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Keywords Coconut lethal yellowing disease; Land use change; Multinomial probit model; Markovian chain analysis; Grand-Lahou; Cote d'Ivoire.

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Conflict of interest

All authors involved in the work corresponding to Economics of land use dynamics in coconut plantations of Grand-Lahou in Cote d’Ivoire have no potential nor actual conflict of interest including any financial, personal or other relationships with other people or organizations that could inappropriately influence, or be perceived to influence our work. Results presented as part of our work have not been published previously nor under consideration for publication elsewhere in the form of an abstract or as part of a published lecture or academic thesis or as an electronic preprint.

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1. Introduction

Coconut (*Cocos nucifera* L.) is cultivated on approximately 50,000 hectares in Côte d'Ivoire; the top African country that exports coconut oil from copra to Europe and West Africa (Arocha et al. 2014). It is the main income source for coconut smallholder farmers of the south littoral of Grand-Lahou. A severe outbreak of the Côte d'Ivoire lethal yellowing disease (CILY), which rapidly spread throughout the coconut-growing farms, has been wreaking havoc since 2013. The disease resembles the Cape St. Paul Wilt that destroyed the coconut industry in Ghana in the last 20 years (Danyo, 2011), therefore prompt actions are required to improve disease management and control.

Due to the impact of CILY on coconut farms in Grand-Lahou, conversion of coconut land to other uses is becoming a major issue in this region. As noted by Marawila et al., (2011), conversion of agricultural lands to other more intense land uses has been observed in developing as well as developed countries, in particular where the economy is heavily dependent upon the earnings from agricultural products. Changes in land use patterns significantly impact environmental conditions (biodiversity, water pollution, soil erosion, and climate change), as well as economic and social welfare. A good understanding of how these factors influence the land use patterns over time and space can help policy-makers evaluating existing, or drawing up new public policies that are environmentally sustainable (Chakir and Parent, 2009).

Linkages between the sectoral composition of growth and poverty reduction outcomes have been shown via econometric approaches (Martin, 2016). These allow hypotheses to be tested against real-world data, and provide possible alternative channels of effect to those originally hypothesized to be assessed and compared. This study provides an analysis of crop-specific land use change. The objective was to identify the determinants of coconut land use change in Grand-Lahou, and predict future spatial distribution of land use with an econometric model. This study employs a discrete choice framework to model land use change in the coastal coconut growing area. The econometric model was estimated with an extensive panel data set developed using satellite images and land use maps spanning a period from 1988 to 2015. The state transition probability matrix generated from the econometric results and Markovian Chain Analysis (MCA) was used to predict the future land use change of the department of Grand-Lahou. Based on the Markovian probability analysis, a Cellular Automata Analysis (CAA) was performed to predict the spatial distribution of land use for the next 30 years.

2. Methodology

2.1. Conceptual framework and the econometric model

According to Marawila et al. (2011), a landowner will convert his plot denoted by *i*, from the type of use *u* to the use *d* at time *t* under the maximization condition expressed by Equation 1.

$$R_{idt|u} - C_{idt|\mathrm{u}} \geq R_{ijt|u} - C_{ijt|u} \text{ for } j = 1, \ldots\ldots, J. \quad (1)$$

Where:

$R_{idt|u}$ is the present value of future stream of returns generated by parcel *i* when the type of use has been changed from *u* at period *t-1* to *d* at time *t*,

$C_{idt|u}$ is the cost of converting parcel *i* from initial land use *u* to use *d* in the period *t,*

$R_{ijt|u} - C_{ijt|u}$ is the net benefits of converting the parcel *i* from initial land use *u* to one of the *j* possible alternatives choices of land uses.

The Equation 1 can be rewritten as follows in Equation 2

$$Y_{ijt|u}^{d} = \left[R_{idt|u} - R_{ijt|\mathrm{u}}\right] - \left[C_{idt|u} - C_{ijt|u}\right] \geq 0 \quad (2)$$

Where

$Y_{ijt|u}^{d}$ can be view as the marginal benefit of changing the land use from *u* to *d*.

If this marginal benefit is bigger than 0 for each potential alternative, the landowner will then finally decide to change the use of land from *u* to *d*.

Therefore, if A_{it}^{d} represents the event that led the landowner to decide to change the use of his parcel *i* from *u* to *d* at the period *t*, the probability of moving to the land use *d* could be expressed as follows in Equation 3.

$$P(A_{it}^{d}) = P(Y_{ijt}^{d} \geq 0, \forall j = 1, \ldots, J) \quad (3)$$

The marginal benefit $Y_{ijt|u}^{d}$ can be decomposed on deterministic components which depend on observables covariates and some idiosyncratic shocks as shown in Equation 4:

$$P(Y_{ijt}^{d} = \beta_{du} X_{idut} + Z_{it} + u_{it} + \varepsilon_{it} \geq 0) \quad (4)$$

Where:

β_{du} is a choice specific parameter vector to be estimated,

X_{idut} is a vector of parcel and location specific observable variables,

Z_{it} captures the spatial dependencies across decision makers,

u_{it} is the individual and choice specific effect (which can be random or fixed) observable by the landowner at the time of the decision making but not observable by the analyst, and

ε_{it} is the idiosyncratic error which is individual as well as time specific.

