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Spatio-temporal dynamics of land use on the expansion of coffee agroforestry systems in Cameroon's production basins

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Diachronic analysis of satellite images was used to assess the spatiotemporal dynamics of land use and land cover change in the coffee production basins of Cameroon, located in the forest agro-ecological zones (Moungo and Haut-Nyong) and the highland humid savannah (Noun). A survey of farmers was carried out to identify land use and changes in the area of coffee agroforests over time. While the period 1980 to 2001 was marked by an increase in the area of the forest/agroforest land-use unit, the period 2001 to 2019 shows significant regressions ranging from 14 to 22% of the total area of each basin. Significant changes in the land use units have repercussions on the areas dedicated to coffee growing, which have decreased significantly; today, the largest areas under cultivation are in Haut-Nyong (1.51±1.27 ha), the medium areas in Moungo (1.14±1.13 ha) and the smallest in Noun (0.67±0.72 ha). Coffee abandonment coupled with anthropogenic factors such as agriculture and housing expansion are mainly responsible for the degradation of coffee agroforests, with notable repercussions on land cover changes. The cocoa-coffee revival encouraged by sectoral Ministries in recent years seems to have encouraged cocoa production, since in agro-ecological regions; the increase in forest/agroforest area is mainly attributable to *Theobroma cacao* and *Elaies guineensis*.

Key words: Spatio-temporal dynamics, land use/land cover, agroforestry system, coffee agroforest, coffee area, agro-ecological zone.

INTRODUCTION

Land use change through deforestation and/or forest cover degradation due to unsustainable agricultural practices emits significant amounts of carbon into the atmosphere (Cortez and Stephen, 2009; Mangion, 2010). According to the Global Environment Facility (FEM, 2012), the activities of land use and forestry sector contribute 31% to global greenhouse gas (GHG) emissions that is, 14% in agriculture and 17% of

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deforestation and land degradation due to unsustainable practices, which have profound impacts on maintaining ecosystem services. Research on land use and land cover change is important at a basic level to explore the dynamics and drivers of change (socio-economic or biophysical) associated with it in order to support conservation planning and policy development (Ellis et al., 2010); the processes and drivers associated with these changes being complex and resulting from the interaction of the human-environment system which is influenced by socio-economic, environmental and political-institutional aspects that can be considered as drivers (Rindfuss et al., 2004; Overmars and Verburg 2005, 2006).

The monitoring of land use and land cover changes in the Congo Basin is necessary in view of the significant decrease in forest area recorded during this century (Karsenty, 2004; Tchatchou et al., 2015). In this regard, forests and agroforests constitute a major component for the maintenance of tree cover (Ellis et al., 2010). Indeed, agroforestry systems (AFS) are recognized as privileged places for biodiversity conservation and important carbon reservoirs (Zapfack et al., 2002). Recent studies show that the management of agroforests based on perennial crops constitutes a means of afforestation of savannah ecosystems, through the introduction and or preservation of trees for shade and the provision of many other services (Jagoret et al., 2014). In Central Africa, a significant part of agriculture is based on complex AFS, mainly based on cocoa and coffee trees, which contribute to the income and food of millions of rural families. These complex cocoa- and coffee-based AFS are considered intermediate land-use systems between natural forest extraction and modern plantations (Foresta and Michon, 1997; Correia et al., 2008). The conversion of agroforests to non-agroforestry systems can occur if the economic and institutional conditions are not favourable compared to the deforestation process and thus generate similar environmental impacts (Ellis et al., 2010).

Cameroon, the second largest country in the Congo Basin in terms of forest area (20 million ha of forest) and the fifth most biodiverse country in the continent (WRI, 2006), is made up of five agro-ecological zones, three of which form the south of the country and are the main coffee and cocoa production basins. These are the monomodal forest zone (coastal and mountainous zone with a humid equatorial climate), the bimodal forest zone and the high altitude humid savannah zone (Western Highlands) with an equatorial climate (MINEPIA, 2011). The forest agro-ecological zones are recognized as Robusta coffee growing areas while the highlands are the preferred area for Arabica coffee. According to Kamga (2002), the cultivation of Arabica coffee in the highlands of West Cameroon, introduced in 1924 by the colonial administration has experienced an unprecedented boom. Thanks to this crop, the Bamileke peasant was able to improve his social status. However, the economic crisis of the 1980s, coupled with the devaluation of the CFA franc, led to a gradual abandonment of coffee cultivation due to the cost of inputs and the lack of subsidies in favour of market gardening and food crops (Fongang, 2008; Kuete, 2008). These phenomena have significantly marked the history of coffee growing and, by extension, the agrarian landscapes of Cameroon's coffee-growing regions. Considering the construction of coffee landscapes in the 1960s, followed by their deconstruction in the 1980s with the advent of the crisis, one could envisage encouraging prospects for a spatial reconfiguration of coffee agroforests in the different production basins thanks to the cocoa-coffee revival encouraged in recent years by the sectoral ministries, organizations and institutions under their supervision. However, this revival does not take into account the evaluation of changes in land use and occupation. It is therefore important to examine the influence of these changes in coffee growing on the landscape dynamics of humid forest and savannah ecosystems, which are recognized as the main production basins in Cameroon.

Remote sensing data are frequently used for landscape studies (Morant, 1999; Djiongo et al., 2020). Remote sensing offers an important data source for studying the spatio-temporal dynamics of several environmental parameters; it is necessary for monitoring land use. The objective of the study is to characterize the changes in land use patterns in the main coffee production basins in Cameroon between 1980 and 2018, taking into account the following eco-zones i.e. the Noun Division (Foumbot, Nkouoptamo) for the high savannah agro-ecological zone where Arabica coffee is grown and the Divisions of Moungo (Melong, Baré-Bakem, Nkongsamba 2) and Haut-Nyong (Angossas, Mboma) for the forest agro-ecological zones with monomodal and bimodal rainfall regimes, respectively, which are the preferred zones for Robusta coffee.

