CO_2 before use. In the hourly interval, the syringes were shaken to record gas volumes at 3, 6, 12, 24, 48, 72 and 96 h of incubation and corrected for blank syringes incubated in each run.

The model below was used for the calculation of gas production (GP):

$$GP = b\,(1-Exp\,(^{-ct}))$$ …………………………………………… (**Equation 5.3**)

Where b = potential gas production
c = rate of gas production
GP = gas produced at time t

5.3.8. Goats preparation and experimental design

Twenty Djallonké goats having a mean initial body weight of 13.77 ±1.16 kg and approximately 1-year of age were used for the trial. The goats were fed a basal diet of *Pennisetum purpureum* and *Brachiaria decumbens* and a supplement of *Oxytenanthera abyssinica* and *Bambusa balcooa*. The diets were chopped into 2.5 cm pieces and offered *ad libitum* in two equal proportions, twice daily (0900h and

1600h). The basal diets were given after the complete consumption of the supplement. Urea molasses block was given *ad libitum* to the experimental animals in the individual cages. Five goats were randomly allocated to four dietary treatments namely; 1) *Pennisetum purpureum* plus *Oxytenanthera abyssinica* 2) *Brachiaria decumbens* plus *Oxytenanthera abyssinica* 3) *Pennisetum purpureum* plus *Bambusa balcooa 4*) *Brachiaria decumbens* plus *Bambusa balcooa* in a completely randomized block design with five replicates per treatment. Prior to the experiment, the animals were maintained on the experimental diets for a two-week adjustment period. The feeding trial was carried out for 12 weeks spanning from 3rd June to 5th September 2016.

5.3.9. Blood sampling and parameters measured

Blood samples were collected from all the goats in the four treatments prior to and immediately after the trial. Five milliliters (mL) of blood were collected from each of the animals via the jugular vein. Subsequently, three milliliters (mL) were emptied into a vial containing Ethylene Diamine Tetra Acetic Acid (EDTA) for hematological study. Immediately, the bottles were capped and the content mixed gently for approximately a minute by repeated inversion or rocking. The remaining 2 mL was emptied into another vial free of Ethylene Diamine Tetra Acetic acid (EDTA) for biochemical studies. The blood from both sampling units was analyzed immediately after collection in the Haematological and Biochemical laboratory of the KNUST's Hospital. Parameters measured included red blood cell, white blood cell, total protein, and the albumen.

5.3.10. Statistical analysis for fodder quality trial

Data from the chemical composition and feeding trial were analyzed as replicated completely randomized and completely randomized block designs respectively using Wang and Goonewardene's (2004) approach. The gas production assay adopted the PROC NLINMIXED procedures of SAS. Where there was a significant effect (at $P < 0.05$) treatment means were compared by least-square means. The mean separation was done using Student-Newman-Keels Test.

5.4. Results

5.4.1. Characteristics of respondents

Table 5.1 shows the demographic characteristics of the respondents used in the study. Respondents were male-dominated (53%) and were mostly between 45 to 60 years old. There was a low percentage (10%) of youth (18 – 30 years).

Table 5.1: Demographic characteristics of respondents based on gender

	Male (%)	Female (%)	Total (%)
Age			
18-30	5	5	10
31-45	17	10	27
45-60	22	19	41
above 60	9	13	22
Education level			
Illiterate	40	40	80
Primary	8	5	13
Secondary	2	2	4
Tertiary	3	0	3
Marital status			
Single	2	4	6
Married	51	28	79
Divorced	0	3	3
Widowed	0	12	12
Number of dependents			
None	1	2	3
1-3	9	9	18
4-6	25	20	45
≥ 10	18	16	34
Religiosity			
Christian	41	40	81
Islam	7	6	13
Traditional	5	1	6
Tribe			
Akan	38	40	78
Ga	0	1	1
Northerner	15	6	21
Land ownership			
Personally owned	34	19	53
Hired	2	4	6
Family-owned	17	24	41
Land size (ha)			
< 1	29	38	67
1 – 3	24	9	33

N = 100

In the focus group discussion, the demography of the participants is shown in Table 5.2. The majority was within the age group of 31-45 (40%). Those with no formal educational background constituted (70%), those married (80%), those with dependents of people of 1-3 (50%). The religious community consisted of 70% Christians and 30% Moslems.

Tble 5.2: Demographic characteristics of participants of focus group discussion based on gender

	Male (%)	Female (%)	Total (%)
Age			
18-30	20	10	30
31-45	10	30	40
45-60	10	10	20
above 60	10	0	10
Education level			
No formal Education	30	40	70
Primary	10	10	20
Secondary	10	0	10
Marital status			
Married	50	30	80
Divorced	0	10	10
Widowed	0	10	10
Number of dependents			
1-3	10	40	50
4-6	30	10	40
≥ 10	10	0	10
Religiosity			
Christianity	25	45	70
Islam	20	10	30

N=10

5.4.2. Characteristics of livestock production systems

Respondents reared goats, sheep, cattle, poultry or a combination of any of these animals mainly kept under free-range or semi-intensive production (Figure 5.2).

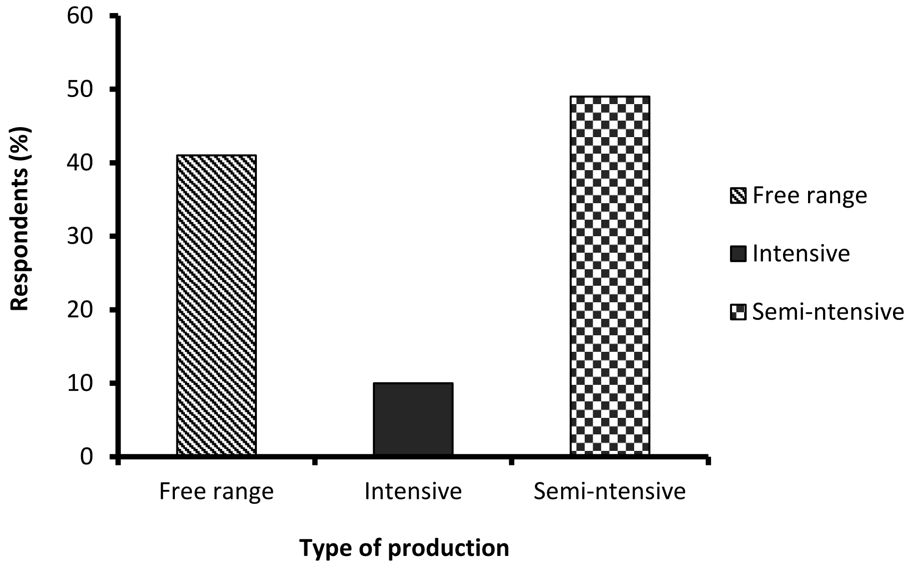

Figure 5.2: Characteristics of livestock production systems.

However, crop-livestock systems were also common among 94% of farmers with animals kept together with crops such as maize, plantain, yam, groundnut, and cassava. The survey results showed the dominance of goat production (71%) in the study area (Table 5.3).

The results showed significant (χ^2 = 10.081, d.f = 4, p = 0.039) association between gender and type of livestock. The survey showed that goats were more popular among female than male farmers (Table 5.3). The interest in goat among women also makes their production a key strategy for women empowerment. The study also revealed that while farmers reared goats for subsistent and commercial interests, the latter was an utmost priority (Table 5.3).

Again, during the focus group discussion, it came out that farmers mainly kept livestock as an adaptation strategy in the event of crop failure. Almost every farmer rears some kind of livestock to support income from farming activities.

Table 5.3: Type of livestock and production objective among farmers in Jeduako in the dry semi-deciduous zone of Ghana

Item	Male (%)	Female (%)	Total (%)
Livestock			
Only goat	33	38	71
Only Sheep	1	0	1
Goat + Sheep	10	9	19
Goat + Cattle	2	0	2
Goat + Sheep + Cattle	7	0	7
Production objective			
Wholly subsistent	2	0	2
Wholly commercial	1	2	3
Subsistent + Commercial but subsistent a priority	0	1	1
Subsistent + Commercial but commercial a priority	50	44	94

N = 100

5.4.3. Fodder sources and feeding challenges for livestock production

Table 5.3 shows various trees, herbs, grasses and forbs that provide palatable fodder for livestock in the study area. These fodder sources are plants (Table 5.4) deliberately grown or managed on farmlands. Most of the trees had been left on farmlands to provide shade, serve as windbreaks, for charcoal or timber. Animals were either fed with leaves from the species or browse on them freely. Respondents expressed feeding challenges for livestock in the study area. Based on the questionnaire interviews and focus group discussions, the respondents claimed that owing to seasonal rainfall, the year-round feed availability and quality fluctuate substantially. A typical example is, pasture abundance increases with a concurrent improvement in quality in the rainy seasons, the situation changes when pasture abundance and quality decline during of the prolonged dry periods.

Table 5.4: Fodder sources for livestock in Jeduako in the dry semi-deciduous forest zone of Ghana based on interviews

Scientific name	Local Name	life form	Management
Antiaris africana	Kyenkyen	Tree	Wild
Berlinia grandiflora	Papa	Tree	Wild
Ceiba pentandra	Onyina	Tree	Wild
Millicia excels	Odum	Tree	Wild
Spondias mombin	Atoa	Tree	Managed
Tabernaemontana crassa	Pepea	Tree	Wild
Bombax buonopozense	Okum	Tree	Wild
Ficus exasperate	Nyankyerene	Tree	Wild
Millettia thonningii	Sante	Tree	Wild
Moringa oleifera	Moringa	Shrub	Planted
Spathodea campanulate	Kokoanisuo	Tree	Wild
Albizia zygia	Okoro	Tree	Wild
Tetrapleura tetraptera	Prekese	Tree	Wild
Triplochiton scleroxylon	Wawa	Tree	Wild
Dalbergia oliveri	Krayie, Rosewood	Tree	Wild
Anogeissus leiocarpus	Kane	Tree	Wild
Chromolaena odorata	Acheampong	Fern	Wild/managed
Khaya senegalensis	Kuntukuri	Tree	Wild
Gmelina arborea	Shading Tree	Tree	Wild
Morinda lucida	Konkroma	Tree	Wild
Hypselodelphys poggeana	Baba dua	Tree	Wild
Afzelia Africana	Opapao	Tree	Wild
Alchornea cordifolia	Gyama	Shrub	Wild
Daniellia oliveri	Senya	Tree	Wild
Griffonia simplicifolia	Atooto	Tree	Wild
Millettia zechiana	Frafraha	Tree	Wild
Ricinodendron heudelotii	Nwama	Tree	Wild
Ficus sur	Odoma	Tree	Wild
Funtumia elastic	Funtum	Tree	Wild
Holarrhena floribunda	Sese	Tree	Wild
Lophira lanceolate	Kraku	Tree	Wild
Albizia adianthifolia	Pampana	Tree	Wild
Pennisetum purpureum	Elephant grass	Grass	Wild
Brachiaria decumbens	Esere	Grass	Wild
Saccharum officinarum	Sugar cane	Grass	Planted

(See Appendix 12 for species and authors of most common species)

5.4.4. Knowledge and determinants of bamboo leaf as fodder for livestock

The results showed respondents knew about bamboo and confirmed they use bamboo for diverse purposes: staking yam tendrils, as firewood and charcoal, for building fences, roofing, building construction, building silos, mounting TV antennas, as a source of herbal medicine, producing thread for sowing, fishing and as a source of herbal medicine. Meanwhile, only 26% of respondents (17% of males and 9% of females) knew bamboo leaves could serve as fodder for livestock as indicated in Table 5.5. They had learned of this by seeing someone feed goats with it, personally fed goats with it or heard someone talked about it. Moreover, in Table 5.6, 64% of the respondents expressed willingness to feed their animals with bamboo leaves if shown to be suitable.

Table 5.5: Known uses of bamboo in Jeduako in the dry semi-deciduous forest zone of Ghana based on interviews

Known Use	Males %	Females %	Total %
Staking Yam Tendrils	31	35	66
Firewood and Charcoal	8	12	20
Building Fences	31	27	58
Roofing	43	15	58
Building Construction	19	10	29
Building Silos	47	8	55
Fodder	17	9	26
Mounting TV Antennas	38	30	68
Source of Herbal Medicine	11	8	19
Producing Thread for Sowing	6	6	12
Fishing	21	11	32

(N=100) Data represent multiple responses.

Results from Table 5.6 indicate gender as the most influencial indicator for the acceptance of bamboo leaf as fooder for livestock. Men were more likely ready to try bamboo fodder for their livestock than their female counterparts.

Table 5.6: Determinants of acceptance of bamboo leaf as fodder for livestock in Jeduako in the dry semi-deciduous zone of Ghana

		B	Std. Err	Wald	df	Sig.	Exp(B)	95% Confidence Interval for Exp(B)	
								Lower Bound	Upper Bound
Yes	Intercept	-1.076	1.856	.336	1	.562			
	A1_Age	.520	.323	2.591	1	.107^{ns}	1.683	.893	3.171
	A2_Gender	2.406	.615	15.330	1	.000***	11.091	3.326	36.990
	A3_Education	.605	.461	1.721	1	.190^{ns}	1.832	.742	4.525
	A4_Marital_Status	.133	.540	.060	1	.806^{ns}	1.142	.396	3.291
	A5_Dependants	-.481	.370	1.694	1	.193^{ns}	.618	.300	1.276
	A6_Religion	-.569	.478	1.416	1	.234^{ns}	.566	.222	1.445
	A7_Tribe	.059	.324	.033	1	.856^{ns}	1.061	.562	2.000
	B1_type_of_animal	.009	.140	.005	1	.946^{ns}	1.009	.767	1.329

a. The reference category is: no

*-2 Log Likelihood = 82.783; Chi-square = 33.623; Pseudo R-square = 0.392; *** = significant at 0.1% probability level; ns = not significant*

5.4.5. Gas production

The result of the gas production from the four grasses is shown in Table 5.7. The grasses significantly differed (P = 0.0037) in the quantity of readily fermentable material (*a* %) and the potentially fermentable fraction (*b* %) (P < 0.0001) as well as the rate of gas production $k(h^{-1})$ (P = 0.0007).

Table 5.7: Least Square (LS) means of Dry matter (DM) fermentation (%) of the four grass species

Species	*a* (%)	*b* (%)	$k(h^{-1})$
Pennisetum purpureum	5.1677^{a}	10.8303^{d}	0.003667^{b}
Brachiaria decumbens	1.0963^{b}	15.5237^{b}	0.05400^{a}
Oxytenanthera abyssinica	0.3800^{b}	21.5073^{a}	0.06767^{a}
Bambusa balcooa	3.5967^{a}	12.9473^{c}	0.06433^{a}
SE	0.8232	0.1916	0.005686
P-value	0.0037	<.0001	0.0007

Means with the common superscripts (a, b, c) within columns are not significantly different according to Student-Newman-Keuls Test; Where a = initially fermentable fraction; b = fermentable DM fraction; k = rate constant for fermentation of b; SE = standard error. P=0.05

The *P. purpureum and B. balcooa* had the highest percent readily fermentable material (P = 0.0037) while *B. decumbens* and *O. abyssinica* recorded the lowest readily fermentable material. Different pools (P = 0.0037) of digestible fiber (represented as "b") that fermented at the different rates (P = 0.0007) were observed among the grasses (Table 5.8).

The highest gas accumulation was recorded by *O. abyssinica* and the least by *P. purpureum* (Figure 5.3). Gas accumulation differed significantly (p>0.05) among the various feedstuffs.

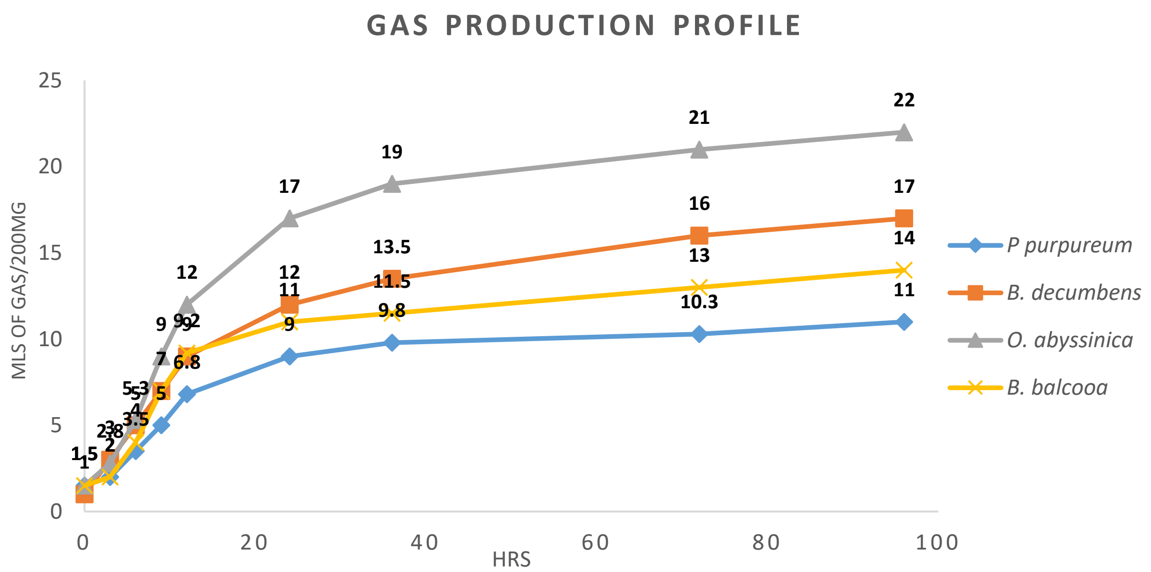

Figure 5.3: Gas production profiles of grasses and bamboo leaves used in the trial.

Data points are the means of four replicates of the samples.

5.4.6. Chemical composition of grasses used as fodder

The chemical composition of the grasses used in the study is shown in Table 5.8. The mean dry matter (DM) of the grasses was 276.37 g/kg with the two bamboo species recording a higher DM (P < 0.0001) than *B. decumbens and P. purpureum*.

Crude protein (CP) is an important indicator of the nutritional quality of feedstuff. The CP of the species under study was highly variable (P = 0.0009) ranging from 66 g/kg DM (*P. purpureum)* to 124 g/kg DM (*O. abyssinica)*. The *Oxytenanthera abyssinica* recorded the highest CP (P < 0.001) among the grasses assayed and was 1.3, 1.87 times greater than *B. balcooa* and *B. decumbens*; and *P. purpureum* respectively.

Table 5.8: Nutrient Characteristics of grasses and bamboo leaves

Feed Type	**Chemical composition (g/kg DM)**				
	DM	CP	Ash	NDF	ADF
Pennisetum purpureum	206.73^{b}	66.07^{c}	120.00^{a}	502.02^{a}	377.97^{a}
Brachiaria decumbens	187.30^{b}	97.90^{b}	115.00^{a}	464.16^{a}	179.68^{b}
Oxytenanthera abyssinica	342.73^{a}	124.08^{a}	80.00^{a}	564.46^{a}	367.96^{a}
Bambusa balcooa	368.70^{a}	95.08^{b}	95.00^{a}	598.35^{a}	326.13^{a}
P-value	< 0.0001	0.0009	0.6641	0.1690	0.0097
SE	8.39	4.82	24.83	39.21	29.11

Means with the common superscripts (a, b, c) within columns are not significantly different according to Student-Newman-Keuls Test at a 5% significant level. Where SE = standard error. Data are the means of three replicates of the parameters (DM, CP, NDF, and ADF) assayed. DM= Dry matter; CP= Crude protein; Ash= Ash content; NDF= Neutral Detergent Fibre and ADF= Acid Detergent Fibre.

The ash content was similar (P = 0.6641) among the grasses being considered. The Neutral Detergent Fibre (NDF) gives an indication of the fiber constituents of feedstuffs as it measures cellulose, hemi-cellulose, lignin, silica, tannins. The mean estimate of the Neutral detergent fiber NDF in the grasses is presented in Table 5.8. No significant difference (P = 0.1690) in NDF were observed among the grasses. The acid detergent fiber (ADF) represents the least digestible fraction of roughages and gives an indication of how digestible a feedstuff is. The ADF in the grasses differed significantly (P = 0.0097) among the treatments with the two bamboo species and *P. purpureum* recording the highest ADF.

5.4.7. Feed intake

Intake of the basal diets and the supplements averaged 86.3 and 141.4 g/kg respectively and were similar (P = 0.4561; P = 0.6336) among the treatments (T1= *Pennisetum purpureum* plus *Oxytenanthera abyssinica*, T2=*Brachiaria decumbens* plus *Oxytenanthera abyssinica* and T3= *Brachiaria decumbens* plus *Bambusa balcooa* T4=*Brachiaria decumbens* plus *Bambusa Balcooa*). Likewise, the total feed intake averaged 141.4g/kg with no significant differences (P= 0.5750) observed among treatments.

5.4.8. Weight gain

The average daily weight gain ranged from 38g for animals in *Pennisetum purpureum* plus *Bambusa balcooa* group to 77g for animals in *Brachiaria decumbens* plus *Oxytenanthera abyssinica* group.

Treatment effect on average daily weight gain was significant (P = 0.0457). Goats' weight in *Pennisetum purpureum* plus *Oxytenanthera abyssinica*, *Brachiaria decumbens* plus *Oxytenanthera abyssinica* and *Brachiaria decumbens* plus *Bambusa balcooa* group were significantly higher than those in *Pennisetum purpureum* plus *Bambusa balcooa* group.

5.4.9. Feed conversion ratio

A high feed conversion ratio (FCR) is an indication that animals do not efficiently utilize ingested feed to body mass. The type of feed significantly influenced the FCR (P = 0.045) with *Pennisetum purpureum* plus *Oxytenanthera abyssinica* (T1) and *Pennisetum purpureum* plus *Bambusa balcooa* (T2)groups recording the lowest and highest FCR respectively. Goats in *Pennisetum purpureum* plus *Oxytenanthera abyssinica* group efficiently utilized the feed into building body tissues hence the highest weight gain was obtained by the animals within that treatment group. The highest FCR for animals in the *Pennisetum purpureum* plus *Bambusa balcooa* group explains the lower weight gain of sheep in that group (Table 5.9).

Table 5.9: Effect of bamboo leaves supplementation of the intake and growth performance of goats

Parameters	Treatment				P-Value	SE
	T1	T2	T3	T4		
Basal feed intake (g DM/d)	88.790^{a}	89.440^{a}	81.227^{a}	88.913^{a}	0.051	3.779
Supplement Intake (g DM/d)	130.75^{a}	158.94^{a}	129.20^{a}	146.77^{a}	0.056	18.110
Total Feed Intake	219.54^{a}	248.38^{a}	210.42^{a}	235.68^{a}	0.061	20.555
Average Daily gain (g)	77.38^{a}	65.48^{ab}	38.09^{b}	65.48^{ab}	0.047	7.467
FCR**	2.8133^{b}	3.293^{ab}	5.5243^{a}	3.60^{ab}	0.045	0.543

n = 5 for each treatment group. Where T1=*Pennisetum purpureum plus Oxytenanthera abyssinica*; T2=*Brachiaria decumbens* plus *Oxytenanthera abyssinica*; T3=*Pennisetum purpureum* plus *Bambusa balcooa* T4=*Brachiaria decumbens* plus *Bambusa balcooa*; FCR = Feed conversion ratio (intake /gain). *Means with common superscripts (a, b) within rows are not significantly different according to Student-Newman-Keuls Test at 0.05 significant level.*

5.4.10. Haematology and blood biochemistry of goats fed a supplement of bamboo leaves

The blood profile of animals is an important indicator of animal health. Red blood cell (RBC) count in the blood showed significant differences ($P < 0.05$) due to treatment effect while the white blood cell (WBC) count, total protein and albumin showed no significant differences ($P > 0.05$) (Figures 5.4 a,b, c & d). The current study recorded RBC (5.8-8.0 L^{-1}), total protein (63-70 g dL^{-1}) and albumin (23-28 g dL^{-1}). Generally, there was a decline in the parameters measured at the end of the trial except for the WBC (Figures 5.4 a, b, c and d)

The WBC recorded in the current study ranged between 30.0 x 10^9/L and 40.0 x 10^9/L whiles the range of values for total protein was between 63-70 g dL^{-1} and that of albumin was between 23-28 g dL^{-1} (Figure 5.4 c,d) The range of values recorded for total protein in the present study was (63-70 g dL^{-1}) and that of albumin was (23-28 g dL^{-1}) (Figure 5.4).

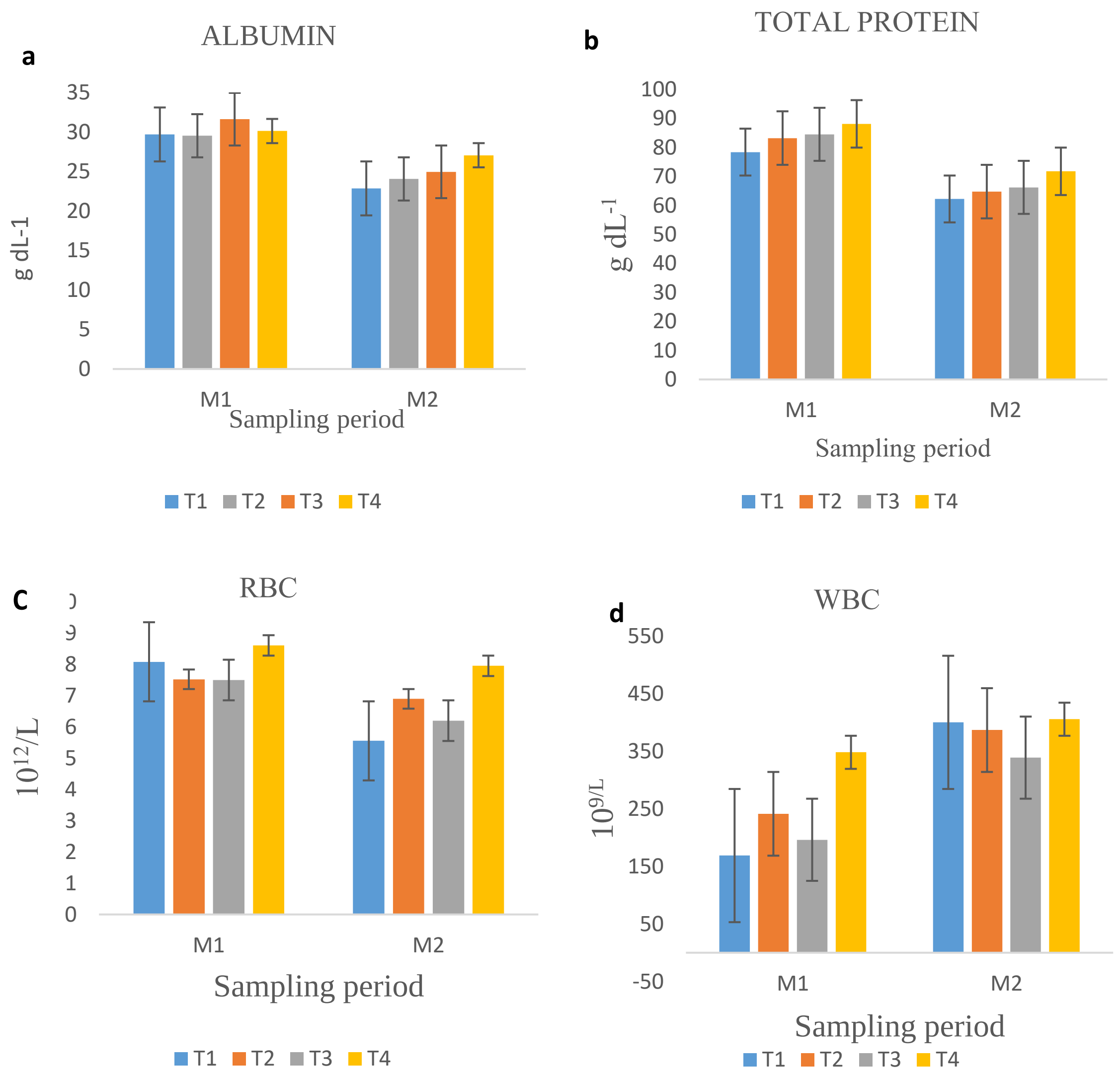

Figure 5.4: Effect of bamboo leaves supplementation on the Albumin, Total Protein, RBC and WBC of goats. N= 20.

