Oil palm (protected from pig predation) and young rubber among old rubber trees that may still recover from intensive tapping, in a farmers' plot on Sumatra

Photo credit: Ratna Akiefnawati/World Agroforestry

CHAPTER 24

Rubber and oil-palm production and value addition in Asia: relevance for Africa

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Highlights

- The historical development of supply and value chains of rubber and oil palm in Asia suggests that the elasticity of family-farm labour has an advantage in the political economy of scale
- Rubber can be grown as part of highly diverse agroforests, oil palm mostly (so far) in regularly spaced monocultures, but double-row intercropped systems deserve attention
- In rubber the main production costs is labour for tapping that can be shifted elsewhere if farmgate prices are not attractive; oil palm requires higher investment and continued input use to maintain productivity; there are portfolio advantages in maintaining a foot in each door, reducing risk at farm, landscape and national economy scale
- External concerns in global markets over social and ecological consequences of expansion have led to certification standards in oil palm, but hardly yet in rubber; as prevention of reputational damage is more cost-effective than cure, transparency is needed
- Lessons for Africa include that it may be attractive for local governments to start 'development' by creating cheap access to land and (externally recruited) labour in an emerging vertically linked plantation industry, but for longer term positive development impacts an evolution to a smallholder dominated sector must be foreseen and facilitated without single-buyer dominance.

1. Origins and trends

Oil-rich fruits and seeds (e.g. coconut, castor oil) (Van der Vossen and Umali 2001) and the latex that plants exude when wounded have been harvested, processed and used from a wide variety of plants as part of the ethnobotanical history of Asia. Latex species that attracted market attention include gutta-percha (*Palaquium* spp.), chewing-gum tree (*Dyera* spp.)

van Noordwijk M, Khasanah N, Jelsma I, Dewi S, Leimona B, Suyanto. 2021. Rubber and oil-palm production and value addition in Asia: relevance for Africa. In: Minang PA, Duguma LA, van Noordwijk M, eds. 2021. Tree commodities and resilient green economies in Africa. Nairobi, Kenya: World Agroforestry (ICRAF)

and *Ficus elastica* (Boer and Ella 2000). In both categories, however, the intercontinental germplasm theft and exchange of the colonial period brought in trees from other parts of the tropics that started new value chains, serving global markets and pushing 'indigenous' trees producing such commodities to become a footnote in history. Rubber (*Hevea brasiliensis*) was brought to Asia from the Amazon basin in the middle of the 19th century and boomed around 1920 when its primary use for car tyres started a long period of growing demand. Oil palm (*Elaeis guineensis*) (Corley and Tinker 2016) came a little later from W. Africa – but developed slowly at first. The relative importance of smallholders and large-scale plantations in the area varied in time and space for the two commodities, as did the number of people involved and the economic value generated.

In the period 2009-2019, global production of natural rubber, according to FAO statistics (FAO 2020), increased from 10.2M to 14.6M ton and the area from 9.2M to 12.3M ha, with 88% in Asia; oil palm increased from 220M to 410M ton fresh fruit bunches, and the area from 16.0M to 28.3M ha, with 89% in Asia. The economic value of global trade was 35 billion USD in 2014 for oil palm (Pacheco et al 2017), and nearly 30 billion USD for natural rubber. The total value of the national economy of Uganda or Cameroon, ranking 14 and 15 among African countries, is in this order of magnitude. The combined area of global rubber and oil palm, around 40M ha, equals the size of Zimbabwe but has three times its GDP. Rubber and oil palm share the same landscape, competing for land, labour, and investment and facilitating mutual innovations. Family farms interact with large-scale plantations employing labour often from outside the local community. The two scales of production compete but also allow transfer of knowledge and technology. Intensive plantations pioneered in uniform management, optimizing the use of inputs and logistics. Family farms showed how permanent soil cover and diversity of companion trees can be beneficial.

The value addition achievable in processing gradually shifted primary production closer to the areas with comparative advantage economically. This chapter will compare and analyse the interactions between the social, ecological and economic histories of rubber and oil palm in Asia rather than in the continents of origin (van Noordwijk et al 2019). Several similarities and differences between the two crops in terms of social, ecological, economic and political history may be relevant for the African focus of this book. African countries considering increased involvement in either crop may learn from the types of system change in supply and value chains that are part of 'development' and often involve a 'race to the bottom' of lowest-cost producers. Increasing the quality of all aspects of the production process and value chains can form an alternative to this race to the bottom that starts with oversupply, depressing prices and allowing only the lowest-cost producers to stay in business. In the remaining sections, this chapter will cover macro- (national economy), micro- (household production) and meso-scale (landscapes, geographic identity) patterns and processes, referencing more specialized literature on a wide range of topics.

2. Patterns of expansion: insular and mainland SE Asia

While rubber can grow almost anywhere in the humid tropics (Dewi et al 2017) and oil palm in a substantial part of this climatic zone, Asia dominates production of both with 88.0% (Thailand 33.1%, Indonesia 23.6%, Viet Nam 8.1%, India 6.8%, China 5.7%, Malaysia 4.3%, Philippines 2.9%, other Asian countries 3.0%) and 88.9% (Indonesia 59.7%, Malaysia 24.0%, Thailand 4.0%, other Asian countries 0.8%) of global production in 2019, respectively.

The historical expansion of rubber into the lowlands of the humid tropics in Asia and its more recent replacement in dependable-rainfall locations by oil palm, shifting rubber to drier regions, holds many lessons on how tree commodity production can be scaled up. The process can be driven by smallholder interests, understood and supported by traders and processors who connect local production to a global value chain (Byerlee et al 2017). It also reflects the interests of processors and traders, who stimulate the expansion and adoption of crops for which they see opportunities for positive margins on their part of the value chain.

