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Cocoa Farming and Carbon Footprint in the New Cocoa Production Area in Côte d'Ivoire: The Case of the Biankouma Department

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Abstract **Original Research Article**

Côte d'Ivoire remains the world's leading cocoa producer, but this success has come at the cost of severe pressure on forest ecosystems and the uncontrolled use of chemical inputs to increase cocoa production. Unfortunately, all these practices have an impact on the environment, particularly in terms of greenhouse gas emissions. Against this backdrop, this study aims to assess the impact of agricultural practices related to cocoa farming on greenhouse gas emissions, particularly carbon, in the department of Biankouma. To achieve this, semi-structured surveys using a questionnaire were conducted among cocoa farmers. The questions asked focused mainly on how the plots were maintained, the types and quantities of inputs used, the previous crop, and the means of transport used. In addition, the total volume of carbon emitted was determined according to the age of the plantations. The main results showed that forest conversion is the main route of cocoa expansion, with 74.12% of plantations located on former forests in the department of Biankouma. The use of plant protection products in cocoa plantations is also widespread in Biankouma, with a rate of 87.34% of producers. Plantations aged 26 to 30 years and those aged 11 to 15 years have the highest annual yields, at 1,321.08 kg/ha and 1,144.7 kg/ha, respectively. In terms of carbon footprint, in Biankouma, cocoa plantations between 26 and 30 years old emit more carbon, with a value of 5.19E+04 $kgCO_2$. These results confirm that the carbon footprint of Ivorian cocoa farming is mainly linked to land use change, chemical intensification, and high cocoa tree productivity.
Keywords: Cocoa farming, deforestation, agricultural practices, carbon footprint, cocoa production area, Côte d'Ivoire.
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1. INTRODUCTION

Agriculture plays a key economic role in the development of sub-Saharan African countries. In many sub-Saharan African countries, it accounts for an average of 70% of jobs, 40% of export earnings, and 35% of gross domestic product (Tano, 2012). Like other sub-Saharan African countries, Côte d'Ivoire has focused its economic development on the agricultural sector since gaining independence. The agricultural sector, which is mainly based on cocoa farming, is now a key area for the socio-economic development of the State of Côte d'Ivoire. In social terms, cocoa farming employs around 600,000 farm managers and supports 6 million people in Côte d'Ivoire, as well as contributing to various jobs in the secondary and tertiary sectors (Tano, 2012). Economically, cocoa farming accounts for around 40% of Côte d'Ivoire's export earnings and contributes 28% of GDP (Koffi, 2023). Globally, Côte d'Ivoire is the leading producer of cocoa beans due to the large quantities produced on its territory (ICCO, 2012). However, the development of the cocoa industry has often been accompanied by unsustainable agricultural practices, characterized mainly by deforestation, soil degradation, and the uncontrolled use of chemical inputs. All these practices have an impact on the environment, particularly in terms of greenhouse gas emissions and biodiversity loss (REED+, 2017). Indeed, the massive conversion of forests into vast cocoa plantations has led to a decline in Côte d'Ivoire's forest cover, which fell from 16 million hectares in the 1960s to just 3.6 million hectares in 2015 (REED+, 2017).

In this context, Côte d'Ivoire, although it remains the world's leading producer of cocoa beans, is now at the heart of environmental issues related to the sustainability of its agriculture. Faced with the climate emergency, it is becoming necessary to question current production methods and their implications for the carbon footprint of the agricultural sector. This raises several questions: What are the current agricultural practices in cocoa-producing households? How are producers managing to maintain their yields in the current context of climate change? How do these practices impact greenhouse gas emissions in the environment?

The overall objective of this study is to assess the impact of agricultural practices in Ivorian cocoa plantations on the environment, in the context of global warming. More specifically, it aims to [1] characterize agricultural practices (crop rotation, use of plant protection products) in cocoa plantations in the department of Biankouma; [2] determine plantation yields [3] estimate the quantities of carbon emitted by cocoa plantations in the department of Biankouma. Understanding these agricultural practices and their effects on the carbon footprint is an essential step in promoting sustainable and environmentally friendly cocoa farming in Côte d'Ivoire.

2. METHODOLOGY

2.1. Study site

This study was conducted in the department of Biankouma, located in western Côte d'Ivoire (between 7°21'00" and 8°06'00" north latitude and 7°03'00" and 8°15'00" west longitude) (Figure 1). The population living in this department is mainly engaged in agriculture. In fact, these populations are mainly engaged in the cultivation of coffee, rice, cassava, and oil palms (N'Guessan, 2020). More recently, they have become interested in cocoa farming (Koua *et al*., 2020), making this department the new area for cocoa cultivation. However, its production remains marginal, contributing only 5% of the national harvest. In terms of soil, the soil in the Biankouma department is ferralitic, according to the classification of (Perraud, 1971).

