We would like to extend our sincere gratitude to the editor and the two reviewers for their insightful comments and constructive suggestions. We believe these contributions have significantly enhanced the quality of our manuscript.

A significant change in this revised version is the inclusion of additional species in our models. Our analyses now encompass 59 species, compared to 23 in the original submission.

The inclusion of these new species strengthen our findings, particularly highlighting the positive effect of the spontaneous origin on timber yield (reflected in reduced credible intervals). Additionally, the updated results align more closely with field observations and expert knowledge, particularly regarding the faster growth rates observed for *Cedrela odorata*, *Gmelina arborea*, and *Ceiba pentandra*.

We have updated all tables and figures in the manuscript and in the Supplementary Information to reflect these changes. Similarly, we revised the abstract and all numerical values presented in the main text.

Below, we provide responses to all comments from the reviewers and the editor. Each comment is presented in bold, followed by our detailed response in italics.

SUGGESTED ANSWERS FOR REVIEWERS

Decision for round #1 : *Revision needed*
Decision for round 1
Based on the reviewer's expertise and my own one, the paper is found as an interesting and original contribution to a specific case of agro-forestry for cocoa plantations in West Africa.
The paper can be improved in some ways by minor corrections or complements that are suggested in the 2 reviews and the comments added by me in the text (attached file vu BTh).

GENERAL COMMENT :
In a wider view, mostly for further works on the same subject, I would like to make a general comment.
I find very interesting your way of changing the usual paradigm of planted forest associated to planted agro-food, letting trees naturally colonize the crop from the existing seed bank made of a large number of tree species, well adapted to the local climate conditions, with a low planting cost. But I am a little disappointed by your conservatism in the way to take values from the trees which is half of forestry job. In my opinion, classical concepts as "Minimum logging diameter" (MLD) or "species identified as potentially suitable for wood production" i.e. "commercial species" are totally out of scope considering both available sawing of veneer cutting technologies using mostly log diameters between 30 to 45 cm DBH, and the specific socio-economic situations of cocoa farmers.
Wood stems are always very good mechanical beams allowing trees to resist external forces, whatever the species. So timber issued from every species

growing in the cocoa field is always a good solution for mechanical conception of many objects or structure. This can be checked in cultural heritage everywhere in the world. The reasons for use are linked to different timber availability, the existence of local knowledge and know-how and socio-economic consideration, but not to wood ability to perform a mechanical function. This is the reason why I suggest you to take into consideration all the species that you have measured in order to be able to have a sound base for forest products use in the cocoa AF system.
Besides, there are strong differences between species and trees within a species for stem geometry, and wood properties that are not strictly linked to structural uses: resistance to fungi, insects or bacteria, aesthetical advantages, dimensional stability, acoustic properties and so on. Most of these properties are linked to the large cocktail of organic molecules (extractives) which is a species chemical signature and are and treasures for fine chemistry.
At the end of a cascade use of timber all wood species are excellent fuels with the same energy content par unit dry mass.
Cocoa farmers are nor big timber companies looking a very homogeneous resource for a given fruitful process and, at least at the R&D level, all opportunities should stay open.
Your experimental data is a very good mine of information and you should share it with the scientific community as well as enhance R&D projects for AF systems.

Regarding the use of Minimum Logging Diameter (MLD) in our study, we would like to clarify the rationale behind our approach:

MLD values used in this study are legally defined thresholds below which logging is prohibited. These values correspond to the diameter at which approximately 80% of trees of a given species reach a stage of abundant and regular fruiting (Sodefor, 2019). This criterion ensures the sustainable renewal of tree populations. We added these sentences (L74-77).

Our decision to base our analysis on the legal values of MLD stems from practical considerations: our results provide information that is directly useful to the stakeholders of the wood industry and can be used to improve their practices in the current legal context. Additionally, in the current context of widespread deforestation, we are particularly cautious about the potential implications of our work. Using lower MLD thresholds, for instance, could inadvertently send a message that might encourage unsustainable logging practices, further exacerbating deforestation. By sticking to established MLD values, we aim to promote responsible forestry practices.

Finally, we would like to emphasize that height and volume values can still be calculated for any species included in our analyses at any diameter using the model equations and parameter values presented in this article.

