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Spatial projection of dynamic modeling system: Exploration of Rubber tree plantation and the consequences of REDD+ for the populations of Toumodi in Côte d'Ivoire

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Abstract

This study aims at developing a model to investigate agricultural land change in the District of Toumodi due to the introduction of rubber tree and to evaluate the subsequent impact on the forests and the revenue of farmers. Using Landsat images processed with GRASS software, and VENSIM as dynamic modeling tool, three scenario were evaluated:(1)the actual trend of rubber tree planting in the District, (2) an accelerated trend of plantations by entrepreneurs mostly from cities, and (3) preserving land through REDD+ program. The results indicated that under scenario 1, deforestation rate was 0.85 %, which resulted, 30 years later, to 33,000 ha of land cleared while the second scenario lead to 2.13 % deforestation. In the third scenario, the rate was 0.62%, and forest will represented 12.23 % of the territory. Land converted to rubber tree plantation was mainly located nearby the villages or alongside roads leading. Planting rubber reduces lands traditionally devoted to subsistence crops, which may lead to food shortage and food insecurity in the District. It may also cause biodiversity erosion because rubber plantation is a monoculture, leading to the disappearance of non-forest products. The revenues of farmers nearly doubled in scenario 2 due the benefit from sharing with the entrepreneurs, the production of their lands while preserving or maintain forest lands will halve the revenues of farmers. In scenario 3, about 329,000 tons of carbon was gained but its revenue was clearly not enough to motivate farmers to protect or expand protected forests.

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Introduction

In the years 1990 and 2000, while production of industrial plantations was stagnant, Côte d'Ivoire has experienced a boom in rubber production by farmers. Early 2006, according to a survey of 1,100 farmers in 12 Districts, conducted on the behalf of the European Union, rubber was "already and yet" ranked second best profitable crop, just behind cocoa, long before palm and coffee (Ruf, 2014).In 2008, farmers perceived rubber as the crop at the forefront profitability. Nurseries and young plantations of rubber trees were emerging everywhere alongside roads. Already exhausted by a desperately low price of cocoa for several years and, the short dry season of 2007 that extends and increases cocoa mortality, many farmers lose confidence in their historical culture (Ruf and Akpo, 2008 unpublished). In the countryside and in the cities everyone wants to plant rubber tree. Local and international media seized it and draw reports reinforcing the promotion of rubber.

Today, Côte d'Ivoire is the first largest African producer of natural rubber. Private own farms cover 44,500 ha of which 85% is producing; 2,300 ha of whom 98% are operational are owned by research institutes. Farmers own 59 500 ha of which 77% was in production (Valognes *et al.*, 2011). The master plan for the development of rubber sector forecasted 330,000 ha planted and a production of 365,000 tons by the year 2015 (Ruf, 2014). Even though this might not feasible because of the drop of the price, however there is a very rapid conversion of land to rubber trees. Indeed, the cultivation of rubber trees, mainly done originally in the forest regions of western, southern and eastern Côte d'Ivoire is becoming more and more done in the savanna regions in the center of the country.

Since 2005, the Reduction of Emissions from Deforestation and Forest Degradation (REDD+) is a voluntary process which aims to encourage developing countries to adopt measures to reduce deforestation and forest degradation. Countries that manage to effectively reduce deforestation will be rewarded either by carbon credits or financially by an international fund created for this purpose (Karsenty and Pirard, 2007). Since 2008, it has become a key instrument for tropical countries in the negotiations on climate change carried out within the United Nations framework (AFD, 2011 unpublished).

The implementation of this mechanism bestows three advantages to these countries. The first one is environmental and corresponds to both local and global effects concerned country will receive rewards or financial compensation. The third advantage is commercial and is bestowed to developed countries who will voluntarily participate in REDD+ projects (Karsenty *et al.*, 2012) obtaining tradable carbon credits in international markets.

In the Region of Toumodi, we observed in recent years, a strong tendency of the peasants to grow in terms of reduction of greenhouse gases (GHG) emissions due to the avoidance of deforestation and forest degradation. The second is of socio-economic concerns by reducing the national rates of deforestation and forest degradation. Within a few years, this District could be the new Eldorado for rubber cultivation. Even though it is more costly to grow, according to farmers, it is a safe and profitable investment, especially after the destruction of cocoa plants affected by swollen shoot. Therefore, in many villages of this District, rubber plantations are increasingly replacing gradually forest lands, savannah, fallow or old cocoa plantations.

It was therefore, necessary to understand the dynamics of the interactions between communities and land resources and how this affects forest cover, the well-being of farmers, and forest resources under different scenarios. This research was initiated to model and predict future rubber tree plantation growth in the Region of Toumodi. The objectives were to: (1) develop an operational model for regional agricultural land use change; (2) simulate future farmer’s income growth in the region based on different scenarios; and (3) predict spatial extents of future agricultural expansions through to the year 2030.Quantified, visualized, and specialized information on future land use obtained through this research will benefit decision-making regarding planning, environmental impact studies, and general public education.

Material and methods

Study area

The study was conducted in the Region of Toumodi, located between the latitudes 6°12' W and 6°50' N and longitudes 4°50' and 5°20' in the southern part of the "V" Baoulé in the central part of Côte d'Ivoire (Fig. 1).