MATERIALS AND METHODS

Study site

The main coffee production basins of Cameroon are located in the southern part of Cameroon, between 2°10' and 7°00' North latitude and between 8°30' and 16°10' East longitude, covering an area of 242620 km^2 (Figure 1). It corresponds essentially to the West and North-West regions for the agro-ecological zone of humid highland savannah (AEZ 3) characterized by a tropical mountainous climate of sub-equatorial type influenced by a rugged relief and with a long rainy season and a short dry season of 2 to 4 months (UNDP, 2013); the South-West and Littoral regions for the monomodal forest zone (AEZ 4) where a hot and humid oceanic equatorial type climate prevails with two seasons; the Central, Eastern and Southern regions for the bimodal forest zone (AEZ 5), characterized by a sub-equatorial Congo-Guinean type climate with two dry seasons alternating with two rainy seasons. According to Letouzey (1985), the AEZ 3 is made up of a herbaceous stratum dominated by *Pennisetum purpereum* and *Imperata cylindrica* and the woody cover is highly disturbed by human activities. A mangrove flora composed of *Rhizophoras* and *Avicennia* in AEZ 4; AEZ 5 is composed on the one hand by the dense evergreen forest of low

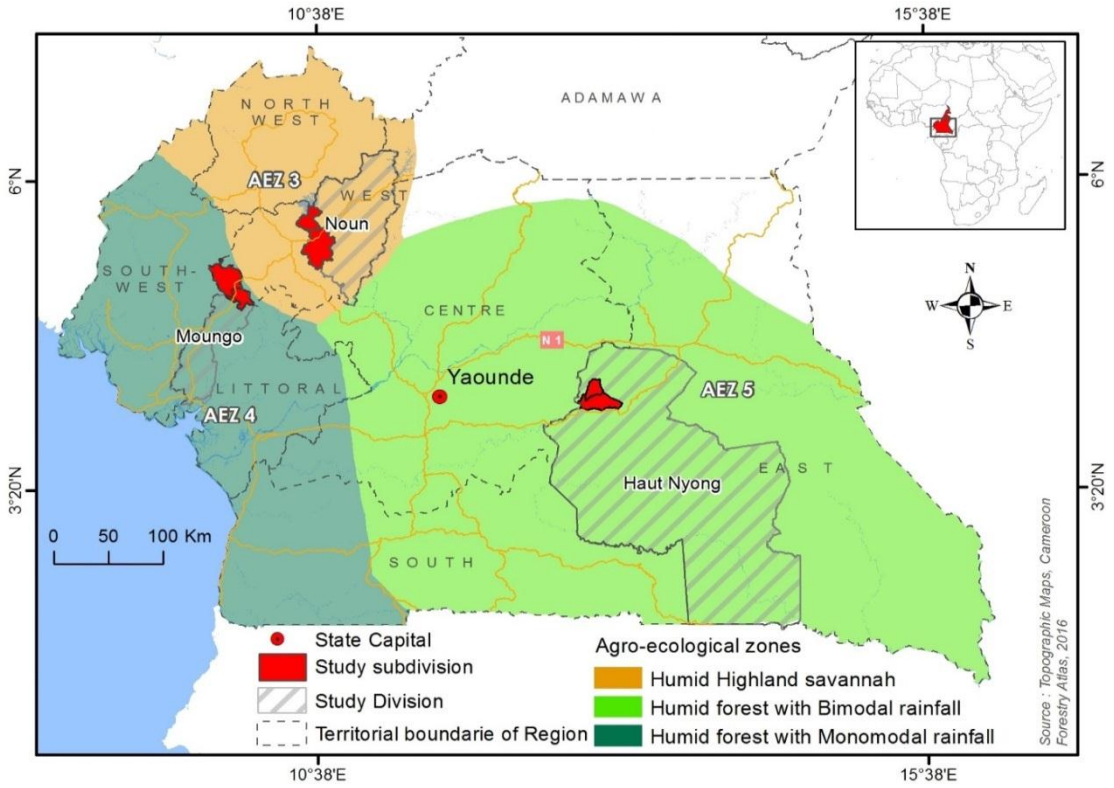

Figure 1. Location of study sites. **Source:** Topographic maps of Cameroon; Forestry Atlas, 2016.

and medium altitude and Atlantic of medium altitude and on the other hand, by the dense semi-deciduous forest of medium altitude. The Subdivisions of Foumbot and Kouoptamo are the study localities for AEZ 3; the Subdivisions of Melong, Baré-Bakem and Nkongsamba 2 are the study localities for EAZ 4; the Subdivisions of Angossas and Mboma are the study localities for EAZ 5.

Data collection and analysis

Remote sensing and field data

The remote sensing data consists of Landsat MSS, Landsat 7 ETM+ and Landsat 8 OLI_TIRS satellite images for the years 1980, 2001 and 2019, respectively. These images contain location information provided by National Aeronautics and Space Administration (NASA) and United State Geological Survey (USGS). The images have the advantage of being orthorectified, so they can be easily integrated into a geographic information system (GIS). These images have a resolution of 30 m for the multi-spectral bands and 15 m for the panchromatic band. They are provided in standard GeoTIFF format with a Universal Transverse Mercator (UTM) projection. The dry season images were used to discriminate between perennial crops and food crops and between rainy season crops. Landscape unit discrimination points were identified in the localities of the three production basins corresponding to four land use forms of interest in Noun and Moungo (forest/agroforest, clear forest, cropland, built-up areas/bare soil) and five in Haut-Nyong (valley vegetation, forest/agroforest, clear forest, cropland, built-up areas/bare soil).

DEM ASTER (Digital Elevation Model) images with a resolution of 30 m were first used to produce the Digital Terrain Model; coupled with field surveys, they were used to identify the altitudes at which coffee is grown in the production basins. A questionnaire was administered to 240 producers on the evolution of coffee-growing areas and the identification of land use types.

Data analysis

The first phases of the processing consisted of image pre-processing (atmospheric and radiometric corrections), combination of the different spectral bands and extraction of the study area from the image scenes for each of the three dates. The images used were all already geo-rectified according to the UTM WGS 84 projection system. Next, the normalized vegetation index (NDVI) analysis was used to highlight the vegetation surfaces. The NDVI varies from -1 to 1 with negative water values, bare and nearly bare soil values close to 0 and dense and green vegetation values close to 0.8 (Lambin and Ehrlich, 2007). It is the ratio of the Near Infrared (NIR) band minus the Red (R) band to the NIR + R band. The thresholding technique is then applied to extract information on AFS and forest formations. Finally, the composite bands were used to produce the best colour compositions to determine the spectral signatures of the objects for a supervised maximum likelihood classification of the land cover patterns. Four main classes of interest were identified: forest/agroforest, open forest, cropland and built-up/bare soil. The classification results were used to quantify land cover and highlight vegetation cover in 1980, 2001 and 2019. The pixel confusion matrix coupled with Global Positioning System (GPS) data from the field campaigns were used for final validation of the land cover maps. The image processing was carried out using ENVI 5.3 software. The processed images were then introduced into ArcGIS 10.3 software for the creation of maps and the calculation of areas.

