OCL 2025, 32, 31
© D.E. Munévar-Martínez et al., Published by EDP Sciences, 2025
https://doi.org/10.1051/ocl/2025022

OCL
Oilseeds & fats Crops and Lipids

Available online at:
www.ocl-journal.org

REVIEW OPEN ACCESS

Sustainable intensification of oil palm production through integration with other crops: a review☆

Daniel Eduardo Munévar-Martínez, Elizabeth Ruiz-Álvarez, María Celina Estupiñán-Villamil and Mauricio Mosquera-Montoya*

Research Results Validation Unit, Colombian Oil Palm Research Center – Cenipalma, Colombia

Received 23 December 2024 – Accepted 20 June 2025

Abstract – Unsustainable monoculture systems practices, driven by global demand for agricultural commodities like palm oil, contribute to deforestation, biodiversity loss, and soil degradation, compromising livelihoods and environmental health. With increasing land scarcity, sustainable practices maximizing productivity and minimizing ecological impact, such as intercropping, are crucial. This review of over 116 publications examines global oil palm intercropping systems, analysing their technical, economic, environmental, and social implications. While companion crop productivity is relatively well-studied, long-term effects on adult palms require further investigation. Crop design (species selection, type of oil palm used and spatial arrangement) and crop management are key to mitigating interspecific competition and optimizing productivity, given diverse intercropping patterns. Economic performance varies, with benefit-cost ratios from 0.26 (palm with onion) to 2.86 (palm with corn/pepper). Intercropping offers socio-environmental benefits: enhanced food security through integrating food crops, diversified income, increased biodiversity (birds, arthropods), and efficient resource use. Land equivalent ratios (LERs) range from 0.98 to 4.10, indicating more efficient land use than monocultures. However, research gaps remain regarding long-term intercropping impacts on palm cultivation, particularly fertilization and pest/disease management, water use, pollinators, yields, and environmental impacts.

Keywords: sustainability / production systems / equivalent land index / profitability / ecosystem services

Résumé – Intensification durable de la production d'huile de palme par intégration d'autres cultures : une revue. Les pratiques de monoculture non durables, motivées par la demande mondiale de produits agricoles comme l'huile de palme, contribuent à la déforestation, à la perte de biodiversité et à la dégradation des sols, compromettant les moyens de subsistance et l'environnement. Avec raréfaction des terres cultivables, les pratiques durables maximisant la productivité et minimisant l'impact écologique, comme les associations de cultures, sont cruciales. Cette revue de plus de 116 publications examine les systèmes d'associations avec le palmier à huile à l'échelle mondiale, analysant leurs implications techniques, économiques, environnementales et sociales. Bien que la productivité des cultures associées soit relativement bien étudiée, les effets à long terme sur les palmiers adultes nécessitent des investigations supplémentaires. La mise en place de la culture (choix des espèces, type de palmier à huile utilisé et arrangement spatial) et les techniques culturales sont essentielles pour atténuer la compétition interspécifique et optimiser la productivité, compte tenu des divers schémas d'association. La performance économique varie, avec des ratios coût-bénéfice allant de 0,26 (palmier avec oignon) à 2,86 (palmier avec maïs/poivre). L'association offre des avantages socio-environnementaux : une sécurité alimentaire améliorée grâce à l'intégration de cultures vivrières, des revenus diversifiés, une biodiversité accrue (oiseaux, arthropodes) et une utilisation efficace des ressources. Les *Land equivalent ratios* (LERs) varient de 0,98 à 4,10, traduisant une utilisation plus efficace des terres que les monocultures. Cependant, des lacunes subsistent concernant les impacts à long terme des associations sur la culture du palmier, en particulier la fertilisation, la gestion des ravageurs/maladies, l'utilisation de l'eau, les pollinisateurs, les rendements et les impacts environnementaux.

Mots-clés : durabilité / systèmes de production / land equivalent ratio / rentabilité / services écosystémiques

☆ Contribution to the Topical Issue: "Innovative Cropping Systems / Systèmes innovants de culture oléoprotéagineux".
*Corresponding author: mmosquera@cenipalma.org

Highlights

Unsustainable oil palm monoculture involves several environmental challenges. Intercropping offers a sustainable alternative, improving food security and biodiversity. Economic benefits vary, with some intercropping systems showing high yields. More research is needed on the long-term impacts of intercropping on mature palm plants.

1 Introduction

Technological advances in the 21st century have significantly improved the ability to meet the basic needs of much of the global population. However, persistent economic, political, health, and social challenges in the world's poorest countries have given rise to two critical and urgent issues: hunger and poverty. Despite progress in reducing poverty indicators over the past decade, it is currently estimated that 828 million people are at risk of malnutrition and 648 million live in poverty (Harari, 2018; Organización Mundial del Comercio, 2010; World Bank, 2022).

The problem of how to adequately feed and supply a growing population has led to the intensification of agricultural production systems, in a process that has been characterized by the increase in production yields through the use of technology, the globalization of agricultural markets, the intensive use of agrochemicals, the exploitation of large areas in monoculture, the concentration of land tenure and asymmetries in the governance of agricultural value chains between small, medium and large-scale farmers (Baccar *et al.*, 2019; Lamine & Marsden, 2023; Reisman and Fairbairn, 2020). The inefficient use of land in agri-food systems, both by underutilization and overutilization, has led to complex socio-environmental conflicts that have impacted on the quality of life of communities and the ecosystems that host them (Petrescu-Mag *et al.*, 2018). Conflicts over land use lead to negative environmental impacts such as erosion of the topsoil, loss of biodiversity, reduction in the supply of water resources, and forced displacement, among others, which affect the sustainability of rural areas (Kangas *et al.*, 2022; Pacheco *et al.*, 2014; Petrescu-Mag *et al.*, 2018; Rodrigues *et al.*, 2019).

Oil crops play a significant role in global agricultural markets, accounting for approximately 27.2% of total crop production. Among these, oil palm is the most productive, with palm oil serving as a key commodity for the food, energy, and industrial sectors (Adade, 2022; Mesa, 2016). In 2023, global oilseed production exceeded 667 million tonnes, with soybeans (59.09%), rapeseed (13.37%), and sunflower (9.39%) being the most prominent (USDA FAS, 2024). However, in terms of oil production, oil palm has reported a productivity of 2.88 t oil/ha, while soybean, rapeseed and sunflower can be 84%, 72% and 73% less productive, respectively.

Oil palm is cultivated commercially in tropical regions, with Indonesia (59.3%), Malaysia (23.97%), Thailand (4.35%), Colombia (2.27%), Nigeria (1.77%), and Guatemala (1.16%) leading global production in 2023 (USDA, 2022). In these countries, the palm agroindustry has contributed to economic development, improved quality of life and increased income for palm growers (Escobar *et al.*, 2010; Meijaard and Sheil, 2019; Mosquera and Beltrán, 2017; Santika *et al.*, 2019). The Asian and American countries also leaded the global crude oil palm exports with Indonesia (35.7%) and Malaysia (35.2%) heading the list in 2023 (World Integrated Trade Solution, 2024a). The main destinations of these exportations were India (48.04%), European Union (15.53%) and the Netherlands (7.93%) (World Integrated Trade Solution, 2024b)

Oil palm monoculture is the most common production system of this crop globally. It seeks to maximize crop yields through the homogeneity of the agroecosystem, the intensive use of agrochemicals (chemical fertilizers and pesticides) and increasing mechanization (Emanuelli *et al.*, 2011; Liu *et al.*, 2018). However, there are challenges related to phytosanitary problems and the decrease in biological diversity inside and outside the plantation (Dhandapani *et al.*, 2020; Gebru, 2015; Salaheen and Biswas, 2019).

The global oil palm industry faces challenges to ensure its sustainability, an increasingly important aspect for the global consumer. The expansion of this crop has led to environmental impacts such as loss of biodiversity, environmental pollution, waste discharge into water sources, effects on soil regeneration and greenhouse gas emissions, among others. (Dhandapani *et al.*, 2019; Qaim *et al.*, 2020; Ramírez-Contreras *et al.*, 2020; Shahputra and Zen, 2018). At least 50% of the planted oil palm area has developed through the clearing of forests, especially in the Southeast Asia (in Malaysia, 60% of oil palm land replaced the native forests), while the rest of the oil palm plantation area, however, was a replacement for former crops or poorly preserved natural ecosystems, especially in America (21% of oil palm expansion occurred through deforestation, in Ecuador, Peru, Guatemala and Brazil) (Lesage *et al.*, 2021; Qaim *et al.*, 2020). Some authors relate the expansion of cultivation with negative social impacts on issues such as public health, food insecurity, conflicts between communities, labor formalization and social inequity (Hamann, 2018; Morand and Lajauni, 2020; Ordway *et al.*, 2019; Sibhatu, 2023).

The requirement for environmental certifications, the institutional strengthening of the management of sustainability, the design of environmental policies for the planning and regulation of agribusiness and the improvement of technical processes are some of the strategies that have been implemented to improve the sustainability of the sector and contribute to the achievement of the Sustainable Development Goals (Purwanto *et al.*, 2020).

Intercropping is understood as the planting and management of two or more crops in the same space and under a defined temporal arrangement. It is recognized as an agronomic practice that can promote the sustainability of agricultural activity through improved ecosystem services such as the provision of resources (raw materials) and the regulation of natural processes (Duchene *et al.*, 2017; Glaze-Corcoran *et al.*, 2020). Carbon sequestration, efficient soil use, assurance of food security and stabilization of productivity are some of the general benefits documented in relation to the implementation of intercropped production systems (Glaze-Corcoran *et al.*, 2020; Yang *et al.*, 2021).

In oil palm, crop intercropping is expected to optimize land and resource use, especially during the early years of the

Table 1. Terms of search.

Topic	Descriptor	Registers retrieved
General aspects	(intercrop* OR agroforest* OR “intercalado”) AND (“oil palm” OR “palmier a’huile” OR “palma de aceite” OR “Elaeis guineensis”)	Google Scholar: 2250; Scopus: 339
Economics aspects	(intercrop* OR agroforest* OR “intercalado”) AND (“oil palm” OR “palmier a’huile” OR “palma de aceite” OR “Elaeis guineensis”) AND “yield”	Google Scholar: 64; Scopus: 61
	(intercrop* OR agroforest* or “intercalado”) AND AND (“oil palm” OR “palmier a’huile” OR “palma de aceite” OR “Elaeis guineensis”) AND profit*	Google Scholar: 39; Scopus: 24
Social aspects	(intercrop* OR agroforest* OR “intercalado”) AND (“oil palm” OR “palmier a’huile” OR “palma de aceite” OR “Elaeis guineensis”) AND (“work” OR “labor”)	Google Scholar: 55; Scopus: 41
	(intercrop* OR agroforest* OR “intercalado”) AND (“oil palm” OR “palmier a’huile” OR “palma de aceite” OR “Elaeis guineensis”) AND wom*	Google Scholar: 11; Scopus: 6
	(intercrop* OR agroforest* OR “intercalado”) AND (“oil palm” OR “palmier a’huile” OR “palma de aceite” OR “Elaeis guineensis”) AND (“food” OR “food security”)	Google Scholar: 15; Scopus: 62
Environmental aspects	(intercrop* OR agroforest* OR “intercalado”) AND (“oil palm” OR “palmier a’huile” OR “palma de aceite” OR “Elaeis guineensis”) AND (“environmental” OR “biodiversity” OR “ecosystem*)	Google Scholar: 69; Scopus: 184
	(intercrop* OR agroforest* OR “intercalado”) AND (“oil palm” OR “palmier a’huile” OR “palma de aceite” OR “Elaeis guineensis”) AND “carbon”	Google Scholar: 49; Scopus: 86

plantation development. This technique has been adopted mainly by independent smallholders as a strategy to improve the profitability of their production systems. In addition, some farmers have considered intercropping as an option to strengthen the food security of their households. In Africa, the place of origin of the oil palm, smallholder production systems have traditionally included the integrated oil palm-based intercropping; although this practice is less popular in more technical production systems (Nkongho *et al.*, 2015). In countries in which the oil palm has been recently introduced, agroforestry and intercropping practices have been adapted over monoculture systems, which are the most widely adopted. In Indonesia, for example, agroforestry systems in rubber have been more popular than in oil palm (Drescher *et al.*, 2016).

The adoption of intercropping in oil palm-based systems can be considered as an opportunity to improve the sustainability of the palm oil sector. This has stimulated the interest of academia in answering questions about the feasibility and success of these production systems. Therefore, the purpose of this article is to describe the state of the art on the particularities of adopting a diversified production system. In the first section, we describe the various systems reported in the literature. In the second section, we describe the implications from the point of view of the productivity of the systems. Finally, we analyse the key factors for the improvement of environmental sustainability.

2 Methodology

This study conducted a comprehensive review of key literature, including both peer-reviewed scientific articles (white literature) and grey literature such as institutional reports, master's and doctoral theses, and official websites. The review focused on the productivity, economic, environmental, and social implications of adopting intercropping systems in oil palm cultivation.

The literature search was performed using keywords in Spanish, English, and French across academic databases and search engines, including Google Scholar and Scopus (Tab. 1). Boolean operators were employed to refine the search results. Articles that did not mention “oil palm" in their abstracts or were not aligned with the objectives of this study were excluded.

Although the review includes publications prior to 2018, these were selected based on the relevance and significance of their content. It is important to note that no quantitative bibliometric analysis was conducted. In total, 122 documents were selected for inclusion in this review.

