Sustainable rebuilding of forest cover in deforested agricultural landscapes in Côte d'Ivoire: Reconciling farmers' objectives with governance

Juvenal Zahoui Gnangoh
CIFOR-ICRAF
Christophe Kouamé
CIFOR-ICRAF
Peter Minang
CIFOR-ICRAF
Alain René Atangana (A.Atangana@cifor-icraf.org)
CIFOR-ICRAF

Article

Keywords: Cocoa agroforestry, Degraded landscapes, Forest restoration, Tree priority species

Posted Date: June 14th, 2023

DOI: https://doi.org/10.21203/rs.3.rs-2971804/v1

Abstract

Commodity production in Côte d'Ivoire has led to significant forest loss, prompting interest in promoting forest restoration in agricultural landscapes. This study analyzed interviews with 1,752 cocoa farmers in 24 protected forests, representing 59.48% of the protected areas in the cocoa production zone. Farmers cited arable land scarcity, low soil fertility, and poor forest control as reasons for forest infiltration. They are willing to introduce 57 woody species, including 32 indigenous species, in and around the surveyed protected areas. Farmers assigned bequest values to preserved forest patches, and economic values to woodlands varied by farmers' origin. Actions to sustain woodland preservation were proposed, and the findings will aid decision-making on land use and forest regulation for restoration in Côte d'Ivoire.

Main

Human-induced deforestation is largely driven by agricultural expansion, with the production of commodity crops being a significant contributor[1]. Cocoa (*Theobroma cacao* L., Malvaceae) is one of the most important commodities in the tropics, with the global cocoa bean market estimated to reach USD 16.32 billion by 2025, while the chocolate industry is expected to reach a retail market value of USD 189.89 billion by 2026[2]. In Côte d'Ivoire, the world's leading cocoa producer with over 40% of cocoa production, pure cocoa stands covered an estimated area of 2,522,170 ha in December 2020, while mixed stands of coffee and cocoa covered 588,160 ha the same year[3]. Almost all of this cropping area results from the conversion of forest areas into croplands, with cocoa deforestation and degradation accounting for 45% of the total forest deforestation and forest degradation from 2000 to 2019[4]. The country had an estimated 993,000 cocoa farmers in December 2020, including foreign migrants from neighboring countries, in-country migrants, and native populations[3]. To stop deforestation and restore forest cover, the Government of Côte d'Ivoire has pledged to restore 5 million ha of agricultural-led degraded lands by 2030 under the Bonn Challenge and has enacted a new forestry code (Law Number 219–675, dated 23 July 2019) with subsequent application decrees that promote tree planting to rebuild forest cover in agricultural landscapes.

For tree planting or "retention" when clearing land for crop establishment to be successful, it must be farmer-driven and consider farmers' objectives. These objectives can be categorized into economic, environmental, or social benefits that farmers can expect from trees[5]. Such benefits would include cash from the sales of tree products, including fruits, nuts, gums, resins, timber, and bark extracts; spices and stimulants; soil fertility improvement; and shade provided to perennial crops such as cocoa[6]. These objectives may also include the total economic value attributed to tree-crop systems[7,8]. While farmers' preferences for tree species should always be considered in programs of tree introduction on farms[9,10,11,12,13,14], the total economic value of tree-based land-use systems as perceived by farmers has been overlooked.

The economic value of an environmental asset reflects the extent to which people are willing to sacrifice something else to obtain or safeguard a quantity of it. This value can be measured as use value or non-use value. Use value can be divided into actual use (direct and indirect) and potential use or option value. Non-use value refers to the existence value of a landscape or values for others such as bequests and altruistic gifts. From a farmer's perspective, tree-based land-use systems can be considered environmental assets as they produce food, timber, and non-timber forest products. They may also provide shade for cocoa and contribute to the build-up of leaf litter as humus beneficial for sustainable crop production. Therefore, it is important to determine whether farmers preserve forest patches for present or future use and whether these patches are protected for future generations or for global conservation.

Measuring the value that farmers attribute to tree-based land-use systems is crucial for their conservation and the formulation of forest conservation policy. This can also help fine-tune the design of perennial crop-based agroforestry systems or other tree-based enrichment-planting scenarios. Perennial crop-based agroforestry systems are complex multi-strata systems whose components are arranged in a spatial or temporal sequence. Designing such systems requires consideration of the social and economic benefits that the trees provide to the farmer, as well as information on the space occupied by the trees for a better optimization of tree-crop interaction in terms of resource capture. Trees should be selected based on their height at maturity, crown diameter, growth rate, and the soil volume explored by their roots, as well as their function in the system and the period of the year when they produce fruit or nuts. Such an approach would increase biodiversity on farms while reducing food insecurity in the rural tropics through the provision of socio-ecologically important fruits and spices all-year-round. However, to achieve the benefits of agroforestry, agricultural reforms that combine environmental benefits and the improvement of smallholders' livelihoods in the tropics are necessary.

To propose best-bet scenarios and policy recommendations for the sustainable rebuilding of forest landscapes in Côte d’Ivoire, this study aims to determine why farmers infiltrate protected forests, the agroforestry tree species that cocoa farmers would like to introduce, and the economic value that farmers attribute to wooded lands they preserve.