This study was conducted in six (06) villages in the Biankouma Department, namely Bounta, Touoba, Moroulé, Somba, Chocopleu, and Klapleu (Figure 1).

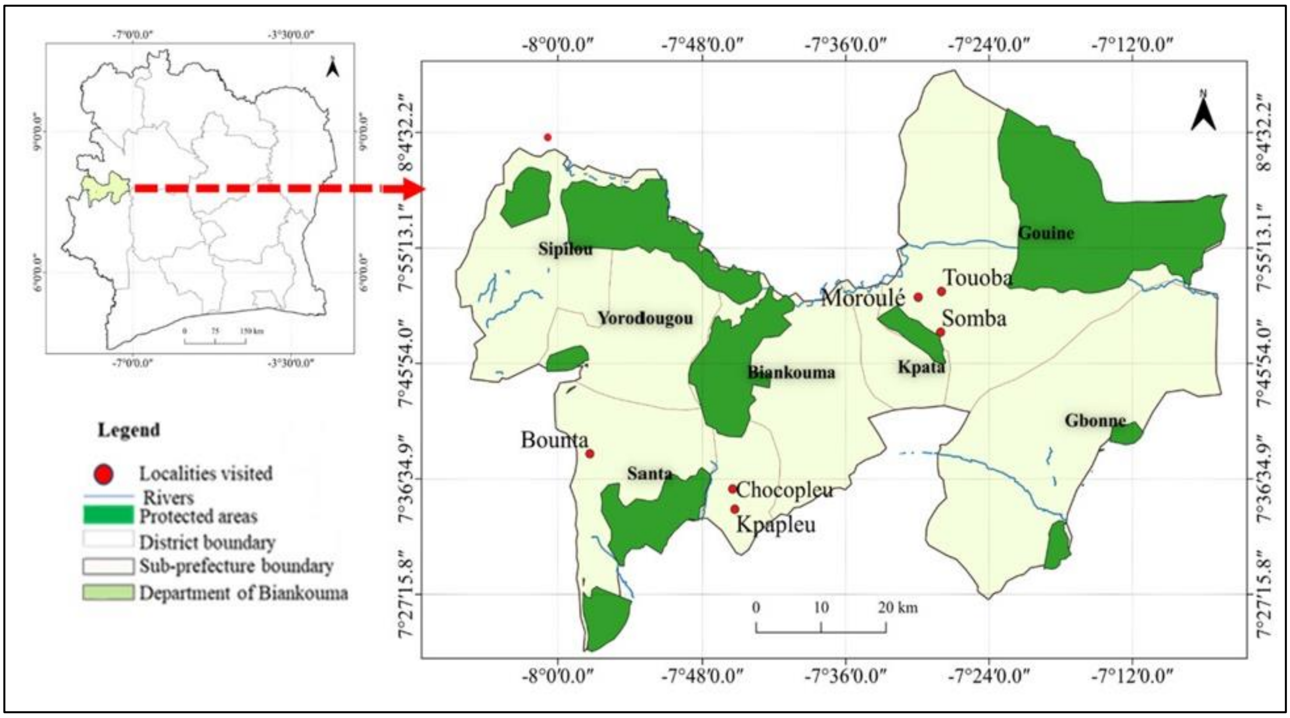

Figure 1: Geographical location of the study areas and sites in Côte d'Ivoire

2.2. Selection of villages, producers, and plantations

The choice of localities and plantations visited was based on various criteria, including the number of cocoa farmers, annual cocoa bean production, accessibility of the locality, presence of trees in the plantations, and age of the plantation. In addition, the various cocoa farms surveyed were divided into seven age groups. These age groups were [0-4] years, [5-10] years, [11-15] years, [16-20] years, [21-25] years, [26-30] years, and ≥ 30 years. The different age classes were determined based on data from surveys conducted during the Cocoa4future project. A total of five (05) plantations were included in each of the pre-established age groups. This gives a total of 35 plantations per locality. The producers surveyed were selected from a list provided by ANADER agents in each study area.

2.3. Socio-economic surveys

Data collection was based on socio-economic surveys conducted among landowners of the selected plantations. Semi-structured interviews, supported by a questionnaire structured according to specific themes (Dubois & Michaux, 2006), were conducted according to the availability of producers, either in the village or on the plantations. The questionnaire focused in particular on the characteristics of the plantation (area, age, maintenance), the use and quantity of inputs, yield per hectare, distance between the plantation and the home, and the method of transporting the beans.

2.4. Data analysis

Characterization of agricultural practices

After the field phase, the survey forms were analyzed and the data entered into an Excel spreadsheet. The results were then summarized and presented in tables and graphs. The data analysis focused mainly on calculating relative frequencies in order to identify the dominant practices within the different categories of plantations. This calculation was performed using the following formula:

$$F = \frac{ni}{N}\ x\ 100 \qquad \text{(Equation 1)}$$

where F represents the relative frequency (%), N represents the total number of respondents, and n_i represents the number of individuals corresponding to a given modality.

