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Agriculteurs et artisans transformateurs, l'autre facette des filières d'huile de palme / Smallholders and artisanal millers: the least known actors of the global oil palm sector.
Coordonnateurs : Sylvain Rafflegeau, George N. Curry

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ARTICLE DE SYNTHÈSE / REVIEW ARTICLE — OPEN ACCESS

Promoting oil palm-based agroforestry systems: an asset for the sustainability of the sector

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Abstract – Until recently, the massive development of industrial and smallholder oil palm (*Elaeis guineensis* Jacq.) plantations has generally been conducted according to the monocrop model. However, alternative cropping systems have emerged, based on more diversified systems that combine various crops within the oil palm plots. By giving this plant a status equivalent to that of a tree, these practices correspond to agroforestry systems. In the present study, 39 agroforestry systems were identified worldwide through a preliminary literature review, a review of NGO websites and expert surveys. Our results reveal five different types of oil palm agroforestry systems: (i) associations with livestock during the production phase of the oil palm; (ii) traditional African palm and food crop systems sustained over time; (iii) associations with food crops during the juvenile phase of the oil palm; (iv) systems developed by family farms that permanently associate other plants; and (v) prototype designs developed by research institutions, often at the request of local agricultural enterprises. The spatiotemporal description of these systems enabled us to identify associated ecosystem services. Building on various proposals of biodiversity insertion in a monoculture to convert it into an agroforestry system, the present study offers new perspectives for the sustainable development of palm oil production.

Keywords: oil palm / agroforestry / agroecosystem / diversification / resilience

Résumé – Promouvoir l'agroforesterie à base de palmiers à huile : un atout pour la durabilité de la filière. Le développement massif des palmeraies industrielles et villageoises s'est réalisé en suivant un dispositif de plantation en culture pure du palmier à huile (*Elaeis guineensis* Jacq.). Cependant, divers systèmes de culture alternatifs ont émergé, dans lesquels sont associés des cultures et des animaux à diverses phases du cycle de culture du palmier. En attribuant à cette plante un statut équivalent à celui d'un arbre, ces systèmes correspondent à des systèmes agroforestiers. Dans cette étude, trente-neuf systèmes agroforestiers à base de palmier à huile ont été identifiés dans le monde à partir de la littérature, de la consultation de sites internet et d'enquêtes. Cinq types de systèmes agroforestiers ont émergé : i) l'agropastoralisme, correspondant à l'introduction d'élevage pendant la phase productive du cycle de culture du palmier ; ii) l'agroforesterie traditionnelle africaine à base de palmiers et de cultures vivrières ; iii) l'agroforesterie temporaire avec des cultures vivrières en palmeraie juvénile ; iv) l'agroforesterie permanente avec des cultures pérennes ; et enfin v) des prototypes de systèmes agroforestiers à base de palmiers sélectionnés, conçus par des institutions de recherche et développement, souvent à la demande d'entreprises agricoles ou d'agro-industries. La description spatio-temporelle de ces systèmes a permis de mettre en évidence les services écosystémiques rendus par les espèces associées. Diverses perspectives de développement de l'agroforesterie sont discutées en tant qu'alternative aux palmeraies monospécifiques, pour introduire de la biodiversité dans des territoires historiquement spécialisés en élaeiculture, pour initier du développement élaeicole en zones suboptimales, ou encore pour s'adapter au changement climatique.

Mots clés : palmier à huile / agroforesterie / agroécosystème / diversification / resilience

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1 Introduction

Until the 19th century, the harvesting of oil palm, *Elaeis guineensis* Jacq., in humid, tropical Africa consisted of gathering bunches of palm fruit in subspontaneous palm groves, extracting the oil by washing with water and then skimming (Hartley, 1988). These subspontaneous palm groves, referred to as "wild palm groves", corresponded to human clearings spontaneously recolonized by palm trees or sown by broadcasting, as well as low-density palm stands (about 30 plants/ha) in food crop plots under crop fallow rotation. In the 19th century, settlers invested in the first plantations of palm trees of local origin (Cochard *et al.*, 2001), planted in rows, as well as in oil mills. In the 20th century, genetic improvements led to selected planting material that provided bigger fruit and oil yields, while technological advances increased the processing capacity of oil mills (Ndjogui *et al.*, 2014). Thus, the first private agro-industries emerged in Africa and Asia in areas where the palm tree had been introduced. At Independence, international donors financed oil palm development plans there by supporting public agro-industries developed for this purpose. These agro-industries consisted of industrial palm plantations and industrial oil mills with large processing capacities (20–60t/h), supplied in part by "smallholders" who cultivated their oil palm "smallholdings" (Cheyns and Rafflegeau, 2005). These palm plantations were planted with selected *Tenera* palms according to the equilateral triangular design with 9 m spacing. This monocrop plantation system was consequently adopted by the majority of oil palm farmers, including the beneficiaries of development projects in Africa and Southeast Asia. Since then, the massive development of industrial and smallholder oil palm plantations has been mainly based on private investments and reproduces this dominant spacing design. This monocrop plantation spacing design, generally with a density of 143 or 160 plants/ha (PalmElit, 2019), has also been introduced in Latin America within both industrial plantations and smallholdings.