Expansion of any commodity tree crop requires know-how, planting material, land, labour, capital to bridge the time to a positive cash-flow and access to markets in the storable form via local processing (e.g. to sheet or slab rubber, or crude palm oil). The two main expansion modes are based on an adaptive, stepwise change in local, forest-edge communities and large-scale forest clearing under plantation management bringing in external labour. These two pathways have been recognized across the tropics for multiple commodities (Meyfroidt et al 2014 ; Agus et al 2013), but their interaction is still only partly understood. In Indonesia, Malaysia and Thailand, rubber mostly followed the smallholder expansion mode. Still, the more recent expansion in mainland Southeast Asia (especially China, Laos) had a larger role for companies and external funding. Oil palm started in most areas with the large-scale company model but is now shifting, especially in Sumatra, to a smallholder dominated process (Figure 24.1). Most of the social conflicts oil palm generated and the negative press it received globally was due to the plantation expansion (Colchester and Chao 2011; van Noordwijk et al 2017; Purwanto et al 2020). At the same time, smallholder adoption of the same crop remained below the policy radar screen for a considerable length of time (Sheil et al 2009).

***Figure 24.1:** Jungle rubber tapping, rubber agroforest, oil palm and satellite evidence of smallholder oil palm replacing rubber agroforest in Sumatra in a GoogleEarth perspective (Photo: Meine van Noordwijk, ICRAF)*

The way people living in and around forests responded to market demand for commodities they could produce in their area has been described as a dual economy (Dove 2011): decisions over primary needs such as food production were kept separate from those about marketable goods. Opportunistically engaging in markets while having a food-secure basis in local staple food production, mainly in a swidden-fallow cycle, proved to be a safe strategy. Yet, when the terms of trade were tempting, part of the food production could be 'outsourced' (van Noordwijk et al 2014), as happened in Indonesia during the first 'para' rubber (*Hevea brasiliensis*) boom, around 1920. Rubber spread on Sumatra and Borneo into rather remote areas, depending on transport by river. Rubber, however, could be easily floated down-river, and traders from the towns where the rivers connected to maritime transport knew they had sufficient control over trade that they were willing to invest. Rubber seeds were distributed free of charge, and production became limited by the availability of labour for tapping rather than the presence of trees. Rubber introduced in swiddens thrived in the fallow stage, requiring little labour for maintenance until at age 7-10 years, trees could be tapped. Integration of rubber into secondary (fallow) forests ('jungle rubber') proved to be both ecologically (forest-like soil conditions, protection of watershed functions, retention of desirable forest species as sources of fruit and timber) (Murdiyarso et al 2002) and economically (low production costs) superior to the colonial-style plantations that acquired large tracts of land, but had difficulties in securing workforce. Forest-edge communities in Sumatra reserved part of the village area as swidden-fallow areas for use by poorer families, preventing the further privatisation that was the consequence, within local rules, of tree planting (van Noordwijk et al 2008). The frequency at which swiddens were cleared and planted with rubber within the already privatised areas came into equilibrium with tapping labour available. In the late 1960s and 1970s, however, when roads were constructed and communities could expect to attract share-tappers on their land, the rate of forest clearing increased, and share-tapping arrangements with migrant farmers became common (Miyamoto 2006). Share-tapping means that the harvested rubber is shared between landowner and share-tapper, with details depending on the quality of the stand and its preceding investment (Vincent et al 2011).

A difference has been noted in how rubber value chains developed in areas where river transport dominated and rubber slabs were floated downstream, and areas where transport from the beginning depended on overland vehicles. In the latter, a drier and cleaner product such as ‘sheet’ rubber became the basis of trade with higher farmgate prices but more effort in converting cup-rubber to sheets. Elsewhere, trade became based on slabs with higher water content and less noticeable incorporation of other materials for lower farmgate prices. Where processing plants were set up to deal with these undesirable additions, and farmgate prices assumed they would be there, there was little incentive for higher quality products to emerge.

Oil palm entered the landscape via large-scale plantations with a central processing mill for Fresh Fruit Bunches (FFB). While rubber can be stored on-farm until a trading opportunity emerges, FFB have to be harvested within a week of their optimal ripeness and has to reach the mill within 24 hours for the best quality of the product. Depending on the transport network and quality of roads, this favoured direct contracts between mill and farmer. Only where a large share of the landscape has been converted to oil palm and distances to the second-nearest mill are manageable do the opportunities for ‘independent’ smallholder oil palm producers increase. This can be seen when comparing the situation in Sumatra and Kalimantan (Figure 24.2).

Increasingly, rubber agroforests were converted to smallholder oil palm under these conditions, when access to remaining forests in the landscape became hard (Villamor et al 2014c) (Figure 24.3). Several studies have analysed farmer decision making facing the choice between rubber and oil palm (Schwarze et al 2015; Dharmawan et al 2020). Once opportunities for ‘independent’ oil palm producers increased, migration to the last ‘forest frontier’ on Sumatra in the province of Riau made this a hotspot of problems (Purwanto et al 2020; Budidarsono et al 2013; Ekadinata et al 2015). In mainland Southeast Asia, conversion to oil palm of the main rubber producing areas in Malaysia and South Thailand pushed rubber to less favourable climates, including Northeast Thailand. Rubber is more tolerant to climates with a pronounced dry season than oil palm. Expansion of rubber, especially for the Chinese markets, in Laos and Southwest China, became an issue of social and environmental concern (Ziegler et al 2009).