Results

Infiltration of protected forests and national carks for Cocoa farming

The infiltration of cocoa farmers in protected forests is significantly influenced by the unavailability of arable land, the fertility of forest soil, and the classification of family land (Table 3). Men are more likely to infiltrate protected forests for farming than women (Table 1). Foreign migrants significantly invade protected forests in the Center-West area for farming compared to native populations and in-country, and poor monitoring was cited as a reason for cocoa cultivation inside protected forests (Table 1). In contrast, farmers who grow cocoa outside protected forests are not motivated to infiltrate protected forests for farming (Table 1). Household size, conservation of woodland, and marital status do not influence farmers' decision to infiltrate protected areas for farming (Table 1). In-country migrants revealed that the land they are farming on in or around protected areas was guaranteed by the alleged landowner (Table 1). However, no interviewed farmer had a land title.

Table 1
Probit model estimates of the determinants of infiltration in protected forests by cocoa farmers in Côte d'Ivoire

	Native populations		**In-country migrants**		**Foreign migrants**	
	Coefficient	z	Coefficient	z	Coefficient	z
Zone						
West	Reference		Reference		Reference	
South-West	0.773	1.63	-0.177	-0.66	-0.461	-1.25
Center-West	0.953	1.65	1.197***	4.22	0.985**	2.67
East	-0.149	-0.53	-0.161	-0.53	0.279	1.29
Characteristics of the farmer and his plots						
Age	0.00522	0.08	-0.00239	-0.06	-0.0855	-1.55
Age^2	-0.000208	-0.30	-0.0000193	-0.05	0.000944	1.82
Education level						
Primary	Reference		Reference		Reference	
Secondary	-0.321	-1.21	-0.771*	-2.03	-0.0650	-0.22
University	0.405	0.71	-0.247	+ 0.68	1.302	1.38
None	0.201	0.71	-0.312	-1.64	0.124	0.54
Gender	0.671*	2.06	0.890**	2.96	0.989*	2.43
Marital status						
Married	Reference		Reference		Reference	
Widow	0.652*	2.16	0.468	1.56	0.475	0.58
Single	0.548	1.08	0.668	1.76	-0.156	-0.16
Number of dependents	0.0587**	2.62	0.0103*	2.23	0.0242	1.38
Household size	-0.00904	-0.44	0.000723	0.42	-0.0353	-1.60
Member of a cooperative	0.743	1.77	0.372	0.80	0.0107	0.04
Farming out of protected areas	-0.918**	-2.96	-0.727***	-4.06	-0.694**	-3.26
Preserve woodlands	-0.0537	0.18	-0.421	-1.52	-0.239	-0.54
Reasons why farmers grow cocoa inside protected forests						

	Native populations		In-country migrants		Foreign migrants	
The family’s land has been classified	2.158***	7.60	1.419***	5.03	1.290**	2.90
Unavailability of arable land	3.232***	5.42	2.474***	5.21	2.158***	5.52
Forest soils are fertile	-		3.083***	6.34	2.922***	7.40
Poor forest monitoring	-		-0.630	-1.14	1.027***	4.50
Guarantee of the alleged landowner			-0.682**	-2.81	0.269	0.73
Sample size	310		578		626	
adjusted R-square	45%		66%		72%	

Table 2
Woody species and perennial crops that farmers growing cacao (*Theobroma cacao*) inside and around 24 protected forests in Côte d'Ivoire would like to introduce on farm

	Tree species	Use	Native/exotic
1	*Acacia_auriculiformis*	Soil fertilizing species, wood fuel	Exotic
2	*Adansonia_digitata*	Fruit species	Native
3	*Afzelia_africana*	Timber, fodder and wood fuel	Native
4	*Albizzia_lebbeck*	Soil fertilizing	Exotic
5	*Anacardium_occidentale*	Nut and fruit species	Exotic
6	*Beilschmiedia mannii*	Nut species	Native
7	*Cedrela_odorata*	Timber and wood fuel	Exotic
8	*Ceiba_pentandra*	Timber and nut (extraction of fat)	Native
9	*Chrysophyllum beguei*	Timber	Native
10	*Citrus limon*	Fruit	Exotic
11	*Citrus paradisi*	Fruit	Exotic
12	*Citrus reticulata*	Fruit	Exotic
13	*Citrus sinensis*	Fruit	Exotic
14	*Cocos nucifera*	Fruit	Exotic
15	*Coffea spp*	Nut	Exotic
16	*Cola nitida*	Nut	Native
17	*Coula edulis*	Nut	Native
18	*Distemonanthus benthamianus*	Timber, medicinal	Native
19	*Entandrophragma angolense*	Timber, wood fuel	Native
20	*Entandrophragma utile*	Timber, wood fuel	Native
21	*Ficus sur*	Timber, medicinal, wood fuel	Native
22	*Garcinia kola*	Nut (cash generation/stimulant), medicinal	Native
23	*Gliricidia sepium*	Soil fertilization	Exotic
24	*Hallea ledermannii*	Medicinal	Native

* The species is preferred by foreign migrants originating from West Africa savannas; ** exotic to the forest zone