Family farms and local agricultural enterprises account for 41% of the world's cultivated palm area at this time (Rafflegeau *et al.*, 2014). Some farmers implement oil palm cropping systems by combining them with other crops. There are two types of associations: one consists of associating food crops during the juvenile phase of the palms, and the other, specific to Africa, consists of cultivating isolated palms in plots under crop fallow rotation according to a traditional design that predates oil palm development plans. By giving this plant a status equivalent to that of a tree, these cropping systems correspond to agroforestry systems (AFS) (Torquebiau, 2007). These AFS produce a diversity of agricultural products that meet farmers' objectives and needs, and provide a range of ecosystem services (Seghieri and Harmand, 2019). In a context of climate change, increasing demand for palm oil, societal demand to reduce the environmental impacts of palm oil development (Rival and Levang, 2013), and reduced availability of optimal land for this crop (Pirker *et al.*, 2016), these AFS offer alternative cropping systems that are more resilient and better adapted to this context

By identifying the diversity of experiences with oil palm AFS around the world, this article aims to provide a better understanding of agroforestry spacing design, the actors who implement them, and the choices that lead these actors to seek alternatives to the dominant monocrop spacing design. This work has led to the identification and characterization of AFS on the basis of a typology of existing spacing designs. Their analysis allows us to outline the development perspectives offered by these AFS for the oil palm sector.

2 Methodology

To carry out this study, we adapted the innovation tracking method of Salembier *et al.* (2016), in which the first three steps allow us to identify the actors using the snowball method and to describe their innovations *via* semi-structured interviews. The next step consists of a multi-criteria analysis of the descriptors associated with each interview.

The implementation of the method consisted in (i) identifying AFS in articles, reports, NGO websites and interviews with stakeholders in the sector (*e.g.*, PalmElit and CIRAD); (ii) identifying the description model of an AFS; (iii) proposing a characterization typology of AFS to highlight their diversity; and (iv) defining a description model of ecosystem services. The analysis consisted in comparing the ensuing description of the AFS on the basis of these three models.

2.1 Description of an agroforestry system

The description model of an AFS was based on the representation of a system proposed by systemic modeling, which describes it in the form of interdependent interacting systems (Le Moigne, 2006). The systemic formalization obtained (Fig. 1), using concepts from agronomy and agro-economics, was then reformulated in the form of a hierarchical vocabulary of AFS descriptors. Describing an AFS thus consists in associating the data collected with the corresponding descriptors.

2.2 Characterization of the diversity of agroforestry systems according to a typology

To describe the diversity of AFS, we built a typology that combines two criteria: the initiator of the AFS and the characterization of the agroforestry phase of the cropping system. The initiator of the AFS may be an actor in R&D or in agricultural production. Based on the farm typology proposed by Marzin *et al.* (2014), which distinguishes several types of agriculture as a function of the organization of work, adapted to the context in which it was used (Baron *et al.*, 2017), three types of actors were defined: the R&D institution, the family farm and the farm enterprise.

The agroforestry phase of the cropping system was characterized by its duration and the stage of the cycle of the oil palm crop in order to distinguish three different situations: (i) temporary agroforestry at the beginning of the cycle (immature palms); (ii) temporary agroforestry at the end of the cycle (mature palms whose crowns are at least 2 m high); and (iii) permanent agroforestry (during the entire oil palm crop

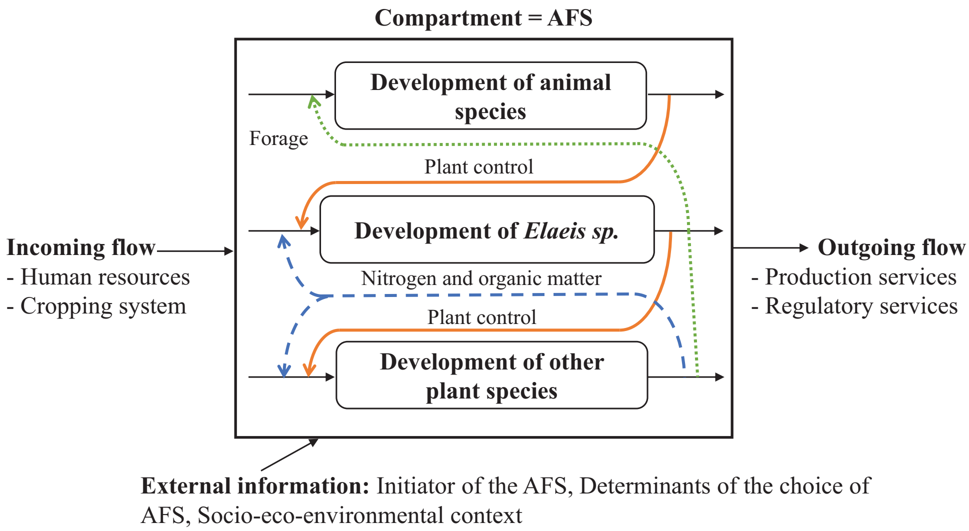

Fig. 1. Model describing an oil palm agroforestry system (AFS), built using the systemic approach (Le Moigne, 2006).
Fig. 1. *Modèle de description d'un système agroforestier à base de palmiers (SAF), élaboré selon l'approche systémique (Le Moigne, 2006).*

cycle). Two cultivation practices were taken into account for these three situations: the regularity of the spacing design (regular *vs.* irregular), and the origin of the planting material (local/diverse origin *vs.* selected).

2.3 Description of ecosystemic services

Ecosystem services (ES) represent the benefits provided by ecosystems to human societies. The services mobilized by AFS were classified according to the Common International Classification of Ecosystem Services (CICES) (Haines-Young and Potschin, 2018). We adopted the concept of the ecosystem services functional motif (ESFM) in order (i) to represent the spatial organization of an agroforestry palm grove and its temporal evolution in the presence of other plant and/or animal species; and (ii) to represent the interactions between species in the plot including ecosystem services of interest to the stakeholders). The EFSM is defined as the smallest spatial unit of a cropping system in which all targeted ecosystem services are represented by the species present in the same proportion as on the whole plot (Raffegeau *et al.*, 2019). Because our goal was to highlight the targeted services recognized by the developers, only those services cited in the literature and mentioned during interviews were taken into account.