As for the request to include more species:
We acknowledge that our initial approach was somewhat conservative, and we have now expanded our analyses to include additional species. Specifically, among the 284 species identified in the field, we now consider all species listed in the national list of timber species (Sodefor, 2017; table S1 of the Supplementary Information), as well as

all species commonly used by Ivorian cocoa farmers for construction purposes (Dago et al., in press; table S1 of the Supplementary Information). However, for the sake of clarity and simplicity, we focus, in the main text, on presenting the analyses and results for the 23 species identified as the most suitable for timber production in cocoa agroforestry systems (Kouassi et al., 2023a). This targeted approach ensures that the results are more accessible and easier to interpret for readers. The details of this adjustment have been included in the sampling data section (L107-123):

"A total of 11 999 trees belonging to 284 species were inventoried (a summary of this inventory is presented in table S1 of the Supplementary Information (Kouassi et al., 2024)). In this study, we only considered the species listed in the national list of timber species (Sodefor, 2017; table S1 of the Supplementary Information), or the species listed as commonly used by Ivorian cocoa farmers for construction purposes (Dago et al., in press; table S1 of the Supplementary Information). Also, here we only consider spontaneous and (trans)planted trees excluding remnant trees. Remnant trees are expected to have different development trajectories as they have grown, at least in part, in a forest environment. Finally we only consider species with at least 5 individuals. Our dataset thus includes a total of 4634 trees belonging to 59 species, including 2530 spontaneous trees and 2104 (trans)planted trees.

For the sake of clarity and simplicity we focus in the main text on presenting the analyses and results for 23 species identified as the most suitable for timber production in cocoa agroforestry systems (Kouassi et al., 2023a). These species were identified based on their good cylindricity, straightness, and overall health, key indicators of high-quality commercial timber. A summary of the dendrometric characteristics of these 23 species is presented in table 1. A summary of the dendrometric characteristics of the other 36 species is presented in table S2 of the Supplementary Information (Kouassi et al., 2024)."

We also added this sentence in the Results section (L221-224):
"In this section, we present the results obtained for the 23 species identified as the most suitable for timber production, as previously mentioned. The parameter values and credible intervals for all 59 species considered in this study are provided in Tables S3 to S12 of the Supplementary Information."

The inclusion of additional species allowed us to relax some of the constraints previously applied in the model. We reverted to the "default" version described in Hérault et al. (2011) and Schmitt et al. (2023). Specifically, in the former manuscript, we modeled $Ks = wds \,.\, \theta k + \theta k$ *to help convergence. In the revised model, we redefined* $Ks = \theta k \cdot wds$ *with* $\theta k \sim LN(\log(\mu\theta k), \sigma\theta k)$*.*

The updated outputs are more consistent and satisfactory:
The previously observed poor performance of Gmelina arborea has been resolved. In the earlier model, it reached its MLD in 53 years, whereas it now reaches it in 28 years. Consequently, we have removed the following sentence (after L366):

"Our results show a poor performance of Gmelina arborea despite its reputation for remarkable growth (Vallejos et al., 2015). This result could be an artefact due to our sampling. In fact, we only observed 10 individuals of this species, all of which were no more than 4 years old."

Similarly, Cedrela odorata now exhibits faster growth, reaching its MLD in 15 years compared to 27 years in the previous model. Ceiba pentandra also shows improved growth, reaching its MLD in 30 years instead of 34 years. These updated results align much more closely with the known fast-growing characteristics of these species and our field experience.

L71 : MLD should be questioned: is it a technical processing optimum, for all species?; is it a heartwood production optimum for species with desirable heartwood?; is it a good choice in harmony with the cocoa tree cycle?
See answer to general comment

L102 : what is a species potentially suitable for wood production?; is it based on commercial notions, tree "quality" notions or wood quality notions? for what uses these wood production are looked at: only solid wood, solid wood + fiber wood + fuel wood in a cascade approach?

The 23 species identified as potentially suitable for wood production were selected exclusively for timber (solid wood) production. Their suitability was determined based on specific criteria: their cylindricity, straightness, and overall health which are good indicators of timber quality. We added a sentence (L117-120) to clarify this point:

"For the sake of clarity and simplicity we focus in the main text on presenting the analyses and results for 23 species identified as the most suitable for timber production in cocoa agroforestry systems (Kouassi et al., 2023a). These species were identified based on their good cylindricity, straightness, and overall health, key indicators of high-quality commercial timber."