	Tree species	Use	Native/exotic
25	*Heritiera utilis*	Timber, dye	Native
26	*Hevea brasiliensis*	Latex	Exotic
27	*Irvingia wombolu*	Nut, sauce thickener	Native
28	*Khaya ivorensis*	Timber, wood fuel	Native
29	*Mangifera indica*	Fruit, medicinal	Exotic
30	*Mansonia altissima*	Timber, medicinal	Native
31	*Milicia excelsa*	Timber, medicinal, dye	Native
32	*Moringa oleifera*	Leaves (food), medicinal	Exotic
33	*Morus mesozygia*	Wood fuel, charcoal production, construction	Native
34	*Nauclea diderrichii*	Timber, dye, spice	Native
35	*Nesogordonia papaverifera*	Timber, medicinal	Native
36	*Parkia biglobosa**	Spice, stimulant, food, dye	Exotic**
37	*Pericopsis elata*	Timber, medicinal	Native
38	*Persea americana*	Fruit	Exotic
39	*Piptadeniastrum africanum*	Timber, medicinal	Native
40	*Pouteria aningeri*	Timber, fruit	Native
41	*Psidium guajava*	Fruit	Exotic
42	*Pycnanthus angolensis*	Wood fuel, medicinal, fat, timber	Native
43	*Ricinodendron heudelotii*	Nut (cash generation), spice, medicinal	Native
44	*Spondias mombin*	Fruit	Exotic
45	*Swartzia fistuloïdes*	Timber, medicinal	Native
46	*Tectona grandis*	Timber	Exotic
47	*Terminalia ivorensis*	Timber, medicinal, wood fuel	Native
48	*Terminalia superba*	Timber, wood fuel, medicinal	Native
49	*Tieghemella heckelii*	Fat, timber, food (nut)	Native
50	*Triplochiton scleroxylon*	Timber, food (vegetables: leaves)	Native

* The species is preferred by foreign migrants originating from West Africa savannas; ** exotic to the forest zone

	Tree species	Use	Native/exotic
51	*Vitellaria paradoxa**	Fruit, fat (nut), medicinal	Exotic**
52	*Xylopia aethiopiaca*	Spice	Native
	Shrubs		
1	*Cajanus cajan*	Soil fertilizing species	Exotic
2	*Gliricidia sepium*	Soil fertilizing species	Exotic
	Perennial crops and monocotyledons		
1	*Carica papaya*	Fruit	Exotic
2	*Borassus aethiopum**	Fruit*	Exotic**
3	*Cocos nucifera*	Fruit	Exotic
4	*Elaeis guineensis*	Nut (vegetable oil)	
5	*Musa spp.*	Fruit (food)	Exotic

* The species is preferred by foreign migrants originating from West Africa savannas; ** exotic to the forest zone

Table 3
Top 14 priority species preferred by cocoa farmers for introduction on farm in and around 24 protected forests in Côte d’Ivoire

	Preferred tree species	Percentage (%) of interviewed farmers
1	*Garcinia kola*	24.99
2	*Ricinodendron heudelotii*	20.77
3	*Terminalia superba*	12.29
4	*Terminalia ivorensis*	5.59
5	*Irvingia wombolu*	5.08
6	*Milicia excelsa*	4.86
7	*Persea americana*	3.84
8	*Cola nitida*	3.69
9	*Citrus sinensis*	2.63
10	*Triplochiton scleroxylon*	2.34
11	*Mansonia altissima*	1.82
12	*Ceiba pentandra*	1.1
13	*Khaya ivorensis*	1.06
14	*Mangifera indica*	1.03
Note : 1.91% of interviewees did not want to introduce trees on cocoa farms		

Species that farmers would like to introduce on cocoa Farms

A total of 54 woody species and 4 monocotyledon species (*Borassus aethiopum* Mart., *Cocos nucifera* L., *Elaeis guineensis* Jacq., Arecaceae; *Musa* spp. L., Musaceae), including 32 indigenous species, were listed for introduction on farms (Table 2). These species provide farmers with numerous products and services, including fruits, nuts, soil fertilization, cash from the sales of fruits and nuts, medicinal products, and timber (Table 2). Top priority species for introduction on cocoa farms varied significantly with the ethnic origin of farmers (Pearson χ^2 = 460.69; P = 0.000) and amongst regions (Pearson χ^2 = 1.3e^{03}; P = 0.000). However, *Garcinia kola* Heckel (Clusiaceae), *Ricinodendron heudelotii* (Baill.) Pierre ex Heckel (Euphorbiaceae), and *Terminalia superba* Engl. & Diels (Combretaceae) ranked top amongst the priority species in each surveyed zone and for all surveyed ethnic groups (Table 3). The same species ranked top overall (Table 3). No gender difference was found among woody species preferences for introduction on the farm (Pearson χ^2 = 71.22, P = 0.250).

