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REVIEW OPEN ACCESS

# Oil palm plantation systems are at a crossroads☆

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**Abstract** – The future of most tropical sectors is clouded by growing constraints linked to, among many other parameters, climate change, price volatility and labour scarcity. Perpetuating agricultural systems inherited from the colonial era (a time of abundant arable land, protected markets, and cheap and disciplined labour) will not be enough to prepare these sectors in facing immediate crucial challenges unless substantial structural transformations are made.
Implementing a successful agroecological transition in a 70-billion USD sector, covering 25 million ha worldwide, calls for drastic changes in mind-sets and practices. The key issue is no longer simply to increase productivity, but to foster innovations designed to support endangered tropical biodiversity, while providing a decent living for shrinking agricultural communities in the Global South.
Agroforestry practices have a role to play in providing substantial climate change mitigation with an impact comparable to other climate-focused solutions, such as reforestation. The expected contribution of oil palm-based agroforestry relies on agro-environmental services, as basic agricultural functions such as soil preservation, pollination, or pest control can be ensured by living organisms inside and around the plantation. Diversified systems are able to achieve both economic and environmental gains, as they use land more efficiently than monocultures. Building on regenerative agriculture, new plantation designs are emerging and deserve to be thoroughly assessed to establish evidence-based advocacy for change.

**Keywords:** Agroforestry / agroecology / conservation agriculture / perennial crops / plantation system / regenerative agriculture

**Résumé – Les plantations de palmiers à huile à la croisée des chemins.** L'avenir de la plupart des filières tropicales est assombri par des problèmes croissants liés, entre autres, au changement climatique, à la volatilité des prix et à la pénurie de main-d'œuvre. Perpétuer les systèmes agricoles hérités de l'ère coloniale (une époque révolue de terres arables abondantes, de marchés protégés et de main-d'œuvre disciplinée et bon marché) ne suffira pas à préparer ces secteurs à faire face à des défis cruciaux, à moins que des transformations structurelles substantielles ne soient rapidement mises en œuvre.
Pour le palmier à huile, réussir la transition agroécologique dans une filière qui pèse 70 milliards de dollars et couvre 25 millions d'hectares de par le monde va nécessiter des changements drastiques dans les mentalités et les pratiques. La question clé n'est plus simplement d'augmenter la productivité, mais de favoriser les innovations pour préserver la biodiversité tropicale, tout en offrant une vie décente à des communautés agricoles en difficulté.
Les pratiques agroforestières ont un rôle à jouer dans l'atténuation du changement climatique, avec un impact comparable à celui offert par d'autres solutions comme le reboisement. La contribution attendue de l'agroforesterie basée sur le palmier à huile repose sur les services agro-environnementaux, car les fonctions agricoles de base telles que la préservation des sols, la pollinisation ou la lutte antiparasitaire peuvent être assurées par des organismes vivants à l'intérieur et autour de la plantation. Les systèmes biodiversifiés sont ainsi capables de produire des gains économiques et environnementaux, en utilisant les terres plus efficacement que les monocultures. S'appuyant sur l'agriculture régénérative, de nouveaux modèles de plantation émergent ; ils méritent aujourd'hui d'être évalués de manière approfondie, afin de plaider en faveur d'un changement de modèle à l'aide de données scientifiques solides.

**Mots clés :** Agroforesterie / agroécologie / agriculture de conservation / cultures pérennes / systèmes de plantation / agriculture régénérative

☆ Contribution to the Topical Issue "Palm and palm oil / Palmier et huile de palme".
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**Highlight**

- Palm oil is a major source of foreign reserves in tropical countries, as well as a main instrument 44 of poverty alleviation and rural economic development.
- The oil palm is a champion in terms of productivity, but is it resilient enough to face the intrinsic 46 risks caused by the large-scale monoculture of a single species over extended areas?
- It is now about time R&D addressed the long-term resilience of 'the plantation' as an 48 agricultural system, since the current 'so far so good' attitude might not be an option anymore.
- Building on restored ecosystem functions, agroforestry-based solutions are slowly emerging 50 and gaining ground.