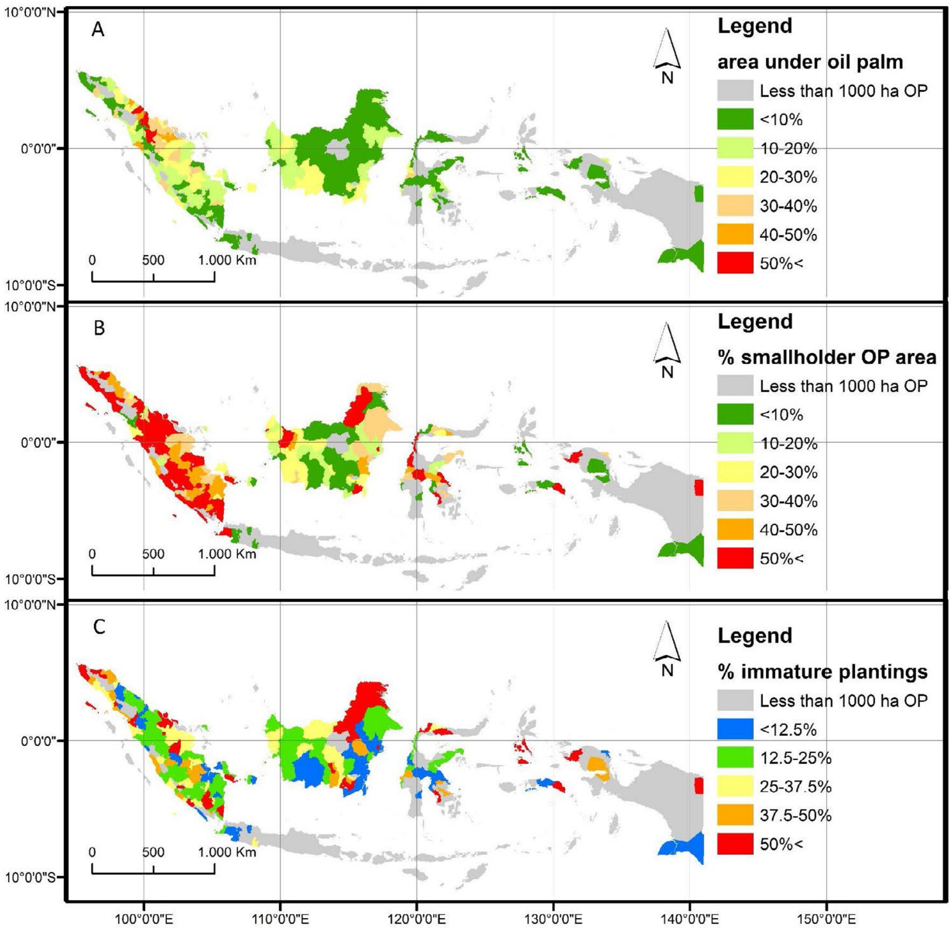

Figure 24.2: *Oil palm distribution at the district level in Indonesia in 2017:* **A.** *the share of area under oil palm;* **B.** *the share of oil palm that does not yield yet (usually less than three years old);* **C.** *the share of oil palm cultivated by smallholders. Source: (Purwanto et al 2020)*

Figure 24.3: *Oil palm interplanted in rubber monoculture (left) and cleared land (right) (Photos: Meine van Noordwijk, ICRAF)*

3. Agronomy and sources of planting material (germplasm)

3.1. Rubber

Rubber trees are compatible with intercropping upland rice or maize in the first two years. The trees need some protection when they are young, with wild pigs requiring fencing of plots in the forest margin and leaf-eating monkeys requiring human presence as deterrence (Table 24.1). Weeding the direct surroundings of young trees stimulates tree growth. It makes that the minimum girth for tapping (50 cm) be reached within 5 years (supported by fertilisation) rather than after the 7-9 years of jungle rubber that is virtually abandoned after the early years and part of the local nutrient cycle. Once tapping has started, farmers may, in a rubber agroforest management style, selectively retain other trees that have spontaneously established and are of recognized use, clearing others if they stand in the way of a path to reach the tappable tree (Gouyon et al 1993; Tata et al 2008).

Table 24.1: *Contrast between management of jungle rubber and intensified plantations (Gouyon et al 1993; Joshi et al 2003)*

Phase	Agroforest: 'jungle rubber' started from swidden or modified forest	Intensive plantation rubber
Start	Use and build on what you have; transplant local rubber seedlings into the swidden and/or partially cleared forest	Clear-fell and plant grafted seedlings of optimized clones, at regularly spaced final density
Protect	Protect the plot from external disturbance; around the temporary dwelling used to guard the swidden in the first years, preferred fruit tree seedlings will emerge	Use plantation design and roads to make it easy to supervise plots and protect them from human and non-human intruders
Manage	Reduce growth of species that hinder other, more valuable components (especially local fruit trees, high-value timber)	Clean-weed in the tree rows, use legume cover crops in between rows, fertilize trees to reach tappable girth after ~4 years
Tap	When rubber trees are tappable (7-10 years), clear paths for easy access; harvest what you need, but leave something for tomorrow; rest trees that need it	Optimize tapping strategy to utilize all available panel, use stimulants, saving labour
Sustainability	Forest-like soil conditions, little effect on water and nutrient cycling, few sustainability concerns	Soil is less protected, can get compacted and induce overland flows under intense rainfall
Renew	If you want, actively introduce valuable components from outside; use patch-level rejuvenation and enrichment for adaptive management	At the end of economic life span, clear-fell and start a new cycle

A wide range of management intensities is possible between the low-external-input 'jungle rubber' and intensive monoculture plantation (Table 24.1). Efforts to speed up rubber establishment will generally pay off, but for a wide range of management intensities, the returns to labour are relatively similar. If tapping is delayed, as prices aren't interesting or family labour is in short supply, future harvests will increase, as the bark (panel) can recover. Fungal diseases and leaf blight have been the main diseases, with microclimate a modifying factor. The latex is a natural defence mechanism against intruders of the stem. Intensive tapping reduces the tree's growth rate, which is the primary reason to delay tapping till the minimum girth has been reached. Tapping can damage the tree if the cambium layer below the bark is damaged, with most of the higher-yielding clones more sensitive to tapping damage. The flow of latex can be stimulated by chemicals applied to the bark (Yunta and Dede 2019), but techniques that are considered labour-saving in large-scale plantations are not commonly used by smallholders.