3 Production systems for oil palm-based intercropping are heterogeneous

The concept of intercropping is closely related to several other practices such as agroforestry, mixed crops and polyculture. Masure *et al*. (2023) have identified four main types of intercropping or agroforest system in oil palm that are classified by the duration along the lifecycle of the oil palm and by the purpose of the system. Intercropping can be temporary at the beginning of the cycle of the oil palm, at the end, or permanent. Also, intercropping can have can be based on the planting designs following a regular pattern, or not (like the traditional oil palm agroforestry in Africa). Intercropping systems can also be associated with livestock production, adding more complexity to the agroecosystem (Ruiz-Álvarez *et al.*, 2024).

A wide variety of species have been intercropped with oil palm. The choice of companion crops depends on several factors, including climate, soil conditions, the age of the oil palm, local food culture, market value, the farmer's economic capacity, and the specific objectives of the intercropping strategy. (Khasanah *et al.*, 2020; Salleh and Harun, 2015). The complexity of this kind of production system depends not only on the spatial arrangement (vertical and horizontal) but also for the time frame of the planting (Bybee-Finley and Ryan, 2018; Maitra *et al.*, 2021; Yang *et al.*, 2021). According to Costa *et al.* (2024), the effectiveness of these production systems depends on their level with respect to plant diversity (influences the resilience of the system), functionality (interactions strengthen the resilience and productivity of the system) and economic diversity (increases the economic benefits of the system and decreases the risks of loss).

Although intercropping is primarily practiced by smallholders, numerous initiatives have also emerged from researchers (Costa *et al.*, 2024; de Castro and Futemma, 2021; Dhandapani *et al.*, 2020; Feintrenie *et al.*, 2008; Lee and Kasbi, 1978; Oomen, 2023; Yahya *et al.*, 2017).

There are two main groups of crops usable for intercropping: food crops and cash crops, which can be rather annual or permanent. Food crops, such as maize and cassava, are planted due to their importance in the food security of the communities and the ease of marketing their surplus, and they are more frequent during the immature stage of the palm (ETA and TBI, 2021; FAO, 2001; Koussihouèdé *et al.*, 2020; Okere *et al.*, 2015; Orewa, 2008). Food crops are not usually highly mechanised, as their purpose is often to provide for subsistence and to increase household income, but in maize intercropping mechanisation can be possible (FENALCE, 2008; Nchanji *et al.*, 2016).

Cash crops are species with high commercial value such as cocoa, timber, pineapple or pepper, that also are generally permanent or semipermanent crops. As they are grown in the long term, along with the oil palm often modification in the special distribution of the plant is made (ETA and TBI, 2021). Forestal species are also included into agroforestry-based production systems, and they are used as green barriers or for timber.

Literature shows that several crops, although not produced in a commercial scale, could be promising, such as watermelon, ornamental plants or medicinal herbs.

The association of crops with oil palm has been carried out in all the continents where it is planted and at different stages of its development, mainly in Asia and Africa. The experiences reported in the literature in the Americas are scarce, except for Brazil (Tab. 2 and Tab. 3).

4 Intercropping systems can contribute to the economic sustainability of the palm sector

One of the economic objectives of palm production systems is to ensure competitiveness, which can be measured, among other indicators, through productivity and production costs. In intercropping systems, productivity is a central concern and often a limiting factor in adoption.

4.1 How intercropping affects productivity

The integration of crops with oil palm generates impacts on the yields of the system; the literature records more frequently only the yields associated with integrated cultivation (Tab. 4). Reports are more frequent in semi-annual crops. For example, in the palm-watermelon system, the yield of intercropped palms was 6.8% lower than that of monoculture (Oomen, 2023). In a soybean and corn plot intercropped with immature oil palms, yields varied –51.8% and –4.16%, respectively, compared to monoculture (Rizki *et al.*, 2020). In cassava and maize, yield can diminish as oil palms grow and are lower than their respective monoculture, but the total performance of the production system is higher than a typical oil palm monoculture, given that oil palm productivity is not affected (Agele *et al.*, 2019).

Despite these findings, there is a notable gap in understanding the long-term effects of intercropping on oil palm yield dynamics. The results showed in Tables 4 and 5 don't explain what the impact of intercropping in the productivity of the production system in the long term is, and what is the response in the yield curve of oil palm, given that most of these researches have focused on the yields of intercropped species. However, the productivity of intercropping systems should be understood as the sum of the partial contributions of all the crops that comprise it, so that as a whole, it can be greater than monoculture (Bybee-Finley and Ryan, 2018). Productivity relies on the quality of the agronomic management that is performed (George, 2014; Giller *et al.*, 2021).

Adopting an intercropping approach requires a shift in how production systems are planned and managed. One of the key factors influencing this system is the planting density and spatial arrangement of the crops, as these factors directly affect both inter- and intraspecific competition within the agroecosystem (ETA and TBI, 2021; Khomphet *et al.*, 2021). In oil palm intercropping systems, the spatial arrangement is generally designed to accommodate the agronomic requirements of the secondary crops (*i.e.* those that accompany oil palm), rather than altering the standard planting density of the oil palm. Companion crops are typically established in inter-row spaces or non-harvest zones, ensuring that their presence does not interfere with palm maintenance or its harvesting operations, also promoting efficient land use.

The spatial arrangement of oil palm in intercropping systems influences both the agronomic response both palm and companion crops. Some intercropping models retain the classical staggered planting density (approximately 143 palms per hectare) allowing for the integration of crops without altering the traditional layout. In contrast, other systems, such as those reported involve modifications to the spatial configuration of the palms—such as increased spacing or rectangular planting patterns—to reduce competition. Some growers have reported changes in palm planting design, shifting from traditional staggered layouts to rectangular ones (Oomen, 2023) or altering palm planting density by increasing the space between palms (Ahmad and Diniyati, 2022; Perez *et al.*, 2024).

The type of oil palm involved in production systems should also be considered. Although the literature is not specific about the characteristics of palms suitable for intercropping, the selected materials such as Tenera are the most used, due to their productive attributes. Regarding *Elaeis oleifera* x *Elaeis guineensis* hybrids, only one case has been reported, in which pineapple and passion fruit were planted in association with oil palm (López, 2021). The slow growth of these species and the

Table 2. Main annual crops planted in intercropping with oil palm.

Associated cultivation with palm	Palm stage	Country in which reported	Source
Corn (*Zea mays*)	Young	Colombia, Nigeria, Ghana, Benin, Cameroon, Uganda, Ivory Coast, India, Indonesia	Agele (2019); Danso *et al*. (2020); Dissanayake and Palihakkara (2019a); FENALCE, (2008); Koussihouèdé, Clermont-Dauphin, *et al*. (2020); Nuertey *et al*. (2010); Obi *et al*. (2023); Rizki *et al*. (2020); Erhabor *et al*. (2002); Hariyadi *et al*. (2019); Jurusan *et al*. (2023); Jeki Daisa *et al*. (2024); Nchanji *et al*. (2016); Orewa (2008); Okyere (2014)
Cassava (*Manihot esculenta*)	Young	Brazil, Nigeria, Benin, Cameroon, Uganda, Ivory Coast, Ghana, Indonesia	Agele (2019); Koussihouèdé *et al*. (2020); Okyere (2014); Carvalho Rocha *et al*. (2020); Nchanji *et al*. (2016); Nuertey *et al*. (2010); Obi *et al*. (2023); Orewa (2008); Sapalina *et al*. (2022); Namanji *et al*. (2021); Cheyns and Rafflegeau (2005)
Rice (*Oryza sativa*)	Young	Indonesia, Brazil, Ivory Coast	Perez *et al*. (2024); Alridiwirsah *et al*. (2019); Alves *et al*. (2013); Cheyns and Rafflegeau (2005)
Sorghum (*Sorghum bicolor*)	Young	Indonesia	Sapalina *et al*. (2022)
Solanaceae (*tomato, eggplant, chili, pepper, garden huckleberry*)	Young	Nigeria, Benin, Cameroon, Indonesia, India	Agele *et al*. (2019); Koussihouèdé *et al*. (2020); Nurjannah *et al*. (2021); Obi *et al*. (2023); Oluwatobi (2020b); Tengoua and Bakoumé, (2005); Hariyadi *et al*. (2019); Nchanji *et al*. (2016); Sapalina *et al*. (2022); Reddi *et al*. (2015); Bakeri *et al*. (2019)
Okra (*Abelmoschus esculentus*)	Young	Nigeria, India	Oluwatobi (2020a); Reddi *et al*. (2015)
Taro, *cocoyam* (*Colocasia sculenta*)	Young, adult	Cameroon, Nigeria, Indonesia	Erhabor and Filson, (1999); Suwandi *et al*. (2024); Nchanji *et al*. (2016)
Yam (*Dioscorea sp.*)	Young	Malaysia, Nigeria, Cameroon, Indonesia	Dhandapani *et al*. (2020); Fadli *et al*. (2023); Nchanji *et al*. (2016); Orewa, (2008)
"Porang" (*Amorphophallus muelleri*).	Young	Indonesia	Amalia *et al*. (2024)
Legumes (beans, peanuts, soybeans)	Young, adult	Nigeria, Benin, Cameroon, India, Indonesia, Ivory Coast	Idawanni and Ferayanti, (2021); Marwoto *et al*. (2012); Putra *et al*. (2012); Rizki *et al*. (2020); Adri and Yardha, (2022); Erhabor *et al*. (2002); Hariyadi *et al*. (2019); Hidayat *et al*. (2019); Nchanji *et al*. (2016); Sapalina *et al*. (2022); Reddi *et al*. (2015); Yuliani *et al*. (2021): Agustira *et al*. (2018); Kusumawati *et al*. (2021); Koussihouèdé, Clermont-Dauphin *et al*. (2020); Sitorus and Zasari, (2023); Cheyns and Rafflegeau, (2005)
Onion (*Allium cepa*)	Young	India	Reddi *et al*. (2015); Rethinam, (2017)
Indian mustard (*Brassica juncea*), cabbage (*Brassica oleraceae*)	Adult	Indonesia	Yanda (2019); Yanda *et al*. (2018)
Edible fern (*Displazium esculentum*)	Adult	Indonesia	Yanda (2019)
Aromatic, ornamental and medicinal plants	Adult	India, Thailand, Nigeria, Sri Lanka	Nwaogu *et al*. (2014); Rethinam, (2017); Treetaruyanont *et al*. (2014); Dissanayake and Palihakkara, (2023)
Watermelon (*Citrullus lanatus*)	Young	Indonesia, Cameroon	de Maijer, (2023); Oomen, (2023); Nchanji *et al*. (2016)
Cucumber (*Cucumis sativus*)	Young	Indonesia	Sitorus and Zasari (2023)

planting distance used (116–128 palms per hectare) could favor the intercropping of crops in the first years of the palm (Romero *et al.*, 2023).

The literature provides different arrangements depending on the type of crop to be integrated and shows various examples of planting arrangements depending on the companion crop. For instance, cassava is typically planted at the end of the non-productive phase of palm plantations, with densities of up to 3200 plants per hectare annually (Carvalho Rocha *et al.*, 2020). Maize is mainly established with young palm crops in all alleys, with planting densities of 50,000 plants/ha. (Danso *et al.*, 2020; FENALCE, 2008; Koussihouèdé *et al.*, 2020; Nuertey, 1999; Nuertey *et al.*, 2010). For pineapple, as for maize, the integration in early stages of palm crops is common with planting densities of 30,000 plants per hectare (Van Leeuwen, 2019). The

Table 3. Main semi-annual and permanent crops planted in intercropping with oil palm.

Associated cultivation with palm	Palm stage	Country in which reported	Source
Musaceae (banana, plantain)	Young, adult	Nigeria, Ghana, Cameroon, Ivory Coast, Indonesia	ETA and TBI (2021); Okyere, (2014); Oomen (2023); Nchanji *et al.* (2016); Nuertey *et al.* (2010); Cheyns and Rafflegeau (2005)
Coffee (*Coffea arabica*)	Adult	Indonesia	Firmansyah and Umami (2021)
Cocoa (*Theobroma cacao*)	Adult	Nigeria, Cameroon, Ghana, India, Malaysia	Amoah *et al.* (1995); Lee and Kasbi (1978); Bourgoing and Todem (2010); Rethinam, (2017); Afolami and Ajobo (1983); Ashraf *et al.* (2019); Rao *et al.* (2019); Adenikinju *et al.* (1991)
Pineapple (*Ananas comosus*)	Young, adult	Colombia, Brazil, Malaysia, Benin, Indonesia	López (2021); Carvalho Rocha *et al.* (2007); Van Leeuwen (2019); Ashraf *et al.* (2019); Koussihouèdé *et al.* (2020); Sapalina *et al.* (2022); Dhandapani *et al.* (2022); Bakeri *et al.* (2019)
Black pepper (*Piper nigrum*)	Adult	Malaysia	Ashraf *et al.* (2019); Khasanah *et al.* (2020); Zulkifli *et al.* (2016); Migeon (2018)
Passion fruit (*Passiflora* sp)	Young	Colombia	López (2021)
Pistachio (*Pistacia vera*)	Young	Cameroon, Ivory Coast	Cheyns and Rafflegeau (2005)
Timber	Adult	Malaysia, Indonesia, Thailand	Ahmad and Diniyati (2022); Khomphet *et al.* (2021); Rahmani *et al.* (2021); Tata *et al.* (2016); Budiadi *et al.* (2019)
Bamboo (*Bambusa* sp)	Adult	Malaysia	Ashraf *et al.* (2019)
Papaya (*Carica papaya*)	Young	India, Indonesia	Maryani *et al.* (2021); Rethinam (2017)
Cinnamon (*Cinnamomum verum*)	Adult	India	Manorama *et al.* (2019)

Table 4. Reported yields in intercropping systems with young palm.