In the context of Land Use Change (LUC) studies, spatial effects refer to spatial dependencies composed of spatial autocorrelation and spatial heterogeneity (Marawila et al. 2011) which arise due to location of the agents in different zones (Vichiensan et al. 2005). The spatial autocorrelation arises from the parcel specific data and neighbourhood characteristics observable to the landowners at the time of the decision making. Spatial heterogeneity arises from the structural instability; it may be due to non-constant error variances. According to Anselin (2002), the spatial autocorrelation can be defined as the coincidence of value similarity with the locational similarity. Spatial autocorrelation is generally associated with heteroscedasticity, however, in this study only the spatial autocorrelation was taken into account in due to the fact that incorporating both spatial autocorrelation and heteroscedasticity within the context of discrete dependent variable data analysis is challenging (Marawila et al. 2011).

In our study, observable characteristics considered include parcel characteristics, which are related to the returns and the cost of conversion, attributes of the local administrative area, as well as macro-economic factors affecting the land use allocation decision. The observed attributes were land quality measured by soil suitability class, distance to urban centre, government support in the coconut sector (subsidies, research and extensions services), population, forest density, and average coconut yield. Following Marawila et al. (2011), we hypothesize that the long term government support schemes are likely to reduce coconut land being converted to urban or other agricultural uses in Grand-Lahou. Government support for the coconut sector, and research and extension services are included in the empirical model to assess if there is any quantifiable impact of such support programmes over the years. According to Marawila et al. (2011), as the suitability of land for coconut farming rates increases, the less likely it will be converted to other uses; as such, land parcels are less likely to get permission for conversion from the government. Following Ricardo and Von Thunen's theory, as the proximity to urban and marketing centres decreases, the possibility of a coconut land converting to urban uses is expected to be higher. Unobserved attributes can be correlated over time and across parcels within local administrative boundaries (Lewis 2009), so that the land use change decision across parcels can be correlated at the administrative division level. To account for any regional level impact, the population and forest density were included in estimating the model.

The discrete choice framework has been successfully employed in land use change analysis (Lewis 2009; Polyakov and Zhang 2008; Carrión-Flores and Irwin, 2005). The LUC study of Grand-Lahou uses a discrete choice framework specified as a multinomial probit model in *Equation 5.*

$$Y_{ijt} = \alpha + \beta_1 LSC_i + \beta_2 dist\_urban_i + \beta_3 pop\_density_{jt} + \beta_4 forest\_density_{jt} + \beta_5 avg\_yield_t + \beta_6 gov\_research_t + Z_i + u_{ijt} + \varepsilon_{ijt} \quad (5)$$

Where:

Y_{ijt} is the dependent variable or a categorical variable representing a grid of 25 ha (500 m x 500 m) size of land use observed at time *t* in an area *j* with five (5) alternatives: denoted as category 1 (where coconut percentage < 50 % of a grid); category 2 (where coconut percentage range from 50 – 75 % of a grid); category 3 (where coconut percentage > 75 % of a grid); category 4 (where urban area > 50 % of a grid) and category 5 (where other agricultural percentage > 50 % within a grid).

j represents the administrative divisions of Grand-Lahou (Fig. 1).

LSC is the Land Suitable Class with two (2) alternatives (0: highly suitable or 1: moderately suitable soil for coconut farming),

dist_urban is the distance (Km) of a grid to the urban centre of the nearest administrative division,