Where T1=*Pennisetum purpureum* plus *Oxytenanthera abyssinica*; *T2=Brachiaria decumbens* plus *Oxytenanthera abyssinica*; *T3=Pennisetum purpureum* plus *Bambusa balcooa T4=Brachiaria decumbens* plus *Bambusa balcooa;* M1=Blood measure at the start of trial, M2=Blood measure at the end of trial.

5.5. Discussion

5.5.1. Characteristics of respondents

The male and aged-farmer dominance, and the relatively lower percentage of youth involved in agriculture in the sampled communities in the current study although could have been influenced by the purposive sampling design it confirms a general observation in several parts of Sub-Saharan Africa (Swarts and Aliber, 2013; Leavy and Smith, 2010; Muhammad-Lawal et al., 2009). Also, this low percentage (10%) of youth (18 – 30 years) gives concern about the future of agriculture in Jeduako, following the seemingly aged population involved in agriculture. The findings from the current study are in line with a study by Ahaibwe et al. (2013) in Uganda who reported that the energetic population (youth) in agriculture was higher than that of the older cohorts although a significant proportion of the youth still derives their livelihood from agriculture. The youth only assists either their parents or guardians in rearing animals in the study area and therefore, decisions on livestock are mostly taken by the adult counterparts. Unless there is a strategic introduction of the youth into livestock rearing, future livestock production in the study region may be hampered by a lack of energetic human force. This assertion is already confirmed by MoFA (2011). Meanwhile, most farmers owned lands less than one hectare which complements the growing evidence that agriculture production systems in Africa have to be intensified and diversified to meet the food security requirements of the region (Partey et al., 2018; Holden and Otsuka, 2014; Tittonell and Giller, 2013; Pretty et al., 2011). These findings from the present study confirm earlier research by HLPE (2013) on the farmland distribution in 14 African countries, it was evident that 80% of holdings are lesser than 2 ha in size and operate roughly 25% of the agricultural land. The report also found that in the European Union (EU), 50% of farms are smaller than 2 ha in size but operate only about 2.4% of the farming land (HLPE, 2013). From a gender perspective, men seemed to have more ownership of larger sizes of land in Jeduako as revealed by this study. This finding confirms numerous reports on the state of gender inequalities in land ownership in Africa (Partey et al. 2018; Doss et al., 2015; Tamale, 2004; Jackson, 2003). Meanwhile, the results showed 80% of respondents had no formal education which could have implications on behavioral changes towards acceptance and adoption of new technologies.

5.5.2. Characteristics of livestock production systems

The most reared livestock in the study region were goats, sheep, and cattle or a combination of any two or three. Livestock was kept in a free-range or semi-intensive system. There were also combinations of crop-livestock systems which allowed advantages of maize, cassava or plantain animal associations as a feed management strategy. The results showed a dominance of goat production

(71%) in the study area which is consistent with national statistics that ranks goat the most second produced livestock (behind poultry) with a current production standing of 485,500 populations contributing about 17% of the total meat production in Ghana (MoFA, 2011). This has been attributed to the prolific reproduction of goats and the cost-effectiveness of raising them (MoFA, 2011).

The segregation of gender to the type of livestock reared was evident in women rearing more goats than their men counterparts. The interest in goat among women also makes their production a key strategy for women empowerment. The study also revealed that while farmers rear goats for subsistent and commercial interests, the latter was an utmost priority. This assertion confirms the findings by Swarts and Aliber (2013), who indicated that the commercial gains from livestock production cumulatively outweigh those of crop production and may increase the preference of farmers for higher adoption of livestock production. Results from the focus group discussions showed that farmers mainly kept livestock to serve as a buffer against crop failure. Besides, the market value of livestock was higher than crops; generating interests for tailoring livestock production, mainly to markets rather than household consumption. While the populations of animals kept by farmers are just up to about 10, farmers noted that sales of animals helped defray some of their expenditures such as child school fees, utility bills and payment of premiums for national health insurance.

5.5.3. Fodder sources and feeding challenges for livestock production

Results from the focus group discussions and interviews showed that due to seasonal rainfall, year-round feed availability and quality substantially fluctuate. For instance, pasture abundance rises with a concurrent improvement in quality in the rainy seasons, whereas pasture abundance and quality generally decline at the onset of the prolonged dry periods. The findings from the current study corroborate research by Oppong-Anane (2013), who indicated that livestock production system in northern Ghana is constrained by several factors of which feed shortages in terms of quantity and quality during the dry season constitute a major part. This observation in the present study is also a general phenomenon particularly during the dry seasons in the arid areas of the tropics where livestock farmers have to always travel far distances in search of forage (Swarts and Aliber, 2013; MoFA, 2011; Leavy and Smith, 2010). In the worst-case scenario, farmers have to feed livestock with costly cereals and grains which decreases capital investment in livestock rearing in this zone.

5.5.4. Knowledge and determinants of bamboo leaf as fodder for livestock

The current study revealed that a great majority of respondents knew bamboo could be used for several domestic and industrial purposes, with only a few knowing bamboo leaves are useful for fodder production (Table 5.5). These findings demonstrate the propensity for bamboo leaf being accepted and used as fodder for livestock, with which evidence revealed, through participatory action research which indicates that farmers' commonly used feed with bamboo either as a sole feed or a supplementary feed. However, the results showed gender was an influential factor in determining the acceptability of bamboo fodder for livestock based on significant results from the logit analysis. Depending on contexts, studies differ on whether male or female farmers are more likely to adopt new technologies (Akoto et al., 2018; Glover et al., 2013; Alavalapati et al., 2001). Households headed by males are often considered to be more likely to receive information on new technologies, and take business risks than households headed by females (Fosu-Mensah et al., 2012). Other studies have shown that female-households are more likely to take up agricultural technologies since they are responsible for agricultural work, have a better experience, and access to information on various management and farming practices (Nhemachena and Hassan, 2007). Similar studies are rare for comparison but give an indication of how gender should be mainstreamed in the introduction of bamboo fodder to farmers.

5.5.5. Chemical composition

In this current study, all grasses did not significantly differ in their chemical compositions (P = 0.0782) with the exception of crude protein (CP) which is an important indicator of nutritional quality of feedstuff and acid detergent fiber (ADF); which also represents the least digestible fraction of roughages and gives an indication of digestibility of a feedstuff. The CP of the species under study was highly variable (P = 0.0009) with *O. abyssinica* recording the highest CP (P < 0.001) among the grasses assayed. The ADF in the grasses also differed significantly among the treatments (P = 0.0097) with the two bamboo species and *P. purpureum* recording the highest ADF. The findings from the present study support a study by Antwi-Boasiako et al. (2011), who reported that *O. abyssinica* leaves has the highest ash and crude protein contents compared with *Bambusa ventricosa* and two varieties of *Bambusa vulgaris (Bambusa vulgaris var. vitata and Bambusa vulgaris var. varigata).* The high values of CP and ADF observed in the bamboos and also in the combination with the other grasses give a high propensity for bamboo use as a choice feedstuff for livestock production in the study region (Engelen et al., 2001).

5.5.6. Gas production

The result of the highest fermentative gas production observed in *O. abyssinica* could be attributed to the relatively high crude protein among the tested grass species. Since gas production is positively associated with feed fermentation, *O. abyssinica* could be described as having a higher feeding value owing to its high gas production. This was evident in the feeding trial where the animal groups receiving the treatment with *O. abyssinica* supplementation significantly recorded the highest average daily weight gains of 77.38 and 65.48g/d (P = 0.0457). The least gas accumulation recorded by *P. purpureum* may be as a result of relatively low concentration of protein and high acid detergent fiber (cell wall content and lignin) as shown in Figure 5.3. According to Jung and Deetz, (1993) lignin concentration is reported to be negatively correlated with gas production. Rendering on the authors purview, the lignification of cell wall limits the functions of rumen microbial flora such as fermentation or enzymatic breakdown of forage polysaccharides and this may result in lower passage rate and digestibility of the grass.

5.5.7. Feed intake

The numerically higher feed intake by animals in *Brachiaria decumbens* and *Oxytenanthera abyssinica* group might be due to the higher nitrogen concentration in the supplement which might have increased microbial fermentation of the feed and hence, an increased passage rate. This current assertion underpins the findings of Radostits et al. (2000)

5.5.8. Weight gain

The relatively lower weight gain recorded in the *Pennisetum purpureum* and *Bambusa balcooa* group may be due to the lower level of feed consumed by the goats in that treatment. The findings from the current study support a study by Galgal et al. (2000), who reported that daily and annual live weight gains from grazing *B. decumbens* comparably exceeded growth rates on *P. maximum* pastures of 0.46 to 0.78 kg/head/day and 0.49 to 0.61 kg/head/day, respectively. The ADG recorded by the goats in this study was however within the range of 44 -109g/day reported by Muhammad et al. (2008), when rice milling wastes were fed to goats; and greater than 48.98g/day and 49.19g/day reported by Obese (1998). Straw with groundnut haulm, cotton seed, and cowpea vines, respectively were fed to the Djallonké goats except for those in *Brachiaria decumbens* and *Oxytenanthera abyssinica* group.

5.5.9. Feed conversion ratio

Animals in the *Pennisetum purpureum* plus *Oxytenanthera* abyssinica group efficiently utilized the feed into building body tissues hence the highest weight gain was obtained by the animals within that treatment group. The highest FCR for animals in the *Pennisetum purpureum* plus *Bambusa balcooa* group explains the lower weight gain of goats in that group (Radostits et al., 2000).

5.5.10. Haematology and blood biochemistry of goats fed on a supplement of bamboo leaves

Athough there was a decline in the parameters measured at the end of the trial except for the WBC, the results reported in this current study are consistent with those obtained by Bello and Tasdo (2013) who fed sheep with sorghum stover supplemented with graded levels of dried poultry droppings. Accordingly, the RBC (5.8-8.0 L^{-1}), total protein (63-70 g dL^{-1}) and albumin (23-28 g dL^{-1}) recorded in the current study compared well with RBC (6.4-9.9 L^{-1}), total protein (63-71g dL^{-1}) except the albumin which was 1.5 times lower than those reported by the authors. Compared to the reference range of values (8.0-18.0L^{-1}) for a normal goat as reported by Radostits et al. (2000), the RBC for the treatments was found to be lower. The low RBC values recorded herein could be an indication of anemia-related disease during the trial period. The WBC recorded in the current study ranged between 30.0 x 10^9/L and 40.0 x 10^9/L above the normal physiological values (6.93 x10^9 /L and12.66 x 10^9 /L) reported by Fadiyimu et al. (2010), for a healthy goat. The spike in the WBC might be an indication of an infection during the trial period. The range of values for total protein (63-70 g dL^{-1}) and albumin (23-28 g dL^{-1}) recorded also compared well with the normal physiological values between 60-93 g dL^{-1} and 30–38 g dL^{-1}reported for sheep and goats by Milne et al. (2006) and Borjesson et al. (2000).

5.6. Conclusions

Although bamboo leaves are not commonly known as livestock feed among livestock farmers in the study region, the study findings suggest that bamboo could be a preferred feed source for livestock, especially goats, if demonstrated through participatory action research. Gender may also be an influential factor in determining the acceptability of bamboo fodder for livestock as a higher number of men were willing to accept bamboo fodder as feed for goats than their women counterparts. This calls for gender consideration in mainstreaming the introduction of bamboo fodder to farmers. Also, there is the revelation that bamboo is a viable feed supplement for livestock especially, goats, as shown by its nutrient profile and the influence on their growth performance. Though bamboo is a non-conventional feed supplement in ruminant livestock production in the study region, the study shows that it is acceptable to the goats which was evident in their higher intake levels when offered *ad libitum*. Hence using bamboo as feed supplement can increase feed intake of the basal diets and weight by 40% and 2.31kg respectively. Despite the comparably higher CP, gas production, ash and the positive influence on goats' growth performance, bamboo should be fed alongside with leguminous forages especially in situations when urea molasses block supplementation is not available in the quest to meet the energy-protein requirement of goats, and to improve their health status through the supply of the minerals and protein. This study has revealed and added bamboo as a suitable livestock feed source to current knowledge and information on and for livestock production in Ghana. Leaves of any of the bamboo species could be used as supplemental feed for goats, however, we recommend the choice of the leaves of *O. abyssinica* for goats' production in Ghana. This has contributed to increasing the range of livestock feed for possible increased livestock production with the potential of improving diets (protein source) of the Ghanaian population. This could, indirectly contribute to improving food security in Ghana. Again, bamboo could now be used as a fodder source in the government of Ghana's flagship policy program of 'Rearing for Food Security and Jobs', currently rolled out in Ghana with a pilot in the study region.

5.7. Acknowledgments

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6. Evaluation of crop performance, soil properties and economic benefit in a bamboo-based intercropping system

This Chapter has been published by the Journal of Agroforestry Systems as: **'***Towards bamboo agroforestry development in Ghana: evaluation of crop performance, soil properties and economic benefit'*, by Daniel S. Akoto, Samuel T. Partey, Manfred Denich, Michael Kwaku, Christian Borgemeister and Christine B. Schmitt

6.1. Abstract

In the quest to promote bamboo agroforestry in the dry semi-deciduous forest zone of Ghana, we evaluated changes in soil properties, crop productivity and the economic potential of a bamboo-based intercropping system. The intercropping system was established from 3-months old sympodial bamboo (*Bambusa balcooa*) seedlings planted at a 5 m x 5 m spacing and intercropped with maize, cassava or cowpea. Separate monocropping fields for maize, cassava, cowpea and bamboo were set up adjacent to the intercropped field. In both the intercropping and monocropping fields, plots were with fertilizer treatments and without. The experiment was laid out in a split plot design with four replicates and studied over three years. Economic analysis was conducted using the financial benefit-cost ratio method. The results showed that regardless of fertilizer treatments, bamboo agroforestry and monocropped fields had comparable effects on soil properties and crop productivity within two years of establishment. In the third year, however, bamboo agroforestry had significantly ($p < 0.05$) higher soil moisture, pH and crop productivity levels. An intercropping advantage over monocropping was evident for all crops with respective partial land equivalent ratios for fertilized and non-fertilized intercropped systems as follows: cowpea (1.37 and 1.54), maize (1.38 and 1.36), and cassava (1.12 and 1.19). The economic evaluation also indicated marginal profitability of bamboo intercropping over monocropping systems. From the results obtained, there are clear indications that where bamboo is a prioritized woody perennial, integrated systems with crops may be encouraged.

Keywords: Agroecology; Crop productivity; Food security; Soil productivity; Sustainable agriculture.

6.2. Introduction

In Africa, forests provide important ecosystem services that support the environment and livelihoods. However, current deforestation figures point to a dire situation for such important natural resources. FAO (2016d, 2015) report that Africa lost about 3.4 million hectares of forest land between the periods of 2000 to 2010. In Ghana, the closed forest reduced from 2,317,166 hectares to 1,785,802 hectares between 2000 and 2010, depreciating at the rate of 192,648 hectares per 5 years (FAO, 2016d).For the last fifteen years, generally, improvement towards sustainable contemporary forest management in Africa seems to have been limited and such could be observed in Ghana which recorded forest cover degradation of about 135,000 hectares between 1990-2000 (FAO, 2010). Increased deforestation has been linked to some anthropogenic activities with the production of wood fuels considered the most paramount (Cerutti et al., 2015; Chidumayo and Gumbo, 2013). Wood fuels are used by about one-third of the world's population (FAO, 2017) with future consumption projected to upsurge to 544.8 million m^3 for firewood and 46.1 million tons for charcoal by 2030 in Africa (Arnold et al., 2003). Detrimental impacts of such increasing demand and consumption of wood fuels on the ecological integrity of forests is inevitable.

In Ghana, about two million tons of wood were consumed in 2010 of which 80% was charcoal or firewood (Kemausuor et al., 2011). With an increasing population and the current unreliable supply of electricity in urban areas, the dependence on fuelwood is expected to increase. The excessive dependence on woodfuels in Africa and in Ghana in particular culminate in wanton destruction of vegetation. This situation exacerbates climate change effects. With climate change affecting food production systems and coupled with other biophysical constraints such as declining soil fertility, farmers are unable to obtain the required yield of crops for subsistence and commercial gains (ACET, 2017; AGRA, 2017). To mitigate this challenge, energy woods plantation is usually recommended despite the risk for competing with food crops production, especially for smallholder farmers (FAO, 2017; Lobovikov et al., 2012). Hence the necessity to find alternatives such as the use of woody energy species that can be intercropped to simultaneously address issues of fuelwood scarcity and food insecurity. Government of Ghana's initiatives such as the introduction of the taungya system has seen the establishment of large plantations to curtail deforestation and provide livelihood options for rural households. However, the relatively long rotation periods of some of the species such as teak and acacia have led to renewed interest in the use of bamboo as an additional option.

Bamboo is fast growing and produces high biomass with calorific values comparable to commonly sourced wood biomass such as teak and acacia (Partey et al., 2017b). An initiative named Bamboo and

Rattan Development Programme (BARADEP) was launched by Ghana's Ministry of Lands and Natural Resources and approved by the cabinet to promote bamboo use as an alternative to some endangered forest tree species for renewable energy and other domestic and industrial uses (e.g. construction and furniture). Due to bamboo's unique contribution to bio-energy production and other ecological benefits (e.g. soil stabilization and water conservation through fibrous root system), several national economies have established bamboo plantations (Partey et al., 2017b). Such bamboo plantations have been reported to have facilitated the reduction in deforestation as it reduces the excessive removal of trees from the natural environment for charcoal and firewood production (Akwada et al., 2018; Van Khuc et al., 2018; Kuehl et al., 2013). This notwithstanding, monoculture bamboo plantations may pose threats to food security unless such lands are marginal or degraded (Partey et al., 2017a). In Asia, productive and economically viable bamboo-based agroforestry systems have been established with reported increased food crop yields and non-food biomass (Nirala et al., 2018; Ahlawat, 2014; Ahlawat et al. 2008; Mailly et al., 1997).

In Ghana, bamboo-based agroforestry is relatively new with no significant studies that provide information on its agronomic and economic potentials. However, such information is necessary for designing bamboo-based agroforestry systems that meet the needs of farmers (Akoto et al., 2018; Partey et al., 2017a). For this reason, bamboo-based intercropping systems with sympodial bamboo (*Bambusa balcooa*), maize, cowpea and cassava were established and studied over three years to determine intercropping advantage over monocropping systems of bamboo, maize, cassava and cowpea in relation to (a) changes in soil properties; (b) crop yields; and (c) economic feasibility.

6.3. Materials and methods

6.3.1. Study site

The study was carried out at Jeduako in the Sekyere Central District of Ghana located within Lat 06°55' and 07°30'N and Long 05000' W (Figure 6.1). The District covers a total land area of 1,564 km2 and has 150 settlements with 70% being rural. Total population of the District is 71,232, distributed as 35,225 males (49.5%) and 36,007 females (50.5%) (Ghana Statistical Service, 2012). It falls within the dry semi-deciduous forest zone of Ghana and borders the savannah in the north and the forest zone in the south (Damnyag et al., 2011; Tom-Dery et al., 2014). It is characterized by a bimodal rainfall pattern with an average annual rainfall of 1,270 mm. The major rainy season starts in March with a main peak in May. There is a slight dip in July and a peak in August, which tapers off in November. December to February is warm and dusty (the driest period). The area has a mean annual temperature of 27°C with mean monthly temperatures ranging from 22°C to 30°C and a mean annual humidity of 70%. The soil type is sandy loam (Ejura – Denteso Association) and classified as ferric acrisol (Vigbedor et al., 2015; Tom-Dery et al., 2014).

This area is a major food basket in Ghana and has high production of fuelwood from natural forest sources. Subsistence agriculture is the major economic activity employing about 65% of the population (Damnyag et al., 2011). Most of the agricultural production is from manually cultivated rainfed crops. Major crops include: maize, cowpea, cassava, yam, and plantain. This site was chosen for this study because of its unique characteristic features which combine those of the forest and savanna zones (Akoto et al., 2018). Furthermore, it is an area in Ghana with a great need for fuelwood. It is also within the zone targeted for the introduction of private and community tree planting for wood energy production (Forestry Commission, 2015).

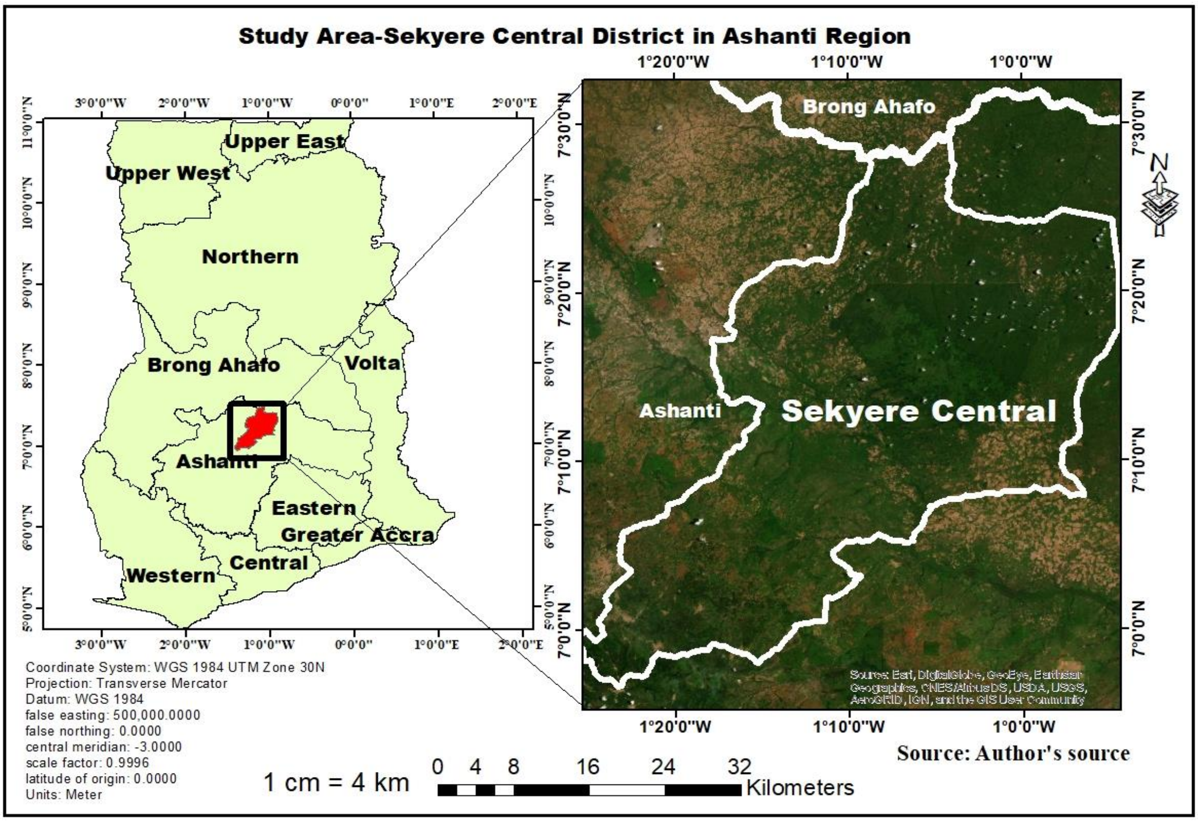

Figure 6.1: Map of Ghana showing the Sekyere Central District where study was carried out

6.3.2. Field establishment and experimental procedure

The bamboo-based intercropping system was designed and established in June 2014 with modification from the design recommended by Nath et al. (2009), as an on-sation experiment. It was laid out as a split plot design with four replicates (Figure 6.2) with cropping/farming system as main plot treatment and fertilizer application as sub-plot treatment. The main plot treatment included: monoculture systems of bamboo, maize, cowpea and cassava; and intercropping systems of bamboo with maize, cowpea and cassava as intercrops. The sub-plot treatment involved fertilizer application or not. The bamboo species used was *Bambusa balcooa* originating from North-Eastern India (Malay et al., 2008). The selection of this species was based on its strong regeneration capacity, ability to grow in dryer soils and high biomass yield (Zhao et al., 2014) for sustainable fuelwood production. It has very low evasive characteristics, and evasiveness can be further controlled through periodic harvesting of culms in coppice management (Malay et al., 2008). The bamboo plants were established from 3-month old seedlings at a 5 m x 5 m spacing (Figure 6.2). Crops of different agronomic classifications (tuber, legume and cereal) were chosen to determine which crop could be most integrative with bamboo. Consequently, different fields were established with maize, cowpea and cassava. The farming systems (bamboo-maize, bamboo-cowpea and bamboo-cassava) were considered as separate experiments. Maize (variety 'Omankwa', locally bred) was intercropped within bamboo rows at 0.4 m x 0.8 m spacing by sowing four seeds per hill and thinning to two per hill within two weeks. Cassava (variety 'Ampong') was planted at a 1 m x 1 m spacing using cuttings which were 40 cm in length. Cowpea (variety 'Bengpla') was planted at 0.2 m x 0.4 m spacing also by sowing four seeds per hill and thinning to two per hill within two weeks. Plots were 5 m x 5 m with the same dimension as the buffer rows between each two plots (Figure 6.2). The selection of crops was based on the preference of the community where the experiment was sited during informal interviews and focus group discussions in early 2014. The field trial was conducted over five continuous planting seasons, i.e. minor rainy season of 2014, major and minor rainy seasons of 2015, and major and minor rainy seasons of 2016. The major rainy season experiments were conducted between June and August, while the minor rainy season experiments were conducted between September and November. For maize and cowpea, we present the average yields of two seasons due to lack of significant seasonal effects. Cassava was harvested and yield recorded once a year.

