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Agroforestry as an Essential Tool for Sustainable Farming Systems: Cacao (*Theobroma Cacao*)

Charles F. King, Jr.

Central Agricultural Research Institute, Liberia.

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ABSTRACT

The conversion of nature forest into cacao landscape is a driver of deforestation. Biodiversity losses, greenhouse gases emission intensification, soil water pollution, depletion of soil nutrients, degradation of the environment and constraint to income diversification are triggers by forest conversion. With this concern, an observation and research articles revision were done in USA, Liberia and Costa Rica to determine a sustainable farming methods in mitigating the effects of natural forest conversation to cocoa landscape. The results indicated that ecological, economic and social dimensions of such sustainable method known as agroforestry differs on land ownership, road connectivity, extension services, access to finance, availability of research, access to market and the rule of law . These differing parameters showed that the adoptions of agroforestry for sustainability tool for Liberia in the cocoa sector is challenging due to shifting cultivation of farming system, lack of proper data record/collection, extension services, expertise in agricultural research. But smallholder land ownership, tropical rainforest, kuu systems and farming cooperative are opportunities. Meanwhile, Costa Rica has the opportunities because of the availability of expertise in agricultural research and better value chain. The challenges exist are land ownership for smallholder in the cocoa landscape and an effective agricultural cooperatives. Adaption for agroforestry in Missouri, USA is constraint due to mechanize and plantation farming systems but technology, advance extension services, farming loan and access to market are opportunities. However, because of the opportunities, cacao agroforestry should be considered as a sustainable tool for sustainability of farming system.

Corresponding Author: Charles F. King, Jr.

KEYWORDS: Biodiversity, social-economic, Ecology, cacao-agroforestry, full-sun

1.0. INTRODUCTION

Cacao (*Theobroma cacao*) is a shade-dependent plant traditionally cultivated under a mix of multi-strata species yielding multiple products (Esmail and Obelbermann, 2011, Obeng and Aguilar, 2015 and Saj et al. 2017). Cacao farming is a central component to the livelihoods of an estimated 40-50 million people (Ladearch et al. 2013, Utomo et al. 2016) and its cultivation drives the conversion of natural forest into various farming system with effects on ecosystem services loss in Africa (Asase and Tetteh, 2010).

Global demand for cocoa is projected to increase from 4.1 million in 2016 to 4.7 million tonnes by 2050 according to Abdulai et al. (2018). The expansion and rehabilitation of cacao farms will likely lead to the deforestation and intensification of traditional cacao systems resulting in ecosystem service losses including negative effects on carbon fixation, soil degradation, water quality and wildlife habitat, among many others. Traditional cacao system is a habitual practice done by smallholders in cultivating cacao plant in dense forest for the purpose of shading without slightest concept of farm's income diversification.

However, such impacts can be ameliorated through a sustainable farming system that can preserve critical ecological functions while also offering social and economic improvements to the wellbeing of smallholder farmers. (Adulai et al. 2018, Asase and Tetteh 2016, Brito-Vega et al. 2018, Jagoret et al. 2012, Saj and Jagoret, 2017, Saj et al. 2017). Agroforestry can be defined as an ecologically-based management of natural resources through an integrated approach of tree, livestock, and crops on the same farmland with the intent of supplying social benefit, diversification of income, and environmental preservation (Asase and Tetteh 2016). Agroforestry systems intentionally improve land productivity through soil, tree, crops and livestock interaction.

This paper aims to assess the ecological and economic roles of agroforestry; opportunities and constraints for such system that can be adopted as a tool for sustainable cacao farming. Specific objectives include to (a) assess the role and contribution of cocoa agroforestry on soil fertilization and soil moisture retention in the tropics and temperate; (b) evaluate the role and contribution of biodiversity conservation and carbon sequestration in mitigating climatic change; and (c) evaluate the social and economic impacts of agroforestry system on smallholders’ livelihood and wellbeing.

2.0. REVISION OF ARTICLES

2.1. Cacao Cultivation in West Africa

Traditional cultivation of cacao in smallholder farms is commonly done by clearing native forests and keeping a few trees intercropped with cacao and other cash and sustenance crops commonly referred to as a traditionally agroforestry system (Jagoret et al. 2018 and Margaret and mulder, 2007). Also, a system that intercropped trees like plantain (*Musa sapientum*), guava (*Psidium guajava*), timber arboreal species (*Terminalia ivorensis, Cordia alliodora, Tabebuia rosa*), nitrogen-fixing arboreal species (*Gliricidia spp., Erythrina spp*.), oil palm (*Elaeis guineensis),* rubber (*Hevea brasiliensis*), citrus (*Citrus sinensis*), and mango (*Mangifera indica*) (Franzen and Mulder 2007) is intentional, with the desirable outcome of income diversification and mitigating climate change in cacao farming which is refers to as cacao agroforestry system. The benefits of intercropping include shade, soil nutrient recycling, soil moisture retention, conserving above- and below-ground biodiversity, income diversification and carbon sequestration (Jagoret et al. 2012, Saj and Jagoret 2017, Obeng and Aguilar 2015 and Satyawali et al. 2018).