It has been remarkable how long the 'wild type' rubber that was first introduced to Southeast Asia persisted on farm, despite the availability of more productive selections ('clones' or 'seed sources'), even though farmers were aware that these existed in their landscape (Joshi et al 2003, 2009). Farmers perceived that paying for such planting material involved a high maintenance requirement in the establishment phase, as observed on the commercial plantations. They preferred the low-risk, low-cost jungle rubber management, even though its yields per ha are lower. However, the difference in the amount of latex that could be obtained per morning of tapping was small, and the local economy was limited by labour rather than land (and tappable tree) availability. On-farm experiments subsequently showed that at least some rubber clones are compatible with low-intensity management (Williams et al 2001; Akiefnawati et al 2021). A further factor that favoured the extensive jungle rubber system was its role in establishing private control over previously communal lands. When land became scarce, innovations emerged that allowed for uneven-aged rubber stands with internal, gap-level regeneration to produce continuously (Wibawa et al 2005), as an alternative to rotational plantations. Planting material for such systems tends to be 'pole' sized trees (van Noordwijk et al 2012), rather than the saplings used in more open conditions.

3.2. Oil palm

In contrast, oil palms are much more sensitive to management from an early stage onwards. Only if water and nutrient stress can be avoided will the palms approximate their potential production. Each palm will have 45–50 unopened leaves in varying stages of development and 32–48 opened leaves. The *phyllochron* time interval between the emergence of two subsequent leaves gradually increases with palm age, from around 40 two years after planting to 20 for twenty-year-old palms. Each leaf can carry an inflorescence in its axil, with either male or female flowers, never both. If female, pollinated and not aborted, an inflorescence becomes a 'fresh fruit bunch' (FFB), with up to 2000 single-seeded fruits that can be harvested about six months after flowering (Woittiez et al 2017). This means that there can be eight to ten developing bunches at any palm and any time if all develop well. Reductions in yield below the potential can be due to any combination of increased phyllochron time, more male inflorescences, poor pollination, more young fruit abortion, lower FFB weights. The extractable oil content can also be affected by growth conditions but is mostly influenced by harvesting time and decreases by delays in transport to the mill.

Within the cultivated populations of oil palm, variation in thickness of the shell around the nuts is the basis of hybridisation. While the early expansion of oil palm in Southeast Asia was based on the thick-shelled 'Dura' type and selections within that line, research in Yangambi (DRC), Nigeria and Ghana (van der Vossen 1974) in the 1950s, showed that hybrid crosses of *Dura* x *Pisifera* (named *Tenera*) are thin-shelled and have a higher oil content and FFB production. *Pisifera* is valued as a male parent in the crosses but does not produce fruits itself. Oil palm breeding has become a specialized undertaking in which several of the larger companies excel. Early expectations that desirable properties could be conserved in forms of tissue culture did not work out, as developmental malformations ('mantling' disease) take their toll. Recently, however, progress appears to be made. For many years the demand for oil palm planting material exceeded the high-quality material available, giving large-scale plantations an advantage over smallholders without good connections. Early surveys already noted oil palm seedlings sold to farmers on local markets with photocopied certificates of origin and uncertain quality. A survey of smallholder oil palm stands found (Jelsma et al 2019) on average more than 50% of their palms to be of the thick-shelled Dura type, which are expected to contain 30% less oil and fetch lower prices.

Figure 24.4: *Intercropping oil palm with rubber, cassava, maize or rice (Photos: Meine van Noordwijk, ICRAF)*

In both rubber and oil palm, intercropping in the early stages is a common practice (Figure 24.4), especially by smallholders who have some labour available and appreciate the income generated. However, with standard plant densities, opportunities in oil palm are restricted to the first two years, before the palm canopy closes. There is growing interest (Khasanah et al 2020) in oil palm agroforestry with longer time frames, based on a modified planting pattern with wider alleys between 'double rows'. However, most oil palm management still matches the 'intensive plantation' style of rubber management in the right-hand column of Table 24.1 rather than the agroforest style.

4. Farmgate economics

Accounting for the activities and inputs required in each part of the production cycle, as specified in the Land Use Profitability Analysis (LUPA) method (Rahmanulloh et al 2013), can lead to several insightful metrics that allow comparison between specific ways of managing oil palm (Papenfuss 2000; Budidarsono et al 2012), rubber (Wulan et al 2008) or other (tree) crops (Miccolis et al 2019) or forest (Belcher et al 2004):

Net Present Value (NPV – e.g. in USD per ha): the sum of discounted benefits (of all kinds) minus costs (of all types) per unit of land over a typical production cycle. The discount rate can refer to the local costs of borrowing money. High discount rates favour land-use systems with quick returns.

Returns to Labour (R2L – e.g. in USD per person day): the highest average wage rate that can be paid before NPV becomes zero. For an enterprise, the difference between R2L and actual wage rate indicates profitability for the managing entity.

Years to positive cash-flow (years): time that the system will be financially indebted. Intercropping tends to reduce this period, even if it has little effect on NPV.

The labour requirement for clearing forest was more than twice as high as that for clearing 'bush' (young fallow vegetation), but forest clearing yielded useful products and lower follow-up crop care (Table 24.2).

Table 24.2: Labour requirement (male + female) in person-days per ha per year of rubber agroforestry as practised in the 1990s in Jambi (Sumatra, Indonesia) (Suyanto et al 2001)

Plot age[1]	Land preparation	Crop care	Harvesting and hauling	Total
1A. Forest clearance	53.3 + 28.6	6.9 + 4.1	9.4 + 25.0	127.4
1B. Bush clearance	19.6 + 12.2	17.8+7.7	1.0+1.0	59.3
Year 4-7	0 + 0	9.8 + 4.2	0 + 0	14.0
Year 11-15	0 + 0	4.8 + 1.4	90.5 + 4.5	101.2
Year 26-30	0 + 0	4.2 + 0	109.3 + 0	113.5
Year 30+	0 + 0	4.8 + 4.2	81.7 +0	90.7

[1] based on 162 households and 550 rubber plots in two villages.

