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Climate-Smart Conservation Agriculture, Farm Values and Tenure Security: Implications for Climate Change Adaptation and Mitigation in the Congo Basin

Ernest L. Molua[1,6], Denis Sonwa[2], Youssoufa Bele[2], Bernard Foahom[3], Jean Pierre Mate Mweru[4], Salomon Mampeta Wa Bassa[4], Martial Gapia[5], Felix Ngana[5], Assoua Eyong Joe[1,6], and Emile Mulotwa Masumbuko[4]

Abstract

Background and Research Aims: Agriculture through deforestation is an important threat to biodiversity conservation in the Congo Basin's tropical forest. The policy challenge is not only to promote adaptation to perceived climate change but also to promote forest conservation. The aim of this study is to provide empirical evidence on the impact of farm-level investments in climate-smart agricultural practices related to conservation agriculture in some Congo Basin countries. The hypothesis is that property rights to land and trees play a fundamental role in governing the patterns of investment, forestland management for conservation, as well as in the profitability of agriculture. **Methods:** A Simulated Maximum Likelihood Estimation using a Mixed Logit model is used to test farmers' choice of agricultural system and a farmland value model for each agricultural system which includes determinants of tenure or property rights, climate, soils, and socioeconomic variables such as education and gender. The data was collected from more than 600 farms covering 12 regions and 45 divisions in 3 countries, Cameroon, the Central African Republic and the Democratic Republic of Congo. **Results:** Farmers choose one of three agricultural systems to maximize farm profit mindful of the current tenure regime and environmental conditions. Conservation agriculture techniques within climate-smart practices show benefits for smallholder farmers through improvements in soil health, soil moisture retention and enhanced crop yields. The rights to access, withdraw, manage, as well as exclude others from land and trees affect both the farmers' choice of system and the profit earned from the chosen system. **Conclusion:** Farm-level investments improve farm incomes and enhance conservation effort for farmers perceiving climate change. **Implications for Conservation:** Climate change adaptation through planting of trees improves soil stability, restores ecosystems and creates a safe haven for biodiversity. Secure land tenure promotes better forestland management and reduces land degradation in vulnerable communities.

Keywords

Congo basin forests, climate-smart conservation agriculture, farm investments, agroforestry, land access, tenure security

Introduction

The tropics remain- an important area for nature conservancy, biodiversity regeneration and precursor for ecological sustainability (Hoang & Kanemoto, 2021; Mason et al., 2020; FAO, 2019; IPBES, 2019; Maddox, 2018). The Congo Basin which is recognized for its megabiodiversity, specifically is home to about 11,000 species of tropical plants, over 1200 species of birds, 450 mammal species, 700 species of fish, and 280 reptile species (Peya, 2018; Endamana et al., 2010; Mittermeier, et al. 1998). When healthy, the terrestrial

[1]Department of Agricultural Economics and Agribusiness Faculty of Agriculture and Veterinary Medicine, University of Buea, Cameroon
[2]Center for International Forestry Research (CIFOR), Yaounde, Cameroon
[3]Institute for Agronomic Research and Development, Cameroon
[4]University of Kinshassa, Democratic Republic of Congo
[5]University of Bangui, Bangui, Republic of Central Africa
[6]Centre for Independent Development Research (CIDR), P.O. Box 58 Buea, SWR, Cameroon

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Corresponding Author:
Ernest L. Molua, Department of Agricultural Economics and Agribusiness FaCulty of Agriculture and Veterinary Medicine, University of Buea, Cameroon, P.O. Box 63 Buea, Cameroon.
Email: emolua@cidrcam.org

ecosystems are important for agricultural production, via its provisioning, regulating, and supporting services (Hupke, 2023). Biodiversity in the Congo Basin Forest (CBF) plays a crucial role of local and international significance in maintaining ecosystem functions and services such as pollination, pest control, and soil formation (FAO, 2011).

This natural wealth in the CBF of the central African subregion is however bedeviled by natural and anthropogenic interference which generates environmental stress,(Pörtner et al., 2021; FAO, 2019; IPBES, 2019). Climate change is inevitable and the consequences are expected to be grim on agroecosystems such as those within tropical forest ecosystems which represent a common heritage with livelihood portfolios shared by a great majority of people, especially in the Congo Basin countries (Djihouessi et al., 2022; Temple et al., 2022; Nkem et al., 2013; Ludwig et al., 2012).

While the biodiversity wealth is challenged by climate change, the agricultural sector on which the survival of millions depend as producers, consumers and employees is significantly impacted by climate change induced biodiversity decline (Leal Filho et al., 2023; IPBES, 2019; IPCC, 2019a). In fact, temperature and precipitation change have influenced some species change (Pörtner et al 2021; IPBES, 2019). Climate change thus remains a pervasive threat to biodiversity and ecosystem services which are linked not only to the agriculture, but also to the water, health and energy sectors (Djihouessi et al., 2022; Pörtner et al 2021). For instance, soil which is paramount for food production, changes in its biodiversity is directly or indirectly linked to the alteration of climatic parameters (Leal Filho et al., 2023). In addition, changing temperature and precipitation impact agrobiodiversity. The IPCC and IPBES acknowledge the interconnectedness of climate change and agrobiodiversity (Pörtner et al 2021). The threats posed by climate change on biodiversity and agrobiodiversity are expected to increase, thus requiring conservation science to generate solutions, change behaviors and obtain better conservation outcomes, particularly at the farm, homestead and community levels (Hellin & Fisher, 2019).

Therefore, in the advent of global warming induced climate change, addressing the food needs of an impending population bulge requires significant farm-level investments for a responsive agriculture system which internalizes ecological, economic and socio-cultural concerns. Conservation agriculture is thus emerging as a climate-smart tool which farmers could adopt to manage ecosystems while boosting soil fertility and crop yields for more food (Mhlanga et al., 2022; Thierfelder & Mhlanga, 2022; Waldron et al., 2017). Farmers investing in conservation agriculture require assurances to access land and associated property rights. While deforestation and degradation are tied to a complex array of socioeconomic and political factors (Robinson, et al., 2014; Molua, 2012), insecure tenure to forestlands breeds conservation concerns (Robinson et al., 2018). For example, Robinson et al. (2014) find evidence that land tenure security is associated with less deforestation, regardless of the form of tenure. Unsuitable land-tenure systems may thus constitute an obstacle to the adoption of farmland level investments (Shittu et al., 2018). In the Congo Basin where forests are a source of livelihood for millions of rural families, security of land tenure and access to land are important for effective environmental management and sustainable land use practices (Wong et al., 2022; Dupuits & Ongolo 2020; Ntirumenyerwa Mihigo & Cliquet, 2020). Hence, the problems of land tenure and land rights on farmers' conservation behavior warrants investigation.

In this study, we specifically present a typology of the Climate Smart Conservation Agriculture (CS-CoA) land management techniques employed by farmers within the Congo Basin. We also document the agricultural land use, land tenure and land institutions in the region. We then proceed to establish the determinants of prevailing land tenure and the effects on tree management and the choice of the agricultural system which are necessary to promote conservation agriculture. The hypothesis is that property rights to land and trees play a fundamental role in governing the patterns of investment, farmland management for conservation, as well as in the profitability of agriculture.

The rationale for our study hinges on the inherent relationship of rain-fed agriculture practiced in many tropical countries, which predestines it to an undisputed correlational relationship with climate variability and change (Pörtner et al., 2021; FAO, 2019; Kurukulasuriya et al., 2006). In a region where the stochastic variability of climate is well established (IPCC 2019a; IPCC 2019b), there is need for a corresponding response to protect agroecosystems and the significant livelihoods associated with it, as well as agriculture's capacity to preserve and protect nature and its essential services to people (IPBES 2019; IPBES 2018). How this plays out in agrarian dependent communities in the CBF will require temporal and spatial policy responses that promote farm investments which curb the strain on production systems and the associated value chain, so that the farm-to-fork effect of exogenous stress from climatic factors are better managed for the dynamic outcomes of food security, livelihood stability and communal stability (IPBES 2018; IPCC 2019a; Branca et al., 2011).

For hotspots like the CBF, which is the second most important lung of the world, climate change further complicates the effects of agriculture linked deforestation on human systems (Pörtner et al 2021; Couturier, 2019). Paradoxically, the system of agriculture practiced similarly remains an important threat to the CBF's wealth of biodiversity. It is estimated that in Cameroon, for instance, about 80% of the deforestation is due to small-scale farmers using extensive slash and burn techniques (Dalimier et al., 2021; Tyukavina et al., 2018). Reversing deforestation in the Congo Basin in particular, and increasing agricultural productivity to meet the demands of a growing population while promoting conservation are mutual objectives, which are vital for sustainable development

(Tegegne et al., 2016; Molua, 2012; Endamana et al., 2010; Nkem et al., 2010). These efforts would have to put not only the farm sector but the entire food system at the center of climate action (Pörtner et al., 2021; Lipper et al., 2014). This calls for a resilient and sustainable agricultural sector in the Congo Basin (Thiombiano et al., 2012).