The analysis of the dynamics was done by calculating the

average annual rate of spatial expansion (T) which measures the growth of macroeconomic aggregates between two given periods (Inoussa et al., 2011). Let S be the area, S1 and S2 corresponding to the areas of a land use class during the first and second periods.

$$T\ (\%) = \left[\frac{S2}{S1} - 1\right] * 100$$

- If S2 - S1 is positive, an increase in land cover unit is concluded;
- If S2 - S1 is negative, a regression of the land cover unit is concluded;
- If S2 - S1 is zero, a stability of the land use unit is concluded.

The development of the transition matrix, a method for describing in a condensed manner, in the form of a square matrix, the changes in state of the elements of a system during a given period (Schlaepfer, 2002). The transition matrix makes it possible to describe in a condensed manner, in the form of a square matrix, the changes in state of the elements of a system during a given period; it contains no information on the spatial distribution of the changes, nor on the processes and causes that led to the changes, but it does provide information on the proportion of assignment of a type "i" of land use to a state "j" that was achieved during the period in question (Bamba, 2010). The analysis of variance with SPSS 21 software has made it possible to compare the evolution of the averages of coffee areas in the production basins.

RESULTS

Land use in coffee growing areas

Status of land use in 1980, 2001 and 2019 in Noun

Figure 2 shows that land use differs from one date to another. In 1980, forest/agroforest occupied 18% of the total area, or 19596.5 ha. Crops occupied 13% (13988 ha) and clear forest 5.96%, that is, 6241.5 ha.

In 2001, the land use has clearly changed for some classes. The area occupied by forest/agroforest increased by 2% and reached 21% (21635.3 ha). Crops follow the same trend with a remarkable evolution of almost 10% of the occupied area between 1980 and 2001. The clear forest has considerably regressed compared to 1980; it does not reach 1% in 2001 and yet it occupied an area of over 5% in 1980. In 2019, built-up/bare soil still occupies a larger area than the other classes. Crops have followed a progressive curve and have evolved in terms of occupancy at the expense of other classes such as clear forest which holds the lowest percentage with 1.1%.

Status of land use in 1980, 2001 and 2019 in the Moungo

In Moungo, the changes and evolutions are as remarkable as in Noun (Figure 3). In 1980, forest/agroforest occupied a larger area than the other classes with 45.43% or 37907.1 ha of the total area.

The next largest area is cultivated with 33.95% (28332.8 ha), followed by built-up areas/bare soil and clear forest with 15.52 and 5.01% respectively. The real estate market with buildings had not yet expanded during this period. This is the reason why the area occupied by built-up/bare soil was not as important. The clear forest occupied only a small part of the total area. In 2001, both forest/agroforest and built/unbuilt land have changed compared to 1980. The area of forest/agroforest increased from 45.43% in 1980 to 55.05% (46677.4 ha) in 2001, that is, an increase of almost 10%, and the area of built-up area/bare soil increased from 15.52% in 1980 to 17.65% in 2001, that is, an increase of almost 1.5%. The clear forest and water have also experienced this evolution. Only crops have experienced a spectacular regression. They occupy 18.63%, which is minimal compared to the year 1980 when they occupied 33.95%. In 2019, crops have regained ground and occupy almost half of the total area with 45.16% (38346.8 ha). Among other things, they have nibbled away at the areas dedicated to forest/agroforest, which currently have only 22.31% (18,943.2 ha) of the area, whereas they occupied more than half of the total area in 2001. The clear forest has practically doubled its coverage rate with 16.44% (13960.3 ha) compared to 2001 when it was 8.57%.

Status of land use in 1980, 2001 and 2019 in Haut-Nyong

In Haut-Nyong (Angossas and Mboma), a new class is included in the analysis, namely valley vegetation (raffia swamp forest), which is a particularity of this zone (Figure 4). Globally, the class that has grown since 1980 to 2019 is the built-up/bare soil class with an evolution of more than 10% each time compared to the clear forest class which has suffered a degradation of its space going from 26.36% (16210.1 ha) of the occupied area in 1980 to 2.36% (1726.7 ha) in 2019. The other classes have undergone evolutions and changes over time; recording periods of oscillations that all have in common almost similar profiles in terms of evolution. In 2001, they reached their peak before falling in 2019.

Dynamics of land use patterns

From 1980-2001 to 2001-2019 in Noun

Between 1980 and 2001, forest/agroforest occupied more space with an increase in area of 2038.8 ha while clear forest lost over 90% of its area. The crop class gained the most in terms of area with a gain of over 11000 ha. The period 2001 to 2019 is characterized by gains in the clear forest and crop land use units and a decline in forest/agroforest and non-forest areas. Table 1 shows the differences in area gained or lost between the three dates (1980, 2001 and 2019).