The total labour requirement per unit of land averaged over the systems life cycle of around 100 person-days for rubber indicates that about 3 ha per person is manageable. With assumptions about the economically active fraction of a population, this shows an 'equilibrium' human population density at which the supply of labour matches demand. For rubber, the labour demand is higher than for oil palm, and equilibrium population density is 60-70 rather than around 40 km^{-2}, indicating that a shift from rubber to oil palm is an extensification in terms of labour (Murdiyarso et al 2002).

In subsequent studies, the estimates of labour requirements per stage of rubber agroforestry could be reconfirmed or adjusted based on smaller sample sizes. Simultaneously, the process for inputs, the market process for outputs and wage rates had to be regularly updated to allow comparisons across land uses and between mineral soil and peat areas (Table 24.3). Risk can also be compared between tree crops, and an earlier analysis indicated that in three out of four years, oil palm would be more profitable for smallholders in Sumatra than rubber, but a farm having both was most secure financially.

Table 24.3: Private profitability as indicated by Net Present Value (NPV) and Returns to Labour (R2L) of land-use systems in a coastal district in Sumatra (Indonesia) (Sofiyudin et al 2012)

Land use	NPV; *R2L* USD/ha ; *USD p.p.p.d.*		Land use	NPV; *R2L* USD/ha ; *USD p.p.p.d*	
Large Scale	Mineral soil	Peat	***Smallholder***	Mineral soil	Peat
Oil palm	7615;*12.4*	-	Smallholder oil palm	7012;*17.3*	5866;*16.1*
Logging	6114; *8.5*	-	Rubber monoculture	2417; *7.4*	1481; *8.1*
Acacia fastwood	1040;*17.1*	-	Rubber agroforest	1580; *7.1*	-
Annual crops			Coconut monoculture	734; *8.9*	-
Dryland paddy	404; *5.8*	-	Coffee/ betel nut agroforest	-	5722; *8.9*
Irrigated paddy	974; *7.0*	-	Coconut/coffee/betel nut agroforest	-	5301; *8.5*
Tidal paddy	-	882; *6.2*	Betel nut/coconut agroforest	-	2002; *7.8*
Maize	-	595; *7.0*	Jelutung monoculture	-	3590;*16.5*

Market price fluctuations have a strong effect on the NPV and R2L results. In 2011 when world rubber prices reached 4.5 USD per kg dry rubber content, the NPV of rubber agroforestry reached 2508 USD/ha and that of a rubber monoculture 3213 USD/ha, with returns to the labour of 7.1 and 7.4 USD p.p.p.d., respectively. In 2020 when the world rubber process had declined to 1.3 USD per kg dry rubber content, the NPVs had become 401 and 825 USD/ha and R2Ls 4.6 and 4.8 USD p.p.p.d., respectively (Suyanto and Dewi 2021). The economic results for rubber agroforest are lower but more stable than those for rubber monocultures. A study (Arifin 2005) of price fluctuations at farmgate and the world market showed that upward changes in the world price of rubber are not rapidly transmitted to rubber farmers and/or share-tappers. Hence, profits are accumulated by traders and rubber factories.

Most of these analyses so far have suggested that large-scale plantations could afford to pay slightly higher wage rates than the returns to labour in smallholder (family) farms. Still, two aspects are missing from this comparison: part of the plantation labour bill is needed for higher-level managerial jobs, while the plantation system has fewer options to flexible adjustment of labour intensity to current market prices, while smallholder systems, especially those in diverse landscapes may have more options to shift their labour allocations rapidly. It has not been easy to capture this aspect in the standard economic calculations. Another challenge is that rubber tapping is best done in the early morning, leaving part of the day for other tasks, while on rainy days, the tapping can be skipped – but there may not be alternative productive uses of time (Lehébel-Péron et al 2011).

5. Environmental impacts

Environmental impacts of tree crops can be compared with the natural forest as a point of reference (Murdiyarso et al 2002; Dislich et al 2017), or with the land use expected otherwise (De Jong et al 2001). They can be expressed per unit area with a focus on the phase that they occur (e.g. initial expansion and land clearing phase), averaged over the life cycle of the system (or over the landscape as a whole across its various life cycle stages) or per unit product harvested, as a ‘footprint’. Advocates of ‘intensification’ have favoured the latter way of expressing as it suggests that ‘land can be spared’ if yields get closer to their theoretical maximum. Interestingly, intercropping can reduce footprints and achieve ‘land equivalent rations’ above 1.0, higher than any monoculture can achieve (Joshi et al 2005). For most ways of accounting, the land cover preceding the tree crops is important (Ekadinata and Vincent 2011; Agus et al 2013): the same land use may appear environmental degradation when following forest, or improvement (restoration) when started from fire-climax grassland or young secondary vegetation (Villamor et al 2014a).

Impacts vary with the specific environmental parameter of interest. For biodiversity loss, the main interest is in the expansion phase along forest frontiers, where forests that can still recover to the natural forest are converted to low-diversity land uses. The 'jungle rubber' or rubber agroforests still shares many characteristics, including tree diversity, with secondary forests in the same landscape (Tata et al 2008; Gillison et al 2013), as long as there is a sufficient influx of seeds from surrounding forests (van Noordwijk et al 2014; Rahayu et al 2021). For other groups, biodiversity impacts of forest conversion may differ with (Beukema and van Noordwijk, 2004; Beukema et al 2007; Clough et al 2016), for example, relatively high reptile species richness in oil palm plantations. Rubber expansion on mainland SE Asia has adverse effects on biodiversity (van Noordwijk et al 2012; Ahrends et al 2015), but the types of rubber agroforestry in South Thailand results are mixed (Warren-Thomas et al 2020).