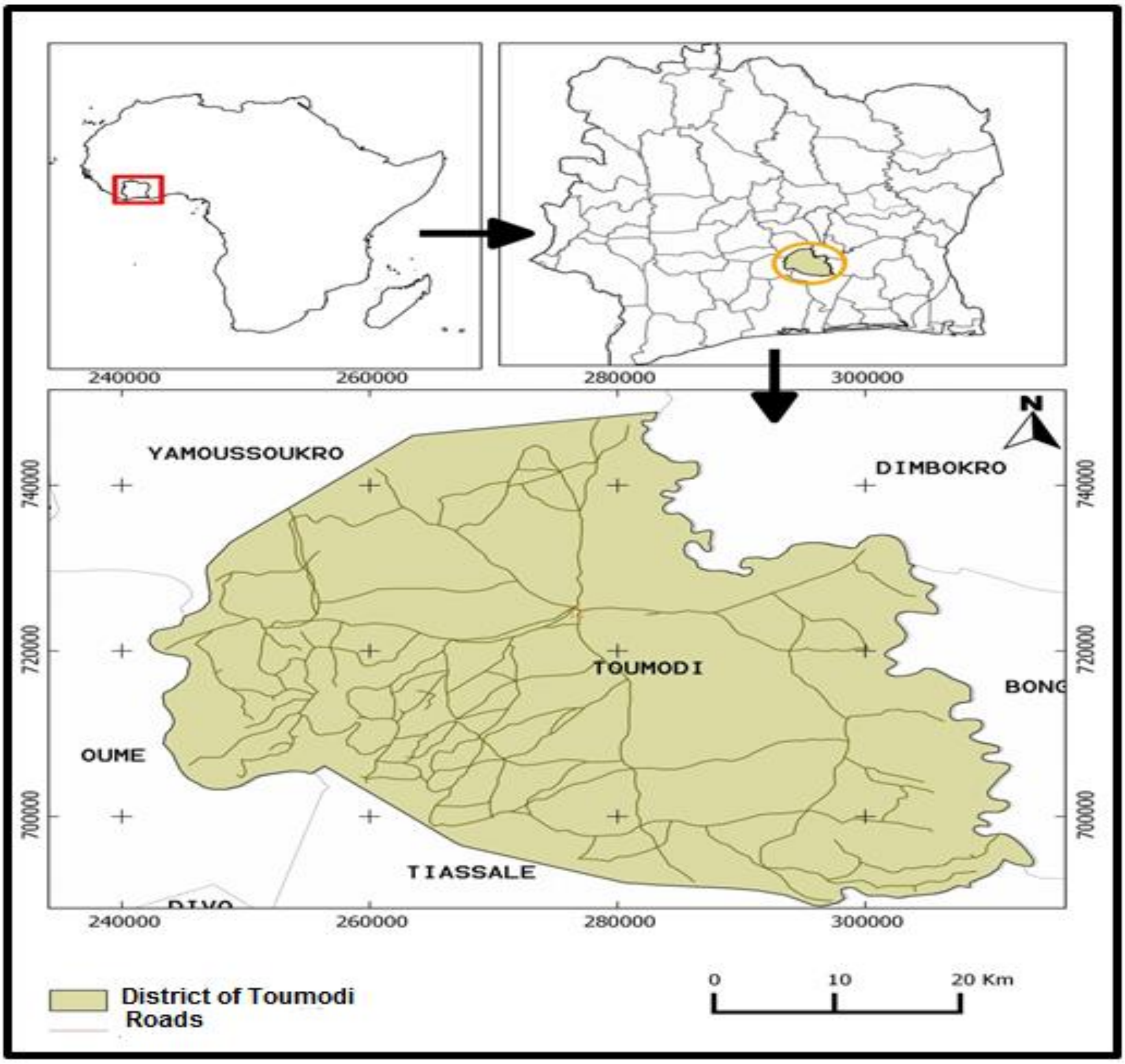

Fig. 1. Localization of the study area, the District of Toumodi in Côte d'Ivoire.

It covers an area of 3032 km². According to the national population census, the population was 130 000 inhabitants (INS, 2002). This population was estimated to be 142.696 inhabitants with a density of 51 inhabitants per km², with an annual growth rate of 2.5%. This population is young, 57% are under 20 years old and the urbanization rate is 35%.

Climate is tropical and humid with alternating two rainy seasons and two dry seasons. The average annual rainfall is less than 1,200 mm. Vegetation is that of the transition zone of forests and savannas (woodland, tree and shrub). It consists mainly of savannah in the north, forest islands in the south and west, and gallery forests alongside rivers covering one-quarter of the Region (Bettignies, 1969).

Agriculture represents 60-65% of the overall economy of the District. Cash crops are dominated by cocoa and coffee, and staple crops by yam and cassava. Livestock is poorly represented and concerns poultry, swine and cattle (ANADER, 2012).

Dynamic modeling

The participatory modeling was based on an approach described by the Center for International Forestry Research (CIFOR) (Mendoza and Prabhu, 2007). A system dynamics model was built using the stock-and-flow model software (VENSIM PLE) with an icon based interface and availability of array functions (Costanza and Ruth, 1998; Costanza and Voinov, 2001). System dynamics is a concept that considers the dynamic interaction between the elements of the studied system and can help to understand their behavior over time, build models, identify how information feedback governs the behavior of the system and develop a strategy for better management of the studied system (Doerr, 1996).

The study was conducted in 2014-2015 using data inputs and assumptions from interviews of farmers, Experts from the Local Agricultural Bureau and the Regional Forestry Bureau. The local Extension Bureau of Rubber company (Tropical Rubber Company of Côte d'Ivoire) were also involved, Unpublished data and other sources of information were also used when necessary (Table 1).