Monoculture (full-sun) cacao farming is another form of cultivation system adopted by leading cultivation countries (Cote d'ivoire, Ghana, Indonesia, Cameroon, Brazil, Costa Rica). A higher density in monocrop cacao systems offers self-crop shading in the absence of taller shade trees (Graefe et al. 2017 and Tondoh et al. 2015). However, a monocrop system creates greater dependence on synthetic fertilizers and pesticides to compensate for some of the ecosystem services lost (animal, birds, insect, tree species and earthworm) when moving away from an agroforestry or natural forest system.

Studies conducted in Ghana (Asase and Tetteh 2016), Cameroon (Saj and Jagoret 2017), Costa Rica (Gateau-Rey et al. 2018), and India (Satyawali et al. 2018) point emphatically to the capacity of cacao agroforestry systems to improve smallholder farmers’ livelihood through the sustainable supply of ecosystem services and income diversification. For instance, in Cameroon, cacao agroforestry systems showed higher levels of soil organic matter of 3.13% compared with 1.7% in a monoculture system (Jagoret et al. 2012). As noted by Obeng and Aguilar (2015) there is a spectrum found in terms of the density and composition of species and structure. Asase and Tetteh (2016) compared a traditional cacao system cultivated under a dense forest cover with an agroforestry system consisting of food crops including cassava (*Manihot esculenta*), cocoyam (*Colocasia esulenta*), maize (*Zea mays*), and banana (*Musa spp.*), and found a higher nitrogen content in the soil of traditional cacao system.

Cacao farming in an agroforestry system has reportedly helped slow down deforestation and conserve biodiversity and socioeconomic activities in rural communities in Cameroon (Jagoret et al. 2012 and Saj et al. 2017) and Ghana (Asasae and Tetteh 2016). Forest land in West Africa faces major market pressures as it competes with alternative land uses such as the cultivation of cacao but also other commodities including oil palm (*Elaeis guineensis*), plantain (*Musa spp.*), coffee (*Coffea*) and rubber tree (*Hevea brasiliensis*) plantations (Bennett et al. 2018, Ordway et al. 2017, Saj et al. 2017, Saj and Jagoret, 2017). For instance, Sub-Sharan Africa and Southern America had experienced intensive deforestation compared to the rest of the world forest to according to FAO 2015.

The expansion of monocrops comes at the expense of forest covers, hence, directly contributes to biodiversity losses, food insecurity, carbon emissions and environmental degradation (Galway et al. 2018 and Tegegne et al. 2016). Africa, along South/Central Americas, continues to have some of the highest rates of deforestation due to the farming system, logging activities and conversion of natural forest (FAO, 2015). Following conversion, new land cover lacks the species composition, structure and nutrient cycling of natural systems. Consequential effects include the deterioration of biodiversity not only above- but also below-ground reported by Sanadaria et al. (2014) regarding a decline in earthworm populations. In the long run, a declining earthworm population can contribute to degraded soil structure and thereby diminish nutrient recycling, and site productivity (Sanadaria et al. 2014).

According to Saj et al. (2017), cacao cultivation in Sub-Saharan Africa is among the drivers of deforestation. Some of the mechanisms for deforestation include land-sparing used for cacao rehabilitation and expansion. Land-sparing involves the intensification of cacao farming in monocrop systems. Secondly, land-sharing is known as an agroforestry-based system that slows down deforestation but still contributes to land use changes. A study conducted in Côte d’Ivoire on full-sun cacao plantation indicated that the conversion of forest to agricultural land used resulted to agro-ecological consequences: degradation of the forest, loss of biodiversity and disruption of the soil quality which leads to low crop yield, food insecurity and greenhouse gas emissions effect (Tondoh et al. 2015). Tondoh et al. 2015 assessed ecological role in full-sun cacao cultivation practiced which showed biodiversity loss in both above (ant population) and below-ground (microbes’ organism-earthworm population), soil fertility depletion and soil quality degradation compared to cacao agroforestry system.