3 Results

A total of 39 AFS were identified worldwide (Masure *et al.*, 2021, 2022).

3.1 Oil palm agroforestry systems across the globe

Figure 2 presents a matrix representation of the AFS, described according to their typology. Five types of AFS can be distinguished, each with its own type of actor. The first type of AFS, referred to as R&D (Fig. 2), includes all actors from R&D institutions. These actors generally set up permanent AFS that associate perennial crops with palms, regardless of the continent considered. They tend to transform the 143 palms/ha spacing design, conducting trials at lower palm densities using various systems (*e.g.*, double twin rows or intensive thinning). AFS trials are also carried out at various periods of the palm tree cycle. Planting material is selected and planted in a regular pattern.

The following three types of AFS, *i.e.*, FOOD CROPS, PASTO and PERM, were developed by family farms and agricultural enterprises. These actors choose selected planting material and plant it in a regular design (square or triangle) with a spacing of 8 to 9 m between palms, corresponding to densities of 143 to 160 palms/hectare. Beyond these similarities, these three types of AFS can be distinguished from each other by the temporality of the AFS during the palm crop cycle, thus highlighting where the producer's interest lies. The second type of AFS, referred to as FOOD CROPS (Fig. 2), includes actors who establish temporary AFS at the beginning of the palm crop cycle. These AFS are found all over the world. Most of the crops grown in association with the palms during their juvenile phase are food crops (maize, groundnuts, cassava, plantains, etc.) intended for self-consumption and/or sale. The third type, called PASTO (Fig. 2), is made up of actors who install temporary AFS at the end of the palm growth cycle, when the palms have become large enough not to risk being damaged by livestock. This is the only type of AFS commonly implemented by agribusinesses. The fourth type, referred to as PERM (Fig. 2), includes farmers who establish permanent AFS in Latin America and Southeast Asia. Family farmers tend to innovate without external advice to implement permanent AFS on their farms.

The fifth type of AFS, known as TRAD (Fig. 2), is made up of family farms that mainly establish permanent AFS using non-selected planting material planted in an irregular pattern, which differentiates them from R&D and PERM. While the first four types are present on all continents, the latter exists uniquely in Africa. Only used by family farms, TRAD AFS continue to exist. There are two sub-types: low-density