Determination of yield

The yield of the plantations was determined based on the annual production reported by each farmer. The following mathematical formula was used:

$$R = \frac{Pt}{Sup} \qquad \text{(Equation 2)}$$

Where R = Annual yield of the plantation per hectare, expressed in kilograms per hectare.

Determining the carbon footprint of cocoa plantations

In order to better assess carbon emissions related to planting, the various components of carbon emissions have been divided into three (03) scopes at the global level.

- **Scope 1:** takes into account direct emissions from the activity (emissions related to soil and cocoa).
- **Scope 2:** indirect emissions related to energy consumption (emissions related to transport).
- **Scope 3:** other indirect emissions (emissions related to the use of inputs).

Carbon emissions linked to the use of inputs (scope 3)

Agricultural inputs include all products used on crops to improve their yield. They mainly comprise fertilizers, which compensate for the loss of mineral ions from the soil, and plant protection products (insecticides, herbicides, and fungicides). The use of these inputs is a significant source of carbon emissions into the atmosphere (Koffi, 2023). For the purposes of this study, only plant protection products were taken into account.

Emissions related to the use of plant protection products were estimated using the equation proposed by (Soenen, 2021):

$$Epi = \sum_{i=1}^{o}[Q_{pl,i} * FE_{pl}] \qquad \text{(Equation 3)}$$

Where Epi represents carbon emissions linked to the use of plant protection products on a plot of land. FE_{pl} represents the emission factor associated with the type of plant protection product used per ton of raw product. $Q_{pl,i}$ is the quantity of plant protection product used on plantation i.

Carbon emissions linked to cocoa (scope 1)

Emissions related to cocoa took into account emissions linked to cocoa shells and cocoa juice. Emissions from shells are those linked to the decomposition of shells, while emissions from juice are those linked to the fermentation of cocoa juice. This study was based on the work of Edoh Adabe & Ngo-Samnick (2014), and Achi *et al*. (2020) to determine the emissions associated with cocoa juice. According to Edoh Adabe & Ngo-Samnick (2014), producing one liter of cocoa juice requires approximately 35 kg of beans. Furthermore, Achi *et al*. (2020) showed that one liter of cocoa juice emits 9.9 gC, or 9.9×10^{-3} kgC. The following mathematical formula was used:

$$E_{jus} = Qjus \times Ec \qquad \text{(Equation 4)}$$

Where E_{juice} is the emission linked to cocoa juice, Qjuice is the quantity of juice produced per kg of cocoa beans, and Ec is the quantity of carbon emitted per liter of cocoa juice, i.e., $9.^{9\times10^{-3}}$kgC/L.

Emissions from cocoa shells were estimated based on the work of Oscar *et al*. (2016). They showed that one kilogram of cocoa shells emits approximately 7.69 kg of CO_2, and that one kilogram of shells is equivalent to 8.5 kg of beans. Thus, carbon emissions related to shells (Ec) were calculated as follows:

$$E_c = Q_{shells} \times E_{CO2} \qquad \text{(Equation 5)}$$

Where Ec is the carbon emitted due to cocoa shells in megatons of CO_2; Q_{shells} is the quantity of shells in kg; and E_{CO_2} is the emission associated with 1 kg of cocoa shells. Emissions from cocoa were obtained by adding together emissions linked to shells and cocoa juice.

Carbon Emissions from soil (scope 1)

Carbon emissions from soil were assessed according to the work of Palmer *et al*. (2019), who estimated that one square meter of soil releases approximately 0.4 kgC. The calculation was performed using the following formula :

$$ES = \frac{si\ x\ Ec}{S} \qquad \text{(Equation 6)}$$

Where ES is 117arbone mission117 from the soil expressed in kg of $_{CO_2}$; s is the surface area of plot i under study ; 117arbo the 117arbone mission factor for the soil expressed in hectares ; and S is the correspondence of 1 $^{m^2}$of soil in hectares.

Carbon emissions linked to bean transports (scope 2)

Bean transportation operations are a significant source of CO_2 emissions. Transportation takes place in two stages. The first involves transporting the beans from the fields to the producer's village or camp. The second stage is transporting the beans from the village to the cooperative or place of sale. Subsequent emissions (cooperative-port and export) have not been calculated due to a lack of data.

Emissions generated by transport (E_{transp}) were estimated according to FAO (2015).

$E_{transp} = A \times FE$ (Equation 7)

Where E is the emission for each stage of transport (plantation to village; village to cooperative) expressed in tons of carbon; A is energy consumption expressed in GJ/t of CO_2 ; and FE is the emission factor linked to energy consumption in tC/GJ.