Vast et al. (2016) and Jagoret et al. (2011) suggest that cacao agroforestry has drastically prolonged the productive life longevity of cacao plantations up to 60 years as compared with monocultures that may be re-established every 20-30 years. Shade trees play a critical role in cacao agroforestry systems by contributing to various ecological functions. Studies such as those of Vaast et al. (2016) highlight the role trees have in reducing thermal and water stress for cacao compared to the fun-sun system. The ecological role also significantly reduced and affected the soil and air temperature around cacao and coffee by 2-5 °C in cacao intercropping system contrary to monoculture system. And shade trees can increase ambient humidity which resulted in higher levels of soil moisture content (Linet al. 2008, Siles et al. 2010, and Vaast et al. 2016). In spite of the essential roles of trees in a cacao agroforestry system, they may compete with cacao for soil moisture in prolong drought period (Cannava 2011). The canopy of shade trees intercepts 5-15% of rainfall helping reduce soil erosion (Vaast et al. 2016).

3.0. METHODS AND APPROACH

1. Research area and Duration: The research area was in the University of Missouri, USA, Central Agricultural Research Institute, Liberia and Earth University, San Jose, Costa Rica through the Borlaugh fellowship for young researcher from Africa sponsored by the USDA. The Duration of the research was for four (4) months.
2. A field visit to farms, meeting and talking to cooperative members, farming kuu groups and an intensive Literature review of articles, reports of Agroforestry and cocoa agroforestry.

4.0. RESULT AND DISCUSSION

4.1. The Ecological Role in Cacao Agroforestry Systems

In agroforestry system, arable crops and integrated trees had significantly minimized human activities over the years in balancing the natural greenhouse gases in the atmosphere (Läderach et al. 2013, Magne et al. 2014, Sharma et al. 2015, Wade et al. 2010). Greenhouse gas emissions and concentrations in the atmosphere have been altered due to fossil fuel burning and massive deforestation of natural forest which have had consequential impacts on smallholders’ cacao yield and ecosystem ranging from loss of biodiversity, soil water pollution (Franzen et al. 2007 and Sharma et al. 2015).

Ecological-based land interventions using trees in farming systems (Wade et al. 2010 and Sharma et al. 2015) can systemically minimize climate change impacts on cacao farming system. Furthermore, the integration of trees on the farm over time had preserved biodiversity and served as a carbon stock sink reported by researchers to be an alternative for natural forest compared to a full-sun production system (Asase and Tetteh 2016, Mbolo et al. 2016, Moser et al. 2010). Biodiversity preservation had altered a habitat for mammals, birds, and insect that connects to the natural forest which had resulted in soil fertilization and hunting ground for smallholder's meat. Additionally, such habitats and the species they support have contributed to as pollinators for cacao and cultural and biological methods of pest control (Esmail and Oelbermann 2011). For instance, a review paper on agroforestry indicated another ecological benefit when trees are integrated into a farming system it serves as a windbreak, a soil water purifier and it's sustainably profitable (Zamora and Udawatta, 2016) for a long period of time.

Besides, carbon sequestration is an essential ecological benefit too of cacao agroforestry system and an ideal strategy for combating global warming in the temperate and tropics (Asase and Tetteh, 2016; Mbolo et al., 2016; Moser et al., 2010; Sharma et al., 2015; Simley and Korschel, 2008; Zamora and Udawatta, 2016). This is done through the process of tree photosynthesis that captures carbon dioxide into cellulose with a consequential role in mitigating greenhouse gases effects (Wade al., 2010; Briton-vega et al., 2018; Somarriba et al., 2018). Evidently, this was demonstrated in a study done in India that showed the integration of trees in an agroforestry system had a greater carbon sequestration level than monoculture (Sharma et al., 2015). Similarly, a studied done by Udawatta and Jose (2012) showed that carbon total stored in a soil and biomass of plants were 5.8 and 8.2 t C ha^{-1} greater in a North American agroforestry system (Douglas fir (*Pseudotsuga menziesii*)–(*Lolium perenne*)/(*Trifolium subterraneum*) silvopasture) than in monoculture pasture or Douglas fir plantation in the temperate region of India.

Moreover, tree diversification on a farm has the potential to enhance the resilience of cacao farming during adverse weather condition- crops failure due to drought, social-cultural crises that lead to family’s land conflict and also an alternative means of chemical fertilizers use (Lasco et al., 2016). Arable crops, animal/pasture and trees integration on the same plot of Land had shown ecological benefits in soil water purification; weed suppression, low level of soil nutrient depletion and serving as a buffer for soil water pollution.