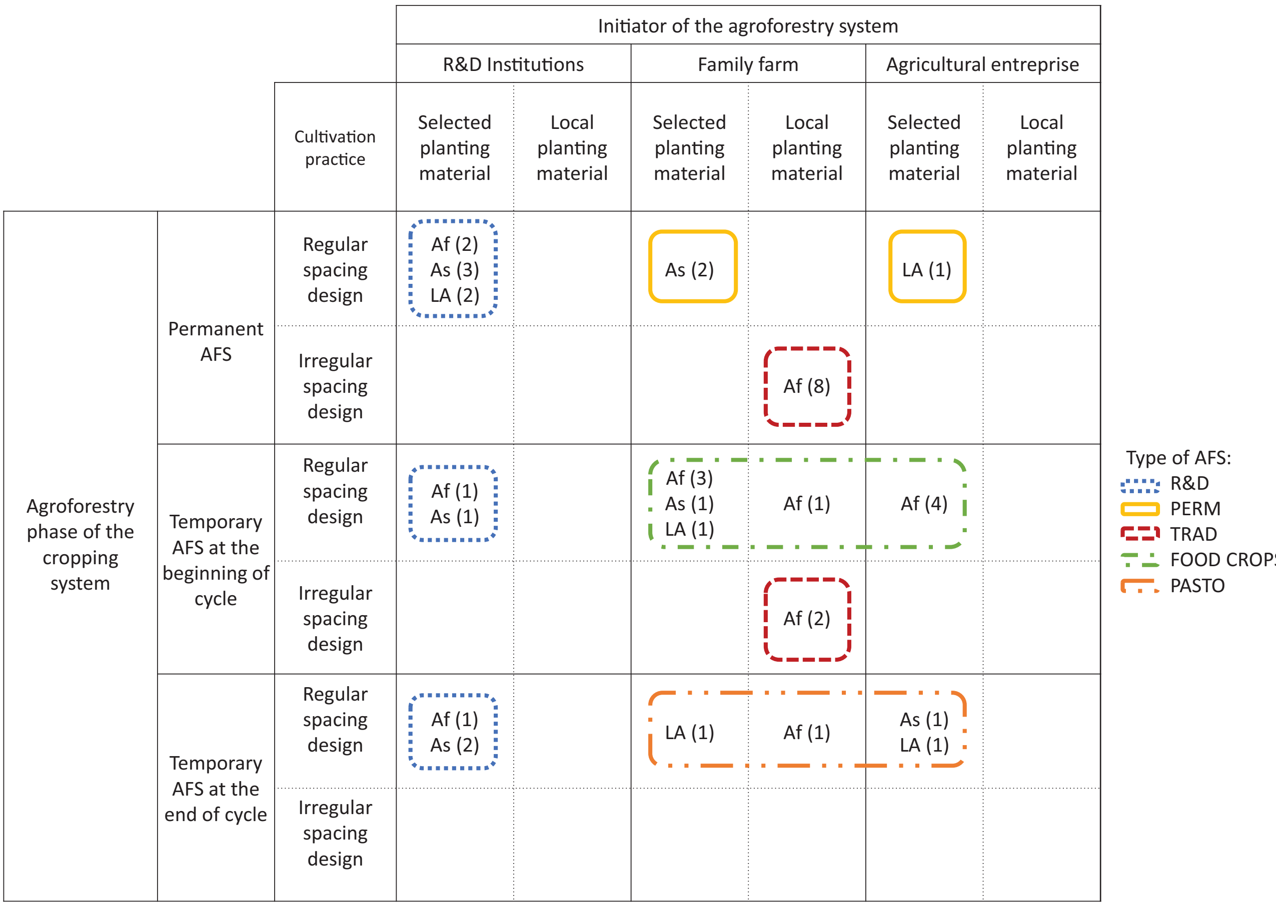

Fig. 2. Number and type of oil palm agroforestry systems (AFS) identified per continent. In order to simplify the presentation of the results, the type of planting material is entered in columns. Af, As and LA correspond, respectively, to Africa, Asia and Latin America.
Fig. 2. *Nombre et type de systèmes agroforestiers à base de palmier à huile (SAF) recensés par continent. Pour simplifier la présentation des résultats, le type de matériel végétal planté est porté en colonne. Af, As et AL correspondent respectivement à Afrique, Asie et Amérique latine.*

permanent agroforests (30–50 palms/ha) under crop fallow rotation (Madelaine *et al.*, 2008), and high-density palm groves harvested for palm wine (Yemadje *et al.*, 2012).

3.2 Benefits of oil palm agroforestry systems for farmers

Some 28 ecosystem services (ES) have been identified in the AFS (Masure *et al.*, 2021). Thirteen ecosystem services fall under provisioning and belong to seven classes, *i.e.*, nutrition, fiber, energy, medicine, water quality, production and animal feed. Among these classes, the largest number of services concern human nutrition (*i.e.*, 36 AFS concerned) and, in particular, crops planted for their seeds/fruits (maize, groundnut, banana), their tubers (cassava, sweet potato), or their leaves (*e.g.*, leafy vegetables). The remaining 15 services provided by AFS are regulatory and are divided into ten classes (*e.g.*, erosion control, water regulation, windbreak). The large number of regulatory services identified in the AFS (101) highlights the richness and diversity of the services provided, other than production.

Many species other than palm are present in the AFS. Table 1 shows the plant species most commonly used to provide the eight main services, each of which is present in at least 25% of the AFS. Oil palm farmers justify the attractiveness of agroforestry by the diversity and distribution of production and income over the year. Moreover, compared to a monocrop palm plantation, interaction between species reduces operational costs. Weed control is based on the use of cover crops, on livestock grazing to regulate spontaneous vegetation, and on shallow tillage for associated food crops. Pest management is ensured through the introduction of service-providing plant species and bio-regulation. Finally, soil fertility can be improved in the short term by the installation of nitrogen-fixing legumes, the incorporation of residual organic matter from other crops and animal waste, and the deep rooting of certain plants that improve soil structure. This fertility is maintained over the long term by permanent soil cover, thus fighting erosion. Figure 3 illustrates the mobilization of some of these species over time within the TRAD, PASTO and R&D AFS.

Table 1. Main plant species used to provide the key ecosystem services in the oil palm agroforestry systems.
Tableau 1. *Espèces végétales majoritairement utilisées pour rendre les principaux services écosystémiques dans les systèmes agroforestiers à base de palmier.*

Ecosystemic service	Total number of species providing this service	Main species	Number of AFS using the species
Fruit harvesting	50	*Zea mays*	16
		Arachis hypogaea	13
		Musa sp.	12
Tuber harvesting	4	*Manihot esculenta*	10
		Ipomoea batatas	5
Timber	25	*Gliricidia sepium*	2
		Inga edulis	2
		Peronema cunescens	2
		Ormosia arbórea	2
Prevention and reduction of erosion	38	*Mucuna* sp.	5
		Cajan cajanus	3
		Pueraria phaseloïdes	3
Regulation of the hydrological cycle	30	*Mucuna* sp.	3
		Gliricidia sepium	3
		Cajan cajanus	3
Weed control	27	*Mucuna* sp.	3
		Zea mays	2
		Pueraria phaseloïdes	2
Residual organic matter	33	*Arachis hypogaea*	7
		Vigna unguiculata	4
Complementarity of access to nitrogen	25	*Arachis hypogaea*	6
		Gliricidia sepium	4
		Vigna unguiculata	4
		Cajan cajanus	4

4 Discussion

General books on the oil palm (*e.g.*, Hartley, 1988; Jacquemard, 2013; Corley and Tinker, 2015) indicate that the oil palm AFS known to agronomists are of the following types: TRAD, FOOD CROPS in immature palm groves, and PASTO under mature palm groves. These books provide various examples of AFS, without describing their diversity. Our study, on the other hand, reveals the existence of other agroforestry systems of selected palm plantations according to a regular spacing design.

4.1 Palm agroforestry systems as alternatives to monocrop palm plantations

Extension and research services involved in oil palm development recommend that farmers establish a monocrop palm plantation with selected palms planted in an equilateral triangle, and then apply mineral fertilizers to them. This recommendation has contributed to the economic success of many stakeholders in the sector. The general literature on oil palm (Jacquemard, 2013; Corley and Tinker, 2015) recommends establishing monocrop palm plantations with a legume cover crop, and suggests using food crops in the juvenile phase instead of the legume cover crop as an option for farmers under economic or family labor constraints. The introduction of long-cycle food crops in an immature monocrop palm plantation results in delayed production and a decrease in palm yields over the long term (Rafflegeau *et al.*, 2010; Koussihouèdé *et al.*, 2020). The implementation of the more recent PERM- and R&D-type AFS thus requires support for the innovation process based on the monitoring of prototypes to confirm the choice of species and design, as well as the maintenance of soil fertility. In the case of TRAD-type AFS, the need for support in agro-ecological intensification is primarily related to the introduction of selected planting material. Finally, the PASTO-type AFS, which have been in existence for a long time, require support for the capitalization and dissemination of knowledge.