Production system	Palm average yield (t FBB/ha*year)	Intercropped average yield (t/ha*year)	Reported by
Cassava (*Manihot esculenta*)	7,84 - 14,11 (calculated)	25 – 33	Agele *et al.* (2019)
Rice *(Oryza sativa)*	–	3	Alves *et al.* (2013)
	–	3,48 - 4,47	Alridiwirsah *et al.* (2019)
Corn *(Zea mays)*	–	7	Danso *et al.* (2020)
	7,84 - 14,11 (calculated)	5 – 10,5	Agele *et al.* (2019)
	–		
Peanut *(Arachis hypogaea)*	–	1,32	Putra *et al.* (2012)
Corn + soybean *(Glycine max)*	–	Corn: 9.86 - 11.59	Rizki *et al.* (2020)
	–	Soybean: 1 - 1.03	
Tomato *(Solanum lycopersicum)*	–	6	Tengoua and Bakoumé (2005)
	–	2,7	Reddi *et al.* (2015)
Onion *(Allium cepa)*	–	0,26	Reddi *et al.* (2015)
Okra *(Abelmoschus esculentus)*	–	3,82	Reddi *et al.* (2015)
Chili *(Capsicum annuum)*	–	2,02	Reddi *et al.* (2015)
	–	0,35	Tengoua and Bakoumé (2005)
Black pepper *(Piper niger)*	–	1 - 3	Zulkifli *et al.* (2016)
Pepper *(Capsicum annuum)*	–	0,7	Tengoua and Bakoumé (2005)
Watermelon *(Citrullus lanatus)*	3,429	–	Oomen, (2023)
	–	5.6 - 8,4	de Maijer (2023)

integration of palm with other perennial crops makes it necessary to modify traditional planting densities: in cocoa, there is evidence of systems where one row of palm and one row of cocoa are planted, while others plant quintuple rows (one row of palm and five rows of cocoa), with planting distances of 2.5 × 10 m and 2.5 × 3 m, respectively (Afolami and Ajobo, 1983; Lee and Kasbi, 1978).

In most cases it has not been found that the integration of palm with crops such as corn, peanuts, vegetables, soybeans, cocoa, chili, watermelon, pineapple, harms the development of

Table 5. Reported yields in intercropping systems with adult palm.

Production system	Palm average yield (t FBB/ha*year)	Intercropped average yield (t/ha*year)	Reported by
Black pepper *(Piper nigrum)*	15,5	3	Migeon, (2018)
Cocoa *(Theobroma cacao)*	13	1	Bourgoing and Todem, (2010)
	20- 28	0,138 - 0,795	Amoah *et al.* (1995)
Cassava *(Manihot esculenta)*	21,17	6,37	Carvalho Rocha *et al.* (2020)
Pineapple *(Ananas comosus)*	20,5	11,7	Carvalho Rocha *et al.* (2020)
Banana *(Musa paradisiaca)*	21,35	7,98	Carvalho Rocha *et al.* (2020)

oil palm. (Koussihouèdé *et al.*, 2020; Nurjannah *et al.*, 2021; Oomen, 2023). In corn-palm systems, the selection of cultivars tolerant to conditions such as drought or low soil fertility has made it possible to make fertilization more efficient (Danso *et al.*, 2020; Louarn *et al.*, 2021; Nuertey *et al.*, 2010; Rizki *et al.*, 2020). In cassava, the adoption of creeping cultivars is preferred, since they do not interfere with the development of the palm canopy (Leihner, 1983; Nuertey *et al.*, 2010) Generally, there is no negative effect on palm productivity or development in the short term, but this can do occur in the intercropped specie compared to its monoculture (Amalia *et al.*, 2024; de Maijer, 2023; Firmansyah and Umami, 2021; Obi *et al.*, 2023; Rizki *et al.*, 2020). In some cases intercropping can favor greater palm height or fronds etiolation and can have physiological effects on intercropping, such as increased chlorophyll content, increased stomata density, or a change in plant architecture, because of light competition (Hariyadi *et al.*, 2019; Hidayat *et al.*, 2019, 2021; Jeki Daisa *et al.*, 2024; Jurusan *et al.*, 2023; Oomen, 2023; Perez *et al.*, 2024; Rizki *et al.*, 2020; Treetaruyanont *et al.*, 2014). Leaf area index is clue to determinate the optimal distance between plants (Ahmad and Diniyati, 2022).

The integration of crops with oil palm requires differentiated nutrient management strategies (Khomphet *et al.*, 2021; Tanaka *et al.*, 2009) since nitrogen and potassium nutritional imbalances have been recorded mainly in integrated systems (Essono *et al.*, 2023; Rafflegeau *et al.*, 2010). Good nutrition management is crucial in plantations where intercropping has been carried out to compensate for the nutritional imbalances that are generated in young palms, given that macronutrient content may be depleted more rapidly as nutritional demand increases, and that can affect productivity in the long term (Essono *et al.*, 2023; Nuertey *et al.*, 2010; Rizki *et al.*, 2020). In fact, Koussihouèdé *et al.*, 2020, highlight that prioritizing fertilizer application for one crop, and waiting for the other to take advantage of nutrients that were not used, does not meet the nutritional needs of both. In a system of intercropping with young palm, this can cost oil palm productivity in the long term (Koussihouèdé *et al.*, 2020; Rafflegeau *et al.*, 2010).

Root development patterns also play a significant role in minimizing competition between oil palm and companion crops. When crops occupy different soil strata, they are less likely to compete for the same resources, which can enhance overall system efficiency (Erhabor *et al.*, 2002; Erhabor and Filson, 1999; Khomphet *et al.*, 2021; Oluwatobi, 2020a; Oomen, 2023; Putra *et al.*, 2012; Rizki *et al.*, 2020). This principle has been particularly well demonstrated in systems that incorporate leguminous cover crops, which not only improve soil fertility through nitrogen fixation but also contribute to erosion control and organic matter accumulation. These benefits make leguminous species among the most widely used in oil palm intercropping systems (Al Manar *et al.*, 2023; Ruiz and Molina, 2014).

The effects of intercropping on the phytosanitary status of the oil palm plantations are not yet clear. While some evidence suggests that intercropping may reduce pest and disease pressure, the overall impact appears to depend on the specific crop combinations and management practices employed (Blessing *et al.*, 2022; Saravanan *et al.*, 2022). In general, pest and disease management in intercropped systems follows similar protocols to those used in monocultures (Firmansyah and Umami, 2021; Oluwatobi, 2020b, 2020c; Saravanan *et al.*, 2022; Van Leeuwen, 2019). However, in systems such as palm-cacao, there are shared phytosanitary problems. (Afolami and Ajobo, 1983; Bourgoing and Todem, 2010; Dhileepan, 1991; Saravanan *et al.*, 2022). Particularly in the case of plantations in the Americas, *Phytophthora palmivora*, a causal agent of diseases in the two crops, could limit their association, although it is still necessary to clarify which pathovars are involved. (Afolami and Ajobo, 1983; Perrine-Walker, 2020; Torres *et al.*, 2016). Modifying planting distance and layout and including host species of natural enemies can help manage pests and diseases. In cocoa, disease incidence may be higher in the intercropping system than in monoculture. In palm, there may be a decrease in the incidence of *Ganoderma* (Afolami and Ajobo, 1983; Boudreau, 2013; Shameer *et al.*, 2018; Suwandi *et al.*, 2024). Taro intercropped with oil palm can reduce root necrosis caused by Ganoderma in a 82%-96%, thanks to the allelochemical exudated by the tuber (Suwandi *et al.*, 2024).

Water resource management in this type of system has not been widely studied either. Intercropping, in general, can improve water use due to the spatiotemporal distribution of water demand by the different crops and to the conservation of soil moisture, thanks to the decrease in evaporation (Yin *et al.*, 2020). Intercropping oil palm with yam and pineapple has been shown to favor a higher soil moisture content, compared to palm monoculture (Dhandapani *et al.*, 2020). Although water consumption is higher in intercropped systems, due to the water requirements of all crops, there is greater conservation of water in the soil but separate irrigation systems may be required for palm and other crops (Dhandapani *et al.*, 2020; Khasanah *et al.*, 2020; Reddy *et al.*, 2004; Yin *et al.*, 2020). Van Oosterhout *et al.* (2023) found that infiltration rate of the soil in an oil palm agroforest is similar to that of a natural forest, but higher than a soil of a monoculture, highlighting that agroforestry can improve soil water parameters.

Table 6. Benefit/cost ratio of different production systems intercropped with young oil palm.

Production system	Data referred to[1]	Ratio B/ C	Time lapse[2]	Source
Corn (*Zea mays*)	IC	2,86	I	Manorama *et al.* (2019)
	IC	1,43	HC	Koussihouèdé *et al.* (2020)
	IC	1,76	Y	Agustira *et al.* (2018)
Soy (*Glicine max*)	IC	1.51	Y	Agustira *et al.* (2018)
Cassava (*Manihot esculenta*)	IC	1,70	HC	Koussihouèdé *et al.* (2020)
Pineapple (*Ananas comosus*)	IC	2,14	HC	Koussihouèdé *et al.* (2020)
Tomato (*Solanum lycopersicum*)	IC	4,18	HC	Koussihouèdé *et al.* (2020)
Okra (*Abelmochus esculenta*)	IC	1,33	I	Manorama *et al.* (2019)
Onion (*Allium cepa*)	IC	0,26	Y	Reddi *et al.* (2015)
Chili (*Capsicum annuum*)	IC	1,78	I	Manorama *et al.* (2019)
Heliconias (*Heliconia spp.)*	P + IC	2,80	Y	Ramachandrudu *et al.* (2014)
	P + IC	2,38	I	Manorama *et al.* (2019)
Cowpea bean (*Vigna unguiculata*)	IC	1,28	HC	Adri and Yardha (2022)

[1] IC= values only for intercropped crop; P = values only for oil palm crop; P + IC = values considering palm + intercropping
[2] HC =values per harvest cycle; Y = values per year; I =values for the duration of intercropping.

4.2 Profitability of intercropping with oil palm

The profitability of intercropping systems in oil palm cultivation depends on several interrelated factors, including total productivity, market prices, and production costs. Total productivity encompasses the combined yields of both the oil palm and the associated crops, and this aggregate output plays a crucial role in determining the economic viability of the system. However, profitability is also highly sensitive to fluctuations in market prices, which are often influenced by environmental, political, and economic variables. This volatility is particularly relevant in agri-food systems, where commodity prices can shift rapidly and unpredictably (Doporto Miguez and Michelena, 2011; Komarek *et al.*, 2020).

In terms of production costs, intercropping has been shown to reduce certain expenses associated with oil palm maintenance. For example, tasks such as weed control and mulch application may be required less frequently in intercropped systems, thereby lowering labor and input costs. In some cases, the frequency of these tasks can be reduced from five to three times per year (Dissanayake and Palihakkara, 2019; López, 2021; Oluwatobi, 2020c). However, in watermelon, the development of weeds can increase herbicide use costs (Oomen, 2023).

On the other hand, intercropping requires a greater use of workforce to attend to the maintenance and harvesting of all the crops in the system, which means that the cost of labour has a greater share in the cost of production per hectare. (Adri and Yardha, 2022; Khasanah *et al.*, 2020; Slingerland *et al.*, 2019). In pineapple, maize and cassava intercropped systems, labour can represent up to 40% of operational costs (Carvalho Rocha *et al.*, 2020)

Several studies have concluded that the intercropping of transitory crops with palm can become a profitable business, presenting favourable benefit/cost ratios, as shown in (Tab. 6) and (Tab. 7). However, the reports of the studies considered do not necessarily include the cost associated with oil palm cultivation, especially for short-cycle crops, which makes it difficult to estimate economic indicators for intercropping systems.

Certain crops, such as maize, pineapple, cassava and vegetables can generate profits high enough to pay for their own production costs and help to finance part of the production costs of the palm crop during its unproductive stage. (Carvalho Rocha *et al.*, 2020; Carvalho Rocha, Lobato Rodrigues, Texeira, *et al.*, 2007; Koussihouèdé *et al.*, 2020; Leeuwen *et al.*, 2019). For example, Carvalho Rocha et al (2020) estimated that agroforest system with pineapple, cassava or banana could cover between 64.5% and 100% of the production system costs. It is higher than the 13.5% of the cost of oil palm maintenance in the unproductive stage (up to 36 months after planting), reported by Sitorus and Zasari (2023), for a maize-oil palm system.

In long-term crops, such as cocoa, the seasonality of *commodity* prices may contribute to cushioning declines in oil palm yields, compared to monocropping (Khasanah *et al.*, 2020). Although pepper has been mentioned as a potential crop for association with palm because of its price, yields may affect the profitability of the system (Migeon, 2018; Tengoua and Bakoumé, 2005; Zulkifli *et al.*, 2016). Other aspects to be considered include the fact that the integration of semiannual crops allows for profits to be made while the palm begins to produce bunches (Slingerland *et al.*, 2019; Van Leeuwen, 2019). This contributes to generate an early economic entry compared to monoculture palm plantations. (Kosová and Prášil, 2011; Norman, 1979; Trevellan, 2017).

5 Intercropping can boost environmental sustainability of the oil palm agroecosystem

Intercropping has emerged as a promising strategy for enhancing the environmental sustainability of oil palm production systems. This approach contributes to a range of ecosystem services that are essential for maintaining ecological balance and supporting long-term agricultural productivity (Tab. 8) (Abubakar *et al.*, 2023; Masure *et al.*, 2023).

Table 7. Benefit/cost ratio of different production systems intercropped with adult oil palm.