Institutions operating in the Congo Basin such as the Center for International Forest Policy (CIFOR) lead the voices which address the vulnerability of communities to climatic variability and climate change, and the precariousness of the ecosystem and livelihood. The Congo Basin thus remains an important real-life laboratory challenged by climate change which add pressure on local and regional agriculture and food systems (Thiombiano et al., 2012; Brown et al., 2011), as well as on the ecosystem stability and the biodiversity that is crucial for agriculture (FAO, 2019). Properly managed ecosystems within the basin will provide advantages for both adaptation and mitigation of climate change. Some studies such as Locatelli et al (2010) have examined the twin options of adaptation of tropical forest ecosystems and positioning tropical forests for adaptation, and called for an integrated cross-sectoral approach to address mitigation and adaptation such that benefits derived in one area are not to be lost or counteracted in another.

Overall, the vulnerability of the Basin is thus underscored in livelihoods highly dependent on climate-sensitive sectors like forests for household energy, agriculture, fisheries, food security, pastoral practices, water supply, herbs and tree barks (Bele et al., 2015; Branca et al., 2011).

This vulnerability and sensitivity of communities in the CBF raise an important researchable question: do farm-level conservation agriculture practices thought to be climate-smart significantly influence agricultural outcomes?

Despite the plethora of studies on climate and agriculture in other parts of the world (e.g. Mujeyi et al., 2021; Shahzad and Abdulai, 2021; Sardar, et al., 2021), very few agro-economic surveys have been undertaken in the Congo Basin to analyze and quantify the extent of different agroeconomic practices that shape households' access to food security and income for sustainable agriculture. Our study sought to contribute to the few studies on Congo Basin agriculture and climate change, and gauged the wealth of natural capital in the region for meeting the needs of millions of households, simultaneously safeguarding food security, protecting the ecosystem and promoting conservation of nature via agricultural interventions. Other studies such as Bele et al. (2015), Somorin et al. (2012) and Nkem et al. (2010) have previously highlighted the institutional priorities to enhance resilience and sustainability in the Congo Basin, without exploring the stakes and challenges prevalent at the farm and household levels.

We therefore proceed in the current study to examine how the property rights to ecological assets relating to land and trees impact the patterns of farmland management for conservation, as well as in the profitability of agriculture. We employ the discrete choice logistic regression[1] with a Simulated Maximum Likelihood Estimation of farmer's choice of agricultural system and a farmland value regression function. Farms and households in the three countries of Cameroon, the Central African Republic and the Democratic Republic of Congo are studied. We reveal that conservation agriculture techniques show benefits for smallholder farmers. Furthermore, farm-level investments are shown to enhance farm incomes and conservation effort for farmers.

Our observation that accessibility to land promotes better forest management and reduces land degradation in vulnerable areas in the CBF is instructive of policy and corroborates previous studies (Somorin et al., 2012; Brown et al., 2011; Justice et al., 2001). The implications is on the plausibility of stronger tenure to promote farm level adaptation as well as lead to better outcomes for conservation (Leal Filho et al., 2023; Robinson et al., 2018; Robinson et al., 2014). According to Justice et al. (2001) the CBF, a major transboundary natural resource pool spanning approximately 200 million hectares is likely to be impacted with significant losses and damage by climate change. With the second-largest contiguous tract of humid tropical forest in the world after the Amazon Basin forest and is the largest in Africa covering almost 2 million sq. km, the forest extends to six countries namely Cameroon, the Republic of Congo, the Democratic Republic of Congo (DRC), the Central African Republic (CAR), Gabon and Equatorial Guinea; with about 65 million people living inside or at the margins of the Basin, depending on it directly for livelihood. Subsistence small-scale slash-and-burn shifting cultivation is the dominant economic activity and farm practice of the inhabitants (Dalimier et al., 2021; Couturier, 2019; Tyukavina et al., 2018). Poverty and underdevelopment are significant in the region. About 73% of the population in the Basin is found in the CAR and DRC which are classified among the lowest income countries in the world (Nkem et al., 2010). Ecosystem damage and biodiversity related losses will without doubt lead to significant economic costs.

Figure 1 conceptualizes how institutions, tenure, farm revenue and conservation are connected to drive the outcomes of climate-smart conservation agriculture. Four key sectors are identified including the drivers (biophysical, socioeconomic and institutional), adoption, values (economic, ecological and social) and outcome related to increased production, income and conservation levels. The decision to invest and adopt either long-term or short-term CS-CoA is driven by capacity to invest, incentives, external agency that include institutional and policy factors (e.g. extension, credit, land tenure regime) as well as infrastructure (e.g. rural roads, storage) (Thiombiano et al., 2012). Both the biophysical factors espoused as farm characteristics (e.g. slope, erosion status) and households' biographic characteristics (e.g. farm experience, family size, gender, level of education) remain

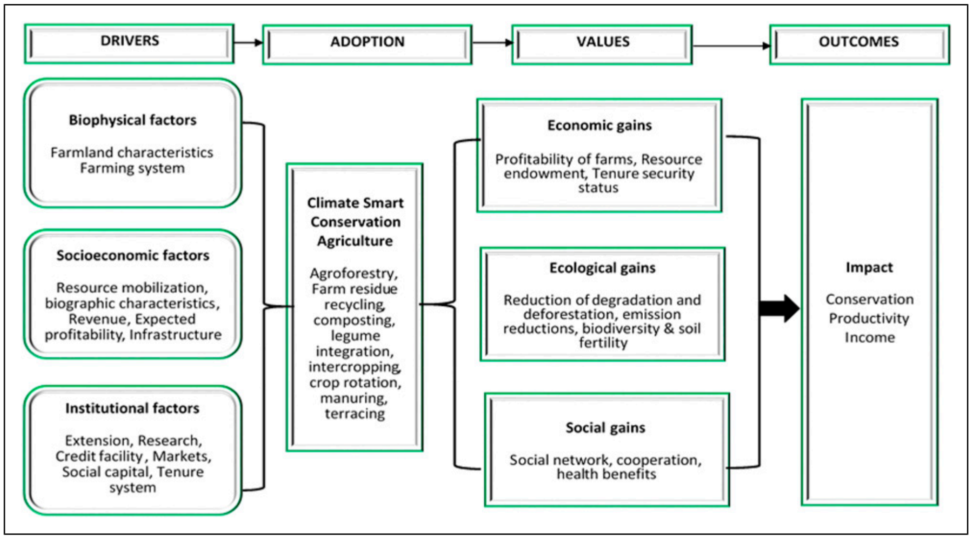

Figure 1. Drivers and gains of Climate-smart sustainable agriculture.

important determinants for investment in CS-CoA (Molua, 2011; Meinzen-Dick et al., 1997). The empirical evidence we generate in this study on the impact of farm-level investments on CS-CoA practices in the CBF may provide policy relevant insights for tropical conservation science.

Our examination of these issues is undertaken at a time when the UN system to which member states are committed to ending hunger, achieving food security and improved nutrition while promoting sustainable agriculture, protecting nature and taking urgent action to combat climate change. However, achieving these development goals comes at the behest of frontline communities such as those in the CBF which are bedeviled by tenure insecurity, declining soil fertility, degraded ecosystems, poor market access, inadequate funding and inadequate infrastructure.

Materials and Methods

Study Area

The Congo Basin is selected for this study for varied reasons. The Basin's interconnected tropical forest holds 70% of the total plant cover in the African continent, with a 2.9 ha of forest area per capita compared to a global forest area per capita of 0.8 ha (CARPE, 2021). More than 70 million people inhabit this transboundary pool of natural resources, with about 60% of whom still live in rural areas (Shapiro et al., 2021; Tegegne et al., 2016; FAO 2009a) and depend directly on forest ecosystem goods and services for household consumption, including food, fuelwood and medicinal plants (Dalimier et al., 2021). They also generate income from the trade of many forest goods, especially non-timber forest products. In addition to its environmental services such as watershed management, soil and biodiversity conservation and carbon sequestration, the CBF has enormous carbon stocks which represent a carbon reserve of global significance for regulating greenhouse gas (GHG) emissions (Couturier, 2019).

The Basin while endowed with very rich but fragile ecoregions (Ceríaco et al., 2022; Molua, 2019), the highland physiographic features vary considerably. They occupy East of Cameroon and the Great Lakes region. They show different altitudes but are all above 1,000 m and are found in highly different bioclimatic contexts (Walters et al., 2021). These highlands are characterized by high population densities and continuous pressure on land (Walters et al., 2021; Kleinschroth et al., 2019). Major humid zones are found on the coasts, from Cameroon to the banks of the River Congo (Nest et al., 2022; Tshimanga et al., 2022). The population density of the Basin though varied is increasing. While the highlands of Cameroon has a higher population density (300 inhabitants/sq. km locally), some areas such as east Cameroon, the north of Congo and the Central African Republic have less than 5 inhabitants/sq. km (Tshimanga et al., 2022; Walters et al., 2021; Molua, 2019).