Economic analyses of the viability of AFS are seriously lacking in the literature. Nevertheless, the AFS established and maintained by farmers are a viable alternative to the dominant monocrop palm plantation design. By enriching the biodiversity cultivated in oil palm cropping systems in this way, many agroecological transition paths are open to farmers, both for new palm plantations and for the replanting of old palm plantations. This strong, deep-rooted agroecology, which relies on the introduction of biodiversity into cropping systems

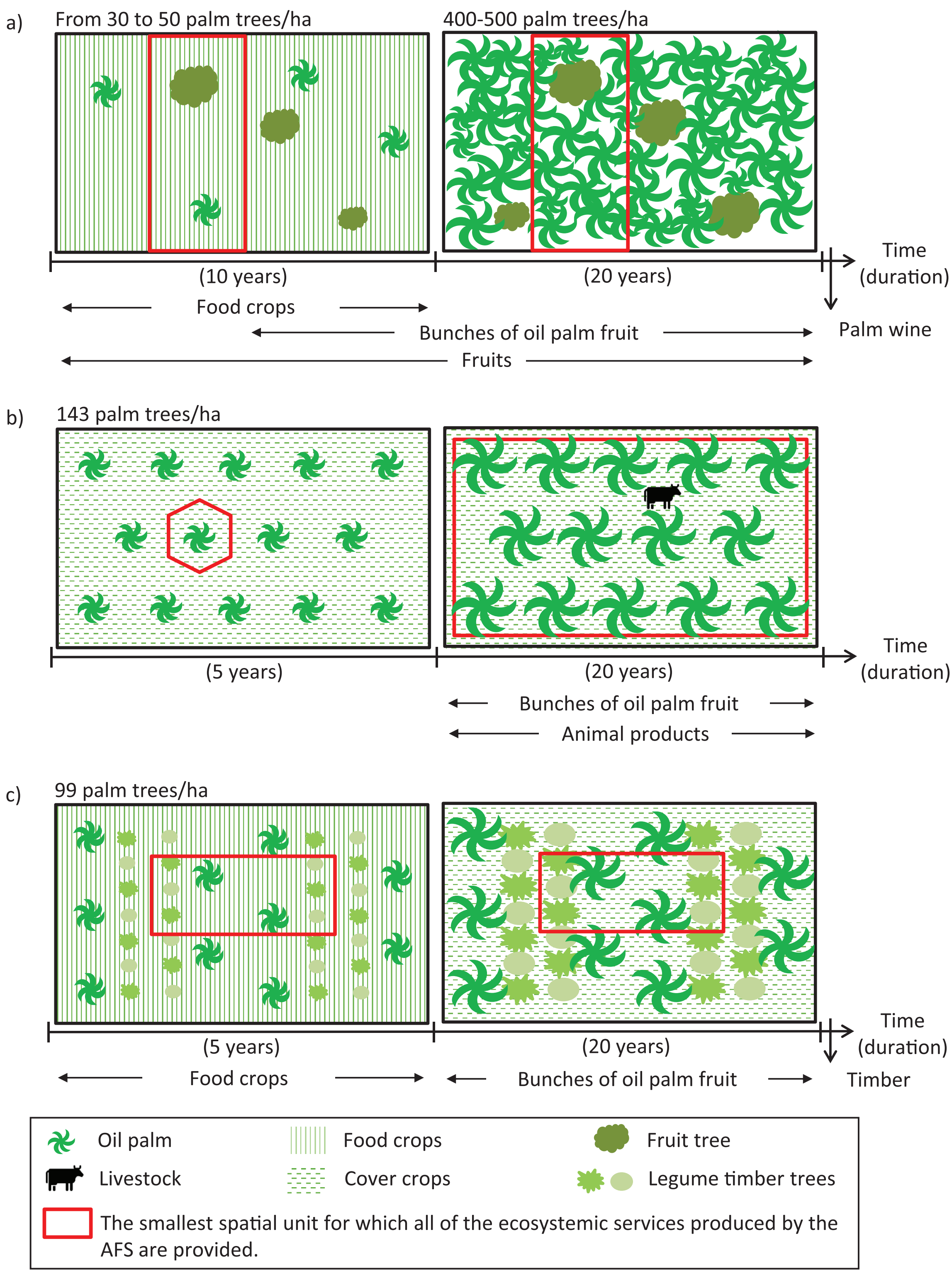

Fig. 3. Illustration of oil palm agroforestry system (AFS) diversity through three examples of AFS: (a) traditional (TRAD) adopted for palm oil production followed by palm vine and alcohol production; (b) pastoral (PASTO) based on the industrial model that integrates livestock; (c) R&D in double twin rows of oil palms associated with nitrogen-fixing species that produce timber.

Fig. 3. *Illustration de la diversité des systèmes agroforestiers à base de palmier à huile (SAF) par trois exemples : a) traditionnel (TRAD) exploité pour la production d'huile de palme, puis d'alcool de palme ; b) pastoral (PASTO) d'après le modèle industriel exploitant du bétail ; c) recherche et développement (R&D) en doubles lignes jumelées de palmiers associés à des espèces ligneuses fixatrices d'azote, également exploitées pour le bois d'œuvre.*

(Duru *et al.*, 2014), targets ES that fall under provisioning or regulation. These services can help (i) to overcome the financial constraint of no income during the three years of the immature phase; (ii) to diversify crop and livestock production throughout the cycle in order to secure income, maintain regular plot maintenance and, ultimately, be more economically resilient with respect to markets and climatic hazards; and (iii) to increase the ecological resilience of the agroecosystem, especially in marginal areas where adaptation to climate change is imperative.