L103 : What are the species with the minimum diameter (10 cm) found in all the plots?In Kouassi 2023a it is written : Overall, 12,409 trees were inventoried, among which 2429 (19.6%) have been identified as belonging to timber species. They come from 55 species grouped in 21 families.Is it possible to have the total list of species with the number of trees and their mean, min and max diameter among the 12 409 trees?
Approximately 12 000 trees were inventoried in the field (11,999 after data curation, excluding trees with a diameter below 10 cm that were accidentally measured). We added a table in the Supplementary Information (Table S1) presenting this inventory. This table includes the number of trees for each species, as well as their mean, minimum, and maximum diameters, heights and ages. We also clarified how we selected the species considered in this study in the sampling data section (L107-116; see answer to general comment above).

Table1: this (MLD value) seems high when looking at the evolution of processing techniques for small diameter logs very common in many wood industry both in temperate and tropical zones
See answer to general comment

Table1 : please give one more digit (0.33 or 0.28 for example)
Done as suggested

Table1 : for all the uses except slicing, MLD for first machining of trunks should be around 30 to 35 cm today
As mentioned in our answer to the general comment, the legal MLD values used in our study are designed to ensure the sustainable renewal of tree populations. While establishing a second, lower MLD specifically for artisanal uses in cocoa agroforestry systems might be theoretically feasible, it would present significant challenges under the current timber resource governance framework in Côte d'Ivoire. Such a measure could lead to earlier harvesting of trees in forest areas, potentially exacerbating deforestation, due to the limited traceability of timber resources.

Table1 : rotary peeling?
Unwinding replaced by rotary peeling as suggested.

L223 : What is the age of cocoa trees when they are replaced by new ones? Is it very different from 25 years ? In this case can you give the results at this age of replacing cocoa trees?
Cocoa trees are generally replaced when they become unproductive, typically after 30-35 years. However, in cocoa AFS, several cohorts of cocoa trees often coexist, as trees are gradually replaced due to mortality caused by diseases or climate factors. Under these conditions, aligning tree harvesting with cocoa tree renewal becomes impossible. Cocoa agroforestry in West Africa rather aims to establish a perennial system without successive farming cycles.

Based on this rationale, we have chosen to present the bole volumes reached at age 25. This corresponds to a commonly used logging age in forest plantations and also to the approximate age at which fast growing species reach their MLD in our study. We believe this approach is well-suited to presenting our volume results.

L224 : it should be interesting to give also the anhydrous wood mass (using the mean basic density for the species)
We added the anhydrous wood mass as suggested (L250-L254) :
"The fastest growing species is Ceiba pentandra (FROMAGER), which reaches 2.1 m³, corresponding to an anhydrous wood mass of 630 kg, at age 25. The slowest growing species, Distemonanthus benthamianus (MOVINGUI) and Funtumia africana (POUO), reach 0.5 m³, corresponding to an anhydrous wood mass of 300 kg and 200 kg, respectively, at the same age."

L262 : you should take into account the influence of "juvenility" on the "value" of the AFS trees

We acknowledge the influence of juvenility on wood quality especially regarding heartwood differentiation. In response to this comment and to reviewer 1's comment on the same topic (wood quality) we added these sentences in the discussion section (L322-326):

"The rapid diameter growth we observed in AFS could limit heartwood formation, which could affect wood quality in certain species. However, we currently lack the data to test this hypothesis. More generally, the quality of wood from cocoa AFS has yet to be assessed. Future studies could explore the link between growth rate and wood

quality, as well as investigate the typical defects of wood in AFS and their impact on commercial value."

L343 : are you sure that pruning will increase bole height?
Pruning involves the removal of lower branches and, when performed early, helps prevent defects in the wood, thereby increasing the commercially valuable length of the bole. We clarified this point (L379-382):

"Besides, our results show trees in West African cocoa AFS have low bole height. This suggests pruning could be an effective lever for improving wood production. Indeed, by removing lower branches at an early stage, pruning helps prevent defects in the wood, which increases the commercially valuable length of the bole."

Review by Tancrède Alméras, 04 Sep 2024 09:26
This article addresses the question of the productivity (change in bole volume with age) of trees in agroforestry systems (AFS) in Côte d'Ivoire. The applicative context is very well described, and the implications of the study for AFS management are provided. The study is based on a large dataset about the age and size of trees (diameter at breast height and bole height) in AFS in Côte d'Ivoire. Using a Bayesian scheme, the authors build models to predict (1) the changes in diameter with tree age, (2) the relationship between diameter and height, (3) the relationship between tree dimensions and bole volume. From these models, predictions about the change in bole volume with age are deduced. The authors consider the origin of the tree (natural regeneration or transplanted) and evidence a strong effect of this origin, natural regeneration having a better potential for wood production.

