Traditional cacao agroforestry in Central Africa can provide both respectable yields and levels of ecosystem services

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Abstract

Since it moved toward - and tried to apply - intensive production patterns, cacao cultivation in Sub-Saharan Africa represents a major driver of deforestation. In Cameroon, most cacao is still cultivated in low-input traditional agroforests (CAFS). Such systems are still criticised for their presumed low cocoa production and seemingly economic and ecological inefficiency of their associated tree community (ATC). Yet, these household systems proved to be sustainable on the long run and marginally threaten forest land when compared to other producing regions or agricultural systems.

We studied a cAFS' 100-year chronosequence and checked for three ecosystem services they provide: (i) cacao production; (ii) carbon (C) storage in tree biomass and (iii) tree species conservation. Within this chronosequence we also studied a large array of associated trees densities (ATD) to better appreciate the role of competition on the services studied. We used, among other variables, basal area (BA) of the different components of the systems to gauge interspecific competition, functional group dynamics and cacao trees productive abilities.

Yields were highly depending on the age of the plot, the BA of the ATC and the structure of the cacao stand. Very long-term production seemed achievable if the BA of the cacao stand remained under 40% of CAFS' total BA. High accessible yields underlined a good production potential which was mitigated by interspecific competition. Yet, for a given level of competition some associated functional groups of the ATC were consistently related to higher cacao yields. Furthermore, CAFS were able to combine high levels of tree species richness with long-term conservation abilities and C storage. However, tree species conservation potential depended on ATD and remained difficult to appraise. C storage was highly dependent on large trees and not systematically mitigated by ATD - underlining the possible "uncoupling" of tree species conservation and C sequestration in those systems.

ATD reduction emphasised consistent shifts of functional traits / groups that are to alter CAFS functioning and ATC diversity of uses. Thus, a "rough simplification" - as regularly advocated to alleviate the competition between cacao stands and ATC – is most likely to impair traditional CAFS ecosystem sustainability. We argue that cacao productivity in these systems can be raised combining consistent rejuvenation and densification practices with site-specific intensification in terms of inputs and/or manpower. Such intensification would not compulsorily include ATD reduction and therefore would, at least partly, facilitate the preservation of some of the ecosystem services supported.

Keywords: traditional farming system, cocoa yield, basal area

1. Introduction

Cocoa world production averages a yearly 4 million tons (ICCO, 2014). About 80% of this production is achieved by farmers whose orchards do not exceed five hectares (Rafflegeau et al, 2015). Cocoa has represented and still represents a major cause of deforestation in some parts of the world – notably in Africa (Cleaver, 1992). Indeed, the economic conditions needed to manage on the long term monocultural cocoa rarely match smallholders financing abilities. Such discrepancies between the extension models, set up for instance in Côte d'Ivoire or Ghana, and smallholders' practices pushes cyclically the latter toward pioneer fronts (Ruf, 1987; Ruf, 1995). Yet, cocoa can be grown in pluri-specific systems which are most likely sustainable and could slow down deforestation by settling down on longer time scales the farmers that are managing them. Such cocoa agroforests (CAFS) are often referred to as "complex" since they associate cocoa trees to several other perennial species of various uses and functions (Clough et al., 2009; Somarriba et al., 2013). On the one hand, this complexity enable these systems to provide a continuous production of cocoa and other commodities over several decades. On the other hand, it largely prevented them to emerge as solutions which could be (i) economically acceptable for the industry and (ii) technically accessible for conventional agriculture extension services. Thus, the productive potential of these systems is still today understated and poorly evaluated. CAFS are to some extent contributing to deforestation in the humid tropics. Yet, they can concomitantly be perceived as biodiversity preservation tools if they are maintained and untransformed gradually to cocoa monocultures or other of species (eg. hevea or palm; Ruf, 1995).

The region of Central Cameroon produces cocoa for more than a century (Assoumou, 1977) and contributes significantly to the national production of the 5th world producer (ICCO, 2014). It is characterized by a diversity of CAFS, all using very few inputs (some pesticides but rarely fertilizers), that are created in an array of environmental conditions. Those systems are now getting well documented (eg. Bisseleua et al., 2008, 2009; Jagoret, 2011, Jagoret et al. 2011, 2014, 2017; Saj et al., 2013, 2017a, 2017b). The region still houses spaces of protected and unprotected forests (AGTER, 2012). These forests can serve as references that are essential to assess the levels of carbon (C) storage and conservation services CAFS can offer. Therefore, Central Cameroonian CAFS and forests represent a valuable case study that could be useful for Sub-Saharian regions which are undergoing a dynamic installation of cocoa in pioneer fronts and/or which needs to change their cocoa production paradigm.