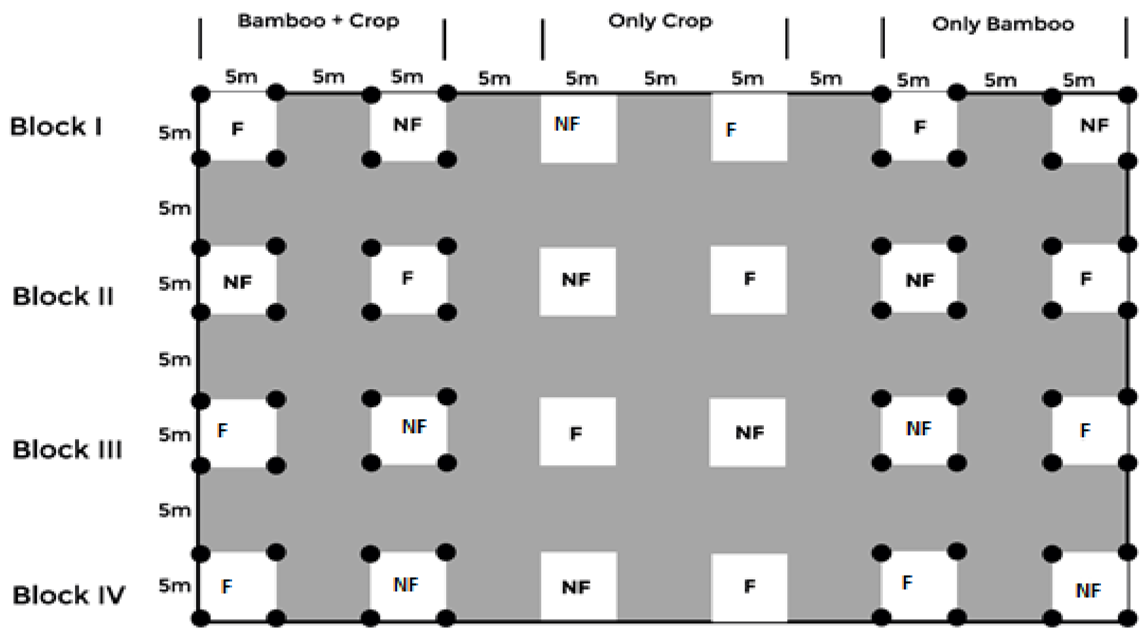

Figure 6.2: Layout of bamboo intercropping (bamboo + crop) and monocropping systems (only crop, only bamboo) established at Jeduako in Sekyere Central District of Ghana.
Seemingly oval shaped dots= bamboo. Grey area = buffer zone. NF = Non-fertilized plot, F = Fertilizer

A separate monocropping field for maize, cassava and cowpea was set up adjacent to the intercropping field. In addition, there were three separate fields of bamboo (one adjacent to each crop trial). In both intercropping and monocropping fields, the crops and bamboo were with fertilizer treatment and without. This was done to depict low-input and high-input systems. Fertilizer was applied at the following rates: Maize (90 kg N ha^{-1}, 60 kg P_2O_5 ha^{-1}, 60 kg K_2O ha^{-1}), cassava (68 kg N ha^{-1}, 45 kg P_2O_5 ha^{-1}, 68 kg K_2O ha^{-1}), cowpea (only 60 kg P_2O_5 ha^{-1}) (Partey et al., 2018) and bamboo (90 kg N ha^{-1}, 60 kg P_2O_5 ha^{-1}, 60 kg K_2O ha^{-1}) (Pande et al., 2012). Nitrogen was applied as urea, P as triple superphosphate and K as muriate of potash. The fertilizer was split applied at 7 days after planting (DAP) and 30 DAP using 40 % and 60 % of the total fertilizer, respectively, according to the local practice. The fertilizer treatments were applied in all five seasons. Weeds were managed by hand weeding after weed emergence, and late emerging weeds were removed by hoeing as and when needed.

Crop productivity was determined as grain and stover yield for maize; tuber and stem biomass yield for cassava; and grain and shoot biomass for cowpea. For cowpea and maize, grain yield was determined by collecting pods and cobs, respectively, into perforated harvesting bags and sun drying over two weeks until the grain reached 12.5% moisture content, which is the acceptable moisture content in most African markets (Kurwakumire et al., 2014). To determine biomass yield, the plants were uprooted from the soil after watering the surface soil. The aboveground biomass (leaf and stem) was separated from the roots and oven dried in the laboratory at 65°C for 72 hours. For cassava, the standing biomass, including the leaves and stem was separated from the root tubers after 10 months of planting and yields expressed on a fresh weight basis.

6.3.3. Soil sampling and analysis

Soil conditions were characterized using a random composite soil sampling approach (Crozier et al., 2010; Gelderman et al., 2006). Each treatment plot of 5 m x 5 m was sampled from three different locations in a zigzag pattern using a stainless-steel auger at 0-20 cm depth. Samples that were taken at the onset of the experiment were composited and homogenized for each block by hand mixing before sending to the laboratory for physicochemical analysis (total n = 4). For soil sampling and analysis in the 2014, 2015 and 2016 cropping periods, all 72 treatment plots were sampled every year as described above. Subsequently, for each cropping year, the samples for each of the annual crop plots were homogenised into fertilized and non-fertilized samples across the four blocks, yielding a total of 12 composited samples. The same was done for the bamboo only treatment plots, yielding a total of 6 composited samples. In all, 18 composited samples were collected for laboratory analysis. This was done to monitor soil property changes per treatment per cropping year.

In the laboratory, four replicates of each field soil sample were created. Soil samples were air-dried till constant weight and passed through a 2-mm sieve and analyzed using four replicates. Soil pH was analyzed using a glass electrode with a soil/water ratio of 1:2, total N was determined by dry combustion using a LECO TruSpec^{TM} CN autoanalyzer (LECO Corporation), organic carbon by the dichromate oxidation method (Motsara and Roy, 2008), cation exchange capacity (CEC) using ammonium acetate extract (Motsara and Roy, 2008), available P by the ammonium molybdate Bray-1 method, available K using ammonium acetate (flame photometer method), moisture content and base saturation (%) using the gravimetric method, and soil texture by the hydrometer method (Motsara and Roy, 2008). The initial physicochemical properties of soils at the study site are shown in Table 6.1.

Table 6.1: Initial physicochemical properties of the topsoil (0-20 cm) of the experimental site at Jeduako in Central Ghana.

Parameter	Value
pH (H_2O)	5.83 (0.30)
Total nitrogen (g kg^{-1})	0.50 (0.00)
Organic carbon (g kg^{-1})	2.10 (0.10)
Available P (mg kg^{-1})	7.81 (0.20)
Available K (mg kg^{-1})	82.87 (3.50)
Effective cation exchange capacity (cmol kg^{-1})	4.92 (0.10)
Base saturation (%)	90.85 (0.10)
Texture (%)	
Sand	62. 04 (0.43)
Clay	15. 01 (0.81)
Silt	22. 95 (0.79)
Textural class	sandy loam

Values are means of four replicates. Values in parentheses are standard error of means

6.3.4. Bamboo Litter accumulation, collection and nutrient analysis

Two litterfall traps per treatment plot were fixed randomly to cover all the 48 treatment plots with bamboo over the entire experimental period. The litter accumulated from each treatment plot of four individual bamboo clumps was composited and average value determined. The same litterfall trap sizes were fixed due to same plant distance except where canopy cover varied. Determination of the bamboo litter was performed weekly for the period of collection to ensure uniform results (Breda, 2003). *Bambusa balcooa* litter was cleaned and separated into twigs, buds and leaves. However, only leaf litter was sub-sampled for the laboratory analysis. The leaf litter biomass was determined by drying in an oven at 65°C for 72 hours. To determine the initial chemical quality of the leaf litter, 100g out of the oven-dried matter were ground into a powder and sieved to a 0.5 mm size. Carbon and nitrogen were analyzed using a LECO Carbon-Nitrogen analyzer, calcium and magnesium by the EDTA titration method, phosphorus by the spectrometric vanadium-phosphomolybdate method while potassium was determined by absorption spectrophotometry according to Motsara and Roy (2008). Lignin was determined by the acid detergent fiber method (Eneji et al., 2005). The samples were analyzed in three replicates.

6.3.5. Statistical analysis of field experiment

The partial land equivalent ratio (LER) was used to determine intercropping advantage over monocropping using the relation by Darish et al. (2006) for agricultural crops. This ratio was used because the focus of the experiments was on the effect of bamboo on the associated crops, and therefore, only agricultural crop yields in the intercropped and monocropped fields were compared using the following equation:

$$\text{Partial LER} = \frac{Ypi}{Ymi} \quad \dots\dots\dots\dots\dots\dots\dots\dots (6.1)$$

where Ypi = yield of intercrop and Ymi = yield of monocrop.

Data on crop yield and soil properties were analysed using the Analysis of Variance (ANOVA) test. Where test results were significant, the Tukey test method was used for mean comparison at a 5% probability level. All statistical analyses were conducted with GenStat 12 software (VSN International).

6.3.6. Estimated bamboo yields

Only bamboo culms were considered for this economic analysis. It has been recommended that about 33% of the old culms per clump are harvested throughout the life of a bamboo plantation (Pande et al., 2012). For this analysis, bamboo culms were first harvested in the third year of establishment, and subsequently, harvesting was done monthly for sale as culms. Moderate harvesting levels are assumed with an average of 3 culms per clump per month from the bamboo agroforestry plots, and 6 culms per clump per month from the bamboo monocropping plots. Consequently, the number of culms harvested per month from the 220 clumps per ha was 3*220 = 660 per ha for the bamboo agroforestry plot. For the monocrop bamboo plot, the number of culms harvested per month from the 220 clumps per ha = 6*220 =1320 culms per ha (see Appendix 1).

It is only the main stem of the culm measuring 2 m on average that is considered for sale, and hence, not the cubic volume. There is no standard measure of bamboo culm sale in the study area.

6.3.7. Costs and revenue streams for food and bamboo culm production from bamboo agroforestry

Input and output data over five cropping seasons (only minor season of 2014 and major and minor seasons of 2015 and 2016) were collected from the trial plots. Costs and revenues streams in Ghanaian Cedis (GH¢) (later converted to US Dollars (USD$) were estimated at 2017 market rates for the analysis for 5 production cycles over a period of 3 years. Bamboo can grow over very long periods (Pande et al., 2012), however, 3 years was adopted as the minimum rotation for the financial analysis. Cost streams in this study included inputs used for establishment of bamboo agroforestry and monocrop stands (land, farm tools/equipment, crop seeds, tree seedlings and labor (for land preparation, planting and herbicides application, weeding/maintenance and harvesting of maize, cassava, cowpea and bamboo culms) estimated per ha (Appendix 1). Revenues/benefit streams were determined from the value of crops per unit area, i.e. maize, cassava, and cowpea and bamboo culms harvested per ha. The value of potential carbon sequestered by the agroforestry system was not included in the analysis.

6.3.8. Financial Benefit-Cost Analysis

The Financial Cost Benefit Analysis (FCBA) methodology adopted from Gittinger (1982) was used for the comparative economic valuation of the bamboo agroforestry system and monocrop food production in this study. The FCBA is used to assess the desirability of technologies by determining whether the costs of establishment are offset by higher returns from sustained crop yields compared to traditional practices. For the FCBA, the data on cost and revenue for bamboo agroforestry and monocrop food crop trials were analyzed using Microsoft Excel. The cost and revenue streams and cash flows were estimated at 25% (i.e. bank borrowing rate in Ghana for agricultural and forestry investments/projects in 2017) to estimate the profitability of the bamboo agroforestry for culm production compared with the best alternative use of the land for food crop cultivation for 3 years.

The main assumptions for the financial analysis are:

1. Nominal prices are used for the cost and revenue cash flows; they are not adjusted for inflationary effects over the 3-year period of the financial analysis (Inflationary values were very marginal but occurred very rapidly within the study period distorting the financial analysis; the average of 25% interest rate for agricultural borrowing as given by the Bank of Ghana was therefore adopted. Sensitivity analysis, considering such inflationary dynamics are recommended in further studies).
2. It is also assumed that ecological variables influencing growth will be constant throughout the analysis period. Possible changes could be accounted for in a sensitivity analysis.

6.3.9. Comparative estimations of Benefit-Cost Ratio

The Benefit Cost Ratio (BCR) was estimated and used to evaluate the profitability of the bamboo agroforestry system with the equation below:

$$\frac{B}{C} Ratio = \sum_{t-1}^{t-n} \frac{B_i}{(1+i)^t} \div \sum_{t-1}^{t-n} \frac{C_i}{(1+i)^t} \qquad \dots\dots\dots\dots..(6.2)$$

where B = benefit, C = cost, t = time in years/production period, ἰ or r = discounted rate, and n = length of production period in years. The trial production systems are profitable if BCR ≥ 1.0 (Gittinger, 1982). Where B_t and C_t are the benefits and costs in year t, r is the discount rate and n is the project life time (i.e. length of a complete production cycle or rotation). Consequently, a technology is attractive for adoption if the B/C ratio is > 1.0.

6.4. Results

6.4.1. Effects of bamboo-based agroforestry on soil properties and agronomic performance of maize

6.4.1.1. Soil properties under bamboo-maize intercropping system

The combined cropping system and fertilizer application (treatments) had no significant effect on soil moisture, soil pH, CEC, total N, available P and available K until the third year (2016) of the experiment (Table 6.2). In 2016, ANOVA and Tukey post-hoc test showed a significant ($p < 0.001$) increase in soil moisture, soil pH and CEC under bamboo agroforestry system with and without fertilizer application. In 2016, soil moisture values under bamboo-based agroforestry with fertilizer were 7.1% on average, while monocropped fields recorded 4.2%. The CEC under agroforestry was about 13% higher than under monocropped fields considering cropping system and fertilizer application (combined treatment effects) with and without fertilizer. Soil pH values were 10% higher on agroforestry fields than on monocropped fields.

Table 6.2: Soil characteristics as influenced by bamboo-based agroforestry and maize monocropping systems from 2014 to 2016.

Year and parameters	With fertilizer		Without fertilizer		P-value
	Agroforestry	Monocropping	Agroforestry	Monocropping	
2014					
Soil moisture (%)	4.34±0.01^{a}	4.33±0.01^{a}	4.32±0.03^{a}	4.29±0.05^{a}	0.724
CEC (cmolc kg^{-1})	5.70±0.04^{a}	5.80±0.08^{a}	5.68±0.08^{a}	5.63±0.09^{a}	0.475
Total N (g kg^{-1})	0.39±0.00^{a}	0.44±0.03^{a}	0.39±0.00^{a}	0.39±0.00^{a}	0.100
Available P (mg kg^{-1})	4.75±0.03^{a}	4.78±0.03^{a}	4.73±0.03^{a}	4.73±0.03^{a}	0.487
Available K (mg kg^{-1})	123.70±1.01^{a}	123.50±0.62^{a}	123.60±0.72^{a}	123.20±0.84^{a}	0.979
pH	5.78±0.03^{a}	5.83±0.04^{a}	5.73±0.03^{a}	5.80±0.04^{a}	0.122
2015					
Soil moisture (%)	4.26±0.03^{a}	4.26±0.02^{a}	4.31±0.03^{a}	4.25±0.03^{a}	0.593
CEC (cmolc kg^{-1})	6.05±0.06^{a}	6.03±0.08^{a}	6.00±0.09^{a}	5.95±0.09^{a}	0.767
Total N (g kg^{-1})	0.49±0.00^{a}	0.54±0.03^{a}	0.49±0.00^{a}	0.48±0.01^{a}	0.074
Available P (mg kg^{-1})	4.55±0.10^{a}	4.50±0.10^{a}	4.58±0.13^{a}	4.40±0.04^{a}	0.539
Available K (mg kg^{-1})	127.60±0.30^{a}	127.40±0.22^{a}	127.50±0.30^{a}	127.50±0.29^{a}	0.990
pH	5.83±0.05^{a}	5.84±0.04^{a}	5.80±0.04^{a}	5.78±0.05^{a}	0.769
2016					
Soil moisture (%)	7.13±0.06^{b}	4.27±0.02^{a}	7.01±0.07^{b}	4.25±0.03^{a}	<0.001
CEC (cmolc kg^{-1})	6.65±0.10^{b}	5.93±0.03^{a}	6.68±0.08^{b}	5.85±0.09^{a}	<0.001
Total N (g kg^{-1})	0.48±0.00^{a}	0 .53±0.03^{a}	0.48±0.00^{a}	0.48±0.00^{a}	0.092
Available P (mg kg^{-1})	4.90±0.11^{b}	4.79±0.20^{b}	4.83±0.21^{b}	4.20±0.04^{a}	0.010
Available K (mg kg^{-1})	127.80±0.53^{a}	127.60±0.37^{a}	127.60±0.39^{a}	127.50±0.41^{a}	0.969
pH	5.98±0.09^{b}	5.45±0.09^{a}	6.00±0.11^{b}	5.40±0.17^{a}	0.011

Values are means of 4 replicates ± standard error. Values with the same letters in a row are not significantly different according to Tukey test at a 5% significance level.

6.4.1.2. Maize yields under bamboo-maize intercropping system

The combined effects of cropping system and fertilizer application (treatments) on the grain and stover yields of maize were significant ($p < 0.05$) throughout the experimental period (2014 – 2016) (Table 6.3). In 2014 and 2015, however, grain and stover yields increased only with fertilizer application. No significant differences were observed between fertilized agroforestry and fertilized monocropped fields. Similar observations were recorded for both cropping systems without fertilizer application during the same period. For monocropped fields, grain yield increase with fertilizer was 50% and 164% higher than on non-fertilized fields for 2014 and 2015, respectively. For agroforestry fields, grain yield increase with fertilizer was 74% and 177% higher than on non-fertilized fields for 2014 and 2015, respectively. Stover yields were almost two times higher with fertilizer application. In 2016, the grain and stover yields of maize differed significantly ($p < 0.05$) between agroforestry and monocropped fields with or without fertilizer application (Table 6.3). Compared to fertilized monocropped fields, grain and stover yields were 37.5% and 17.2% higher on fertilized agroforestry plots, respectively. Non-fertilized agroforestry fields also recorded significantly ($p < 0.05$) higher grain and stover yields than non-fertilized monocropped fields. It was evident that cropping system and fertilizer application (treatments), time and their interaction significantly influenced the grain and stover yields of maize (Table 6.3). For the fertilized agroforestry fields, grain yield of maize in 2016 was 42% and 48% higher than in 2015 and 2014, respectively. The partial LER showed an advantage of intercropping maize with bamboo over monocropping during the third year of the experiment. The partial LER for fertilized and non-fertilized maize intercropping systems was 1.38 and 1.36, respectively.

Table 6.3: Maize productivity as influenced by bamboo-based agroforestry and monocropping systems

Year and parameter	With fertilizer		Without fertilizer		P-value
	Agroforestry	Monocropping	Agroforestry	Monocropping	
2014					
Grain yield (t ha^{-1})	$1.86±0.02^b$	$1.58±0.09^b$	$1.07±0.15^a$	$1.05±0.06^a$	<0.001
Stover yield (t ha^{-1})	$4.53±0.19^b$	$4.50±0.18^b$	$3.34±0.09^a$	$3.33±0.07^a$	<0.001
2015					
Grain yield (t ha^{-1})	$1.94±0.07^b$	$1.90±0.08^b$	$0.70±0.08^a$	$0.72±0.10^a$	<0.001
Stover yield (t ha^{-1})	$4.75±0.21^b$	$4.71±0.23^b$	$2.96±0.12^a$	$2.89±0.09^a$	<0.001
2016					
Grain yield (t ha^{-1})	$2.75±0.06^d$	$2.00±0.09^c$	$0.79±0.03^b$	$0.58±0.03^a$	<0.001
Stover yield (t ha^{-1})	$6.20±0.17^d$	$5.29±0.17^c$	$3.37±0.10^b$	$2.46±0.05^a$	<0.001

Values are the means of 4 replicates ± standard error. Values with the same letters in a row are not significantly different according to Tukey test at a 5% significance level.

6.4.2. Effects of bamboo-based agroforestry on soil properties and agronomic performance of cowpea

6.4.2.1. Soil properties under bamboo-cowpea intercropping system

Similar to the results for maize, the ANOVA test showed no significant ($p > 0.05$) combined effect of cropping system and fertilizer application (treatments) on soil properties (pH, soil moisture, total N, available P, available K and CEC) in the first (2014) and second (2015) years of the experiment. In 2016, significant ($p < 0.05$) effects of cropping system and fertilizer application (treatments) were recorded for soil moisture, CEC, available P and pH. Soil moisture, CEC and pH were significantly ($p < 0.05$) higher on agroforestry fields than on monocropped fields regardless of fertilizer application. Soil moisture, CEC and pH on agroforestry fields were about 169%, 118% and 110%, respectively higher than on monocropped fields. Moreover, available P levels did not differ significantly between agroforestry plots and monocropped plots receiving fertilizer (Table 6.4). Particularly for agroforestry plots, values recorded for soil parameters such as CEC, soil moisture and available K were significantly higher in 2016 compared with 2015 and 2014. Data for 2014 and 2015 were generally comparable.

Table 6.4: Soil characteristics as influenced by bamboo-based agroforestry and cowpea monocropping systems

Year and parameter	With fertilizer		Without fertilizer		P-value
	Agroforestry	Monocropping	Agroforestry	Monocropping	
2014					
Soil moisture (%)	4.04±0.05[a]	4.01±0.04[a]	3.97±0.10[a]	3.89±0.09[a]	0.150
CEC (cmolc kg^{-1})	5.58±0.05[a]	5.56±0.08[a]	5.62±0.01[a]	5.42±0.04[a]	0.267
Total N (g kg^{-1})	0.36±0.03[a]	0.38±0.04[a]	0.34±0.04[a]	0.37±0.04[a]	0.370
Available P (mg kg^{-1})	4.64±0.02[a]	4.68±0.02[a]	4.66±0.08[a]	4.64±0.06[a]	0.776
Available K (mg kg^{-1})	123.9±0.83[a]	123.50±0.58[a]	124.00±0.50[a]	122.10±0.28[a]	0.200
pH	5.75±0.04[a]	5.68±0.03[a]	5.68±0.03[a]	5.69±0.03[a]	0.601
2015					
Soil moisture (%)	4.26±0.19[a]	4.27±0.12[a]	4.25±0.12[a]	4.15±0.06[a]	0.655
CEC (cmolc kg^{-1})	5.98±0.05[a]	6.04±0.06[a]	6.06±0.06[a]	5.93±0.03[a]	0.092
Total N (g kg^{-1})	0.40±0.02[a]	0.41±0.01[a]	0.39±0.01[a]	0.39±0.01[a]	0.379
Available P (mg kg^{-1})	4.57±0.08[a]	4.56±0.07[a]	4.67±0.07[a]	4.51±0.10[a]	0.436
Available K (mg kg^{-1})	127.50±0.11[a]	127.40±0.16[a]	127.60±0.23[a]	127.30±0.12[a]	0.497
pH	5.72±0.03[a]	5.73±0.06[a]	5.70±0.03[a]	5.70±0.04[a]	0.811
2016					
Soil moisture (%)	7.06±0.05[b]	4.13±0.04[a]	7.03±0.05[b]	4.22±0.11[a]	<0.001
CEC (cmolc kg^{-1})	6.64±0.13[b]	5.71±0.07[a]	6.71±0.07[b]	5.65±0.08[a]	<0.001
Total N (g kg^{-1})	0.41±0.06[a]	0.42±0.01[a]	0.41±0.06[a]	0.40±0.06[a]	0.983
Available P (mg kg^{-1})	4.96±0.07[b]	4.82±0.18[b]	4.73±0.16[b]	4.14±0.06[a]	0.002
Available K (mg kg^{-1})	128.00±0.40	127.60±0.34	127.70±0.29	127.00±0.12	0.205
pH	5.94±0.09[b]	5.36±0.12[a]	5.88±0.10[b]	5.41±0.09[a]	0.003

Values are means of 4 replicates ± standard error. Values with the same letters in a row are not significantly different according to Tukey test at a 5% significance level.

6.4.2.2. Cowpea yields under bamboo-cowpea intercropping system

The ANOVA showed that combined cropping system and fertilizer application (treatments) significantly ($p < 0.05$) affected the grain and shoot yields of cowpea in all 3 years of the experiment with application of fertilizers. In 2014 and 2015, agroforestry and monocropped fields receiving fertilizer recorded comparable results. Non-fertilized plots in both systems also produced comparable results. In 2016, grain and shoot yields on fertilized and non-fertilized agroforestry plots were significantly ($p < 0.05$) higher than on monocropped fields. Compared to fertilized monocropped fields, grain and shoot yields in fertilized agroforestry fields were 136% and 109% higher, respectively. Moreover, the results show that grain yield on non-fertilized agroforestry fields was higher than on both fertilized and non-fertilized monocropped fields (Table 6.5). Especially on agroforestry fields, there was a general increase in grain and shoot yields with time, with the highest value recorded in 2016. For fertilized agroforestry fields, grain and shoot yields in 2016 were 172% and 165% higher compared to 2015 and 2014, respectively. The partial LER showed an advantage of intercropping cowpea with bamboo over monocropping during the third year of the experiment. The value for fertilized and non-fertilized cowpea intercropping systems was 1.37 and 1.54, respectively.

Table 6.5: Cowpea productivity as influenced by bamboo-based agroforestry and monocropping systems

Year and parameter	With fertilizer		Without fertilizer		P-value
	Agroforestry	Monocropping	Agroforestry	Monocropping	
2014					
Grain yield (t ha^{-1})	1.58±0.06^{b}	1.61±0.05^{b}	1.40±0.07^{a}	1.42±0.03^{a}	0.007
Shoot yield (t ha^{-1})	3.86±0.16^{b}	3.91±0.18^{b}	3.37±0.06^{a}	3.42±0.05^{a}	0.003
2015					
Grain yield (t ha^{-1})	1.52±0.02^{b}	1.53±0.04^{b}	1.41±0.02^{a}	1.37±0.06^{a}	0.017
Shoot yield (t ha^{-1})	4.07±0.11^{b}	4.05±0.16^{b}	3.80±0.18^{a}	3.91±0.17^{a}	0.002
2016					
Grain yield (t ha^{-1})	2.62±0.10^{d}	1.92±0.13^{b}	2.03±0.13^{c}	1.32±0.10^{a}	<0.001
Shoot yield (t ha^{-1})	4.78±0.11^{c}	4.38±0.21^{b}	4.32±0.24^{b}	3.26±0.29^{a}	<0.001

Values are the means of 4 replicates ± standard error. Values with the same letters in a row are not significantly different according to Tukey test at a 5% significance level.

6.4.3. Effects of bamboo-based agroforestry on soil properties and agronomic performance of cassava

6.4.3.1. Soil properties under bamboo-cassava intercropping system

Similar to maize and cowpea, there was no significant ($p > 0.05$) combined effect of cropping system and fertilizer application (treatments) on soil properties in 2014 and 2015. However, in 2016, soil moisture and soil pH were significantly ($p < 0.05$) affected. Soil moisture on agroforestry plots was significantly ($p < 0.05$) higher than on monocropped fields (Table 6.6) indicating the sole effect of bamboo on soil properties.