Each type of stakeholder has its own operating opportunities and constraints. After initiating PASTO-type AFS, the agro-ecology trend has gradually led palm agribusinesses to introduce cultivated biodiversity into their industrial plantations through the establishment of service-providing plant species. Family farms and agricultural enterprises tend to combine other crops in their AFS. Consequently, different strategies for the establishment of AFS can be considered depending on the agronomic, economic and environmental objectives of each one.

4.2 Introducing biodiversity in areas specialized in palm cultivation

The "*Nucleus-Estate & Smallholders*" development model adopted in Indonesia and Malaysia is based on the establishment by agribusiness of industrial palm plantations and "plasma" plantations for smallholders, all monocrop, accompanied by high-capacity oil mills (40–60 t/h). This model has led to the conversion of forests into a homogeneous "sea of palms". To reintroduce biodiversity within this type of landscape, some authors, *e.g.*, Zemp *et al.* (2019), propose to introduce islands of biodiversity within the plantations. Other authors, *e.g.*, Luke *et al.* (2020) and Woodham *et al.* (2019), propose to maintain ecological corridors such as riparian zones along waterways or elsewhere in the palm estate to improve connectivity between protected areas, thus preserving the mobility of wildlife species within these territories (Ancrenaz *et al.*, 2021).

Generally speaking, cultivated biodiversity can be integrated at the outset without renewing the plantation or changing its density. Ayob and Kabul (2009) and Tohiran *et al.* (2019) thus propose to integrate livestock activities and the cultivation of cover and service-providing crops at the end of the cycle that correspond to the PASTO-type AFS. According to these authors, this system would be relatively quick and easy to integrate into palm plantations, even industrial ones. Budiadi *et al.* (2019) and Mathur *et al.* (2017) suggest intercropping perennial sciaphilous crops between the rows and under the palms, *i.e.*, PERM-type AFS. Gawankar *et al.* (2018) and Slingerland *et al.* (2019) suggest combining species at the beginning of their cycle while the palm is in the juvenile stage, like in the FOOD CROPS-type AFS model. Finally, Miccolis *et al.* (2019) recommend adapting the palm planting design (double twin rows or intensive thinning) in order to favor the introduction of other perennial species that will provide provisioning (production) and/or regulatory services, *i.e.*, R&D-type AFS).

Regardless of the solution chosen, reintroducing biodiversity into areas specialized in palm cultivation requires that farmers become aware of the potential value of the services provided by associated species. These services can not only enhance the value of their farms, but can also have a positive impact on their sustainability through the diversification of production (food crops, forest products), the improvement of soil fertility (nitrogen fixation, organic matter), erosion control and the regulation of the hydrological cycle, as well as the biocontrol of weeds and pests. In the case of the implementation of FOOD CROPS-type AFS, however, care must be taken to avoid innovations that could turn into a disservice to soil fertility maintenance and palm fruit production.

4.3 Development perspectives

Oil palm agroforestry offers new development perspectives that tend to favor cultivated biodiversity within the plots. Compliance with the sustainability criteria of the RSPO standard (2021) leaves only two possible precedents for establishing an AFS: a monocrop palm plantation at different stages of its cropping cycle, or an agricultural plot under cultivation or fallow. In both cases, the transition to an AFS can be made by eliminating the entire existing cover, or by transforming the existing cover into a palm AFS.

Agroforestry based on oil palms can be envisaged both in the current oil palm production areas, as well as in new cultivation zones, including suboptimal zones in terms of climate. The reduction of palm density and the establishment of judicious associations with species that complement each other in terms of access to resources make it possible to envisage higher yields per plant than those that would be obtained in a monocrop palm plantation grown under the same conditions. In suboptimal zones like southern Benin where the water deficit is severe, very few bunches of palm fruit reach maturity during the palm's low production season. It would therefore be advantageous to include crops harvested during the low fruit production season in palm AFS.

According to this same principle of associations of species that complement each other in terms of access to resources, agroforestry offers possibilities of adaptation to climate change, compared to the same species cultivated in monocrops. Family farms and the agricultural enterprises of local investors are the major entities capable of setting up and managing complex AFS, and of capitalizing on all of the products resulting from AFS through sale and self-consumption. Family farms have easier access to scattered and small landholdings, even in populated areas, unlike agribusinesses.

Many trials and experiments with oil palm-based AFS have already been conducted, but few papers have been dedicated to this topic. Promotion of successes, failures and lessons learned, critical and detailed analyses of the prototypes being tested (Miccolis *et al.*, 2019; Koussihouèdé *et al.*, 2020) are still lacking. The same is true for studies concerning the choice of associations between species and designs. This is the case for the AFS prototypes with palm and cocoa trees, tested in the Central region of Cameroon, in which the cocoa tree is severely affected by competition for access to water and soil resources, more or less rapidly depending on the richness and depth of the soil and the proximity of a watercourse (Masure *et al.*, 2021).

5 Conclusion

While monocrop palm plantations planted in equilateral triangles remain the most widely used spacing design in the world, our results highlight a wide diversity of oil palm agroforestry systems. We were able to identify five types of AFS planted in Africa, Latin America and Southeast Asia, which we then characterized according to their initiator and the agroforestry phase of the palm cultivation system considered.

The identification of these new types of AFS clearly shows that farmers are interested in these alternative approaches that integrate practices that are compatible with a satisfactory level of palm fruit production. The lack of dedicated economic analyses observed today, both in the literature and on the websites of development actors, remains an obstacle to a true evaluation of the economic performance of AFS.

A synchronic approach to the study of AFS would provide short-term annual results, whereas a diachronic approach would allow us to consider the transition to the most suitable type of AFS for the farmer. Identification of the ecosystem services provided by the various plant species, as presented in this paper, can be used as a decision aid for prototyping the type of AFS selected.