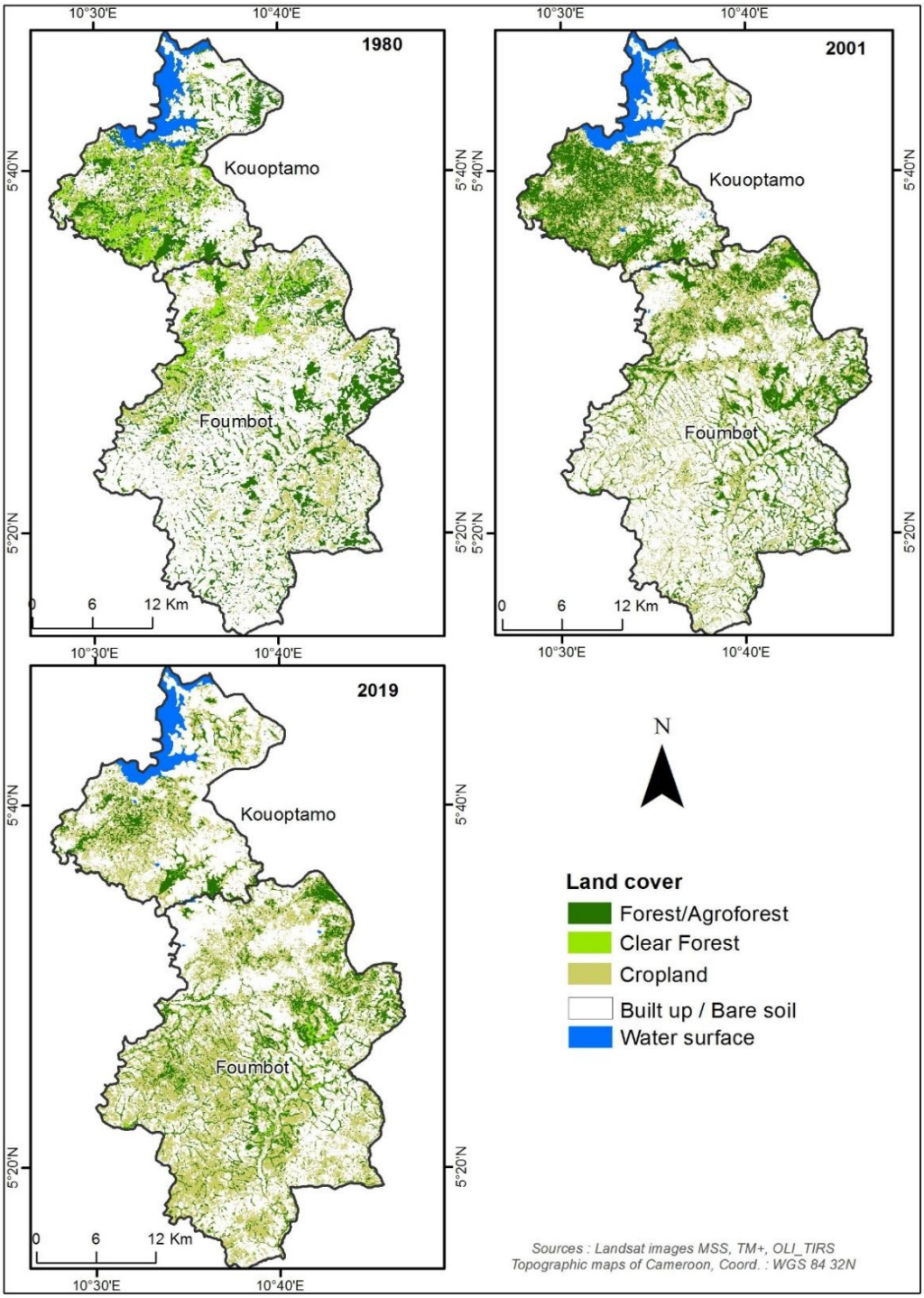

Figure 2. Land use/land cover classification in Noun Division (Foumbot and Nkouoptamo) in 1980, 2001 and 2019. Source: Landsat images MSS, TM+, and OLI-TIRS; Projection system: WGS 84 32N.

The transition matrix shows that between 1980 and 2001, 45.5% of the land in Noun underwent changes, including 42.30% of conversions, that is, 44281.6 ha, and 3.30%, that is, 3457 ha of modifications. The unchanged areas represent 54.40% of the total area of the study area, that is, 56943.2 ha. Table 4 highlights the changes that have affected forests at the expense of cultivated areas and built-up areas and bare soil. Between 2001 and 2019, 45.08% of the land in Noun underwent changes, 43.79% of which were conversions, that is, 45841.6 ha, and only 1.29%, that is, 1353.3 ha, were modifications. As for the areas without changes, they represent 54.92% of

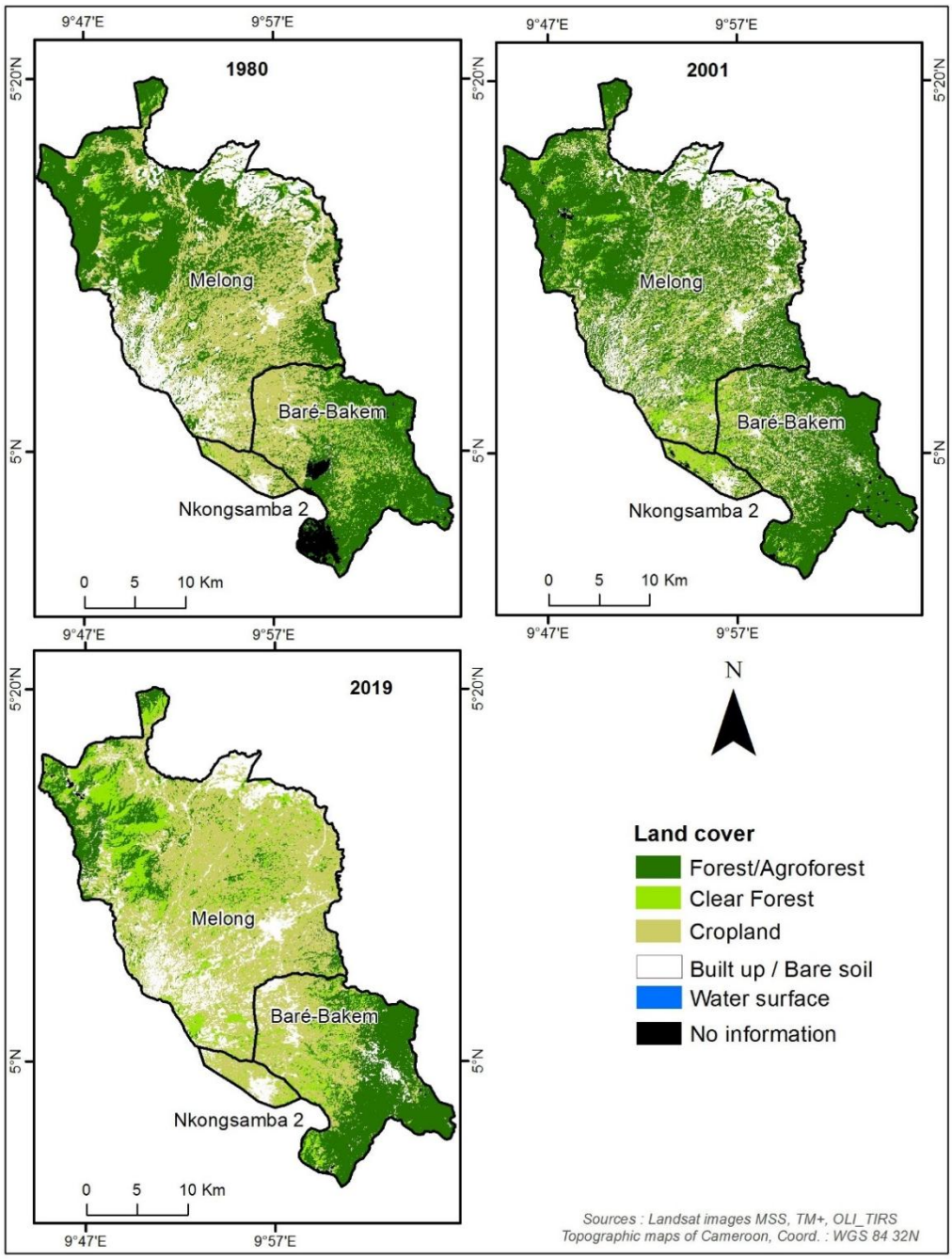

Figure 3. Land use/land cover classification in Moungo Division (Melong, Baré-Bakem and Nkongsamba 2) in 1980, 2001 and 2019. Sources: Landsat images MSS, TM+, and OLI-TIRS; Projection system: WGS 84 32N.

the total area of the study area, that is, 57487 ha (Table 5).