Soil moisture on agroforestry fields was about 166% higher than on monocropping fields. The pH values on agroforestry fields were significantly higher than on monocropping fields regardless of fertilizer application. Moreover, the results show that total N, CEC, available K, soil moisture and soil pH significantly ($p < 0.05$) increased with time. This was particularly evident on agroforestry plots where the highest values were recorded in 2016 (Table 6.6).

Table 6.6: Soil characteristics as influenced by bamboo-based agroforestry and cassava monocropping systems

Year and parameter	With fertilizer		Without fertilizer		P-value
	Agroforestry	Monocropping	Agroforestry	Monocropping	
2014					
Soil moisture (%)	4.18±0.02[a]	4.17±0.06[a]	4.20±0.01[a]	4.12±0.04[a]	0.493
CEC (cmolc kg^{-1})	5.58±0.03[a]	5.65±0.03[a]	5.58±0.12[a]	5.54±0.02[a]	0.503
Total N (g kg^{-1})	0.46±0.00[a]	0.45±0.01[a]	0.45±0.00[a]	0.44±0.01[a]	0.452
Available P (mg kg^{-1})	4.68±0.02[a]	4.68±0.02[a]	4.64±0.02[a]	4.65±0.02[a]	0.549
Available K (mg kg^{-1})	121.60±0.43[a]	121.10±0.63[a]	121.10±0.73[a]	120.30±0.53[a]	0.605
pH	5.76±0.004[a]	5.77±0.03[a]	5.76±0.003[a]	5.75±0.05[a]	0.992
2015					
Soil moisture (%)	4.32±0.04[a]	4.31±0.00[a]	4.30±0.02[a]	4.26±0.02[a]	0.433
CEC (cmolc kg^{-1})	5.40±0.09[a]	5.50±0.11[a]	5.50±0.09[a]	5.27±0.03[a]	0.289
Total N (g kg^{-1})	0.43±0.01[a]	0.44±0.00[a]	0.44±0.00[a]	0.43±0.01[a]	0.544
Available P (mg kg^{-1})	4.61±0.11[a]	4.49±0.09[a]	4.50±0.11[a]	4.46±0.11[a]	0.144
Available K (mg kg^{-1})	118.90±0.61[a]	118.90±0.87[a]	119.10±0.77[a]	118.50±0.68[a]	0.922
pH	5.44±0.12[a]	5.47±0.10[a]	5.49±0.07[a]	5.48±0.06[a]	0.916
2016					
Soil moisture (%)	7.05±0.07[b]	4.21±0.03[a]	7.03±0.07[b]	4.26±0.03[a]	<0.001
CEC (cmolc kg^{-1})	5.34±0.10[a]	5.56±0.06[a]	5.54±0.17[a]	5.24±0.08[a]	0.185
Total N (g kg^{-1})	0.45±0.01[a]	0.43±0.01[a]	0.45±0.01[a]	0.43±0.01[a]	0.170
Available P (mg kg^{-1})	4.33±0.17[a]	4.73±0.27[a]	4.63±0.15[a]	4.38±0.28[a]	0.581
Available K (mg kg^{-1})	121.30±0.45[a]	120.90±0.45[a]	121.00±0.51[a]	121.80±1.28[a]	0.884
pH	6.10±0.07[b]	5.88±0.03[a]	6.11±0.01[b]	5.95±0.03[a]	0.006

Values are means of 4 replicates ± standard error. Values with the same letters in a row are not significantly different according to Tukey test at a 5% significance level.

6.4.3.2. Cassava yields under bamboo-cassava intercropping system

Combined effect of cropping system and fertilizer application (treatments) significantly ($p < 0.05$) affected the root tuber and leaf and stem yields of cassava (Table 6.7). The increased cassava yield was mainly due to the application of fertilizer. Regardless of fertilizer application, there were no significant differences between agroforestry and monocropped fields until 2016. In that year, agroforestry plots, both with and without fertilizer application recorded significantly ($p < 0.05$) higher yields for root tuber and leaf and stem. Differences in root tuber yield between fertilized agroforestry and fertilized monocropped fields were about 1.35 t ha^{-1} and 4.61 t ha^{-1} for leaf and stem yield. For non-fertilized plots, root tuber yield was about 119% higher on agroforestry plots compared to monocropped plots. Consistent with the soil properties, increases in yields with time were particularly evident on agroforestry fields. The partial LER showed an advantage of intercropping cassava with bamboo over monocropping during the third year of the experiment. The partial LER for fertilized and non-fertilized cassava intercropping systems was 1.12 and 1.19, respectively.

Table 6.7: Cassava productivity as influenced by bamboo-based agroforestry and monocropping systems

Parameter	With fertilizer		Without fertilizer		P-value
	Agroforestry	Monocropping	Agroforestry	Monocropping	
2014					
Root tuber yield (t ha^{-1})	11.49±0.48^{b}	11.52±0.11^{b}	10.33±0.07^{a}	10.26±0.14^{a}	<0.001
Biomass yield (t ha^{-1})	36.26±0.16^{b}	35.92±0.64^{b}	31.42±0.76^{a}	31.53±0.46^{a}	<0.001
2015					
Root tuber yield (t ha^{-1})	12.15±0.33^{b}	11.92±0.08^{b}	10.09±0.08^{a}	9.99±0.10^{a}	<0.001
Biomass yield (t ha^{-1})	36.31±0.07^{b}	36.41±0.24^{b}	31.48±0.31^{a}	31.44±0.29^{a}	<0.001
2016					
Root tuber yield (t ha^{-1})	13.09±0.19^{d}	11.74±0.24^{b}	12.65±0.11^{c}	10.67±0.07^{a}	<0.001
Leaf and stem biomass yield (t ha^{-1})	40.30±0.51^{d}	35.69±0.89^{b}	38.34±0.45^{c}	33.30±0.52^{a}	<0.001

Values are means of 4 replicates ± standard error. Values with the same letters in a row are not significantly different according to Tukey test at 5% significance level.

6.4.4. Bamboo growth and litter accumulation under bamboo-crops intercropping system

The cropping system had a significant (p = 0.014) effect on bamboo growth only when bamboo was 3 months old (Table 6.8). Among the crops, bamboo seemed to integrate better with maize and cowpea than with cassava during the initial establishment stages. However, no significant growth effects were observed after 6 months. On average, there was a higher number of stems/culms per clump per ha in the monocrop bamboo (40-50 culms per clump and about 1100 culms/ha) than in the agroforestry system (30 culms per clump and 660 culms/ha) although there was an equal number of seedlings of bamboo per ha planted in both monocropped and agroforestry plots.

Due to the role of bamboo litter on soil properties, we monitored litter accumulation after the first incidence of litter fall, which occurred during the second year of the experiment. The mean litter accumulation during the experimental period increased from 0.22 t DM ha^{-1} in the second year to 1.83 t DM ha^{-1} in the third year (DM= dry matter content). Data are the means of 6 replicates (six bamboo clumps) per ha.

We also monitored bamboo litter quality in the system. The composited oven dried and ground *Bambusa balcooa* leaf litter was characterized in the laboratory for N (1.99%), P (0.36%), K (0.60%), Mg (0.17%), C (125.1%), Ca (0.59%), Lignin (91.9%) C/N (12.6) and Lignin/N (46.2) as recommended by

Palm et al. (2001). The results showed comparatively low macro and micro nutrients as against high lignin content and C contents.

Table 6.8: Height (m) of bamboo when grown as a monocrop and in combination with maize, cowpea, and cassava over 36 months under field conditions

Cropping system	Age (months)					
	6	12	18	24	30	36
Bamboo monocropping	3.74±0.10^b	7.77±0.09^a	9.67±0.09^a	10.53±0.17^a	12.57±0.18^a	14.68±0.23^a
Bamboo + maize agroforestry(intercropping)	3.59±0.06^b	7.17±0.12^a	9.28±0.20^a	10.18±0.22^a	11.98±0.26^a	14.64±0.25^a
Bamboo + cowpea agroforestry(intercropping)	3.73±0.03^b	7.45±0.06^a	9.45±0.07^a	10.43±0.06^a	12.40±0.08^a	14.65±0.26^a
Bamboo + cassava agroforestry(intercropping)	3.41±0.08^a	7.41±0.22^a	9.55±0.12^a	10.15±0.21^a	12.45±0.19^a	14.57±0.22^a
SED	0.090	0.220	0.190	0.210	0.290	0.100
P value	0.014	0.128	0.292	0.276	0.253	0.792

Values are means of 4 replicates ± standard error. Values with the same letters in a column are not significantly different according to Tukey test at 5% significance level. Values are combined data for both fertilized and non-fertilized plots from 24 plots.

6.4.5. Economic evaluation of bamboo agroforestry and monocropping systems: costs and benefits from agroforestry and monocropping systems

The summary cash flow from producing bamboo and food crops from the agroforestry (intercropping) and monocropping systems is presented in Table 6.9. All the tested combinations proved to be profitable as indicated by the positive net cash flows ranging from the highest value for the fertilized monocrop bamboo (GH¢ 87,758.50/US$ 20,649.06) to the lowest value (GH¢ 6,732/US$ 1,584) for the non- fertilized monocrop food production systems over a period of 3 years (Table 6.9). Bamboo cultivated in an agroforestry system with or without fertilizer contributed up to 70% of total income due to the proliferation of culms that can frequently be harvested throughout the year as compared to the seasonal income from food crops under rain-fed conditions. Results from the bio-physical aspects of the experiment show higher food crop yields with application of NPK 15-15-15 in the sub-plots over those without fertilizer. Clump productivity was almost the same with and without fertilizer in the agroforestry system, hence, incomes were almost similar in these systems.

Table 6.9: Summary cash flow of bamboo agroforestry, monocrop bamboo and monocrop food production from 2014-2016.

Input-Output	Cash flow/ha (GH¢)					
	No Fertilizer Bamboo Agroforestry (food /culms)	Fertilizer Bamboo Agroforestry (food/culms)	Fertilizer Monocrop /Bamboo (culms)	No Fertilizer Monocrop Bamboo (culms)	No Fertilizer Monocrop (food)	Fertilizer Monocrop (food)
Revenue						
Food crops	37,752	51,168	0	0	34,632	48,204
Bamboo culms	87,120	87,120	154,800	122,400	0	0
Total revenue	**124,872 ($29,381.65)**	**138,288 ($32,538.35)**	**154,800 ($36,423.53)**	**122,400 ($28,800.00)**	**34,632 ($8,148.71)**	**48,204 ($11,342.12)**
Cost						
Land & other material inputs	7,690	10,093	6,130.00	5,620.00	4,390	8,293
Tools/equipment	1,830	1,830	939.00	939.00	1,830	1,830
Labor	69,350	70,100	59,722.50	55,680.00	21,680	22,430
Transport	250	250	250.00	250.00	0	0
Total cost	**79,120.00 ($18,616.47)**	**82,273 ($19,358.35)**	**67,041.50 ($15,774.47)**	**62,489 ($14,703.29)**	**27,900 ($6,564.71)**	**32,553 ($7,659.53)**
Net cash flow	**45,752.00 ($10,765.18)**	**56,015 ($13,180.00)**	**87,758.50 ($20,649.06)**	**59,911 ($14,096.71)**	**6,732 ($1,584.00)**	**15,651 ($3,682.59**
% of Labor	**88**	**85**	**89**	**87**	**78**	**69**
BCR	**1.1**	**1.9**	**1.22**	**1.2**	**1.01**	**1.07**

Dollar/Cedi exchange rate: US$ 1=GH₵ 4.25 (2017 bank base exchange rate). Cost variables: Material inputs= planting material, herbicides, fertilizer, storage, boots, packaging sacks. Tools/equipment= cutlass/machete, hoe, chisel, rake. Labor inputs= plot establishment, maintenance, harvesting processing and storage of food crops, harvesting, and processing bamboo culms). Transport = seedlings for planting. Marketing= products purchased by middlemen at the farm gate. The values of crops are averages of the 3 years per ha of each cropping system. Bamboo values are the average values for products in the third year and afterward.

6.5. Discussion

6.5.1. Soil properties under bamboo agroforestry systems and monocrop fields

Soil properties such as CEC, soil moisture, pH and in some cases available P increased in the agroforestry fields compared with the monocropped plots (Tables 6.2, 6.4 and 6.6). This can be attributed to increased litter accumulation from the bamboo during the third year of the experiment (Shanmughavel et al., 2000). Bamboo litter has been shown to improve soil properties. According to Nath et al. (2009) and Shanmughavel et al. (2000), bamboo litter can act as an input-output system of nutrients which regulates energy flow and improves soil properties. Moreover, the ability of bamboo to grow in wider variety of soils allows its use for soil rehabilitation (Nath et al., 2009). This has been alluded to the rich litter content of bamboo, and could thus help in maintaining and improving soil physical, chemical and biological properties as it returns substantial amounts of N P K, Ca and Mg to the soil (Shanmughavel et al., 2000). For instance, the potassium content in bamboo litter has been reported to be crucial in bamboo agroforestry systems as it acts as a soil amendment catalyst (Ahmad et al., 2007). Considerable amounts of nutrients are returned to the soil through litterfall, which plays an important role in the biogeochemical cycling of nutrients (Mahmood et al., 2011). A similar observation of higher carbon deposition and greater nutrient return, especially N and P, in litterfall components of bamboo has been reported (Borisade and Odiwe, 2018). Therefore, on the agroforestry fields, the increase in pH may have resulted from the displacement of hydroxyl ions from sesquioxide surfaces of the soil due to the presence of organic anions in the bamboo litter (Nalivata et al., 2017). Soil pH levels on agroforestry fields during the third year were higher than in the initial data (Table 6.1), which implies bamboo litter may have had a liming effect on the soil. This was consistent for all crops. Moreover, increased soil CEC in the presence of organic matter such as plant litter has been reported, and it is shown to be an indication of an increased nutrient holding capacity of soil (Oorts et al., 2003). The increased CEC within the bamboo agroforestry systems implies its potential to remediate low-acidity clay soils within tropical agroecological zones, which are characterized by inherently low soil fertility due to low levels of organic matter (Nalivata et al., 2017; Tully et al., 2015; Zingore et al., 2015). For soil moisture, bamboo litter may have provided a mulching effect reducing the evaporation of soil water. The litter from bamboo adds nutrient and plays an important role in maintaining soil fertility (Bellingham et al., 2013) and improvement of the nutrient status of the soil (Kleinhenz et al., 2001). Although our current study showed a relatively low bamboo leaf litter quality, the leaf litter may have served as mulch, providing moisture conditioning effect which is crucial for agricultural crop growth as it serves as a catalyst for other soil chemical dynamics as reported by Gogoi and Bhuyan (2016).

Bamboo rehabilitates over-burdened soils by conserving soil and managing water flow with large biomass accumulation and abundant litterfall (Fu et al., 2010). Similar observations were reported by Gogoi and Bhuyan (2016), who confirmed that bamboo litter improved soil moisture for horticulture crops and tubers in India. The significant soil water conservation effect of bamboo litter has also been reported as it retains 80-100% of rainfall (Pande et al., 2012).

The ecological role of bamboo has been well studied and reported. For instance, Nath et al. (2008) indicated the contribution of the dense bamboo root system to soil aeration and porosity and potential role in soil nutrient fast re-cycling and improvements through root decay. Thus, the ecological benefits of bamboo in climate change mitigation and its ability to restore marginal lands add to the growing interest for its use in agroforestry (Sharma et al., 2018; Patel et al., 2017).

6.5.2. Yields of crops under agroforestry and monoculture systems

The first two years of establishing bamboo with the crops showed no significant differences between crop yields in monocropped and agroforestry plots. Within tree-based intercropping systems, competitive and complementary interactions can be expected, but this is dependent on farm management practices and physiological stages of components (Li et al., 2014; Atangana et al., 2014). From the results obtained, there are clear indications that maize, cowpea and cassava could be planted with *B. balcooa* albeit without crop productivity enhancement or reduction at least within the first two years of establishment. Although the height of 6-month old bamboo was comparatively lower (Table 6.8) due to potential competition with cassava, its recovery over the subsequent periods shows both components can be combined. Moreover, the results in the third year of the experiment provide evidence that planting crops within bamboo rows may increase crop productivity. This finding is supported by the observation of Seshadri (1985), who studied the bamboo agroforestry (*Dendrocalamus strictus*) with soybean, and observed that sowing soybean as an intercrop of bamboo during the first six years was technically feasible and economically viable, and recommended that the period of intercropping can be extended further in wider spacing of the bamboo clumps and judicious manipulation of the bamboo canopy. The study again confirms the feasible integration of bamboo into cropping systems as was observed by Khilesh (2012) in a study which found a highly significant yield performance of wheat (*Triticum aestivum*) under a bamboo-based agroforestry system in four years. The rainfall data of the study site (Appendix 2) indicates relatively low rainfall in the major cropping season in the third year, and rather than declining, crop yield increased significantly in the bamboo agroforestry plots compared to the monocropping system. This could have resulted from the mulching effect of the bamboo litterfall as asserted by Nath et al. (2009).

In terms of crop yields, most of the similar studies were carried out in India or Asia rather than in Africa. However, our results provide evidence that instead of competitive interactions, planting cowpea, maize and cassava within the rows of a 3-year old bamboo may improve the productivity of the associated crop. Yet not all such studies arrive at the same conclusions. For example, lower yield was recorded for bamboo intercropping with Kharif crops compared to monocropping of same crop (Rahangdale et al., 2014). It has also been documented that bamboo and tree species gradually become more competitive with age and progressively reduce crop yield (Ahlawat et al., 2008; Bihari, 2001; Shanmughavel and Francis 2001; Handa et al., 1995). Eyini et al. (1989) reported reduction in groundnut growth and yield, which may have resulted from the allellopathic effect of bamboo leaves (which contain phenolic acids) and shade under an agroforestry system. Nevertheless, there are a good number of studies that corroborate our findings that intercropping allows more efficient use of available resources such as sunlight, moisture and soil nutrients leading to higher crop productivity (Karasu et al., 2015; Poodineh et al., 2014; Wang et al., 2014). Judicious manipulations of bamboo clumps and good cultural practices as in adopting appropriate spacing, mulching and root extension control could enhance bamboo intercropping with tested crops (Pande et al., 2012).

We found partial LER >1.0 for both fertilized and non-fertilized bamboo-based agroforestry systems, which demonstrates the advantage of combining crops with bamboo in an integrated manner. Shanmughavel and Francis (2002 and 2001) recommended intercropping of pigeon pea, soybean and turmeric in bamboo (*B. bambos*) plantations based on comparative growth and yield, where the LER for the bamboo-turmeric system was 1.2. There is adequate evidence from the current study that integrated systems of maize, cowpea or cassava with bamboo may be encouraged in the study region. However, the results of this study should not be generalized.

6.5.3. Cost and benefit analysis of bamboo agroforestry and monocrop systems

Based on the partial LER analysis and the results from the comparative economic assessment of the bamboo agroforestry vs. monocropped bamboo, it seems that integrating bamboo into smallholder agricultural intercropping systems can contribute to food security, diversification of income sources and sustainable bio-energy production. There are numerous studies indicating declining yields under intensive cropping even on some good lands, e.g. the Indo-Gangetic plains (Vira et al., 2015; FAO, 2011; ILEIA, 2000). Tropical agroforestry systems have been proposed as a mechanism for sustaining both biodiversity and its associated ecosystem services in food production areas to forestall rapid deforestation and land degradation (Steffan-Dewenter et al., 2007; Schroth et al., 2004). While the biodiversity effect of bamboo agroforestry has yet to be assessed, it can be assumed that bamboo agroforestry helps to avoid land degradation and to maintain certain ecosystem services that would be lost from intensive farming systems.

Most economic assessments of bamboo agroforestry systems have proven to be economically viable. Literature has proven that, net present value, internal rate of return, benefit-cost ratio, return-to-land and return-to-labor of bamboo-based intercropping systems have much higher productivity than those of traditional/conventional agricultural systems in many areas (Rahman et al., 2016; Roshetko et al., 2013; Rahman et al., 2008, 2007; Rasul and Thapa, 2006; Alavalapati et al., 2004; Elevitch and Wilkinson, 2000). The benefit-cost ratios in the current study indicate that production under all six tested scenarios is profitable albeit marginal.

In bamboo agroforestry, the woody bamboo culms are noted to produce important products, such as fuelwood, fodder and other wood products, which serve as extra income sources to farmers and could contribute to poverty reduction (Tscharntke et al., 2011; Snelder and Lasco, 2008; McNeely and Schroth, 2006). This is, particularly, the case of marginal farmlands where agricultural crop production is no longer biophysically or economically viable (Rahman et al., 2016; Roshetko et al., 2008), and may become incompatible with the sustainable development aspirations (Snelder and Lasco, 2008). This bamboo attribute is important in sustaining the system for long-term productivity and for sustainable economic and ecological/environmental stability. The sustained soil quality and maintained crop productivity under bamboo agroforestry in the present study is an indication of the potential of bamboo agroforestry to support the ecosystem in the study region for environmental quality and sustained food production. The potential of agroforestry systems in ensuring ecosystem services such as enhanced food production, carbon sequestration, watershed functions (stabilization of stream flow, minimization of sediment load) and soil protection has been reported (Lasco et al., 2014; Idol et al., 2011; Jose, 2009; Roshetko et al., 2008; Alavalapati et al., 2004). Although labour intensive, bamboo agroforestry system could promote intensification and therefore could also contribute to reducing deforestation (Rahman et al., 2016).

6.6. Conclusions

The results revealed a greater advantage of growing crops with bamboo over monocropping systems. This underpins the benefits of establishing bamboo agroforestry systems, especially in areas where bamboos have been identified as priority species by other initiatives, such as the Ghana Energy Commission’s Bioenergy Initiative and the Ghana BARADEP areas. The economic analysis indicates that once bamboo clumps mature, culms can be harvested throughout the year. Monocrop bamboo cultivation may be suitable for restoring degraded lands and beneficial to large-scale charcoal producers, or where farmers have enough land to permit its establishment. Small-scale farmers however, could benefit from bamboo intercropping systems through increased system productivity, diversified income streams and environmental sustainability at least for a period of three years. Ghana Forestry Commission may adopt this bamboo-agroforestry model in their quest to using bamboo for reforestation of degraded forests in Ghana. Moreover, the Ghana Ministry of Food and Agriculture may use the results of this study to underpin the current government’s flagship programme of planting for food, jobs and environmental quality. It may also facilitate the re-invigoration of the 1986 Ghana National Agroforestry policy by introducing bamboo as a key multipurpose woody species. Farmers could then diversify income streams, increase resilience against climate change effects, sustain cropping system productivity, and improve environmental quality. Finally, this study can provide useful land-use management inputs for other African countries particularly Ethiopia, Kenya and South Africa, which are strongly pursuing the bamboo agroforestry concept and other developing countries which are equally faced with food and bio-energy security threats. Further studies could investigate component interactions within bamboo-based intercropping systems beyond 3 years with different bamboo species, planting spacing, use of coppice-system and root pruning to control possible invasiveness of bamboo. Also, economic sensitivity analysis with inflationary borrowing rates are necessary for a robust economic assessment. We recommend a careful choice of appropriate bamboo species for different cropping systems. We again, anticipate a biodiversity trade-off in using exotic species against using native species; which could be looked into in future studies complementing this study to develop a comprehensive outlook for upscaling bamboo agroforestry in Ghana.

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7. Leaf litter decomposition and nutrient release pattern of bamboo: a comparative analysis with traditional agroforestry species in Ghana

7.1. Abstract

In Ghana, bamboo has been recommended for plantation schemes to meet biomass needs for bioenergy production and for other needs. In meeting such aspirations, bamboo-based agroforestry rather than sole bamboo cultivation is being recommended to avoid putting further pressure on limited arable lands. As expected from any woody perennial in an agroforestry system, bamboo provides environmental/ecological benefits which may lead to soil fertility improvement as in the breakdown of compounds and the release of nutrients to support crop production via improved soil productivity. Meanwhile, our knowledge of decomposition and nutrient release in bamboos, as in some traditional woody perennials like *Leucaena leucocephala*, *Senna siamea, Gliricidia sepium*, is limited in Ghana but is necessary to plan crop/plant interactions for system improvement. Subsequently, this study was conducted at the bamboo-based agroforestry pilot field at Jeduako in the Sekyere Central District of Ghana to determine the decomposition and nutrient release of leaves of different bamboo species (*Oxytenanthera abyssinica*, *Bambusa balcooa*, *Bambusa vulgaris*), rarely used woody perennials in agroforestry system in Ghana, and compared with commonly used agroforestry species; *Albizia lebbeck*, *Senna siamea*, *Gliricidia sepium*, *Leucaena leucocephala,* and *Eucalyptus grandis*. Litterbag approach was used and fresh fallen leaves of the species (equivalent to 100 g on a dry weight basis) were collected and put into 30 cm x 45 cm nylon litterbags with a 2-mm mesh size. The weight of the samples in the litterbags was based on local plant litter application rates (5 t dry matter ha^{1}) for maize production in the study location. There was a total of 216 litterbags (27 per species) for the study. Eight transects spaced at 1.0 m apart were laid in a randomized complete block design. Twenty-seven litter bags spaced 0.5 m apart were placed on each transect. The litterbags were buried at 2 cm depth. Three litterbags (representing 3 replicates) for each species were retrieved and weighed on 7, 14, 30, 60, 90, 120, 150, 180 and 210 days to determine weight loss and nutrient release. From the results, the rate of decomposition of *Oxytenanthera abyssinica* was comparable with *Senna siamea* and higher than other traditionally known species in agroforestry. The highest rate of N, P, K and Ca release was recorded for *Albizia lebbeck*. However, rates of P, Ca and Mg release, were comparable to the other non-bamboo species. Initial nitrogen and lignin concentrations and release were most dominant in *Eucalyptus grandis* and *Bambusa vulgaris*. Therefore, it may be imperative to consider using bamboo as green manure and in addition, provide a substantial and sustainable source of P, Ca and Mg.

7.2. Introduction

In Sub-Saharan Africa, declining soil fertility, rising degradation of land and inadequate application of fertilizers are among the major biophysical factors that are challenging efforts to boost crop productivity levels and end hunger as defined in the Sustainable Development Goals (SDGs; Holden, 2018). Traditional shifting cultivation and land rotation practices are no longer sustainable as they offer limited opportunities to improve soil productivity due to increased population, limited availability of land and the conflicting use of land for other purposes rather than crop production (Partey and Thevathasan, 2013). To sustainably improve soils, increase crop yields and maintain ecological integrity, agroforestry innovations are often cited as the mainstream opportunity. The integration of trees (particularly leguminous species) improves soils by fixing nitrogen, reducing erosion, stabilizing soils, maintaining litter cover for soil moisture retention, the addition of nutrients through decomposition and N mineralization, etc. (Partey and Thevathasan, 2013). Despite limited large-scale landscape adoption, agroforestry practices such as improved fallows and alley cropping have shown positive influences in improving soil quality and crop yields under varying agro-ecologies (Bayala et al., 2018; Wolz et al., 2018; Partey et al., 2017a). However, selection of efficient tree species in agroforestry system for soil amendment still remains a challenge (Partey et al., 2011). Over the years, there has been exploration of several agroforestry species for soil amendment. Quite recently, bamboos are being promoted for agroforestry development in Ghana. Meanwhile, our knowledge of decomposition and nutrient release in bamboos, as in some traditional woody perennials like *Leucaena leucocephala*, *Senna siamea, Gliricidia sepium*, is limited in Ghana but is necessary to plan crop/plant interactions for system improvement. Therefore, this study sought to determine decomposition rate and nutrient release of different bamboo species in comparison with those of commonly used woody perennials in agroforestry systems in Ghana.