DRC is the most urbanized country in the Basin (Nest et al., 2022). In the Central African Republic, more than 70% of the inhabitants live in rural areas. One of the major trends of the population of this region is the extreme diversity of the ethnic groups and indigenous cultures (Walters et al., 2021). Cameroon and DRC have respectively 234 and 350 different ethnic groups, one of the best-known being the Pygmy (Mbenga, i.e Aka and Baka of the western Congo basin, the Mbuti of the Ituri Rainforest, and the Twa of the African Great Lakes). The key natural resources of Central Africa are forest and oil (Kleinschroth et al., 2019; Molua, 2019). The population growth creates competition for access to and control over resources (Achille, 2020). This leads not only to unsustainable use of resources but also likely creates conflicts between countries (Kleinschroth et al., 2019; DeLancey, 2019).

There is evidence of increasing pressure on resources in all the ecosystems of the region (Ceríaco et al., 2022; Walters et al., 2021; CARPE, 2021). Deforestation continues to affect habitats and livelihoods in the humid zones of the Basin where these effects are difficult to reverse (Badibanga & Ulimwengu, 2020; Kleinschroth et al., 2019; Molua, 2012). Cameroon, the Democratic Republic of Congo (DRC) and Gabon are the main timber producers (Nest et al., 2022; DeLancey, 2019). Efforts at the conservation of Central African forests and their contribution of this sector in the gross domestic product (GDP) of the majority of the countries testify to the importance of this sector (Kleinschroth et al., 2019; DeLancey, 2019). The *Commissariat des forêts d'Afrique Centrale* (COMIFAC) has been created to enable the Central African states to harmonize their policies on the sustainable use of forest resources (Nago and Krott, 2022; Tshimanga et al., 2022; Achille, 2020).

Data Collection

Socioeconomic data used in this study came from CIFOR's Congo Basin Adaptation and Mitigation Project (COBAM) dataset on rural households and farms. The dataset is based on household surveys collected from more than 600 farms across three countries, using pretested Questionnaire. The survey elicited information about infrastructure and distance to markets, ethnic composition and extent of in-migration, cropping and livestock activities, tree species composition, major tree-planting projects, prices of agricultural and wood products, natural and man-made shocks such as floods or war, and a set of tenure variables including rights over land and trees across broad tenure categories. Probability samples were drawn from Cameroon, the Republic of Central Africa and the Democratic Republic of Congo (see figure 2).

In each country, between 3 and 4 regions were selected to cover a broad range of environmental and socioeconomic conditions. Our research uses cross-section data on 12 regions/provinces and 40 divisions in Cameroon, Central African Republic and the Democratic Republic of Congo to determine statistically the factors determining farm profits. The econometric model is developed from a theoretical model which also internalizes perception of climate change and prevailing land tenure institutions within the customary sector. The analysis is performed using the Stata 17 statistical software. This is supplemented with qualitative information from focus group discussions of key informants (local leaders, respected elders and agricultural officers) and unobtrusive observation of farming in the selected communities within the three countries.

During the data collection process there were six sets of participants, which included trained Enumerators who conducted the actual surveys. Quality assurance was assured by the research team, using intepreters and translators where necessary. Some of the researchers served as Supervisors in selected regions with the role to manage the teams of enumerators, check surveys for completeness, keep records of completed interviews, and ensured smooth communication between different teams. Graduate research assistants were hired to serve as Data entry coordinators and Data entry clerks charged with electronically entering data. Some of the Authors of this research served as Field managers for the different country teams with the responsibility to plan and

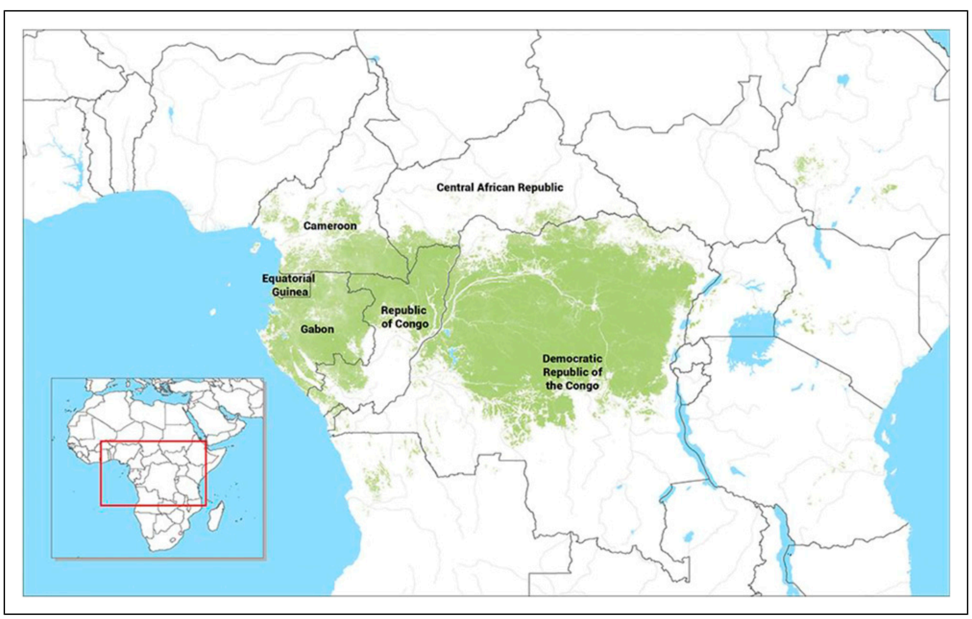

Figure 2. Map of Congo-Basin Region.

oversee the entire process of field data collection and managed all country field teams including drafting of the logistics and budget for the field work, as well as acting as primary liaison at the country level. The lead Author served as the Regional Field coordinator who decided important aspects such as the team setup and hiring criteria.

Data Analysis

A microeconometric model is employed and refined to study how the farming systems respond to institutions and environmental conditions in the CBF. The hypothesis is that property rights to land and trees play a fundamental role in governing the patterns of investment in crop and farmland management, as well as in the welfare of individuals and households who depend on natural resources.

To examine how farmers under different tenure arrangements may choose their respective tropical farming systems we employ a robust analytical framework, the Mixed Logit, which is particularly appropriate in experiments of discrete choice behaviour (von Haefen and Domanski, 2018; Claassen, et al., 2013 Claassen, et al., 2013), where farmers' behaviour may vary across agroecologies with heterogeneity in their preferences (Scarpa et al., 2021; Ahmed & Tesfye, 2021; Tesfaye et al., 2020).[2] The Mixed Logit relaxes the restrictive "independence from irrelevant alternatives" assumption and allows every individual to have their own preference, that is, it assumes that marginal utilities of individuals are not constant but vary across the sample (Hensher and Greene, 2003). The axiomatic foundations of the Mixed Logit are based on Multinomial Logistic regression[3] as established in Hensher & Greene (2003) as well as McFadden and Train (2000), and efficient in measuring the change in the probability of farmers' action given a unit change in any explanatory variable, keeping constant all other factors (Tesfaye et al., 2020; Seo & Bhattacharjee, 2012).

The Mixed Logit model is selected for this research which deals with mixtures of revealed and stated preference for farmers' ex-ante adoption behaviour due to the inherent shortcomings of other choice methods such as the Multinomial probit models and Conditional logit models (Greene & Hensher, 2003; Hensher & Greene, 2003). The Mixed Logit overcomes limitations of the standard logit model by allowing for random output variation across farmers, unrestricted substitution patterns across farmers' choices, and the correlation in unobserved factors over time (David & Train, 1998).[4] This model has been used in several studies of choice experiment, where estimated parameters of the model are analyzed in terms of their marginal effects (von Haefen & Domanski, 2018; De Jalón et al., 2017; Seo & Bhattacharjee, 2012).

The Simulated Maximum Likelihood Estimators (SMLE) from a Mixed Logit model is thus employed to explain a farmer's choice of agricultural system and farm returns (gross revenues) for each system after correcting for selection biases (Claassen, et al., 2013; Rigby et al., 2009; Alfnes, 2004; McFadden & Train, 2000; McFadden, 1973). The regressors in the equation include tenure or property rights, climate, soils, and socioeconomic variables such as education, gender, and country dummies. In line with the empirical framework of Seo and Bhattacharjee (2012) and Seo (2010a,b), we assume that farmers choose one of three agricultural systems to maximize farm profit mindful of the current tenure regime and environmental conditions.