The present study involved a process of model building with active participation of 50 informants (focus group) representing purposively selected farm households from five villages and diverse categories of wealth, age and gender within these villages to obtain diverse information. The selection was made with the help of district Agricultural Bureau and the Rubber Company representative by picking up those individuals who had formal education and considered reasonably able to understand the topics, express feelings, opinions and perspective on the situations.

The purpose was to obtain good understanding of their objectives in resource management and building on their knowledge about the trends of the local environment and livelihood (Sayer and Campbell, 2004). Wherever data was lacking, information was provided through the focus group dialogue and consensus. This helped to improve the input data of the different sectors of the model for exploring reasonable socio-economic and environmental pathways.

Three main scenarios were elaborated. The first one was named "business as usual" and did not assume any significant change in the future conditions or farmers' behavior. The second scenario, "willingness to grow more rubber trees", was reflected by a number of assumptions (government and local efforts for socioeconomic development). The third scenario, "REDD+" was put in focus and modeled as a pathway for preserving the woody vegetation and benefit from carbon credit (e.g., woodland forest is a source of firewood, charcoal, construction material, medicinal plants for the local farmers' consumption). We introduced this last scenario in order to express the availability of wood for households' consumption, medical use and resuming of additional forest cash income for livelihood. Currently, the woodland forest is almost disappearing and the forest resources and biomass collection (firewood and charcoal for sale and consumption, NTFP) are shrinking rapidly.

The model structure included three sub-models or sectors representing components of the socio-economic and environmental systems. These are land-use and cover, population, farmers' incomes and carbon stock in the biomass (Fig. 2).

The model simulated all variables over a period of 30 years. In the model the land-use stock is described as a function of changes in different categories of land-uses, human population dynamics and forest increase scenario. Land-use data inputs and assumptions are presented in Table 1. Those assumptions were based on historically observed trends and a discussion with the local farmers on what would be reasonable in the dynamics of land-use.

The human population size is described as a function of growth rate, death rate and emigration. The population growth is influenced by the proposed family planning, health and education scenarios. Crop production was based on farm size of the households, human population dynamics, the variability of rainfall and the availability of financial resources.

The model was built for an average household whose farm size is 2 ha, with a cropping area of mixed cassava-yam-banana-vegetables (70%), cocoa (25%), and rubber trees (5%). The estimated average annual crop productivity of cassava was 10 tons/ha while yam was25tons/ha. Cocoa annual productivity was 2.0-2.4tons/ha while it was 0.5 tons/ha (0.45 – 1.5) for rubber tree. On the farmland, food crops are grown for subsistence and cash needs of the farming households. Crop net income (both consumption and cash) was calculated by subtracting the estimated crop cost and loss (43% of total crop income) from the total household crop income. In the study area, the economic contribution of the livestock sector is nearly zero. All farmers do not have all kind of livestock goods throughout the year but buy and exchange internally for their own use. All monetary values were reported in the franc CFA, where €1 = 565 FCFA in 2014.

Model testing is an essential part of the model development process. If the model is to be used, it should provide relatively accurate information about the system being modeled. In this study, because of the lack of data, the model could not be validated.

Spatial modeling

For statistical modeling, a multivariate logistic regression model was selected to represent the nonlinear nature of land use (Landis and Zhang, 1998). This model is a special case of the multinomial log it model developed by McFadden (1987) and conceptually based on the random utility theory and discrete choice theory in urban economics and behavior science. Whether the utility of land is measured in terms of farmer income, rubber price, or land availability, it is a function of attributes of land use choices and characteristics of land decision-makers. The utility function can be defined as a linear combination of attributes of land use choices.

Six images from LANDSAT scenes 196-55 and 196-56, each covering part of the District of Toumodi were obtained freely from the USGS (www.glovis.usgs.gov). These pictures were taken in the dry season in order to reduce the reflectance due to cloud cover. Digital elevation model layer (DEM), administrative boundary grid layers of the District, road network and village's layers were provided by the Forestry Department of Toumodi.

The processing of the image with ENVI software consisted on using the compositions of 5-4-3 bands of each scene in order to distinguish vegetation types. The maximum likelihood classification was used to assign each pixel of the image to class of land use identified during the field visit (KOUADIO, 2010). Then, the free software GRASS was used for the spatial modeling of land use/cover. As proposed by Ben Said *et al.* (2003), the multi-criteria statistical analysis (MCA) was used to determine the risk factors underlying land use. Four factors: altitude (Alt), distance to localities (Dvillage), distance from road (Droad) and distance to rivers (Driv) were used for this purpose (Sow, 2012 unpublished).

Logistic regression was used considering land cover change as the dependent variable and the independent variables the four factors. The logistic regression model used is given by the formula.

$$Y = \log\left(\frac{P_i}{1-p_i}\right) = \beta_0 + \sum \beta_i X_{ij} \quad (1)$$

Where $P_i$isthe probability that there is deforestation;β_o, a constant; βj, a coefficient (available for each criterion); X_{ij}, the explanatory variables or factors.

The probability P is given by the formula

$$P_i = \frac{e^Y}{1+e^Y} \quad (2)$$

A code was assigned to different variables in order to rank the importance of the phenomena and variables, but also to take into account the range of values of the phenomenon or variable subjected to review (Bannari *et al.*, 2007).

For the realization of the map of risks, a factorial map correlated with the dependent variable was made by making buffers around the selected variables. Thereafter, the resulting risk map of the district was made according to the complete aggregation method used by several authors (Jourda *et al.*, 2006; Conchita and Kêdowidé, 2010).

The objective of this method was to aggregate the n criteria (factorial map) to reduce them to a single map.

Aggregation is the combination of the criteria thus expressing the probability Pi of the occurrence of deforestation in the study area.