## 1 A champion or a clay-footed colossus?

Palm oil is the most consumed vegetable oil globally demand has accelerated with the emergence of new outlets in the agrofuel sector, adding to traditional food and oleochemical uses (Rival and Levang, 2014). This strong growth has undeniably contributed to the economic development of the major producing countries, mainly Indonesia and Malaysia, which now supply 83% of world demand (USDA, 2023). The sector is a key source of foreign reserves, as well as a major instrument of poverty alleviation and rural economic development (Feintrenie *et al.*, 2010; Rist *et al.*, 2010). Palm oil is also a major source of nutritional energy for millions of people in West and Central Africa and in coastal regions of Brazil, for whom palm oil is of high cultural value. Areas of these unaccounted traditional African oil palm plantations were estimated in 2013 to be 6,665,000 ha (Carrere, 2013).

Today, the comparative advantages of palm oil compared to competing vegetable oils still rely on low production costs that are structurally based on an abundance of arable land, the natural high productivity of the crop and cheap labour costs (Corley and Tinker, 2015; Sinaga, 2021). Land productivity depends on the availability of suitable terrains: Pirker (2016) considered land availability to be the main factor limiting oil palm expansion. Austin (2017) and Tapia (2021) showed that large non-forested areas are still available in Indonesia, but the suitable areas are scattered and remote, while oil palm fruits need to be processed within 24 h after harvesting. Expansion of the oil palm area in Indonesia therefore occurs in areas that are suboptimum, but located close to roads and mills (Numata, 2022). This trend greatly limits the productivity-related competitive advantage that was once the rule for oil palm systems.

To the careful observer, many aspects of the rapid and large-scale development of oil palm cultivation bring to mind the image of a clay-footed colossus, as a sector showing very strong growth and commercial success, but which is nevertheless masking several worrying weaknesses (Figure 1). Many issues are plaguing the sector: its dependence on foreign labour, especially in Malaysia (Crowley, 2020), sluggish growth in productivity (Monzon *et al.*, 2021), and its overall sustainability (Barral, 2017; Crowley, 2020; Meijaard *et al.*, 2020; Murphy *et al.*, 2021,). Recently, El Pebrian and Mohiddin (2021) estimated the average degree of mechanization in field operations in Malaysia's oil palm plantations at around 11%, considering it to be a slow pace when compared to the 74.22% of mechanization reported for Malaysia's rice cultivation.

Monzon *et al.* (2021) investigated how intensification in existing plantations could help Indonesia meet palm oil demand while preserving fragile ecosystems. They found that the average current yield amounts to 62% and 53% of the attainable yield in large and smallholder plantations, respectively. Narrowing yield gaps through improved agronomic management, together with limited expansion that excludes fragile ecosystems, would save 2.6 million hectares of forests and peatlands and avoid 732 MtCO2e compared to following historical trends in yield and land use.

Apart from the intrinsic questions related to the large-scale monoculture of a single plant species over extensive areas, it should be noted that global palm oil production is limited –in its vast majority- to a rather narrow geographical region that is virtually restricted to either side of the Strait of Malacca. This concentration might lead to serious problems should either an extreme climate event or a pest/disease invasion arises, which could be interconnected (Paterson, 2019; Paterson *et al.*, 2013; Aidoo *et al.*, 2022).

Furthermore, another source of vulnerability lies in the genetic base of the current oil palm hybrid material (dura x pisifera) that is selected, produced and cultivated worldwide. Exploited and cultivated agro-biodiversity remains quite narrow when compared to other industrial crops of major importance. Would this restricted genetic diversity be broad enough to enable the oil palm to survive a major pathology/agronomy/climate-related disaster (Paterson and Lima, 2018)?

## 2 Questionable climatic resilience

The expansion of oil palm cultivation has caused serious environmental damage: through tropical deforestation, it has played a large role in biodiversity erosion, with the decline of emblematic species such as orangutans in Southeast Asia (Santika *et al.*, 2022). Oil palm cultivation contributes to climate change through deforestation, but also through the conversion of peatlands that promote carbon sequestration in soils (Gomez *et al.*, 2023). In order to insure their future resilience, production systems based on intensive oil palm monocultures need to be explored from a new perspective embracing climate change (Rival, 2017; Paterson and Lima, 2018, Sarkar *et al.*, 2020).