7.2.1. Decomposition and nutrient release

Litter decomposition is a biological process characterizing the breakdown of dead organic materials into smaller sized particles until the structure can no longer be recognized, and organic molecules are mineralized to their prime constituent (Chandrasekhara, 1997; Wachendorf et al., 1997). Plant litter breakdown is controlled by three main factors: litter quality, environmental factors and the nature and abundance of decomposing organisms (Isaac and Nair, 2005). Evidence from related studies has concluded that the two most important factors are climate and the chemical nature of the litter (Swarts et al., 2013). Climate is the dominant factor in areas subjected to unfavorable weather conditions, whereas litter quality largely prevails as the regulator under favorable conditions (Kirschbaum, 2000; Lloyd and Taylor, 1994). For litter quality perspective, rate of decomposition is high in species with abundant ash, nitrogen and lowest C/N ratio and lignin. Kucera (1959) reported a strong correlation between the rate of decay and the ash content of hot-water-soluble materials and was confirmed by Gonzalez and Seastedt (2001). The rate of decomposition is high in species with extreme ash and nitrogen contents and lowest C/N ratios and lignin contents (Chapman and Koch, 2007). Species showing average ash, nitrogen and lignin contents and a normal C/N ratio appear to decay at a transitional rate. Kucera (1959) reported a strong correlation between both the rate of decay and the ash content of hot-water-soluble materials and confirmed by Gonzalez and Seastedt (2001). Decomposition is one of the major ways in which certain nutrients become available to plants to utilize for their survival and reproduction.

Due to the role of trees in nutrient cycling within agroforestry systems, the assessment of litter quality and decomposition dynamics of leaf biomass of agroforestry species is key to designing agroforestry systems for soil improvement and conservation (Isaac and Nair, 2006; Partey and Thevathasan, 2013). Assessment of litter quality often resorts to the levels of chemical elements and compounds particularly, nitrogen, phosphorus, carbon, lignin, polyphenols and associated ratios such as C/N, lignin/N, (lignin + polyphenol)/N (Xiao et al., 2019; Tenkiano and Chauvet, 2018; Partey et al., 2011). Generally, plant litter with high N (≥2.5%), low C/N ratio (≤32: 1) and low lignin and polyphenol contents decompose relatively faster and can be used for providing an adequate supply of nitrogen in agroecosystems although high amounts of biomass may be required (Partey et al., 2014; Partey and Thevathasan, 2013)**.** Meanwhile, low-quality litter, generally with low N, wider C/N ratio and high levels of secondary metabolites may cause immobilization of nitrogen except when applied with inorganic nitrogen fertilizers (Partey et al., 2014; Bhupinderpal-Singh and Rengel, 2007).

In Ghana, the International Bamboo and Rattan Organization (INBAR) is making strong advocacy for the integration of bamboo into cropping systems as a viable biomass resource for wood fuels due to the rapid decline of traditional woody species for fuel production. The recommendations have been based on bamboo’s shorter rotation cycles compared with commonly used trees, faster growth rate and comparable calorific values to trees and fossil fuel (INBAR, 2006b). In addition, bamboo leaf litter reportedly improve soil moisture retention and serve as an important source of soil organic matter for soil carbon sequestration (Partey et al., 2017b). Unlike common agroforestry species such as *Gliricidia sepium*, *Leucaena leucocephala*, *Albizia zygia,* and *Senna siamea* species leaf litter decomposition of bamboo species has been limitedly studied in the Ghanaian context (Tripathi et al., 2006; Tripathi and

Singh, 1992; Nath and Das, 2011; Xie et al., 2016). However, such studies are crucial as a means to understanding some of the potential ecological interactions in bamboo-based agroforestry systems (Vanhie et al., 2015; Partey et al., 2011; Beedy et al., 2010). In addition, findings from the decomposition and nutrient release dynamics of bamboo litter will be useful in understanding the role of bamboo in soil improvement within agroforestry systems (Mailly et al., 1997). It was, therefore, the objective of this study to determine the decomposition rates and nutrient release patterns of bamboo species (*Oxytenanthera abyssinica*, *Bambusa balcooa*, and *Bambusa vulgaris*) in comparison with commonly used agroforestry species (*Albizia lebbeck*, *Senna siamea*, *Gliricidia sepium*, *Leucaena leucocephala,* and *Eucalyptus grandis*) in Ghana. *Albizia lebbeck* is the only indigenous agroforestry multipurpose trees and shrubs (MPTs) in Ghana used in this trial. *Leucaena leucocephala, Senna siamea,* and *Eucalyptus grandis* are the introduced exotic agroforestry MPTs doing well in Ghana. *Oxytenanthera abyssinica* was selected for this trial because it is an introduced bamboo species that has been coping well with the ecological conditions of Ghana and being used for diverse traditional and cultural purposes. *Bambusa balcooa* (also an exotic) was also selected for this trial because of its bioenergy potential, but its leaf litter could be crucial for its integration into agroforestry systems in Ghana. *Bambusa vulgaris*, on the other hand, is an indigenous Ghanaian bamboo species that has not been explored for its uses except for fence making and firewood (Forestry Commission, 2016). Exploration of the decomposition and nutrient release from these various bamboo species vs. the traditional agroforestry MPTs could provide new vistas for their uses especially in agroforestry development in Ghana.

7.3. Materials and methods

7.3.1. Study site

The study was carried out at Jeduako in the Sekyere Central District of Ghana, located within Lat. $06^{o}55^{1}$ and $07^{o}30^{1}$N and Long. $05^{o}00^{1}$ W (Figure 7.1). The District covers a total land area of 1564 km^2 and has 150 settlements with 70% being rural. The research area falls within the dry semi-deciduous forest zone (DSFZ) of Ghana. It is characterized by a bimodal rainfall pattern with an average annual rainfall of 1270 mm. The major rainy season starts in March with a major peak in May. There is a slight dip in July and a peak in August, tapering off in November. December to February is warm and dusty (the driest period). The area has a mean annual temperature of $27^{o}C$, with variations in mean monthly temperature ranging between $22^{o}C$ and $30^{o}C$ throughout the year. The soil type of the study site is sandy loam (Ejura – Denteso Association). Subsistence agriculture is the main economic activity engaging about 65% of the population. The majority of agricultural production is from manually cultivated rain-fed crops. The predominant crops are maize, plantain, beans, cassava, and yam. The DSFZ was chosen because of its unique characteristic features which combine those of the forest and savanna zones. The DSFZ is the zone where the Forestry Commission of Ghana has proposed and earmarked for massive community tree (including bamboo) planting for fuelwood production (Forestry Commission, 2015).

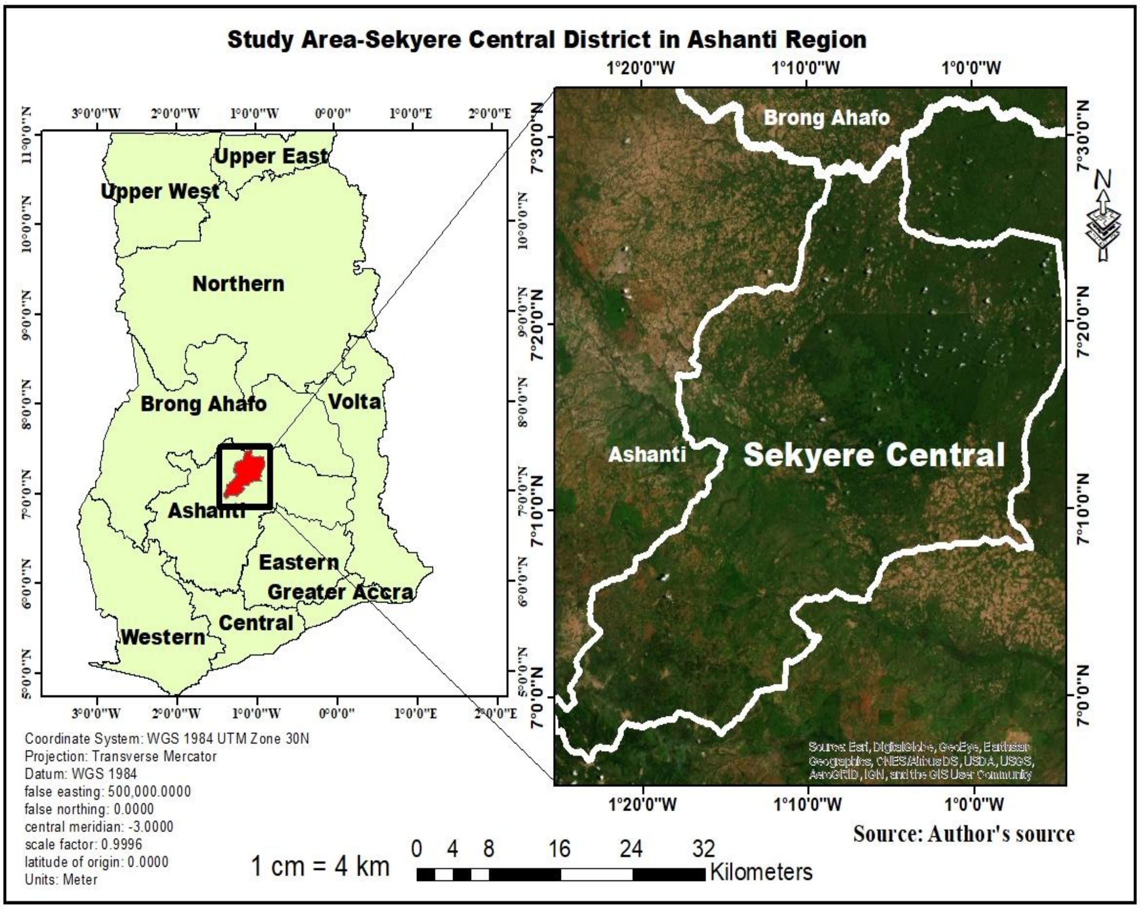

Figure 7.1: Map of Ghana showing the Sekyere Central District where study was carried out

7.3.2. Plant sampling and characterization

Plant species used in the study were: *Oxytenanthera abyssinica, Bambusa balcooa, Bambusa vulgaris, Albizia lebbeck, Senna siamea, Gliricidia sepium, Leucaena leucocephala, and Eucalyptus grandis* (see Appendix 12 for authors). The selection of the traditional species was based on their relative abundance and their use on farmlands in the study region, (exploration of their potential for nutrient release for soil improvement along with other exotic bamboo species and in comparison, with other traditional species is to bring out possible new uses of this species.

7.3.3. Leaf litter collection and sample preparation

Bambusa balcooa and *Oxytenanthera abyssinica* leaf litter were collected from already established BiomassWeb/INBAR led bamboo-agroforestry experimental field plots at Jeduako whilst litter from the other species were collected from Ghana Forestry Commission and Ministry of Food and

Agriculture field plots at the study location. Three litterfall traps were fixed randomly under each species to cover all 48 treatment plots. Litter collection was done in February to April 2016 until sufficient quantities (about 4000g (4kg) each of leaf litter of the various species were collected (Breda, 2003). Litter was cleaned and separated into twigs, buds, and leaves. Only leaf litter was sub-sampled for the laboratory analysis and further decomposition trials. To determine the initial chemical quality (N, P, K, Ca, Mg, C and lignin (Palm et al. ,2001) of the species, sub-samples were oven-dried at 70 ^{o}C for 72 hours in May 2016 and the oven-dried samples were ground into a powder and sieved to a 0.5 mm size. Carbon and nitrogen were analyzed using a LECO Carbon-Nitrogen analyzer, calcium and magnesium by the EDTA titration method, phosphorus by the spectrometric vanadium-phosphomolybdate method while potassium was determined by absorption spectrophotometry according to Motsara and Roy (2008). Lignin was determined by the acid detergent fiber method (Eneji et al., 2005). The samples were analyzed in three replicates.

7.3.4. Decomposition and nutrients release study

The study of decomposition and nutrient release dynamics of the species followed Partey et al. (2011) using the litterbag approach. Litterbag method remains the most generally engaged technique for determining litter decomposition in terrestrial ecosystems notwithstanding numerous drawbacks (Moore et al., 2017; Sun et al., 2017). Though the method may underestimate real decomposition, it is assumed that the results of litterbag studies will reflect trends characteristic of unconfined decomposing litter and as such allow for comparisons among species, sites and experimental manipulations (Wieder and Lang, 1982). The decomposition of the leaf litter of *Oxytenathera abyssinica*, *Bambusa balcooa*, *Bambusa vulgaris, Albizia lebbeck*, *Senna siamea*, *Gliricidia sepium*, *Leucaena leucocephala,* and *Eucalyptus grandis* were studied for eight months (June 2016 to January 2017) under field conditions, culminating into 210 days of trial period. Oven-dried leaves of the species (equivalent to 100g on a dry weight basis) were collected and put into 30 cm x 45 cm nylon litterbags with a 2-mm mesh size. The weight of the samples in the litterbags was based on local plant litter application rates (5 t dry matter ha^{-1} for maize production in the study location; Partey and Thevathasan, 2013). There was a total of 216 litterbags (27 per species) for the study. Eight transects spaced at 1.0 m apart were laid in a randomized complete block design. Twenty-seven litterbags spaced 0.5 m apart were placed on each transect. The litterbags were buried at 2 cm depth. Three litterbags (representing 3 replicates) for each species were retrieved and weighed after 7, 14, 30, 60, 90, 120, 150, 180 and 210 days to determine weight/mass loss and nutrient release.

To determine weight loss and nutrient release, leaf litter remaining in the litterbags on the sampling dates were first cleaned by hand and oven-dried at 65 ^{o}C for 24 hours. The oven-dried samples were separately weighed to determine weight loss (expressed as a percentage of the initial weight) and afterward ground by mortar and pestle. The ground materials were then sieved to 0.5 mm for nutrient analysis using the analytical methods aforementioned: carbon and nitrogen were analyzed using a LECO Carbon-Nitrogen analyzer, calcium and magnesium by the EDTA titration method, phosphorus by the spectrometric vanadium-phosphomolybdate method while potassium was determined by absorption spectrophotometry according to Motsara and Roy (2008). Lignin was determined by the acid detergent fiber method (Eneji et al., 2005). The samples were analyzed in three replicates.

7.3.5. Statistical data analysis

The rates (k) of decomposition and nutrient release were estimated by fitting the mass loss to a single exponential model (Robertson and Paul, 2000). The equation is Y=A*exp(B*t), where Y is the mass of litter remaining, A is the mass decomposed and B is rate of decompostion (slope). The quality of the regression was adjudged by the coefficient of determination (r^2) and the root mean square error (RMSE). Rates of decomposition were compared among species by analysis of variance using the R environment for statistical computing (R Core Team, 2017).

7.4. Results

7.4.1. Leaf litter decomposition rate

After 210 days *O. abyssinica and S. siamea* had the highest decomposition rate of 0.014 g/day on average, followed by *G. sepium* with 0.011 g/day on average. *E. grandis* had the lowest decomposition rate of 0.005. *Bambusa balcooa* and *Bambusa vulgaris* had 0.007 g/day and 0.004 g/day rates of decomposition respectively. There were significant differences in decomposition rates among all the species for the duration except for 60th and 90th days periods with p-values of 0.07 and 0.34 respectively as shown in Table 7.1. The significance is to depict the actual anticipated rate of decomposition of the different leaf materials with time and its suitability for possible soil amendment in agroforestry system.

Table 7.1: Decomposition rate (grams/day) of leaf material of the different agroforestry species (Sampling period value is for day 0 to the respective sampling days)

Species	Time (days)								
	7	14	30	60	90	120	150	180	210
O. abyssinica	0.029	0.022	0.015	0.009	0.007	0.019	0.018	0.016	0.014
B. balcooa	0.018	0.013	0.009	0.008	0.009	0.009	0.008	0.008	0.007
S. siamea	0.018	0.017	0.013	0.015	0.012	0.024	0.024	0.019	0.014
B. vulgaris	0.021	0.012	0.009	0.006	0.006	0.005	0.005	0.004	0.004
A. lebbeck	0.011	0.010	0.009	0.009	0.009	0.009	0.009	0.009	0.009
G. sepium	0.035	0.033	0.019	0.011	0.008	0.008	0.009	0.012	0.011
L. leucocephala	0.020	0.018	0.011	0.010	0.009	0.009	0.010	0.010	0.010
E. grandis	0.009	0.011	0.008	0.006	0.006	0.006	0.006	0.005	0.005
P-value	0.00	0.00	0.01	0.07	0.34	0.01	0.02	0.02	0.03
$LSD_{0.05}$	0.01	0.04	0.03	0.11	0.10	0.05	0.03	0.01	0.03

Values are the means of 3 replicates. Significance level p = 0.05

7.4.2. Decomposition patterns

Figure 7.2 shows the decomposition patterns exhibited by the species under study. The single negative exponential model describes with sufficient accuracy the litter mass loss from experimental day 0 to 210 of all eight species tested (Figure 7.2, Table 7.2). The best-fitting model curves were recorded for

B. vulgaris (RMSE = 1.83) and *E. grandis* (RMSE = 1.94) which gave the lowest magnitube of error predicted. After 210 days, only 3% of the leaf litter of *O. abyssinica* and *S. siamea* remained, but 32% of *B. vulgaris* remained.

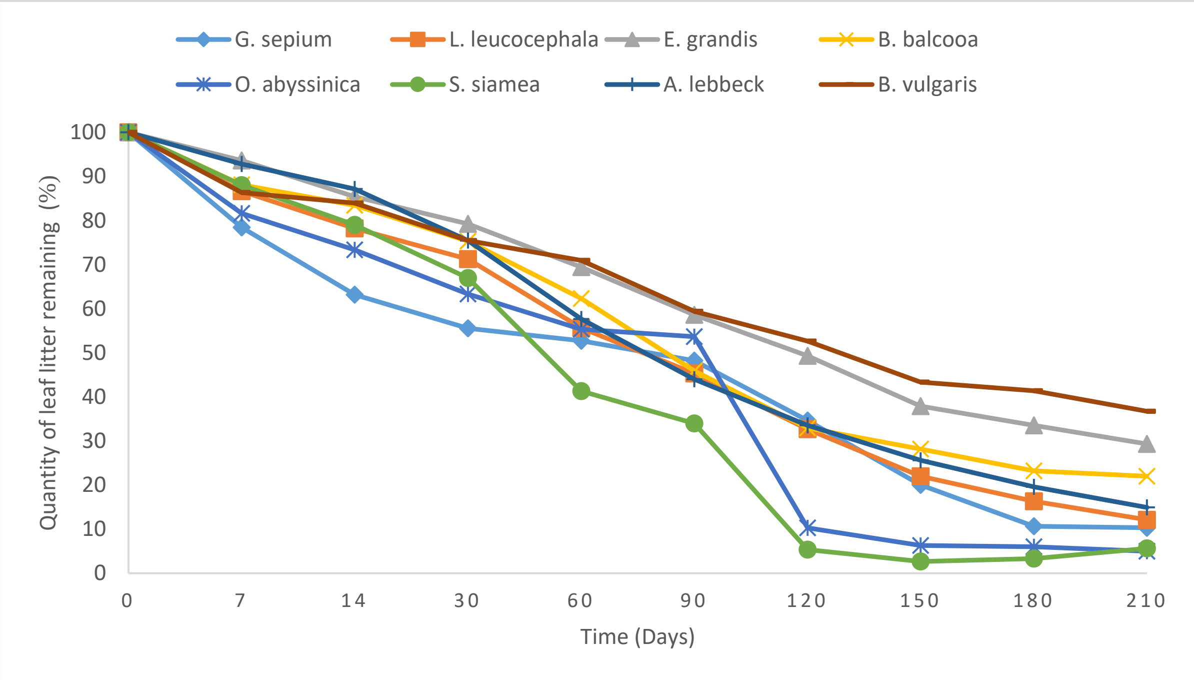

Figure 7.2: Relative quantity (%) of leaf litter remaining from decomposing leaf material of different agroforestry species during the study period of 210 days

Comparative analyses show that decomposition rates vary from species to species (Table 7.2). The rate at which all the species decompose is in the order *Senna siamea > Oxytenanthera abyssinica > Leucaena leucocephala > Albizia lebbeck > Gliricidia sepium > Bambusa balcooa > Eucalyptus grandis> Bambusa vulgaris* according to the half-life analysis.

Table 7.2 gives the predictive decomposition trends (B) per time; the Asymptote Model results for the various species and also shows the total decomposition (A) and half-life (HL=time taken for 50% of the mass to decompose) at the end of the 210 days study period for the various species at a 95% confidence level. Generally, it was observed that rate of decomposition (B) was averagely slower in species with higher lignin/Nitrogen and Carbon/Nitrogen ratios (Table 7.4). Only *O. abyssinica* differed slightly from this trend.

Table 7.2: Model parameters (A= Total Decomposition and B= Rate of Decomposition per Day) of decomposing leaf material of different agroforestry species tested in the study under field conditions.

Sp.	r^2	A	S.E	CI (95%)		B	S.E	CI (95%)		HL	S.E.	CI (95%)		P
				LL	UL			LL	UL			LL	UL	
Oa	0.970	94.26	3.75	86.58	101.93	-0.0119	0.001	-0.0141	-0.0096	58.44	5.37	47.43	69.44	<0.001
Bb	0.998	95.97	1.09	93.74	98.2	-0.0080	0.000	-0.0084	-0.0076	86.62	2.36	81.79	91.45	<0.001
Ss	0.990	99.98	2.32	95.58	105.07	-0.0158	0.000	-0.0173	-0.0139	44.42	2.42	39.48	49.37	<0.001
B v	0.997	92.06	1.26	89.48	84.64	-0.0047	0.000	-0.0051	-0.0043	148.0	5.95	135.8	160.21	<0.001
Al	0.999	99.29	0.55	98.16	100.42	-0.0091	0.000	-0.0093	-0.0088	76.59	1.00	74.54	78.64	<0.001
Gs	0.979	85.36	2.86	79.50	91.22	-0.0087	0.000	-0.0102	-0.0073	79.24	6.27	66.40	92.07	<0.001
Ll	0.997	94.88	1.24	92.33	97.42	-0.0093	0.000	-0.0098	-0.0087	74.80	2.30	70.10	79.50	<0.001
Eg	0.998	96.86	1.02	84.77	98.95	-0.0058	0.000	-0.0062	-0.0055	118.5	3.31	111.7	125.31	<0.001

r^2 =adjusted coefficient of determination, A= total decomposition, B=rate of decomposition, CI 95% = confident interval, LL and UL denote lower and upper limits, HL=half-life in days, P= the significance level (for A, B and HL), S.E.= the estimated standard error, sp.= species, Oa= *Oxytenanthera abyssinica*, Bb= *Bambusa balcooa*, Ss= *Senna siamea*, Bv= *Bambusa vulgaris*, Al= *Albizia lebbeck*, Gs=*Gliricidia sepium,* Ll =*Leucaena leucocephala* and Eg= *Eucalyptus grandis.*

Relatively, decomposition was faster in *S. siamea* (half-life = 44.42 days), *O. abyssinica* (half-life = 58.44 days) and *L. leucocephala* (half-life = 74.80 days). *Bambusa vulgaris* had the slowest decomposition with half-life of 148.02 days (Table 7.2).

7.4.3. Nutrient release patterns

From Table 7.3, it is observed that aside phosphorus, the chemical composition of the litter samples deferred significantly among the species at the start of the experiment. Generally, residual nutrients and other chemical constituents decreased over time among the species, except carbon which was fairly constant across the entire study period.

Table 7.3: Relative initial nutrient, carbon and lignin content of leaf litter of the different agroforestry species used in the experiment

Species	N (%)	P (%)	K (%)	Mg (%)	Ca (%)	C (%)	Lign (%)	C/N	Lign/N
O. abyssinica	1.78 (0.41) ^{a}	0.29 (0.31) ^{b}	0.49 (0.38) ^{c}	0.72 0.45) ^{c}	0.62 (0.23) ^{c}	35.9 (0.19) ^{a}	66.7 (0.23) ^{c}	20.2 (0.43) ^{a}	37.5 (0.89) ^{a}
B. balcooa	1.99 (0.51) ^{a}	0.36 (0.23^{b}	0.60 (0.19) ^{b}	0.17 (0.54) ^{d}	0.59 (0.56) ^{c}	25.1 (0.47) ^{a}	91.9 (0.41) ^{a}	12.6 (0.18) ^{b}	46.2 (1.15) ^{a}
B. vulgaris	2.70 (0.31) ^{b}	0.26 (0.37) ^{c}	0.51 (0.42) ^{b}	0.24 (0.50) ^{d}	0.49 (0.38) ^{d}	33.1 (0.47) ^{a}	78.1 (0.25) ^{b}	12.3 (0.34) ^{b}	28.9 (0.54) ^{b}
S. siamea	2.06 (0.32) ^{bc}	0.29 (0.35) ^{b}	0.10 (0.37) ^{d}	0.72 (0.17) ^{c}	0.58 (0.47) ^{c}	28.7 (0.32) ^{a}	78.1 (0.31) ^{b}	13.9 (0.41) ^{b}	37.9 (0.91) ^{a}
L. leucocephala	4.26 (0.64) ^{d}	0.61 (0.31) ^{a}	1.02 (0.55) ^{a}	0.72 (0.22) ^{c}	1.27 (0.71) ^{b}	29.1 (0.25) ^{a}	65.1 (0.29) ^{c}	6.8 (0.37) ^{c}	15.3 (0.12) ^{c}
A. lebbeck	3.12 (0.25) ^{b}	0.29 (0.52) ^{b}	1.16 (0.19) ^{a}	1.20 (0.49) ^{b}	1.54 (0.58) ^{a}	26.7 (0.33) ^{a}	59.7 (0.42) ^{c}	8.6 (0.37) ^{c}	19.1 (0.14) ^{c}
G. sepium	3.20 (0.30) ^{b}	0.72 (0.59) ^{a}	1.02 (0.36) ^{a}	1.68 (0.34) ^{a}	0.79 (0.23) ^{c}	34.3 (0.35) ^{a}	68.1 (0.26) ^{c}	10.7 (0.25) ^{c}	21.3 (0.78) ^{b}
E. grandis	1.92 (0.29) ^{a}	0.22 (0.08) ^{c}	0.74 (0.30) ^{b}	0.96 (0.38) ^{c}	1.46 (0.26) ^{a}	30.3 (0.41) ^{a}	66.7 (0.51) ^{c}	15.8 (0.37) ^{a}	34.7 (1.14) ^{a}
P-value	0.021	0.015	0.023	0.043	0.035	0.071	0.031	0.022	0.011
$LSD_{0.05}$	0.001	0.0022	0.0055	0.0033	0.0022	0.0044	0.0044	0.0011	0.003

Values are the means of 3 replicates. Values with the same letters in columns are not significantly different at P= 0.05. Values in brackets are Standard Errors of the respective means in columns. Lign means lignin.