4.2. The Economic Importance of Agroforestry Systems

Over the years, cacao cultivation by smallholders has had an immense contribution in improving the livelihood and the GDP of producing countries (Jagoret et al. 2012 and Saj et al. 2017). For example, in Cameroon, a study was conducted in 21 villages, showed that cacao revenues were their major source of income accounting for one-third of their income (Sonwa et al. 2002). The additional incomes that are generated from medicines tree, timber, fruit, and plantain is a clear understanding of income diversification that had improved the social wellbeing for smallholder's household (Pédelahore 2014, Bisseleua et al. 2009, Franzan et al. 2007 and Nunoo and Owusu, 2017). Researchers and policy-makers have highlighted the economic importance of agroforestry in smallholder’s income diversification, and the challenges that confront such system for adopters. Many cacao farmers in West Africa are cultivating cacao without perceived economic benefits for integrated trees or fruit trees component in agroforestry system for revenue generation which is gear towards sustainability. Nevertheless, recently the economic benefits of integrating tree and animal components have been highlighted and encouraged in reported studies where cacao farmers integrated *Terminalia ivorenesis* for income generating purposes because of its awareness (Asase and Tetteh, 2016 and Cerda et al. 2014, Peprah, 2015 and Somarriba et al. 2014).

Cacao farming is traditionally practiced by a myriad of smallholders in West African because of perceived considerations: securing property right (land ownership), future income, high price (premiere), low labor and family custom. But these considerations have agroforestry economic sense pointing to intercropping of cacao and a fruit tree or plantain, mostly practice in West Africa, on the same piece of plot for temporary shading and supplementary income generation that contributes to household upkeeps (Pédelahore, 2014, Peprah, 2015 and Salazar et al. 2018).

In Ghana, a comparative analysis of the financial stability of agroforestry studies reported that the system is profitable with optimizing ecological benefits in sub-Saharan Africa (Nunoo and Owusu 2017). Oppositely, the same studied outlined that no-shade cacao showed higher yield compared to cacao agroforestry indicating for short possible period and the yield is better but not sustainable in a long period of time like agroforestry system. And its intensification method is detrimental to the ecosystem management.

Also, Land Equivalent Ratio (LER) has been used in the intercropping system to determine the productivity and profitability of land or system under cultivation (Sesermann et al. 2018). Furthermore, using this as an indicator for highlighting the economic considerations of transitioning from agroforestry to monoculture was satisfied in a studied in India where the LER was persistently above its threshold favoring agroforestry efficiency compared to monoculture (Sesermann et al. 2018).

Social-culture and demographic helps understand the economic impacts, and effects of agroforestry adoption in temperate and tropical regions. Comparatively, many farmers in temperate regions have access to market outlooks, source of knowledge, resourceful and liquidated farmer's cooperative can strengthen their economic positions in agroforestry adoption compared to tropical farmers. The economic outlooks and considerations for cacao agroforestry system in the tropics is constraint due to the cost that is incurred during production when additional tree/fruit is incorporated into agroforestry system. Certification for the observance of local cultures and adequate wages is now formally recognized with ‘fair trade’ practices among smallholders in Ghana and Ecuador. These farmers experience sound economic returned on the cacao agroforestry sector (Franzen et al., 2007). Additionally, fair trade has benefited Ecuadorian and Ghanaian cacao farmers by providing them transparency in weighing, availability of market information, higher prices (premiere), capacity building of extension officers and smallholders and directly buying from farmers’ cooperatives (Nelson et al. 2002 and Franzen et al. 2007). Interestingly, corollary benefits associated with fair trade certification among farmer cooperatives include the establishment of credit unions, the building of the school, construction of agricultural inputs store, clinic building and expansion and rehabilitation cacao agroforestry farms all improve smallholders' livelihood (Kumar et al. 2015, Piekielek et al, 2010 and Valentino 2007).

4.3. Comparative analysis of agroforestry systems in temperate and tropical areas

Over the years, Europe, Africa, Asia and part of North and South America have persistently cultivated trees along with arable crops and pasture/animal with the focus of sustainable agriculture production, soil conservation and protection of ecosystem (Somarriba et al. 2014 and Wartenberg et al. 2017)**.** But there have been similar and dissimilar objectives in agroforestry practices and research in temperate and tropical regions. For instance, in temperate agroforestry system, there is a large focus on resource management policies, labor costs, and real estate values, farming technology, alley cropping, silvopasture, integrated systems, windbreaks, forest farming whereas in tropics its focus is on land management practices and landowner self-sustenance (Oelbermann et al. 2004 and Zamora and Udawatta, 2016).