The poor climatic resilience of current oil palm cultivation systems was highlighted by the sizeable drop in global palm oil production as a consequence of the severe El Niño-Southern Oscillation (ENSO) episode that occurred in Southeast Asia in 2015. Plantations had to face the double effect of extreme drought, directly through water stress-induced responses, such as changes in sex ratio and a drop in fruit development and oil synthesis, and indirectly through the impact of bushfires surrounding estates, as they hampered photosynthetic activity

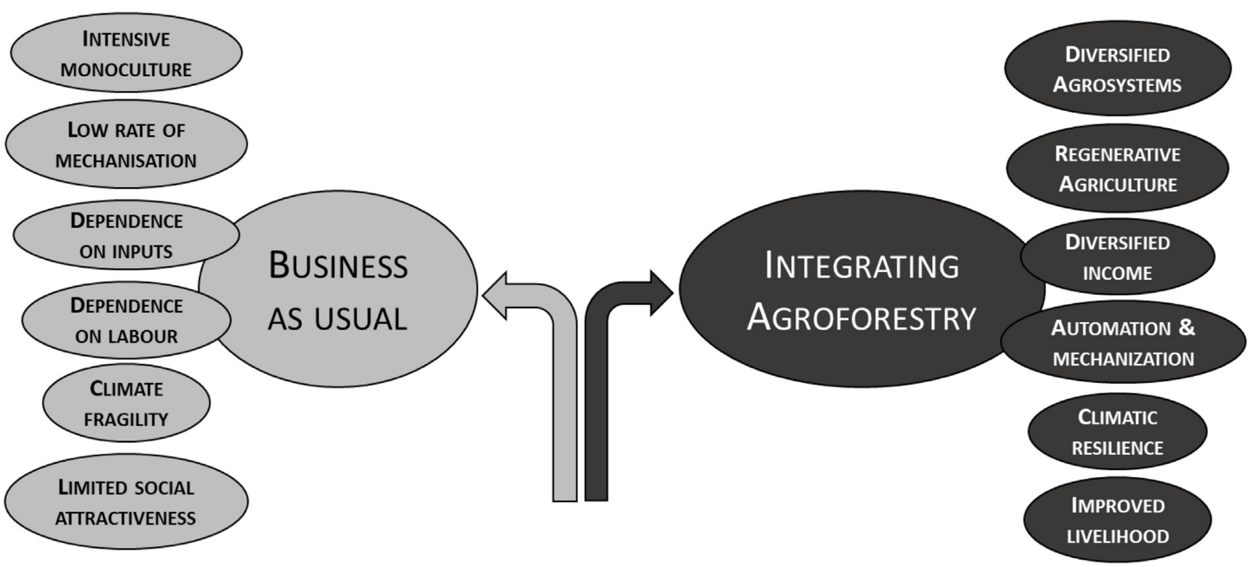


**Fig. 1.** A sustainable future for sustainable palm oil production calls for drastic changes.

for months when a thick haze covered the entire region (Rival, 2017, Meijide *et al.*, 2018). Stiegler *et al.* (2019) showed that haze conditions during ENSO 2015 led to a complete pause in oil palm net carbon accumulation, which lasted for almost 1.5 months and this situation was found to cause a 35% decline in oil palm yields. Additionally, a more severe haze, in combination with drought, could induce some pronounced losses in productivity and net C02 uptake in oil palm stands.

## 3 From plantations to agroforests

In the climate change context, agricultural management strategies must innovate to improve biodiversity and ecosystem functions in oil palm-dominated landscapes (Rafflegeau *et al.*, 2023). Agricultural practices in tree crop plantations are changing in response to growing social (Barral, 2017) and environmental (Bessou *et al.*, 2017) concerns. Plantation management now increasingly relies on agro-environmental services, meaning that basic agricultural functions, such as soil preservation, pollination, or pest control can be ensured by living organisms (plants, insects, microbes).