Production system	Data referred to[3]	Ratio B/ C	Time lapse[4]	Source
Cocoa *(Theobroma cacao)*	P + IC	2,78	I	Manorama *et al.* (2019)
	P + IC	1,21 – 2,08	I	Rao *et al.* (2019)
	P + IC	2,43	Y	Ramachandrudu *et al.* (2014)
	P + IC	2,4 - 3,3	I	Khasanah *et al.* (2020)
Pepper *(Capsicum annuum)*	IC	0,73	Y	Tengoua and Bakoumé (2005)
Black pepper *(Piper nigrum)*	P + IC	1,9 - 2,2		Khasanah *et al.* (2020)
Banana *(Musa paradisiaca)*	P + IC	2,69	I	Manorama *et al.* (2019)
Tomato *(Solanum lycopersicum)*	IC	1,88	Y	Tengoua and Bakoumé (2005)
Timber	P + IC	1,21 - 2,01	I	Rahmani *et al.* (2021)
Bush pepper *(Capsicum annuum)*	P + IC	2,86	I	Manorama *et al.* (2019)
Ginger *(Alpinia purpurata)*	P + IC	2,56	Y	Ramachandrudu *et al.* (2014)
	P + IC	2,58	I	Manorama *et al.* (2019)

[3] IC= values only for intercropped crop; P = values only for oil palm crop; P + IC = values considering palm + intercropping
[4] HC =values per harvest cycle; Y = values per year; I =values for the duration of intercropping.

One of the main benefits of intercropping is the increase of the biodiversity of the productive units without affecting (Meijaard and Sheil, 2019). In palm, these biodiversity increases have been found for arthropods, birds and microorganisms (Ashraf *et al.*, 2018; Sapalina *et al.*, 2022; Yahya *et al.*, 2017). This brings on the provision of other ecosystem services such as natural pest and disease control, due to the enrichment of interspecific predation and parasitism relationships. (Ashraf *et al.*, 2018; Ghazali *et al.*, 2016; Saravanan *et al.*, 2022).

Another environmental contribution of intercropping is the regulation of the atmosphere, mainly due to the modification of microclimates (Ashraf *et al.*, 2019; Dhandapani *et al.*, 2020) and the capture of greenhouse gases. It has been found that the practice of intercropping increases carbon sequestration in the form of biomass in crops such as pineapple, corn, cocoa and turmeric (Ahirwal *et al.*, 2022). However, the impact on greenhouse gas emissions can vary depending on the crop combination and site conditions. According to Hariyadi *et al.* *(*2019) emissions (t CO_2 /ha*year) are higher in an eggplant intercrop (10.28) and lower in a chili bell pepper intercrop (8.66), compared to the palm monoculture (8.78). In the palm-pineapple system, methane emissions have been reported to be higher than those of the palm monoculture, related to soil drainage conditions (Dhandapani *et al.*, 2020).

GHG emissions depend on environmental conditions: the rate of CO_2 emission in the soil is higher when the soil is wet, since the respiration of roots and soil microorganisms is stimulated by the decomposition of accumulated leaf litter during the dry period and after a period of water stress (Dhandapani *et al.*, 2020; Linn and Doran, 1984; Rodrigues *et al.*, 2016; Zanchi *et al.*, 2009). In addition, the size of the plant root system influences the carbon content accumulated in the soil.

Land is a fundamental factor of production for the existence of agricultural activity and its access is a determining factor in the human development of rural communities (de Vos, 2016). Intercropping is a production alternative that makes land use more efficient, since it achieves higher productivity per unit area compared to monoculture systems. The Table 9 shows the estimated values of the equivalent land ratio or LER, *i.e.*, the relative area required by a monoculture to produce the same as its intercropping system (Bitew *et al.*, 2019; Bybee-Finley and Ryan, 2018; El-Ghobashy *et al.*, 2018; Hong *et al.*, 2020; Khasanah *et al.*, 2020; Mead and Willey, 1980; Petrie and Bates, 2017). Semi-annual and semestral intercrops seem to be more efficient than their monoculture homologue, as their LER is higher than 1. It is important to mention that the data are referred to a same area unit, given that intercropped crops don't occupy the same extension than its monocrop equivalent. Of course, these results aren't enough to support a decision-making process, given that few of those reports are including a long-term vision of oil palm production system and have focused more on the intercropped specie, as productivity data are faster to collect.

6 The adoption of oil palm intercropping systems is influenced by the perception of their effectiveness

Intercropping has a positive impact on rural communities by promoting food security, generating well-being in productive units and strengthening the social fabric. This is particularly important among small-scale producers, who, depending on the mix of crops they choose to grow, may use the production to supply household food or to sell all or part of it. In Indonesia, for example, 80% of the daily diet of households comes from their own crops. (Ahirwal *et al.*, 2022; Cheyns and Rafflegeau, 2005; Hervas, 2021; Koczberski *et al.*, 2012, 2018).

However, the perception of usefulness that producers have is decisive in the adoption of crop intercropping, despite its possible benefits. This perception is dynamic and is conditioned by factors inherent to the producer (such as their socioeconomic and cultural profile) and by external factors (such as the environmental and economic context) (Susanti *et al.* 2021; Hendrawan and Musshoff 2024).

Intercropping with palm is seen as a more complex system, difficult to manage and more labour-intensive (Madjid *et al.*, 2023; Susanti, *et al.*, 2021; Susanti *et al.*, 2021). An oil palm + cocoa system may require 338 additional man-days per

Table 8. Environmental services provided by the palm production system with intercropping.

Environmental service type	Environmental service description	Finding	Source
Provisioning	Terrestrial plants grown for nutrition, materials or energy.	The intercropping systems provide food, building materials, inputs for energy production and ornamentation.	Koczberski *et al.* (2012); Maitra *et al.* (2021); Okere *et al.* (2015); Sagna *et al.* (2019)
Regulating	Control of erosion rates	Cover crops (mainly legumes) provide protection against erosion and regulate runoff.	Erhabor *et al.* (2002); Satriawan *et al.* (2021)
	Temperature and humidity control	The systems intercropped with black pepper showed a reduction in air and soil temperature of 1.3 and 2.1 °C.	Ashraf *et al.* (2019)
	Regulation of the chemical composition of the atmosphere	Intercropping can increase capture of CO_2 in the atmosphere and storage of carbon in soil reserves, up to 44%.Intercropping with pineapple can generate 30% more carbon stock compared to palm monoculture but generate methane emissions. Also, the system with cocoa can offer a lower carbon debt and have higher above and below ground carbon accumulation (116.7 Mg C/ha).	Ahirwal *et al.* (2022); Albrecht and Kandji, (2003); Besar *et al.* (2020); Budiadi *et al.* (2019); Chinade *et al.* (2015); Gomes *et al.* (2021); Khasanah *et al.* (2020); Lal and Kimble (1997); Montagnini and Nair (2004); Ramos *et al.* (2018); Tscharntke *et al.* (2011)
		Decrease in CO_2 emissions due to increased photosynthetic activity per unit area and carbon sequestration in the soil. Emissions can decrease between 12.54% and 27.28% compared to bare soil.	Kusumawati *et al.* (2021).
		Palm height and canopy diameter reduce understory tree growth and allow the oil palm to sequester 12 to 500 times more carbon.	Besar *et al.* (2020).
	Pest and disease control	Increased number of predatory and parasitoid insects	Ashraf *et al.* (2018)
		Reduction of damage generated by pathogens (*Ganoderma boninense*) on oil palm-cocoa system.	Fadli *et al.* (2023); Suwandi *et al.* (2024)
Supporting	Regulation of the hydrological cycle and water flow.	Intercropping palm oil with cocoa can replenish more groundwater compared to monoculture.	Khasanah *et al.* (2020)
	Maintenance of populations and habitats	Increase in the abundance of bird species between 4 and 41% higher in the plots with polycultures than in the oil palm monoculture.	Yahya *et al.* (2017).
		Increased richness and diversity of arthropods (predatory and decomposing insects).	Ashraf *et al.* (2018).
		Three times higher mycorrhizal colonization in intercropping systems, especially in palm alleys.	da Silva Maia *et al.* (2021)
Cultural	Enjoyment activities	The value of the landscape and biodiversity may allow for passive recreation activities.	Yahya *et al.* (2017).

hectare, compared with sole oil palm (Rao *et al.*, 2019). In small producers, the cultivation work is generally carried out by the members of the family nucleus, so intercropping could increase the costs of hiring external workers (Adri and Yardha, 2022; Okere *et al.*, 2015; Orewa, 2008). This perception is not only observed among producers who have monoculture palm systems, but also among producers who already have agroforestry systems without oil palm (Perez Braga *et al.*, 2024). Intercropping is also not easily adopted in industrial plantations with mechanized labor, as it reduces work efficiency (Dhandapani *et al.*, 2020).

Palm growers have also considered crop intercropping as a production system with high uncertainty regarding profitability since it is thought that crop integration causes a detriment to palm productivity due to interspecific competition (Hendrawan and Musshoff, 2024; Perez Braga *et al.*, 2024; Susanti *et al.*, 2020). The positive financial results of the monoculture system, the management recommendations made by the

Table 9. Land equivalent ratio (LER) reported for intercropping with palm.

Intercropping	LER	Comparison monoculture	Reported by
Cassava (*Manihot esculenta)*	1,38	Cassava	Carvalho Rocha *et al.* (2020)
Pineapple *(Ananas comosus)*	0,98	Pineapple	Carvalho Rocha *et al.* (2020)
Banana (*Musa paradisiaca*)	1,36	Banana	Carvalho Rocha *et al.* (2020)
Corn (*Zea mays*) + soybean (*Glicine max*)	1,14 - 1,76	Corn and soybeans	Rizki *et al.* (2020)
Peanuts (*Arachis hypogaea*)	4,10	Peanuts	Putra *et al.* (2012)
Corn (*Zea mays*)	1,32	Corn	Agustira *et al.* (2018)
Soy (*Glicine max*)	3,30	Soy	Putra *et al.* (2012)
	1,18	Soy	Agustira *et al.* (2018)
Black pepper *(Piper nigrum)*	0,77	Palm	Migeon, (2018)
	0,99	Palm	Khasanah *et al.* (2020)
Cocoa (*Theobroma cacao)*	1,44	Palm	Khasanah *et al.* (2020)

technical assistants of the oil extraction companies and the lack of knowledge about the management of interleaving reinforce this idea. However, the possible income left by integration, whether with species with high commercial value or with easy marketing, also make these systems attractive, especially to face fluctuations in commodity prices (Madjid *et al.*, 2023; Salleh and Harun, 2015; Susanti *et al.*, 2020)

The gaps can be overcome through better agronomic practices that have been developed from the traditional knowledge and experiences of the communities that have adopted these production systems, but also, in an incipient way, from the scientific development of the institutions (de Castro and Futemma, 2021; Sagna *et al.*, 2019). Particularly in Brazil, de Castro and Futemma (2021) have described the SAFTA (Sistema Agroflorestal De Tomé-Açu) system as a success story in the adoption of agroforestry systems with oil palm, which has allowed the exchange of indigenous knowledge, scientific knowledge and commercial knowledge, improving the relationship between the different actors in the community. In addition, SAFTA has made it possible to strengthen peasant identity and local empowerment.

The sustainability of intercropping systems implies that producers have adequate training to enable good agronomic management, which is especially important for small producers who, for the most part, rely on empirical knowledge for decision making (Hong *et al.*, 2020; Okere *et al.*, 2015). Likewise, educational level, having another economic activity and whether or not the farmer lives near the oil palm crop, determine the decision to implement intercropping systems with oil palm (Susanti *et al.*, 2021).

Women's participation is important in palm agroforestry systems, especially in the planning and management of production units. Koczberski *et al.* (2018) also reported that men tend to work in the palm while women tend to do the work of the intercropped species, especially, when they are food crops. Although each community has its own dynamics, intercropping could reduce women's vulnerability to food insecurity and lack of income.

7 Summary and perspective

Intercropping is a means of sustainable intensification that increases the overall productivity of a production unit and improves the efficiency of resource use - such as water and soil nutrients - even though the yields of the crops involved may be lower than those reported if they were planted under monoculture (Martin-Guay *et al.*, 2018; Oluwatobi, 2020a; Rizki *et al.*, 2020; Sun *et al.*, 2021; Yin *et al.*, 2020). Additionally, intercropping favors the resilience of agricultural systems to scenarios such as climate change, since the diversity of species in the agroecosystem reduces the use of pesticides, attracts the natural enemies of pests and provides them with refuge (Khatun *et al.*, 2020; Petrie and Bates, 2017). They also strengthen the food sovereignty and security of the communities that adopt and adapt them to their conditions and culture. (Knörzer *et al.*, 2009; Maitra *et al.*, 2021; Santika *et al.*, 2019).

The adoption of intercropping as a complementary piece on the road to sustainability in the palm sector requires adequate technical, financial and training bases for producers. The adoption of this practice is easier for small-scale palm growers, who account for at least 40% of the area planted in Malaysia and 27% in Indonesia. (RSPO, 2023). In Ivory Coast, at least 70% of palm growers are small-scale. (Solidaridad, 2022). In Colombia, they represent 75% of the total number of palm growers, but only 10% of the total area. (Fedepalma, 2022).

However, this vision of the oil palm cropping breaks with the current paradigm on crop management. Perceptions on the management of palm plantations differ among the various actors of the crop, according to their interests, but putting in the debate the dichotomy of instrumental - relational value of production (Lusiana *et al.*, 2023; Susanti *et al.*, 2021). The transition from monocultures to more complex agroforestry systems may not be seen as necessary, due to the risk of loss of competitiveness of the plantations, the socioeconomic benefits derived from the *status quo*, and the fact that the implementation of Good Agricultural Practices already classify them as equal or similar to agroforestry systems (Rivera-Mendez and Romero Angulo, 2018). In contrast, the arguments in favor of the paradigm shift focus and the need to increase food security in farming families, income diversification, the perceived generation of environmental impacts of poor monoculture management, the weaknesses of crop governance, among others (Purwanto *et al.*, 2020; Rival and Chalil, 2023; Susanti *et al.*, 2020).