From 1980-2001 to 2001-2019 in the Moungo

Overall, the land use classes in this area have varied over time and no class has been able to maintain the extent of area that it has increased or decreased. Table 2 shows the differences in area (gained or lost) of the five land use classes between 1980 and 2019. Between 1980 and 2001, only crops experienced a decrease in terms of area and the other classes experienced remarkable increases. Forest/agroforest has the largest increase with 8770.2 ha; this class is strongly correlated with crops since an increase in area in one of these classes leads to

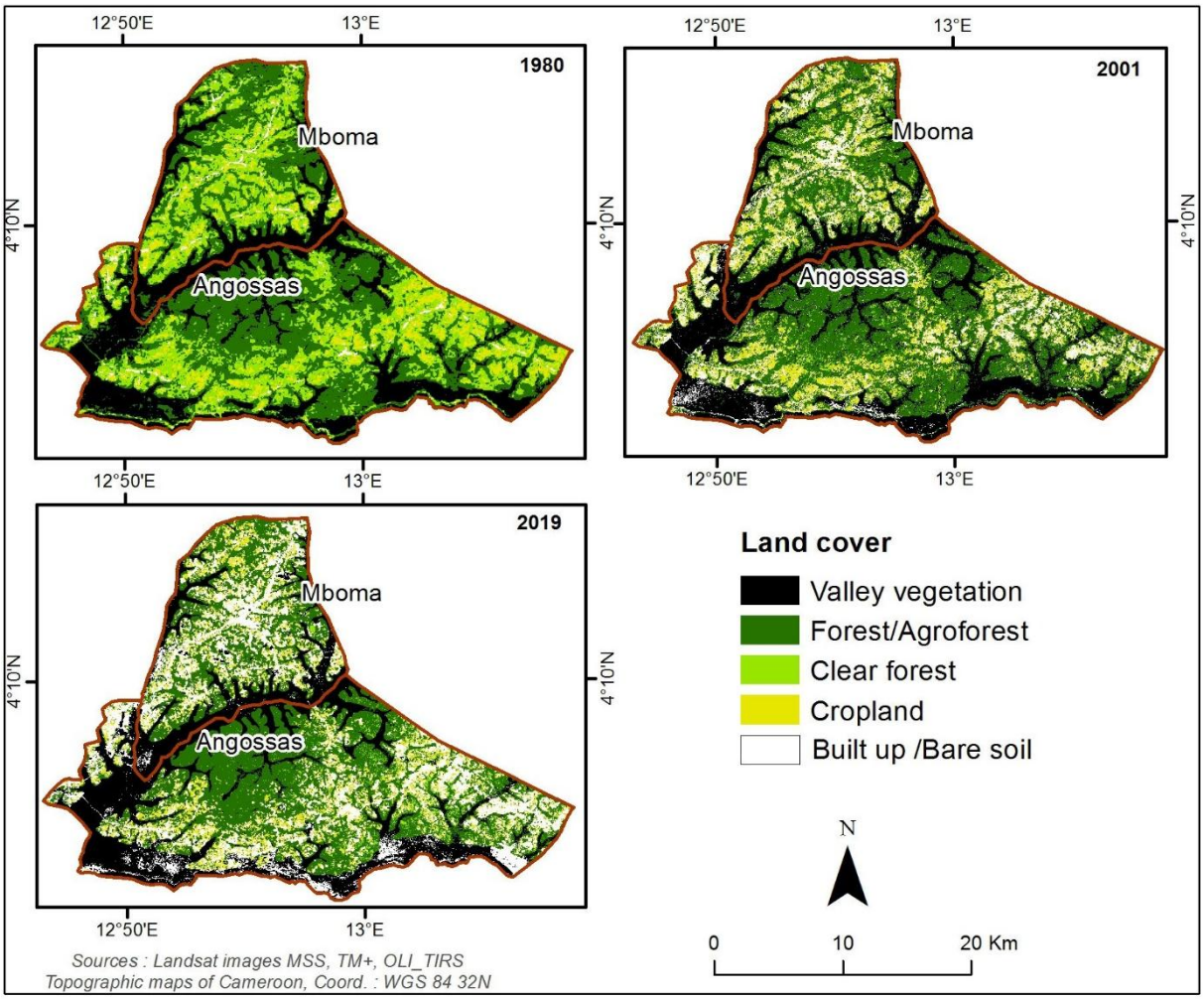

Figure 4. Land use/land cover classification in Haut-Nyong Division (Angossas and Mboma) in 1980, 2001 and 2019. Sources: Landsat images MSS, TM+, and OLI-TIRS; Projection system: WGS 84 32N.

Table 1. Areas of land use/land cover gained or lost (ha) between 1980 and 2019 in Noun.

Period	Areas in 1980	Areas in 2001	Areas in 2019	Area gained/lost between 1980 and 2001	Area gained/lost between 2001 and 2019
Land use patterns			**Areas (ha)**		
Forest/Agroforest	19596.6	21635.4	14164.4	2038.8	-7470.9
Clear Forest	6241.6	585.3	1242.1	-5656.2	656.7
Cropland	13988.9	25959.1	35291.5	11970.3	9332.4
Built up / Bare soil	61932.7	53423.4	51080.4	-8509.3	-2343.1
Water	2922.2	3078.5	2903.4	156.4	-175.1

a decrease in the other class and vice versa. The period 2001 to 2019 is marked by gains in the crop and clear forest land use units and a decrease in forest/agroforest. This confirms the interrelation between the forest/ agroforest class and crops.

Table 6 shows that between 1980 and 2001, 39.39% of the land in the Moungo underwent changes, of which 34.80% were conversions, that is, 28936.4 ha, and 4.59%, that is, 3813.6 ha, were modifications. The unchanged areas represent 60.61% of the total area of

Table 2. Areas of land use/land cover gained or lost (ha) between 1980 and 2019 in Moungo.

