

Full Length Research Paper

Agromorphological characteristics of *Irvingia gabonensis* (Aubry-Lecomte ex O'Rorke) Baill. (Wild mango) and its effect on *Theobroma cacao* L. in traditional agroforestry systems

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The study was conducted in the localities of Buyo, Duekoué, and Gueyo in western Côte d'Ivoire, within agroforestry systems that combine cocoa trees with *Irvingia gabonensis*. The aim was to enhance cocoa production in Côte d'Ivoire by associating it with *I. gabonensis* to achieve sustainable production. To achieve this goal, plots with radii of 10 and 20 m around *I. gabonensis* trees were established to assess diameter, height, morphological characteristics of fruits and seeds, biomass, and carbon stock. The results showed uniformity in the morphological characteristics of *I. gabonensis*, fruit production, biomass, and carbon stock across all localities, except for height. The vigor and pod yield of cocoa trees near *I. gabonensis* were reduced, likely due to lower cocoa density in its vicinity. However, its presence in cocoa plantations increased biomass production and carbon stock. *I. gabonensis* also stabilized the incidence of rotted and gnawed pods. Therefore, integrating *I. gabonensis* into agroforestry plots could be beneficial, provided that cocoa density around it is reduced to minimize its impact on cocoa vigor and yield.

Key words: Cocoa, *Irvingia gabonensis*, agroforestry, sustainable system.

INTRODUCTION

Cacao (*Theobroma cacao* L., Malvaceae) farming employs over 14 million people in West Africa (Alverson et al., 1999). In Côte d'Ivoire, cocoa beans represent on average 70% of total employment, 40% of export products, and 15% of gross domestic product (FAO, 2015). The financial incentives generated by cocoa have

spurred rapid development in the southern half of the country, supported by successive governments. Cocoa farming has expanded exponentially, covering over 4 million hectares of cultivated land by 2019 (World Bank, 2019). The predominant westward expansion of cocoa farming has contributed to forest landscape degradation,

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with a deforestation rate of 3.8% per year (Goetze et al., 2010; Koulibaly et al., 2010). For instance, in the South-West zone, two million hectares of forest—equivalent to 80% of the zone's total forest area—have been cleared in 20 years for cocoa cultivation (Guessan-Bi et al., 2023).

Despite its economic and agronomic successes, cocoa cultivation faces numerous constraints that impact its yield. These include infestations, aging plantations, difficulties in regenerating unproductive orchards, and declining soil fertility (Läderach et al., 2013; Kouamé et al., 2015; Koulibaly et al., 2018). Moreover, climatic constraints render certain regions unsuitable for cocoa farming (Schroth et al., 2016).

Today, restoring the environment and forest cover is crucial for all agricultural development programs, including cocoa farming (Jagoret et al., 2014). Thus, agroforestry remains a socially sustainable, acceptable, and ecologically profitable alternative to conventional cocoa farming (Sonwa et al., 2007; Yao et al., 2016). Agroforestry is a dynamic system of natural resource management based on ecological foundations that integrate trees into farms, diversifying and sustaining production to improve the social, economic, and environmental conditions of land users (Blaser et al., 2016). It represents one of the most promising solutions for effectively linking agricultural production with environmental protection (Kouadio et al., 2016; Vroh et al., 2017; Jagoret et al., 2020). However, several uncertainties persist regarding the selection of suitable woody species and their ecological interactions with cocoa trees (Aimé, 2023). From a technical perspective, it is crucial to select species that positively influence cocoa trees to ensure satisfactory agricultural production. In traditional agroforestry systems, the cocoa tree is generally associated with forest species such as *Garcinia kola* (Bitter cola), *Ricinodendron heudelotii* (Akpi), *Tieghemella africana* (makore), *Terminalia ivorensis* (Black afara), *Terminalia superba* (Ofram), *Persea americana* (avocado tree) and *Irvingia gabonensis* (Wild mango) (Gockowski et al., 2010). The *I. gabonensis* species is highly valued by farmers in western and south-western Côte d'Ivoire for food and trade (Mateus-Reguengo et al., 2020). *I. gabonensis* kernels are an important nutritional supplement (vitamins, fats, proteins, minerals), and their marketing provides rural populations with financial income. However, there is still a lack of knowledge about the characteristics of *I. gabonensis* and its interaction with cocoa. Hence the initiative for this study, which aims to improve the income level of Smallholder farmers by strengthening traditional cocoa-based agroforestry systems. The study was initiated with a view to ensuring sustainable cocoa production in Côte d'Ivoire. In western and south-western Côte d'Ivoire, *I. gabonensis* is frequently grown in association with cocoa trees. The hypothesis behind this study is that the ecological interaction between *I. gabonensis* and the cocoa tree influences the agromorphological

characteristics of the cocoa tree. The study will contribute to improve cocoa production systems for sustainable cocoa farming. More specifically, the study aim to describe the structural characteristics (height and diameter) of *I. gabonensis*, assess its productivity and describe its effect on the agro-morphological and yield parameters of cocoa trees.

Study area and geolocation of *I. gabonensis*

The present study was conducted in the Buyo, Duekoué and Gueyo cocoa-growing zones located in the west and south-west of Côte d'Ivoire (Figure 1). The west and south-west constitute high production zones that benefit from an average of 115 days with rainfall in excess of 1,200 mm per year with relative humidity approaching 98% (LA NAWA, 2016, Météo et Climat, 2020). The average temperature fluctuates between 26 and 28°C, and is very high all year round. The vegetation is dense evergreen forest with ferrallitic soil. A survey was carried out in the various study areas to identify cocoa plantations with one or more *I. gabonensis* trees. Those selected for this study were cocoa orchards in full production in which the presence of one or more trees was noted. Eighty-one trees were identified in the cocoa orchards, including 30 trees in Duekoué, 25 in Buyo and 26 in Gueyo.

MATERIALS AND METHODS

Plant

Plant material for this study consisted of *I. gabonensis* (Wild mango, Figure 2) in cocoa (*T. cacao*) orchards (Figure 3).

Study of *I. gabonensis* tree characteristics

Dendrometric measurements

For each tree, the height was measured using a VERTEX dendrometer and the circumference at breast height (CBH) at 1.30 m from the ground. Individual circumference values were converted to DBH using the following formula (Equation 1):

$$D = C / \pi \quad (1)$$

where C = Circumference, D = Diameter, and $\pi = 3.14$.

Estimation of biomass and carbon stock

Above-ground biomass (AGB) was calculated using the allometric model of Chave et al. (2014) (Equation 2):

$$AGB = 0.673 \times (\rho D^2 H) 0.976 \text{ (kg)} \quad (2)$$

where D = Diameter at breast height (cm), AGB = Above-ground biomass (kg), ρ = Specific density of wood (g/cm³), and H = Total height of *I. gabonensis* trees (m).