forest_density is the forest density (ha per sqKm),

pop_density is the population density (per sqKm),

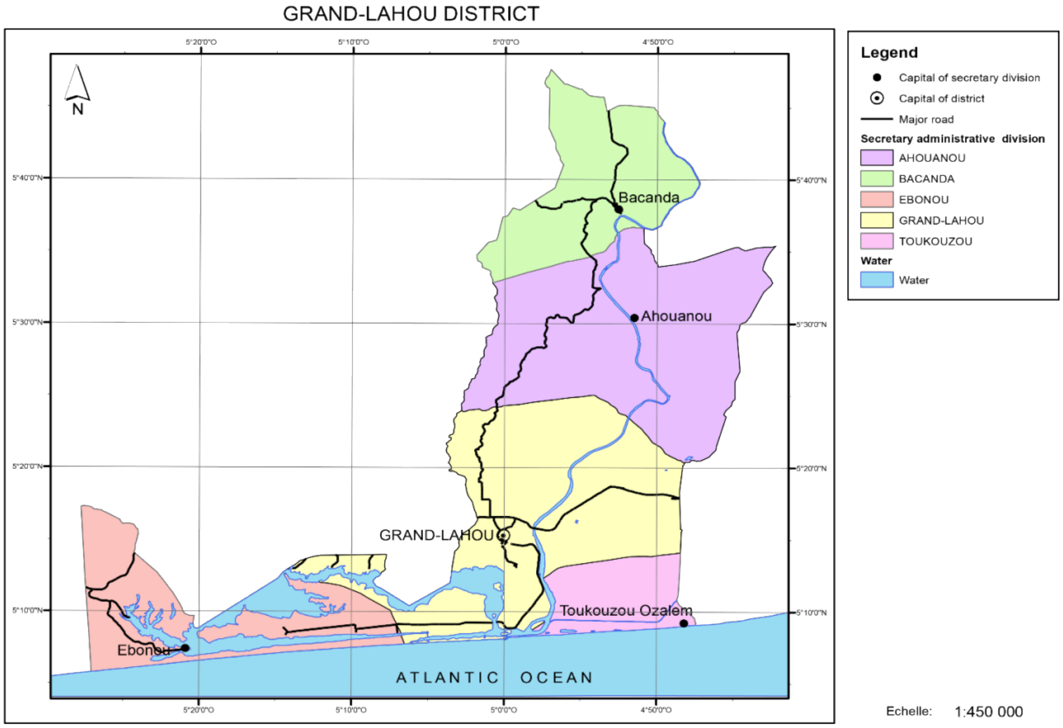
A*vg*_yield is the ten (10) yearly average yield of coconut,

gov_research is the government subsidies for coconut research and extensions services (XOF) in the Grand-Lahou and

Z_i is the spatial dependence across decision makers, u_{ijt} the unobserved individual specific random effect and ε_{ijt}, the idiosyncratic error.

The constant term α captures the individual unobserved heterogeneity assumed to be identically and independently distributed.

Figure 1: Administrative divisions of Grand-Lahou in Cote d'Ivoire



2.2. The Data

The econometric model used an extensive panel data set developed using satellite images and land use maps of Grand-Lahou from 1988 to 2015. This period covers two important stages; 1988 to 2000 is the period before the outbreak of CILY and 2000 to 2015 corresponds to the spreading of CILY in Grand-Lahou. Due to the cloud-less quality of satellite images, land use maps of the three (3) years: 1988, 2000 and 2015 were used. The land maps were converted to raster files and raster images for the 3 years, and were initially classified into 7 land suitability classes (coconut, urban, forest, water, other agriculture, savannah and rocks). Using the images, the proportion of coconut, urban and other agricultural were calculated for each grid and reclassified maps of 5 classes: coconut < 50 %, coconut 50 – 75 %, coconut > 75 %, urban > 50 % and others agricultural > 50 %) for each year. Land uses maps of 1988 and 2015 are presented in Fig. 2 and Fig 3.