Period	Areas in 1980	Areas in 2001	Areas in 2019	Area gained/lost between 1980 and 2001	Area gained/lost between 2001 and 2019
Land use patterns			**Areas (ha)**		
Forest/Agroforest	37907.1	46677.4	18943.2	8770.2	-27734.2
Clear forest	4178.5	7263.8	13960.3	3085.2	6696.4
Cropland	28332.8	15792.6	38346.8	-12540.1	22554.2
Built up / Bare soil	12955.1	14969.8	13647.5	2014.6	-1322.2
Water	73.8	88.4	21.2	14.6	-67.2

Table 3. Areas of land use/land cover gained or lost (ha) between 1980 and 2019 in Haut-Nyong.

Period	Areas in 1980	Areas in 2001	Areas in 2019	Area gained/lost between 1980 and 2001	Area gained/lost between 2001 and 2019
Land use patterns			**Areas (ha)**		
Valley vegetation	14613.3	18080.1	14841.9	3466.8	-3238.2
Forest/Agroforest	24772.7	25944.7	23361.9	1172.1	-2582.9
Clear Forest	16210.1	1726.7	1436.4	-14483.4	-290.3
Cropland	4939.2	7998.4	6526.8	3059.2	-1471.7
Built up / Bare soil	956.2	7954.4	14746.3	6998.2	6791.8

Table 4. Dynamic characteristics of land use/land cover patterns from 1980 to 2001 in Noun.

2001/1980	Forest /Agro forest (ha)	Clear forest (ha)	Cropland (ha)	Built up/Bare soil (ha)	Water
Forest/Agroforest	9110.7	371.1	5439.2	4567.1	108.3
Clear forest	3085.9	26.8	2289.5	838.6	0.8
Cropland	2617.9	30.9	4268.5	7053.6	18.0
Built up/Bare soil	6754.3	156.5	13898.4	40854.6	268.9
Water	66.6	0	63.4	109.6	2682.6
	Modified areas in forest vegetation		Areas unchanged		

the study area, that is, 50390.7 ha. Between 2001 and 2019, 56.43% of the Moungo's land area underwent changes, of which 45.62% were conversions, that is, 38597.8 ha, and 10.81%, that is, 9141.1 ha of modifications. The unchanged areas represent 43.57% of the total area of the study area, that is, 36860.9 ha (Table 7).

From 1980-2001 to 2001-2019 in Haut-Nyong

Between 1980 and 2001, the first remark that stands out is that clear forest is the only class that has regressed and this area has reached 14483.4 ha. All other classes have gained in area. Between 2001 and 2019, valley vegetation is the class that lost the most area. Forest/agroforest is decreasing; in contrast to the period 1980 and 2001 when it had the largest area loss, it becomes the class with the least area loss during this period. Table 3 provides further clarification on land use in zone 5.

Table 8 shows that between 1980 and 2001, 48.64% of the land in Haut-Nyong underwent changes, of which 38.40% were conversions, that is, 23,614.3 ha, and 10.24%, that is, 6,298.6 ha, were modifications. As for the areas without changes, they represent 51.35% of the total area of the study area, that is, 31578.4 ha. Between 2001 and 2019, 46.02% of the land in Haut-Nyong underwent changes including 37.56% of conversions or 23178 ha and 8.46% or 5218 ha of modifications. As for the areas without changes, they represent 53.98% of the total area of the study area, that is, 33308 ha (Table 9).

Table 5. Dynamic characteristics of land use/land cover patterns from 2001 to 2019 in Noun.

2019/2001	Forest /Agro forest (ha)	Clear forest (ha)	Cropland (ha)	Built up/Bare soil (ha)	Water
Forest/Agroforest	8344.9	951.3	7800.5	4489.6	49.2
Clear forest	402.0	107.2	52.9	22.8	0.4
Cropland	3457.8	136.2	11156.7	11188.7	19.7
Built up/Bare soil	1949.2	47.1	16235.0	35118.1	74.1
Water	10.5	0.2	46.4	261.3	2760.1
	Modified areas in forest vegetation		Areas unchanged		

Table 6. Dynamic characteristics of land use/land cover patterns from 1980 to 2001 in the Moungo.

2001/1980	Forest /Agro forest (ha)	Clear forest (ha)	Cropland (ha)	Built up/Bare soil (ha)	Water
Forest/Agroforest	31790.6	1591.2	2252.5	2018.0	47.8
Clear forest	2222.4	1202.1	501.4	223.5	1.7
Cropland	9079.8	3658.2	10149.8	5388.2	7.3
Built up/Bare soil	2320.0	621.0	2742.8	7235.1	14.1
Water	43.7	0.8	1.2	14.4	13.1
	Modified areas in forest vegetation		Areas unchanged		

Table 7. Dynamic characteristics of land use/land cover patterns from 2001 to 2019 in the Moungo.

2019/2001	Forest /Agro forest (ha)	Clear forest (ha)	Cropland (ha)	Built up/Bare soil (ha)	Water
Forest/Agroforest	17557.0	8810.1	17423.9	2737.8	3.9
Clear forest	331.0	2278.9	3813.4	818.5	0.1
Cropland	414.9	1841.0	10267.7	3262.7	0.1
Built up/Bare soil	458.6	983.0	6768.9	6743.3	3.1
Water	20.5	5.1	10.4	31.9	14.0
	Modified areas in forest vegetation		Areas unchanged		

Table 8. Dynamic characteristics of land use/land cover patterns from 1980 to 2001 in Haut-Nyong.

2001/1980	Valley vegetation (ha)	Forest /Agro forest (ha)	Clear forest (ha)	Cropland (ha)	Built up /Bare soil (ha)
Valley vegetation	12418.8	1493.3	28.2	82.3	590.5
Forest/Agroforest	4805.3	15922.1	770.0	1790.5	1484.8
Clear forest	680.4	7208.3	773.7	4072.0	3475.7
Cropland	86.6	1112.1	137.4	1845.5	1757.6
Built up/Bare soil	27.0	118.5	11.6	180.8	618.3
	Modified areas in forest vegetation		Areas unchanged		

Influence of coffee growing on agrarian dynamics

In the Department of Noun, an Arabica coffee growing area (Foumbot and Kouoptamo Subdivisions), coffee growing is practiced between 800 and 1400 m altitude. The Kouoptamo area is higher in altitude and coffee is grown at an average altitude of 1200 m. In Moungo, the Robusta coffee production basin (Melong, Bare-Bakem

Table 9. Dynamic characteristics of land use/land cover patterns from 2001 to 2019 in Haut-Nyong.