Societal demand for greater sustainability in palm oil production is challenging the development models adopted by the majority of agribusinesses and contract farmers due to their direct and indirect negative impacts (deforestation, biodiversity loss and land grabbing). Even though the innovations adopted within AFS currently concern only a small portion of the world's palm plantations, they have an enormous potential to diversify cropping systems, reintroducing biodiversity with the potential of restoring soil fertility, while promising better adaptation to climate change than intensive monocrop systems. These AFS offer the opportunity for family farms located in suboptimal areas to have more resilient palm cropping systems, capable of satisfying local needs in vegetable oil for human consumption.

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References

Ancrenaz M, Oram F, Nardiyono N, Silmi M, Jopony MEM, Voigt M, *et al.* 2021. Importance of small forest fragments in agricultural landscapes for maintaining orangutan metapopulations. *Frontiers in Forests and Global Change* 4: 560944. https://doi.org/10.3389/ffgc.2021.560944.

Ayob MA, Kabul MA. 2009. Cattle integration in oil palm plantation through systematic management. In: *1st International Seminar on Animal Industry, Faculty of Animal Science, Bogor Agricultural University, Indonesia*, pp. 66–73. http://repository.ipb.ac.id/handle/123456789/33810.

Baron V, Rafflegeau S, Dubos B, Flori A, Burgos R, Louise C. 2017. Exposition des plantations de palmier à huile au risque de la pourriture du cœur dans le bassin de Quevedo, Équateur. *Cahiers Agricultures* 26: 55002. https://doi.org/10.1051/cagri/2017036.

Budiadi, Susanti A, Marhaento H, Ali Imron M, Permadi DB, Hermudananto. 2019. Oil palm agroforestry: an alternative to enhance farmers' livelihood resilience. *IOP Conference Series: Earth and Environmental Science* 336: 012001. https://doi.org/10.1088/1755-1315/336/1/012001.

Cheyns E, Rafflegeau S. 2005. Family agriculture and the sustainable development issue: possible approaches from the African oil palm sector. The example of Ivory Coast and Cameroon. *Oléagineux, Corps Gras, Lipides* 12(2): 111–120. https://doi.org/10.1051/ocl.2005.0111.

Cochard B, Adon B, Kouamé R, Durand-Gasselin T, Amblard P. 2001. Intérêts des semences commerciales améliorées de palmier à huile (*Elaeis guineensis* Jacq.). *Oléagineux Corps Gras Lipides* 8 (6): 654–658. https://doi.org/10.1051/ocl.2001.0654.

Corley RHV, Tinker PB. 2015. The oil palm, 5th ed. Chichester, London (UK): John Wiley & Sons, pp. 654–658. https://doi.org/10.1002/9781118953297.

Duru M, Fares M, Therond O. 2014. Un cadre conceptuel pour penser maintenant (et organiser demain) la transition agroécologique de l'agriculture dans les territoires. *Cahiers Agricultures* 23: 84–95. https://doi.org/10.1684/agr.2014.0691.

Gawankar MS, Haldankar PM, Salvi BR, Haldavanekar PC, Malshe KV, Maheswarappa HP. 2018. Intercropping in young oil palm plantation under Konkan region of Maharastra, India. *International Journal of Current Microbiology and Applied Sciences* 7(12): 2752–2761. https://doi.org/10.20546/ijcmas.2018.712.312.

Haines-Young R, Potschin M. 2018. Common International Classification of Ecosystem Services (CICES) V5.1 and guidance on the application of the revised structure, 32 p. https://cices.eu/content/uploads/sites/8/2018/01/Guidance-V51-01012018.pdf.

Hartley CWS. 1988. The oil palm (*Elaeis guineensis* Jacq.), 3rd ed. Essex (UK): Longman Scientific and Technical Ed., (Tropical Agriculture Series), 771 p.

Jacquemard JC. 2013. Le palmier à huile en plantation villageoise. Versailles (France) : Éditions Quæ, 141 p. https://doi.org/10.35690/978-2-7592-1987-2.

Koussihouèdé H, Aholoukpè H, Adjibodou J, Hinkati H, Dubos B, Chapuis-Lardy L, *et al.* 2020. Comparative analysis of nutritional status and growth of immature oil palm in various intercropping systems in southern Benin. *Experimental Agriculture* 56(3): 371–386. https://doi.org/10.1017/S0014479720000022.

Le Moigne JL. 2006. La théorie du système général. Théorie de la modélisation, 2^{e} éd. Paris (France) : Presses universitaires de France, 338 p.

Lesage C, Cifuentes-Espinosa J, Feintrenie L. 2021. Oil palm cultivation in the Americas: review of the social, economic and environmental conditions of its expansion. *Cahiers Agricultures* 30: 27. https://doi.org/10.1051/cagri/2021015.

Luke SH, Advento AD, Aryawan AAK, Adhy DN, Ashton-Butt A, Barclay H, *et al.* 2020. Managing oil palm plantations more sustainably: large-scale experiments within the Biodiversity and Ecosystem Function in Tropical Agriculture (BEFTA) Programme. *Frontiers in Forests and Global Change* 2: 1–20. https://doi.org/10.3389/ffgc.2019.00075.

Madelaine C, Malézieux E, Sibelet N, Manlay R. 2008. Semi-wild palm groves reveal agricultural change in the forest region of Guinea. *AgroForestry Systems* 73(3): 189–204. https://doi.org/10.1007/s10457-008-9146-1.

Marzin J, Daviron B, Rafflegeau S. 2014. Agricultures familiales et autres formes d'agriculture. In: Sourisseau J-M, ed. *Agricultures familiales et mondes à venir*. Versailles (France) : Éditions Quæ, pp. 75–92.