Based on the combination of crops and livestock that a farmer holds, three agricultural systems (j) are distinguished: a specialized mixed arable cropping system, a specialized integrated tree–arable crop system (agri-silviculture), and a mixed tree arable crop-livestock system (agrosilvopastoral). The prevailing tenure arrangement may therefore affect both the farmer's choice of system and the net revenue earned from the chosen system. The novelty of this approach, distinct from previous cross-sectional studies, is that we expect to quantify adoption behaviours explicitly and measure the differential effects of tenure rights on various agricultural systems.

Assuming the net revenue (π) from farm system j and 1 is written as follows:

$$\pi_1 = X\beta_1 + \mu_1 \tag{1}$$

$$\pi_j = Z\gamma_j + n_{j,\, j=1,\ldots,J} \tag{2}$$

where $E(u_1|X,Z) = 0$ and $var(u_1|X,Z) = \sigma^2$(Dubin and McFadden 1984), and the error terms may capture such factors as measurement errors, omitted variables, and other unobserved factors. These terms are assumed to average to zero and have equal variance. The subscript j is a categorical variable indicating the choice amongst J systems (in our analysis J =1 a specialized mixed arable cropping system, J = 2 denotes an agri-silviculture system, and J = 3 indicates an agrosilvopastoral system). Vector Z represents the set of explanatory variables relevant for all the alternatives and vector X contains the determinants of the profit of the first alternative, i.e. specialization in crops only. We identify choice equations by two variables: slope of terrain and walking time to district capital (Ahmed & Tesfye, 2021), which are excluded in the second stage regressions.

Assuming η_j 's are iid extreme value distributed, the choice probability can be written as the following integral over all possible values of γ_j:

$$P_1 = \int \left(\frac{\exp(Z\gamma_1)}{\sum_{k=1}^{K} \exp(Z\gamma_k)} \right) f(\gamma|\theta)d\gamma \tag{3}$$

This probability (P) is simulated by assuming the mixing function $f(\gamma|\theta)$ to be normally distributed (McFadden & Train 2000). Having chosen agricultural system 1, the farmer chooses inputs and outputs to maximize the net revenue from operating the system. The maximum profit can be estimated as a function of the exogenous variables X directly from equation (1) above. However, it is likely that the errors in equations (1) and (2) are correlated. Since profits are only observed for those farms that actually chose farm type 1, the selection bias should be corrected to obtain consistent estimates of climate parameters (Scarpa et al., 2021; Ahmed & Tesfye, 2021; Heckman, 1979). Following Claassen, et al. (2013); Rigby et al., (2009), Alfnes (2004) as well as Dubin and McFadden (1984) for a multinomial choice, we assume the linearity condition with correlations among alternatives (r_k) summing up to zero. Thus, the conditional net revenue function for the crop-only system (or farm type 1) can be written as follows:

$$\pi_1 = X_1\varnothing_1 + \sigma.\sum_{k\neq 1}^{J} r_k.\left[\frac{P_k.lnP_k}{1-P_k} + lnP_1\right] + \delta_1 \quad (4)$$

Where P_1 is the probability of choice system 1 and P_k the probability of alternative farming systems. The regressors (X_i) in the above equation include environmental and socioeconomic variables such as tenure (land ownership), education, gender, distance to markets and country dummies.

Ethics Consideration

For Cameroon, Central African Republic and the Republic of Congo we applied and obtained clearance from the respective Ministries of Scientific Research. We later presented the research permit to respective region, district and village leaders. We sought verbal agreement from all respondents prior to the interviews to guarantee their willingness to participate. To protect confidentiality, respondents' names and personal information are kept anonymous.

Results and Discussion

Agricultural Land use, Land tenure and Land institutions

During the focus discussion we examined important issues surrounding land tenure, and rights for improved land management and sustainable development. We propped about problems associated with land ownership (titling, tenure and customary rights); the current trend of policy and regulatory regimes within land law; the status and challenges of land administration and institutions; marginalization of some social groups, such as women, local communities and indigenous people; violation of land rights; and existence of land conflicts.

As expressed clearly in the focus group discussions, land in the Congo Basin embodies different meanings: it is a factor of production; it is a family or community property; a capital asset; and a source of cultural identity and/or citizenship. Hence, the importance of land issues to the socio-economic development of communities in the Basin is unquestionable. Growth and poverty reduction; governance in access and control of land; sustainable use of natural forests; and migration conflicts are in many ways integral parts of the land question in the region.

Unobtrusive observation in the surveyed sites show that the land management choices adopted have multiple objectives including serving as a strategy for nature conservation and agroecology protection. For farmers who wished to do more, they reported that "the conservation agriculture practices and agroecological techniques of farming demanded more access to land, as not only the primary requirement for food production, but as means to expand activities to benefit from natures contribution in farms." The demand for land hinges on the premise that when farmers own or control their farmlands they are likely to invest in sustainable land management practices such as tree planting and soil conservation.

While it is expected that when tenure leads to increases in farm investment, higher agricultural productivity, and improved food security, it is an incentive for conservation, thus benefitting society as espoused by IPBES (2019). Farmers with secure ownership of land are therefore more likely to invest on its conservation, which results in a range of economic, social, and ecosystem benefits (FAO, 2021; IPBES, 2019; Endamana et al., 2010). However, the field reports indicate that for all the countries some farms operate in conditions where there are unequal land rights, or more precisely the laws or customs hinder small-scale famers especially youth and women's ownership and access to land.

In Eastern Cameroon lying on the western flanks of the Congo Basin, an official of the Regional Delegation of the Ministry of Forestry and Nature Protection provide a succinct account of the role of tenure security in agroforestry conservation: "Tenure systems vary from one rural community to another but hinges on three broad systems of communal, individual and family ownership." In his review, "tenure security affects farmers' land use decisions, their welfare, and the biodiversity on the land. Land tenure security empowers farmers with agency over their land, to make farm decisions that may align with conservation goals such as proper soil management." This may imply that land tenure is a possible tool for conservation. He however admits that, "land tenure systems are dynamic, responding to socio-economic and political changes put in place for resource utilization."

Three countries in the Basin have been subjected to colonial domination of different origins: this includes French colonization, (The Central African Republic, part of Cameroon), Belgium colonization (in DRC) and British (part of Cameroon). All these external dominations have influenced land policies and laws, as well as the related institutional setting. One consequence of the colonial history in the region is the legal dualism, land and natural resources being governed by statutory law as well as by customary law. However, this legal dualism has been developing at the expense of customary land laws, as the latter were never clearly recognized (Majambu et al., 2019; Sartoretto et al., 2017). Another legacy of colonial history is the State sovereignty over land. The colonial legacy continues to shape the land policy, legislation and land administration systems in the region. The State sovereignty over land in these countries - is the origin of the key land issues, as this sovereignty is not accompanied by the development of appropriate land policy instruments likely to enable sustainable land management (Inogwabini, 2021; Valkonen, 2021; Brawn, 2017).

The question of considering customary rights in sustainable land management has been identified in almost all countries covering the Congo Basin. Customary land tenure is the foundation for the livelihoods of rural populations. These systems include the possession of land exclusively by individuals or households for residential use, farming or some other business activity within a given community. In addition, they incorporate the 'commons' - land shared by multiple users for grazing and for gathering field and tree products (fuel, construction poles, medicinal plants, fruits, grass) found in controlled and open access areas. However, customary land tenure is still not recognized in the majority of Central African countries. But, in reality, most people in the region occupy their land under a customary system. This means the absence of formal tenure rights and consequently insecurity of land tenure.

The major ethnic groups studied largely reported 'patrilineal' inheritance and 'patrilocal' residence systems with largely male-headed households. Traditionally, lineage land has been owned collectively by a group of kin members, and this group usually consisted of a grandfather, sons and grandchildren. The land is bequeathed to brothers, nephews and sons in accordance with the decision of a family head. The head is selected from uncles, that is, a male member of the second generation, who exercises strong authority regarding land inheritance. The basic principle of land allocation is to maintain equity among lineage members.

According to our interviews with farmers, it is primarily husbands who make farm management decisions. Even in *de facto* female-headed households, male figures like older sons and commuted husbands are still responsible for major farming decisions. In some communities, females make decisions in *de jure* female-headed households. However, females may make decisions even though they have no customary land rights. Land sales or exchange exist. Men are typically the custodians of lineage and family land and sign to the transfer of land to non-family members. Sons may jointly inherit private land, which was acquired either by opening forest land or by purchasing already exploited bush-fallow. Table 1 shows key characteristics of the major land tenure categories reported in all the communities studied. The Basin is largely dominated by 'patrilineal' communities with inherited land sourced largely through dominant male figures in families.