Figure 2: Land use of Grand-Lahou in 1988

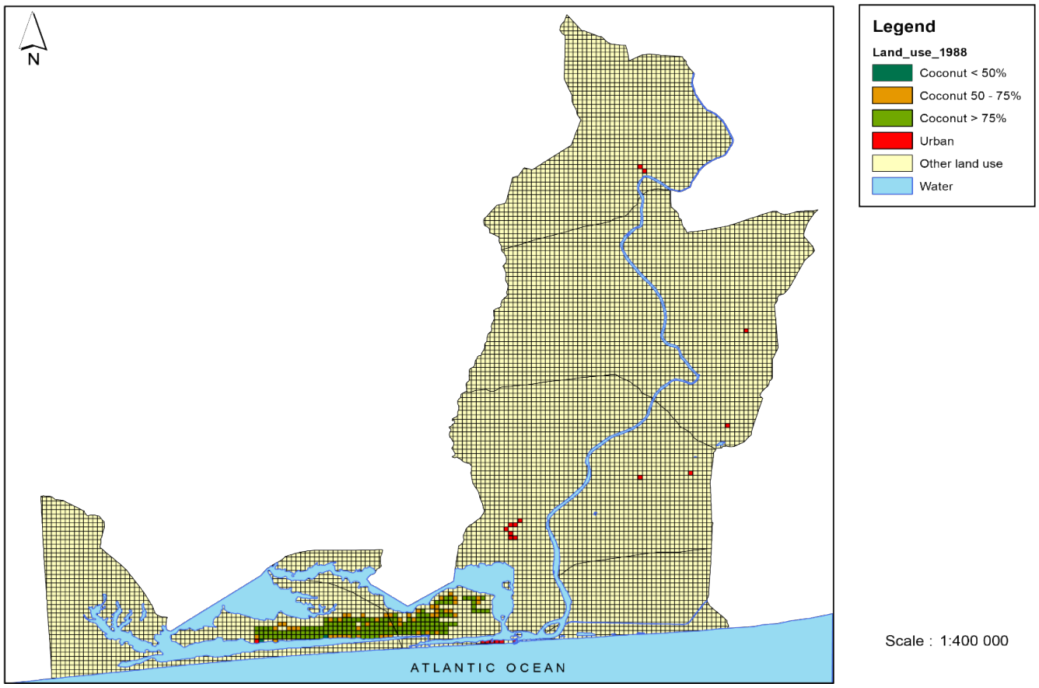


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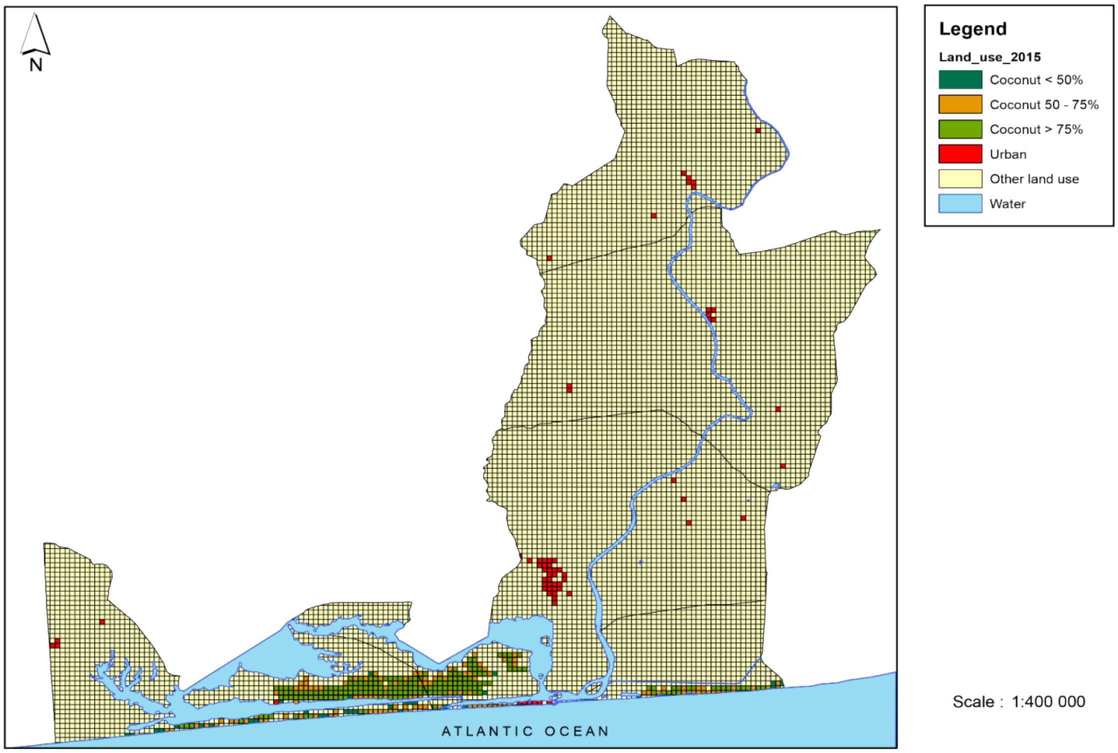
Figure 3: Land use of Grand-Lahou in 2015



The study used a sample of 9,342 grids covering the department of Grand-Lahou. Two (2) soil suitability categories for coconut (highly suitable or moderately suitable) were assigned to each grid from the spatially joined maps. The percentage of land covered by forest within an administrative division and the density of forest (per ha of total area) was calculated for each year. The centroids were calculated for each grid and then the Euclidean distance to the administrative division urban centre from each grid was computed. The data on population for the years 1988, 1998 and 2014, obtained from the National Institute of Statistics (INS), were used as approximations of population for 1988, 2000 and 2015, respectively. The average yield of coconut as well as subsidy, research and extension costs, were obtained from the Centre National de Recherche Agronomique (CNRA) of Cote d'Ivoire. Descriptive statistics of variables of the econometric model showed an average distance of 9.71e+09 m from a grid to the nearest urban center of SAD, 42.14196 ha per sqKm of forest and 33.28544 inhabitants per sqKm in SAD and 2 tons of copra per ha per year for the coconut average yield. Government subsidies for research and extensions services for coconut farming were approximately 1.69e+08 XOF per year in Grand-Lahou (Table 1).