2019/2001	Valley vegetation (ha)	Forest /Agro forest (ha)	Clear forest (ha)	Cropland (ha)	Builtup/Bare soil (ha)
Valley vegetation	12065.8	3156.9	152.1	368.5	2336.8
Forest/Agroforest	2061.1	15313.7	985.3	2632.6	4951.8
Clear forest	70.6	962.6	50.1	240.5	402.9
Cropland	157.0	2560.8	143.5	1882.1	3255.0
Built up /Bare soil	682.3	1594.2	110.8	1570.7	3996.3
	Modified areas in forest vegetation		Areas unchanged		

Table 10. Evolution of average coffee growing areas according to production zones.

Production basins	Locations	Average area at origin (ha)	Current average area (ha)
Noun	Foumbot, Nkouoptamo	1.25±1.02[a]	0.67±0.72[a]
Moungo	Melong, Baré-Bakem, Nkongsamba 2	1.59±1.07[b]	1.14±1.13[b]
Haut-Nyong	Angossas, Mboma	1.93±1.09[c]	1.51±1.27[c]

Means with identical letters in each column are equal to the significance level $\alpha = 0.05$, P = 95%.

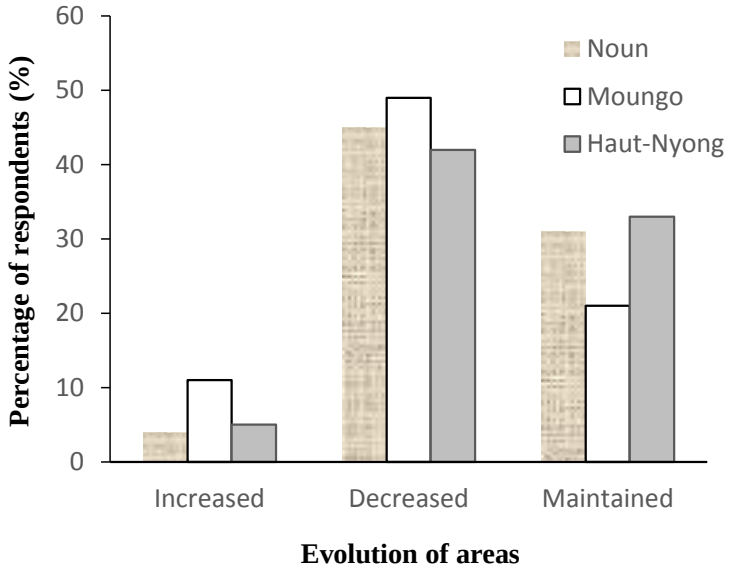

Figure 5. Producers' perception of the evolution of coffee areas over time according to production basins.

and Nkongsamba 2 Subdivisions), coffee is also grown at altitudes of up to 1,400 m. However, there are dissimilarities at the locality level, with the highest localities being in Melong and Nkongsamba 2. In Bare-Bakem, the altitude does not exceed 1000 m. In Haut-Nyong, another Robusta coffee production basin, the is altitude varies from 590 to 780 m (Mboma and Angossas Subdivisions) and coffee growing is practiced at all levels of altitude. The influence of coffee growing on the agrarian landscape of Cameroon's production basins significant and relates to the distribution of land per farmer according to the localities of each basin (Table 10 and Figure 5).

Table 10 shows that the largest areas under cultivation are in Haut-Nyong (1.51±1.27 ha), the medium areas in Moungo (1.14±1.13 ha) and the smallest in Noun (0.67±0.72 ha); however, Melong is the second largest area after Mboma. The smallest areas are found in Foumbot in Noun with 0.58±0.73 ha. For the first period (areas at origin), the analysis of variance shows that

there is a significant difference (0.010) between the area means between localities and area classes. The Newman-Keuls test for separation of means shows that the area means of Melong, Angossas and Mboma differ from those of the other four smaller localities. For the first period (areas at origin), the analysis of variance shows that there is a significant difference (0.010) between the area means between localities and area classes. The Newman-Keuls test for separation of means shows that the area means of Melong, Angossas and Mboma differ from those of the other four smaller localities.

For the second period (current areas), the analysis of variance shows that there is a significant difference (0.006) between the area means between localities and area classes. The test of separation of means shows that the area means of Melong and Mboma differ from those of the other five smaller localities. However, there is a significant difference between the area means of the different basins. However, Moungo is the basin that has experienced the most decreases and increases in area, with peaks of nearly 50 and 12% for decreased and increased areas respectively; the areas that have been maintained are found in Haut-Nyong (33%) and Noun (31%).

DISCUSSION

Land use/land cover dynamics

Studies on land cover change are essential for the development of effective natural resource management plans (Gilani et al., 2015). The diachronic analysis of the landscapes of the different coffee production basins developed from Landsat MSS, ETM + and OLI TIRS images, allowed a monitoring of landscape changes that occurred between 1980 and 2019. The knowledge of the terrain has made it possible to identify the constituent elements of the environment and to accurately characterize the occupation modes through thresholding methods and supervised classification. The use of remote sensing has already been used in the analysis of land cover dynamics by many authors (Tabopda, 2012; Ellis et al., 2010; Temgoua et al., 2018; Momo et al., 2018; Djiongo et al., 2020; Tsewoue et al., 2020), but this approach has the advantage of allowing for more accurate extraction of vegetation information. The confusion matrix reveals that the pixels of some land use units were confused with others; but the Kappa index obtained which varies between 0.90 and 0.98 for the images of each site confirms the statistical acceptability of these classifications.

The results of this study show after using the FAO soil classification system (2012) applied to our context, that coffee AFS are part of the forest/agroforest land use class. Since 1980, forest/agroforest compared to other land use classes has been the most important in Moungo in particular with 45% of the total area of the study area against 40% in Haut-Nyong and 18% in Noun. The 2001 period is marked by an increase in the area of this class in all production basins (55% in Moungo, 42% in Haut-Nyong and 21% in Noun). Between 2001 and 2019, there was a significant decline in the area of forest/agroforest, most notably in Moungo (22% in Moungo, 38% in Haut-Nyong and 14% in Noun). These decreases in area are in contrast to the continuous increases recorded in the crop and housing classes. In a similar study conducted on the eastern slope of the Bamboutos Mountains (Kuete, 2017; Fogaing, 2019), where population densities are higher, the period 2001-2017 is instead marked by a resurgence of forest/agroforest areas due to plantations of eucalyptus and other multipurpose woody species. These results on land use in Cameroon's coffee production basins, which show a continuous increase in cultivated areas, are similar to those obtained by Oszwald (2005); in fact, in a study conducted on agroforestry dynamics between 1980 and 2000, the author highlights deforestation in favour of cultivated areas, mainly for commercial purposes, through the establishment of coffee or cocoa plots; this period corresponds to a transition in Cameroon towards food and perennial crops (cocoa and oil palm).