This article summarizes the main results our research team undertook in Central Cameroon on the study of three ecosystems services (SE): C storage, forest trees conservation and cocoa production. It then addresses trade-offs and synergies between these services.

2. Ecosystems services assessment

2.1. Carbon storage in live biomass

Our investigations especially focused on the carbon (C) storage in CAFS' and forests' woody biomass. Although other data on C storage in soils and non-woody biomass were collected, those results are not presented in this article. C storage had been assessed according to Chave et al. (2005). Plots' sampling methodology, sites and CAFS studied are described in Saj et al. (2013, 2017a, b). Interestingly, in Central Cameroon, CAFS can be created after forest partial clearing (slash-and-burn) but can also be created after savannah (Jagoret et al., 2012; Nijmeijer, 2017). This paper deals only with the systems created after forest.

Our results show that the time of the installation of the cocoa stand may mark the lower C storage level of those systems (Fig 1). Yet, the tuning of the shading is a continuous process, which still needs sometimes to cut down significant amounts of - or big sized - trees that were preserved at the beginning of the installation. The farmers regularly wait for newly associated planted/transferred tree to grow enough, before an undesirable tree is girdled or cut down. Hence, the CAFS may often not exhibit significant C increase before 20 years old. During this period C in live tree biomass tends to stagnate around a mean of 60 Mg ha^{-1}. The system then accumulates biomass as the tree community grows while the ATD declines slowly between 20 and ca. 50-60 years (Fig 2). Indeed, when the systems age, there are very few solutions to regulate the shade besides cut down as trees get too high/big to get carved. The C storage level reach its maximum around 60 years old at an average close to 115 Mg ha^{-1}. This maximum may be disturbed when some big trees are cut down when the farmer rehabilitate/renew its cocoa stand and wants some more light to reach young cocoa trees (see. Jagoret et al.,

2017). When this is not the case, some CAFS reach C storage levels that can be similar to those of local secondary forests (Saj et al., 2017a).

However, this storage is mainly due to large trees with a diameter at breast height (DBH) greater than 30 cm which are promoted throughout the life of the cocoa (Saj et al., 2017a, b; Fig. 1). C storage in the biomass of the cocoa stands remains marginal and is comparable to the storage of the associated trees of small size (diameter at breast height: DBH < 30 cm). Thus, it appears that the CAFS from Central Cameroon demonstrate significant C storage abilities, especially if compared to monocultures, but that it actually depends indirectly on cocoa trees.
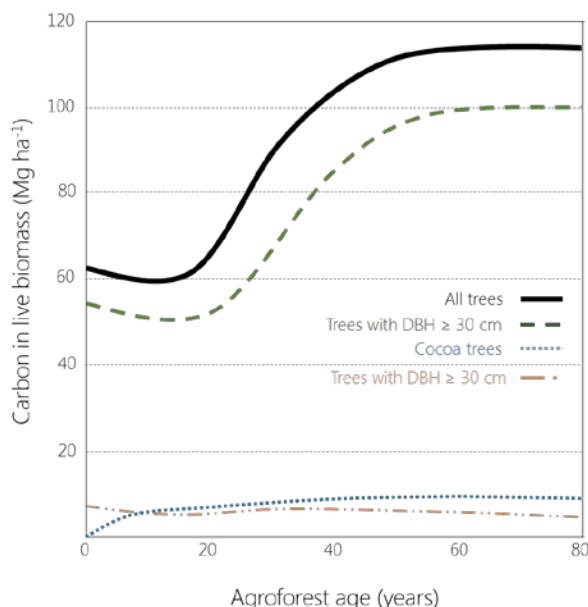

Figure 1

Carbon storage dynamics in live tree biomass of cocoa agroforestry systems in Central Cameroon (n=144). Estimated using allometric equations and sampling methodology described in Saj et al. (2017a).