After 210 days of exposition, residual leaf litter nitrogen is different from species to species (Table 7.4). Mean residual nitrogen was highest in *L. leucocephala* and lowest in *B. balcooa*. *Oxytenanthera abyssinica* also had more nitrogen released during the entire observation period. Similar trends can be seen in Potassium (K) release (Table 7.4). *Oxytenanthera abyssinica* and *B. balcooa* leaf litter released much more potassium than in *E. grandis*, *L. leucocephala,* and *G. sepium.* On the other hand, *B. balcooa* recorded the highest rate of Magnesium release whilst comparable release rates were observed in *O. abyssinica* and *L. leucocephala*.

Table 7.4: Relative residual nutrient, carbon and lignin content of leaf litter of different agroforestry species after 210 days.

Species	N (%)	P (%)	K (%)	Mg (%)	Ca (%)	C (%)	Lignin (%)	C/N	Lign/N
O. abyssinica	1.26 (0.39) c	0.39 (0.13) bc	0.30 (0.12) a	0.51 (0.31) a	0.86 (0.21) a	26.04 (0.23) ab	51.26 (10.2) a	20.67 (0.37) a	40.68 (0.51) a
B. balcooa	1.13 (0.51) c	0.32 (0.15) c	0.55 (0.3.4) a	0.16 (0.05) a	0.34 (0.29) a	25.59 (0.45) ab	64.31 (0.89) a	22.65 (0.14) b	56.91 (0.54) a
B. vulgaris	1.95 (0.31) b	0.33 (0.11) bc	0.78 (0.22) a	0.19 (0.04) a	0.23 (0.34) ab	31.37 (0.51) a	64.41 (1.05) a	16.09 (0.10) b	33.03 (0.02) b
E. grandis	1.72 (0.14) b	0.27 (0.10) c	0.81 (0.24) a	0.51 (0.46) a	1.31 (0.22) a	28.28 (0.21) a	52.62 (0.25) a	16.44 (0.17) b	30.59 (0.49) a
G. sepium	2.62 (0.32) a	0.72 (0.21) a	0.91 (0.47) a	0.53 (0.44) a	1.48 (0.41) b	27.78 (0.33) ab	58.47 (0.71) a	10.6 (0.51) c	22.32 (0.78) c
L. leucocephala	2.82 (0.57) a	0.40 (0.10) b	0.78 (0.68) a	0.37 (0.15) a	1.34 (0.33) b	21.09 (0.31) c	57.57 (0.43) a	7.48 (0.47) c	20.41 (0.81) c
A. lebbeck	2.64 (0.77) a	0.48 (0.13) b	0.91 (0.29) a	0.51 (0.35) a	1.78 (0.18) c	26.68 (0.41) ab	49.21 (1.09) a	10.11 (0.41) c	18.64 (0.07) b
S. siamea	1.78 (0.52) b	0.33 (0.08) bc	0.54 (0.27) a	0.44 (0.09) a	2.16 (0.23) c	24.24 (0.71) b	64.41 (0.22) a	13.62 (0.31) a	36.19 (0.44) a
P-value	<0.001	<0.001	0.06	0.08	<0.002	0.01	0.11	0.012	0.014
$LSD_{0.05}$	0.002	0.001	0.003	0.002	0.001	0.004	0.003	0.0013	0.0031

Values with the same letters in columns are not significantly different at P = 0.05. Values in brackets are Standard Errors.

Results from the decomposing leaf materials in this study show differences in N, P, K, Ca, Mg and lignin release patterns, with generally visible matching decomposition rate among all species (Figure 7.3).

Mass loss of leaf litter correlated positively with temperature as well as rainfall among all species although higher with temperature (See Appendices 10 and 11).

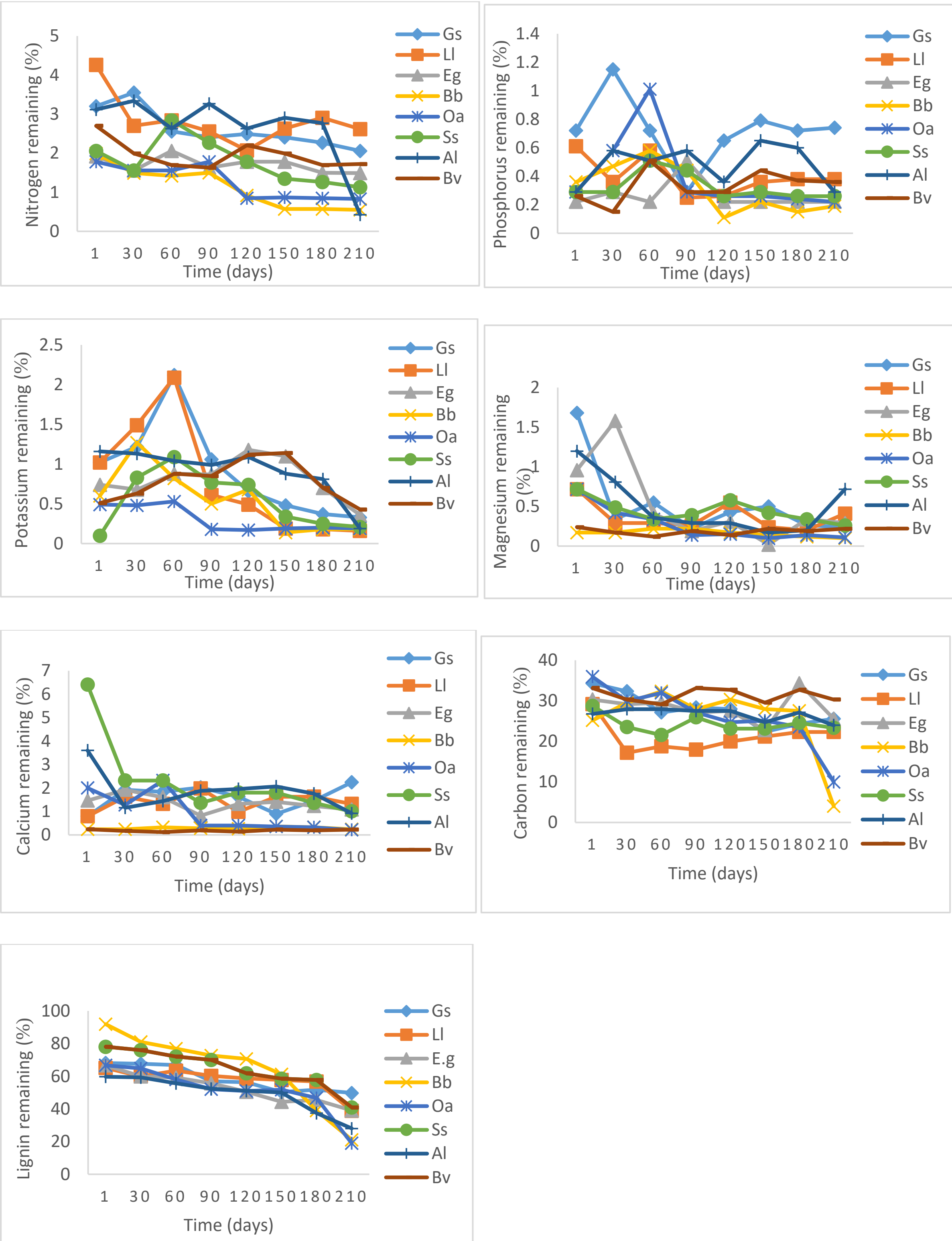

Figure 7.3: Chemical constituents remaining in the decomposing leaf litter of *Senna siamea* (Ss), *Eucalyptus grandis* (Eg), *Leucaena leucocephala* (Ll), *Gliricidia sepium* (Gs), *Oxytenanthera abyssinica* (Oa), *Bambusa vulgaris* (Bv), *Bambusa balcooa* (Bb) and *Albizia lebbeck* (Al) after 210 days.

7.5. Discussion

7.5.1. Leaf litter decomposition of the woody agroforestry species

The predictive model as depicted in Tables 7.2, shows high rates of decomposition (r^2) and is significant (<0.001) among all species in this study. Compared with other studies, the observed 44 days of half-life of *Senna siamea* in this study is not consistent with 0.97 month for pruned foliage of *Senna spectabilis* (De Costa and Attapattu, 2001), 3.3 months of fresh leaves of *Senna siamea* (Mwinga et al., 1994) and 2.48 months *Acacia auriculiformis* fresh fallen leaves (Kunhamu et al., 1994). Moreover, the recorded half-life of *Oxythenanthera abyssinica* at 58 days is far higher and inconsistent with 2-3 weeks of *Erythrina abyssinica* reported by Abey (2018). According to De Costa and Atapattu (2001), half-life of pruned *Gliricidia sepium* foliage was 0.99 month which demonstrated faster decomposition rate compared to 79.24 days observed in this study. The differences in half-life may not be attributed to pruned or fresh fallen leaves dynamics as no significant difference in decomposition rate was observed in *Jatropha curcas L* using different foliar parts and conditions (Negussie et al., 2015). The model in this study shows 119 days half-life of *Eucalptus grandis* leaf litter which differs from 5.4 months reported by Bahuguna et al. (1990). A similar half-life result which is inconsistent with the current study is realized in *Albizia lebbeck* (77 days) compared to O'Connell and Sankaran (1997) who confirmed 5 months for fresh fallen *Albizia* leaves. However, the present experimental evidence of 74 days half-life in respect of *Leucaena leucocephala* is consistent with 2.4 months reported by Jamaludheen and Kumar (1999).

Decomposition rates follow a biphasic pattern with relatively high rates during the first 7 days of the experiment (e.g. *G. sepium* and *O. abyssinica*) and lower rates in the subsequent phases. This observation may be attributed to the breakdown of non-lignified carbohydrates (Prescott, 2005) and the release of water-soluble components such as starch, proteins, and sugars (Munthali et al., 2015; Preston et al., 2009). However, the fast rate of litter mass loss in the first 7 days and the subsequent slower phase (60 and 90 days) for all species may be ascribed to the breakdown of lignified carbohydrates (Lui et al., 2007; Tetteh, 2004). Lignin as an aromatic polymer, non-hydrolyzed remains and complex in structure is a recalcitrant compound that slows down the litter mass loss. On the other hand, a study by Silveira et al. (2011) confirms that decomposition is likely to occur relatively and averagely faster when the N content is higher in the initial stages of decomposition and concentration of polyphenols and lignin are not in excess.

Different studies have attributed slow rates of leaf litter mass loss to the C/N ratio. The higher the C/N ratios, the slower the N-mineralization and decomposition rate (Gaisie et al., 2016; Bardgett and Wardle, 2010; Wall et al., 2008). Moreover, the comparative mass loss observed in *S. siamea* and *O.*

abyssinica after 120 days in this study may be due to similar chemical composition (Bonanomi et al., 2013), and, accordingly, has the same efficacy and capacity to function. In a 12-week study by Gaisie et al. (2016), the order of mass loss was *Gliricidia sepium* > *Leucaena leucocephala* > *Senna siamea* > *Albizia lebbeck*, which is inconsistent with the present study. The dissimilarities in the studies may be influenced by the following major reasons: The study by Gaisie et al. (2016) was from April to July (major rainy season) with 200g of leaf litter in bags with 1.0 mm mesh size and buried at a depth of 15cm. The present experiment was performed in June to February (from major to minor rainy seasons) with 100g of leaf litter in 2.0 mm mesh size and buried at a depth of 2cm. Differences in temperature and other factors such as duration of the experiment, decomposer interactions due to the mesh size of the litter bags and also the quantity of litter in the bag might have influenced different litter decomposition patterns. In this present study, it was observed that mass loss of leaf litter correlated positively with temperature as well as rainfall among all species but higher with temperature (Appendix 11). Aside making leaf litter susceptible for breakdown, temperature is the single more sensitive factor for decomposition than rainfall; mostly influencing the activities of decomposer organisms. Decomposer organisms become inactive or may even die above or below certain temperature threshold/gradient (Negussie et al., 2015; Swarts et al., 2013; Isaac and Nair, 2005).

The present study has, however, a similar order of mass loss regarding *B. balcooa* and *B. vulgaris* compared to the work by Nath and Das (2011) where leaf mass loss of *B. balcooa* was 13.96%, compared to 12.26% of *B. vulgaris.* Again, the result from the present study is not entirely consistent with the finding by Cornelissen et al. (1999) who indicate that high amounts of calcium and magnesium may contribute to high decomposition rates. The two elements make litter less acidic, more palatable and are important resources for decomposer organisms; and such occurrences were evident in *S. siamea.* However, the attribution of calcium and magnesium to accelerate leaf litter decomposition does not hold for *A. lebbeck*. *O. abyssinica* decomposed faster than *A. lebbeck* which, however, is contrary to the findings of Tripathi et al. (2013), who stated that bamboo has a slower decomposition rate due to its silica-rich litter. The results from this study, therefore, establish clear evidence of comparable mass loss in *O. abyssinica* and *B. balcooa* with the other traditionally known agroforestry woody species.

7.5.2. Nutrient release among the agroforestry species

Litter quality, particularly the chemical composition of a decomposing material is considered as a critical factor in determining the rate of litter decomposition (Jacob et al., 2010). Nitrogen is essential for plant growth as it is a constituent of proteins. Litter decomposition and nitrogen release are positively related to initial litter quality. Statistically, nitrogen showed significant results at 1% with the highest concentration observed in *L. leucocephala* (2.82 $\pm$ 0.63) and lowest in *B. balcooa* (1.13 $\pm$ 0.55). The high mean residual nitrogen content in *L. leucocephala* is evident in its initial concentration; which aids in the rapid rate of mass loss compared to *B. vulgaris* and *E. grandis*. This result confirms the assertion by Maria (2011) that a high nitrogen level in the initial stages of decomposition increases the rate of mass loss. However, *O. abyssinica* released more nitrogen compared to *G. sepium* and *S. siamea*. The amount of nitrogen released is consistent with the work done by Gaisie et al. (2016); while nitrogen release for *A. lebbeck* was higher than *S. siamea*. Normally, the N level is higher than K, where K is equally in excess compared to P in that order. This was observed in this current study and consistent with the findings by Prasath et al. (2014), who studied the decomposition rate and nutrient release of *B. vulgaris*. Phosphorus plays a fundamental role in different metabolic processes. For P increase in the process of decomposition, a study by Moore et al. (2006) attributed it to P deficiency which in effect brings a reduction in the nutrient release. From the initial concentration, the increase in P levels during the decomposition process was observed only in *B. balcooa*, *L. leucocephala,* and *S. siamea*. However, there was no effect of such nutrient concentration on the other species. The lower mean residual P in *E. grandis* (0.27 $\pm$ 0.10) observed could be a result of low P initial level causing immobilization. When P content in the leaf litter is not sufficient for the consumption of C that the decomposers need for energy, the decomposer inclines to obtain P through immobilization. However, according to Ball et al. (2008), the immobilized P will then be released later. The process of decomposition is said to be related to the concentration of lignin in the litter. The rate of lignin loss due to nitrogen-rich or poor phenomenon was observed entirely in all the species. This means that, species with higher intial nitrogen concentration had slower lignin loss resulting also in faster decomposition rate, and vice versa. This confirms the findings of Carnevale and Lewis (2009), who reported that lignin loss is slower in nitrogen-rich litter than in a nitrogen-poor litter. Potassium is an extremely mobile element, occurring in excess amount for the demand of the decomposer community and readily leached (Bargali et al., 2015). Potassium was released higher in *O. abyssinica* (0.30 $\pm$ 0.16) and *B. balcooa* (0.55 $\pm$ 0.39) compared to *G. sepium*, *E. grandis,* and *L. leucocephala.* The release of K is extensively due to characteristics such as high solubility in water and not bound by the cell wall. According to the study by Gaisie et al. (2016), *A. lebbeck* released more P and K than *S. siamea* which is consistent with this current study. Generally, the low release of P in all the species in this study may be due to the concentration of lignin which is relatively higher (Kaizzi and Worttmann, 2001; Mao et al., 2001).

The trend of decomposition and the limitation observed in *B. vulgaris* may be due to the relatively low quality of the litter, either toughness or higher lignin content and the environmental conditions prevailing during the study period. *Senna siamea* and *Bambusa vulgaris* had the same initial lignin and mean residual lignin concentration even though *B. vulgaris* was higher in initial nitrogen concentration. This is inconsistent with the general notion that in the process of decomposition, high lignin loss is fundamentally correlated with poor nitrogen content. Gaisie et al. (2016) observed a similar pattern and increases in N P K concentrations overtime for all species, which is contrary to findings of this study. The observed variations in the nutrients released values may be due to environmental factors such as soil fertility and water availability (heterogeneity of the site) amongst others which coexist to build up the physical and chemical traits of the plants as reported by Ackerly and Cornwell (2007). However, the observed trend of higher N P K released in *B. vulgaris* compared with a low level in *B. balcooa* is consistent with the report by Nath and Das (2011). Based on the results pertaining to the release of N P K, *O. abyssinica* and *B. balcooa* could be comparable to the traditionally known tree species if used in any land use system such as agroforestry system where soil improvement or conservation is a pririorty.

7.6. Conclusion

Results from this study give clear indications that irrespective of the species type, it is rather the biomass quality that functions as a major catalyst to decomposition and nutrient release patterns of the chosen plant leaf biomass. From the results, the leaf litter from *Albezia lebbeck, Senna siamea, and Gliricidia sepium* are evaluated as high-quality litter and could be used as green manure to short-duration crops such as vegetables as well as most annual crops, due to their high N and P concentrations. Imperatively, the fast decomposition and nutrient release rates of *S. siamea* and *B. vulgaris* may limit their potential for long term build-up of soil fertility. *Leucaena leucocephala* leaves are rated as intermediate-quality litter due to the relatively low P concentration which might lead to immobilization of P or reduce the rate of mineralization, notwithstanding the significant levels of N in the leaves. Therefore, such materials may be composted to commence their breakdown before application to crops. On the other hand, the leaves of *Bambusa balcooa, Oxythenathera abyssinica and Eucalyptus grandis* are rated as low-quality litter due to the low levels of N and P. These leaves may be unsuitable for use for soil fertility improvement but for such use as mulch. That is, *O. abyssinica, B. balcooa,* and *E. grandis* leaves could be applied as a surface mulch to protect soil against evaporative losses or to control surface water flow. Alternatively, *B. balcooa and O. abyssinica* fresh leaves may be incorporated with very high-grade organic matter or N and P fertilizers to supplement the low N or P or both N and P levels. Moreover, *L. leucocephala* and *O. abyssinica* and *B. balcooa* organic residues, which breakdown and release minerals slowly can be considered for soil fertility build-up.

Although bamboos are not known and commonly used for soil amendment in Ghana, the current study has revealed that they could be used to improve soils for various agronomic purposes. Bamboos may be considered for integration into various land-use systems, particularly for land reclamation programs (e.g. on mined sites) as having been explored in other tropical regions. They could serve for soil moisture conservation and erosion control through the mulching effect of their heavy litter accumulations and wider root networks respectively. Furthermore, they could be considered in crop integration or agroforestry systems where their slow release of nutrients could be harnessed by selecting the appropriate crops and planting times for nutrient release and crop nutrient intake synchrony. The Ministry of Food and Agriculture of Ghana may adopt lessons from this study by selecting bamboos as new MPTs for agroforestry systems in the attempt to revitalize the seemingly defunct 1986 agroforestry policy in Ghana.

7.7. Acknowledgments

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8. Synthesis

Deforestation and forest degradation continue to be global environmental problems currently escalating in developing countries especially in Sub-Saharan Africa (FAO, 2010). This has been alluded to unsustainable harvesting of wood and non-wood biomass as in food production (as in agricultural schemes) and bioenergy production (fuelwood and charcoal production) (Hazell and Wood, 2008). In Ghana, slash and burn agriculture and excessive harvesting of woody biomass for wood energy have been reported for accounting for forest vegetation decline (Al-Hassan et al., 2006; FAO, 2004; 2003). Whereas this is precarious, the phenomenon is the means by which the larger majority of rural dwellers (who form about 65% of the population) depend on for their livelihoods. Ghana is rated 6th among the top 10 countries globally, for largescale charcoal production (FAO, 2017). Bamboo agroforestry has been recommended as a suitable land-use system to ameliorate this environmental challenge whilst making woody biomass available and accessible for socioeconomic and environmental gains (Partey et al., 2016; Forestry Commission, 2015). The potentials of bamboo agroforestry have been explored through preliminary research findings hinging on the socio-economic needs of the people, and also exploring complementary ecological interactions of bamboo and associated crops. In the following, the results from each Chapter of this thesis are briefly summarized.

8.1. Socio-economic indicators and potential adoption of bamboo agroforestry in Ghana

Socio-culturally, it was observed that bamboo agroforestry would not infringe on any local community rights- for instance, there were no cropping system nor traditional knowledge incompatibility and proscriptions with bamboo on farmlands in the study region. In this case study, many farmers (respondents), particularly, the women fold (64%), as well as many households in the semi-deciduous forest zone of Ghana, are ready to embrace bamboo agroforestry for sustained food production and fuelwood needs. The key socioeconomic factors indicating the preparedness of households to embrace bamboo agroforestry are knowledge of farmers on bamboo use and management, gender, education, type of cropping system and the practice of leaving trees on farms. Women are, in particular, very supportive of the bamboo agroforestry because they are responsible for the production of fuelwood for domestic use. The dire need for sustainable fuelwood supply and long distances for firewood collection have necessitated bamboo agroforestry. However, intensive sensitization and more education on bamboo agroforestry are necessary to increase the upscaling and adoption of bamboo agroforestry technology.

8.2. Farmer perception of bamboo litter as fodder and its quality for livestock production

The majority of farmers in the transitional zone of Ghana in particular rear livestock to complement gains from farm produce mostly on the subsistence level. Sustainable livestock production is challenged by sustainable fodder supply, especially in the dry season. While bamboo is a useful woody perennial for various household's needs, only a few (26% of respondents) inhabitants of DSFZ were aware bamboo leaves could be used as fodder for livestock. This, they learned from seeing someone or had heard someone fed livestock with bamboo leaves before. Nonetheless, most farmers especially, men (70%) and women (about 90%) are prepared to try the use of bamboo leaves as fodder for livestock. Bamboo fodder is being considered because there is a downtrend (MoFA, 2011) of available quality fodder. Goat rearing was observed as the major livestock production and bamboo fodder quality trial recorded high nutritive value/content of bamboo as supplemental feed to goats. Goat growth and serum improvement were observed under supplemented feed from bamboo. There is, therefore, the high potential for increased goat production in the DSFZ from the discovery of bamboo leaves as fodder or as a feed supplement to support goat production in the DSFZ especially in the dry season.

8.3. Evaluation of soil and crop productivity and economic viability within bamboo intercropping system in Ghana

The intercropping of bamboo with maize, cowpea, and cassava was compatible with traditional cropping systems and enhanced crop production in the DSFZ. The partial LER of near 1.0 and subsequent viable economic potential from the economic analysis of the bamboo intercropping system over the monocropping system of the bamboo, cassava, cowpea, and maize indicate that bamboo agroforestry could be a potential land-use system to salvage declining agricultural productivity in the DSFZ of Ghana. This suggests that the intercropping of bamboo would not inhibit the productivity of associated crops like cassava, maize, cowpea in Ghana.

8.4. Decomposition and nutrient release patterns in bamboos as compared with traditional agroforestry MPTs

As expected from any MPT in an agroforestry setting, the bamboo in the bamboo agroforestry could be a substantial source of biomass for charcoal production, fodder for livestock production and enhancement of food production by moderating temperature and soil moisture in the intercropping system. These potentials of bamboo have been reported also in the literature (Partey et al., 2017a; Pande et al., 2012; Nath and Das, 2011). This latter ecosystem function could be achieved through the moderate rate of decomposition of bamboo litter and gradual nutrients release of soil nutrients which were comparable to those of the traditionally known and used agroforestry MPTs in Ghana. Although there were relatively high C/N ratios for the tested bamboos, the rate of breakdown of compounds and their subsequent release of nutrients like nitrogen, phosphorus and magnesium makes bamboo a suitable alternative candidate species for agroforestry systems in Ghana.

8.5. Bamboo agroforestry for increased agro-ecologically efficient agricultural systems in Ghana

Improving agricultural production requires a holistic systems management approach (Altieri et al., 2012; Partey et al., 2011). It involves building synergies from all production components/entities. In a typical agroforestry system, evaluation of the whole system's productivity is necessary to ascertain the impact of the systems and to provide for necessary measures (Thevathasan and Gordon, 2004) to refine the design of technologies. Bamboo agroforestry could add to agro-ecological efficient agricultural systems (Altieri et al., 2012) in Ghana through sustained soil and crop yield improvements as achieved with the integration of bamboo in an alley system in this current study. The bioenergy potential of bamboo may add to the expected socio-economic benefits through the production of new wood fuels in bamboo charcoal (FAO, 2016a). The potential social acceptability of new technologies (Derkyi et al., 2013) like the bamboo agroforestry expressed in the current study is a good indication that it could be adapted to the needs of farming communities in Ghana. This fits well into the Ghana poverty reduction programs and could align with government initiatives for bioenergy production as pursued by the Ghana Energy Commission and agricultural and forestry initiatives by the MoFA and Forestry commissions in their respective master plans (Forestry Commission, 2015; MoFA, 2011). Bamboo agroforestry may also provide another option for economic opportunity for smallholder charcoal producers and traders especially the majority among the women fold in Ghana as they constitute a substantial percentage in the charcoal trade (FAO, 2010). In the bamboo agroforestry currently under study, we anticipate social and ecological incompatibilities such as possible social rejection of the technology by local community members and ecological challenges like the introduction of diseases or invasion from the bamboos. These could be dealt with through trade-offs management (increasing bamboo stand density for more culms at the expense of food crops and other land use components or vice-versa) and enhancement of complementary system productive functions (the use of designs which support increased agricultural systems productivity), and also the choice of the appropriate bamboo and food crop species for effective combination in a system (Buckingham et al., 2011). Future crop yield decline from possible shading of bamboo can be expected (Nath et al., 2009) and this could be ameliorated through regular bamboo stem reduction or increase in planting distance. Some bamboo species have been reported as being invasive through the proliferation of rhizomes, especially most monopodial bamboo species. These have the tendency to colonize and invade already limited arable lands. A careful selection of sympodial bamboo species like *Oxytenanthera abyssinica* and *Bambusa balcooa;* non-invasive species as described by Buckingham et al. (2011) (used in this current study) could forestall such ecological backslashes in any agroforestry design. Coppice management of clumps for charcoal production and root pruning would curtail rhizome proliferation of rhizomes of monopodial bamboo species (Pande et al., 2012). Bamboo roots extension management (monitoring and reduction of bamboo lateral and fibrous root networks) is necessary for the design to delineate complementary and competitive zones in the bamboo agroforestry systems. Information on exotic species intended to be introduced into any new ecological systems may come with new challenges which bother on their management and use. Further studies and efforts to curtail possible future challenges like disease and pest outbreaks would be necessary for improved system productivity. The sociocultural compatibility of the bamboo agroforestry system in the DSFZ as observed in this current study is an indication of social acceptance of the system in the agro-ecological zone. However, the sustainability of the system will require socioeconomic refinements as the system could be seen as a social safeguard.