Nevertheless, temperate and tropical agroforestry systems integrate trees as a component that has the ability to restore and re-fertilizer degraded soil; maintain biodiversity, sequestering carbon dioxide emissions as a climate change mitigation strategy. Therefore, knowing that fossil fuel burning is mostly in temperate regions whereas deforestation is intensively in the tropics which contributing to CO_2 emissions, and the need to adopt a counter measure for ecosystem protection is vital. Agroforestry practices in both regions offer an option to ameliorate fossil fuel burning and deforestation effects on the environment (Oelbermann et al. 2001 and Esmail and Oelbermann, 2011)

However, the adoption of agroforestry in both regions presents its own opportunities and challenges for adapters which are highlighted in Table 1. These systematically burden smallholders who are challenged with limited access to resources and often weak to non-existent public policy programs. Agricultural productivity and sustainability are more successful and profitable for smallholders when there is good road connectivity, electricity, access to finance, good road connectivity, availability of research, and availability of a market for integrated crops and rule of law (Acheampon et al. 2018 and Sign-peter and Iranacolaivalu 2018. Most tropical countries like Liberia fall short to their potential to adopt agroforestry systems. Cacao agroforestry in the tropics is an ancient practice and illustrates the potential to adopt other and improved systems due to the fact that cacao. Tropical and temperate agroforestry is unique with the goal of diversifying farmer's income in a sustainable way of farming that will protect the ecosystem and thereby mitigating global warming but with differing adoption challenges and opportunities.

Table 1.0 Comparison of ecological, economic and social dimensions of agroforestry

	Missouri, USA		**Liberia**		**Costa Rica**	
	Challenges	Opportunities	Challenges	Opportunities	Challenges	opportunities
Ecological	• Mechanize farming system • Adoption of Agroforestry Syst. • Agroforestry practice in Urban communities • Smallholder practice Agroforestry	• Available expertise • Extension service • Data/Record services • Conservation of flora & Fauna • No shifting cultivation	• Shifting cultivation • Record/data collection • Expertise • Extension services • Agricultural Research • Deforestation • Conservation flora & fauna	• Tropical Vegetation • Perennial & annual crops • New Technology Adoption • Agroforestry by smallholder	• Land ownership • Intensive farming system	• Expertise • Extension service • Data/Record service • Agroforestry by smallholder • Tree crops cultivation • Access to improved planting materials
Economic	• Expensive labor • Forming comparatives • Labor force (lacking)	• Financial support for Agroforestry Research • Access to farming Loan • Access to market • Postharvest Technology • Cooperative is profitable • Yield potential • Better farmers income • Access to price support or cost-share programs to implement environmentally-friendly land practices	• Poor Farmers • Low yield of Crops • Lack of Adequate market for intercrops • Lack of access to agricultural finance • Lack of access to market roads • Uneducated farmers • Accessing commercial bank loan (high-interest rate)	• Cooperatives formation • Agriculture-competitive advantage • Cheap Labor • Village saving loans • Socially-responsible micro-financing	• Access to credit • Formation of cooperative • Village saving loan • Uneducated farmers •	• Access to market • Road connectivity • Agricultural loan •
Social	• Land ownership	• Small family size		Smallholders own land Traditional land ownership	Small family and lacking of landownership	Good governance

5.0. CONCLUSION

The demand for cacao world-wide is triggering the expansion of farms leading to deforestation and losses in biodiversity, depletion of soil, soil water pollution and greenhouse gas emissions. Cacao agroforestry is a practical response in a safer way and a pathway to be adopted for rehabilitation or expansion of cacao in the threatening climate change scenario in leading producing regions like West Africa. Cacao agroforestry offers unique economic incentives in case of income diversification and longevity of cacao tree or plantation.

Therefore, the below cultivation systems are being recommended for sustainable cacao farming in cultivating countries

- The cultivation of plantain + cacao + Erythrina (nitrogen fixing) and Terminalia ivorensis is a cacao agroforestry system that is needed for diversify of farmer's income and soil fertilization at the same time comforting climate change.
- The system of cultivating cacao + Glylicide sepium + Fruit trees (Mango, Avocado, Citrus) is an essential cacao agroforestry system for diversification of smallholder's income.

With these recommended systems, an extension services can help narrow the knowledge gap and training challenges to farmers' benefit. Introducing a public policy and implementing developmental plans that encompass enhanced road connectivity, research and farmer focus, and environmentally sensitive support the adoption of agroforestry practices in tropical country.

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