Results and discussion

Trend of land utilization

Fig.3 illustrated land utilization in the three scenarios. The scenario 1 corresponded to the normal trend of land clearing for the growth of rubber tree in the District of Toumodi.

The map showed that forests were found in the southeast and west/northwest of the District.

The central part of the District where roadways are well developed and more villages are found were the areas where lands' clearing was prevailing.

Table 1. Data inputs and assumptions for 'land-use model sector' in studying the trends of land-use using three scenarios.

Data	Parameters	Assumptions		
		1	2	3
Total area of the department: 3025 km²	1. average conversion of woodlands to rubber tree plantations (ha/year)	120	350	50
Current area of cropland: 315,60 km²	2. Land converted to other agricultural plantations woodlands (ha/year)	150	0	90
woodland: ~300 km²	3. Mean reforestation rate (ha/year)	70	0	75
Savannah and others: ~2409 km²	4. annual conversion of agricultural land to rubber plantations (ha/year)	~150	250	0
Conversion for agriculture: 0,5-1,5 ha	5. annual conversion of agricultural land to fallow (ha/year)	~35	0	0
Annual reforestation 1 ha/150 m3 of logging	6. Fallow converted to farmland (%)	60	60	0
Annual logging volume: 8000 - 15000 m3	7. Fallow converted to rubber tree plantations (%)	20	40	0
Total population : 105 656 habitants	8. land area favorable to rubber cultivation (ha)#	10 730	29 800	0
rural population: 35% urban population: 65% Birth rate: 2.5 - 4.5%	9. Reforestation (ha/m3) of timber logged	0	0	0.007

actual planted area of cocoa

Some croplands are put in fallow after two years of farming, and part of fallow is converted into cropland.

Rubber tree gives its full potential on land between 300 and 600 meters above sea.

Considering that tolerance of rubber tree cultivation to factors such as altitude, soil fertility and, rainfall will result in the increase on land devoted to rubber tree plantations.

Data sources: District Forest Bureau, ANADER, District Agriculture Bureau, National Institute of Statistics.

Scenario 2 represented the new trend of growing rubber tree in the District. The map showed a progress of forest clearing and degradation for the settlement of rubber tree plantations. This trend was more important in the south-east and in the west where the access to land was easier because of the proximity of villages and roads.

In the scenario 3, the accent was put on the reduction of deforestation and forest degradation in the vein of preserving forests.

It was noticed that although deforestation was curbed, forest land cover will be under the level of 2002 which was the reference level. Land use change.

Table 2. Part (%) of each activity in the household's income based on the three scenarios.

Scenario	Agriculture without rubber plantation	Forest products	Rubber tree plantation
1	13.28	0.21	86.51
2	3.62	0.17	96.21
3	18.58	0.24	81.18

Fig.3 showed the evolution of land cover/use over time for the three scenarios. Scenario 2 presented the highest conversions of forest to agriculture use mainly rubber tree plantation. The outcomes of Scenarios 1 and 3 did not differ significantly with regard to farmland conversions. Currently, rubber tree plantations occupied 833 ha of land in the Region or 4.3 % of the land devoted to cash crops and 2.7 % of all agricultural land.