Energy consumption (A) was obtained by multiplying the amount of energy consumed (C_d) by the lower calorific value (LCV in GJ/t) of this energy. Hence the following formula :

$A = C_d \text{ x CPI}$ (Equation 8)

The carbon emission rate resulting from bean transport was obtained by summing the carbon emissions generated by transport vehicles on these two sections.

$E_{transp} = E_{pv} + E_{vc}$ (Equation 9)

With E_{transp}, total emissions related to transport; E_{pv}, carbon emissions related to transporting beans from the field to the village and/or the producer's camp ; and E_{vc}, emissions related to transporting beans from the village to the cooperative.

Emissions from different sources (soil, cocoa, inputs, transport) were converted into CO_2.

This was done by multiplying the quantity in kg, tons, or megatons of carbon emitted (E_c) by the molar mass of carbon dioxide (M_{CO2}= 44) and the molar mass of the carbon atom (M_C= 12).

$E_{CO2} = E_C \text{x} \frac{MCO2}{MC}$ (Equation 10)

Transport vehicles used for transport

The various vehicles used to transport cocoa beans are listed in Table 1. Estimates of transport-related emissions were based on the type of vehicle used. They took into account the type of energy consumed by the vehicle and the distance traveled.

Table 1: Different types of vehicles used to transport beans

Transport vehicle	Type of energy	Consumption (L)	PCI (GJ/T)	FE (TCo2/GJ)
Motorcycle	Gasoline	0.021	43.5	0.07
Tricycle	Gasoline	0.031	43.5	0.07
Kia-type car	Diesel	0.08	42.8	0.08
Bicycle	None	---	---	---

LCV: Lower Calorific Value; EF: Emission Factor

2.5. Statistical analysis of data

Analysis of variance (ANOVA) was performed to compare the means of quantitative variables between different age groups within each area. This method is based on three assumptions: independence of observations, normality of residuals, and homogeneity of variances. Normality was tested using the Shapiro-Wilk test and homogeneity of variances using Levene's test. The significance threshold was set at 5% ($p < 0.05$). In the event of a significant difference in Fisher's F-test, a post hoc test was used to identify statistically distinct classes.

3. RESULTS

3.1. Practical agricultural characteristics within cocoa plantations

Area and previous crops

Across all the plantations studied in the Biankouma department, there is variation in size (Figure 2). The average size of cocoa farms ranges from 1.56 ha to 2.96 ha. The smallest farms are in the [0–4] year class, and the largest in the [26–30] year class (Figure 2).

Furthermore, surveys revealed that the various cocoa plantations were established on four (04) types of previous crops. These were forest, fallow land, savanna, and other crops (Figure 3). However, taking into account the age of the plantations, the types of previous crops vary from one plantation to another. It was found in this area that plantations over 5 years old were mainly established on forest croplands, with rates ranging from 60 to 100%. Unlike plantations over 5 years old, those between 0 and 4 years old were mainly established on both forest croplands (40%) and savanna croplands (40%).