Our observations have some implications. Though not necessarily formal titling, tenure security is associated with tropical cropland conservation practices and improvements. Reports such as Kombat et al. (2021), Amadu et al. (2020), Akugre et al. (2021) as well as Geist & Lambin (2002) document that customary land tenure institutions, greater population pressure and poor access to markets are significant causes of land conversion to agriculture, and hence to loss of trees. Private ownership of converted land promotes greater integration of trees and crops and leads to the highest density of trees on agricultural land. While Ketema et al. (2020) among others find that population pressure induces land conversion; the matrilocal system of household residence is noted to induce agricultural conversion, however with some improvement in the management of resources as their scarcity increases. Secure, long-term rights of access to land, particularly in the form of locally recognized use rights, create an incentive for people to make landscape-improving investments (Azadi et al., 2021; Jellason et al., 2021). For example, terracing or other investments in soil erosion control are generally associated with secure, long-term rights to land in some regions of SSA (Kombat et al., 2021; Mangaza et al., 2021). The right to at least bequeath, if not sell parcels, increases the likelihood that a farmer makes at least one long-term improvement on a parcel of land.

Table 2 reports the proportion of land use under different tenure arrangements in the three countries studied. In Cameroon, 36% of arable croplands are inherited, 14% are under joint extended family ownership, 31% under single-family ownership and 19% are private owned whether purchased or cleared forest. In RCA, a higher proportion (42%) of arable cropland is inherited and the lowest proportion (8%) of farmlands is privately purchased land. In all three countries, tree plots are largely inherited, highlighting the socio-cultural importance of tree resources in farmlands. Tenure security

Table 1. Land tenure categories and their major characteristics.

Ownership categories	Owners	Inheritance	Joint ownership
Lineage	Lineage members	Brothers, nephews and sons	Yes
Joint family	Male (sons) figures	Male (sons) figures	Yes
Single family	Male (sons) figures	Male (sons) figures	No
Private	Single persons	Sons	No

Notes: Computed from Survey Data, 2022.

Table 2. Land use by tenure (%).

Land use	Country	Lineage	Joint family	Single family	Private
Arable crop fields	Cameroon	36	14	31	19
	RCA	42	32	18	8
	RDC	27	36	26	11
Tree plots	Cameroon	41	23	29	7
	RCA	48	27	16	9
	RDC	29	35	12	24
Bush-fallow	Cameroon	23	36	27	14
	RCA	39	27	23	11
	RDC	31	35	16	18

Notes: RCA = Republic of Central Africa, DRC = Democratic Republic of Congo. Tenure arrangements: Lineage (inherited), single or joint family use (family ownership), private ownership (leased, purchased and cleared primary forest). Computed from Survey Data, 2022.

which has to be at the heart of any agricultural development plan is achieved when property rights are clarified and widely acknowledged (Jellason et al., 2021; Kombat et al., 2021; Mangaza et al., 2021; Brawn, 2017; Andersson 2007). In most cases, progress will consist of (a) the reconciliation of diverse and conflicting claims, (b) the clarification of latent or overlapping rights in resources, and (c) the reconciliation of statutory and customary regimes.

The essentiality of customary rights in sustainable land management is identified in almost all the countries examined. Currently, customary land tenure is not adequately recognized in the majority of Central African countries. However, in reality, most people in the region occupy their land under a customary system. This means the absence of formal tenure rights and consequently insecurity of land tenure. Concerns about population growth and pressure on land in urban areas and coastal zones have been raised in countries like Cameroon, Congo, Gabon and Equatorial Guinea (Mangaza et al., 2021; Kombat et al., 2021; Gilland, 2002). Forced evictions, expropriations and related land issues are also critical issues in Central Africa. These observations on land access have significant implications on forest management and resource conservation via controlling for deforestation and land degradation in vulnerable tropical areas (Long, 2013; Endamana et al., 2010).

The focus group discussions identified priorities in their communities within the CBF, including a lack of a comprehensible land policy, inadequate regulations, security of tenure, State sovereignty over land, good governance in land administration, funding for the development and implementation of land policies, and protecting customary land rights, gender issues with special attention to access to land for women and marginalized groups, centralized land management administration and lack of participation. These reports reiterate the salient need for land reforms and effective land policy for countries in the region.

A functioning land policy is crucial to sustainable livelihoods.[5] Land policy-making is usually led by the State through the pronouncement of specific laws and policy statements. Land policy reviews have recently been conducted in some CBF countries, leading to new land laws and/or the redefinition of the necessary institutional framework under which land policy is administered. In Central Africa, the State has the overall mandate for the formulation and the implementation of land policy. Formulation of land policy is generally influenced by the colonial legacy; it does not take into consideration customary land rights. In some cases, there is a dualism that does not necessarily give room to customary rights. The States implement land policy through a set of instruments. They are fiscal, institutional, legal and technical. In general, the ministry in charge of land and domains has the overall responsibility to elaborate and implement the land policy.

In all the countries different agencies under the umbrella of the State are noted to be in charge of different sub-sectors. It appears that the objectives of land policy in many countries of the region target financial objectives, particularly land taxation or forestry taxation. In Cameroon and DRC, the states have created parastatal agencies in charge of implementing land policies. The role and responsibilities of these parastatal agencies vary according to the stakes of the sector (forests, mines, habitat etc.) concerned. The sectoral instruments, notwithstanding, available legislations are old and characterized by the absence of consultation either in elaborating or updating the existing legislation. Since there is no formal coherent land policy in the region, some sectoral instruments are available. They target sectors like forest and urban areas. Rural areas are not sufficiently covered. The process of land law formulation does not take into consideration the other sectors (agriculture, mines, town planning and others). These observations are similar to previous studies in the region (Inogwabini, 2021; Ongolo et al., 2021; Windey and Van Hecken, 2021; Majambu et al., 2019).

These are important bottlenecks which hamper access to land, as well as the utilization and investment on land. Access to land and land tenure relations are critical where communities depend on control of land to ensure not only their food security but overall wellbeing. Appropriate land administrative and adjudicatory instruments are crucial to the effective distribution, use and management of tenure relations. Given the powerful coalition of interests, such as agri-business, land tenure administration is critical in determining rules of access and use, and systems of monitoring and sanction.

The main question emanting from reports in the CBF relates to how secure the tenure systems are and whether there is equity or not. Tenure, as a bundle of rights, determines who owns what resources and why. The way land is transferred, adjudicated and owned is critical for determining the management regimes for both land and natural resources. It may also correlate with the employment of climate-smart farmland management measures. In the ensuing subsection, we attempt to demonstrate that access to more productive land and control of natural resources by agriculturists offers the most profitable form of agri-investment by smallholders. The extrapolation is that enhancing access to land, security of tenure, or sustainability of land resource use will ultimately enhance welfare, including food security (Lipper et al., 2014).

Determinants of Prevailing Land Tenure and Effects on Tree Management

Establishing the determinants of land tenure and tree management we rely on the mixed logit as a random-utility discrete choice model, where the expected utility of a choice farmers employ depends on the characteristics of the alternatives available and forgone, the characteristics of the farmers making the choices, and the socioeconomic factors which are specific to a combination of farmer and alternative practices (Akugre et al., 2021; Breitmoser, 2021). The results confirm that long-term agricultural growth for communities in the Basin hinges upon sustaining and improving the productivity of the natural resource base, particularly trees and tree products. Growing or maintaining trees protect at-risk ecosystems and habitats, with possibility to increase food supply (Kalkuhl et al., 2020). Excavating new farmlands via deforestation means losing habitats, as well as biodiversity. Farm trees are used to improve soil stability, restore ecosystems and protect endangered spices. Farmers report that their expectation to "planting trees is to help rebuild the soil with nutrients, to soak up excess water, and reduce erosion". The sustainable management of trees within the farming systems may not only increase farm incomes but also helps diversify production and thus spreads risk against agricultural production or market failures.

Agroforestry systems and practices employed in the CBF come in many forms, including improved fallows, taungya[6], home gardens, growing multipurpose trees and shrubs, boundary planting, farm woodlots, orchards, plantation/crop combinations, shelterbelts, windbreaks, conservation hedges, fodder banks, live fences, trees on pasture and tree apiculture (Gonçalves et al., 2021; Reang et al., 2021; Waldron et al., 2017). Empirical research has already identified important driving forces behind household decisions to plant trees on their farms (Duffy et al., 2021; Ngoma et al., 2021). Another body of research has centered on understanding changes in forested areas at the national and international levels (Ngoma et al., 2021).

Very important, however, is the role of tenure in facilitating agroforestry systems. According to the logit regression of land tenure arrangements in table 3, some key socioeconomic characteristics explain the tenure conditions in which farm households operate. The size of area exploited, the age and gender of household head, years of schooling, family size, nativity or origin of household head and the distance of the exploited land from the homestead combine to explain the tenure arrangement. Of these factors, the age of the household

Table 3. Determinants of farmland tenure.