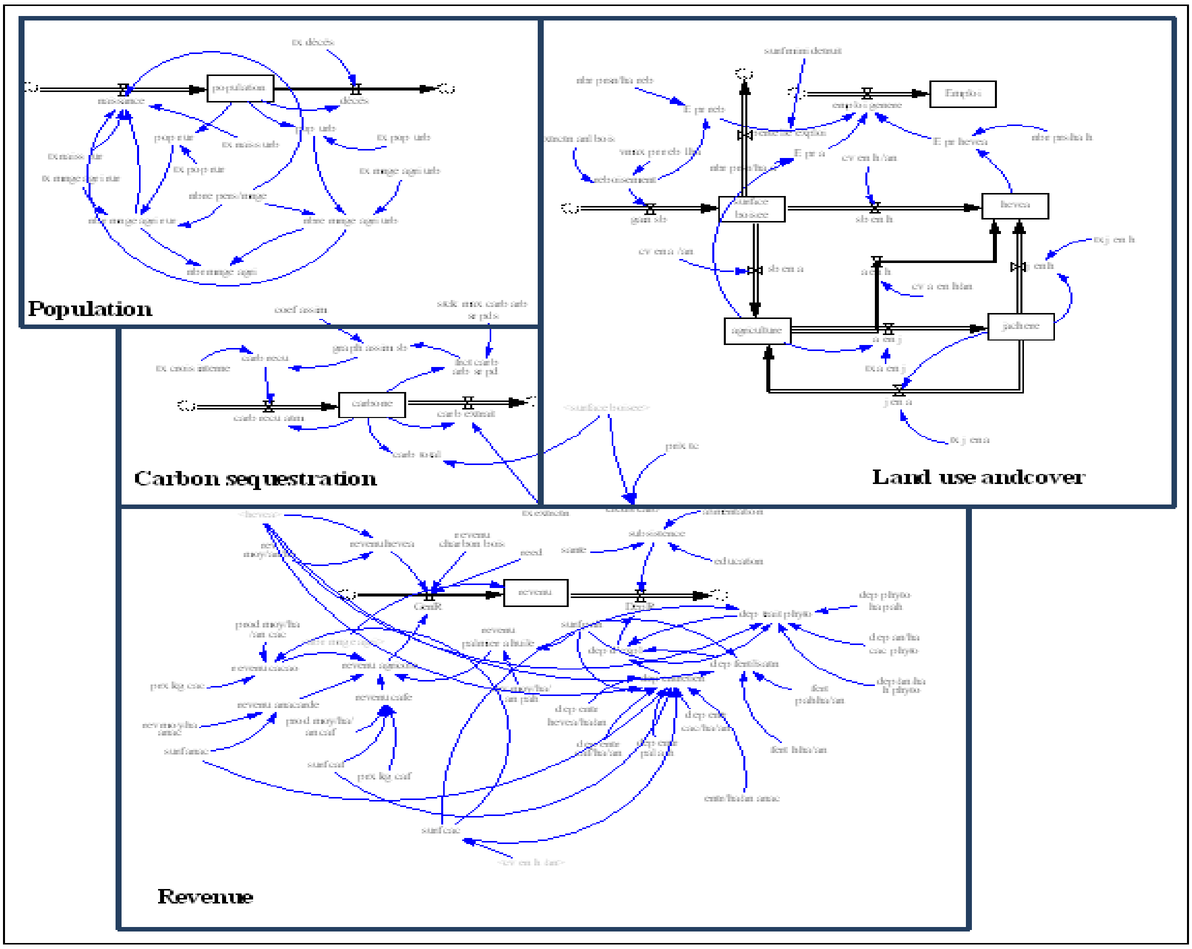

Fig. 2. Map of the four sub-models used in the modeling process.

If we consider the current situation (scenario 1), the simulation gave a deforestation rate of 0.85 %, which will result,30 years later, to 33,000 ha, approximately 11% of the total land cover. In scenario 2, which considers a high trend for rubber tree plantations, the deforestation rate was found to be 2.13 % after 30 years, the wooded land will account for about 28,000 ha or 9.26%. In the case of environmental consideration (REDD+), the deforestation rate was found to be around 0.62%, and woodlands will represent 37,000 ha or 12.23 % of the territory.

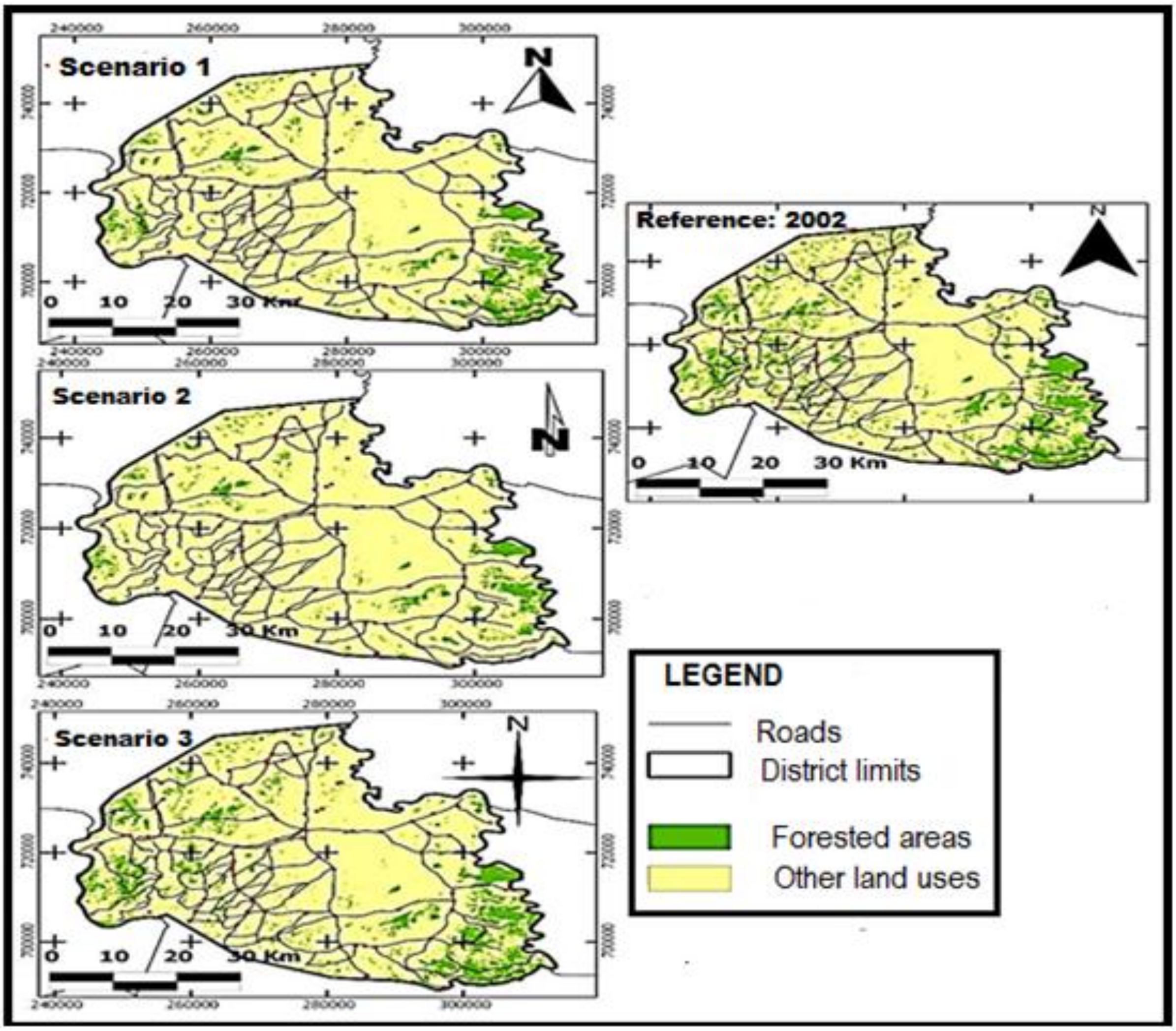

Fig. 3. Maps of land use and cover, produced projection GRASS under the three explored scenarios.