Woodland preservation and economic value that farmers attribute to conserved woodlands

Chi-squared tests revealed that the type of woodland preserved varied with farmers' origin (Table 4). Indeed, 53% of interviewed native farmers preserved forest patches, whereas 40% of foreign migrants and 40% of native farmers preserved secondary forest (long-term fallows) patches (Table 4). 45.8% of in-country migrants preserved fallows, whereas 42.4% of foreign migrants and 38.25% of in-country migrants do not want to conserve wooded land at all (Table 4). Farmers mostly attributed bequest value (i.e., value associated with the desire to preserve an environmental asset for future generations) to the forest patches that they preserved, whereas secondary forests and fallows were attributed, respectively, bequest and option (i.e., the use value placed on preserving an asset for future use) values (Pearson χ^2 = 21.01 P = 0.000; Table 4).

Table 4
Percentage of farmers growing cocoa in and around protected forests in Côte d’Ivoire that preserve woodlands ($\chi^2 = 44.68$; $P = 0.000$)

	In-country migrants	**Foreign migrants**	**Native**
Preserve no woodland	38.25%	42.40	19.35
Forest	20.41	26.53	53.06
Secondary forest	20.00	40.00	40.00
Fallow	45.83	35.42	18.75
Total	38.04	41.22	20.74

Discussion

Agroforestry has emerged as a promising approach for restoring forest cover in agricultural landscapes, as it offers a range of benefits, including enhanced soil fertility, increased crop yields, and improved biodiversity. However, the success of agroforestry in restoring forest cover in agricultural landscapes depends on effective governance, which is often lacking in many parts of Côte d'Ivoire, the World’s leading cocoa beans producer. Farmers' objectives for agroforestry may not always align with broader conservation goals, and the absence of clear property rights and weak enforcement mechanisms can make it difficult to ensure that agroforestry practices are sustainable and contribute to the restoration of forest cover. To address these challenges, there is a need for policies and institutions that promote sustainable agroforestry practices and ensure that farmers are incentivized to participate in restoration efforts. This requires a shift from a top-down approach to governance to one that is more participatory, with a focus on building the capacity of local communities to manage their natural resources effectively. For this reason, there is a need for a fine-scale analysis to increase our understanding of the causes of smallholder-driven deforestation for cocoa production.

Results from this study indicate that the unavailability of arable land, forest soil health, frustrations arising from forest classification, and guarantees offered by alleged landowners to migrant farmers are the main drivers of forest infiltration for cocoa farming in Côte d'Ivoire. The study also highlights the need for increased monitoring of protected areas as the migration of populations in search of income is increasing pressure on land. A viable alternative is the restoration of the rural domain through a combination of (i) the participatory development of multi-strata and diversified cocoa-based agroforestry systems that increase, diversify, and sustain farmers' income, (ii) an increase in forest monitoring, (iii) the involvement of farmers' organizations such as cooperatives in the monitoring of forest encroachment reduction process, and (iv) the development and implementation of a truthful traceability system for cocoa beans that would discourage farmers from encroaching on protected forests for cocoa farming.

The development of diversified, productive, resilient, and sustainable cocoa-based agroforestry is underway in Côte d'Ivoire. The cocoa-based agroforestry systems being developed include at least three strata and nine tree species. Concomitantly, the effects of tree species diversity on cocoa crop vigor, productivity, and resilience to climate change are being tested, as well as their effects on farmers' income. Additionally, the effects of tree density and strata on the productivity and resilience of cocoa agroforestry are being examined. The first step in this participatory process was to identify the species that farmers would like to introduce to their cocoa production systems.

Results from this study revealed that 55% of the species that farmers listed for introduction on cocoa farms are indigenous, which is positive news for biodiversity conservation. From the list of top priority species identified in this study, cocoa-based agroforestry systems are being designed and tested for each study site and for farmers' groups surveyed. An important question guiding this research is how many trees of how many species should be introduced on one hectare of cocoa farm to increase the productivity of the system, make it resilient to climate change by reducing evapotranspiration in the event of an increase and prolonged drought, increase carbon stock potential in the system, reduce pest attacks, and manage soil health to sustain production while increasing and diversifying farmers' income. The systems that are developed are suggested to farmers for validation and tested, considering the time it would take for trees in the system to yield fruits and nuts.

Profitability simulations using econometric tools[15] are planned for 4 to 5 years after establishing cocoa agroforestry in order to promote the most profitable strategies. We assume that increasing and sustaining cocoa productivity on one plot while diversifying farmers' income would reduce forest encroachment. However, actions need to be taken to involve farmers in reducing forest encroachment. Cocoa farmers in Côte d'Ivoire often belong to cooperatives, which may have coercive power over farmers during cocoa trade. The creation and animation of environmental committees within cooperatives, as well as training on good environmental practices, may raise awareness among farmers about the reduction of forest encroachment.

Improving the existing traceability systems of cocoa beans and monitoring protected areas using remote sensing tools are necessary to achieve forest encroachment reduction. A recent study[4] revealed that 55%

of Ivorian cocoa beans are still untraced, which is a major concern as cocoa is known to drive deforestation in the country. Traceability can be improved through the establishment of a national database on the geographical coordinates and farm size of each cocoa producer by the regulatory authority of cocoa supply. Additionally, setting a common vision, definition, and standards of traceability to all entities involved in traceability systems in the country can help. The establishment of such a database is possible as each cooperative possesses such information. Therefore, a farmer cannot declare a volume of commodity that is much higher than the known yields. Monitoring forest encroachment reduction can be effectively achieved using satellite time series[16] coupled with very high-resolution drone imagery[17].