The heterogeneity of agroecological conditions implies an agronomic management of intercropping that is different from that of monoculture and that has not yet been standardized. Given that each crop combination has an inherent management, it is necessary to deepen the knowledge of which are the optimal species, materials and planting distances to implement these systems, as well as the ecophysiology, pollinator dynamics and phytosanitary behaviour of these crops (Budiadi *et al.*, 2019).

Although the agronomic practices that are implemented in this type of production systems have been generated from the knowledge of the producer, there is currently interest from academia to transform current production systems into more sustainable, participatory and technically viable ones. Therefore, of the research referenced in this document, 31% of the results (58 documents) come from trials carried out by researchers. Initiatives such as the TRIAL Project, the SAFTA Project or are examples of mature innovations on sustainable oil palm production at a commercial level: species diversification, knowledge exchange between producers and researchers and monitoring of palm productivity are key elements of their success/implementation (Braga *et al.*, 2024; de Castro and Futemma, 2021; Rival *et al.*, 2022; Rival and Chalil, 2023). The application of models to simulate the agronomic behaviour of these systems is another strategy by academia to promote the adoption of intercropping, offering producers tools for decision-making (Khasanah *et al.*, 2020; Slingerland *et al.*, 2019).

In economic terms, oil palm monocultures face challenges related to competitiveness and profitability. The investment and maintenance costs of the crop during the unproductive period - which, in the case of oil palm, can take between 2 to 3 years to start producing fruit - can range from USD 61.47 to USD 201.5 per tonne. (LMC, 2022). Also, palm oil is a *commodity* characterized by volatile prices, which in turn depend on the dynamics of oil prices (due to its use in biodiesel) and palm oil inventories in Southeast Asia (Arshad *et al.*, 2012; LMC International, 2022). Intercropping can help to reduce the financial risk of a production system by diversifying income sources. Economic benefit, of course, depends on the market prices of each crop, but commodities such as cocoa and pepper may be interesting due to their high value. Nevertheless, the transition from a monoculture to a polyculture implies higher investment costs, labour costs and access to information, so financing and the purchasing power of producers play an important role in the adoption of intercropping.

Workforce scarcity is a reality that oil palm growers are facing and so conditionate the will to adopt. In monocropping system, a worker can be assigned to at least eight hectares, so an intercropping system would not be efficient if the production unit is not able to supply enough workers by area unit (Azman *et al.*, 2015; Ruíz Álvarez *et al.*, 2022). Studying how work productivity can be increased is challenging, especially if it is considered that mechanization can be restrained in some cases. Gaps of information in this area represents a great opportunity for further research, particularly in the design of new machines of new planting patterns.

Intercropping contributes to the fact that less land is needed to achieve similar productivities to those of monoculture systems, of course, per unit area. Efficient land use reduces pressure on natural resources. Specifically, it reduces the need to expand the agricultural frontier or to convert forest into cropland. The association of palm with corn, cassava, plantain or cocoa can be an alternative with higher productivity than monoculture. However, it is important to analyse the negative environmental impacts, especially those that may have an impact at the river basin level. Aspects such as water consumption, impact on erosion, waste and pollutant management and territorial planning require greater attention. Likewise, regional socioeconomical impact must be considered, given that intercropping can have difficulties in adapting to economies of scale, as they are highly site-specific, more complex to manage and productive uncertain.

Finally, institutional and public infrastructure support must be sufficient to enable producers, especially small producers, to access marketing channels for their products (Susanti *et al.*, 2021). The promotion of the association of oil palm crops requires strong institutional support from both the public and private sectors to enable the definition of comprehensive environmental and agricultural public policies. For example, in Indonesia, Ministerial Decree Permen LHK No. 9/2021 and specific environmental regulations in Brazil set a political precedent for transforming oil palm production systems (Costa *et al.*, 2024; Madjid *et al.*, 2023).

8 Conclusion

The adoption of intercropping in the palm sector represents a critical step towards sustainability, offering numerous benefits such as increased productivity, improved resource efficiency, and enhanced resilience to climate change. The potential for greater food security, income diversification, and environmental benefits makes it a promising alternative, despite the challenges posed by the transition from monoculture to intercropping, such as higher initial investment costs, need for specialized knowledge, and potentially unpredictable environmental impacts. Successful implementation requires robust technical, financial, and training support for producers, particularly smallholders.

Funding This study was funded by Fondo de Fomento Palmero.

Conflicts of interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.

Author contribution statement

All authors contributed to the study conception and design. Daniel Eduardo Munévar Martínez made the conceptualization, data curation, methodology, visualization and writing of the paper. María Celina Estupiñán Villamil made the conceptualization and writing of the paper. Elizabeth Ruiz Álvarez made conceptualization, editing and supervision of the paper. Mauricio Mosquera Montoya made the reviewing of the paper.

References

Abubakar A, Gambo J, Ishak MY. 2023. Chapter Three - Navigating climate challenges: Unraveling the effects of climate change on oil palm cultivation and adaptation strategies. In M. J. Cohen (Ed.), Advances in Food Security and Sustainability (Vol. 8, pp. 95–116). Elsevier.

Adade FB. 2022. Oil Palm (Elaeis guineensis) Cultivation and Food Security in the Tropical World. In H. Kamyab (Ed.), Elaeis guineensis. IntechOpen. https://doi.org/10.5772/intechopen.98486

Adenikinju SA, Afolami CA, Ajobo O. 1991. Preliminary comparative analysis of cocoa yield under three treatments in combination with oil palm in Nigeria. In Ghana Journal of Agricultural Science (Vol. 24, Issue 1). https://doi.org/10.4314/gjas.v24i1.2021

Adri Y. 2022. Farming analysis of intercropping of long bean on palm oil plantations (case study). IOP Conf Ser: Earth Environ Sci 978. https://doi.org/10.1088/1755-1315/978/1/012039

Afolami CA, Ajobo O. 1983. An economic evaluation of a croping system: the case of cocoa grown in combination with oil-palm. Café Cacao Thé 27: 121–126.

Agele SO, Obi AE, Aiyelari OP. 2019. Effects of age of oil palm on the growth, competitive interactions and mixture productivity of cassava, maize and pepper in oil palm-based strip intercropping system in the rainforest of Nigeria. London J Res Sci: Natl Formal 19. https://research.journalspress.com/index.php/science/article/view/653

Agustira M, Lubis I, Listia E, Akoeb E, Harahap I, Lubis M. 2018. Analisis Finansial dan Ekonomi Tanaman Sela (Jagung dan Kedelai) pada Areal Tanaman Belum Menghasilkan Kelapa Sawit. J. Penelitian Kelapa Sawit 26: 141–152.

Ahirwal J, Sahoo UK, Thangjam U, Thong P. 2022. Oil palm agroforestry enhances crop yield and ecosystem carbon stock in northeast India: implications for the United Nations sustainable development goals. Sustain Product Consumpt 30: 478–487.

Ahmad B, Diniyati D. 2022. Intercropping of short rotation trees species with the oil palm (*Elaeis guineensis* Jacquin) plantations: lesson learned from smallholder farmers in Indonesia. Asian J Adv Res 12: 25–33.

Al Manar P, Hikmat A, Zuhud EAM. 2023. The role of Leguminosae plants for soil fertility in oil palm plantations. IOP Conf Ser: Earth Environ Sci 1243: 012016.

Albrecht A, Kandji ST. 2003. Carbon sequestration in tropical agroforestry systems. Agric Ecosyst Environ 99: 15–27.

Alridiwirsah, Harahap EM, Akoeb EN, Hanum H. 2019. Integrated cropping system of rice with oil palm: local and new varieties. Bulgar J Agric Sci 25: 494–498.

Alves P, Borges M, Ferreira E, Cravo M. 2013. Avaliação da produtividade das cultivares de Oryza sativa nas entrelinhas da palma de óleo (*Elaeis guineensis*) - Tailândia-PA. 17o Semin. Iniciação Científica e 1o Semin. Pós-Graduação Da Embrapa Amaz. Orient. https://ainfo.cnptia.embrapa.br/digital/bitstream/item/91966/1/Resumo41.pdf

Amalia R, Susanto A, Nurkhoiry R, Farr, Nugrahaeni N, Amanah A. 2024. Study of porang (*Amorphophallus muelleri* blume) as intercrops in oil palm immature plants. IOP Conf Series: Earth Environ Sci 1308: 012052.

Amoah FM, Nuertey B, Baidoo-Addo K, Oppong FK, Asamoah TSO. 1995. Underplanting oil palm with cocoa in Ghana. Agroforestry Syst 30: 289–299.

Arshad FM, Awad A, Hameed A. 2012. Crude oil, palm oil stock and prices: how they link. Rev Econ Finance 3: 48–57.

Ashraf M, Sanusi R, Zulkifli R, *et al.* 2019. Alley-cropping system increases vegetation heterogeneity and moderates extreme microclimates in oil palm plantations. Agric Forest Meteorol 276-277: 107632.

Ashraf M, Zulkifli R, Sanusi R, *et al.* 2018. Alley-cropping system can boost arthropod biodiversity and ecosystem functions in oil palm plantations. Agric Ecosyst Environ 260: 19–26.

Azman I, Siti A, Zuraihan S. 2015. Labour productivity in the Malaysian oil palm plantation sector. Oil Palm Ind Econ J 15: 10.

Baccar M, Bouaziz A, Dugué P., Gafsi M, Le Gal PY. 2019. The determining factors of farm sustainability in a context of growing agricultural intensification. Agroecol Sustain Food Syst 43: 386–408.

Bakeri SA, Maidin MST, Masri MMM. 2019. Soil bacterial biodiversity in development of secondary logged-over forest to oil palm plantation in mineral soil of Belaga, Sarawak. J Oil Palm Res 31: 394–411.

Besar NA, Suardi H, Phua MH, *et al.* 2020. Carbon stock and sequestration potential of an agroforestry system in Sabah, Malaysia. Forests 11: 1–16.

Bitew Y, Alemayehu G, Adego E, Assefa A. 2019. Boosting land use efficiency, profitability and productivity of finger millet by intercropping with grain legumes. Cogent Food Agric 5. https://doi.org/10.1080/23311932.2019.1702826

Blessing DJ, Gu Y, Cao M, Cui Y, Wang X, Asante-Badu B. 2022. Overview of the advantages and limitations of maize-soybean intercropping in sustainable agriculture and future prospects: a review. Chilean J Agric Res 82: 177–188.

Boudreau MA. 2013. Diseases in intercropping systems. Annu Rev Phytopathol 51: 499–519.

Bourgoing R, Todem H. 2010. Intercropping Cocoa with Oil Palm or Coconut. Setting up a new plot on fallows or savannah areas. https://agritrop.cirad.fr/569519/1/document_569519.pdf

Budiadi, Susanti A, Marhaento H, Imron MA, Permadi DB. 2019. Oil palm agroforestry : an alternative to enhance farmers ’ livelihood resilience. https://doi.org/10.1088/1755-1315/336/1/012001

Bybee-Finley KA, Ryan MR. 2018. Advancing intercropping research and practices in industrialized agricultural landscapes. Agriculture (Switzerland) 8. https://doi.org/10.3390/agriculture8060080

Carvalho Rocha RN, Lobato Rodrigues M. do R., Lopes R, Cysne A, Vasconcelos de Macedo J. 2020. Production and cash flow of oil palm intercropping systems an amazonian degraded area. Nativa 8: 52–57.

Carvalho Rocha RN, Lobato Rodrigues M. do R., Texeira P, Lopes R, Vieira R, Vasconcelos J. 2007. Rentabilidade economica comparativa entre o custo de producao do dendezeiro (*Elaeis guineensis*) em monocultivo e intercalado com mandioca (*Manihot esculenta*) em areas degradadas na Amazonia Ocidental. 4° Congresso Brasileiro de Plantas Oleaginosas, Óleos, Gorduras e Biodiesel.

Carvalho Rocha RN, Lobato Rodrigues M. do R., Vasconcelos de Macêdo JL, Lopes R, Teixeira PC, Alves de Lima WA. 2007. Análise financeira do custo de produção do dendezeiro (Elaeis guineensis jacq.) em monocultivo e intercalado com abacaxi (Ananas comusus l. merril) em áreas degradadas na Amazônia Ocidental. 4° Congresso Brasileiro de Plantas Oleaginosas, Óleos, Gorduras e Biodiesel, 702–708.

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. OCL 12: 111–120.

Chinade AA, Siwar C, Ismail SM, Isahak A. 2015. A review on carbon sequestration in Malaysian forest soils: opportunities and barriers. Int J Soil Sci 10: 17–27.

Costa C, Costa I, Costa M, Lima B, Souza G, Silva R. 2024. Criteria for scaling up oil palm agroforestry in northeastern Pará, Brazil. Trop Forest Issues 62. https://agritrop.cirad.fr/608907/1/608907.pdf#page=80

da Silva Maia R, Vasconcelos SS, Viana-Junior AB, Castellani DC, Kato OR. 2021. Oil palm (*Elaeis guineensis*) shows higher mycorrhizal colonization when planted in agroforestry than in monoculture. Agroforestry Syst 95: 731–740.

Danso I, Larbi E, Andoh-Menash E, Ribeiro PF, Adjarko IK, Agyarko-Mintah E. 2020. Nitrogen fertilizer management strategy for oil palm-maize intercropping system in the semi-deciduous forest zone of Ghana. Ghana J Agric Sci 55: 75–86.

de Castro F, Futemma C. 2021. Farm knowledge co-production at an old amazonian frontier: Case of the agroforestry system in tomé-açu, brazil. Rural Landscapes 8: 1–11.

de Maijer D. 2023. Evaluation of Intercropping Watermelon and Immature Oil Palm: Implications for Vegetative Growth, Fruit Weight and Yield. Wageningen University.

de Vos RE. 2016. Multi-functional lands facing oil palm monocultures: a case study of a land conflict in West Kalimantan, Indonesia. Aust J South-East Asian Stud 9: 11–32.