DBHs were measured at 1.3 m from the ground (Saj et al., 2013)

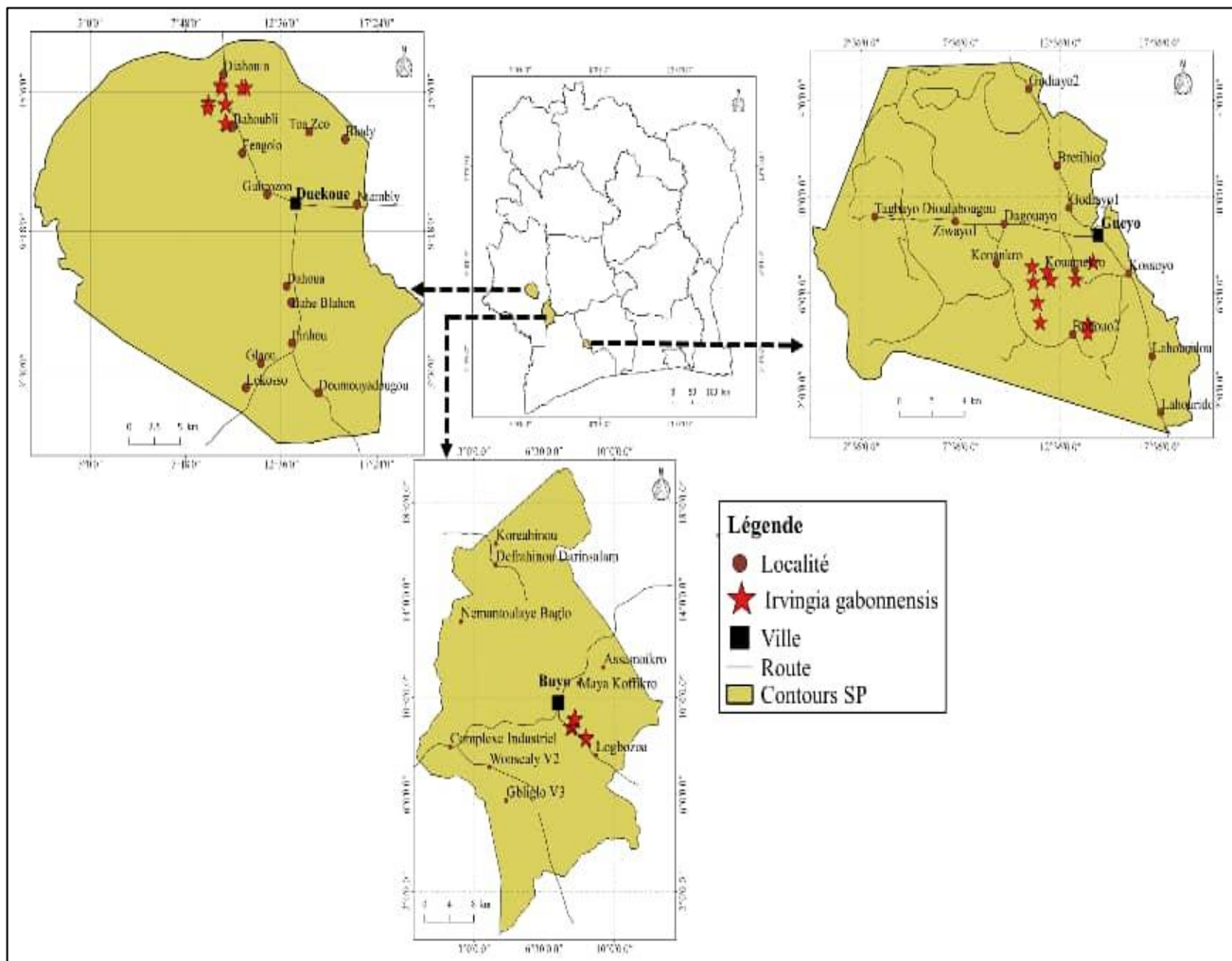


Figure 1. Geographical location of Buyo, Duekoue and Gueyo zones.

and the wood density ($\rho = 0.71 \text{ g.cm}^{-3}$) of *I. gabonensis* (Zanne et al., 2009). The Underground Biomass (UGB) of the trees was estimated by multiplying the value of the above-ground biomass (AGB) by R, a coefficient of value estimated at 0.24 (GIEC, 2006) (Equation 3):

$$UGB = AGB \times R \text{ (kg)} \quad (3)$$

where R = Conversion coefficient from above-ground to below-ground biomass.

The total biomass (TB) of standing woody plants was estimated by adding the above-ground biomass to the underground biomass. Carbon stock was determined by Zanne et al. (2009) formula (Equation 4):

$$C \text{ (tC/ha)} = \rho \times TB \text{ (kg)} \quad (4)$$

where $C(tC/ha)$ represents carbon stock in tons of C per hectare.

Evaluation of *I. gabonensis* productivity

Productivity was assessed on the basis of tree fruit load over a 12 month period. The number and weight of fruits collected were

determined per tree. Fruit shape, seed and fruit length and width were determined using a graduated scale in centimeter.

Influence of *I. gabonensis* on *T. cacao* agronomy

The circle method (Figure 4) (Kouakou et al., 2011), adapted for this study, was employed to analyze the interaction between *I. gabonensis* and cocoa trees. For each tree, circles with radii of 10 and 20 meters centered around each *I. gabonensis* were delineated. Data on cocoa tree density, vegetative vigor, yield, biomass, and carbon sequestration capacity were collected within these circles.

Cocoa tree density

Cocoa density was assessed by counting the number of cocoa trees in each radius.

Cocoa tree vigor

The vigour of cocoa trees in the vicinity of *I. gabonensis* was

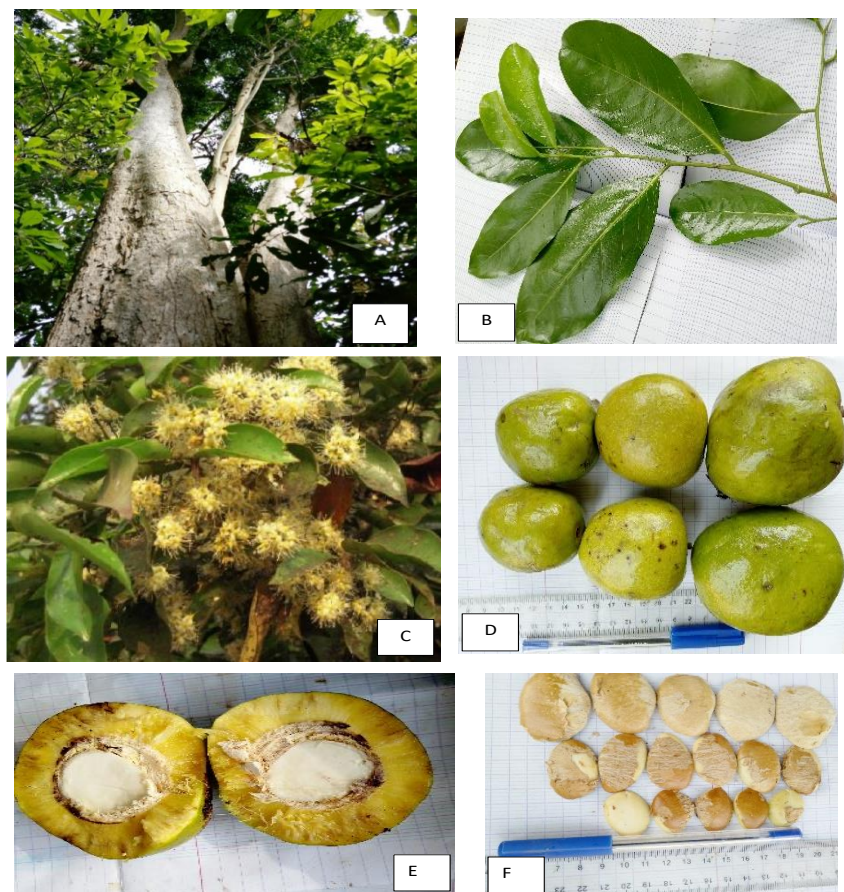


Figure 2. Vegetative and reproductive organs of *I. gabonensis*: A. whole tree, B. leaves, C. panicles, D. drupes, E. drupe flesh and seeds, F. kernels.



Figure 3. *Theobroma cacao* in the farm setting.