Variables	Joint family	Single family	Private	Cleared
Area exploited (hectares)	0.11** (0.0022)	0.18 (0.32)	0.25 (0.10)	0.20** (0.001)
Age, household head (years)	0.06** (0.001)	0.09 (0.01)	0.05** (0.001)	0.04 (0.01)
Gender, household head	0.01 (0.02)	0.03* (0.02)	0.08* (0.02)	0.01 (0.02)
Schooling, household head (years)	0.001 (0.06)	0.002 (0.06)	0.03* (0.05)	0.001 (0.06)
Family size	0.32** (0.0012)	0.37 (0.12)	0.19 (0.13)	0.16** (0.0011)
Nativity (dummy)	0.51 (0.31)	0.28* (0.032)	0.25 (0.31)	0.09* (0.042)
Walking time to plot (hours)	-0.0008 (0.004)	-0.0005 (0.003)	-0.0003 (0.004)	-0.0007 (0.005)
Distance (km)	-0.0015 (0.04)	-0.0019 (0.02)	0.0027 (0.07)*	0.0023 (0.26)*
Slope (dummy)	0.0017* (0.042)	0.0021* (0.053)	0.0003* (0.037)	0.0001 (0.29)
RCA, country dummy	0.60 (0.58)	0.80 (0.62)	0.50 (0.64)	0.20 (0.67)
DRC, country dummy	0.26 (0.43)	0.35 (0.47)	0.52* (0.051)	0.67 (0.52)
Intercept	0.008 (0.002)	0.003 (0.004)	0.027 (0.001)	0.019 (0.003)
Number of observations	93	249	121	137
Log likelihood	-149.23	-146.17	-135.31	123.62

Notes: Numbers in parentheses are standard errors. ** indicates significance at the 1%, and * at the 5% level. Computed from Survey Data, 2022.

head has a significant impact on private and jointly owned land. Increasing levels of female household-headship may be less important for joint family ownership, but results in higher levels of single-family ownership and a higher incidence of private ownership. Women were observed playing a pivotal role in maintaining and strategically using land and natural resources. However, gender relations are governed by the prevailing socio-political structures and religious-ideological value systems. The predominance of patriarchal systems ensures that women only have access to land and related natural resources through their spouse or male relatives.

The insecurity of land tenure is a possible obstacle to increasing the agricultural productivity and income of rural women. Security of tenure is the key to having control over major decisions, such as what crop to grow, what techniques to use, what to consume and what to sell. Without this, women cannot access credit and membership of agricultural associations, particularly those responsible for processing and marketing. Inadequate access to credit and loss of membership in livelihood enhancing cooperation activities drive poverty of vulnerable groups, with consequences on locale biodiversity conservation. The persistence of extreme poverty and continued rapid loss of biodiversity appear intimately related. For example, IPBES (2019) documents geographic coincident of poverty and biodiversity loss especially in tropical areas in the Congo Basin where livelihoods depend disproportionately on natural capital embodied in forests, soils, water, and wildlife.

It is informative in Table 3 to observe that the origin (nativity) of the household head though positive is less significant in explaining the prevailing tenure. This may be expected because a larger settler population increases the population pressure on land. This variable being less significant may increase access to land in the short-run, but also increase pressure on land in the long run. Larger family size is also noted to lead to the preservation of lineage ownership. By and large, walking time to forests, though negative, has no significant effects on the distribution of land ownership. There is significant evidence that scholarization induces private land ownership.

We further observed that terrain and distance to district capital are significant. While farmers in general prefer flat terrains, however, farmers who make use of open cleared forestlands are indifferent whether its slope or flat land. There are significant correlations between the distance of farms from city centers and the ownership rights. Farmlands that are privately owned as well as operated in open cleared-forest land tend to be located closer to urban centers as proxy by distance. On the contrary, farms in family-owned lands are increasingly located further into the hinterlands. That with private tenure these factors are significant provides indication on such tenure condition for potential land cover change and possible deforestation thus causing degradation of biodiversity and carbon stocks. These findings have implications for who owns forestland, who has access and use, who manages, and who makes decisions about forest resources. However, regardless of the form of tenure of land and forests, better policymaking is required to strengthen biodiversity conservation and accountability particularly for programs related to the Reducing of Emissions from Deforestation and forest Degradation, while minding the role of conservation, sustainable management of forests and enhancement of forest carbon stocks (REDD+).

A major question is the relative speed by which primary forest and bush-fallow areas may be converted to commercial agriculture plantations under different land tenure institutions. If the major source of land is primary forest, agroforestry development comes at the expense of the natural environment. On the other hand, if agricultural plantations were primarily through enhanced utilization of existing arable lands through increased integrated agriculture, then this may bring environmental benefits. The environmental benefits may include addressing the triple challenge of ensuring food security, mitigation and reducing vulnerability and increasing the adaptability of agricultural systems to climate change. This will be increasingly important as the impacts of climate change become more pronounced. Trees and shrubs can diminish the effects of extreme weather events, such as heavy rains, droughts and wind storms. They prevent erosion, stabilize soils, raise infiltration rates and halt land degradation. They can enrich biodiversity in the landscape and increase ecosystem stability. Agroforestry practices in the CBF are therefore important both for climate change mitigation as well as for adaptation, and the socio-cultural needs to safeguard access to land (FAO 2009b).

The inferences from these findings indicate fundamental implications in the management of local and global land and forest commons, as well as for adaptation and mitigation of climate change in the CBF. The significant probability that land tenure drives farmland efforts of tree crop management in a prevailing socioeconomic environment influenced by the bioeconomic nature of the farm holdings and operators' households is instructive of efforts required to meet global requirements in managing the commons in the Congo Basin. Pledges in the 26th UN Climate Change Conference of the Parties (COP 26), for instance, and the call for reduction in deforestation amidst quest by local communities to exploit natural assets for direct productive gains and welfare, would require complementary national and communal efforts promoting better agricultural land use especially agricultural practices.

Empirical field surveys such as in our study which show that agriculturists choose different farming systems to maximize profit while internalizing the tenure regime and environmental conditions they face have important policy implications on how local institutions should be managed to promote farm-level investments that enhance welfare in the face of climate perturbations and perception of climate change so that these agrarian agents at the frontlines could be veritable partners in conservation efforts in global commons such as the CBF.

Determinants of Agricultural System Choice and Land Value Regressions

Some studies (e.g. Tseng et al., 2021; Alban Singirankabo & Willem Ertsen, 2020; Akram et al., 2019; Gottlieb & Grobovšek, 2019) have presented a range of views on the implications of different tenure regimes for agricultural productivity. They argue that the system of land tenure sets the context within which all efforts to raise agricultural output must operate. Land tenure will influence the farming system, social equity and agricultural productivity, and hence overall economic development (Akugre et al., 2021; Brawn, 2017). This is plausible since farmers with titles to their land may have better access to credit, which can enhance their productivity. We therefore examined how farmers in the selected Congo Basin communities have chosen their respective systems. Table 4 reports the parameter estimates for a mixed logit agricultural land-use choice. The independent variables, include area exploited, walking time to plot, ownership, climate-smart management practices, access to climate information, and access to extension services. The primary concern of our study is whether the choice of agricultural system is dependent upon tenure. Tenure variables are highly significant as a group.[7]

As is clear from this table, the results are quite robust with respect to land use types. The more positive significant effects of private ownership imply that trees were more often planted/protected in private lands with secured tenure than when the land was jointly owned or in privately cleared public land. Recall that the bequest of land rights to sons is more important with increasing private ownership, whether as cleared land or purchased land. Thus, the dummies for private ownership being significant at the 5% level is consistent with our hypothesis that the management of trees in farmlands for its product and service benefits is largely independent of the level of tenure security.

Anecdotal evidence from focus groups suggests land rights of single or joint family inherited land tend to increase when trees (fruit and non-fruit woody perennials) are planted. The trees are planted to lay claim to territory rather than for its environmental benefit. This may explain the lower significance of joint family ownership on tree planting compared with the effect of single-family ownership. Perhaps, this is

Table 4. Determinants of agricultural land use choice.