2.2. Conservation of forest trees

Our research team focused on woody species conservation and sums up some of the results from Saj et al., 2017a). We do not tackle here the biodiversity on non-woody plants and animals. One of the specificities of the Central Cameroon's CAFS lies in the fact that they are composed of a large number of associated species, yet represented by quite reduced numbers of individuals when it comes to forest species. On average the CAFS studied exhibit 10 to 30 associated species per hectare for densities (ATD) varying from 30 to over 200 ind ha^{-1}. These figures are lower than the estimates for forest systems in the region. It appears thus CAFS can retain some kind of forest "environment", and constitute one of the most tree-diverse agricultural system that can be found on earth. They contain significant amounts of individuals from certain species such as *Terminalia superba*, *Milicia excelsa*, *Albizia adianthifolia* that may be compatible with conservation programs implementaion. Furthermore, they may reveal to be efficient buffer zones since because they allow the conservation all along their lives of many trees belonging to species facing conservation issues (Fig 2).

Figure 2

Mean number of associated trees in cocoa agroforestry systems from Central Cameroon according to the age of the system and to their potential conser-vation issue. AT: associated tree. CI: conservation issue (n=144).
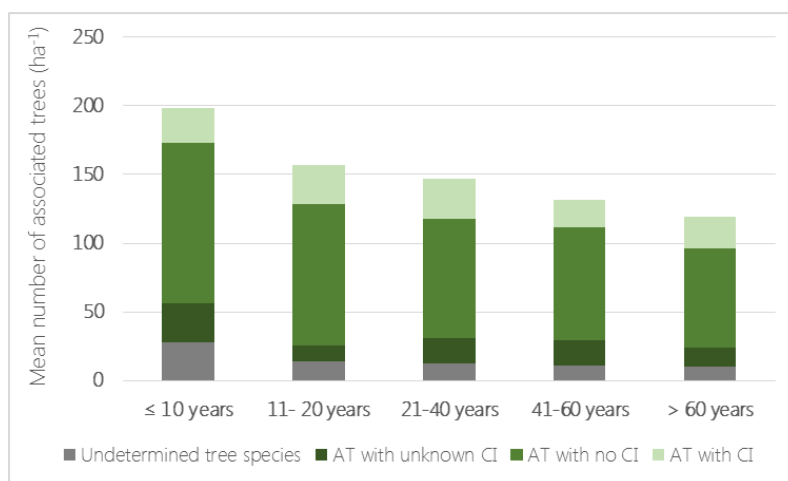
The ecological potential of Central Cameroon CAFS however depends on the ATD and has to be taken cautiously. Indeed, the average tree density for the control forests sampled is ca. 650 ind ha^{-1}, in other words 6 times higher than that of CAFS'. Furthermore, unlike C storage, the simplification of such CAFS is to lead to a drastic reduction in this fragile species conservation potential. Saj and al. (2017b) showed the number of associated species declined by more than 70% and alpha diversity indices by 50% when ATD passed from $\geq$ 200 ind ha^{-1} to < 50 ind ha^{-1}. CAFS' conservation potential

depends on their multifunctional nature: trees that are preserved have one or several uses (Jagoret et al, 2014). If the use of the associated tree community (ATC) is only referred to cocoa growing (shading and soil fertility upkeep) as is the case low ATD systems, local and traditional use of the ATC is to disappear. Since most of these traditional uses make sustainable use of endangered/vulnerable tree species, the long-term conservation abilities of CAFS seem on the long run to rely on extensive and multifunctional farm management schemes.
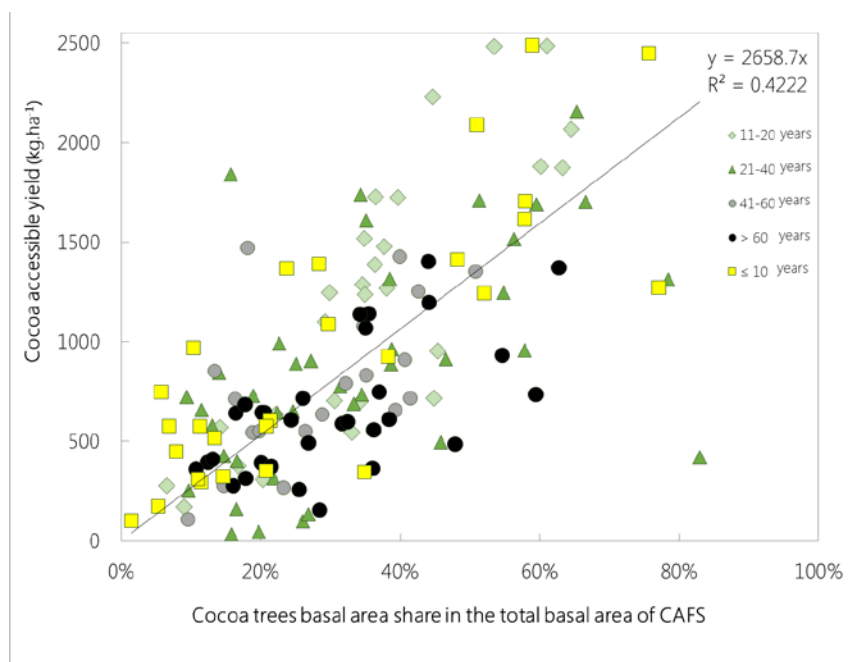
2.3. CAFS cocoa production