Dhandapani S, Girkin NT, Evers S, Ritz K, Sjögersten S. 2020. Is intercropping an environmentally-wise alternative to established oil palm monoculture in tropical peatlands? Front Forests Glob Change 3: 1–8. https://doi.org/10.3389/ffgc.2020.00070

Dhandapani S, Girkin NT, Evers S, Ritz K, Sjögersten S. 2022. Immediate environmental impacts of transformation of an oil palm intercropping to a monocropping system in a tropical peatland. Mires Peat 28: 1–17.

Dhandapani S, Ritz K, Evers S, Sjögersten S. 2019. Environmental impacts as affected by different oil palm cropping systems in tropical peatlands. Agric Ecosyst Environ 276: 8–20.

Dhileepan K. 1991. Insect pests of intercrops and their potential to infest oil palm in an oil-palm-based agroforestry system in India. Trop Pest Manag 37: 57–58.

Dissanayake SM, Palihakkara IR. (2019). A Review on Possibilities of Intercropping with Immature Oil Palm. International Journal For Research in Applied Sciences and Biotechnology, 06(06), 23–27. https://doi.org/10.31033/ijrasb.6.6.5

Dissanayake SM, Palihakkara IR. (2023). Effects of intercropping of immature oil palm (Elaeis guineensis) with banana, ginger, and turmeric in the Galle District, Sri Lanka. Environmental Quality Management. https://doi.org/10.1002/TQEM.21980

Doporto Miguez I, Michelena G. (2011). La volatilidad de los precios de los commodities: el caso de los productos agrícolas. In Documentos de trabajo (Issue 19). https://www.google.com/url?sa=t&source=web&rct=j&url=http://www.cei.gov.ar/userfiles/parte%25203a_1.pdf&ved=2ahUKEwj36tax-NfqAhURTd8KHZtgBU0QFjAAegQIAxAB&usg=AOvVaw0eH38aEleVvuWpSKebJBlQ

Drescher J, Rembold K, Allen K, *et al.* (2016). Ecological and socio-economic functions across tropical land use systems after rainforest conversion. Philosophical Transactions of the Royal Society B: Biological Sciences, 371(1694). https://doi.org/10.1098/rstb.2015.0275

Duchene O, Vian JF, Celette F. (2017). Intercropping with legume for agroecological cropping systems: Complementarity and facilitation processes and the importance of soil microorganisms. A review. Agriculture, Ecosystems and Environment, 240, 148–161. https://doi.org/10.1016/j.agee.2017.02.019

El-Ghobashy YE, Shams AS, Lamlom MM. (2018). Maximizing Land Use Efficiency by Intercropping Cowpea with Some Maize Cultivars under Different Maize Planting Geometries. Agricultural Sciences, 09(12), 1601–1620. https://doi.org/10.4236/as.2018.912112

Emanuelli MS, Jonsén J., Monsalve Suárez S. (2011). Azúcar roja, desiertos verdes. In S. Trujillo (Ed.), *2009* (Vol. 1, Issue 54). FIAN Internacional. https://doi.org/10.22201/fcpys.24484938e.2011.54.25679

Erhabor JO, Aghimien AE, Filson GC. (2002). The Root Distribution Pattern of Young Oil Palm (Elaeis guineensis jacq) Grown in Association with Seasoned Crops in Southwestern Nigeria. Journal of Sustainable Agriculture, 19(3), 97–110. https://doi.org/10.1300/J064v19n03_09

Erhabor JO, Filson GC. (1999). Soil fertility changes under an oil palm-based intercropping system. Journal of Sustainable Agriculture, 14(2-3), 45–61. https://doi.org/10.1300/J064v14n02_06

Escobar D, Olivera M, Parra M, *et al.* (2010). Estudio de caracterización del empleo en el sector palmero colombiano.

Essono DM, Batamack Nkoué B., Voundi E, *et al.* (2023). Nutrient availability challenges the sustainability of low-input oil palm farming systems. Farming System, 1(1). https://doi.org/10.1016/j.farsys.2023.100006

ETA, TBI. (2021). Intercropping in oil palm plantations A technical guide (Ecological Trends Alliance & Tropenbos International (eds.)).

Fadli R, Suwandi S, Damiri N, Muslim A, Irsan C. (2023). Effect of mixed cropping of water yam (Dioscorea alata) on Ganoderma disease of oil palm. Journal of Phytology, 15, 7–11. https://doi.org/10.25081/jp.2023.v15.7641

FAO. (2001). El maíz en los trópicos. https://www.fao.org/3/x7650s/x7650s00.htm

Fedepalma. (2022). Informe de Gestión FEDEPALMA 2022.

Feintrenie L, Chong WK, Levang P. (2008). Why do farmers prefer oil palm? Lessos learnt from Bungo district, Indonesia. Journal of the Illuminating Engineering Institute of Japan, 92(8), 508–510.

FENALCE. (2008). Maíz en asocio con otros cultivos.

Firmansyah E, Umami A. (2021). Intercropping potential of oil palm (E. guineensis Jacq.) and liberica coffee (C. liberica L.): a case study in smallholder plantation. Journal of Applied Agricultural Science and Technology, 5(2), 106–116.

Gebru H. (2015). A Review on the Comparative Advantage of Intercropping Systems. Journal of Biology, Agriculture and Healthcare, 5(9), 28–38. http://www.iiste.org/Journals/index.php/JBAH/article/view/21387

George T. (2014). Why crop yields in developing countries have not kept pace with advances in agronomy. In Glob. Food Sec. (Vol. 3, Issue 1, pp. 49–58). https://doi.org/10.1016/j.gfs.2013.10.002

Ghazali A, Asmah S, Syafiq M, *et al.* (2016). Effects of monoculture and polyculture farming in oil palm smallholdings on terrestrial arthropod diversity. Journal of Asia-Pacific Entomology, 19(2), 415–421. https://doi.org/10.1016/J.ASPEN.2016.04.016

Giller KE, Hijbeek R, Andersson JA, Sumberg J. (2021). Regenerative Agriculture: An agronomic perspective. Outlook on Agriculture, 50 (1), 13–25. https://doi.org/10.1177/0030727021998063

Glaze-Corcoran S, Hashemi M, Sadeghpour A, *et al.* (2020). Understanding intercropping to improve agricultural resiliency and environmental sustainability. In Advances in Agronomy (1st ed., Vol. 162). Elsevier Inc. https://doi.org/10.1016/bs.agron.2020.02.004

Gomes MF, Vasconcelos SS, Viana-Junior AB, *et al.* (2021). Oil palm agroforestry shows higher soil permanganate oxidizable carbon than monoculture plantations in Eastern Amazonia. Land Degradation and Development, 32(15), 4313–4326. https://doi.org/10.1002/ldr.4038

Hamann S. (2018). Agro-industrialisation and food security: dietary diversity and food access of workers in Cameroon's palm oil sector. Canadian Journal of Development Studies, 39(1), 72–88. https://doi.org/10.1080/02255189.2017.1336079

Harari Y. (2018). 21 lecciones para el siglo XXI (Vol. 4, Issue 1).

Hariyadi H, Jarwadi P, Rosa D, Tri M, Ani K. (2019). Response of Immature Oil Palm Growth and CO2 emission on Intercropping System After Replanting. International Journal of Oil Palm, 2(2), 81–86. https://doi.org/10.35876/ijop.v2i2.30

Hendrawan D, Musshoff O. (2024). Risky for the income, useful for the environment: Predicting farmers' intention to adopt oil palm agroforestry using an extended theory of planned behaviour. Journal of Cleaner Production, 475(January), 143692. https://doi.org/10.1016/j.jclepro.2024.143692

Hervas A. (2021). Mapping oil palm-related land use change in Guatemala, 2003-2019: Implications for food security. Land Use Policy, 109(August 2020), 105657. https://doi.org/10.1016/j.landusepol.2021.105657

Hidayat T, Koesmaryono Y, Impron, Ghulamahdi M. (2019). Intensifying of reflected radiation under oil palm canopy and its effect on growth and production of soybean. IOP Conference Series: Earth and Environmental Science, 365(1). https://doi.org/10.1088/1755-1315/365/1/012001

Hidayat T, Koesmaryono Y, Impron I, Ghulamahdi M. (2021). The effectiveness of reflective mulch in the intercropping system between soybean and oil palm: Effects on growth, chlorophyll content, and photosynthetic characteristics. Journal of Agricultural Meteorology, 77(2), 128–138. https://doi.org/10.2480/agrmet.D-20-00042

Hong Y, Heerink N, van der Werf W. (2020). Farm size and smallholders' use of intercropping in Northwest China. Land Use Policy, 99(August), 105004. https://doi.org/10.1016/j.landusepol.2020.105004

Idawanni, Ferayanti F. (2021). Pertumbuhan Dan Hasil Kedelai Sebagai Tanaman Sela Diantara Tanaman Kelapa Sawit Di Kabupaten Aceh Barat Daya. Jurnal Penelitian Agrosamudra, 8 (2), 39–45. https://doi.org/10.33059/jupas.v8i2.4344

Jeki Daisa, Wawan M. Amrul Khoiri, Zakaria. (2024). Growth and production of sweet corn (Zea mays saccharata Sturt.) as an intercrop in immature oil palm plantations (TBM 2) on dystrudepts soil given MB green manure (Mucuna bracteata) and NPK fertilizer. International Journal of Science and Research Archive, 11(1), 1271–1280. https://doi.org/10.30574/ijsra.2024.11.1.0138

Jurusan D, Fakultas A, Universitas P. (2023). Growth Effects of Corn Plants (Zea mays) on Agronomic Aspects of Oil Palm Tree Stands. 20(1).

Kangas K, Brown G, Kivinen M, *et al.* (2022). Land use synergies and conflicts identification in the framework of compatibility analyses and spatial assessment of ecological, socio-cultural and economic values. Journal of Environmental Management, 316(April). https://doi.org/10.1016/j.jenvman.2022.115174

Khasanah N, van Noordwijk M, Slingerland M, *et al.* (2020). Oil Palm Agroforestry Can Achieve Economic and Environmental Gains as Indicated by Multifunctional Land Equivalent Ratios. Frontiers in Sustainable Food Systems, 3(January), 1–13. https://doi.org/10.3389/fsufs.2019.00122

Khatun K, Maguire-Rajpaul VA, Asante EA, McDermott CL. (2020). From Agroforestry to Agroindustry: Smallholder Access to Benefits From Oil Palm in Ghana and the Implications for Sustainability Certification. Frontiers in Sustainable Food Systems, 4(March), 1–13. https://doi.org/10.3389/fsufs.2020.00029

Khomphet T, Eksomtramage T, Anothai J, Popet P. (2021). Effects of Perennial Intercrops on Oil Palm Agronomic and Yield Traits. Indian Journal of Agricultural Research, 55(3), 317–322. https://doi.org/10.18805/IJARe.A-610

Knörzer H, Graeff-Hönninger S, Guo B, Wang P, Claupein W. (2009). The Rediscovery of Intercropping in China: A Traditional Cropping System for Future Chinese Agriculture - A Review. Climate Change, Intercropping, Pest Control and Beneficial Microorganisms, 13–44. https://doi.org/10.1007/978-90-481-2716-0_3

Koczberski G, Curry GN, Bue V. (2012). Oil palm, food security and adaptation among smallholder households in Papua New Guinea. Asia Pacific Viewpoint, 53(3), 288–299. https://doi.org/10.1111/j.1467-8373.2012.01491.x

Koczberski G, Curry GN, Bue V, Germis E, Nake S, Tilden GM. (2018). Diffusing Risk and Building Resilience through Innovation: Reciprocal Exchange Relationships, Livelihood Vulnerability and Food Security amongst Smallholder Farmers in Papua New Guinea. Human Ecology, 46(6), 801–814. https://doi.org/10.1007/s10745-018-0032-9

Komarek AM, De Pinto A, Smith VH. (2020). A review of types of risks in agriculture: What we know and what we need to know. Agricultural Systems, 178(November 2019), 102738. https://doi.org/10.1016/j.agsy.2019.102738

Kosová K., Prášil I. (2011). Annual field crops. In K. B. Storey & K. K. Tanino (Eds.), Temperatura adaptation in a Chancing Climate: Nature at Risk. CAB International.

Koussihouèdé H, Aholoukpè H, Adjibodou J, *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

Koussihouèdé H, Clermont-Dauphin C, Aholoukpè H, *et al.* (2020). Diversity and socio-economic aspects of oil palm agroforestry systems on the Allada plateau, southern Benin. Agroforestry Systems, 94(1), 41–56. https://doi.org/10.1007/s10457-019-00360-0

Kusumawati SRI. A, Yahya S, Mulatsih SRI, Istina IDA. N. U. R. (2021). The dynamic of carbon dioxide (CO2) emission and land coverage on intercropping system on oil palm replanting area. Journal of Oil Palm Research, 33(2), 267–277.

Lal R, Kimble JM. (1997). Conservation tillage for carbon sequestration. Nutrient Cycling in Agroecosystems, 49(1-3), 243–253. https://doi.org/10.1023/a:1009794514742

Lamine C, Marsden T. (2023). Unfolding sustainability transitions in food systems: Insights from UK and French trajectories. Proceedings of the National Academy of Sciences of the United

States of America, 120(47), 1–10. https://doi.org/10.1073/pnas.2206231120

Lee AK, Kasbi H. (1978). Intercropping cocoa and oil palm. International Conference of Cocoa and Coconuts, 158–171.