Overall, the results indicated that conversion of land to rubber tree plantation was mainly located nearby the villages or alongside roads. In general, arable lands are encountered nearby villages. For this reason, they are the first to be cleared for rubber tree plantations. Studies have demonstrated that deforestation was strongly correlated with demography (N'Da, 2008). Similarly, it is through roads that agriculture inputs and production will reach farmers and consumers.

In scenario 3, deforestation due to rubber tree plantation is not due to peasants who could only grow one to two ha per year.

It will be done mainly by entrepreneurs (city dwellers) who have financial resources and afford to purchase lands or practice the “aboussan” system which consists of planting then share the revenue from the production with the land owner. Here the size of farms can reach 100-300 ha even more.

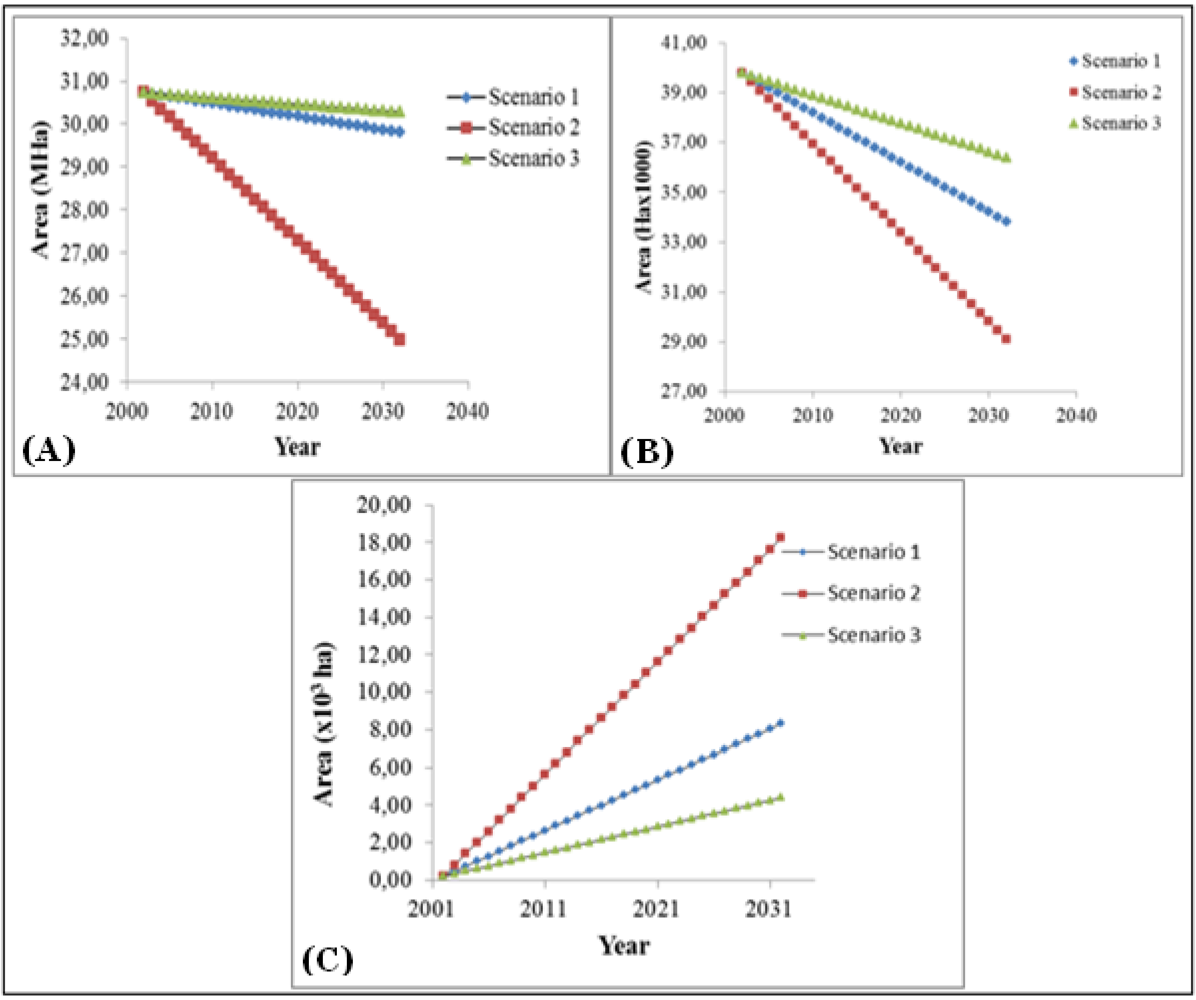

Fig. 4. Evolution of the area of land devoted to rubber tree (A), to agriculture (B), and forests (C).

Traditional farming agriculture as practiced in the District of Toumodi was dominated by cocoa (82% of the area of cash crops), and yam-cassava (61%of the land occupied by food crops) and gardening. Whereas in scenarios1 and 3, the lands devoted to agriculture (excluding grubber trees) remained stationary, about 30,000 ha after 30 years of simulation, inscenario2, there is a decrease of land allocated at the rate of 0.81% going from 25,000ha to reach 5,000haafter30 years which corresponds to a conversion of more than5,000ha of agricultural land to rubber tree cultivation.