Oil palm plantations generally show reduced ecosystem functioning when compared to rainforests (Dislich *et al.*, 2017), an ecosystem that abruptly replaces oil palm in frontier zones. Several functions show decreases with potentially irreversible global impacts (*e.g.*, reductions in gas and climate regulation, habitat and nursery functions, genetic resources, medicinal resources and information functions). Such impacts become more serious when the forest is cleared to establish new plantations and immediately afterwards, especially on peat soils. Several specific changes in plantation management can prevent or reduce losses of various ecosystem functions, and synergistic mitigation measures can improve multiple ecosystem functions simultaneously (Abram *et al.*, 2014). In Indonesia, the zero-deforestation commitment appears to have had a limited impact in Sumatra, as oil palm plantations have mostly expanded onto degraded forest and rubber plantations over the past 20 yr (Nugroho *et al.*, 2023). In contrast, that commitment could have significant impacts in Kalimantan and Papua, which still have abundant forest (Austin, 2017).

Agroforestry can help to diversify agricultural outputs and enhance crop yield and will therefore be more efficient in terms of nutrient cycling, water use and light capture than conventional agricultural systems (Nair, 2019; Reith *et al.*, 2022). Even if they should not replace the protection of remaining forests, such systems may ensure food security, create additional C sinks and help the sustainable management of degraded ecosystems (Feintrenie *et al.*, 2010). Potential benefits rely on a diversification of crops and rural activities, bringing improvements in food safety, nutrition and financial resilience (Duffy *et al.*, 2021). Agroforestry systems can provide multiple benefits including reduced bank erosion and soil loss, maintenance of water quality and natural hydrology, carbon storage, together with the provision of habitats for a wide range of biodiversity.

Robust and multidisciplinary research is needed to characterize and assess intercropping and agroforestry-based systems (Ntawuruhunga *et al.*, 2023; Low *et al.*, 2023), so as to identify appropriate crops, systems and markets. Terasaki Hart *et al.* (2023) recently showed that expanding agroforestry could provide substantial climate change mitigation (up to 0.31 Pg C yr−1), in a way comparable to reforestation. Agroforestry can be valued as a potential natural climate solution (NCS) — a land-use practice that sequesters carbon or reduces emissions without reducing yields or compromising biodiversity.

Besar *et al.* (2020) comparatively assessed the carbon stock and sequestration potential of an agroforestry system in Malaysia. These authors showed that the amount of carbon stock in a high-to-low order was the natural tropical forest, the oil palm agroforestry systems, and the monoculture oil palm plantation. The total ecosystem carbon stock in agroforestry systems was found to be higher than the monoculture plantation. Converting a monoculture plantation into an agroforestry system can show several positive impacts, such as increased carbon storage and sequestration. The authors pinpointed that the total carbon stock in different land uses depends on vegetation, tree ages, and soil management.

Zemp *et al.* (2023) conducted large-scale, 5 yr ecosystem restoration experiment in an oil palm landscape enriched with 52 tree islands. They found that larger tree islands led to larger benefits in multidiversity through changes in vegetation structure. It is key to note that tree enrichment did not decrease landscape-scale oil palm yield, a key argument in favour of agroforestry-based planting systems in the oil palm sector. Combining assessments from ten different indicators of biodiversity and 19 indicators of ecosystem functioning, the authors described the biodiversity enrichment of oil palm-dominated landscapes with tree islands as a promising restoration strategy. Oil palm plantations are more often located in remote areas, where diversifying the production systems and establishing a market for new crops or NTFP (Non-Timber Forest Products) can be challenging for both estate companies and smallholders. Previous studies seeking to demonstrate the economic benefits of oil palm intercropping often took either a qualitative or a quantitative approach associated with a number of assumptions, including production yields and prices (Masure *et al.*, 2022). In such studies, oil palm productivity is assumed to follow a simplified pattern, in which the buying process for FFB is constant. One period of cross-section survey data or annual data is often used to calculate the financial feasibility of agroforestry (Khasanah *et al.*, 2020). In reality, FFB prices in Indonesia follow a more complex pattern, following different seasons, namely high, low and normal based on productivity rates. (Rahmani *et al.*, 2021) showed that oil palm agroforests planted in experimental plots potentially generated much better values for financial indicators. However, such studies need to consider how the fertilisers used for oil palm production affect the productivity of oil palm and other intercropped plants cultivated in such agroforestry systems.

Agroforestry practices involve innovative planting designs for a precise and long-term estimation of the benefits of simultaneous cultivation of forest species and perennial plantation crops (Rival *et al.*, 2022). In demonstration plots of various sizes, compositions and shapes, a series of precise measurements of bioclimatic parameters can provide data on both the agronomic performance and the resilience of such mixed agroforestry systems (Gomez *et al.*, 2023, Zemp *et al.*, 2019, 2023).