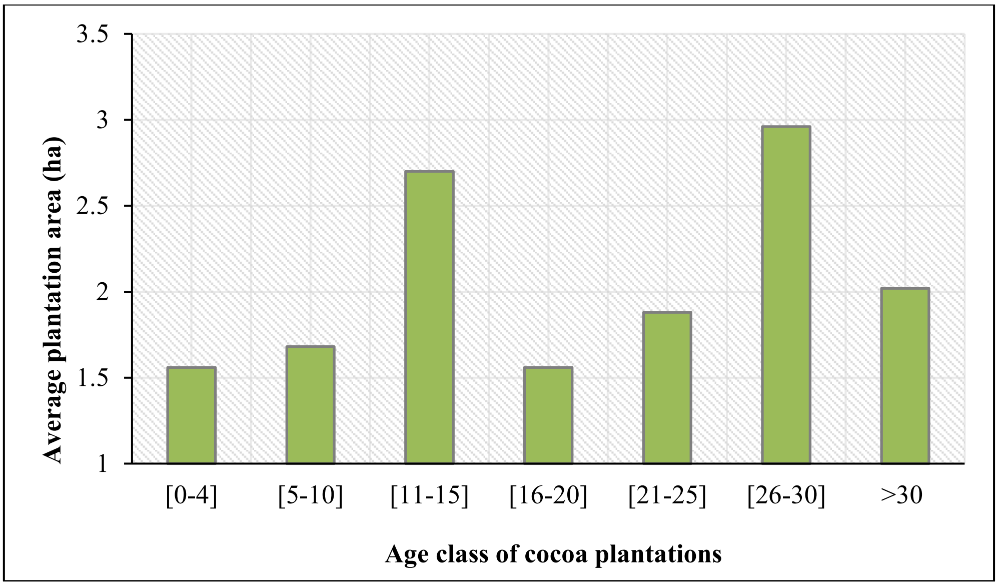

Figure 2. Average plantation area by age class in the department of Biankouma

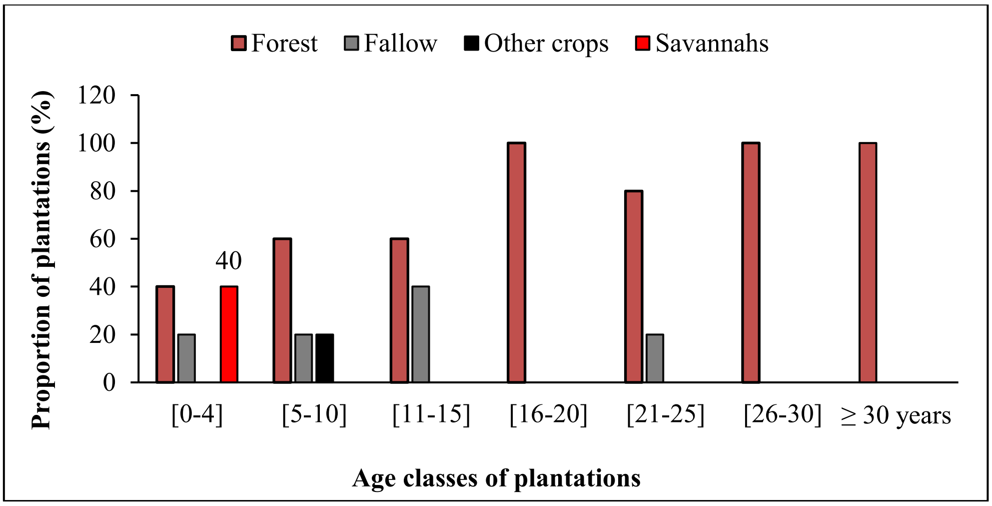

Figure 3: Main previous crops of cocoa plantations in the department of Biankouma

Use of plant protection products

The results showed that the majority of cocoa farmers in the department of Biankouma use plant protection products, with a usage rate of 87%. Only 13% of producers do not use plant protection products to maintain their plots (Figure 4).

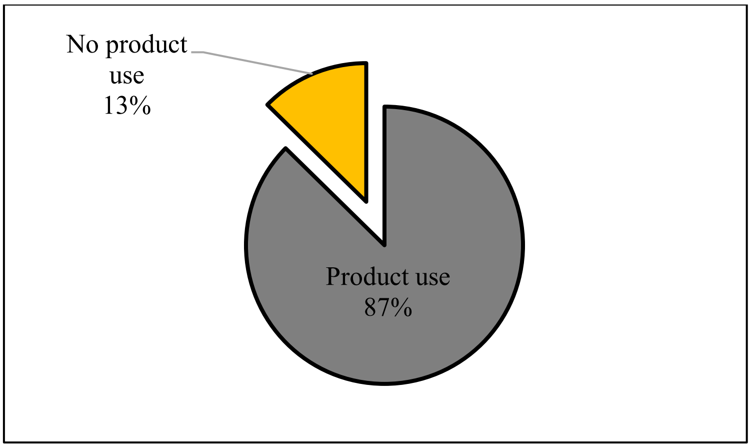

Figure 4: Rate of use of plant protection products

Types of products used in cocoa farms by age group

Three (03) main plant protection products are used by cocoa farmers. These are herbicides, insecticides, and fungicides (Figure 5). The use of these plant protection products depends on the age of the plantation. In addition, heavy use of insecticides was observed in all plantations in the department. In fact, the proportion of insecticide-type products varies from 33.33% to 80%. Fungicides are used much more in plantations aged 16 to 20 years, then 21 to 25 years and 26 to 30 years, with respective rates of 44.44%, 40% and 33.33%.

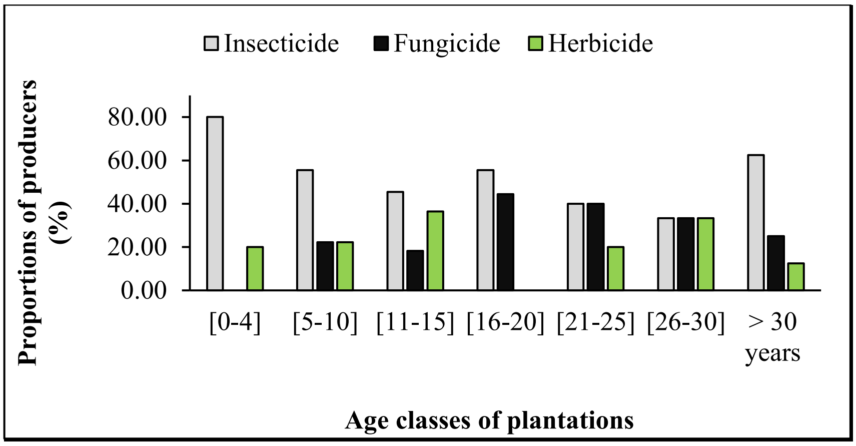

Figure 6: Differents types of plant protection products used

Quantity of products used in different plantations

The average quantities of plant protection products used by producers according to the different age classes of cocoa plantations are shown in Table 2. Analyses showed that plantations aged 11 to 15 years recorded the highest amount of carbon, at 4.87 kg. Conversely, the lowest values were observed in plantations aged 16 to 20 years (1.92 kg) and those aged 0 to 4 years (1.97 kg).