Leeuwen S, Slingerland M, Woittiez L. (2019). Analysis of a pineapple - oil palm intercroping system in Malasia. https://bscmsc.pps.wur.nl/analysis-pineapple-oil-palm-intercropping-system-malaysia

Leihner D. (1983). Yuca en cultivos asociados. In CIAT Centro internacional de Agricultura Tropical. http://ciat-library.ciat.cgiar.org/articulos_ciat/2015/18475_yuca.pdf

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. https://doi.org/10.1051/cagri/2021015

Linn DM, Doran JW. (1984). Effect of Water-Filled Pore Space on Carbon Dioxide and Nitrous Oxide Production in Tilled and Nontilled Soils. Soil Science Society of America Journal, 48(6), 1267–1272. https://doi.org/10.2136/sssaj1984.03615995004800060013x

Liu CLC, Kuchma O, Krutovsky KV. (2018). Mixed-species versus monocultures in plantation forestry: Development, benefits, ecosystem services and perspectives for the future. Global Ecology and Conservation, 15, e00419. https://doi.org/10.1016/j.gecco.2018.e00419

LMC. (2022). The LMC Oilseeds & Oils Report.

LMC International. (2022). LMC Oils Price View (Issue April).

López D. (2021). Evaluación de los efectos del intercalado de cultivos de ciclo corto al interior del cultivo de palma de aceite Híbrido OxG y su aporte en la seguridad alimentario durante el periodo improductivo del palmar, en el Urabá Antioqueño. Pontificia Universidad Javeriana.

Louarn G, Bedoussac L, Gaudio N, *et al.* (2021). Plant nitrogen nutrition status in intercrops- a review of concepts and methods. European Journal of Agronomy, 124(December 2020). https://doi.org/10.1016/j.eja.2021.126229

Lusiana B, Slingerland M, Miccolis A, Khasanah N, Leimona B, van Noordwijk M. (2023). Oil palm production, instrumental and relational values: the public relations battle for hearts, heads, and hands along the value chain. Current Opinion in Environmental Sustainability, 64, 101321. https://doi.org/10.1016/j.cosust.2023.101321

Madjid MIN, Marhaento H, Permadi DB, *et al.* (2023). Potential adoption of oil palm agroforestry in Sungai Jernih Village, Jambi, Indonesia. IOP Conference Series: Earth and Environmental Science, 1145(1), 0–8. https://doi.org/10.1088/1755-1315/1145/1/012001

Maitra S, Hossain A, Brestic M, *et al.* (2021). Intercropping-A Low Input Agricultural Strategy for Food and Environmental Security. https://doi.org/10.3390/agronomy11020343

Manorama K, Mathur RK, Prasad M. V, Suresh K, Ramachandrudu K, Rao BN. (2019). Doubling oil palm yield through technological interventions — a review. Current Horticulture, 7 (2), 28. https://doi.org/10.5958/2455-7560.2019.00015.3

Martin-Guay MO, Paquette A, Dupras J, Rivest D. (2018). The new Green Revolution: Sustainable intensification of agriculture by intercropping. Sci Total Environ, 615, 767–772. https://doi.org/10.1016/j.scitotenv.2017.10.024

Marwoto M, Taufiq A, dan Suyamto S. (2012). Potential of Soybean Development in Oil Palm Plantation. Jurnal Penelitian Dan Pengembangan Pertanian, 31(4), 169–174.

Maryani AT, Fathia NME, Bahar FF. (2021). The study of distribution of chicken manure fertilizer for papaya growth and production beneath unproductive palm oil. IOP Conference Series: Earth and Environmental Science, 637(1). https://doi.org/10.1088/1755-1315/637/1/012075

Masure A, Martin P, Lacan X, Rafflegeau S. (2023). Promoting oil palm-based agroforestry systems: an asset for the sustainability of the sector. Cahiers Agricultures, 32. https://doi.org/10.1051/cagri/2023008

Mead R, Willey RW. (1980). The concept of a 'land equivalent ratio' and advantages in yields from intercropping. Experimental Agriculture, 16(3), 217–228. https://doi.org/10.1017/S0014479700010978

Meijaard E, Sheil D. (2019). The Moral Minefield of Ethical Oil Palm and Sustainable Development. Frontiers in Forests and Global Change, 2(May). https://doi.org/10.3389/ffgc.2019.00022

Mesa J. (2016). La productividad, un compromiso gremial. 37(4), 56–65. http://web.fedepalma.org/bigdata/reunion2016/1drmesa.pdf

Migeon AF. (2018). Assessing the possibilities of intercropping oil palm and pepper, under the double-row avenue system (Issue June) [Wageningen University]. https://bscmsc.pps.wur.nl/system/files/Thesis_Final_AF_Migeon.pdf

Montagnini F, Nair PR. (2004). Carbon sequestration: An underexploited environmental benefit of agroforestry systems. 61(July 2004), 281–295. https://doi.org/10.1023/B

Morand S, Lajauni C. (2020). Outbreaks of Vector-Borne and Zoonotic Diseases Are Associated With Changes in Forest Cover and Oil Palm Expansion at Global Scale. SRSS, 1–35. https://ssrn.com/abstract=3710299

Mosquera M, Beltrán J. A. (2017). Mejores prácticas como estrategia para enfrentar el cambio climático : análisis de la productividad en Colombia para 2016. El Palmicultor, 2015–2018.

Namanji S, Ssekyewa C, Slingerland M. (2021). Intercropping food and cash crops with oil palm - Experiences in Uganda and why it makes sense.

Nchanji YK, Nkongho RN, Mala WA, Levang P. (2016). Efficacy of oil palm intercropping by smallholders. Case study in South-West Cameroon. Agroforestry Systems, 90(3), 509–519. https://doi.org/10.1007/s10457-015-9873-z

Nkongho RN, Ndjogui TE, Levang P. (2015). History of partnership between agro-industries and oil palm smallholders in Cameroon. OCL - Oilseeds and Fats, 22(3). https://doi.org/10.1051/ocl/2015005

Norman MJT. (1979). Annual Cropping Systems in the Tropics (Vol. 71, Issue 4). Univeristy Presses of Florida. https://doi.org/10.2307/214521

Nuertey B. (1999). Studies on oil palm based cropping systems in Ghana. University of Ghana.

Nuertey B, Ofori I, Tetteh F. (2010). Intercropping oil palm with food crops in Ghana: 1. Effect on nutrient dynamics, soil moisture retention and light interception. Ghana Journal of Agricultural Science, 42(1-2), 43–54. https://doi.org/10.4314/gjas.v42i1-2.60643

Nurjannah H, Robiartini L, Susilawati S. (2021). Chili Pepper Cultivation Using Several Spacings Intercropped with Immature Oil Palm. Jurnal Lahan Suboptimal : Journal of Suboptimal Lands, 10(1), 27–36. https://doi.org/10.36706/jlso.10.1.2021.498

Nwaogu EN, Echendu TN, Nwauzor EC. (2014). Potentian usefulness of planting ginger (Zingiber officinale Rosc.) in or Near Established Oil Palm Plantation in South Eastern Nigeria. Agricultural Journal, 9(1), 45–50.

Obi EI, Awanlemhen BE, Agele SO, Aiyelari OP, Imogie AE, Osazuwa A. (2023). Effects of Intercrops on Growth and Yield of Oil Palm in Rainforest Zone of Nigeria. International Journal of Agriculture and Earth Science, 9(1), 18–30. https://doi.org/10.56201/ijaes.v9.no1.2023.pg18.30

Okere RA, Uwubanmwen IO, Garba ID, Oisakede LI, Akparanta DC, Maduike AI. (2015). Economic analysis of intercropping oil palm with food crops by smallholder farmers in Edo state. Journal of Agricultural Research and Policy, 10(1), 1–7.

Okyere S. (2014). Residual Effect of Intercropping on the Yield and Productivity of Oil Palm. International Journal of Plant & Soil Science, 3(7), 854–862. https://doi.org/10.9734/ijpss/2014/9038

Oluwatobi AS. (2020a). Growth assessment of juvenile oil palm (Elaeis guineensis Jacq.) intercropped with fruit vegetables in a rainforest zone of Nigeria. Acta Agriculturae Slovenica, 4(1), 1–9. https://pesquisa.bvsalud.org/portal/resource/en/mdl-20203177951%0A; http://doi.org/10.1038/s41562-020-0887-9%0A; http://doi.org/10.1038/s41562-020-0884-z%0A; https://doi.org/10.1080/13669877.2020.1758193%0A; http://sersc.org/journals/index.php/IJAST/article

Oluwatobi AS. (2020b). Physiological responses of two accessions of tomato to three distance regimes in juvenile oil palm-tomato intercrop in rainforest zone of Nigeria. http://doi.org/10.1101/2020.05.31.126771

Oluwatobi AS. (2020c). Weed species composition and diversity of 2 year old oil palm tree/fruit vegetables intercrop in rainforest zone of Nigeria. BioRxiv (Pre-Print), 151–156. https://doi.org/10.1101/2020.05.31.126722

Oomen D. (2023). Establishment intercropping: The effects of watermelon, banana, cassava and maize on oil palm performance How land sharing in oil palm plantations can lead to land sparing in nature. Wageningen University.

Ordway EM, Naylor RL, Nkongho RN, Lambin EF. (2019). Oil palm expansion and deforestation in Southwest Cameroon associated with proliferation of informal mills. Nature Communications, 10 (114), 1–11. https://doi.org/10.1038/s41467-018-07915-2

Orewa S. (2008). Designing agricultural development projects for the Small Scale Farmers: some lessons from the World Bank Assistance Small Holder Oil Palm development scheme in Nigeria. Journal of Applied Sciences, 8(2), 295–301. https://doi.org/10.3923/jas.2008.295.301

Organización Mundial del Comercio. (2010). Problemas mundiales, soluciones mundiales: Hacia una mejor gobernanza mundial. http://onlinebookshop.wto.org

Pacheco FAL, Varandas SGP, Sanches Fernandes LF, Valle Junior RF. (2014). Soil losses in rural watersheds with environmental land use conflicts. Science of the Total Environment, 485-486(1), 110–120. https://doi.org/10.1016/j.scitotenv.2014.03.069

Perez Braga DP, Miccolis A, Nascimento Ramos HM, *et al.* (2024). Implications of smallholder livelihoods for scaling oil palm agroforestry in Brazilian Eastern Amazon. World Development Sustainability, 4(November 2022). https://doi.org/10.1016/j.wds.2024.100128

Perez RPA, Vezy R, Bordon R, *et al.* (2024). Combining modeling and experimental approaches for developing rice-oil palm agroforestry systems. Journal of Experimental Botany, 75(13), 4074–4092. https://doi.org/10.1093/jxb/erae137

Perrine-Walker F. (2020). Phytophthora palmivora - Cocoa Interaction. Journal of Fungi, 6(167), 1–20. https://doi.org/10.3390/jof6030167

Petrescu-Mag RM, Petrescu DC, Azadi H, Petrescu-Mag IV. (2018). Agricultural land use conflict management—Vulnerabilities, law restrictions and negotiation frames. A wake-up call. Land Use Policy, 76(February), 600–610. https://doi.org/10.1016/j.landusepol.2018.02.040

Petrie CA, Bates J. (2017). 'Multi-cropping', Intercropping and Adaptation to Variable Environments in Indus South Asia. Journal of World Prehistory, 30(2), 81–130. https://doi.org/10.1007/s10963-017-9101-z

Purwanto E, Santoso H, Jelsma I, Widayati A, Nugroho HYS. H., van Noordwijk M. (2020). Agroforestry as policy option for forest-zone oil palm production in indonesia. Land, 9(12), 1–34. https://doi.org/10.3390/land9120531

Putra ETS, Simatupang AF, Sriyanto Waluyo S, Indradewa D. (2012). The Growth of One Year-Old Oil Palms Intercropped with Soybean and Groundnut. Journal of Agricultural Science, 4(5), 169–180. https://doi.org/10.5539/jas.v4n5p169

Qaim M, Sibhatu KT, Siregar H, Grass I. (2020). Environmental, economic, and social consequences of the oil palm boom. Annual Review of Resource Economics, 12, 321–344. https://doi.org/10.1146/annurev-resource-110119-024922

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

Rahmani TA, Nurrochmat DR, Hero Y, Park MS, Boer R, Satria A. (2021). Evaluating the feasibility of oil palm agroforestry in harapan rainforest, Jambi, Indonesia. Forest and Society, 5(2), 458–477. https://doi.org/10.24259/FS.V5I2.10375

Ramachandrudu K, Arulraj S, Suneetha V. (2014). Making grown-up oil palm gardens more remunerative. Indian Horticulture, *December*, 15–16.

Ramírez-Contreras NE, Munar-Florez DA, García-Nuñez JA, Mosquera-Montoya M, Faaij APC. (2020). The GHG emissions and economic performance of the Colombian palm oil sector; current status and long-term perspectives. Journal of Cleaner Production, 258, 120757. https://doi.org/10.1016/j.jclepro.2020.120757

Ramos HMN, Vasconcelos SS, Kato OR, Castellani DC. (2018). Above- and belowground carbon stocks of two organic, agroforestry-based oil palm production systems in eastern Amazonia. Agroforestry Systems, 92(2), 221–237. https://doi.org/10.1007/s10457-017-0131-4

Rao BN, Suresh K, Behera SK, Bhagya HP. (2019). Oil Palm-Cocoa based Cropping System for Economic Viability and Sustainability. . . . Journal of Oil Palm. http://sopoprad.org/wp-content/uploads/2019/08/IJOP2019Jun02_NarsimhaRaoetal.pdf

Reddi S, Patil D, Chandravathi B, Maheshwarappa H. (2015). Studies on vegetables as intercrops in juvenile oil palm plantation and its economics. Karnataka Journal of Agricultural Sciences, 28(4), 494–496.

Reddy VM, Suresh K, Saraswathi MS, Bijimol G, Nagarnani C. (2004). Inter cropping in irrigated Oil Palm in India. Journal of Plantation Crops, 32, 218–220.