Potential barriers to large-scale adoption include high implementation costs and the knowledge-intensive nature of agroforestry compared to standard monocultures. Further research (and series of convincing demonstration plots) focusing on the economic benefits of intercropping, or multi-cropping, will be needed if oil palm-intensive agroforestry is to be adopted by smallholders (Chalil and Barus, 2019). Very few small-scale farms have the capacity and the resources to undergo profound transformations of their cropping systems (Chalil and Barus, 2018) that might bring uncertainties in an already fragile socio-economic system.

## 4 Scaling up to demonstrate

The process of scaling up oil palm-based agroforestry experiments (from demonstration plots to large plantation areas) will require a large body of research, which should also focus on buffer zones between forests and plantations, such as riparian areas. Indeed, Bhagwat and Willis (2008) suggested that oil palm plantations managed as agroforestry systems could foster conservation efforts through the provision of habitats for forest-dwelling species, the establishment of connections between biodiversity-rich areas, and the securing of livelihoods for local people.

The long-term challenge is to restore landscape continuity by establishing connectivity channels linking diverse and complementary habitat patches. Animal species like the orangutan typically make use of connected oil palm landscapes, as small forest fragments when connected can facilitate orangutan movement (Ancrenaz *et al.*, 2021; Seaman *et al.*, 2021). The enrichment of oil palm-dominated landscapes with native tree species may rapidly provide solutions. Indeed, experiments are under way (Messier *et al.*, 2022; Zemp *et al.*, 2019, 2023) seeking to restore some degree of structural complexity in existing plantations. Changes in structural complexity have been associated with denser and more complex filling of three-dimensional space, whereas vertical stratification was found to be mainly influenced by oil palm.

Oil palm plantations managed as agroforestry systems (Bhagwat and Willis, 2008) can bolster conservation efforts. When oil palm is cultivated in mixed-tree orchards rather than monoculture plantations, such complex systems can provide habitats for forest-dwelling species. Mixed plantations within the landscape act as buffer zones and biodiversity corridors, connecting separate forest reserves. Further, forest and agricultural resources in mixed plantation landscapes provide livelihoods for local people.

Agroforestry systems have an important role to play in mitigating climate change, as they have the ability to sequester atmospheric carbon dioxide (CO2) in plant organs and soil. Indeed, changes in soil organic carbon (SOC) stocks can be monitored after land conversion to agroforestry. Donfack *et al.* (2021) showed that oil palm agroforests are able to regulate extreme microclimates and that stand structural complexity and tree island size can control microclimates, although alleviating the harsh microclimate conditions in oil palm plantations might take longer to achieve.

Wildlife-friendly management practices can go hand-in-hand with Best Agricultural Practices and the subsequent enhancement of yields according to the concept of agroecology and ecological intensification. Foster *et al.* (2011) and Zemp *et al.* (2019, 2023) stressed the importance of conserving biodiversity and ecosystem processes within the oil palm habitat itself. However, little is known about how local management practices and landscape design affect biodiversity and its relation to ecosystem services or disservices, specifically in oil palm agroecosystems (Foster *et al.*, 2011, Savilaakso *et al.*, 2014, Rafflegeau *et al.*, 2023).

In the global oil palm sector, 'business as usual' is no longer an option; it is now at a crossroads and urgent and concrete responses are needed to deeply transform its production systems. Given the increasing uncertainties (price volatility, climatic vulnerability, dependence on imported labour), the multisite assessment of the capacities of oil palm-based agroforestry systems must become a priority for scientists, policy makers and the oil palm industry in all producing countries (Purwanto *et al.*, 2020). Since the pioneering work launched in 2007 by Miccolis *et al.* (2019) on an 18-ha plot in Brazil, such initiatives have remained rather scarce and more often disconnected, so a significant effort in collaborative research is needed to generate relevant data and share knowledge.

## Authors contributions

Alain Rival and Diana Chalil equally contributed to the conceptualization and investigation, then to the writing (original draft preparation, review & editing) of the present article. Alain Rival was in charge of funding acquisition.

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