Table 2: Quantity of products applied by age class of plantations in the department of expressed in kilograms (kg)

	Age class of cocoa plantations						
Pesticides	[0-4	[5-10	[11-15	[16-20	[21-25]	[26-30]	≥ 30 years
Insecticide	0.87	1.03	1.06	0.60	1.20	1.22	1.15
Herbicide	1.10	1.07	2.60	0.82	1.00	1.00	0.33
Fungicide	0	0.30	1.21	0.50	1.75	0.55	0.90
Total	1.97	2.40	4.87	1.92	3.95	2.77	2.38

Average yield of cocoa farms in the department of Biankouma

The average yield of cocoa plantations throughout the Biankouma department is very high, with an average value of 730.81 kg/ha. However, the average annual yield varies according to age class (Figure 7). Analysis of variance showed a significant difference in yields between the different plantations (P< 0.05). Plantations aged 11 to 15 years and those aged 26 to 30 years recorded the highest average yields, with values of 1,144.7 kg/ha and 1,321.08 kg/ha, respectively.

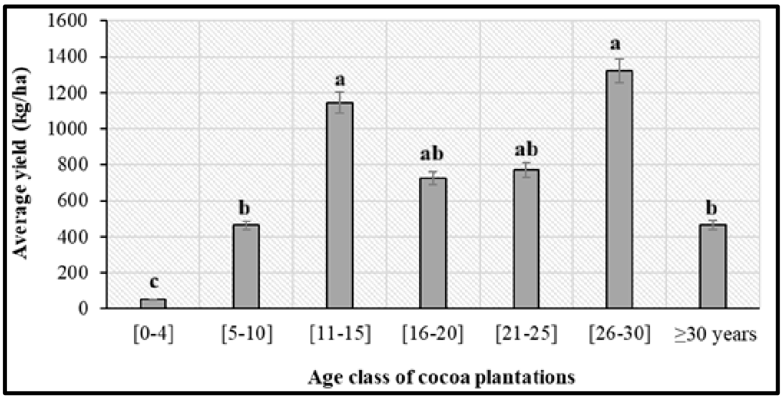

Figure 7: Average cocoa yield by age class Values followed by the same letter are not significantly different at the 5% threshold. Statistical test significance threshold: * < 0.05

3.2. Carbon footprint of cocoa farms in the department of Biankouma

Emissions related to cocoa, inputs, soil, and transport within the department

The carbon footprint in this study took into account emissions related to soil, cocoa, plant protection products, and transport. With regard to soil-related emissions (scope 1), statistical analyses showed that there is no significant difference between plantations across the department (p> 0.05). However, the results showed that plantations aged 26 to 30 years emit more carbon, with emissions of 48,018.67 $kgCO_2$ (Table 4).

With regard to emissions from plant protection products (scope 3), the analyses showed that across the department as a whole, there is no significant difference between the amounts of carbon emitted in the different plantations (p > 0.05). However, compared to other classes, these carbon emissions are higher in plantations aged 11 to 15 years, with a rate of 0.29 $kgCO_2$. In contrast, low carbon emission rates were observed in plantations aged 16 to 20 years and those aged [0-4] years, with 0.12 $kgCO_2$ of carbon emitted in each case (Table 4).

With regard to cocoa-related emissions in Biankouma, variance analyses showed that there is a significant difference between the various carbon emission rates at plantation level (P < 0.05). Consequently, plantations aged between 26 and 30 years and between 11 and 15 years emit large amounts of carbon, with values of 1196.56 $kgCO_2$ and 1036.87 $kgCO_2$. Plantations aged 0 to 4 years also emit carbon, with an emission rate of 47.57 $kgCO_2$ (Table 4).

In terms of transport-related emissions (scope 2), no significant difference was observed with the probability values (P>0.05) between the different plantations in the department of Biankouma. However, plantations aged 0 to 4 years emit 226.32 $kgCO_2$ (Table 4). Significant emissions were observed in plantations aged 11 to 15 years (4087.52 $kgCO_2$), 21 to 25 years (2745.22 $kgCO_2$) and 26 to 30 years (2697.27 $kgCO_2$).