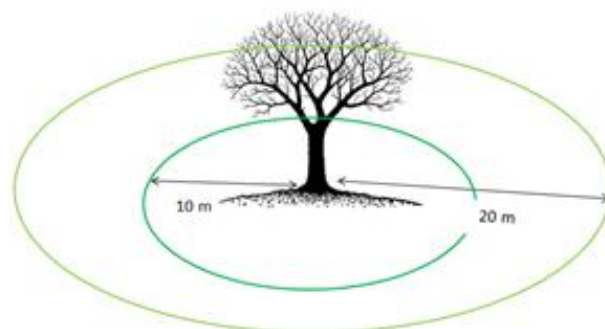


Figure 4. Data collection design for *Irvingia gabonensis* and cocoa interaction.

Table 1. Morphological characteristics of *Irvingia gabonensis* in the study localities.

Parameter ^a	Localities			Means	CV (%)	F	P
	Duekoué	Gueyo	Buyo				
Height (m)	29.30 ^{a*}	24.10 ^a	10.81 ^b	24.97	31.8	20.97	0.0001
DBH (cm)	186.55 ^a	158.50 ^a	118.50 ^a	169.58	55.04	2.1	0.1336
Above Biomass (kg)	77904.65 ^a	40801.20 ^a	11036.75 ^a	60078.65	137.34	2.72	0.076
Underground biomass (kg)	18697.12 ^a	9792.28 ^a	2648.82 ^a	14418.88	137.34	2.72	0.076
Total Biomass (kg)	96601.76 ^a	50593.48 ^a	13685.57 ^a	74497.53	137.34	2.72	0.076
Stock of CO ₂ (tC/ha)	48300.88 ^a	25296.74 ^a	6842.79 ^a	37248.76	137.34	2.72	0.076

^aMeans, on the same line, followed by the same letter are not statistically different at the 5% threshold (Newman-Keuls). DBH = Diameter at breast height; CV = Coefficient of variation; F = Fisher's value; P = Probability.

estimated by measuring crown diameter and height, using the method of Lachenaud and Oliver (1998).

Cocoa tree biomass and carbon stock

The calculation method used for *I. gabonensis* trees was the same as that used for cocoa trees. However, the diameter of the cocoa trees was measured at 20 cm from the ground and the density is 0.43 g/cm³ (Zanne et al., 2009).

Cocoa productivity

The rate of healthy, gnawed and rotten pods on each tree was determined in each radius. The data collected allowed us to estimate cocoa productivity and pod health under the influence of *I. gabonensis*.

Statistical analysis of *I. gabonensis* and cocoa tree interaction data

The collected data were formatted in Excel files. Excel files were validated with SAS software (9.4) and outliers were corrected. For the interaction between cocoa and *I. gabonensis*, an analysis of variance following the General Linear Model (GLM) at the 5% threshold was carried out using SAS (9.4) software. It was also used to estimate differences between study areas. Multivariate analyses were performed with three agro-morphological parameters (height, diameter, and total biomass) and two yield parameters

(number and mass of fruits) using Xlstat 2020 software. Correspondence factorial analysis (CFA) and hierarchical ascending classification (HAC) were used to study all seven variables simultaneously (Dagnélie, 1986). The analyses enabled us to characterize the links between the variables and to group *I. gabonensis* trees on the basis of their similarity according to the different variables.

RESULTS

Characteristics of *I. gabonensis* trees in traditional agroforestry systems

Structural parameters of *I. gabonensis*

The structural parameters of *I. gabonensis* trees did not reveal any statistical difference between the three study localities except for tree height (P = 0.0001). The average height and diameter values obtained per locality are respectively: 29.30 m and 186.55 cm at Duekoué; 24.10 m and 158.50 cm at Gueyo; 10.81 m and 118.50 cm at Buyo (Table 1). Similarly, for biomass and carbon stock, the values recorded are 96601.76 kg and 48300.88 t C/ha respectively for Duekoué; 50593.48 kg and 25296.74 t C/ha for Gueyo; 13685.57 kg and 6842.79 t C/ha for Buyo. The height of *I. gabonensis* varied from one locality to another, with the highest value observed at

Table 2. Number and weight of fruit per tree and locality.

Locality	Trees code	Number of fruit ^a	Total fruit weight (g) ^a
Buyo	WOkple1	510 ^a	39550 ^a
	WOkple2	205.75 ^b	14937 ^a
	WOkple3	131.44 ^b	12418 ^a
	WOkple4	90.88 ^b	23389 ^a
	WOkple5	103.75 ^b	29288 ^a
	WOkple6	137.29 ^b	12969 ^a
	WOkple7	25 ^b	535 ^a
	WOkple8	95.27 ^b	9823 ^a
	WOkple9	35 ^b	4137 ^a
	WOkple10	78.75 ^b	22414 ^a
Duekoué	DIAkple1	239.33 ^b	7985 ^a
	DIAkple3	211.75 ^b	7361 ^a
	DIAkple4	84.50 ^b	2778 ^a
	DIAkple5	27 ^b	740 ^a
	DIAkple6	58 ^b	1405 ^a
	DIAkple7	48.3 ^b	1765 ^a
	DIAkple8	76.67 ^b	6169 ^a
	DIA_kple10	113.67 ^b	4762 ^a
Means		114.44	11529.07
P		0.0001	0.4995
F		3.86	1.63
CV (%)		90.83	135.26

^aMeans, in the same column and followed by the same letter, are not statistically different at the 5% threshold (Newman-Keuls). CV = Coefficient of variation; F = Fisher's value; P = Probability. WOkple1 tree from Wonsaley in Buyo referred as tree number 1; DIAkple1 tree from Diahouin in Duekoué referred as tree number 1.

Table 3. Number and weight of *Irvingia gabonensis* fruit.

Parameter ^a	Localities		Means	CV (%)	F	P
	Buyo	Duekoué				
Number of fruit	118.42 ^a	105.83 ^a	102.11	135.26	1.63	0.687
Weight of fruit (kg)	14,829 ^a	4,379 ^a	1,529.07	90.83	3.86	0.4956

^a Means, on the same line, followed by the same letter are not statistically different at the 5% threshold (Newman-Keuls). CV = Coefficient of variation; F = Fisher's value; P = Probability.

Duekoué. However, the diameter, biomass and carbon stock of *I. gabonensis* remained statistically the same in all three localities. The analysis revealed a significant difference in tree height in the different localities (F = 20.97; P = 0.0001).

***I. gabonensis* productivity in traditional agroforestry systems**

Number and weight of fruit and seeds of *I. gabonensis*

The overall average values for the number and mass of

tree fruit in all the zones considered were 114 and 11,529.07 kg, respectively (Tables 2 and 3). Among the trees in the Buyo locality, WOkple1 and W_kple2 recorded the highest values in terms of number of fruit (510 fruits for WOkple1 and 205 fruits for WOkple2). The lowest value was observed at WOkple7 (25 fruits). In Duekoué, the highest values were recorded for DIAkple1 (239 fruits) and DIAkple3 (211 fruits). The lowest values were observed on DIAkple5 (7 fruits). Analysis of variance of the mean values obtained individually for each tree in Duekoué and Buyo revealed a significant difference in the number of fruits (F = 3.86; P = 0.0001). Concerning the number and weight of *I. gabonensis* fruits

Table 4. *I. gabonensis* fruit and seed characteristics.