Cocoa accessible yields were estimated according to a methodology as developed by Jagoret (2011). Precision about this methodology and the definition of "accessible yield" can be found in Saj et al. (2017b). The method set up by our team distinguishes itself from those usually reported in research. Indeed, the figures obtained this way correspond to maximum yields that could be obtained in Central Cameroonian CAFS by providing an idea of the real *in itinere* productive potential while getting rid of some seasonal management practices (such as weeding and input uses) - which may greatly influence the CAFS final performance and varies substantially according between years and farmers. We argue that CAFS agronomical performances should be assessed this way if they are to be fairly compared with monospecific - input intensive – systems.

Cocoa productivity in CAFS depends on inter- and intra- specific competition. We appraised the competition between the cocoa stand and the ATC using the concept of basal area. Even if not exhaustive, this approach permitted us to build a simple indicator which highlights the relationships between cocoa yields and interspecific competition levels from real on-field data (Fig 3; Saj et al., 2017b).

Figure 3

Linear regression between accessible yields and cocoa stand' basal area share in cocoa agroforestry systems from Central Cameroon (n=144). Colored/shaped dots indicate different age categories of the systems.

Our results show that interspecific competition negatively alters cocoa production but they also underline that it is far from explaining it solely (Fig 3). Yearly accessible yields were found to vary from 100 kg ha^{-1} up to 2490 kg ha^{-1} according to the share the basal area the cocoa stand takes. But the yields also clearly depend on age of the system: few CAFS seem able to produce more than 1000 kg ha^{-1} after 40 years old (Fig. 3 Saj et al., 2017b). ATC basal area (BA) varies according to the species and the number of trees ATC comprise, which participate to the variability observed. This raise the question of optimum ATC composition and ATD that are still be found according to the yield objectives that could be set up by the farmers. The accessible yields found also show that a better day-to-day management (potentially including synthetic inputs) of the stands is probably to greatly improve actual yields, which are regularly reported between 250 and 750 kg ha^{-1}.

Finally, despite a very large sampling effort (3 different sampling zones, ca. 150 plots studied; cf. Saj et al., 2017a,b) we could not identify CAFS of over 60 years old with a cacao BA share higher than 50%. To our opinion, such a failure indicates that the BA ratio used may reveal an interesting indicator for the sustainability of CAFS, which would exhibit a threshold beyond which cocoa cultivation may not be undertaken on the very

long term. We suggest further investigations on that topic and hypothesize that a 40% share of the cocoa BA is to enable long term cocoa production in CAFS.

3. Ecosystems services interactions

3.1. Conservation of forest trees and carbon storage

In Central Cameroonian CAFS, carbon (C) storage and conservation of forest trees are two services more or less directly related to ATD. Therefore, it is not surprising to observe a positive relationship between tree species richness and C content in live tree biomass (Fig 4). The distribution of points around the regression line of the figure 4 also shows that, for a given C storage, such as 100 Mg ha^{-1} of C, a gradient of specific richness levels can be found. This distribution allows to look for most favorable situations in order to try to maximize the synergy between the two services studied.

However, this relationship is not as simple as it seems as underlined by the poorly satisfying R^2 observed. Species richness doesn't account for the nature and size of the trees within the ATC: compared to the average, some CAFS can comprise an ATC characterized by low ATD but large sized trees (eg. square dots, Fig 4) while others CAFS can be characterized by a high ATD with small sized trees (eg. triangle dots, Fig 4). Such cases demonstrate that some ATC structures and compositions may play a significant role only for one of the two services studied. Hence, it appears that some room exists, on a field management point of view, to dissociate the two services.