The title of the article may be a good summary of its content, but I found it difficult to understand (it is a complex phrase without verb).
We changed the title for:
"Tree growth in West African cocoa agroforestry systems : high timber yields and superior performance of natural regeneration."

L46-47: "more subject to variations in temperature and humidity, influencing their mechanical structure". I don't really understand this argument. I think the main effects of microclimate on AFS are those mentioned earlier, light and wind. Please either develop of delete this comment.
We agree this sentence might not be necessary and somehow adds confusion. We deleted it.

L100: please specify the number of trees in that subset.
added as suggested:
L104-106: "Finally, we measured successive diameters along the bole (every meter) of a subset of 200 trees using a Bitterlisch relascope in order to calculate their bole volume".

L115: unfortunately, Bayesian statistics are not yet so widespread, so that it would be useful to remind the reader what are the advantages of this technique compared to classical statistics.

We added the following sentence (L132-135):
“The Bayesian approach offers great flexibility and transparency in modeling complex phenomena and uncertainty. It makes it possible to incorporate prior knowledge (priors) and to obtain probability distributions (posteriors) for model parameters, from which credible intervals are derived.”

L116: “Team et al.” is probably not the appropriate citation for the R software (it’s R Core Team, not Team, RC).
L131-132: *“R Core Team 2021” corrected*

L148-149: here you mention measurements of annual growth rates. Are they used later in the manuscript?
Yes, as mentioned at the end of the sentence these values are used “for comparison with measurements taken in forests in the same region”. These comparisons are made in the Discussion section. We added (L171) “(see Discussion section)” to make that clearer.

L193: “(equation 2)”: missing parenthesis
L215: “(equation 2)”: parenthesis added

L205-208: to me, the fact that Dopt is lower than the minimal diameter you set is an indication that the model of annual growth rate (eq. 3) is in some way not really adapted to describe the evolution of AGR in AFS. This is probably linked to the changes in light availability during ontogeny, that strongly differ between forest trees and AFS.
We believe our model can be used to describe AGR in both forests and AFS. It is flexible enough to adjust to the monotonically decreasing AGR observed above the minimum diameter in AFS. In this case, Dopt is necessarily lower than the minimum diameter.
To be noted that, in the updated version of the model, Ks = θk.wds with θk ~ LN (log(µθk), σθk), we obtained Dopt values above the minimum diameter for some species.

L235: I was surprised by the low value of exponents of the allometric model. I would expect them to be closer to 2 and 1, since the volume of a cylinder is proportional to DBH^2*BH. These exponents suggest that the “form factor” ($BV/DBH^2/BH$), which is related to stem taper, strongly decreases with size. I suggest that you comment about these exponents, and show the relationship between predicted and measured bole volumes, to convince the reader that this model is not biased.
We added a paragraph in the Discussion section to answer your comment about the form factor (L307-312):

“Prioritizing diameter growth also enhances tree stability and resilience to wind, especially in resource-limited environments. As a result, trees tend to develop more conical boles rather than perfectly cylindrical ones, as evidenced by the low values of the volume model parameters ($\beta = 1.45$ and $\gamma = 0.43$, compared to the expected $\beta = 2$ and $\gamma = 1$). These parameters indicate that as trees grow larger, their shape becomes increasingly conical, reinforcing the hypothesis of prioritized diameter growth in AFS.”

As suggested we added a figure showing the relationship between predicted and measured bole volumes in the Supplementary Information. This figure shows a good agreement between observed and predicted values. We modify a sentence in the text to refer to it (L264-266):
"The model parameter values and their credible intervals are presented from table S11 to table S12 of the Supplementary Information while the relationship between predicted and measured bole volumes is presented in Figure S1 (Kouassi et al., 2024)."

L282: the relationship between diameter and volume is a power relationship rather than exponential (you may also say "convex" relationship).
L316: "exponential relationship" replaced by "power relationship"

L313: "(transp)lanted": parenthesis not at the right place
L349: "(trans)planted": parenthesis corrected

L321-322: It is not surprising that the bole volume is found negatively correlated to wood density, since a negative relationship between AGR and wood density has been assumed in the model (L136). Please reformulate, to avoid that the reader believes that this relationship is purely an output of the model.
Here, we disagree with this statement. The negative relationship between bole volume and wood density is an output of the model and is not induced by our modeling approach.