Masure A. 2021. Capitalisation des connaissances et expériences, des systèmes de culture agroforestiers à palmier à huile dans le monde. Mémoire de fin d'études ISTOM, Angers, France, 98 p. https://agritrop.cirad.fr/598179/.

Masure A, Feumba LB, Lacan X, Rafflegeau S. 2021. Agroforesterie à palmier à huile : adoption et adaptation de prototypes de systèmes agroforestiers (SAF) par des agriculteurs de la région Centre du Cameroun. Projet PalmElit-Cirad : Design 2.0 (Rapport technique), Cameroun, 27 p. https://agritrop.cirad.fr/599408/.

Masure A, Lacan X, Rafflegeau S. 2022. Jeu de données sur des systèmes agroforestiers à palmier à huile dans le monde capitalisé en 2020. CIRAD Dataverse, Montpellier, France. https://doi.org/10.18167/DVN1/NQ7WJD.

Mathur RK, Suresh K, Bhanusri A, Naveen Kumar P, Prasad MV, Rao BN, *et al.* 2017. Research highlights 2011–2015. Andhra Pradesh, India: ICAR-Indian Institute of Oil Palm Research, 58 p.

Miccolis A, Robiglio V, Cornelius JP, Blare T, Castellani D. 2019. Oil palm agroforestry: fostering socially inclusive and sustainable production in Brazil. In: Jezeer R, Pasiecznik N, eds. *Exploring inclusive palm oil production*. ETFRN News 59, pp. 55–62.

Ndjogui TE, Nkongho, Levang P, Rafflegeau S, Feintrenie L. 2014. Historique du secteur palmier à huile au Cameroun. Jakarta (Indonésie) : CIFOR, 56 p.

PalmElit. 2019. Manuelde l'élaeiculteur. Montferrier-sur-Lez, France, 140 p. https://www.palmelit.com/ressources-et-publications/documentation-generale.

Pirker J, Mosnier A, Kraxner F, Havlík P, Obersteiner M. 2016. What are the limits to oil palm expansion? *Global Environmental Change* 40: 73–81. https://doi.org/10.1016/j.gloenvcha.2016.06.007.

Rafflegeau S, Michel-Dounias I, Tailliez B, Ndigui B, Papy F. 2010. Unexpected N and K nutrition diagnosis in oil palm smallholdings using references of high-yielding industrial plantations. *Agronomy for Sustainable Development* 30(4): 777–787. https://doi.org/10.1051/agro/2010019.

Rafflegeau S, Losch B, Daviron B, Bastide P, Charmetant P, Lescot T, *et al.* 2014. Contribuer à la production et aux marchés internationaux. In: Sourisseau J-M, ed. *Agricultures familiales et mondes à venir*. Versailles (France) : Éditions Quæ, (Collection Agricultures et défis du monde), pp. 129–143.

Rafflegeau S, Alline C, Barkaoui K, Deheuvels O, Jagoret P, Garcia L, *et al.* 2019. Ecosystem services functional motif: a new concept to analyse and design agroforestry systems. In: Dupraz C, Gosme M, Lawson G, eds. *4th World Congress on Agroforestry, Montpellier, France – Book of abstracts*, pp. 733–733.

Rival A, Levang P. 2013. La palme des controverses. Versailles (France) : Éditions Quæ, 98 p. https://doi.org/10.3917/quae.rival.2013.01.

RSPO. 2021. Roundtable for sustainable palm oil. https://rspo.org/standards (last consult.: 2021/10/19).

Salembier C, Elverdin JH, Meynard JM. 2016. Tracking on-farm innovations to unearth alternatives to the dominant soybean-based system in the Argentinean Pampa. *Agronomy for Sustainable Development* 36(1): 1–10. https://doi.org/10.1007/s13593-015-0343-9.

Seghieri J, Harmand JM. 2019. Agroforesterie et services écosystémiques en zone tropicale. Versailles (France) : Éditions Quæ, 254 p. https://doi.org/10.35690/978-2-7592-3059-4.

Slingerland M, Khasanah N, Susanti A, Meilantina M. 2019. Improving smallholder inclusivity through integrating oil palm with crops. In: Jezeer R, Pasiecznik N, eds. *Exploring inclusive palm oil production*. ETFRN News 59, pp. 147–154.

Tohiran KA, Nobilly F, Zulkifli R, Ashton-Butt A, Azhar B. 2019. Cattle-grazing in oil palm plantations sustainably controls understory vegetation. *Agriculture, Ecosystems & Environment* 278: 54–60. https://doi.org/10.1016/j.agee.2019.03.021.

Torquebiau E. 2007. L'agroforesterie : des arbres et des champs. Paris (France) : Éditions L'Harmattan, 156 p.

Woodham CR, Aryawan AAK, Luke SH, Manning P, Caliman JP, Naim M, *et al.* 2019. Effects of replanting and retention of mature oil palm riparian buffers on ecosystem functioning in oil palm plantations. *Frontiers in Forests and Global Change* 2: 29. https://doi.org/10.3389/ffgc.2019.00029.

Yemadje RH, Crane TA, Vissoh PV, Mongbo RL, Richards P, Kossou DK, *et al.* 2012. The political ecology of land management in oil palm based cropping system on the Adja plateau in Benin. *NJAS – Wageningen Journal of Life Sciences* 60(63): 91–99. https://doi.org/10.1016/j.njas.2012.06.007.

Zemp DC, Ehbrecht M, Seidel D, Ammer C, Craven D, Erkelenz J, *et al.* 2019. Mixed-species tree plantings enhance structural complexity in oil palm plantations. *Agriculture, Ecosystems & Environment* 283: 106564. https://doi.org/10.1016/j.agee.2019.06.003.

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