Table 1: Descriptive statistics of variables used in the econometric model

Variables	Description	Average	Min	Max
Y	the land use observed in a grid	4.915685	1	5
Lsc	Land suitability (0 = highly or 1 = moderately suitable)	0.6714836	0	1
disturb	Distance to urban centre (m)	9.71e+09	1 048 652	2.20e+10
Popd	Population density (Per sq.km)	42.14196	10.62	95.8
Forestd	Forest density (ha per sq.km)	33.28544	7.73	52.12
avegyield	Average yield (Tons Coprah/ha)	2	1.5	2.25
gov_research	Research subsidies and Extensions services (XOF)	1.69e+08	0	5.02e+08

XOF = F CFA, 1 USD = 500 F CFA

2.3. Econometric challenge and spatial analysis

The study analyses the land use change between five distinct nominal categories of land uses over a period of 27 years (1988 to 2015). It's shown that when observed data are nested within clusters or repeatedly measured over time, the observations are likely to be correlated. There may also be factors that affect land owner's decision at the time of decision making which are unobservable to the researchers. In that situation, collected data may be best used in a multinomial response panel data model which accounts for unobserved effects correlated over time and space. Unobserved characteristics vary across individuals and may exhibit two possible types of effects: fixed effects and random effects. The fixed effects approach allows the unobserved heterogeneity to be correlated with the included variables; however, it is theoretically as well as computationally cumbersome to estimate fixed effects for non-linear models with short panels (Greene 2002). In the case of random effects, the probit model is easier to implement computationally than the logit model (Madalla 1987). As previously mentioned, the multinomial probit model with random effects is likely to account for the unobserved spatial and temporal correlations and provide consistent estimates. When dealing with a qualitative dependent variable which falls into several mutually exclusive categories that is unordered, multinomial distribution is assumed and random effects can be introduced to capture unobserved heterogeneity. Hence, multinomial probit model with random effects can be used to estimate the coefficients.

We applied a method analogous to the mixed logit model in which the multinomial data were transformed into a set of binary data by expanding the observations and allowing for pair wise comparison of alternatives. The expanded data set consisted of five (5) duplicate records of each observation, while the grids were identified by a unique identification number, so that, a new binary variable was developed for each record. Random effects were specified to capture unobserved characteristics that vary across individuals. When panels are short and estimation methods are limited, the random effects assumption seems to be more appealing (Pesaran et al. 1996). With random effects, non-linear probit specification is more computationally feasible compared to logit specification (Greene (2002), Madalla (1987)). Using this transformed data, and taking category 3 (coconut percentage >75%) as the base category, a binary probit panel model with random effects and spatial effects was estimated. Markov transition probabilities were calculated using the econometric results. Using the probability matrix, transition probabilities for the land use classes for the next 30 years period were predicted.

MCA and CAA techniques were employed in modelling land use change of Grand-Lahou. Based on the probability matrix for land use transition for the past two periods, before CILY (1988 – 2000) and during the spread of CILY (2000 - 2015), the Markovian process projects land use change for the next 30 years (2015 to 2045). Following Petit et al. (2001), spatial distribution of occurrence within each land use category was performed using CAA. According to Parker et al. (2003), CAA can be used effectively with MCA to model the spatial developments of a location. Econometric analyses were performed using STATA software.

3. Results and discussion

The matrix transition between land uses categories are shown in Table 2.

Table 2: Transition between land use categories as a percentage

	Category 1: Coconut < 50 %	Category 2 Coconut 50 – 75 %	Category 3 Coconut > 75 %	Category 4 Urban > 50%	Category 5 Others > 50 %
Year 1988-2000					
Coconut < 50 %	0.00	100.00	0.00	0.00	0.00
Coconut 50–75 %	0.00	100.00	0.00	0.00	0.00
Coconut > 75 %	0.00	10.65	88.17	0.00	1.18
Urban > 50 %	0.00	0.00	0.00	66.67	33.33
Others > 50 %	0.31	0.54	0.54	0.20	98.42
Year 2000-2015					
Coconut < 50 %	100.00	0.00	0.00	0.00	0.00
Coconut 50–75 %	0.85	98.31	0.00	0.00	0.85
Coconut > 75 %	0.00	0.51	94.95	0.00	4.55
Urban > 50 %	0.00	0.00	0.00	90.00	10
Others > 50 %	0.00	0.00	0.11	0.40	99.49

Results showed that within the first period (1988 to 2000), coconut plantation of category 2 (coconut 50 - 75% of a grid) remained stable while lower coconut farms (< 50 % of a grid) were expanded with a probability of 100%. Highest percentages of coconut (> 75 % of a grid) were reduced to the category 2 (coconut 50 - 75% of a grid) with a probability of 10.65 %. A probability of 33 % was observed for the transition from urban lands to other agricultures. These results revealed that before the outbreak of CILY disease, land uses of Grand-Lahou was characterized by a significant conversion of small coconut farms (< 50 % of a grid) to large ones (coconut 50 – 75 % of a grid) and from urban (> 50 % of a grid) to other agricultures (> 50 % of a grid).