In the previous version of the manuscript, we modeled Ks = wds . θk + θko, and obtained a negative value for θk. While this indicates a negative relationship between wood density (wd) and K, it does not imply a negative dependency between annual growth rate (AGR) and wd, or between bole volume and wd.

Our model describes AGR as a function of diameter, assuming it first increases to a maximum value (Gmax) at an optimum diameter (Dopt) and then declines. The K (Kurtosis) parameter determines the shape of this growth trajectory. Specifically, a larger K produces a flatter curve, so that Gmax is reached more gradually and is followed by a slower decrease in AGR. Conversely, a smaller K produces a steeper curve, with Gmax reached more quickly and followed by a faster decline.

Thus, the trajectories of bole volume, derived from the sum of AGR (eq.1), are controlled by the combined effects of Gmax, Dopt, and K, and the direction of the relationship between bole volume and wd is not determined by the sign of θk. In fact, in the revised version of the model, we defined Ks = θk · wds, and obtained a positive value for θk. Despite this change, a negative relationship between bole volume and wood density still persists (albeit weaker).

We updated Figure S1 presenting this relationship in the Supplementary Information with our new dataset.

Review by anonymous reviewer 1, 30 Jul 2024 13:34

- **The title clearly reflects the content of the article;**
- **The abstract presents the main finding of the study;**

- **The research questions are clearly presented;**
- **The introduction describes the relevant research in the field;**
- **Analyses are sufficiently detailed, but methods can be improved;**
- **Results are well described, but interpretation can be improved;**
- **The limits of their study are not considered in the discussion, but the conclusions are strongly supported by the results.**

Interesting paper on agroforestry for fruit (cocoa) and timber production, full of interesting data coming from a large amount of study areas (150 plots) representing the cocoa production regions of Cote d'Ivoire.
To be published this paper needs some small improvements that could help the readers in understanding the whole study.

First of all it would be good to have some explanation about the methods of cocoa cultivation in the introduction. Without an explanation that emphasizes that cocoa trees must be covered by other trees because they suffer from direct sunlight, the reader may find it a little strange that an agricultural crop can accept the birth and growth of spontaneous trees within the cultivation.
To answer this comment, we added these sentences in the second paragraph of the introduction (L28-31) :
Cocoa agroforestry consists in cultivating cocoa trees under the shade of larger trees. At low-to-intermediate shade levels, this practice can help reduce disease prevalence, buffer climate extremes, mitigate climate change and conserve biodiversity, while maintaining cocoa production levels (Blaser 2018). Thus, the agroforestry promotion initiatives primarily aim to achieve sustainability and long-term stabilization of cocoa production (Carimentrand, 2020).

Secondly, it is not clear whether the list of trees in Table 1 is valid for both planted and spontaneous tree species. Of course only Cedrela cannot be spontaneous, but all the other trees can be found among the transplanted and spontaneous trees?
To clarify that point, we specified the number of spontaneous and (trans)planted trees for each species in Table 1 and table S2 of the Supplementary Information.

Thirdly, very little is said about the commercial quality of logs. Has an assessment been made of the typical defects and how they could limit the profitability of wood for the most valuable uses?
The quality of wood from cocoa AFS has yet to be assessed. Unfortunately, we do not have the data to address this issue. In response to this comment and to reviewer 2's comment on the same topic (wood quality) we added these sentences in the discussion section (L322-326):

"The rapid diameter growth we observed in AFS could limit heartwood formation, which could affect wood quality in certain species. However, we currently lack the data to test this hypothesis. More generally, the quality of wood from cocoa AFS has yet to be assessed. Future studies could explore the link between growth rate and wood quality, as well as investigate the typical defects of wood in AFS and their impact on commercial value."

This is a series of important assessments, which should cover both the quality of cocoa produced and that of wood production. Agroforestry is an activity that

must have an economic value: those who produce cocoa are interested in obtaining the maximum possible yield from the sale of the product. But if you add wood to cocoa, it means that the farmer wants to keep the remuneration from cocoa, but by adding that from timber. But the remuneration is obtained through the quality of both products, not only by the quantities.

We fully agree. This study is part of a larger effort to analyze the economic trade-offs between timber and cocoa production in agroforestry systems. While this paper focuses on timber performance, our broader research examines how timber and cocoa interact to evaluate the financial viability of both products.