Tree	Fruit size (cm)		Tree	Seed characteristics (cm)	
	Length	Width		Length	Width
WOkpl1	7.45 ^a	6.83 ^a	WOkpl1	4.26 ^a	4.53 ^a
DIAkpl1	6.84 ^b	6.50 ^{ab}	DIAkpl8	4.22 ^a	3.48 ^{ab}
WOkpl4	6.84 ^b	6.33 ^b	DIAkpl6	3.82 ^b	3.20 ^{ab}
DIAkpl8	6.44 ^c	5.86 ^c	DIAkpl1	3.79 ^b	3.19 ^{ab}
DIAkpl3	6.40 ^c	5.76 ^c	DIAkpl7	3.73 ^{bc}	3.18 ^{ab}
WOkpl3	6.23 ^{cd}	5.74 ^c	DIAkpl3	3.71 ^{bc}	3.15 ^{ab}
DIAkpl7	6.07 ^{cd}	5.58 ^{cd}	WOkpl4	3.71 ^{bc}	2.98 ^{ab}
WOkpl2	6.06 ^{cd}	5.56 ^{cd}	DIA_kpl8	3.67 ^{bc}	2.90 ^b
WOkpl8	6.03 ^{cd}	5.51 ^{cde}	DIA_kpl7	3.65 ^{bc}	2.84 ^b
DIAkpl10	5.91 ^{ed}	5.50 ^{cde}	WOkpl3	3.57 ^{bc}	2.78 ^b
DIAkpl6	5.86 ^{ed}	5.38 ^{cdef}	Wkpl8	3.52 ^{bcd}	2.77 ^b
WOkpl7	5.84 ^{ed}	5.30 ^{cdef}	WOkpl2	3.44 ^{bcd}	2.77 ^b
DIAkpl7	5.78 ^{edf}	5.06 ^{gdef}	WOkpl10	3.39 ^{bcde}	2.68 ^b
WOkpl10	5.76 ^{edf}	5.01 ^{gef}	WOkpl7	3.26 ^{cde}	2.52 ^b
DIAkpl8	5.72 ^{edf}	4.94 ^{gf}	DIAkpl10	3.11 ^{de}	2.42 ^b
DIAkpl5	5.49 ^{ef}	4.92 ^{gf}	DIAkpl4	2.98 ^{ge}	2.32 ^b
WOkpl5	5.36 ^f	4.69 ^g	DIAkpl5	2.80 ^{fg}	2.30 ^b
WOkpl6	4.74 ^g	3.89 ^h	WOkpl6	2.79 ^{fg}	2.28 ^b
WOkpl9	4.62 ^g	3.77 ^h	WOkpl9	2.68 ^{fg}	2.22 ^b
DIAkpl4	4.24 ^h	2.86 ⁱ	WOkpl5	2.57 ^g	2.17 ^b
Means ^a	5.88	5.25	Means ^a	3.43	2.66
CV	8.96	11.29	CV	15.02	57.96
F	43.51	51.91	F	17	2.46
P	0.0001	0.0001	P	0.0001	0.0005

^aMeans, followed by the same letter, are not statistically different at the 5% threshold (Newman-Keuls). CV = Coefficient of variation; F = Fisher's value; P = Probability; Kpl = Kplé.

in Buyo and Duekoué, the analysis revealed no significant difference ($p > 0.05$).

Morphological characteristics of fruits and seeds of *I. gabonensis* trees

The morphological characteristics of the fruits were analyzed on some trees in Buyo and Duekoué that were carrying fruit at the time of the study. The results of this analysis are shown in Table 4. *I. gabonensis* fruit length and width ranged from 4.24 to 7.45 cm and 2.86 to 6.83 cm, respectively. *I. gabonensis* fruit length and width averaged 5.88 and 5.25 cm, respectively. Mean seed length was 3.43 cm and seed width 2.66 cm. Seed lengths ranged from 2.57 to 4.26 cm, while seed widths varied from 2.17 to 4.53 cm. Analysis of variance of *I. gabonensis* fruit and seed length and width revealed a significant difference in these parameters ($P < 0.0001$). Trees DIAkpl1, WOkpl4, WOkpl1 and DIAkpl8 recorded the highest values for all parameters studied. The lowest values were observed in trees WOkpl9 and WOkpl5

(Table 4).

Potential elite trees of *I. gabonensis*

The Correspondence Factor Analysis (CFA) relates the agronomic and morphological parameters of *I. gabonensis*. The analysis shows that axis 1 (dimension 1) and axis 2 (dimension 2) are sufficient to characterize their relationship (Figure 5). They respectively express 25.03 p.c. and 18.25 p.c. of the total inertia. Projection of these parameters onto the various axes revealed three distinct groups (G1, G2, G3) distributed across the factorial plane (Figure 6). Group G1 is characterized by shorter individuals and comprises DIAkple1, DIAkple5, DIAkple8, DIAkple15, DIAkple17, DIAkple22, DIAkple27, DIAkple28, DIAkple29 and haut1, dbh1, cour1, BiomT2. Group G2 is characterized by medium-sized individuals and comprises DIAkple4, DIAkple6, DIAkple11, DIAkple12, DIAkple14, DIAkple16, DIAkple18, DIAkple20, DIAkple21, DIAkple24, DIAkple26 and haut2, cour2, nbf2, maf2. Group G3 is characterized by large individuals and

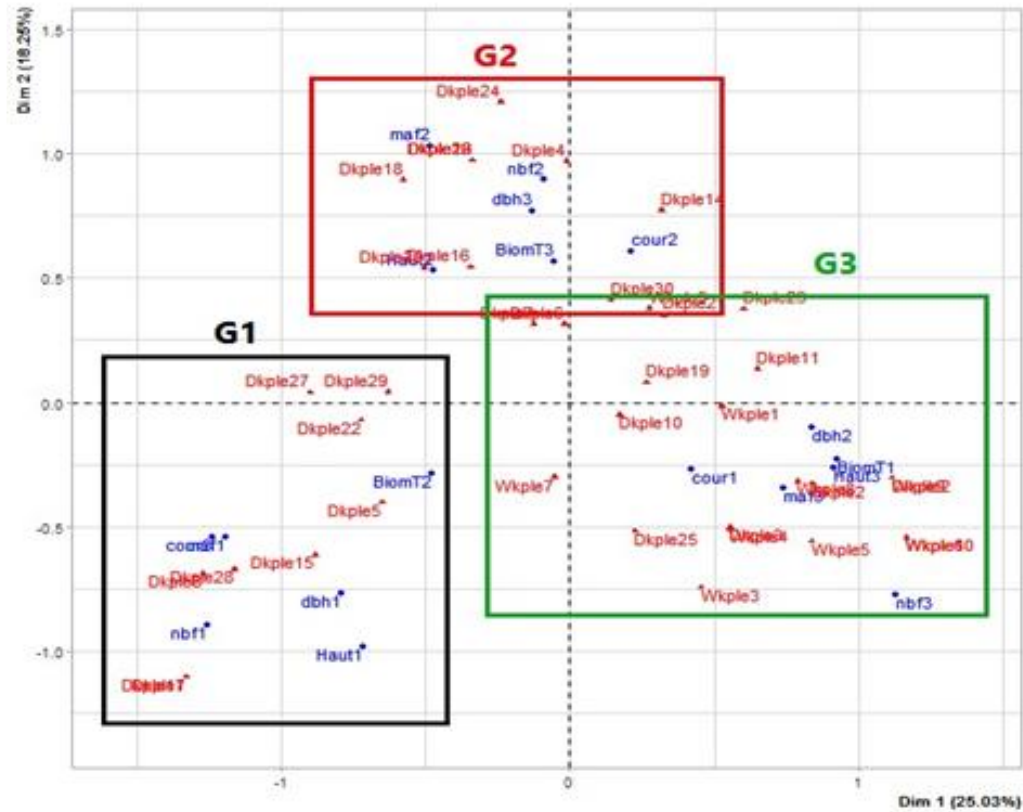


Figure 5. Ordination diagram of *Irvingia gabonensis* plants and agromorphological parameters studied. dbh = Diameter at breast height; biomT = total biomass; haut = height; cour = crown; maf = fruit mass; nbf = number of fruits. Dkple = diahouin kple; Wkple = wonsaley kple.