Fire bans that are enforced induce changes in land clearing, reducing the opportunity for early-stage intercropping (Ketterings et al 1999), but have little impact on the longer-term C balance. As the time-averaged C stock of oil palm is around 40 Mg C ha^{-1}, and rubber agroforests around 60 Mg C ha^{-1}, a shift from rubber agroforest to oil palm induces net emissions (for the first production cycle) (Khasanah et al 2015b). Soil carbon tends to decrease in the early phases of tree crop plantations (Guiillaume et al 2016), but recover subsequently, and at the life cycle stage, conversion of forest to tree crops can be carbon neutral from a soil carbon perspective (Khasanah et al 2015b). The net effects of tree crop intensification on the footprints of the resulting products can be mixed as the use of nitrogen fertilizer increases both yields and greenhouse gas emissions, suggesting that there is some intermediate, environmentally optimum level of intensification (van Noordwijk et al 2016). Negative impacts on water quality may focus on concentrated pollution by the rubber and oil palm mills and/or the more dispersed groundwater pollution by agrochemicals used in the plantations (Comte et al 2015).

A recent claim that coconut oil has stronger negative impacts, per unit oil produced, than palm oil (Meijaard et al 2020) showed the challenges in these calculations (ICRAF 2020). As coconut is grown on many small islands with vulnerable endemic species, a relatively small production volume is associated with high extinction risks. However, these high risk refer to 7% of global coconut production, while biodiversity impacts in the main production countries are less than those for palm oil (partly in the same countries). To an uninformed consumer audience, it may be hard to see through the politics of the choice of metric for such comparisons. Still, we need to understand the statistical distributions beyond the means that are reported.

6. Family farms vs plantations, sharecropping

For most agricultural commodities, family farms have been the most efficient producers, partly because of the elasticities of labour supply. Enterprises with hired labour face largely fixed costs, while family farms have more opportunities to juggle their time in 'bricolage' mode. Rubber has followed this pattern from its early expansion in SE Asia. However, commercial plantations under private or state-company management held on to some 30% of production by adjusting tapping regimes, using chemical stimulants for latex flow, and targeting higher-value rubber products depending on direct processing of latex, rather than slab or sheet rubber production. Some family farms work with hired labour (Dib et al 2018), but more common are forms of share-tapping (a form of share-cropping) in which the owner of the trees gets an agreed share of the rubber while paying for some of the inputs used. As tapping can damage the trees, share-tapping agreements require trust between the partners, as can be found within extended networks and intergenerational relations with in-laws. Indeed, a study (Sofiyuddin et al 2012) found that rubber trees are over-exploited under renting arrangements due partly to the short-run nature of the land tenancy contracts and partly to the difficulty landowners face in supervising tapping activities of tenants in spatially dispersed rubber fields.

Its start oil palm has been a company-based crop, as it involves a different economy of scale. To commercially run a mill, an area of around 10,000 ha is needed as a supply shed, with efficient logistics that avoid delays between harvesting and delivery to the mill. Where access to good quality planting material has been limited, and the use of inputs such as fertilizer about 30% of production costs, plantation-style management had a clear edge in the initial expansion of the crop. Companies interacted with local communities to get access to land and labour, and the 'nucleus-estate plasma program' initially promoted by the Worldbank, became a common scheme. Part of the oil palm remained nominally owned by the local community whose land had been converted but often under central management and charges for plantation establishment to be recovered from yields.

When external criticism on social and environmental impacts of oil palm expansion increased, these 'smallholder schemes' became a major line of defence for the industry. The challenge shifted to the degree of 'free and prior informed consent' (FPIC) when the agreements were made with local elites on behalf of the community but without formal authority to do so (Colchester et al 2006; Filer et al 2020).

'Independent' or 'non-tied' smallholders (IFC 2013; Jelsma et al 2017), without a contractual link to mills, but selling to middle-men (Figure 24.5) who may supply to multiple mills have become a relevant part of the supply chain in landscapes where large blocks of land for plantation expansion could no longer be found, and where mills without their own plantations land developed mostly in Sumatra (Figure 24.2). In rubber, it is common to find that some families own (at least within the locally applied standards of ownership) large tracts of rubber agroforest. They generally don't employ labour but rely on share-tapping arrangements with trusted (often younger) people, often relatives, to benefit from the products. In oil palm, in contrast, an increasing role is played by middle-scale landowners who employ labour to harvest their plots. However, lack of transparency on the employment rules applied, while social conditions on large plantations are increasingly scrutinised, make this middle category challenging.

Studies of the social impact of oil palm expansion have shown mixed results (Gato et al 2017; Euler et al 2017), with a considerable role in how community-scale leadership negotiated with the companies that bought their land. The evidence so far on the impacts of a change from rubber to oil palm on gender relations is mixed. Several studies, especially in the forest frontier expansion of oil palm, have emphasised women's vulnerability to such changes (Morgan 2017), elsewhere women appeared to be more open to interactions with companies than men (Villamor et al 2014b).

Figure 24.5: *Independent smallholder oil palm:* **A.** *Village-level collector buying fresh fruit bunches (FFB) in the morning, bringing selected fruits to the nearest mill in the afternoon;* **B.** *Rejects may still feed a goat (Photos: Meine van Noordwijk, ICRAF)*

7. Social impacts, political economy and government policies

The history of tree crops in Southeast Asia has been a synergy and competition between a large-scale plantation sector and smallholders, with the former setting up processing facilities and market channels. Generally, family farms proved to be the more flexible and economically efficient producers, even when yields per ha may be lower.