Reducing forest encroachment in Côte d'Ivoire can also be achieved by encouraging the preservation of forested land by farmers and establishing market mechanisms that consider the economic value derived from natural resources by cocoa producers. Several innovative efforts are being made to adapt the use of market mechanisms to address environmental issues such as greenhouse gases, water rights, and the promotion of agricultural or organic production methods[18,19,20]. Thus, for a better conservation of forest massifs in cocoa zones, it would be necessary to establish conservation strategies based on indirect incentives whereby the protection of the environment constitutes the secondary benefit. Indeed, forest conservation is neither financially attractive nor ecologically satisfactory[21]. One of the important results of our study is the high proportion of producers giving bequest values and option values to their portions of immobilized forests. These two values granted by cocoa producers, being a deferred use of the natural resource, could be considered in incentive strategies for the conservation of forest massifs in cocoa zones. Based on the theory of incentives, which preserves the neoclassical hypothesis of perfect rationality of agents[22], only direct incentive strategies based on remuneration for conservation efforts can be effective. The theory of incentives, which is based on the notion of agency relationships, generates three types of costs:

- Monitoring and incentive costs (e.g., incentive schemes) incurred by the authority or donors to guide the behavior of the cocoa producer.
- Obligation costs refer to the expenses or losses incurred by cocoa farmers due to the non-exploitation of forest resources. In order to guarantee that they will not undertake actions that may harm the administrative authority or donor, producers may commit to certain behaviors or compensate if necessary.
- Residual loss is the unavoidable difference between the cocoa producer's actions and the results that would have been achieved if the administrative authority or lessor had maximized the welfare of the authority or lessor by preserving natural resources.

The theory of incentives can serve as the basis for implementing biodiversity offsets. This can be achieved through legal obligations outlined in clear regulations, which can help finance the restoration of forests and remunerate forest owners for conservation and restoration measures. Furthermore, large chocolate companies could purchase use rights as a means of biodiversity conservation and reducing economic losses associated with the non-use of natural resources.

The study found that no farmer had land titles for the land they were farming on, the land they offered to migrants for farming, or the woodlands that they preserved for future use. Some farmers even infiltrated protected areas due to frustrations with forest classification. Therefore, land securitization should be encouraged and facilitated, and actions should be taken to encourage woodland preservation for future use. In Côte d'Ivoire, the law supports this acquisition of land in rural areas. Farmers can include woodlands they own in the forest estate of natural persons, as stipulated in Article 25 of Chapter I of the Ivorian Forestry Code. Ownership of a natural forest is vested in the owner of the land on which the forest is located, while ownership of a created forest is vested in the landowner or the person who created the forest under an agreement with the landowner, as stipulated in article 27 of chapter I of the Ivorian forest code. The Ivorian forestry code provisions support the landowner, and awareness campaigns should be conducted to encourage farmers to establish land titles on the land they occupy, supported by a procedure to facilitate obtaining these land titles.

Methods

Sampling

We employed a stratified sampling method for our research. Firstly, we randomly selected 24 protected forests (shown in Fig. 1), which represented 59.48% of the total protected forest area in the cocoa production zone of Côte d’Ivoire[23]. As cocoa is cultivated in and around classified forests, nature reserves, and national parks in Côte d’Ivoire (as evident in Landsat images in Fig. 1), we also considered the major sociological/ethnic groups in our study sites (as listed in Table 5) to investigate farmers' preferences for tree species. Farmers' preferences may be influenced by local cultures, which determine the use of the desired product either for cooking or for traditional pharmacopoeia. Cocoa is grown by smallholders from three different origins in each site, including native populations, in-country migrants, and foreign migrants.

Table 5
Main native sociologic groups that were sampled in a study aimed at identifying the reasons of protected forests infiltration by farmers for cocoa farming in Côte d’Ivoire

Geographical zone	Divisions	Main ethnic groups
East	Zaranou, Abengourou, Agboville	Akan (Agni, Abbey, Krobou)
South-West	San Pedro, Gabiadji	Krou (Kroumen, Bakwé)
Centre-West	Diégonéfla, Oumé	Mandé (Gagou, Gouro)
West	Duékoué, Zagné, Bloléquin, Guiglo	Krou (Guéré, Wobè), Mandé (Yacouba)

Secondly, we randomly selected households farming cocoa inside the selected protected areas or within 2 km of the protected area borders. We interviewed a total of 1572 households, representing native populations, in-country and foreign migrant farmers, using a questionnaire that included both open format and closed questions with single/multiple choices. The questionnaire focused on key issues such as protected forest infiltration for cocoa farming, species that farmers would like to introduce on farms, products or services obtained from tree planting on farms, land tenure, conservation of woodlands, and economic value of woodlands that farmers conserve. The interviews were conducted from January to June 2022.

Data analysis

Infiltration of protected forests and economic value of woodlands

We used the probit model[24] to analyze the data on farmers infiltrating protected areas and preserving wooded lands. The model is defined as follows:

$$y_i = \beta_0 + \sum \beta_i X_i + e_i$$

where y is a dichotomous variable representing infiltration or non-infiltration of the farmer in the protected area, β_0 and β_i are parameters to be determined, X is a matrix representing the sociodemographic, technical, and tenure characteristics of the farmer, and e_i is the error term. The matrix contains variables characterizing the occurrence of cocoa farming activities within protected areas.