With the introduction of bamboo agroforestry as an added and improved land-use technology to existing land-use systems in this agro-ecological zone of Ghana, the danger of climate change to agriculture could be reduced by expanding adaptive capacity of farmers, intensifying resilience, and resource use efficiency and enhancing the mitigation capability of the agro-ecological landscape (Partey et al., 2017a). Bamboo agroforestry presents a new and improved farming system for Ghana- the incorporation of shorter rotation woody species with the potential of quicker medium-term/intermediate returns to farmers would provide resilience to farmers and thereby improving agricultural output in Ghana. Bamboo agroforestry could best be practiced in areas with marginal arable lands especially where further agricultural production is restricted by marginal soils and declining crop yields (Peprah et al., 2014). Also, severely mined areas could be planted by bamboos to aid in the soil restoration and reclamation exercises and to allow for future farming (Chaturvedi et al., 2015). Obiri and Oteng-Amoako's nationwide survey report from the study towards sustainable development of the bamboo industry in Ghana in 2007 supports the assertions in this current study that bamboos could be planted almost in all the sixteen (previously ten) regions of Ghana. Their report indicated the readiness of the Ghanaian community to accept and use bamboo products. Improvement in and extension of bamboo marketing networks were recommended; and also, an emphasis on the need to increase the production of bamboo through cultivation (example through agroforestry) to meet the growing demand was made (Obiri and Oteng-Amoako, 2007). Another nationwide survey on bamboo, conducted by Ebanyenle and others in 2014 on a general socioeconomic perspective indicates the socio-cultural readiness of the Ghanaian society to accept bamboo agroforestry and bamboo products. The conclusion that Ghana has the potential to use bamboo for socioeconomic gains but would require a national effort and the assessment of regional and local socioeconomic potentials for the use and development of bamboo sector in Ghana (Appiah-Kubi et al., 2014; Bowyer et al., 2014; Ebanyenle and Oteng-Amoako, 2007) is underpinned by this current study as we have explored and confirmed the socioeconomic and ecological potential of bamboo-based agroforestry and the adoption potential. Farmers income streams could be improved through new vistas like improved charcoal production levels increased livestock production (Partey et al., 2017a; Pande et al., 2012) as a result of additional sources of fodder from bamboo whiles enhancing the system for food crop production and environmental quality and sustainability.

Bamboo agroforestry is feasible and has huge potential for socioeconomic and environmental development in Ghana. However, the success is largely influenced by the potential adoption of the system which correlated with farmers' demographic factors such as age, gender, and education (knowledge acquisition and development on bamboo agroforestry), farmers' socioeconomic referents as in traditional agricultural practices, cropping system, type of farming systems, the practice of leaving trees on farms, land tenure arrangements, labor and farm investment and objective of cropping. In addition, the potential of bamboo agroforestry for income improvement via environmentally sustainable production systems could increase farmers' desire and 'sustainagility' to adopt the bamboo agroforestry concept. From the analysis of the results of this current study, farmers are likely to adopt bamboo agroforestry for the use of the bamboo leaves as fodder for livestock production and bamboo culms for fuelwood and/or charcoal production rather than for food crop production in the forest transition of Ghana. However, through the additional environmental benefits from bamboo as with any agroforestry MPT; enhanced food crop production from the decomposition and nutrient release processes, which may improve soil nutrient and moisture condition, could also be realized. This is particularly important for farming systems in the drier agro-ecological-forest transition zone of Ghana.

9. OUTLOOK

This dissertation lays down the foundation for further integrated research and new approaches to cultural and indigenous practices for rural community development, forest conservation, and sustainable agricultural productivity within the forest transitional zone of Ghana. In the following sub-Chapters, several important, yet unanswered research questions, on the set domain of bamboo agroforestry are detailed out along with their potentials for socio-economic development and environmental sustainability. Government and institutional linkages are indicated and the necessary reviews in existing policies are recommended for upscale and wide-scale adoption of the bamboo agroforestry technology in Ghana.

9.1. Potential of bamboo agroforestry development in Ghana

Although bamboo is underutilized woody perennial in Ghana, it's potential for environmental sustainability as well as agricultural system productivity in an agroforestry design is demonstrated in the current study. The potential for bio-energy production (Charcoal production) improvements in cropping system productivity are all provision functions of the bamboo agroforestry which could facilitate sustainable agricultural productivity and bioenergy production in the study region. Agroforestry is a well-acclaimed contemporary sound land-use system for improving food production to close yield gaps for the escalating world population and to ensure environmental sustainability (FAO, 2016a). To realize the full potential of bamboo agroforestry for socio-economic development would call for further robust scientific research on education and sensitization as well as in-depth ecological and economic analyses.

9.2. Bamboo agroforestry ethnobotany and adoption potential for socio-economic improvement

The key socio-economic indicators for the adoption of bamboo agroforestry were traditional ecological knowledge on bamboo (bamboo ethnobotany), farmer's age and gender. Upscaling of bamboo agroforestry technology would require conscious efforts at increasing information on bamboo agroforestry and adapting the technology to the needs and aspirations of local smallholder farmers.

9.3. Germplasm screening for bamboo species

Globally, there are about 1,500 species of bamboo currently used by people for various socio-economic purposes. The current study reported the potentials of only two (2) exotic species for the bamboo agroforestry ecological trials. Expanding the range of potential bamboo species for bamboo agroforestry in Ghana would require germplasm screening and experimentations for the optimization of several agro-ecological benefits of bamboo in Ghana. Although indigenous bamboo species from Ghana may not be suitable for structural and bio-energy use because of their hollow stems, they could be explored for their fodder quality and land/soil reclamation potential for livestock production and reclamation of mined and degraded forest areas in Ghana.

9.4. Socio-economic viability of gains from bamboo agroforestry

Economic analysis of the bamboo agroforestry system indicated economic viability and marginalized production profit for using bamboo in the bamboo agroforestry system, especially for culm production. It is recommended for the promotion of the integration of bamboo among smallholder farmers in agricultural landscapes for food, culm and charcoal production.

9.5. Opportunity for bamboo agroforestry in Ghana

Although the methods used in the current study are not new, the study findings bring out new vistas of bamboo use in Ghana; especially the potential for bio-energy production in meeting Ghana's bioenergy production policy aspirations as enshrined in the Ghana bio-energy policy strategies, whilst sustaining agricultural production systems for cowpea, cassava, and maize. Although bamboo fodder is not a known feedstock for livestock production, the study has revealed the potential for bamboo leaves as supplemental feedstock to support livestock production in Ghana, especially in the savannah and forest transition zones. An increase in traditional-ecological knowledge on bamboo and its impact in the agro-ecological setting through bamboo-based agroforestry could facilitate better understanding to sustain and facilitate sustainable agriculture and bio-energy production in Ghana. This would require further studies in the environmental ecosystem functioning and the economic potentials of the new bamboo-based agroforestry concept being envisaged. This could facilitate effective policy uptake and sustainable adoption of the bamboo agroforestry concept in Ghana.

9.6. Uptake

Further and robust research on bamboo agroforestry, education, and sensitization of farmers on bamboo's nutrient management/fertilizer use efficiency, different bamboo intercropping designs and economic sensitivity analysis such as for factors such as changes in interest rates; would be imperative for smallholder agriculture as they are necessary to facilitate sustainable adoption of the bamboo agroforestry technology in Ghana. Inclusion of bamboo as MPT in the revitalization of the 1986 Ghana agroforestry policy and its introduction as bio-energy crop for the Energy Commission and Forestry Commission could catalyze bamboo agroforestry adoption rate whiles making higher woody biomass yields available for energy production and vegetation cover. Policy revisions and uptake, institutional linkages and arrangements for the adoption of bamboo agroforestry are necessary to enhance the potential to safeguard Ghana's food and energy security.

It is recommended that bamboo (*Bambusa balcooa* and *Oxytenanthera abyssinica* species) should be considered as key candidate species in national efforts by the Ghana Forestry Commission and Energy Commission for ensuring sustainable bio-energy supply, particularly charcoal production in the savannah transition zones by both subsistence and commercial producers for domestic and international markets. Up-scaling bamboo agroforestry among producers under smallholder farm conditions would require capacity building to minimize production risks. Although loans could be granted up to 30%, financial assistance at lower interest rates, not more than 10% is recommended to maximize profit and to encourage producers to adopt sustainable practices. Possible consideration under the Government of Ghana's planting for food and jobs program is also proposed, particularly, for the restoration of degraded landscapes in the forest transition zone and excessively mined areas. Again, the Ghana Government's flagship policy initiative of rearing for food/meat security and jobs could adopt the cultivation of bamboo to provide supplemental feed/fodder for livestock in Ghana. In the REDD+ initiatives by Ghana, bamboo cultivation may be included to increase vegetative cover for the restoration of vegetation in Ghana for environmental quality. As part of REDD+ initiatives, the Forest Investment Program (FIP) - tree planting in farmers' farms has been initiated by the Government of Ghana through the Forestry Commission. The aim is to increase tree cover outside forest reserves and to contribute towards REDD+ initiatives and aspirations. Bamboo-*Bambusa balcooa* could be incorporated in the list of woody species recommended for use in the FIP. To realize explicit impacts of the new bamboo agroforestry concept, the 1986 agroforestry policy should be revitalized through political and institutional re-engineering and also through programs like education, sensitization, and introduction of bamboo as a potential agroforestry candidate MPT. Bamboo would provide a suitable substitution to the long rotation species which farmers have been complaining about in agroforestry programs. Relatively, intermediate or medium-term benefits to farmers could be realized in a shorter period through the sale of bamboo culms as opposed to those from traditional agroforestry MPTs. Policymakers may adopt lessons from the socioeconomic and environmental potentials implicitly evolving from this current study. In furtherance to achieving optimum gains from bamboo agroforestry in Ghana, Ghana Government may work through institutions such as the Forestry Commission and the Ministry of Food and Agriculture to ensure and achieve specific gains at local management levels through creation of wider spacing in bamboo intercropping systems for smallholder farmers to reduce shading of crops; although bamboo conserves moisture for use by crop. Labor for managing weed and clumps to reduce invasiveness would be paramount. Smallholder capacity building for efficient establishment and management of bamboo-based intercropping could enhance optimum benefits from the system. For improved socio-economic status of smallholder farmers, guaranteed prices for bamboo culms and other bamboo products should be fixed in Ghana. Social intervention schemes including government planting for food and job schemes can consider bamboo cultivation as a promising venture for poverty reduction in rural areas of savannah and transition zones. The Government of Ghana could give bamboo agroforesters tax rebates or reduce borrowing at interest rates lower than 10% to facilitate sustainable bamboo-based agroforestry in Ghana.

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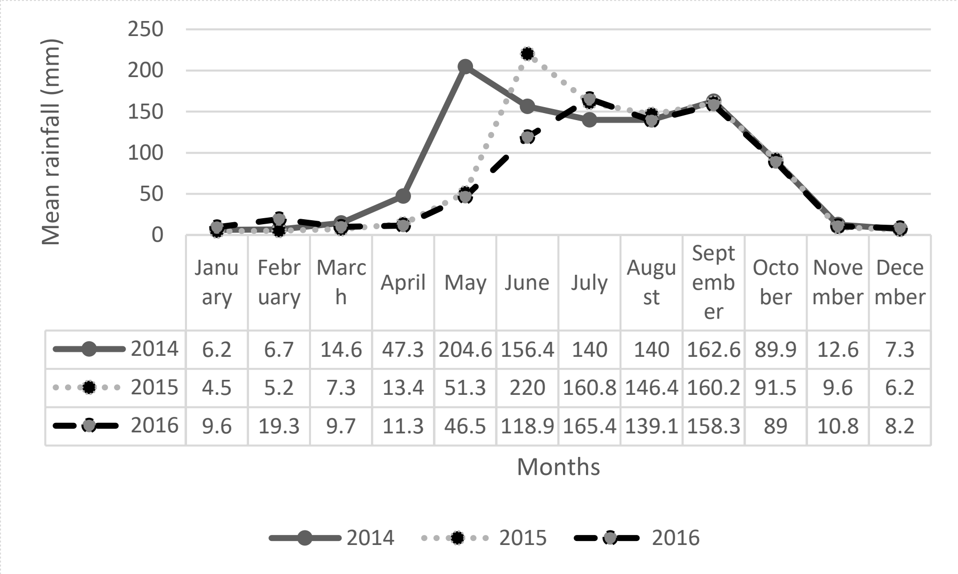
APPENDICES

Appendix 1: Data used in estimating cost and returns in agroforestry and mono crop systems

Description	Cost	Return	Quantity
No. of bamboo stems or culms/ha (Agroforestry)			660
No. of bamboo stems or culms/ha (Monocrop bamboo)			1,320
Mortality replacement (30%)			
Initial fertilizer (50 kg bag/ha)			3
Cost of fertilizer GH¢/50 bag kg	89		
Bamboo seedling price GH¢/seedling	6		
Labor wages (GH¢/man-day) (2016)	15		
No. of harvestable stems per clump (agroforestry plots)		3	
No. of harvestable stems per clump (monocrop plots)		6	
Initial harvest in third year (stems/culms/ha)		3	
Third year, maize yield (t/ha)			
Bamboo agroforestry (Fertilized) (t/ha)		2.75	
Bamboo agroforestry (Not Fertilized) (t/ha)		0.79	
Monocrop maize (Fertilized) (t/ha)		2	
Monocrop maize (Not fertilized) t/ha		0.58	
Third year, cowpea yield (t/ha)			
Bamboo agroforestry (Fertilized) (t/ha)		2.62	
Bamboo agroforestry (Not Fertilized) (t/ha)		2.03	
Monocrop cowpea (Fertilized) (t/ha)		1.92	
Monocrop cowpea (Not fertilized) t/ha		1.32	
Third year, cassava yield (t/ha)			
Bamboo agroforestry (Fertilized) (t/ha)		13.09	
Bamboo agroforestry (Not Fertilized) (t/ha)		12.65	
Monocrop cassava (Fertilized) (t/ha)		11.74	
Monocrop cassava (Not fertilized) t/ha		10.67	

Values of crops are averages per ha of the first three years of each cropping system establishment; Bamboo values are the average values for products in the third year and afterwards, monthly for only one year.

Appendix 2: Mean monthly rainfall distribution recorded during the experimental periods in 2014, 2015 and 2016.



	January	February	March	April	May	June	July	August	September	October	November	December
2014	6.2	6.7	14.6	47.3	204.6	156.4	140	140	162.6	89.9	12.6	7.3
2015	4.5	5.2	7.3	13.4	51.3	220	160.8	146.4	160.2	91.5	9.6	6.2
2016	9.6	19.3	9.7	11.3	46.5	118.9	165.4	139.1	158.3	89	10.8	8.2

Mean monthly rainfall distribution recorded during the experimental periods in 2014, 2015 and 2016. Data points are the means of three replicates. Data were obtained from the Ghana Meteorological Station at Mampong- Ashanti Region (for the study site) and validated at the Earth Observation Research and Innovation Center (EORIC)- University of Energy and Natural Resources- Sunyani, Ghana

Appendix 3: Participation Information Sheet and Informed Consent Form

<u>Name of the project</u>: "***Bamboo agroforestry in the dry semi-deciduous forest zone of Ghana***"

<u>Sub-project</u>: ***"Farmer cropping systems, knowledge and perception of bamboo agroforestry for food production and energy needs in the dry semi-deciduous forest zone of Ghana"***

Hello. My name is ________________________________ and I am part of a team carrying out a survey of ***farmers and farming practices for a research project looking at farmer cropping systems, decision making, interaction and information sharing, energy needs and challenges, knowledge and perception of bamboo agroforestry for food production and energy needs in the dry semi-deciduous forest zone***.

This research is conducted by a doctoral student at the Center for Development Research (ZEF), University of Bonn, Germany in collaboration with BiomassWeb/ International Network for Bamboo and Rattan (INBAR)

This consent form may contain words that you do not understand. Please ask me to stop as we go through the information and I will take the time to explain. If you have questions later, you can ask me or another researcher of the team.

Aim of the study

The study examines ***the possibilities of introducing bamboo agroforestry into farming systems in Ghana.***
The study aims to better understand ***the preliminary socio-ecological contexts and settings of bamboo agroforestry introduction in the dry semi-deciduous forest zone of Ghana***.

Type of Research Intervention

We would like to ask you a set of questions for this study. The type of information we seek include: **Your community, your sources of income/livelihood, farm/land ownership status, tenure arrangement, cropping systems and patterns, number of years of farming, length of your cropping seasons, persons you share information and ideas with, sources of your farming practice information, your decision-making mechanisms, people who influence your farming and cropping decisions, your knowledge on bamboo cultivation and usage, your opinion on bamboo agroforestry in this region and your acceptance or otherwise to incorporate bamboo on your farm.** We value your opinion and there are no wrong answers to the questions we will be asking. We require about **20 minutes of** your time to complete the survey.

Benefits of Participation

There will be no direct benefit to you, but your participation is likely to help us to understand better the social context of bamboo agroforestry in this region. Apart from acknowledging your contribution in sparing time for us in answering the questions, we will also pay some compensation for the loss of your time (in the form of meals for the day in use). There will be no cost to you.

Health and Safety Precaution and commitment!

It is your utmost responsibility to ensure your good health and safety (by eating well and putting on the appropriate protective clothing) especially when this interview involves field (farm) visit. **No injury cost is awarded to participants against the project during the period of the survey!**

Right to refuse or withdraw- (voluntary aspect)

Your participation in this research is completely voluntary. You are free to withdraw your consent and discontinue answering these questions at any time. I will give you an opportunity at the end of the interview/discussion to review your remarks, and you can ask to modify or remove portions of those, if you do not agree with my notes or if I did not understand you correctly.

Confidentiality

This study is conducted anonymously. Your answers will be used only for the purpose of understanding how bamboo agroforestry can be introduced within the farming systems in this region to improve upon agricultural productivity and diversity; and improve the living standards of farmers in this agroecological region. Any information we obtain from you will be kept strictly confidential.

Your participation will be highly appreciated. Your answers will help provide information to use in planning for the introduction of bamboo agroforestry in this region.

CONTACT PERSON:

If you have any questions, you can ask them now or later. If you feel you have been treated unfairly, or you have questions or concerns you may contact:

Name and address of the researcher / doctoral student:

Daniel Akoto Sarfo

Center for Development Research (ZEF)

University of Bonn, Germany

Tel: Ghana: +233(0)244833629; Germany: +49152213347333/+4915733365167

Email: bafsaf7@gmail.com /akoto.sarfo@uenr.edu.gh

INFORMED CONSENT :

The above statement has been read to me orally (or I have read it myself) and its meaning has been explained by the research staff. I agree to take part in this research. I understand that I am free to discontinue participation at any time if I so choose and that the research staff/contact person will answer any questions that arise during the course of the survey.

____Yes, I agree to participate. THEN BEGIN THE INTERVIEW.

____ No, I do not wish to participate. DISCUSSION WITH SUPERVISOR AND THEN TO NEXT HOUSEHOLD/FARMER/FARMER GROUP.

Name of the participant: ____

Signature of Participant: ___________________________________ Date: ______________

REMARK: *2 COPIES TO BE PREPARED, AND ONE COPY WOULD BE GIVEN TO THE PARTICIPANT!*

Signature by the researcher:

Appendix 3: Sample questions for socio-cultural aspects of bamboo agroforestry in Ghana

LOCAL KNOWLEDGE AND SOCIOECONOMIC ASPECTS OF BAMBOO AGROFORESTRY IN GHANA

QUESTIONNAIRE FOR FARMERS

Respondent details

1. Age class 18 – 30 [ ] 31 – 45 [ ] 45 – 60 [ ] Above 60 [ ]

2. Sex Male [ ] Female [ ]

3. Highest level of education

Primary [ ] Secondary [ ] Tertiary [ ] Illiterate [ ]

4. Marital status Single [ ] Married [ ] Divorced [ ] Widowed [ ]

Crop production

5. How long have you been engaged in crop production?

< 1 year [ ] 2 – 5 yrs [ ] 6 – 10 yrs. [ ] > 10 years [ ]

6. What is your primary objective for growing crops?

Wholly subsistence [ ]

Wholly commercial [ ]

Subsistence and commercial with subsistence a priority [ ]

Subsistence and commercial with commercial a priority [ ]

5. Name your top 5 most produced crops in order of preference
……
……
……

8. What influences your preference for a crop?

Duration to maturity [ ] Market value [ ] High demand [ ] Less production inputs [ ] Easiness of establishment [ ] sociocultural reasons [ ]

9. What is your regular cropping method/pattern?

Monocropping [ ] Mixed cropping [ ] Crop rotation [ ] Monoculture [ ]

Intercropping [ ]

10. Assign reasons to your choice of a cropping method in question 9 above

………
………
………

11. Do you consult other people/farmers in your choice of cropping and cropping patterns?

Yes [ ] No [ ]

12. If Yes, who are these?

………..

13.

If No why

………

14 (a). What is your seasonal production target per acre for your most preferred crop (s)?

………
………
………

(b) Is your target regularly met? Yes [ ] No [ ]

15. If yes or no, why?

………
………
………

16. Is soil fertility an issue/problem in your farming system? Yes [ ] No [ ]

17. How do you detect fertility loss or gain?

………
………
………

18. (a) Do you have access to fertilizer Yes [ ] No [ ]

(b) If yes which fertilizers?

………
………
………

(c) If no, how do you maintain soil fertility?

………
………

Livestock production

19. Do you rear livestock? Yes [ ] No [ ]

20. If yes, which livestock do you rear?

Poultry [ ] Goats [ ] Cattle [ ] Sheep [ ] Pig [ ]

Other (rabbits, grasscutter) [ ]

21. What is your primary objective for keeping livestock?

Wholly subsistence [ ]

Wholly commercial [ ]

Subsistence and commercial with subsistence a priority [ ]

Subsistence and commercial with commercial a priority [ ]

22. Under what production system do you keep your animals?

Intensive system [ ] Extensive [ ] Semi-intensive [ ]

23. If intensive or semi-intensive, what feed or feed supplements do you give your animals?

………
………

24. If extensive, what herbs do you see them browsing?

………
………

25. Do you have any problems with accessibility to the feed? Yes [ ] No [ ]

26. If yes what? Unavailability [ ] Cost [ ] Collection [ ]

Other [ ], specify ……

27. Do you know or have you heard bamboo leaves can be used as fodder? Yes [ ] No [ ]

28. If Yes where is your source of information?

………
………

29. If your answer to question 27 is Yes, have you ever fed your livestock with bamboo fodder before?

Yes [ ]   No [ ]

a.If Yes, what difference did you observe with the use of bamboo fodder from the use of other traditional fodder?

………
………

b. If No are you ready to try bamboo fodder on your livestock? Yes [ ] No [ ] If yes how would you try it?

………
………

30. Are you prepared to incorporate bamboo cultivation on your farm to be used as fodder? Yes [ ] No [ ]

If Yes, why?

………

Bamboo use, challenges and integration into cropping systems

31. Have you seen or heard anything about bamboo before? (asked with a sample at hand) Yes [ ] No [ ]

32. If seen, where?

………

33. If heard, what?

………
………

34. Have you personally used or seen someone using the plant for anything?

Yes [ ]   No [ ]

35. If yes, identify uses bamboo has been put to?

………
………
………

36. Are there any taboos or beliefs associated with the production or use of bamboo? Yes [ ] No [ ]

a. If Yes, What are they?

………
………
………

37. Do you know charcoal can be produced from bamboo? Yes [ ] No [ ]

38. If yes, have you produced charcoal from bamboo before? Yes [ ] No [ ]

a. If yes, when and for how long?

………

39. If yes to question 38, where did you get the bamboo for your charcoal?

………
………

40. If yes to question 38, how do you compare bamboo charcoal quality to those produced from other trees/shrubs?

………
………
………

41. If no to question 38, would you want to try producing charcoal from bamboo Yes [ ] No [ ]

42. If yes, how will you get the bamboo for your charcoal?

………

43. Have you personally planted bamboo before? Yes [ ] No [ ]

44. If yes, where did you get the planting materials?

………

45. If yes to question 43, can you tell any challenges associated with planting bamboo?

………

46. Rank the challenges listed in question 44 above starting from the greatest challenge to the least

………
………

47. Do you keep trees/shrubs on your farm? Yes [ ] No [ ]

48. If yes or no, why?

………

49. Will you plant bamboo on your farm? Yes [ ] No [ ]

50. If yes or no, why?

………
………

51. Would you get land to plant bamboo if interested? Yes [ ] No [ ]

52. If yes, from where?

……
……

52. Have you used bamboo leaves to feed livestock before Yes [ ] No [ ]

53. If yes, when and for how long?

……
……

54 (a). Do you have access to labour? Yes [ ] No [ ]

(b) If yes, what is your source of labour?

……
……

(c) If no, what are the challenges of getting labour?

……
……
……

Appendix 4: Questionnaire for general households and charcoal producers

Respondent details

1. Age class 18 – 30 [ ] 31 – 45 [ ] 45 – 60 [ ] Above 60 [ ]

2. Sex Male [ ] Female [ ]

3. Highest level of education Primary [ ] Secondary [ ] Tertiary [ ] Illiterate [ ]

4. Marital status Single [ ] Married [ ] Divorced [ ] Widowed [ ]

Energy needs and sources

5. What type of energy generating material do you use for your daily domestic life?

LPG [ ] Charcoal [ ] Firewood [ ]

6. What is your monthly [ ] annual [ ] consumption in ……………. bags / …………..kg

7. What purpose(s) do you use the energy for? Wholly subsistence [ ] wholly commercial [ ] Subsistence and commercial with subsistence a priority [ ] Subsistence and commercial with commercial a priority [ ]

8. What/where are your sources of the energy? Government aid [ ] Collection from the natural [ ]

Collection from private farm/woodlots [ ] collection from community woodlots [ ]

9. How often do you access this energy provision?

………

10. What challenges do you encounter

a. accessing the energy source?

………
………
………

b. using this energy?