Variables	Arable crops	Agri-silviculture	Agrosilvopastoral
Area exploited (ha)	0.63 (0.33)	0.66 (0.27)	0.79** (0.35)
Age, household head (years)	0.07 (0.06)	0.02* (0.001)	0.04* (0.003)
Gender, household head	0.39 (0.02)	0.43 (0.21)	0.54 (0.29)
Schooling, household head (years)	0.04 (0.06)	0.06 (0.01)	0.02** (0.001)
Family size	0.09 (0.03)	0.05 (0.01)	0.02* (0.001)
Nativity	0.26** (0.015)	0.35 (0.13)	0.61* (0.019)
Walking time to plot	-0.007 (0.13)	-0.009 (0.12)	-0.01 (0.11)
Joint family	0.63 (0.04)	0.59* (0.023)	0.56** (0.009)
Single family	0.81** (0.001)	0.93 (0.05)	0.72* (0.008)
Private ownership (Purchase)	0.99 (0.48)	0.85 (0.12)	1.31** (0.009)
Clearance	0.53** (0.001)	0.37 (0.08)	0.35 (0.02)
Credit access	0.64 (0.22)	0.91 (0.08)	1.49 (0.13)
Soil management	1.22 (0.044) **	0.57 (0.81)	0.46 (0.28)
Crop management	1.07** (0.009)	0.53 (0.26)	0.66* (0.003)
Water management	0.31* (0.008)	1.16** (0.007)	0.59 (0.009)
Ecosystem management	0.27 (0.11)	0.36 (0.19)	1.08** (0.001)
Supply chain management	0.02* (0.05)	0.07* (0.004)	0.09** (0.001)
Perception of climate change	0.001* (0.011)	0.003 (0.02)	0.009 (0.05)
Access to climate information	0.13 (0.22)	0.07 (0.96)	0.19* (0.62)
Access to extension services	0.51 (0.91)	0.39 (0.95)	0.25** (0.099)
RCA	0.011 (0.87)	0.016 (0.80)	0.09 (0.89)
DRC	0.008 (0.91)	0.15 (0.96)	0.06 (0.99)
Intercept	9.35 (0.75)	7.21 (0.74)	11.09 (0.78)
Number of observations	256	196	148
Log likelihood	-536.37	-517.25	-411.61

Notes: Agri-silviculture (tree & crops only), Agrosilvopastoral (crops, trees & livestock). The omitted choice is specialized livestock system. For the country dummy, Cameroon is treated as the base case. Numbers in parentheses are standard errors. ** indicates significance at the 1%, and * at the 5% level. Computed from Survey Data, 2022.

why nativity measured as the region of origin has a positive effect on tree planting, which suggests the importance of ethnic origin as an effective variable to the returns on land use that required investment in trees. It is also instructive to acknowledge that these may be short-term effects, and in the longer run, there may be no significant difference in tree planting behaviour between family ownership and privately claimed lands. Whether in family or private farms, planted trees increase forest cover and contribute to the restoration of holistic ecosystems, which in turn promotes a range of flora and fauna to grow. In the humid tropics of the Congo Basin, such reforestation creates a safe haven for biodiversity, allowing for a wide array of habitats.

Some important results are obtained on the impact of CS-CoA practices with respect to agricultural land-use types. The dummy variables representing soil, crop and water management techniques are positive and significant. Soil and crop management are more significant under arable crop and tree systems and less so under crop-tree-livestock integrated systems. While water and ecosystem management show increasing significance with the increasing complexity of the farming system, post-harvest supply chain management is significant across all land-use types. Given the importance of these efforts, walking time to the plot has a negative effect on tree planting, which suggests that distance as a variable affects return on land uses.

Household characteristics such as size, gender, age, and education are also examined. Among household characteristics, the coefficient for the age of the head of the household is positive across all systems. When the head of household is older, a farmer tends to specialize in integrated crop-tree-livestock systems. Female heads of the household prefer focusing on crops over diversifying into trees and livestock. More educated heads of households tend to specialize in trees and crops. When a family is small, it tends to avoid specializing in livestock. Country dummies were entered to test country-specific conditions e.g. culture, agricultural and land policies. Against Cameroon as the base case, farmers in RCA and DRC farms are more likely to have crops only. Both of these countries heavily rely on forest exploitation.

Having explained the choice of the agricultural system in the first stage, we estimate the land value of each of the three systems after correcting for selection biases in the second stage. In table 5, we run regressions of farm returns (gross revenue) against tenure and other control variables for each system. Tenure has differential effects. For example, cleared forest and single family-owned farms increase the

Table 5. Determinants of Farm revenue (FCFA/ha) conditional on agricultural systems.

Variables	Arable crops	Agri-silviculture	Agrosilvopastoral
Area exploited (ha)	10.34** (1.64)	10.73 (1.55)	20.49 (1.73)
Age, household head (years)	6.09 (4.13)	4.32 (2.12)	9.35 (5.31)
Gender, household head	5.92 (3.13)	7.23 (4.40)	3.94 (1.58)
Schooling, household head (years)	6.46 (2.11)	9.16 (5.17)	11.32 (7.21)
Family size	4.39** (1.62)	5.51* (2.15)	2.72 (1.19)
Nativity	1.25 (2.38)	1.33 (7.29)	2.96 (9.38)
Walking time to plot	-3.75 (3.26)	-9.93 (4.25)	-12.61 (45.31)
Joint family	1.47 (1.48)	1.36 (2.46)	1.97** (2.95)
Single family	1.47 (4.19)	1.58* (5.52)	1.86 (6.43)
Private ownership (Purchase)	2.89** (1.82)	2.47 (1.25)	2.93 (1.78)
Clearance	1.39** (1.21)	1.86 (1.70)	1.29* (1.08)
Credit	230.25 (22.38)	125.83 (35.48)	623.32** (40.36)
Soil management	3.43* (7.59)	3.85 (5.17)	4.68 (9.83)
Crop management	2.97* (2.92)	2.65* (1.64)	2.73 (1.35)
Water management	2.81* (1.76)	4.76 (1.81)	5.99** (1.09)
Ecosystem management	3.12* (5.32)	6.96* (4.93)	8.79* (3.18)
Supply chain management	15.51 (5.05)	23.48 (3.004)	19.19 (8.001)
Access to climate information	2.17 (0.99)	5.23 (0.08)	7.96 (0.09)
Access to extension services	3.22 (0.35)	8.68 (0.68)	12.27** (0.36)
RCA	78.63 (7.74)	75.68 (8.82)	89.77* (9.93)
DRC	124.82 (8.18)	133.69 (5.67)	270.97* (6.90)
Intercept	13500.19 (5.13)	24810.58 (9.54)	35700.33 (5.83)
Number of observations	256	196	148
Log likelihood	-367.64	-317.82	-261.56

Notes: (1) The omitted choice is specialized livestock system. (2) For the country dummy, Cameroon is treated as the base case. (3)The goodness of fit measures: McFadden's LRI = 0.13, Veall-Zimmermann = 0.27. (4) P-value of the Likelihood Ratio test of the set of tenure variables: < 0.0001. (5). Numbers in parentheses are Heteroscedasty Consistent Standard Errors. * indicates significance at 10% while ** at 5%. Computed from Survey Data, 2022.

value of the crop-only system and the mixed system, but decrease that of the arable crop only system because of the higher investments required for the more complex farming system. When a family is large and the household head is older, the farmland used for the crop-only system experiences higher returns. When the farm-head has more years of schooling, the revenue from the mixed farming system is observed to increase.

Ecosystem management significantly contributes to revenue in all three systems more than the other management practices, perhaps due to the marketable wood and non-wood products from tree crops in farmlands. However, crop and water management as climate-smart practices are lowly significant in crop only systems. Water management is more significant in integrated crop-tree-livestock systems. The country dummies too are significant. The gross revenue for the tree-crop-livestock is lower in RCA than in Cameroon, which is the base case. The revenue for the three systems is significantly higher in DRC.[8]

A typology of climate-smart agricultural land management techniques indicates a variety of measures employed in the Congo Basin to include soil management cost-effective cultural practices which are employed to conserve soil nutrient levels. The agricultural land use accounts for mostly inherited arable croplands, with some under joint extended family ownership, single-family ownership and privately exploited cleared forest land. Most of the ethnic groups report patrilineal inheritance of land assets in typically male-headed households.

The predictors of prevailing land tenure and its effects on tree-husbandry are revealed by socioeconomic factors defining the functionality of farm households. These factors are identified to be the size of farm holdings, age and gender of household head, as well as educational levels, family size, and ethnicity or origin of the household head. The distance to farm plots, forms of land ownership, climate-smart management practices, access to climate information and technology appear as principal factors explaining the performance of the agricultural system. Tenure security is the most significant predictor of the returns to farmland investments. These results corroborate the evidence and stylized facts in previous studies beyond the Congo Basin (Ngoma et al., 2021, Shittu et al., 2021; Amadu et al., 2020; Molua, 2011).

The findings of this study have wider implications beyond the CBF. Countries during COP 26 committed to reform policies to promote sustainable agriculture and accelerate the deployment of ecosystem-based green innovations for the agriculture sector, towards reducing the impact of climate change on the agriculture sector and lowering the sector's contribution to global warming. According to the pledge, "if we are to limit global warming and keep the goal of 1.5 degrees Celsius alive, then the world needs to use land sustainably and put protection and restoration of nature at the heart of all we do" (UN, 2021). This pledge encapsulates efforts required to accelerate the transition to more sustainable land-use practices in forest, agriculture and commodity trade.