Farmers' sociodemographic and technical characteristics may impact their adoption of farming practices[25,26,13] and include:

- The location of the farm, i.e., West, South-West, Center, and East zones of the country.
- The gender of the farmer, as a study[27] reported that this variable influenced farmers' infiltration in the Béki and Bossématié classified forests.
- The age of the farmer. However, introducing only this as a continuous variable may be insufficient as it may have a non-linear effect on the probability of infiltrating protected areas. To account for this, we introduced the squared age, age^2, into the model in addition to the age variable. We assume the existence of a threshold for good or bad behavior, which allows us to expect age^2 to have the opposite sign to age.
- Marital status, set as married, widowed, or single.
- Household size, which indicates the number of people living in the household whose age is between 12 and 65 years. This variable provides an indication of the labor supply available within the household and should have a positive impact on the infiltration of the protected area, as the bigger the family, the higher the level of expenses.

- The number of dependents, which indicates the number of people for whom the individual has financial responsibility. This variable provides an indication of the financial burden of the farmer.
- The level of education of the farmer, which is a categorical variable with four values (None; Primary; Secondary; University). We assume that the more educated the producer is, the more likely he is to become aware of the problem of sustainable management of natural resources, and to be more committed to the protection and conservation of natural resources, thus not participating in the infiltration of protected areas.
- Membership in a cooperative, as cooperatives usually provide training in good agricultural practices, including environment protection, to farmers.

Farmers' preservation of any wooded land was captured as follows:

- The farmer does or does not own land outside protected areas.
- The farmer or his relatives had land that was confiscated during the classification process of protected areas.

Indeed, the conditions governing forest classification were most often in conflict with traditional rights. The state has neither fulfilled the rights of use of local populations surrounding classified forests, nor compensated forest classification[28]. Further, the classification of some forests, such as the Rapide-Grah in the San-Pedro included villages inside the perimeters of the classification zone, without, however, delimiting the terroirs of the villages[29]. For these reasons, some populations living around classified forests continue to claim a right of ownership over the neighboring land supporting the classified forests, even though these forests legally belong to the

A preliminary survey conducted prior to data collection identified four main reasons for forest infiltration, namely:

- Unavailability of arable land, indicating a scarcity of land in the rural agricultural domain according to the farmer. This binary variable takes the value 1 if the farmer identifies it as the main reason for their infiltration.
- Difficulty in accessing land, which expresses the challenging conditions for accessing land according to the farmer. This variable takes the value 1 if it is the farmer's main reason for infiltration.
- Health of the land, which expresses the level of fertility of the land in the protected forest according to the farmer. This variable takes the value 1 if it is the main reason for infiltration.
- Poor monitoring of protected areas, a binary variable which expresses the farmer's apprehension about the level of control of protected areas by the local administration. This variable takes the value 1 if the farmer's main reason for infiltration is the low level of control.

Additionally, farmers' priority species for introduction on cocoa farms were identified, and data analysis was conducted using frequency tables, mosaic graphs to observe variable distribution, and the chi-square test of independence for variables[30,31].

Declarations

The authors declare no competing interest.

Acknowledgements

This work was funded by Unilever plc. We would like to thank Valentin Wolf (CIFOR-ICRAF and GIZ) for drawing the map.

Source Data

The data analyzed in the present study are provided in an attached Excel spreadsheet file.

References

1. Loso Bayas, J.C., See, L., Georgieva, I., Schepaschenko, D., Dylo, O. et al. Drivers of tropical forest losses between 2008 and 2019. Scientific Data 9: 146 https://doi.org/10.1038/s41597-022-01227-3 (2022)
2. Voora, V., Bermúdez, S. & Larrea, C. Global market report: Cocoa. IISD https://www.iisd.org/system/files/publications/ssi-global-market-report-cocoa.pdf (2019)
3. Conseil du Café Cacao Cote d'Ivoire. Recensement des producteurs de café cacao et leurs vergers. Report (2020)
4. Renier, C., Vandromme, M., Meyfroidt, P., Ribeiro, V., Kalischek, N. & Ermgassen, E.K.H.J.Z. Transparency, traceability and deforestation in the Ivorian cocoa supply chain. CABI Digital Library https://doi.org/10.31220/agriRxiv.2022.00156 (2022)
5. Leakey, R.R.B. From ethnobotany to mainstream agriculture: socially modified Cinderella species capturing 'trade-ons' for 'land maxing'. *Planta* **250**, 949-970 https://doi.org/10.1007/s00425-019-03128-z (2019)
6. Leakey, R.R.B. A re-boot of tropical agriculture benefits food production, rural economies, health, social justice and the environment. *Nature Food* **1**, 260-265 https://doi.org/10.1038/s43016-020-0076-z (2020)
7. Farber, S.C., Costanza, R. & Wilson, M.A. Economic and ecological concepts for valuing ecosystem services. *Ecological Economics* **41**(3), 375-392. https://doi.org/10.1016/S0921-8009(02)00088-5 (2002)
8. Carrasco, L.R., Nghiem, T.P.L., Sunderland, T. & Koh, L.P. Economic valuation of ecosystem services fails to capture biodiversity value of tropical forests. *Biological Conservation* **178**, 163-170. https://doi.org/10.1016/j.biocon.2014.08.007 (2014)