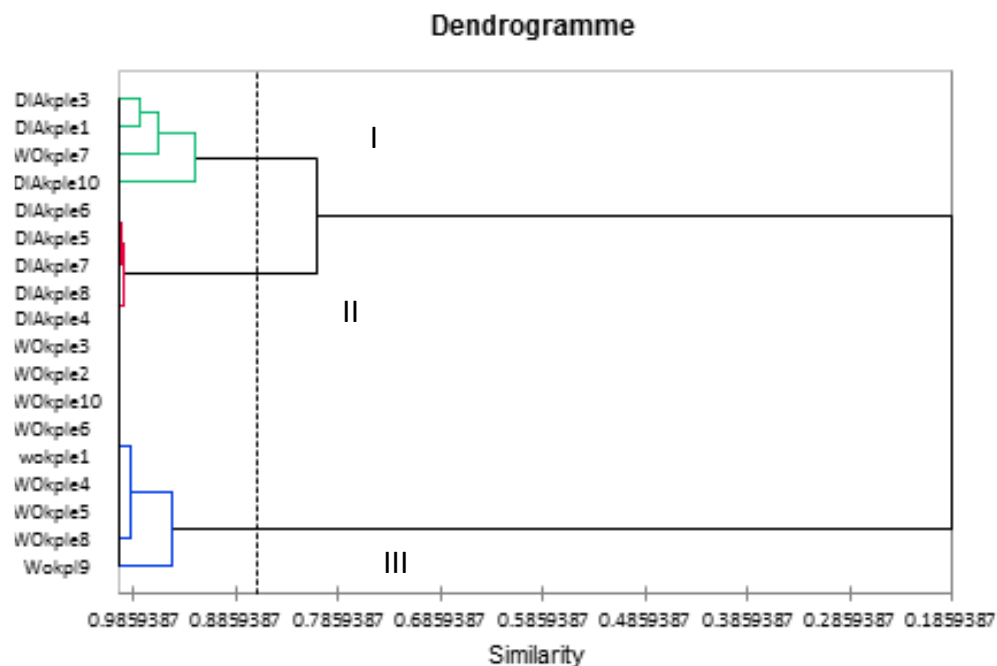


Figure 6. Association of *Irvingia gabonensis* by homogeneous group according to variables studied, similarity method: Spearman's correlation coefficient; aggregation method: complete link; I; II; III – *I. gabonensis* group 3.1.2.

Table 5. Cocoa tree density and vigor around *Irvingia gabonensis*.

Parameter ^a	Radius		Means	CV (%)	F	P
	0-10 m	10-20 m				
Density	51 ^b	113.11 ^a	80.94	38.15	56.54	0.0001
Vigour	0.14 ^b	0.31 ^a	0.259	413.81	24.65	0.0001

^aMeans on the same line followed by the same letter in the same row are not statistically different at the 5% threshold (Newman-Keuls). CV = Coefficient of variation; F = Fisher's value; P = Probability.

Table 6. Yield of pods, rate of gnawed and rotted pods.

Parameter ^a	Radius		Means	CV (%)	F	P
	0-10 m	10-20 m				
TxP	0.37 ^a	0.39 ^a	0.383	29.19	0.45	0.506
TxR	0.02 ^a	0.02 ^a	0.023	65.098	0	0.979
Yield	945.9 ^b	2140.6 ^a	1521.94	46.81	39.31	0.0001

^aMeans, on the same line, followed by the same letter in the same column are not statistically different at the 5% threshold (Newman-Keuls). CV = Coefficient of variation; F = Fisher's value; P = Probability; TxP= Rate of Rotten pod; TxR = rate of gnawed pods.

consists of WOkple1, WOkple2, WOkple3, WOkple4, WOkple5, WOkple6, WOkple7, WOkple8, WOkple9, WOkple10, DIAkple10, DIAkple2, DIAkple3, DIAkple7, DIAkple9, DIAkple10, DIAkple19, DIAkple23, DIAkple25, DIAkple30 and haut3, nbf3, maf3. The trees at Wonsaley (Buyo) are large and have a high number and mass of fruits.

Interaction between *I. gabonensis* and *T. cacao*

Effect of *I. gabonensis* on cocoa density and vegetative vigour

The mean values for cocoa tree density and vigour in the 0-10 m and 10-20 m radii are 80.94 and 0.259, respectively (Table 5). The highest mean values for cocoa density and vigour were observed in the 10-20 m radii. Analysis of variance of these parameters revealed a significant difference between cocoa trees close to *I. gabonensis* in the 0-10 m radius and cocoa trees far from the foot of *I. gabonensis* in the 10-20 m radius ($P < 0.0001$).

Effect of *I. gabonensis* on cocoa pod quality

The mean values for the rate of gnawed and rotted cocoa pods in the 0-10 m and 10-20 m radii are 0.023 and 0.383, respectively. The average cocoa yield was 1522 pods.

Analysis of variance for cocoa yields in the 0-10 m and

10-20 m radii revealed a significant difference ($F=39.31$; $P=0.0001$) between the yields obtained. The highest yield value was obtained in the 10-20 m radius (Table 6).

Effect of *I. gabonensis* on biomass and carbon stock of cocoa trees

The analysis of total biomass and carbon sequestered by cocoa trees showed that cocoa trees located between 0 and 10 m from *I. gabonensis* had more total biomass (171.07 kg) and stored more carbon (85.33 t C/ha) than those located between 10 and 20 m from *I. gabonensis* trees (Table 7).

Analysis of variance also showed a significant difference between the biomass and carbon stock values of cocoa trees in the two radii of the system ($F= 4.12$; $P = 0.0423$).

DISCUSSION

Morphological characteristics and productivity of *I. gabonensis*

Analysis of the morphological characteristics, biomass, and carbon stock of *I. gabonensis* trees revealed variability in tree height across the Buyo, Duekoué, and Gueyo localities. However, diameter, biomass, and carbon sequestration rate remained consistent across these different locations. Thus, the diameter, biomass, and amount of carbon stored by *I. gabonensis* are largely unchanged. The observed variation in tree height

Table 7. Cocoa biomass and carbon stock.

Parameter ^a	Radius		Means	CV (%)	F	P
	0-10 m	10-20 m				
Above biomass (kg)	137.96 ^a	129.01 ^b	131.75	103.73	4.12	0.0423
Underground Biomass (kg)	33.11 ^a	30.96 ^b	31.62	103.73	4.13	0.0423
Total biomass (kg)	171.07 ^a	159.98 ^b	163.37	103.73	4.12	0.0423
Carbon stock (tC/ha)	85.53 ^a	79.99 ^b	81.68	103.73	4.12	0.0423

^aMeans, on the same line, followed by the same letter in the same column, are not statistically different at the 5% threshold (Newman-Keuls). CV = Coefficient of variation; F = Fisher's value; P = Probability.

between areas may be attributed to the climatic differences present in the study regions. Historically, Buyo, Gueyo, and Duekoué were recognized as forested regions in Côte d'Ivoire.