Table 4: Average quantities of carbon emitted ($kgCO_2$) by different scopes in cocoa plantations in the department of Biankouma

Modalities	Age class of cocoa plantations						
	[0-4	[5-10	[11-15	[16-20	[21-25	[26-30]	≥30 years
Soil	22880	24669.33	39541.33	22,821.33	27632	48,018.67	23,672
Plant protection products	0.12	0.14	0.29	0.12	0.24	0.16	0.14
Cocoa (juice + cocoa shell)	47.57	420.57	1036.87	655.81	698.94	1196.56	422.26
Transport	226.36	1025.06	4,087.52	1,690.21	2,745.22	2,697.27	389.04

Total carbon emissions from different plantations in the Biankouma department

The total amount of carbon emitted by age class (Figure 8) is the sum of the different components: scope 1 (emissions related to soil and cocoa cultivation), scope 2 (emissions related to transport) and scope 3 (emissions associated with the use of plant protection products). This amount varies from one plantation age class to another. Plantations over 30 years old recorded the lowest amount of carbon emissions. However, compared to other age classes of plantations, those between 26 and 30 years old emit more carbon (5.19E+04 $kgCO_2$).

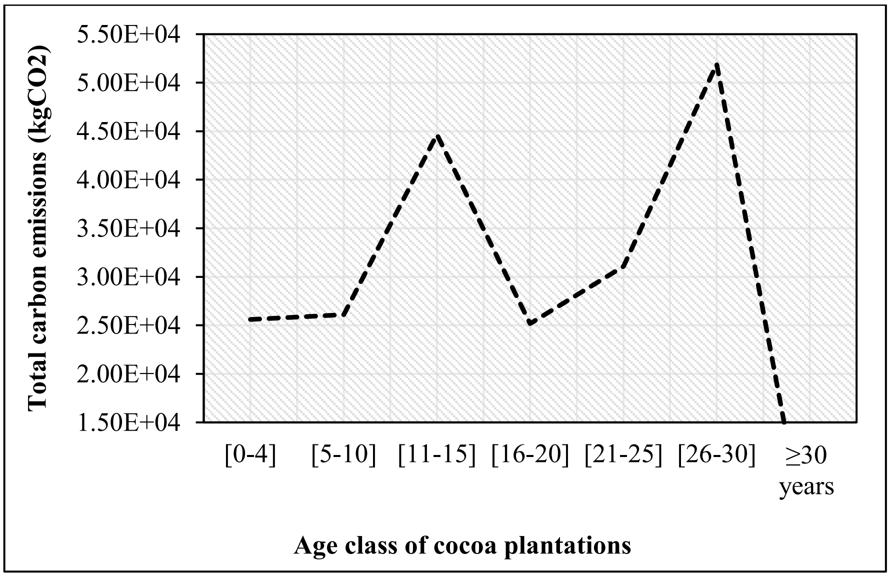

Figure 8: Total carbon emissions by age class

4. DISCUSSION

4.1. Agricultural practices in the new cocoa production area in Côte d'Ivoire

Throughout the Biankouma department, the cocoa farms visited are family-run, with an average area of one (01) to two (02) hectares. This shows that cocoa farming is carried out by small family farms (Pana *et al*., 2022). This result was highlighted in the center of the country, more specifically in the sub-prefecture of Kokoumbo by Kpangui (2015). The work of Kouamé (2010) showed that cocoa plantations are mainly located on small areas. Furthermore, around 70% of cocoa plantations have been established on former forest land throughout the department. This demonstrates the establishment of cocoa cultivation in forest areas. These results are consistent with those obtained by Oszwald (2005) in the east of the country in the Beki classified forest. Indeed, during their work, Oszwald (2005) showed that the majority of cocoa plantations were established on cleared forest land. This shows that the previous forest offers advantages to cocoa plantations, such as soil fertility and shade for young cocoa trees (Pana *et al*., 2022). However, in addition to forest and fallow land, young plantations aged 0 to 4 years were ly established on former savanna land, and those aged 5 to 10 years were established on former cropland. This could be explained by the fact that farmers, due to the depletion of forest reserves, have established their cocoa plantations on non-forest land, or are converting former plantations of other crops to cocoa cultivation (Zanh *et al*., 2019). In addition, 87% of farmers use plant protection products to maintain their plots. Furthermore, three (03) main types of plant protection products were recorded, namely herbicides, insecticides, and fungicides. Insecticides are the most widely used, with rates ranging from 33.33% to 80%. Plantations aged 0 to 4 years and those over 30 years old recorded the highest proportions of insecticide use, at 80% and 62.5% respectively. This reflects the presence of harmful insects in the plantations. Producers use these products to combat pests, protect pods, and prevent disease (Gohourou, 2020). Consequently, as the areas of the different classes are virtually identical and with the help of ANADER agents, farmers would apply roughly the same quantities in all cocoa plantations. However, in addition to insecticides and herbicides, farmers use fungicides to combat brown rot and fungi that attack the pods.