………
………
………

Charcoal production

11. Do you produce charcoal? Yes [ ] No [ ]

12. If yes, what is your primary objective for producing charcoal?

Wholly subsistence [ ] wholly commercial [ ] Subsistence and commercial with subsistence a priority [ ]

Subsistence and commercial with commercial a priority [ ]

13. Name your top 5 most preferred charcoal feedstock

……
……
……

14. Where do you source for feedstock for charcoal production?

Natural forest [ ] Farmland [ ] Woodlot plantation [ ]

15. Identify any problems/constraints associated with the use of the feedstock mentioned in question 13

……
……

16. How many bags of charcoal do you produce a year?

Less than 5 [ ] 5 – 9 [ ] 10 – 15 [ ] 16 – 20 [ ] more than 20 but less than 50 [ ]

50 – 100 [ ] more than 100 [ ]

17. Do you meet your target regularly? Yes [ ] No [ ]

18. If yes or no why?

……
……

Bamboo use, challenges and integration into cropping/farming systems

19. Have you seen or heard anything about bamboo before? (asked with a sample at hand)

Yes [ ] No [ ]

20. If seen, where?

……

21. If heard, what?

……
……

22. Have you personally used or seen someone using the plant for anything?

Yes [ ]   No [ ]

23. If yes identify uses bamboo has been put to?

……
……
……

24. Are there any taboos or beliefs associated with the production or use of bamboo? ……

25. Do you know charcoal can be produced from bamboo?   Yes [ ]   No [ ]

26. If yes, have you produced charcoal from bamboo before?   Yes [ ]   No [ ]

27. If yes, when and for how long?

……

28. If yes to question 26, where did you get the bamboo for your charcoal?

……
……

29. If yes to question 26, how do you compare bamboo charcoal quality to those produced from other trees/shrubs?

……
……
……

30. If no to question 26, would you want to try producing charcoal from bamboo   Yes [ ]
No [ ]

31. If yes, how will you get the bamboo for your charcoal?

……

32. Have you personally planted bamboo before?   Yes [ ]   No [ ]

33. If yes, where did you get the planting materials?

……

34. If yes to question 32, can you tell any challenges associated with planting bamboo?

……

35. Rank the challenges listed in question 34 above starting from the greatest challenge to the least

………
………

36. Do you keep trees/shrubs on your farm? Yes [ ] No [ ]

37. If yes or no, why?

………

38. Will you plant bamboo on your farm? Yes [ ] No [ ]

39. If yes or no, why?

………
………

40. Would you get land to plant bamboo if interested? Yes [ ] No [ ]

41. If yes, from where?

………
………

42. Have you used bamboo leaves to feed livestock before Yes [ ] No [ ]

43. If yes, when and for how long?

………
………

44 (a). Do you have access to labour? Yes [ ] No [ ]

(b) If yes, what is your source of labour?

………
………

(c) If no, what are the challenges of getting labour?

………
………
………

Appendix 5: Questionnaire for the Forestry Commission

Respondent details:

Name:

Current position:

Years of experience:

Level of education:

Sex:

Section A: Charcoal governance

1. Is charcoal production formalized in Ghana? Yes [ ] No [ ]

2. If no what are the barriers to formalizing charcoal production?

………
………
………

3. What tree/shrub species are normally used in charcoal production?

………
………
………

4. Where do the charcoal producers source the species mentioned above?

Natural forest [ ] Farmland [ ] Woodlot plantation [ ]

5. On a scale of 1 to 5 where 1 is the least and 5 is the greatest, how do you assess the dependence of charcoal producers on the forest for wood fuel? 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5 [ ]

6. From your assessment above, does charcoal production pose threats to biodiversity conservation?

Yes [ ] No [ ]

7. If yes, what provision (in relation to alternatives of sourcing wood) does the forestry sector make to curtail the dependence on the forest?

………
………
………

8. Are there any institutional policies that govern charcoal production in Ghana?

Yes [ ] No [ ]

9. If yes, which areas does the policy cover?

……
……
……

10. If no, is it something worth considering or already underway? Yes [ ] No [ ]

11. Do charcoal producers have license on annual allowable cut of tree they can fell from the forest?

Yes [ ] specify…………………………………………………………………. No [ ]

Section B: Bamboo cultivation and land tenure issues

12. Are bamboos deliberately planted in Ghana? Yes [ ] No [ ]
No idea [ ]

13. Does the forestry sector have any bamboo plantations? Yes [ ] No [ ]

14. Whether yes or no, please explain why?

……
……
……

15. Do you know charcoal can be produced from bamboo? Yes [ ] No [ ]

16. If yes which areas in Ghana is that prevalent?

……
……
……

17. If no, does the forestry sector see any potential in that? Yes [ ] No [ ]

18. If yes, explain whether or not bamboo cultivation is likely to face any land tenure issues.

……
……
……
……

Appendix 6: Questionnaire for the energy commission

Respondent details:

Name:

Current position:

Years of experience:

Level of education:

Sex:

Section A: Rural household/domestic energy policy provisions in Ghana

1. Is rural household energy policy formalized in Ghana? Yes [ ] No [ ]

2. a. If yes what are the provisions for improved and sustainable domestic energy?

……
……
……

b. If no what are the barriers

……
……
……

1. What are the future policy provisions and projections for rural household energy in Ghana?

……
……
……

4. Which part of the energy policy in Ghana encourages/incentivizes the use of alternative sources of domestic energy?

……
……
……

5. What are some of the identified potential domestic energy sources?

……
……
……

5. Is the commission aware of the potential use of bamboo for energy (charcoal/firewood)?
Yes [ ] No [ ]

7. If yes, what provision (in relation to alternative sources of energy) does the commission make to harness the use of bamboo for domestic energy?

………
………
………

6. If No, will the commission consider exploring bamboo as potential domestic energy source?

………
………
………

7. Is there any institutional policy that governs charcoal production in Ghana?

Yes [ ] No [ ]

8. If yes, which areas does the policy cover?

………
………
………

10. If no, is it something worth considering or already underway? Yes [ ] No [ ]

11. Do charcoal producers have license on annual allowable cut of tree they can fell from the forest?

Yes [ ] specify………………………………………………………………… No [ ]

Section B: Bamboo cultivation and land tenure and political constraints

12. Are bamboos deliberately planted in Ghana? Yes [ ] No [ ]
No idea [ ]

13. What are the policy incentives for the cultivation and use of bamboo for charcoal production?
………
………
………

14. Please can you explain whether or not bamboo cultivation and its subsequent use as energy source is likely to face any land tenure and political challenges?

………
………
………

Appendix 7: Questionnaire for Ministry of Food and Agriculture (MoFA)

Respondent details:

Name:

Current position:

Years of experience:

Level of education:

Sex:

Section A: Agricultural production and cropping systems

1. What is the general agricultural productivity in Ghana?
……
……
……

2. What are some of the agricultural interventions to enhance farmer productivity?

……
……
……

3. Is intercropping an option for improved agricultural productivity? Yes [ ] No [ ]

4. If Yes what are the intercropping systems practiced in this region?

……
……
……

5. If Yes to Q4, is there a need for improvement or alternative to these intercropping systems?
Yes [ ] No [ ]

Agroforestry

6. Is agroforestry a priority (option) of intercropping of MoFA? Yes [ ] No [ ],
If No, Why?

……
……
……

7. If Yes, to what extent and at what level (District/Regional) is agroforestry practiced by MoFA?

……
……
……

8. What are some of the woody perennials used in agroforestry practices in this region?

………
………
………

9. If yes, what provision (in relation to alternatives of intercropping component combinations) does MoFA make to curtail large clearance of forest (as in slash-and-burn) in agricultural production?

………
………
………

10. Is there any institutional policy that governs/supports agroforestry in Ghana?

Section B: Bamboo cultivation, cropping systems, bamboo agroforestry and land tenure issues

11. Are bamboos deliberately planted in Ghana? Yes [ ] No [ ]
No idea [ ]

12. Is MoFA aware of the agronomic potentials of bamboo? Yes [ ] No [ ]
No idea [ ]

13. Will MoFA explore and recommend bamboo agroforestry in this region? Yes [ ] No [ ]

14. Whether yes or no, please explain why?

………
………
………

15. Is there any institutional policy that governs/supports bamboo agroforestry in Ghana?

Yes [ ] No [ ]

a. If No, what are the barriers?

………
………
………

b. If Yes, what are the provisions and incentives?

………
………
………

16. Do you foresee a feasible integration of bamboo into farming systems? Yes [ ] No [ ]

17. If No, why? Please give reasons

………
………

18. If yes, why? Please give reasons

……
……
……

19. Which areas in this region is bamboo agroforestry potentially feasible and why?

……
……
……

20. From your assessment, does bamboo agroforestry pose threats to biodiversity conservation?

Yes [ ] No [ ]

21. Please, explain whether or not bamboo cultivation is likely to face any land tenure issues.

……
……
……

22. What other socioeconomic and cultural constraints do you foresee to befall bamboo agroforestry in this region?

……
……
……

Appendix 8: Questionnaire for District Assemblies

NAME OF ASSEMBLY:

Respondent details:

Name:

Current position:

Years of experience:

Level of education:

Sex:

Section A: District development planning

1. Does the District have a current strategic development plan? Yes [ ] No [ ]

a. If no, why (barriers)?

………
………
………

b. If yes, what are the key components of the plan?

………
………
………

2. What are your revenue generation sectors (education, sanitation, environment, agriculture, forestry, artisanory, service, fisheries, water etc.)? others (specify)

………
………
………

3. Please rank the above components in order of contribution to District development starting with highest

………
………
………

4. What are the contributions of **agriculture** and **forestry** (in %) to the total District revenue/development?

………
………

5. In your own opinion, what challenges do these sectors face in the District?

………
………
………

6. What other potentials do you foresee from these sectors?

………
………
………

7. What plans/programmes does the District have towards improving these sectors?

………
………
………

Section B: Agroforestry Practice

8. Is agroforestry practiced in the District? Yes [ ] No [ ]

a. If no, why (reasons)

………
………
………

b. If yes, what are the technologies and for how long have they been in practice?

………
………
………

c. If yes, what are some of the contributions of agroforestry to the District development?

………
………
………

9. What are the most common tree/shrub species used in agroforestry in the District?

………
………
………

10. What are some of the reported or known challenges associated with the use of such species in agroforestry in the District?

………
………
………

11. What are the general challenges facing the practice of agroforestry in the District?

………
………
………

12. How is the District helping address these challenges?

………
………
………

Section C: Tree Cover situation

13. What is the current tree cover (% of land area) in the District?

………

a. What is the state of tree cover? Dwindling [ ] Increasing [ ] No Idea [ ]

b. What has contributed to the tree cover situation in 13 a above?

………
………
………

14. What is the District doing to improve the tree cover situation in the District?

………
………
………

15. Are there bye-laws of the District to improve tree cover in the District? Yes [ ] No [ ]

Section D: Bamboo cultivation and use

16. Do you know or have heard/seen of bamboo before? (asked with sample at hand) Yes [ ] No [ ]

a. If yes, how did you know/see/hear about bamboo?

………
………
………

17. Do you have bamboo growing naturally in the District? Yes [ ] No [ ]

a. If yes, where are they located?

………

b. What is the status of the natural bamboo in the district?

……
……

18. What are the common uses of bamboo in the District?

……
……
……

19. Have you heard or do you know some socioeconomic benefits of bamboo to other societies anywhere? Yes [ ] No [ ].

a. If yes, where and what are some of these benefits?

……
……
……

20. Is bamboo deliberately cultivated in the District? Yes [ ] No [ ]

a. If no, why?

……

b. If yes, where are they cultivated and what is the state?

……
……
……

21. If bamboo is not cultivated, is the District considering encouraging bamboo cultivation?

Yes [ ] No [ ]

a. If yes, by who?
Farmers [ ] Cooperatives [ ] The Assembly [ ] Forestry Commission [ ] Private sector [ ]

b. If no, why?

……

22. Are there District bye-laws to encourage/support bamboo cultivation in the District?

Yes [ ] No [ ]

a. If yes, what are the provisions?

……
……
……

b. If no, why?

……

23. If there are no bye-laws, would the district develop one to encourage bamboo cultivation?

Yes [ ] No [ ]

a. If yes, what areas will be covered?

……
……
……

b. If no, why (reasons)?

……
……
……

Section E: Charcoal Production

24. Is charcoal production a major revenue sector in the district? Yes [ ] No [ ]

a. If yes, what is the production rate in the district?

………………………………………………………………………………………….

25. What is the labour force of this sector?

……

26. What challenges does charcoal production in the district face?
……
……
……

27. What are the feedstock for the charcoal production? Trees/shrubs [ ] Agricultural residues [ ] others (specify) ……..

28. Where are the sources of these feedstock? Natural forests [ ] Farmlands [ ] Community plantations [ ] others (specify)

…….

29. How sustainable are the feedstock from the sources?

……
……
……

30. What are some of the environmental problems associated with charcoal production in the district?
………
………
………

31. How is the district addressing or intending to address such problems?

………
………
………
……………

Section F: Bamboo cultivation and Charcoal Production

32. Is the district aware that charcoal can be produced from bamboo? Yes [ ] No [ ]

a. If yes, where have you seen such production in Ghana or elsewhere before?

………
………
………
……………

33. How does the district see the potential of bamboo for charcoal production?
………
………
………
……………

34. Is bamboo cultivation for charcoal production a potential socioeconomic development option/priority for the district? Yes [ ] No [ ]

a. If yes or no why?

………
………
………
……………

35. What challenges (land tenure, political, environmental, social, cultural etc.) do you foresee to face the cultivation of bamboo for charcoal production?
………
………
………
……………

36. How ready and positioned is the district to address the challenges listed in question 37?
………
………
………
……………

37. What benefits does the district perceive to obtain from bamboo cultivation for charcoal production?

………
………
………
………………

38. What benefits does the district perceive to obtain from bamboo cultivation on farmlands in the district?

………
………
………
………………

Appendix 9: Questionnaire for bamboo fodder trial

(*Purposely designed for farmers actively engaged in ruminant production – goat, sheep or cattle in a bamboo dominant location***)**

Key research questions:

(1) What are farmers' perceptions about bamboo use as fodder for livestock?
(2) How do the determinants of fodder choice/preference among farmers inform the adoption potential of bamboo as a feed source?

QUESTIONNAIRE CODE: [_ _ _]

A. DEMOGRAPHY OF RESPONDENTS

A.1 Age class 18 – 30 **[ ]** 31 – 45 **[ ]** 45 – 60 **[ ]** Above 60 **[ ]**

A.2 Gender Male **[ ]** Female **[ ]**

A.3 Highest level of education Primary **[ ]** Secondary **[ ]** Tertiary **[ ]** Illiterate **[ ]**

A.4 Marital status Single **[ ]** Married **[ ]** Divorced **[ ]** Widowed **[ ]**

A.5 Number of dependents 0 **[ ]** 1-3 **[ ]** 4-6 **[ ]** ≥ 10 **[ ]**

A.6 Religion Christian **[ ]** Islam **[ ]** Traditional **[ ]** Other **[ ]**

A.7 Tribe/ethnicity ……………………..

A.8 Land size > 1 **[ ]** 1 – 3 **[ ]** 4 – 6 **[ ]** 7 – 10 **[ ]** < 10 **[ ]**

A.9 Land ownership Owned **[ ]** Hired **[ ]** Family **[ ]**

B. LIVESTOCK PRODUCTION SYSTEM

B.1 Which of the following animals do you rear? Goat **[ ]** Sheep **[ ]** Cattle **[ ]**

B.2 Where multiple choices are made in B.1, ask farmers to arrange in order of preference

……
…

B.3 What is the reason behind your choice in B.1 above?

Economic **[ ]**. *Explain further indicating whether by high demand, low production cost or high profitability*

………
………
………
………………

Sociocultural **[ ]**. *Explain whether it's by tribal reasons, local knowledge, based on belief systems or consumption preference*

……
……
……
………………

Technical know-how **[ ]**. *Explain whether it's by experience or advance knowledge*

……
……
……
………………

Animal physiology **[   ]**. *Explain whether it's by the reproductive biology of animals, easiness of management, adaptation to environmental stress and vulnerability to diseases*

……
……
……
………………

Other **[ ]**. *Specify*

……
……
……
………………

B.4 How long have you been engaged in livestock production?

< 1 year **[ ]** 1 – 5 **[ ]** 6 – 10 **[ ]** more than 10 years **[ ]**

B.5 What is the size of your animals (in terms of numbers)? *Answer where applicable*

Goat < 10 **[ ]** 11 – 20 **[ ]** 21 – 30 **[ ]** 31 – 40 **[ ]** 41 – 50 **[ ]** 51 – 100 **[ ]** > 100 **[ ]**

Sheep < 10 **[ ]** 11 – 20 **[ ]** 21 – 30 **[ ]** 31 – 40 **[ ]** 41 – 50 **[ ]** 51 – 100 **[ ]** > 100 **[ ]**

Cattle < 10 **[ ]** 11 – 20 **[ ]** 21 – 30 **[ ]** 31 – 40 **[ ]** 41 – 50 **[ ]** 51 – 100 **[ ]** > 100 **[ ]**

B.6 Identify your livestock production objective

Wholly subsistence **[ ]**

Wholly commercial **[ ]**

Subsistence and Commercial with subsistence a first priority **[ ]**

Subsistence and Commercial with commercial a first priority **[ ]**

B.7 How do you keep the animals?

Free range **[ ]**. *Provide brief description*

……
……
……
……………

Intensive **[ ]**. *Provide brief description*

……
……
……
……………

Semi-intensive **[ ]**. *Provide brief description*

……
……
……
……………

B.8 If free-range in B.6, what do you normally see the animals browsing?

……
……
……
……………

B.9 If intensive in B.6, what feed do you give the animals?

……
……
……
……………

B.10 If Semi-intensive in B.6 what supplementary feed do you give to the animals?

……
……
……
……………

B.11 Provide feeding challenges where applicable to the following **[***must correspond to choose in B.7***]**

Free range

……
……

………
………………

Intensive

………
………
………
………………

Semi-intensive

………
………
………
………………

B.12 Name some tree/shrub species you know are fodder sources for livestock production in the area

[*local and/or scientific names are fine***]**

SN	Local name	Scientific name	Farmer to rank in order of preference (from 1 to 5 where 1 is most preferred and 5 is least preferred). Where farmers are able to identify 5 or more species, they can pick a minimum of 5 species and rank them from the list. They should rank all species if list is less than 5.
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

B.13 How did you know about the fodder species in B.12 above?

Heard someone talked about it **[ ]** Saw someone fed to animals **[ ]**

From personal experience **[ ]** Other **[ ]**. If other, explain

……
……
……
……………

B.14 Have you planned to feed or ever fed livestock with any of the above fodder species before?
Yes **[ ]** No **[ ]**

B.15 If yes to B.14, which of the trees/shrubs mentioned did you plan to feed or have you fed to livestock before? Also indicate the edible part of this tree.

……
……
……
……………B.16 To which livestock was the fodder in B.14 fed or planned to be fed?

Goat **[ ]** Sheep **[ ]**Cattle **[ ]**

B.17 Why feed the animal with the fodder mentioned in B.15

Nutritious [ ] Available [ ] Animal preference [ ] Local practice [ ]

No/low cost [ ]

B.18 Do you get required quantities of the fodder in B.14 all year round? Yes **[ ]** No **[ ]**

B.19 If no, when is it mostly abundant? Wet season **[ ]** Dry season **[ ]**

EVIDENCE OF INTEGRATED LIVESTOCK PRODUCTION SYSTEMS

C.1 Do you grow crops alongside with keeping livestock? Yes **[ ]** No **[ ]**

C.2 If yes to C.1, which crops?

……
……
……
……………C.3 If yes to C.1 what is your crop production objective?

Wholly subsistence **[ ]**

Wholly commercial **[ ]**

Subsistence and Commercial with subsistence a first priority **[ ]**

Subsistence and Commercial with commercial a first priority **[ ]**

C.4 Do you feed your livestock with any crop residues? Yes **[ ]** No **[ ]**

C.5 If yes to C.4 residues from which crops? Describe the residues (e.g. cobs, husk, grain etc.)

………
………
………
………………

C.6 Do you grow or keep trees/shrubs on your farm? Yes **[ ]** No **[ ]**

C.7 If yes to C.6, which trees/shrubs?

………
………
………
………………

C.8 If yes to C.6, what is your reason for keeping or growing the trees/shrubs?

………
………
………
………………

D. PERCEPTION OF BAMBOO USE AS FODDER FOR LIVESTOCK (Prior to feeding trial)

D.1 Do you know about bamboo (ask with a sample of leaves or culm in hand)? Yes [ ] No [ ]

(NB: If response to D.1 is No, questionnaire ends here) – proceed with introducing respondent to bamboo.

D.2 If yes to D.1, what do you know about bamboo

………
………
………
………………

D.3 What have you ever used bamboo for?

………
………
………
………………

D.4 Do you know bamboo can be used as fodder for livestock? Yes [ ] No [ ]

D.5 If yes to D.4, how did you know?

Heard about it [ ] Read about it [ ] Saw someone fed to animals [ ]

Personally fed animal with bamboo [ ]

D.6 Have you seen any animal browsing on bamboo before? Yes [ ] No [ ]

D.7 If yes to D.6, which animal did you see browsing on the bamboo?

……….

D.8 If yes to D.6, which part of bamboo was the animal eating?

Green leaves [ ] Dried leaves [ ] Culm/stem [ ] Roots [ ]

D.9 Have you planned to feed, ever fed or seen someone feeding livestock with bamboo before?

Yes **[ ]** No **[ ]**

D.10 If yes to D.9, which part of bamboo did you plan to feed, ever fed or seen someone feeding livestock with?

Green leaves [ ] Dried leaves [ ] Culm/stem [ ] Roots [ ]

D.11 To which livestock did you plan, ever fed or seen someone feeding with bamboo?

Goat **[ ]** Sheep **[ ]** Cattle **[ ]**

D.12 Why feed the animal with bamboo?

Nutritious [ ] Available [ ] Animal preference [ ] Local practice [ ] No/low cost [ ]

Other [ ]. Please explain.

………
………
………
……………………..…

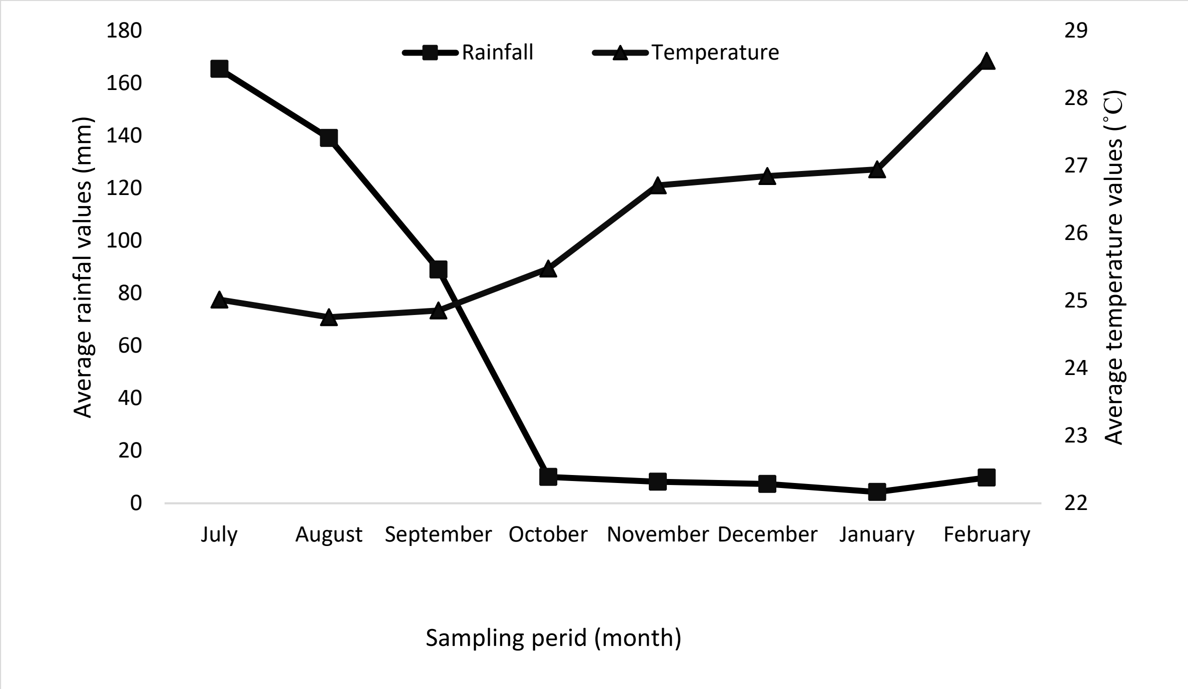
D.13 If you feed livestock with bamboo, do you get required quantities of the fodder all year round?

Yes **[ ]** No **[ ]**

D.14 If no, when is it mostly abundant? Wet season **[ ]** Dry season **[ ]**

D.15 Are you willing to feed livestock with bamboo leaves if tested to be good for them Yes **[ ]** No **[ ]**

Appendix 10: Mean monthly temperature and rainfall recordings during the decomposition study period



Appendix 11: Correlation coefficient between rate of mass loss of agroforestry species leaf litter, temperature and rainfall

Species	Temperature	Rainfall
S. siamea	r= 0.802	r= 0.106
B. balcooa	r= 0.722	r= 0.396
B. vulgaris	r= 0.552	r= 0.248
A. lebbeck	r= 0.692	r= 0.136
O. abyssinica	r= 0.831	r= 0.267
L. leucocephala	r= 0.738	r= 0.177
G. sepium	r= 0.712	r= 0.119
E. grandis	r= 0.915	r= 0.159

Appendix 12: List of common species used in the study and their authors

No.	Taxon name	Family	Author
1	*Albizia lebbeck*	Fabaceae	(L.) Benth
2	*Leucaena leucocephala*	Fabaceae	(Lam.) de Wit
3	*Gliricidia sepium*	Fabaceae	(Jacq.) Steud.
4	*Senna siamea*	Fabaceae	H. S. Irwin and Barneby
5	*Oxytenanthera abyssinica*	Poaceae	(A. Rich.) Munro
6	*Bambusa vulgaris*	Poaceae	Schrad. Ex J. C. Wendl.
7	*Bambusa balcooa*	Poaceae	Roxb
8	*Eucalyptus grandis*	Myrtaceae	W. Hill
9	*Albizia adianthifolia*	Fabaceae	(Schumach.) W. F.
10	*Ceiba pentandra*	Malvaceae	(L.) Gaertn
11	*Milicia excelsa*	Moraceae	(Welw.) C. C. Berg
12	*Terminalia superba*	Combretaceae	Engl. And Diels
13	*Triplochiton scleroxylon*	Malvaceae	K. Schum
14	*Anogeissus leiocarpa*	Combretaceae	(DC) Guill. And Perr.
15	*Bambusa blumeana*	Poaceae	Schult. And Schult
16	*Dendrocalamus hamiltonii*	Poaceae	Gamble
17	*Daniellia oliveri*	Fabaceae	(Rolfe) Hutch. And Dalziel
18	*Antiaris africana*	Moraceae	(Engl.) C. C. Berg
19	*Millettia thonningii*	Fabaceae	(Schumach.) Baker
20	*Gmelina arborea*	Lamiaceae	Roxb