Currently, they have been subjected to various anthropogenic pressures in favor of perennial crops such as cocoa. This change has a negative impact on the growth of *I. gabonensis*, which is now found in cocoa plantations instead of its natural habitat; which, according to Ndoumou et al. (2004), consists of dense rainforests. Akpaca et al. (2017) argue that *I. gabonensis* is generally conserved in situ by farmers in fallow land and cocoa fields. This change of zone could, therefore, be one of the reasons for the variability in the species' height. The variation in height observed does not go hand in hand with the diameter at breast height, which, like biomass and the quantity of carbon stored, has not been influenced by the change in locality.

The chemical and biological composition of the soils in these areas is thought to be a factor that favors this stability in thickness growth. In a study on the characterization of *I. gabonensis* cropping systems, Kang et al. (1994) showed that the species thrives on mineral-rich ferrallitic soils (nitisol). This would appear to be the type of soil found in western Côte d'Ivoire. Kengni [26] adds that *I. gabonensis* achieves optimum growth on well-drained acid soils. A positive relationship also appears to exist between the diameter of this species and its biomass production and carbon storage. The larger the diameter of the trees, the more biomass and carbon they store. These results are in line with those of Chave et al. (2014), who assert that the fundamental element for estimating tree biomass and carbon stock is diameter. However, two recent studies by Goodman et al. (2014) in the Amazon basin and Ploton et al. (2016) in the Congo basin indicate that tree crown dimensions significantly improve biomass estimates.

Concerning the productivity of *I. gabonensis*, analysis of variance did not reveal any difference in the weight and number of fruits of *I. gabonensis* in the different localities. The trees present in the different localities had statistically identical production. However, analysis of the productivity of trees from Duekoué showed a significant difference in the quantity of fruit produced by each tree, but the weight remained the same. The difference in age

or maturity of each tree could be the cause of this difference in value. In fact, some *I. gabonensis* trees appeared more mature, while others appeared younger, which would have an effect on the species' fruit production. It is in this context that Mateus-Reguengo et al. (2020) assert that the variation in fruiting can be explained by the maturity of the plants. According to their report, a young plant fructifies less than a more mature one. Ecological factors and anthropogenic pressures could also be at the root of the values recorded. The trees studied were not found in a single area. They were scattered across a number of villages in the Duekoué locality, and were individually affected by ecological factors such as climate change. Most of them have seen their natural habitat transformed into cocoa plantations, altering their development.

Studies by Barima et al. (2016) have shown that certain patches of Ivorian forest have disappeared in favor of crops, mainly cocoa. According to Kouakou et al. (2017), this situation has led to the rarefaction or even disappearance of certain forest species that are important to people's daily lives, such as *I. gabonensis*, *Ricinodendron heudelotii* and *Carapa procera*. Farmers have even claimed that some *I. gabonensis* trees are experiencing production cycle disruptions due to habitat change. According to these farmers, the trees often alternate between low and high production. Other trees, after a period of high production, take a rest before resuming production. In terms of fruit and seed morphological characteristics, the analysis revealed a significant difference in fruit and seed length and width, depending on the trees encountered. *I. gabonensis* fruit and seed dimensions vary from tree to tree. This may be due to the existence of several fruit varieties within the species. Dahouenon et al. (2012) showed in their study, the existence of three fruit forms of *I. gabonensis*. These are spherical, cylindrical and ellipsoidal. Gbesso et al. (2015) also identified two varieties of *I. gabonensis* trees in their work in Benin. According to these authors, these varieties differ in the size of their fruits. This implies that the seeds of these different fruit forms also differ in size. The study highlighted the relationship between yields obtained and morphological parameters (height, diameter, biomass, and carbon stock) with a view to selecting the most productive trees (elite trees). This

study showed that there is a relationship between tree morphology and yield. Trees such as WOkple9, WOkple8, WOkple5, WOkple4, or WOkple10 present in the Buyo locality are characterized by an excellent fruit yield. On the other hand, trees such as DIAkple4, DIAkple8, DIAkple7, DIAkple5 and DIAkple6 in Duekoué were characterized by high crown diameter and biomass production. They could therefore be used to domesticate the species with a view to setting up agroforestry systems capable of reconciling both ecological needs and the sustainability of cocoa production. The high yield of these trees is also an advantage for farmers, who will be able to use them to increase their income.

***I. gabonensis*-*T. cacao* interaction**

The results showed that the density and vigour of cocoa trees varied according to their proximity to *I. gabonensis*. There were fewer cocoa trees close to the species (10 m radius) than farther away (20 m radius). This difference could be explained by the size of *I. gabonensis*. The species has a rather imposing trunk and buttress roots. According to Atangana et al. (2001), the species has a trunk around one metre in diameter, with aliform buttresses that are sometimes highly developed. It therefore takes up a lot of space in plantations, forcing farmers to reduce the number of cocoa trees around it. This decrease in density also reduces the vigour of cocoa trees within the 10 m radius. This may be explained by competition between the species and the cocoa trees for soil nutrients. Cheikh et al. (2014) confirms this assertion, showing that there is nutritional competition between trees that are well established in their environment and cocoa trees that have been introduced. This competition justifies the reduction in vigour of cocoa trees in the vicinity of the species. *I. gabonensis*' crown could also be a factor in the decline in cocoa tree vigour. Cocoa trees in the vicinity are covered by the *I. gabonensis* canopy. This has a negative impact on the cocoa trees' ability to capture light.

Gala et al. (2017) point out that, although cocoa trees require shade, excessive shade from associated trees has a negative impact on cocoa tree development and yield, because cocoa plants compete with trees for light and mineral elements in the soil. This pressure could, therefore, act as a brake on cocoa tree vigour. However, it would be desirable for farmers to plant fewer cocoa trees around the species, particularly within a 10 m radius, in order to reduce the pressure of this forest species on cocoa trees. Cocoa pod yields were also influenced by *I. gabonensis*. Results showed that cocoa trees located close to the species (10 m radius) recorded lower yields than those located further away. This could be due to the low density of cocoa trees within this radius. As the number of cocoa trees in the 20- radius is higher than that in the 10 m radius, pod yields will also be

higher than those of cocoa trees close to the tree. These allegations are in line with those of Jagoret et al. (2020) who argue that cocoa density indirectly influences cocoa yield.

As for rotted and gnawed pods, their rates remained unchanged despite the low pod yield. This would mean that *I. gabonensis* had no impact on the rate of pod rot and gnawing. It could, therefore, be deduced that the species is neither a disease vector for cocoa trees, nor a host for pod-eating animals and insects. These results were confirmed by Avellino et al. (2011), who showed in a study carried out in Costa Rica that shading associated trees helps control mirids. According to these authors, mirids cause more damage in cocoa trees growing in full sun than in cocoa trees under shade. With regard to biomass and the rate of carbon sequestration by cocoa trees, the results revealed that cocoa trees located within the 10 m radius produced more biomass and sequestered carbon better than those located 20 m from the trees. This suggests that *I. gabonensis* has a positive influence on the biomass production and carbon stock of cocoa trees. The low density and low vigour of cocoa trees recorded above do not therefore interfere with their carbon sequestration. This phenomenon can be explained by the pressure exerted on cocoa trees by the canopy of companion species, which potentially reduces their capture of light energy. Consequently, cocoa trees tend to grow taller quickly to maximize light absorption for photosynthesis. This growth strategy could lead to higher biomass production and increased carbon storage. These findings align with Dixon (1995), who suggests that agroforestry practices enhance CO₂ absorption while mitigating greenhouse gas (GHG) emissions linked to deforestation and intensive agriculture.