Concerning the evolution of rubber tree plantations, the three scenarios showed an increase inland allocated to rubber tree cultivation over time. This increase was very low (0.38%, 0.85% and 0.27% of farmland and wood land respectively in scenarios1, 2 and 3). If agriculture maintains its current level (scenario 1), the land allocated to rubber tree plantation should be around 8,500 ha. In the conservation scenario, the pace of land allocation to rubber tree cultivation was rather low after 30years, 6,000ha. In scenario 2, the rate of rubber tree planting was very high, about 25% of agricultural and woodland will be planted with rubber tree. This should result after 30 years, at 20,000 ha of rubber tree plantations, more than doubling (2.2 times) of the area of rubber plantation under the current situation. In Southeast Asia, the data of 2012, showed that rubber plantations covered more than one millions hectares of non-traditional rubber-growing area (Li and Fox, 2012).

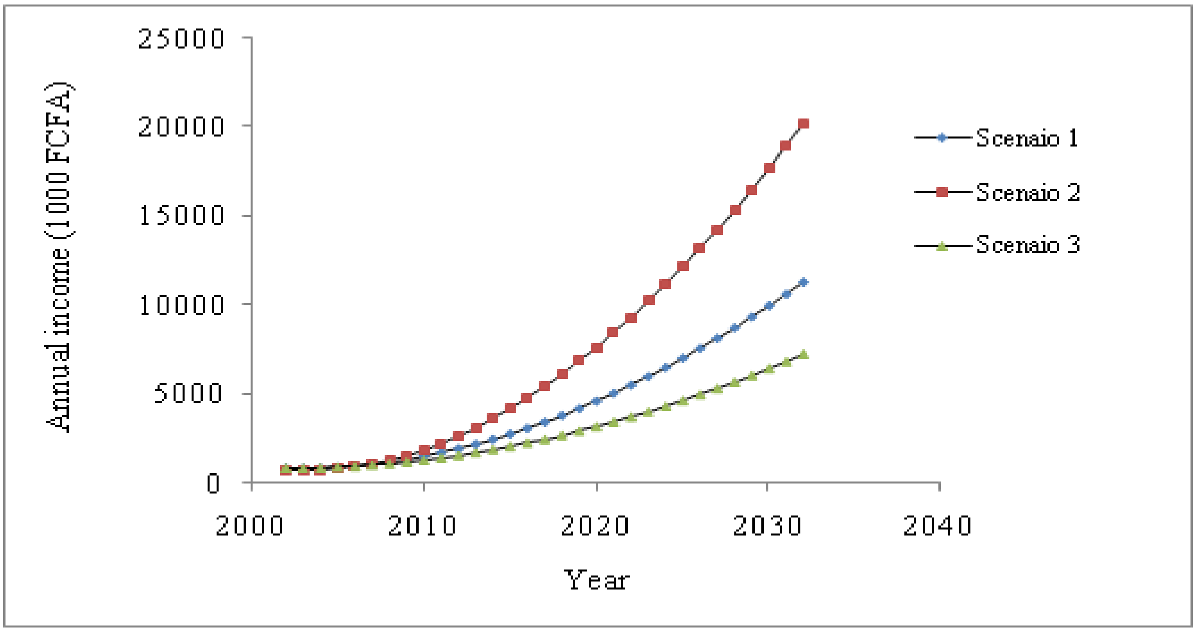

Fig. 5. Evolution of household income (billion FCFA)based the three scenarios.

The prediction indicated that by the year 2054, the area under rubber plantation will increase fourfold, largely replacing forest lands currently under shifting cultivation (Fox *et al.*, 2012.

As it can be observed, there was a high trend in the conversion of lands devoted to traditional subsistence crops and market garden to rubber plantations, which can lead to food shortage and food insecurity in this District. The District of Toumodiis becoming one of the major producers of "attiéké" a staple food largely consumed in Cote d'Ivoire. Besides that, the quality of this food is increasingly better in Toumodi than the one from the so-called traditional producing areas. This is mainly due to the availability of land for cassava cultivation. The expansion of rubber plantations could slow down this specialization. This situation was observed in the areas of rubber tree production such as Dabou and Betié. In these areas, the high revenues coming from rubber tree farming allowed farmers to purchase whatever they want from the city markets. But today, with the collapse of the price of rubber, the alimentary situation has become difficult in these areas.

The deforestation in favor of rubber tree plantation, particularly in its installation phase, may impact climate change which is already a concern in this region of the country (Yao *et al.*, 1998; Otchoumou *et al.,* 2012). The impact of removing secondary forests for rubber tree plantation is not well established. It was argued that in the long run, rubber tree plantations will behave like forest stand and will help restore rains in this area. But certain parts of the region of Toumodi is hilly and the way rubber tree is planted, could accelerate surface erosion.

There is a risk also for the reduction of biodiversity; rubber tree plantations being a monoculture may lead to the disappearance of plant species which may be essential for lives of local populations (culinary, medicinal, etc.). Cocoa, the cash crop in the District of Toumodi (51% of agricultural land), is almost a polyculture. Bananas are initially planted for the shading of young cocoa plants, although they may remain in the plantation as long as possible. Similarly, new banana plants may be introduced later without interfering with the development of cocoa. In addition, women may continue to plant vegetables whose products will be used to partially feed their families and partially sold in order to obtain money for the schooling of their children. This is not the case of rubber plantations which canopy impedes the development of other speculation.

Evolution of income

The diagram of the model compartment" house hold income" based on the evolution of surfaces for each scenario is presented in Fig.4.To estimate the income, we have considered only agricultural activities which generate incomes. Statistics concerning income from food crops are not available from the services of the Ministry of Agriculture. For this reason the model does not take into account the income from these crops.