Inversely, during the second period from 2000 to 2015 with the spread of CILY, small coconut plantations (< 50 % of a grid) remained stable while the probability of transition from large coconut plantations (> 50 % of a grid) to lower percentages of coconut in grids still low (< 0.05) as well as conversion to other agricultures. The probability of conversion of urban areas (urban > 50%) to other agricultures was reduced to 10 %. Over the two periods, no transition was observed from coconut plantations areas to urban or from other agricultures to a different category. This second period was characterized by a non-extension of small coconut plantations and a low probability of conversion of large coconut farms to other agricultures in the Grand-Lahou. Comparing to the first period, the extension of small coconut farms was halted in the second period; while the transition of large coconut farms to other agricultures continued but with low probability. This slight transition of coconut lands to other agricultures in the Grand-Lahou could be related to the presence of CILY which impacted coconut farming incomes.

The results of the estimation of the econometric model are presented in Table 3.

Table 3: Econometric model estimation results

	Coefficients	Standard errors	Z	P value
Constante				
Category1	-35.66931	97.06051	-3.67	0.000
Category2	-19.77059	40.76929	-4.85	0.000
Category4	48.39154	59.38754	0.81	0.415
Category5	31.42959	27.40554	1.15	0.251
Highly suitable soil				
Category1	-1.683462	.2606287	-6.46	0.000
Category2	-1.414335	.0957504	-14.77	0.000
Category4	1.843886	.1249222	14.76	0.000
Category5	.0619409	.0916811	0.68	0.499
Moderately suitable soil				
Category1	.0988908	.1684881	0.59	0.557
Category2	.1007223	.1088187	0.93	0.355
Category4	-.2257871	.089902	-2.51	0.012
Category5	.7289849	.1311903	5.56	0.000
Forest density				
Category1	-.0055969	.0077614	-0.72	0.471
Category2	.012137	.0043898	2.76	0.006
Category4	-.0011912	.004006	-0.30	0.766
Category5	.0092914	.0080615	1.15	0.249
10 yearly Average Yield				
Category1	17.05778	41.96919	4.06	0.000
Category2	100.0021	15.17146	6.59	0.000
Category4	12.67774	12.13278	1.04	0.296
Category5	-9.645872	24.10626	-0.40	0.689
Subsidies, research and extension				
Category1	2.57e-07	6.33e-08	4.06	0.000
Category2	1.51e-07	2.29e-08	6.60	0.000
Category4	1.89e-08	1.84e-08	1.03	0.304
Category5	-1.45e-08	3.66e-08	-0.40	0.691
Population density				
Category1	-.0039838	.0029142	-1.37	0.172
Category2	-.0020588	.0016039	-1.28	0.199
Category4	.0039397	.0015769	2.50	0.012
Category5	.0144007	.003024	4.76	0.000
Distance to urban centre				
Category1	2.01e-11	1.04e-11	1.94	0.052
Category2	4.63e-11	5.86e-12	7.90	0.000
Category4	4.02e-11	4.80e-12	8.39	0.000
Category5	1.19e-11	7.52e-12	1.59	0.113
Insig 2u	12.14197	.8954414	-	-
sigma_u	.4200234	.0766788	-	-
Rho	0.0956	.0081262	-	-
Log likelihood	-4962.4109			

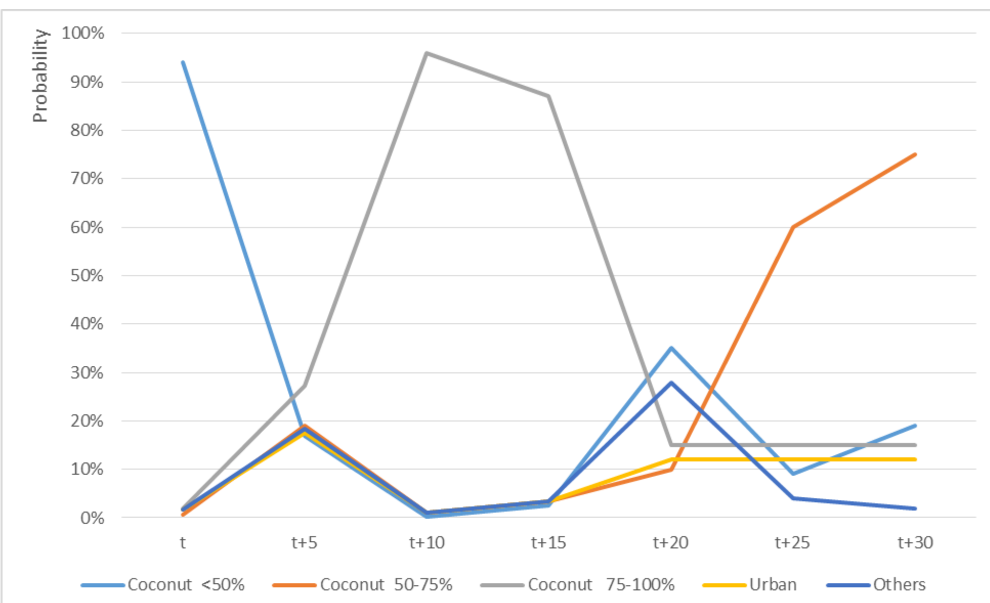
Using category 3 (coconut > 75% of a grid) as the base category, changes to the other categories of land uses were discussed. Coefficients related to government subsidies (research and extensions services) and average yield of coconut were statistically significant and positive for category 2 (coconut 50 - 75% of a grid) and category 1 (coconut < 50 %). This showed that the increase of government subsidies or coconut average yield results in a reduction of percentage of coconut plantations in the grids explained by a transition from large plantations (coconut > 75 % in a grid) to lower ones (coconut 50 to 75 % and < 50 % within a grid). In response to an increase of government subsidies, large coconut plantations were mostly converted to category 2 (coconut 50 – 75 %) while an increase of coconut yield results in a transition to category 1 (coconut < 50 % of a grid). This result revealed that in spite of increased government subsidies in research and extensions services, and also an increase in productivity due to increased availability of hybrids for farmers, coconut plantations tend to reduce in size. This tendency of decreasing coconut farm area in the Grand-Lahou could be related to the outbreak of the CILY disease.