Conclusion

The primary objective of this study was to contribute to the enhancement of cocoa production for sustainable farming practices in Côte d'Ivoire. Regarding the productivity of *I. gabonensis*, no differences were observed among the different localities. However, fruits collected in Duekoué exhibited varying characteristics depending on the trees sampled, a variability also noted in the seeds from trees within the same locality. This variation is likely influenced by climatic differences and human impact on the trees' habitats. The study identified several trees in specific localities: WOkple9, WOkple8, WOkple5, WOkple4, and WOkple10 in Buyo, characterized by excellent fruit yield; and DIAkple4, DIAkple8, DIAkple7, DIAkple5, and DIAkple6 in Duekoué, noted for their large crown diameter and high biomass production. These trees show promise for domesticating *I. gabonensis* and establishing agroforestry systems that can sustainably balance ecological needs with cocoa production requirements. These findings suggest that

selecting specific trees for cultivation could optimize the integration of *I. gabonensis* into agroforestry systems, thereby supporting both ecological sustainability and cocoa production sustainability.

Regarding the interaction between *I. gabonensis* and *T. cacao*, a low density of cocoa trees was observed near *I. gabonensis*. This reduced density could be attributed to either the morphology of *I. gabonensis* or the planting practices employed by farmers. Consequently, cocoa trees in proximity to *I. gabonensis* exhibited decreased vigor. However, high biomass and carbon content were found in these areas, indicating a positive influence of *I. gabonensis* on cocoa tree biomass production and carbon sequestration.

Despite the lower density and vigor of cocoa trees, there was no observable impact on the incidence of rotted or gnawed pods. This suggests that *I. gabonensis* does not act as a vector for cocoa tree diseases nor does it attract pod-eating animals or insects.

Based on these findings, it can be concluded that *I. gabonensis* has the potential to be integrated into agroforestry systems. However, to minimize its impact on cocoa vigor and yield, cocoa tree density should be reduced in the vicinity of *I. gabonensis*. Overall, these results affirm that the association between *I. gabonensis* and *T. cacao* can contribute positively to enhancing cocoa production.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

- Aimé KK, Irié CZ, Raphaël A, Isaac KK., Marie RD, Anny EN, Patrick J, Bruno H (2023). The great mistake of plantation programs in cocoa agroforests-Let's bet on natural regeneration to sustainably provide timber wood, Trees, Forests and People 12:2666-7193. <https://doi.org/10.1016/j.tfp.2023.100386>.
- Akpaca I, Yapi I, Wokou GC, Tente BAH (2017). Characterisation of *Irvingia gabonensis* cropping systems on the Adja Plateau in south-west Benin. *Revue Ivoirienne des Sciences et Technologie* 29:213-232.
- Alverson WS, Whitlock BA, Nyffeler R, Bayer C, Baum DA (1999). Phylogeny of the core Malvales: evidence from ndhF sequence data. *American Journal of Botany* 86:1474-1486. <https://doi.org/10.2307/2656928>.
- Atangana AR., Tchoundjeu Z, Fondoun JM (2001). Domestication of *Irvingia gabonensis*: 1. Phenotypic variation in fruits and kernels in two populations from Cameroon. *Agroforestry Systems* 53:55-64. <https://doi.org/10.1023/A:1012293700774>.
- Avelino J, ten HGM, DeClerck F (2011). Ecological mechanisms for pest and disease control in coffee and cacao agroecosystems of the Neotropics. In: *Ecosystem Services from Agriculture and Agroforestry Measurement and Payment*. Routledge pp. 91-117. <https://doi.org/10.4324/9781849775656>.
- Barima YSS, Kouakou ATM, Bamba I, Sangne YC, Godron M, Andrieu J, Bogaert J (2016). Cocoa crops are destroying the forest reserves of the classified forest of Haut-Sassandra (Ivory Coast). *Global Ecology and Conservation* 8:85-98. <https://doi.org/10.1016/j.gecco.2016.08.009>.
- Blaser-HWJ, Hart SP, Oppong J, Kyereh D, Yeboah E, Six J (2021). The effectiveness of cocoa agroforests depends on shade-tree canopy height. *Agriculture, Ecosystems and Environment* P 322. Article 107676. <https://doi.org/10.1016/j.agee.2021.107676>.
- Chave J, Réjou-Méchain M, Búrquez A, Chidumayo E, Colgan MS, Delitti WB, Duque A, Eid T, Fearnside PM, Goodman RC, Henry M, Martínez-Yrizar A, Mugasha WA, Muller-Landau HC, Mencuccini M, Nelson BW, Ngomanda A, Nogueira EM, Ortiz-Malavassi E, Péliissier R, Ploton P, Ryan CM, Saldarriaga JG, Vieilledent G (2014). Improved allometric models to estimate the aboveground biomass of tropical trees. *Global Change Biology* 20(10):3177-90.
- Chave J, Andalo C, Brown S (2005). Tree allometry and improved estimation of carbon stocks and balance in tropical forests. *Oecologia* 145:87-99. <https://doi.org/10.1007/s00442-005-0100-x>.
- Cheik M, Meine VN, Eike L, Henry N, Peter AM, Godwin K (2014). Agroforestry solutions to address food security and climate change challenges in Africa, *Current Opinion in Environmental Sustainability* 6(61-67):1877-3435. <https://doi.org/10.1016/j.cosust.2013.10.014>.
- Dagnelie P (1986). *Statistical theories and methods*. Vol. 2. Les Presses Agronomiques de Gembloux, Gembloux 88(90):395-398.
- Dahouenon EA, Djenontin TS, Codjia DRM, Tchobo FP, Alitonou AG, Dangou J, Avlessi F, Sohounhoulou DCK (2012). Morphology of the fruits and some physical and chemical characteristics of the oil and oil cakes from *Irvingia gabonensis* (Irvingiaceae). *International Journal of Biological and Chemical Sciences* 6(5):2263-2273.
- Dixon RK (1995). *Agroforestry Systems: sources or sinks of greenhouse gases? Agroforestry Systems* 31:99-116. <https://doi.org/10.1007/BF00711719>.
- FAO, IFAD, WFP (2015). *The state of the food insecurity in the world 2015: meeting the 2015 international hunger targets: taking stock of uneven progress*. Rome FAO.
- Gala J, Bohoussou Y, N'Dri F, Akotto O, Yao KA (2017). Impact of associated trees on cocoa production in forest-savanna transition zones: the case of M'Brimbo (south-central Côte d'Ivoire). *European Scientific Journal* 13(1):164-181. <https://doi.org/10.19044/esj.2017.v13n1p164>.
- Gbesso HGF, Loughbegnon OT, Agbo SP (2015). Farmer recognition criteria and phenotypic variability of two varieties of *Irvingia gabonensis* Aubry-le comte in south-west Benin. *Revue Ivoirienne des Sciences et Technologie* 26(99-114):1813-3290.
- GIEC (2006). *Guide for the national greenhouse gas inventory: agriculture, forestry and other land use*. Institute for Global Environmental Strategies, Japan 4:46-52. <https://unfccc.int/7914.php>.
- Gockowski J, Tchatat M, Dondjang JP, Hietet GFouda T (2010). An empirical analysis of the biodiversity and economic returns to cocoa agroforests in southern Cameroon. *Journal of Sustainable Forestry* 29:638-670. <https://doi.org/10.1080/10549811003739486>.
- Goetze D, Koulibaly A, Porembski S, Traoré D (2010). Recent vegetation dynamics. In: S. Konaté and Kampmann D. (eds). *Atlas de la Biodiversité de l'Afrique de l'Ouest, Tome III: Côte d'Ivoire*. Abidjan and Frankfurt/Main pp. 377-384.
- Goodman RC, Phillips OL, Baker TR (2014). The importance of crown dimensions to improve tropical tree biomass estimates. *Ecological Applications* 24:680-698. <https://doi.org/10.1890/13-0070.1>.
- Guessan-Bi T, Kra K, Kwadjo K, Kouame K, Doumbia M (2023). Farmers' Practices for the Orchard's Maintenance and Post-Harvest Treatment of Cocoa in Infiltrated Classified and Unclassified Zone of Méagui (South-West, Côte d'Ivoire). *Journal of Agricultural Chemistry and Environment* 12:275-295. doi:10.4236/jacen.2023.123021.
- Jagoret P, Saj S, Carimentrard A (2020). Cocoa agroforestry in Africa: the art of combining sustainable production and ecological services. *Montpellier, CIRAD, Perspective* P 54. <https://doi.org/10.19182/perspective/31915>.
- Jagoret P, Kwessu J, Messie C, Michel-Dounias I, Malézieux E (2014). Farmers' assessment of the use of value of agrobiodiversity in complex cocoa agroforestry systems in central Cameroon. *Agroforestry Systems* 88(6):983-1000. <https://doi.org/10.1007/s10457-014-9698-1>.
- Kang BT, Akinnifesi FK, Ladipo DO (1994) performance of selected woody agroforestry species grown on an alfisol and an ultisol in the humid lowland of west africa, and their effects on soil properties." *Journal of Tropical Forest Science* 7(2):303-12. <http://www.jstor.org/stable/43581816>.
- Kengni E (2003). Food value of fruits from indigenous fruit trees in the