9. Franzel, S., Jaenicke, H. & Janssen, W. Choosing the right trees: Setting priorities for multipurpose tree improvement, research report, 8. ISNAR, The Hague, The Netherlands, p 87 (1996)
10. Franzel, S., Akinnifesi F. K., & Ham, C. Setting priorities among indigenous fruit tree species in Africa: examples from southern, eastern and western Africa regions. In: Akinnifesi FK, Leakey RRB, Ajayi O (eds) Indigenous fruit trees in the tropics: domestication, utilization and commercialization. CABI, pp 1–27 (2008)
11. Maghembe, J., Simons, A.J., Kwesiga, F. & Rarieya, M. Selecting indigenous trees for domestication in southern Africa. ICRAF, Nairobi, Kenya, p 94 (1998)
12. Sotelo Montes, C. & Weber, J. C. Priorizacion de especies arboreas para sistemas agroforestales en la selva baja del Peru. *Agroforesterıa en las Americas* **4**(14): 12–17 (1997)
13. Atangana, A.R., Zahoui Gnangoh, J., Kouassi Yao, A., Kouakou, T.A., Mian, N.D.A. & Kouamé, C. Rebuilding tree cover in deforested cocoa landscapes in Cote d'Ivoire: Factors affecting the choice of species planted. *Forests,* **12**, 198 https://doi.org/10.3390/f12020198 (2021)
14. Leakey, R.R.B., Avana-Tientcheu, M.L., Awazi, N.P., Assogbadjo, A.E., Mabhaudhi, T., Hendre, P.S., Degrande, A., Hiahla, S &, Manda, L. The future of food: Domestication and commercialization of indigenous fruit crops in Africa over the third decade (2012-2021) *Sustainability* ***14*** *(*4): 2355 https://doi.org/10.3390/su14042355 (2022)
15. Current, D., Lutz, E. & Scherr, S. The costs and benefits of agroforestry to farmers. *The World Bank Research Observer* **10**(2): 151-180 https://doi.org/10.1093/wbro/10.2.151 (1995)
16. Decuyper, M., Chávez, R.O., Lohbeck, M., Lastra, J.A., Tsendbazar, N., Hackländer, J., Herold, M., Vägen, T.-G. Continuous monitoring of forest change dynamics with satellite time series. *Remote Sensing of Environment* **269**, 112829 https://doi.org/10.1016/j.rse.2021.112829 (2022)
17. Olariu, H.G., Malambo, L., Popescu, S.C., Virgil, C. & Wilcox, B. P. Woody plant encroachment: Evaluating methodologies for semiarid woody species classification from drone images. *Remote Sensing* **14**(7), 1665 https://doi.org/10.3390/rs14071665 (2022)
18. Aykut, S.C. Gouverner le climat, construire l'Europe: l'histoire de la création d'un marché du carbone (ETS). *Critique Internationale* **1**, 39-55 (2014)
19. Le Coq, J.-F., Pesche, D., Legrand, T., Froger, D., Saenz Segura, F. La mise en politique des services environnementaux: la genèse du Programme de paiements pour services environnementaux au Costa Rica. VertigO: *La revue électronique en sciences de l'environnement* **12** (3) https://doi.org/10.4000/vertigo.12920 (2012)
20. Karsenty, A., Sembres, T., Randrianarison, M. Paiements pour services environnementaux et biodiversité dans les pays du sud. *Revue Tiers Monde* **2**, 57-74 (2010)
21. Niesten, E., Rice, R., Gonzalez, D. & Karsenty, A. Gestion durable des forêts et incitations directes à la conservation de la diversité. *Revue Tiers Monde* 129-152 (2004)
22. Jensen, M.C. & Meckling, W. H. Theory of the firm: Managerial behavior, agency Costs and ownership structure. Book chapter; in RI Tricker, Corporate Governance https://doi.org/10.4324/9781315191157 (2000)