The activity data that emerged show that overall, the period 2001-2019 is marked by greater changes (conversions and modifications) in land use units compared to the period 1980-2001. During the period 1980-2001, the greatest changes in land use units are recorded first in Haut-Nyong (48.6% of the total area of this study area) against 51.3% without changes; then in Noun with 42.3% of changes against 54.4% of unchanged areas; finally in Moungo with 39.9% of changes against 60.6% without changes On the other hand, during the period 2001-2019, Moungo recorded the greatest changes with 56.4% of the total area of this study area, followed by Haut-Nyong with 46% of changes; Noun was in last position with 45% of changes. These data differ from those obtained on the eastern slope of the Bamboutos Mountains (Kuete, 2017) where the most significant changes were observed during the period 1980-2001. These data differ significantly from those obtained by Sarr (2009) in a similar study in a drought affected ecoregion.

The identification of land use types from the forms of occupation showed that in addition to coffee AFS which are found in the forest class, sacred forests we also have raffia and bamboo in the valleys and other multipurpose woody trees; eucalyptus stands are found in Noun at all altitudinal gradients while coffee trees are found at medium and low altitudes as indicated by Mbarga et al. (2013) for the western highlands. In Noun (Foumbot and Kouoptamo Subdivisions), the study showed that coffee trees are found between 800 and 1400 m in Moungo and between 590 to 780 m in Haut-Nyong. Contrary to the eastern slopes of the Bamboutos Mountains, where

coffee is grown up to 1800 m in altitude and where all levels of altitude are exploited (potato and market garden crops at high altitude), the high altitudes of Noun and Moungo, which are mostly not exploited, are used for grazing. The non-forest areas (built-up areas/bare soil) are made up of built-up areas, rocky outcrops and bare soil. However, some of the bare soil was found to be cultivated areas due to the preparation of the soil for cultivation during the satellite imaging; this would refer to the larger agricultural areas than those assessed in this study.

Influence of coffee growing on the agrarian landscape of production basins

The introduction of coffee growing in Cameroon has had a significant impact on the agrarian landscape of the different production basins. In the years before the crisis, there was a rapid increase in the area under coffee, followed by a second period marked by a decline. There is a significant difference between the original and current areas under coffee. The average size of the original coffee-growing areas varied between 1.25±1.02 and 1.93±1.09 ha (with a peak of 2.02 ha in Haut-Nyong) depending on the production basin. Today, the largest areas under cultivation are in Haut-Nyong (1.51±1.27 ha), the medium areas in Moungo (1.14±1.13ha) and the smallest in Noun (0.67±0.72 ha); the localities of Haut-Nyong (Mboma and Angossas) and the locality of Melong have the largest average areas. These results show a certain evolution in the area under coffee; the work of Kaffo (2000) placed the average area in the village of Bafou (West Cameroon) at 1.8 ha. Taboula (2000) on the land and coffee crisis on the basaltic plateau of Bafou (West Cameroon) shows that the relief, certain paleoclimates limiting the available surfaces, rocky outcrops and mountainous slopes, and the inheritance system are the causes of these surfaces which he situates at an average of 700 m^2 on the piedmont and 2 ha on the mountain. However, it should be noted that the population growth is more important in this part of West Cameroon.

In general, this study shows a certain concordance with the periods that marked the history of coffee growing on the eastern slopes of the Bamboutos Mountains as studied by Kamga (2002) and Kuete (2008). The year 1980, the period of the coffee crisis, marks the peak of coffee cultivation. This is what justifies the dominance of the forest class in this period. Then, following the negative consequences of this crisis, including the fall in coffee prices, the abandonment of AFS is clearly felt in 2001 and 2019 with a dominance of bare soil and crops. This raises the question of the coffee revival encouraged for several years by the sectoral ministries, organizations and institutions under supervision, which seems to have remained embryonic. This reality is in line with the results of the work of Ellis et al. (2010) on the dynamics of land occupation and use in the marginal lowlands of the State of Veracruz in Mexico; these authors show that tree cover and coffee agroforests were largely conserved during the first decade after the coffee crisis, but losses recorded around 2010 mainly attributable to pasture and agriculture are leading the authorities to encourage the population to diversify, which alone may not stop deforestation.

Conclusion

The introduction of coffee growing in Cameroon by the colonialists in the 1920s saw a total adhesion of a good number of Cameroonian farmers in the 1990s following the liberalization of the sector. Despite the establishment of farmers' organizations that proliferated in West Cameroon following the disengagement of the state, or the installation of development agencies such as the Integrated Priority Action Zone of the East (ZAPI-East), Care Cameroon and Plan Cameroon, which gave a real impetus to development, the second crisis of the 1980s had a significant impact on the coffee economy and led farmers to adopt subsistence strategies. Multiscalar analysis of remote sensing images shows a significant change in the landscape. Land use in 1980 shows that forest/agroforest compared to other land use classes was the most important in Moungo, with 45% of the total area of the study zone, compared to 40% in Haut-Nyong and 18% in Noun.

The 2001 period is marked by an increase in the area of this class in all production basins (55% in Moungo, 42% in Haut-Nyong and 21% in Noun). Between 2001 and 2019, there was a significant decline in the area of forest/agroforest, most notably in Moungo (22% in Moungo, 38% in Haut-Nyong and 14% in Noun). These decreases in area are in contrast to the continuous increases recorded in the crop and housing classes. The identification of land use types based on tenure patterns showed that coffee AFS, forest, valley raffia and bamboo, and other multiple-use woody species are found in the forest/agroforest class; these coffee AFS are found at medium and low altitudes. In Noun (Foumbot and Kouoptamo Subdivisions), coffee trees are found between 800 and 1400 m, up to 1400 m in Moungo and between 590 and 780 m in Haut-Nyong. The high altitudes of Noun and Moungo are mostly undeveloped and used for grazing.

The non-forested areas (built-up areas/bare soil) are made up of built-up areas, rocky outcrops and bare soil. Coffee abandonment has had a significant impact on the development of coffee AFS. Following the negative consequences of this crisis in the 1980s, including the fall in coffee prices, the abandonment of the coffee AFS is clearly felt in 2001 and 2019 with a dominance of cultivated areas where many farmers prefer to devote

themselves to the cultivation of cocoa (mainly in Moungo and Haut-Nyong and a new introduction in Nkouoptamo in Noun), palm and banana.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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