Finally, given the fact ATD in CAFS is rather low compared to that of forests (cf. section 2.2), it underlines the possible practical inefficiency of intended politics toward the coupling of these two services – most probably at the expense of conservation.
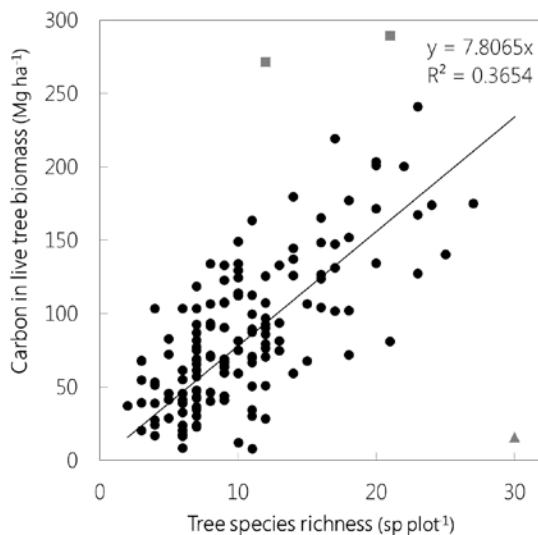

Figure 4

Regression between carbon storage in tree live biomass and species richness in cocoa agroforestry systems from Central Cameroon (n=144). Square dots indicate plots which ATC is characterized by low ATD but large sized trees. Triangle dots indicate plots which ATC is characterized by a high ATD with small sized trees.

3.2. Cocoa yield vs carbon storage

Cocoa accessible yields are clearly negatively correlated to C storage. Yet, this relationship in not linear and exhibits a high variability in the CAFS studied (Fig 5a). On the one hand, it appears that the lower the C storage the higher yield variability. Furthermore, yields lower than 1000 kg ha^{-1} seem to be achievable rather regardless of the C storage. On the other hand, very high yields (>1500 kg ha^{-1}) do not appear reachable above 100-150 t ha^{-1} of C storage. Besides the fact that they can't be reached in too crowded systems, it also appears that such high yields can only be provided by CAFS younger than 40 years old (Saj et al., 2017b).

However, most of the CAFS studied fell in an intermediate situation. The variability of the relationship between C storage and cocoa yield in our CAFS is both depending on the cocoa stand features (age, structure, density; cf. Jagoret, 2011) and on ATC features (ATD, tree size, species richness, functional use; cf. Saj et al. 2013). It thus appears that some leeway exist and could be mobilized to reconcile the two services mentioned despite an acknowledged negative relationship. Yet, technical levers are still to be better studied/understood to achieve this goal.

Finally, some of the plots sampled highlight specific cases (dots outside the grey area Fig 5a) which tend to support the fact that under some conditions the boundaries of the trade-off between C storage and yield could be overstepped and/or reached (Rapidel et al. 2015). These special cases are related either (i) to the unusual presence of several very large trees in plots with a low ATD (square dots, Fig 5a), or (ii) in the presence of high density of small trees (triangle dots, Fig 5a).

3.3. *Cocoa yield vs. conservation*

Unsurprisingly, species richness in the studied CAFS is also negatively correlated with accessible cocoa yield (Fig 5b). As for C storage, a large array of species richness can be found for a given level of yield. Yields over 1000 kg ha^{-1} seem unreachable for species richness above 10 per plot. However, it seems possible to achieve yields in the range of 750 kg ha^{-1} for high species richness (20 and 23 species per plot).