23. SODEFOR. Décision N° 02655 – 19/DG/DARH du 15 Juillet 2019 portant découpage des unités de gestion forestière. SODEFOR, Côte d'Ivoire. Retrieved March 21, from http://sitesodefortest.e-bordereaux.ci/images/pdf/liste-fc.pdf (2019)
24. Godeau, U. & Gosselin, F. Les modèles statistiques classiques d'analyse des données binaires, source de biais d'estimation importants? Premières Journées Scientifiques Annuelles des sites INRAE du Loiret (2020)
25. Etshekape, P.G., Atangana, A. R. & Khasa, D. P. Tree planting in urban and peri-urban of Kinshasa: Survey of factors facilitating agroforestry adoption. *Urban Forestry and Urban Greening* **30**, 12-23 https://doi.org/10.1016/j.ufug.2017.12.015 (2018)
26. Dhakal, A. & Kumar Rai, R. Who adopts agroforestry in a subsistence economy? Lessons from the Terai of Nepal. *Forests* **11**, 565 https://doi.org/10.3390/f11050565 (2020)
27. Atta, J.M.K.., Robin, M., Touré, A.T., Pottier, P. & Oswald, J. (2017) Déforestation et conflits fonciers dans les forêts classées de Béki et de Bossématié dans l'est de la côte d'ivoire. Espaces et tensions en Afrique subsaharienne. Ed. Universitaires Européennes, 357-387 (2017)
28. Akouré, Y. Les Aspects conflictuels liés à La conservation des aires protégées de Côte d'Ivoire : Le cas du Parc National de La Marahoué. Mémoire, Abidjan: Université d'Abobo-Adjamé. (2005)
29. Traoré, K. Le couvert forestier en Côte d'Ivoire : une analyse critique de la situation de gestion des forêts (classées, parcs et réserves). *The International Journal of Social Sciences and Humanities Invention* **5** (2), 4387–97. https://doi.org/10.18535/ijsshi/v5i2.02 (2018)
30. Bosia, E. Les tests du Khi^2: ajustement et association. Editions Publibook (2020)
31. Dufour, A.B. & Lobry, D.C.J. Tests du Khi^2. *Diagnostique* **13**, 7. (2015)

Figures

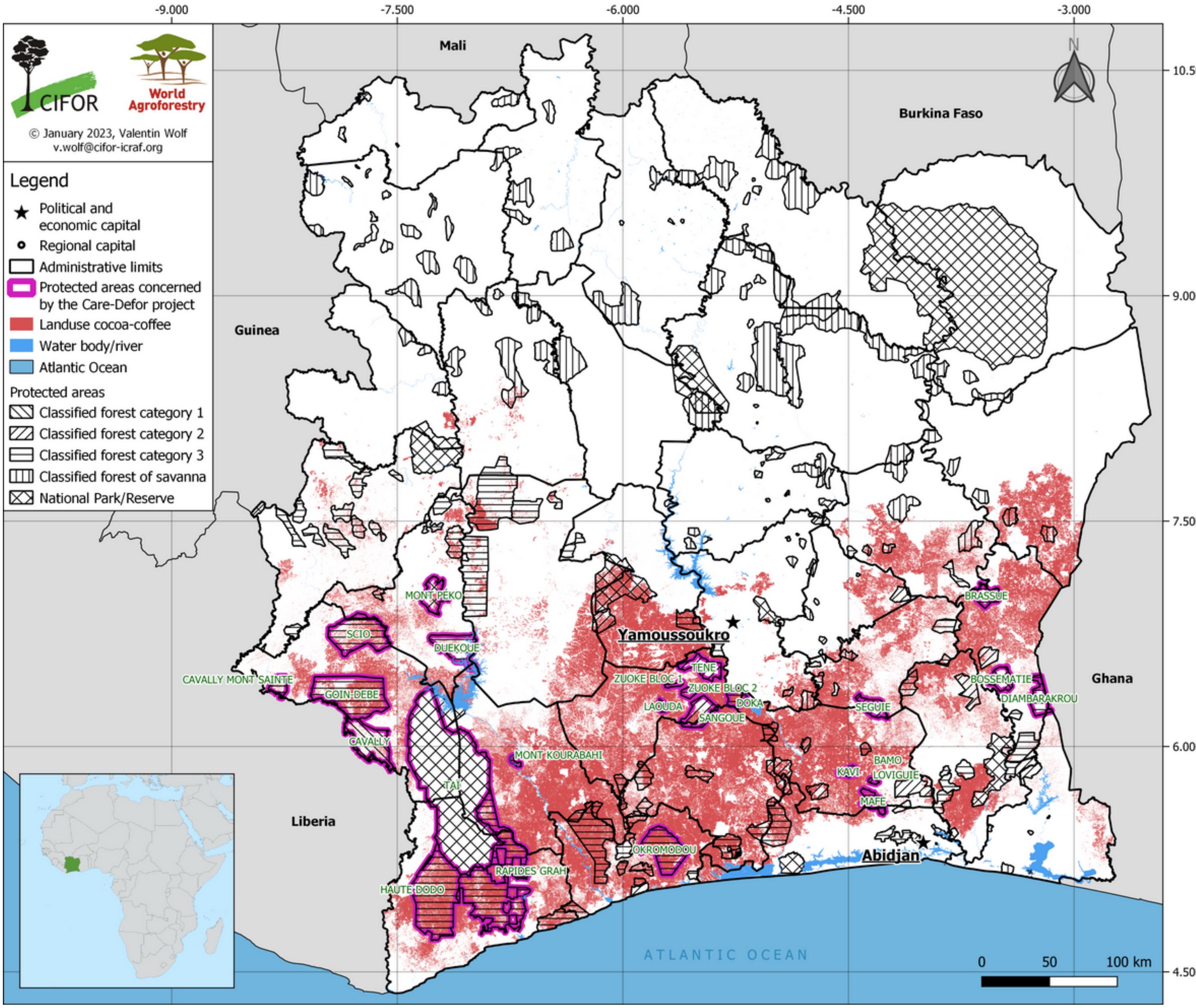

Figure 1

Protected forests that were surveyed in a study aimed at determining why farmers grow cocoa in and around protected areas in Côte d'Ivoire