- lowland humid tropics of west and central Africa: case of *Irvingia gabonensis* and *Dacryodes edulis* in Cameroon. PhD Thesis. University of Yaoundé I, Cameroon pp. 259.
- Kouadio KH, Gala BTJ, Assiri AA, Yao KA (2016). Characterization of traditional agroforestry systems of cacao and their impact on some physical fertility parameters of soil in southwestern Côte d'Ivoire. *International Journal of Multidisciplinary Research and Development* 3(10):145-152.
- Kouakou ATM, Barima YSS, Kouakou KA, Bamba I, Konate S, Bogaert J, Kouadio JY (2017). Management of state-owned forests in times of conflict: the case of the 46 classified forests of Haut-Sassandra, central-western Côte d'Ivoire. *The International Journal of Biological and Chemical Science* 11(1):333-349. <https://doi.org/10.4314/ijbcs.v11i1.26>.
- Kouakou K, Kebe BI, Kouassi N, Anno AP, Ake S, Muller E (2011). Impact of cocoa swollen shoot virus disease on cocoa production in Bazré (Côte d'Ivoire). *Journal of Applied Biosciences* 43:2947-2957. <http://www.m.elewa.org/JABS/2011/43/7.pdf>.
- Kouame N, N'Guessan F, N'guessan HA, N'Guessan P, Tano Y (2015). Variations saisonnières des populations de mirides du cacaoyer dans la région de l'Indénie-Djuablin en Côte d'Ivoire. *Journal of Applied Biosciences* 83:7595-7605.
- Koulibaly A, Piba CS, Kouamé AG, Kouakou DK, Tra BHF (2018). Influence of management on the diversity and preponderance of non-timber forest products (NTFPs) in the Yapo-Abbé classified forest, Côte d'Ivoire. In : *Innovative Space of Scientific Research Journals* 2028(1):222-235.
- Koulibaly A, Traoré D, Goetze D (2010). Cocoa and plant diversity. In: Konaté S, Kampmann D (Eds). *Biodiversity Atlas of West Africa*, Tome III: Côte d'Ivoire. Abidjan & Frankfurt/Main pp. 418-425.
- LA NAWA (2016). The guide to discovering potential. Retrieved November 8, 2019, from <http://www.lanawa.ci>.
- Lachenaud P, Oliver G (1998). Influence of pruning on cocoa yields. *Plantation Research Development* 5:34-40.
- Läderach P, Martinez-Valle A, Schroth G (2013). Predicting the future climatic suitability for cocoa farming of the world's leading producer countries, Ghana and Côte d'Ivoire. *Climatic Change* 119:841-854. <https://doi.org/10.1007/s10584-013-0774-8>.
- Mateus-Reguengo L, Barbosa-Pereira L, Rembangouet W, Bertolino M, Giordano M, Rojo-Poveda O, Zeppa G (2020). Food applications of *Irvingia gabonensis* (Aubry-Lecomte ex. O'Rorke) Baill., the 'bush mango': A review, *Critical Reviews in Food Science and Nutrition* 60(14):2446-2459. DOI:10.1080/10408398.2019.1646704.
- Météo et Climat (2020). Department of Duékoué in Côte d'Ivoire. [online] (Page consulted on 09/09/2020). https://planificateur.a-contresens.net/afrique/cote_d_ivoire/district_des_montagnes/departement_de_duekoue/2289548.html.
- Ndoumou DO, Fotso O, Mbouna D (2004). Propagation of *Irvingia gabonensis* by in vitro micropropagation. *Fruits* 59:31-38. <https://doi.org/10.1051/fruits:2004004>.
- Ploton P, Barbier N, Takoudjou MS, Réjou-Méchain M, Boyemba BF, Chuyong G, Dauby G, Droissart V, Fayolle A., Goodman RC, Henry M, Kamdem NG, Mukirania JK, Kenfack D, Libalah M, Ngomanda A, Rossi V, Sonké B, Texier N, Thomas D, Zebaze D, Couteron P, Berger U, Pélissier R (2016). Closing a gap in tropical forest biomass estimation: taking crown mass variation into account in pantropical allometries, *Biogeosciences* 13:1571-1585, <https://doi.org/10.5194/bg-13-1571-2016>.
- Saj S, Jagoret P, Todem N (2013). Carbon storage and density dynamics of associated trees in the contrasting theobroma cacao agroforests and Central Cameroon. *Agroforestry Systems* 87:1309-302. <https://doi.org/10.1007/s10457-013-9639-4>.
- Schroth G, Jeusset A, Gomes AD, Florence CT, Coelho NAP, Faria D, Läderach P (2016). Climate friendliness of cocoa agroforests is compatible with productivity increase. *Mitigation and Adaptation Strategies for Global Change* 21:67-80.
- Sonwa DJ, Bernard A, Nkongmeneck A, Weise F, Tchatat M, Akin AA, Janssens MJJ (2007). Diversity of plants in cocoa agroforests in the humid forest zone of southern Cameroon. *Biodiversity and Conservation* 16:2385-2400. <https://doi.org/10.1007/s10531-007-9187-1>.
- Vroh BTA, N'guessan KE, Adou Yao CY (2017). Trees species diversity in perennial crops around Yapo protected forest, Côte d'Ivoire. *Journal of Horticulture and Forestry* 9(11):98-108. <https://doi.org/10.5897/jhf2017.0507>.
- World Bank (2019). Economic situation in Côte d'Ivoire. World Bank, Abidjan, Côte d'Ivoire 61 p.
- Yao CY, Kpangui KB, Vroh BTA, Ouattara D (2016). Cultural practices, use values and farmers' perceptions of cocoa companion species in traditional agroforests in central Côte d'Ivoire. *Rev.d'éthnoécol* 9p. <https://doi.org/10.4000/ethnoecologie.2474>.
- Zanne AE, Lopez-Gonzalez G, Coomes DA, Ilic J, Jansen S, Lewis SL, Miller RB, Swenson NG, Wiemann MC, Chave J (2009). Global wood density database. *Dryad Digital Repository* 235 p. <http://hdl.handle.net/10255/dryad.235>.