The discussions and outcome statements at COP 26 refocused the place of the CBF in the climate change debate in serving the global common. While the role of the Congo Basin is not new, the potentials of the CBF has contributed to the stirring debates whether REDD+ under the United Nations Framework Convention on Climate Change (UNFCCC), could create a financial value for the carbon stored in forests, thus offering incentives for developing countries such as in the CBF to reduce emissions from forested lands and invest in low-carbon paths to sustainable development (Tegegne et al., 2021; Molua, 2012; Somorin et al., 2012). The challenges associated with these initiatives raise some key questions which should be addressed to valorize policymaking to safeguard the opportunities and options associated with CS-CoA. Our results show that CS-CoA is expected to meet immediate local demands of households and farmsteads, while at the same time contributing to the global good.

Implications for Conservation

The CBF is home to invaluable biodiversity, provide livelihoods for local people, and store carbon in their soils and trees. What happens in the farmlands of the CBF affects far more than just the Central African subregion. We have attempted to demonstrate the possibility of CS-CoA in the CBF to increase output, hence food production as well as income and safeguard biodiversity. Contrary to intensive and less environmentally friendly agriculture, properly designed CS-CoA use nature's 'environmental services' including more organic amendments which would mean more biological control for increased biodiversity and resilient agriculture. The implication of CS-CoA is that profitable opportunities exist for food production without degrading natural resource base on which agriculture depends with significant promise for biodiversity conservation.

However, profitable agriculture would require ecological and social sustainability driven by tenure security. Land tenure security can be a lever for improving conservation goals. Nonetheless, the perpetration of unequal land tenure would mean inadequate support for conservation measures in the face of land scarcity, via continuous destruction of cultural and economic trees useful to rural economies.

The fragile ecological assets of the Congo Basin remain pivotal for contemporary efforts to manage the global commons. Climate-smart conservation agriculture practices in the CBF protect soil from degradation, mitigate greenhouse gas (GHG) emission, and restore soil health (Bell et al., 2018; Nyasimi et al., 2014). In the Congo Basin tropical environment these actions mitigate climate change impacts by introducing trees in farmlands. These efforts help to reconcile agricultural production and forest conservation by limiting expansion of croplands into new areas.

The inferences from these findings thus indicate fundamental implications in nature conservation, the management of local and global land and forest commons, as well as for adaptation and mitigation of climate change in the CBF. For instance, tenure security is important, since farmers who are unable to gain access to the agricultural land through sale and inheritance may migrate to areas where farmlands are relatively abundant. In fact, the significant probability that land tenure drives farmland efforts of tree crop management in a prevailing socioeconomic environment influenced by the bioeconomic nature of the farm holdings and operators' households is instructive of efforts required to meet global requirements in managing and conserving the commons in the Congo Basin.

The implication of tenure influencing farm decision-making and farm profitability is that individual land ownership and the dominant user rights on resource conservation could promote natural vegetation to exist in contiguous patterns for the stability of wild biotic resources, soils and water sources; as well as control of natural resources such as managing soils for agricultural production to enhance crop yield and eventual environmental protection.

The nature and practice of agriculture is thus an important driver for biodiversity protection in the CBF. This is urgent in the advent of global warming and climate change. Biodiversity loss from unfair agricultural practices, destruction of ecosystems and habitats on the quest for food and income may in turn threaten the ability to sustain the growing human population in the tropics. This therefore call for promoting climate change adaptation via approaches which are ecosystem-based, nature-friendly, biodiversity-supporting and limiting the use of inputs.

Meeting household and regional agricultural production needs while simultaneously conserving biodiversity thus requires innovative solutions. Policy that promotes innovative approaches, such as integrated crop–livestock systems combined with forestry where necessary, must adhere to local contexts and challenges to create opportunities for diversification and agricultural growth while also mitigating environmental damage.

In addition, the pledges of COP 26, for instance, calling for reduction in deforestation amidst quest by local communities to exploit natural assets for direct productive gains and welfare, would require complementary national and communal efforts promoting better agricultural land use and practices. Empirical field surveys which show that agriculturists choose different farming systems to maximize income while internalizing the tenure regime and environmental conditions they face have important policy implications. This generates knowldege on how local institutions should be managed to promote farm-level investments that enhance welfare while protecting nature in the face of climate perturbations and perception of climate change so that agrarian agents at the frontlines could be veritable partners in conservation efforts in global commons such the Congo Basin.

Conclusion

The benefits of biodiversity is fundamental to societal well-being. Ecologically friendly agriculture can transform society's relationship with biodiversity and ensure nature-friendly production systems. On the heels of climate change, conservation agriculture provides a win-win option for ecological sustainability, better farm values and conservation of nature in agroecosystems. The adoption of conservation agriculture and other ecosystem-based approaches enhances the crucial role of biodiversity for food and agriculture.

This research sought to examine the role of climate-smart conservation agriculture practices on farm returns in the Congo Basin. In achieving this goal, we used approximately 600 farm surveys collected from three Congo Basin countries. We then developed a microeconometric selection model which explains both the agricultural land-use choices and net revenues in tropical farming systems. In the first stage, we explained a farmer´s choice of one of the different farm-ownership types whether joint-ownership, single-family, private commercial or cleared-forested land. In the second stage, system-specific land values or revenues for farming system types, e.g. crop-only system, a crop-tree system, or a mixed system of crops, livestock and trees, are estimated after correcting for selection biases.

The empirical analysis reveals that a mixed farm which manages crops, livestock and trees is not only more profitable but cushions the farm households from the vagaries of climate. These findings highlight the importance of farm-trees and reforestation and further evoke some important policy recommendations amongst which are the need for policies that take a system-wide approach to address agriculture's continually expanding footprint under perceived climate change. There is also need for increased cooperation amongst the front line institutions dealing with the environment, forests, agriculture and land with the goal to ensure properly monitored access while preserve and protect nature and its essential services to people. Regular cooperation and collaboration will ensure timely evaluation and improvement of issues related to inadequate land access, promote climate-smart agriculture, and develop the capacity of farmer-based organizations for a resilient environmental practice which conserves soil and enhances ecosystem benefits. Overall, policy on biodiversity conservation is necessary to build a sustainable food system with climate and ecosystem friendly agricultural practices.

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Data and material available upon reasonable request to the corresponding author.

ORCID iD

Ernest L. Molua https://orcid.org/0000-0001-8724-6035

Notes

1. Discrete choice theory is concerned with understanding the discrete behavioural responses of individuals to the actions of business, markets and government when faced with two or more possible outcomes (or choices). The logistic regression is an efficient and powerful way to assess independent variable contributions to a binary outcome.
2. Mixed logit (or Mixed multinomial logit) model is a highly flexible model that can approximate any random utility model. It is a fully general statistical model for examining discrete choices. The Mixed logit accounts for Heterogeneity by estimating ranges of values of the parameters in the model (McFadden and Train, 2000).
3. The Multinomial Logit (MNL) regression belongs to a class of mathematical techniques employed to address input-output interactions in observational studies where the dependent (output) variable consists of several unordered categories, as well as a set of independent variables (input-variables or explanators), which are used to predict the dependent variable. It is a variant of multiple regression in which the response is binary rather than quantitative. It can be used for classification in multiclass problems, i.e. with more than two possible discrete outcomes, and applied when the dependent variable consists of several categories that are not ordinal such that the ordinary least square estimator cannot be used. Instead, a maximum likelihood estimator like the multinomial logit is used.
4. The basic assumptions that must be met for a logistic regression of this nature include independence of errors, linearity in the logit for continuous variables, absence of multicollinearity, and lack of strongly influential outliers.
5. Land policy here relates to the process of drafting all aspects of land management, including setting the benchmark for acquisition/disposal of land; the social and legal tenure regimes; the distribution structure and mechanisms; the regulation and forms of land-use, management; the administration systems; and the adjudication of land disputes.
6. Growing annual agricultural crops during the establishment of a forest plantation.
7. The standard deviation estimates, not reported, indicate that individual climate parameters are highly significant as well.
8. Two measures of the goodness of fit, given under the table, are high, ranging from 0.12 (McFadden's LRI) to 0.27 (Veall-Zimmermann). The tenure variables as a whole are highly significant determinants of the agricultural system according to the P-value of the Likelihood Ratio test. From the estimated parameters, the model predicts a current agricultural system accurately for 61% of the entire sample. The predictive power of the model falls to 45%, however, when tenure variables are dropped from the model. The Adjusted R-sq is 0.26 for the crop-only system, 0.38 for the crop-tree only system, and 0.53 for the mixed system. As the land value of a specific agricultural system is observed only when the system is chosen, we correct for selection biases from the farmlands that are used for the other systems).

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