Furthermore, the average annual yield of cocoa plantations varies according to the age of the plantation. Yields are relatively low in plantations aged 0 to 4 years, 5 to 10 years, and 26 to 30 years, with respective values of 52.5 kg/ha, 464.3 kg/ha, and 466.2 kg/ha. These low yields could be explained, on the one hand, by environmental factors such as lack of rain and the spread of disease, and on the other hand, by the aging of the orchards and the reduction in the density of cocoa trees as the plantation ages. Our results corroborate those of Pana *et al*. (2022) and Assiri *et al*. (2009). These authors have shown in their work that the yield of cocoa trees decreases with the age of the plantations.

4.2. Impacts of agricultural practices on carbon emissions s in the main cocoa-producing areas of Côte d'Ivoire

Cocoa farming, a sub-sector of agriculture, accounts for a significant proportion of GHG emissions. Any agricultural activity, however small, generates GHGs in the atmosphere.

Across the department as a whole, analyses have shown that carbon emission rates depend heavily on production and previous forest cover. Indeed, the highest carbon emissions were observed in high-yield plantations and those established mainly on former forest land. The differences in emissions due to cocoa observed can be explained by the significant differences in production levels, as the quantity of cocoa shells and juice depends on production. The work of Oscar *et al*. (2013) showed that 1 kg of shells comes from 8.5 kg of cocoa and 1 liter of juice is obtained from 35 kg of cocoa beans.

In terms of the amount of CO_2 emitted by transport, plantations aged 11 to 15 years emit more carbon, at a rate of 4087.52 kg CO_2. A study by NITIDAE (2019) showed that transport accounted for only 6.89% of CO_2 emissions. With regard to emissions from the soil, it is very important to note that these emissions are greater than those from other sources. This result is consistent with those obtained by NITIDAE (2019). These authors estimated that 30.7% of emissions result from agricultural land.

Emissions from the use of plant protection products yielded a p-value below the 5% threshold, indicating that the volume of carbon emitted by the different age classes of plantations is statistically different. This difference could be explained by the quantities of products used by producers. A study by the MEDD (2010) stated that the use of plant protection products is a real environmental problem because of the emissions they generate.

CONCLUSION

The overall objective of this study is to assess the impact of agricultural practices on greenhouse gas emissions, particularly carbon, in the department of Biankouma. To this end, the main agricultural practices within cocoa plantations and their impact on carbon emissions in each of the areas were determined. Across the department, cocoa farming is mainly practiced on small areas of less than 2 ha and on former forest land. Only 40% of plantations aged 0 to 4 years have been established on former savannah land. In addition, more than 80% of farmers use plant protection products, particularly insecticides, herbicides, and fungicides.

However, the use of these products depends on the age of the plantations. Analyses showed heavy use of insecticides in plantations aged 0 to 4 years and those over 30 years, with rates of 80% and 62.5% respectively. Furthermore, plot yields vary according to the age of the plantations. Plantations aged 26 to 30 years and those aged 11 to 15 years have the highest annual yields, at 1,321.08 kg/ha and 1,144.7 kg/ha, respectively. The lowest production values were recorded in plantations aged 0 to 4 years, 5 to 10 years, and 26 to 30 years, with respective values of 52.5 kg/ha, 464.3 kg/ha, and 466.2 kg/ha. Furthermore, all these agricultural practices and yields have an impact on carbon emissions in the new cocoa production area in Côte d'Ivoire. Indeed, analyses have shown that soil-related emissions are higher in all plantations. However, plantations aged 26 to 30 years emit more carbon, with emissions of 48,018.67 $kgCO_2$. The highest rates of cocoa-related emissions were recorded in plantations aged 11 to 15 years and those aged 26 to 30 years, with respective rates of 1036.87 $kgCO_2$ and 1196.56 $kgCO_2$. Furthermore, in terms of emissions linked to bean transportation, plantations aged 11 to 15, 21 to 25, and 26 to 30 emit high levels of carbon, with respective values of 4087.52 $kgCO_2$ and 2745.22 $kgCO_2$ and 1196.56 $kgCO_2$. In terms of emissions linked to the use of plant protection products, low emission rates were observed in all age classes of plantations. Combining all emission scopes, cocoa plantations between 26 and 30 years old emit more carbon, with a value of 5.19E+04 $kgCO_2$ per hectare. These results confirm that the carbon footprint of Ivorian cocoa farming is mainly linked to land use change, chemical intensification, and high cocoa tree productivity. It would therefore be important to assess the carbon footprint of these plantations in order to reduce the harmful effects of greenhouse gases.

Author contributions

All co-authors whose names appear on the submission made substantial contributions to this study. They all participated in field data collection, various analyses, and manuscript writing. All authors read and approved the final manuscript.

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Conflicts of interest

There are no conflicts of interest.

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