A century ago, while government policy was focussed on facilitating 'modern' and 'efficient' plantations, smallholder rubber was rapidly overtaking it in Sumatra (Rutgers 1925). Where tree crops expanded into sparsely populated forest margins, e.g. following (over)logging of forests, external labour had to be brought in, often leading to social tensions with local people (Galudra et al 2014). In other areas and phases of history, such influx of migrants could be welcomed by local governments, eager to grow the local economy and split off from the larger entities they were part of. As plantation companies have difficulties recruiting labour for remote locations, in the past, pressures exerted in the government transmigration program in Indonesia (and similar resettlement schemes in Malaysia) had negative social impacts, with gender relations a further point of the contest (Morgan 2017; Elmhirst et al 2017). Elsewhere, local farming communities became interested in rubber (currently in mainland SE Asia) or oil palm as new tree crops and social relations were less affected.

Recently smallholder oil palm crossed the 50% threshold in Riau province (Descals et al 2019). A literature review (Byerlee 2014) of four commodities (tea, rubber, oil palm and cassava) in Southeast Asia shows that all were initiated in the colonial period on large plantations but transited over the 20th century to smallholder systems analysed two interacting groups of explanatory factors. Technical aspects shape economic fundamentals related to economies of scale in processing methods, pioneering costs and risks, sometimes giving an edge, at last initially, to large-scale plantations. As a second group, policy biases and development paradigms often strongly favoured plantations and discriminated against smallholders in the colonial states, especially by increasing access to cheap land and labour. Smallholders overwhelmingly dominated perennial crop exports by the end of the 20th century, with oil palm the last to follow the generic pattern and changes in tea (slow to shift in Indonesia) dependent on specific policy contexts.

The review also discusses the surprising resurgence in the 21st century of investments in plantation agriculture in the frontier countries of Cambodia, Laos and Myanmar, driven by very similar factors to a century ago, especially access to cheap land combined with high commodity prices. The author expects that this may be a temporary aberration from the long-run trend toward smallholders, but much depends on the local political economy.

A contrast between the environmentally and socially 'benign' rubber and the more controversial but more profitable oil palm crop has been discussed in the context of 'best bet' alternatives to slash-and-burn in Indonesia (Tomich et al 1998). The emergence of a smallholder oil palm sector (Cramb and McCarthy 2016) has been uneven within the region, with Thailand in the lead, the transition in Malaysia led by government-sponsored schemes (FELDA) and Indonesia's initial focus on regulated 'outgrower' schemes gradually giving way to 'independent' smallholders (McCarthy and Cramb 2009).

In their capacity to negotiate permits for plantation expansion, local governments have favoured large-scale operations as part of development plans – even when environmental and social concerns became more prominent at national scales (Tata et al 2014). The initial dominance of large-scale plantations in oil palm has contributed to the negative public image of the crop as a destroyer of rainforest and intruder in local social relations. Ironically, the current shift to smallholder production is challenged by the certification rules designed for large-scale plantations and are not easily adjusted to smallholder realities (Hidayat et al 2015; Markne 2016).

For oil palm, the challenge of reconciling 'green economy' ambitions with reality on the ground has been pronounced (Amaruzaman et al 2017). However, the successful voluntary schemes negotiated between the industry and environmental NGO's to self-regulate oil palm production led governments to try to regain the initiative (van Noordwijk et al 2012; Hidayat et al 2018). Being closer to the end-product, consumers are more directly affected by boycotts and threats thereof. The downstream part of the oil palm industry has led to the emergence of voluntary standards in the Roundtable for Sustainable Palm Oil (RSPO) (Ruysschaert and Salles 2014; RSPO, 2017) and subsequent initiatives. This ensures that globally traded palm oil is 'deforestation free' and not co-responsible for peatland conversion (Afriyanti et al 2016). Such certification efforts can be understood as relevant for the actors involved, but whether they go beyond 'shifting blame' and contribute to a reduction of the overall issues remains an open question (Mithöferet al 2017). The current debate on increasing the 'inclusiveness' of global palm oil value chains (Jezeer et al 2019) connects a social agenda (Hidayat et al 2016) with an ecological one in which intercropping and forms of agroforestry are explored (Slingerland et al 2019).

8. Discussion and relevance for Africa

The Asian history of rubber and oil palm has shown some interesting contrasts, especially in the relative role of smallholders and large-scale plantations in the expansion phase. The case studies here suggested convergence over time between the two crops, with economies of scale dominating in the processing and trade part of the chain, but not in the primary production, once access to technical know-how, quality planting material and other inputs are secured. The successful transfer of crops originating in the Amazon basis and West/Central Africa to Southeast Asia has been able to 'undercut' production in the areas of origin when global demand for the products initially increased prices, followed by crashes when production potential had caught up.

Where rubber and oi palm as new tree crops initially contributed to a diversification of the local economy, they reduced diversity when they became locally dominant and exposed farmers to risk when the fluctuations in world market prices reached a downturn. Resisting the temptations of over-investment of land and other resources during 'boom' phases of agricultural commodities to be prepared for an expected subsequent 'bust', however, is hard to achieve – especially where government development programs can initially ignore market dynamics and realities.

The macro-economic policy of exchange rates may account for the paradox that Southeast Asian farmers still see the production of these tree crops as a step up from alternatives that they have. In contrast, for African farmers, the conditions of a 'living wage' can hardly be met. It may be attractive for local governments to start 'development' by creating affordable access to land and (externally recruited) labour in an emerging plantation industry. Still, for the longer term positive development impacts, an evolution to a smallholder dominated sector must be foreseen and facilitated without monopsony (the dominance by a single buyer in local markets). At the interface with global markets, perceptions of negative and positive impacts cannot be ignored, as prevention of consumer boycotts is nearly always more cost-effective than cure.