For the three scenarios, the shape of the curves were the same, the income increases gradually. Considering scenario 1, the income of farmers grew from 750M FCFA to 11 273M FCFA that is 10 523M FCFA over 30 years or 351M FCFA per year while the in scenario 2, it grew from 750M FCFA to 20 112M FCFA, which represented a yearly income of 645M FCFA. In forest preserving scenario, the income growth represented 6 085M FCFA over the 30 year of forecasting leading to an income of 203M FCFA per.

Although these incomes include besides rubber, traditional cash crops (coffee, cocoa, palm tree) and staple crops (cassava, yam, rice, maize, vegetables), the results showed that the revenues nearly doubled with the high trend of rubber tree growing (scenario 2). This could be explained by the fact that most farmers will not sell their lands but will benefit one third of each rubber sale. Therefore, populations are becoming wealthier over the year. In the over side, preserving or maintain forest lands will halve the revenue of farmers over 30 years although it may provide other products such as coal, wood for cooking or house building, and carve tools that are needed for their living. But in all the scenario, the share of rubber tree plantations in household incomes remained significant (81% to 96%)(Table 2) compared to forest products or other agricultural activities.

The results indicated also that, even in the context of conservation, the revenues from rubber plantations remained higher than those from traditional agriculture or the share of forest products.

If we considerscenario2, rubber tree plantation represents 96% of household incomes. Therefore rubber plantations can be introduced at an acceptable rate, even at the current pace (86% of household income) in order to improve the income of rural population in the next thirty years. This will improve the well-being of rural population without jeopardizing the opportunities that offer forest in terms of NTFPs for local populations.

Carbon stock

Fig.5 illustrated the evolution of total carbon stored by rubber trees over 30 years. The trend of the curves was almost the same, and after 30yearsthestocks of carbon were between3.43 and4.26 million tons while carbon emitted was between 0.496and1.328 million tons. The difference between scenarios1 and 3 was very small but there was a slight increase of carbon stocks from 0.35 to 0.8 million tons in thescenario3 (conservation) compared to the other two scenarios.

The share of re forestation in carbon stored was low; it was 6.38%, 10.45%,and4.80% for scenario 1, 2and3 respectively. This reforestation was the outcome of logging because the law required the planting of 1 ha of land for 150m^{3}of timbers extracted from forested areas. Since the District is very poor in exploitable timber, the annual extracted volumes do not reach the proportion that may justify large scale reforestation. On the other hand the most extensive de forestation came from agriculture, which is explained by the fact that there is no constraint on the population regarding a minimum area to be reforested.

At the end of the simulation period, the stock of carbon per hectare was 119.6 tons. These results agree with those obtained by Ouattara Zana (2011 unpublished) in Abokouamekro wildlife reserve which was between 13 and 164 tons of carbon.

The Scenario 2 shows the lowest values due to the high conversion of woodlands to rubber plantations.
The evolution of carbon stocks remains the same in the three scenarios.

Considering scenario 1 as a baseline, carbon credit will be considered only for scenario 3. Because of the high deforestation rate in scenario 2, the level of carbon stock (3.43 million tons) remains below the value of scenario 1 (3.93 million tons). In this context no carbon will be available to be sold on the carbon market. For scenario 3, the recorded carbon stock was 4.26 M tons which corresponded to a gain of about 329,000 tons. In Southeast Asia, the mean of the above carbon in rubber plantations higher, it was estimated to be between 25 and 143 mega grams per hectare (Mg/ha) (Ziegler *et al.*, 2012).

It was less than half of the level estimated for neighboring forests whereas the amount found in shifting cultivation was 25110 Mg/ha. The obtained data on above and below ground carbon suggested that a transition from traditional shifting cultivation to rubber plantations will probably not lead to substantial increase or decrease in levels of carbon sequestration. Only the maintenance of expansion of protected areas such as LAMTO could certainly increase the sequestration rate of carbon.

As stated by Fox *et al.* (2014), the payment for environmental services (PES) programs initiated in several country of Africa and elsewhere provides provide an important model for how REDD+ payment might be distributed to local farmers who convert or maintain land under natural forest.

The payment to rural households ranged from US$4.6 to US$515 a year (Mahanty *et al*, 2013).Carbon price on the market was indicated to around € 4.79 per tons; the stock of carbon will value €1 575 910. Under the REDD+, 10% of this value, €157 951 will be given to the local population that should be distributed over the entire local population. In either way, this is clearly not enough to motivate farmers to protect or expand protected forests rather than planting rubber tree. However, the economic outcome should not be the only concern of population as the preservation of forests offers non merchant's goods such as better weather, supply of non-timber forest products and medicinal plants, as well as re creative value for population.

Conclusion

This study aimed at assessing the dynamics of land use in the District of Toumodi by using GIS approach and system dynamics modeling. GIS approach involved remote sensing, geographic information systems using the free GRASS software. The system Dynamics used the educational simulation software VENSIM-PLE. The results showed that there is a reduction of forest lands, a stagnation of traditional shifting agriculture and an increase of land planted to rubber trees. This has led to an increase of farmer's incomes. The scenario REDD+ has resulted in a small reduction of deforestation; a slight increase of carbon stock but the incomes of farmers were low compare to growing more rubber trees. But this was offset by the gain obtained from the preservation of forests in terms of biodiversity conservation especially endemic species.

Although the two free software, GRASS and VENSIM have allowed us to obtain these results; this study must be continued by integrating the free software R to GRASS in order to be able to simulate the evolution of land uses like the one done with GEOMOD in IDRISSI.

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