A comparable reflection to the one carried out on C storage may be undertaken in order to check for the least "bad" trade-offs between species richness and yield. Yet, the figure 5b underlines that those trade-offs seems stronger for high species richness than for high C storage. Furthermore, the notion of use the components of the ATC is to properly take into account in this case. Indeed, as demonstrated by Jagoret et al. (2014), the choice of associated species is carried out by farmers depending on the uses and benefits they want to get from them. The most traditional CAFS are the richest and most diverse systems whilst often being the less productive in cocoa. On the contrary, farmers focusing on the shading function of the ATC thoroughly select ATC composition in order to get higher yields, which higher income is to compensate for the by-products that they do not provide anymore.
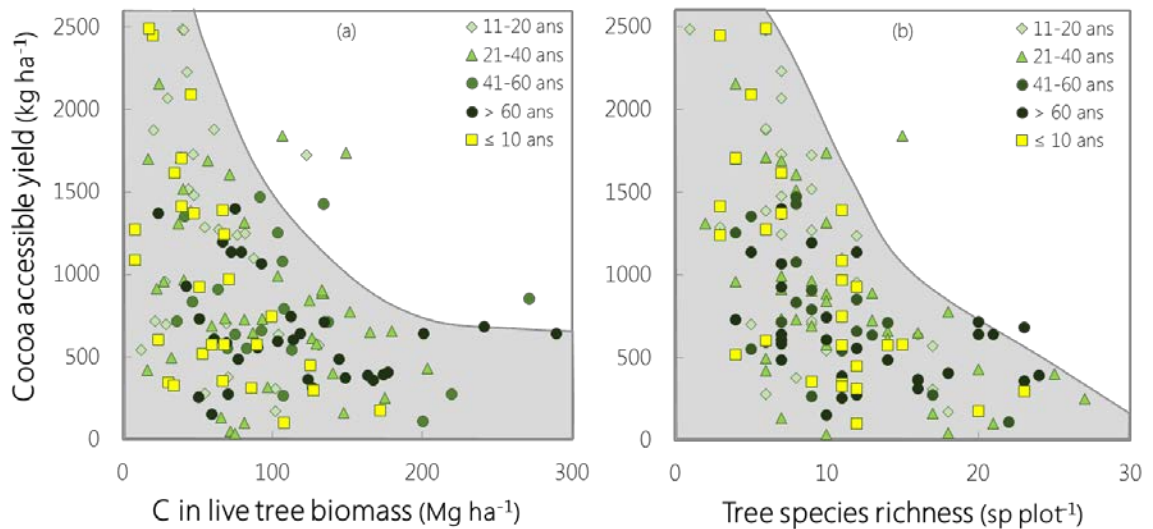

Figure 5

Evolution of cocoa accessible with (a) live trees carbon (C) content; (b) tree species richness. Colored/shaped dots indicate different age categories of the systems. The grey area represents the space in which (a) 96% and (b) 98% of the 144 studied cocoa agroforestry systems occur.

4. Conclusions and perspectives

The analysis of the relationships between the services studied shows that C storage and conservation can be synergistic, while being both being antagonistic to accessible yields. It also shows that these relationships are not compulsorily linear. In many CAFS it seems that neither a synergy nor or trade-off is observed. From a practical point of view the studied CAFS could be categorized in three groups according to the levels of the three services they provide:

(Group 1) Rather "simple" CAFS with yields over 1000 kg.ha^{-1}, that would provide on the long-term low levels of species richness and C storage reaching at most 80-100 t ha^{-1} and 1-10 sp ha^{-1} respectively. These systems are to be transformed after 30-40 years if to continue producing cocoa.

(Group 2) CAFS characterized by an ATD higher than in group 1 resulting in greater competition with the cocoa stand yet allowing yields between 750 and 1000 kg ha^{-1}. This group exhibit rather equivalent species richness as group 1 but would able to produce cocoa on a longer time span, achieve long-term storage of higher C levels over 100 t ha^{-1}, or even 150 t ha^{-1}.

(Group 3) Heterogeneous and complex CAFS. This group seems the most promising with regard to the levels of C storage and conservation provided. Best producers of this group can exhibit accessible yields between 500 and 750 kg ha^{-1} while comprising 15 different tree species and storing more than 150 t ha^{-1} of C. Yet this group also includes the CAFs where no synergies are observed between species richness and C storage while low yielding and which could be gathered in a fourth group (cf. poster attached to this article).

ATD reduction is demonstrated to alter consistently alter ATC functional traits/groups that are to alter cAFS functioning and ATC diversity of uses (Saj et al., 2017a). We argue that a "rough simplification" as often proposed for CAFS from the group 3 is most likely to impair traditional cAFS ecosystem sustainability and if applied to group 2 is to impair the systems long term sustainability. We argue that cacao productivity in these systems can be raised combining consistent rejuvenation and densification practices with site-specific intensification in terms of inputs and/or manpower. Such intensification would not compulsorily include ATD reduction and therefore would, at least partly, facilitate the preservation of some of the ecosystem services supported.

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