The results of the estimation showed that in soil highly suitable for coconut, large coconut plantation (coconut > 75 % of a grid) are more likely to be converted into Urban (Urban > 50% (1.84)) and less likely to be reduced in small coconut farms (50 to 75 % (-1.41) or < 50% (- 1.68) in a grid). Inversely, in moderately suitable soil, it is more likely that large coconut plantations are converted to other agricultures. According to Ricardian theory (Marawila et al. 2011), as in Grand-Lahou, more productive lands are used for large coconut plantations or converted to urban uses with higher rent rather than to other less profitable uses.

Results of the study showed also that conversion of large coconut farms (> 75 % of a grid) to small ones (coconut 50 – 75 %) or in urban areas increases with the distance from the center of the administrative division. In Grand-Lahou, large coconut plantations (> 75 % of a grid) are closer to urban areas than small coconut farms (50 – 75 % of a grid). As the population density increases, large coconut farms (> 75 % of a grid) are more likely to be converted to other agricultural uses. Conversion of large coconut plantations to lower (50 - 75 % of a grid) increases also with the forest density. This implies that the high forest density prevents from the extension of coconut plantations in Grand-Lahou. The study also revealed that the probability of conversion of coconut farms to urban was lower than conversion to other agricultures.

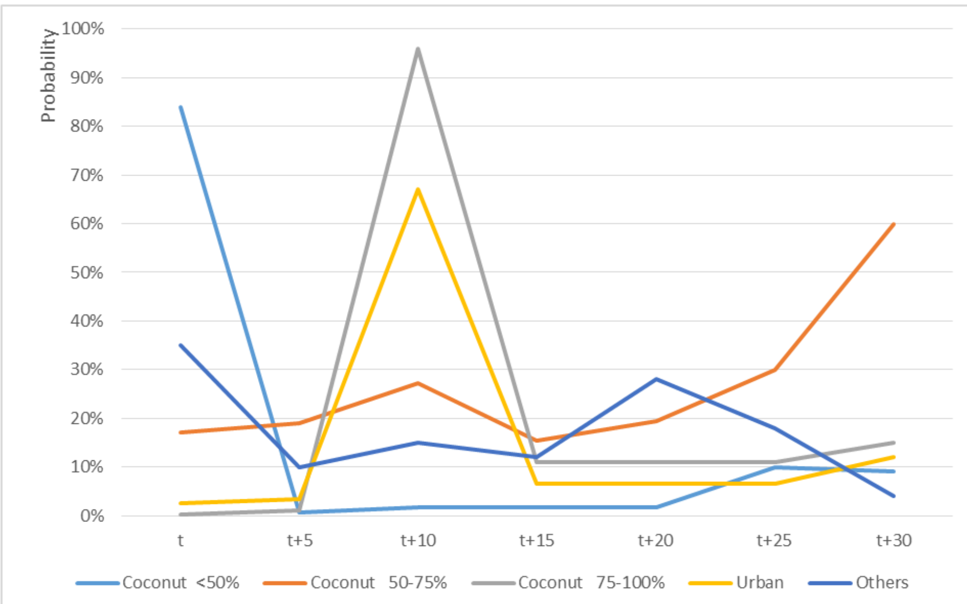
Based on the state transition matrix (Fig. 4), the Markov Chain Analysis performed for the next 30 years on econometric estimates showed an increase in category 3 (coconut > 75% of a grid) in the first ten (10) years following by a drastic drop. Meanwhile, a decrease of category 2 (coconut 50 – 75 % of a grid) and category 1 (coconut < 50 % of a grid) as well as the other agriculture category was predicted. Note that, after the next twenty (20) years, the category 2 (coconut 50 – 75 % of a grid) will increase while urban land use will continuously decline over time.