Reisman E, Fairbairn M. (2020). Agri-Food Systems and the Anthropocene. Annals of the American Association of Geographers, 111(3), 687–697. https://doi.org/10.1080/24694452.2020.1828025

Rethinam P. (2017). Oil Palm in India with difference - in various agro-climatic conditions in the tropical and Sub-tropical conditions with inter/mixed cropping systems under irrigated conditions. International Journal of Oil Palm, 9(1), 1–8. http://sopoprad.org/files/IJOPVol9/IJOP2017Dec01_RethinamReviewPaper.pdf

Rival A, Ancrenaz M, Lackman I, *et al.* (2022). Innovative agroforestry designs for tropical plantation landscapes - the TRAILS project. Acta Horticulturae, 1355, 109–115. https://doi.org/10.17660/ActaHortic.2022.1355.14

Rival A, Chalil D. (2023). Oil palm plantation systems are at a crossroads. OCL - Oilseeds and Fats, Crops and Lipids, 30. https://doi.org/10.1051/ocl/2023029

Rivera-Mendez YD, Romero Angulo HM. (2018). Los mitos ambientales de la palma de aceite. Palmas, 39(4), 58–68.

Rizki DP, Hariyadi, Suwarto. (2020). Alley cropping in immature oil palm. IOP Conference Series: Earth and Environmental Science, 418(1). https://doi.org/10.1088/1755-1315/418/1/012042

Rodrigues SJS. de C., Vasconcelos SS, Chaves SH. dos R. (2016). Efluxo de CO2 do solo em sistemas agroflorestais com palma de óleo na Amazônia Oriental. 20° Seminário de Iniciação Científica e 4° Seminário de Pós-Graduação Da Embrapa Amazônia Oriental. https://ainfo.cnptia.embrapa.br/digital/bitstream/item/148200/1/Pibic2016-p411.pdf

Rodrigues VS, do Valle Júnior RF, Sanches Fernandes LF, Pacheco FAL. (2019). The assessment of water erosion using Partial Least Squares-Path Modeling: A study in a legally protected area with environmental land use conflicts. Science of the Total Environment, 691, 1225–1241. https://doi.org/10.1016/j.scitotenv.2019.07.216

Romero HM, Ruíz Romero R, Forero DC, Guataquira S. (2023). Densidad de siembra e interceptación de luz de los cultivares híbridos interespecíficos OxG. Los Híbridos Interespecíficos OxG de Palma de Aceite, July, 197–218. https://doi.org/10.56866/9789588360959.07

RSPO. (2023). Factsheet on Independent Smallholder (ISH) Credits (Issue October). https://rspo.org/wp-content/uploads/Factsheet-on-ISH-credits.pdf

Ruiz-Álvarez E, Castiblanco JS, Mosquera-Montoya M. (2024). Sustainable intensification of palm oil production through cattle integration: a review. Agroecology and Sustainable Food Systems, 1–19.

Ruíz Álvarez E, Mosquera-Montoya M, Munevar DE, Vargas LE, Vélez Zape JC. (2022). Productividad laboral en plantaciones de palma de aceite en Colombia. In Productividad laboral en plantaciones de palma de aceite en Colombia (Issue 43). https://doi.org/10.56866/9789588360966

Ruiz E, Molina D. (2014). Revisión de literatura sobre beneficios asociados al uso de coberturas leguminosas en palma de aceite y otros cultivos permanentes. Palmas, 35(1), 53–64. https://publicaciones.fedepalma.org/index.php/palmas/article/view/10947

Sagna B, Ngom D, Abdoul M, Diedhiou A, Camara B, Goudiaby M, Seydou A, Coq YLE. (2019). Importance socioéconomique des parcs agroforestiers à Elaeis guineensis Jacq. dans la région de Cacheu (Guinée-Bissau). International Journal of Biological and Chemical Sciences, 13(7), 3289–3306.

Salaheen S, Biswas D. (2019). Organic farming practices: Integrated culture versus monoculture. In Safety and Practice for Organic Food. Elsevier Inc. https://doi.org/10.1016/B978-0-12-812060-6.00002-7

Salleh AM, Harun NZ. (2015). Assessing farmer's interest on agroforestry systems through agricultural sustainability. Advances in Environmental Biology, 9(19), 182–190.

Santika T, Wilson KA, Budiharta S, *et al.* (2019). Does oil palm agriculture help alleviate poverty? A multidimensional counterfactual assessment of oil palm development in Indonesia. World Development, 120, 105–117. https://doi.org/10.1016/J.WORLDDEV.2019.04.012

Sapalina F, Farrasati R, Wiratmoko D, *et al.* (2022). Oil palm intercropping system: A potential nature-based solution to improve soil biology activities in North Sumatra plantation, Indonesia. Malaysian Journal of Microbiology, 18(2), 235–241. https://doi.org/10.21161/mjm.211275

Saravanan L, Phanikumar T, Kumar DD, Arunkumar R. (2022). Seasonal activity of oil palm leaf webworm, Acria meyricki Shashank and Ramamurthy and its natural enemies in oil palm-cocoa intercropping system and their management in oil palm. Journal of Entomological Research, 46(3), 483–489. https://doi.org/10.5958/0974-4576.2022.00085.8

Satriawan H, Fuady Z, Fitri R. (2021). Soil erosion control in immature oil palm plantation. Journal of Water and Land Development, 49, 47–54. https://doi.org/10.24425/jwld.2021.137095

Shahputra MA, Zen Z. (2018). Positive and Negative Impacts of Oil Palm Expansion in Indonesia and the Prospect to Achieve Sustainable Palm Oil. IOP Conference Series: Earth and Environmental Science, 122(1). https://doi.org/10.1088/1755-1315/122/1/012008

Shameer KS, Nasser M, Mohan C, Hardy ICW. (2018). Direct and indirect influences of intercrops on the coconut defoliator Opisina arenosella. Journal of Pest Science, 91(1), 259–275. https://doi.org/10.1007/s10340-017-0904-6

Sibhatu KT. (2023). Oil palm boom: its socioeconomic use and abuse. Frontiers in Sustainable Food Systems, 7(June). https://doi.org/10.3389/fsufs.2023.1083022

Sitorus R, Zasari M. (2023). Identification and Economic Contribution of Intercrops to the Income of Oil Palm Farmers on Bangka Island. Equity: Jurnal Ekonomi, 11(1), 18–25. https://doi.org/10.33019/equity.v11i1.135

Slingerland M, Khasana N, Noordwijk M, Susanti A, Meilantina M. (2019). Improving smallholder inclusivity through integration of oil palm with crops. In ETFRN news 59 Explor. Incl. palm oil Prod.

Solidaridad. (2022). Palm oil Barometer 2022. https://www.solidaridadnetwork.org/wp-content/uploads/2022/09/Palm-Oil-Barometer-2022_solidaridad.pdf

Sun T, Zhao C, Feng X, *et al.* (2021). Maize-based intercropping systems achieve higher productivity and profitability with lesser environmental footprint in a water-scarce region of northwest China. Food and Energy Security, 10(1), 1–14. https://doi.org/10.1002/fes3.260

Susanti A, Marhaento H, Permadi DB, *et al.* (2021). Smallholders' Oil Palm Agroforestry: Barriers and Factors Influencing Adoption. Jurnal Ilmu Kehutanan, 15(1), 69–81. https://doi.org/10.22146/jik.v15i1.1513

Susanti A, Marhaento H, Permadi DB, *et al.* (2020). Smallholder farmers' perception on oil palm agroforestry. IOP Conference Series: Earth and Environmental Science, 449(1). https://doi.org/10.1088/1755-1315/449/1/012056

Susanti A, Marhaento H, Riyanto S, *et al.* (2021). Oil Palm Agroforestry as an Alternative towards Inclusive Oil Palm Production. Elaeis Guineensis [Working Title]. https://doi.org/10.5772/intechopen.98205

Suwandi S, Alesia M, Munandar RP, Fadli R. (2024). The suppression of Ganoderma boninense on oil palm under mixed planting with taro plants. Biodiversitas, 25(3), 1143–1150. https://doi.org/10.13057/biodiv/d250329

Tanaka S, Tachibe S, Wasli ME. Bin, *et al.* (2009). Soil characteristics under cash crop farming in upland areas of Sarawak, Malaysia. Agriculture, Ecosystems and Environment, 129(1-3), 293–301. https://doi.org/10.1016/j.agee.2008.10.001

Tata HL, van Noordwijk M, Jasnari, Widayati A. (2016). Domestication of Dyera polyphylla (Miq.) Steenis in peatland agroforestry systems in Jambi, Indonesia. Agroforestry Systems, 90(4), 617–630. https://doi.org/10.1007/s10457-015-9837-3

Tengoua F, Bakoumé C. (2005). Ventajas de sembrar tomate y pimienta entre líneas de palmas jovenes (Elaeis guineensis) en suelos susceptibles a marchitez vascular. Palmas, 26(4), 25–35.

Torres GA, Sarria GA, Martinez G, Varon F, Drenth A, Guest DI. (2016). Bud Rot Caused by Phytophthora palmivora: A Destructive Emerging Disease of Oil Palm. Phytopathology Review, 106(4), 320–329. https://doi.org/10.1094/PHYTO-09-15-0243-RVW

Treetaruyanont K, Suwannalert S, Keaunkaub N, Saengpenk T. (2014). Influence of monocropping and intercropping systems between para rubber and oil palm plantation on growth and yield of Phlai. Acta Horticulturae, 1023, 307–310. https://doi.org/10.17660/ActaHortic.2014.1023.45

Trevellan D. (2017). The Dynamics of Perennial Crop Production and Processing. University of California.

Tscharntke T, Clough Y, Bhagwat SA, *et al.* (2011). Multifunctional shade-tree management in tropical agroforestry landscapes - A review. Journal of Applied Ecology, 48(3), 619–629. https://doi.org/10.1111/j.1365-2664.2010.01939.x

USDA. (2022). Palm Oil Explorer. Palm Oil 2022. World Production. https://ipad.fas.usda.gov/cropexplorer/cropview/commodityView.aspx?cropid=4243000&sel_year=2022&rankby=Production

USDA FAS. (2024). Oilseeds. Production, Supply, and Distribution Online. https://apps.fas.usda.gov/psdonline/app/index.html#/app/downloads

Van Leeuwen. (2019). Analysis of a pineapple-oil palm intercropping system in Malaysia. MSc Thesis Wageningen University & Research, 1–103.

Van Oosterhout MJ, Marhaento H, Booij MJ, Ridho D. (2023). Differences in soil-water characteristics of monoculture oil-palm plantations, agroforestry oil-palm plantations and natural forest. IOP Conference Series: Earth and Environmental Science, 1233 (1). https://doi.org/10.1088/1755-1315/1233/1/012048

World Bank. (2022). Correcting course. Poverty and shared prosperity 2022. https://doi.org/10.1596/978-1-4648-1893-6

World Integrated Trade Solution. (2024a). Crude palm oil exports by country in 2023. https://wits.worldbank.org/trade/comtrade/en/country/ALL/year/2023/tradeflow/Exports/partner/WLD/product/151110

World Integrated Trade Solution. (2024b). Crude palm oil imports by country in 2023. https://wits.worldbank.org/trade/comtrade/en/country/ALL/year/2023/tradeflow/Imports/partner/WLD/product/151110

Yahya MS, Syafiq M, Ashton-Butt A, Ghazali A, Asmah S, Azhar B. (2017). Switching from monoculture to polyculture farming benefits birds in oil palm production landscapes: Evidence from mist netting data. Ecology and Evolution, 7(16), 6314–6325. https://doi.org/10.1002/ece3.3205

Yanda YSO. (2019). Cultivation of vegetable fern in oil palm plantation : A viable strategy for permanent intercropping? Wageningen University.

Yanda YSO, Fahrurrozi F, Supanjani S. (2018). Growing Caisim (Brassica juncea L.) Using Elaeisponic Production System. Akta Agrosia, 21(2), 29–32. https://doi.org/10.31186/aa.21.2.1-4

Yang H, Zhang W, Li L. (2021). Intercropping: Feed More People and Build More Sustainable Agroecosystems. Frontiers of Agricultural Science and Engineering, 8(3), 373–386. https://doi.org/10.15302/J-FASE-2021398

Yemadje RH, Crane TA, Vissoh PV, Mongbo RL, Richards P, Kossou DK, Kuyper TW. (2012). The political ecology of land management in the 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

Yin W, Chai Q, Zhao C, *et al.* (2020). Water utilization in intercropping: A review. Agricultural Water Management, 241 (February). https://doi.org/10.1016/j.agwat.2020.106335

Yuliani N, Sabur A, Napisah K. (2021). Soybean as ground cover plant and intercrop in immature oil palm plantation. E3S Web of Conferences, 306, 1–10. https://doi.org/10.1051/e3sconf/202130605011

Zanchi FB, Da Rocha HR, De Freitas HC, Kruijt B, Waterloo MJ, Manzi AO. (2009). Measurements of soil respiration and simple models dependent on moisture and temperature for an Amazonian southwest tropical forest. Biogeosciences Discussions, 6(3), 6147–6177. https://doi.org/10.5194/bgd-6-6147-2009

Zulkifli R, James CH, Wahid O, Norkaspi K. (2016). Integration of black pepper with oil palm. MPOB Information Series No 0718, 589, 3–6. http://palmoilis.mpob.gov.my/ publications/TOT/TT589.pdf

Cite this article as: Munévar-Martínez DE, Ruiz-Álvarez E, Estupiñán-Villamil MC, Mosquera-Montoya M. 2025. Sustainable intensification of oil palm production through integration with other crops: a review. *OCL* 32: 31. https://doi.org/10.1051/ocl/2025022