Figure 4: Markov Chain Analysis based on state transition probability matrix of land use



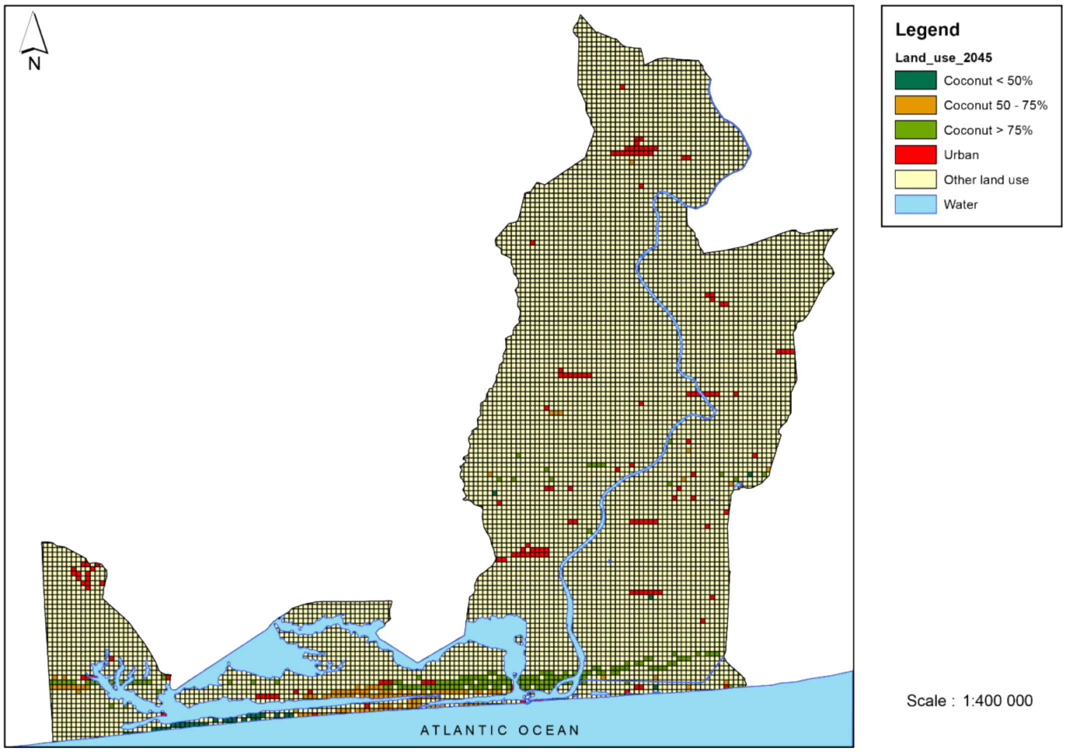
Results from Markov probability analysis (Fig. 5) shown a sharp increase of category 3 (coconut > 75 % of a grid) and urban category within the first ten (10) years following by a decrease and a stability. Inversely, lower coconut categorizes (coconut 50 – 75 % and coconut < 50 %) as well as category 5 (”other”) representing “other” agricultural land uses remained relatively stable with a slightly increase in category 2 (coconut 50 – 75 %) over years 25 - 30.

Figure 5: Markov Chain Analysis based on Markov transition probability matrix



The spatial lands uses of Grand-Lahou for year 1988 (Fig 2) and year 2015 (Fig. 3) compared to predicted spatial land use for year 2045 (Fig. 6) clearly shows the dynamic of land use; there is an increase of urban areas correlated with a spreading of coconut plantations in the continental area which is currently a non-CILY affected zone. Prediction of land use in the following 30 years showed an extension of urban areas as well as an increase in coconut farms in the healthy continental zone of Grand-Lahou.

Figure 6: Predicted land use of Grand-Lahou in 2045



4. Conclusions

Using a multinomial probit model with random effect based on a theoretical land use model, the dynamic of coconut land use of Grand-Lahou was studied. The study covered the past 30 years (1988 – 2015) and took into account the two periods before and after the outbreak and spread of CILY disease in this department. Results showed a significant conversion of small coconut farms (< 50 % of a grid) to large ones (coconut 50 – 75 %) before the outbreak of CILY but this expansion was halted when the disease spread, with a slight conversion of large coconut farms to other agricultures. Conversion of urban areas (> 50 % of a grid) to other agricultures was also observed over time. Prediction for the next 30 years shows a clearly dynamic use of land characterized by an increase of urban areas with a spreading of coconut plantations in non-CILY affected zones of Grand-Lahou. Research and extensions services for fighting the CILY disease should be reinforced to limit its spread and minimize its impact on small coconut farm families.

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Highlights

- The expansion of small coconut areas is limited by the CILY disease in Grand-Lahou.
- The increase of urban areas with an expansion of coconut plantations towards the continental non-CILY affected areas is predicted
- Gender-responsive research and extensions services should be reinforced to halt CILY spread.

Title: Economics of land use dynamics in coconut plantations of Grand-Lahou in Cote d'Ivoire

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