References

Afriyanti D, Kroeze C, Saad A. 2016. Indonesia palm oil production without deforestation and peat conversion by 2050. *Sci Total Environ.* 557: 562–570

Agus F, Gunarso P, Sahardjo BH, Harris N, van Noordwijk M, Killeen TJ. 2013. *Historical CO_2 emissions from land use and land use change from the oil palm industry in Indonesia, Malaysia, and Papua New Guinea*. Kuala Lumpur, Malaysia: Roundtable on Sustainable Palm Oil.

Ahrends A, Hollingsworth PM, Ziegler AD, Fox JM, Chen H, Su Y, Xu J. 2015. Current trends of rubber plantation expansion may threaten biodiversity and livelihoods. *Global Environmental Change* 34:48-58.

Akiefnawati R, van Noordwijk M, Tata HL. 2021. *Rubber agroforestry experiments in Jambi at the end of a 25-Year cycle*. Proceedings RUBIS symposium, Yogyakarta (in press)

Amaruzaman S, Leimona B, van Noordwijk M, Lusiana B. 2017. Discourses on the performance gap of agriculture in a green economy: a Q-methodology study in Indonesia. *International Journal of Biodiversity Science, Ecosystem Services & Management* 13:1:233-247

Arifin B. 2005. Supply Chain of Natural Rubber in Indonesia. *Jurnal of Management & Agribisnis* 2(1):1-16. https://jurnal.ipb.ac.id/index.php/jmagr/article/view/3345

Belcher B, Imang N, Achdiawan R. 2004. Rattan, rubber, or oil palm: cultural and financial considerations for farmers in Kalimantan. *Economic Botany* 58(1):S77-S87.

Beukema H, van Noordwijk M. 2004. Terrestrial pteridophytes as indicators of a forest-like environment in rubber production systems in the lowlands of Jambi, Sumatra. *Agriculture, ecosystems & environment* 104(1):63-73.

Beukema H, Danielsen F, Vincent G, Hardiwinoto S, van Andel J. 2007. Plant and bird diversity in rubber agroforests in the lowlands of Sumatra, Indonesia. *Agroforestry Systems* 70(3):217-242.

Boer E, AB Ella (Eds). 2000. Plants producing exudates. Plant Resources of South-East Asia Volume 18, PROSEA, Bogor (Indonesia)

Budidarsono S, Dewi S, Sofiyuddin M, Rahmanulloh A. 2012. Socioeconomic impact assessment of palm oil production. Technical Brief No 27: palm oil series. Bogor, Indonesia: World Agroforestry Centre - ICRAF, SEA Regional Office.

Budidarsono S, Susanti A, Zoomers A. 2013. Oil palm plantations in Indonesia: the implications for migration, settlement/resettlement and local economic development. In Fang Z editor. Biofuels—Economy, environment and sustainability. Rijeka: InTech: 173–193. doi:10.5772/53586

Byerlee, D. 2014. The Fall and Rise Again of Plantations in Tropical Asia: History Repeated? *Land* 3: 574-597.

Byerlee D, Falcon WP, Naylor RL. 2017. The tropical oil crop revolution: food, feed, fuel and forests. New York, USA: Oxford University Press.

Clough Y, Krishna VV, Corre MD, Darras K, Denmead LH, Meijide A, Moser S, Musshoff O, Steinebach S, Veldkamp E, Allen K. 2016. Land-use choices follow profitability at the expense of ecological functions in Indonesian smallholder landscapes. *Nature communications* 7(1):1-12.

Colchester M, Chao S, editors. 2011. Oil palm expansion in South East Asia: trends and implications for local communities and indigenous peoples. Moreton-in-Marsh, UK: Forest Peoples Programme.

Colchester M, Jiwan N, Sirait M, Andiko FA, Surambo A, Pane H. 2006. Promised Land: Palm Oil and Land Acquisition in Indonesia—Implications for Local Communities and Indigenous Peoples; FPP, Sawit Watch, HuMA and ICRAF: Bogor, Indonesia

Comte I, Colin F, Grunberger O, Whalen JK, Widodo RH, Caliman JP. 2015. Watershed-scale assessment of oil palm cultivation impact on water quality and nutrient fluxes: a case study in Sumatra (Indonesia). *Environ Sci Pollut R.* 22:7676-95.

Corley RHV, Tinker PB. 2016. The Oil Palm, 5th edition. John Wiley & Sons.

Cramb R, McCarthy JF, editors. 2016. The Oil Palm Complex: Smallholders, Agribusiness and the State in Indonesia and Malaysia. Singapore: NUS Press

De Jong W, Van Noordwijk M, Sirait M, Liswanti N. 2001. Farming secondary forests in Indonesia. *Journal of tropical forest science* 705-726.

Descals A, Szantoi Z, Meijaard E, Sutikno H, Rindanata G, Wich S. 2019. Oil Palm (Elaeis guineensis) Mapping with Details: Smallholder versus Industrial Plantations and their Extent in Riau, Sumatra. *Remote Sens.* 11:2590

Dewi S, van Noordwijk M, Zulkarnain MT, Dwiputra A, Prabhu R, Hyman G, Gitz V, Nasi R. 2017. Tropical forest-transition landscapes: a portfolio for studying people, tree crops and agro-ecological change in context. *International Journal of Biodiversity Science, Ecosystem Services & Management* 13(1):312-329.

Dharmawan AH, Mardiyaningsih DI, Komarudin H, Ghazoul J, Pacheco P, Rahmadian F. 2020. Dynamics of Rural Economy: A Socio-Economic Understanding of Oil Palm Expansion and Landscape Changes in East Kalimantan, Indonesia. *Land 2020* 9(7):213.

Dib JB, Krishna VV, Alamsyah Z, Qaim M. 2018. Land-use change and livelihoods of non-farm households: The role of income from employment in oil palm and rubber in rural Indonesia. *Land use policy* 76:828-838

Dislich C, Keyel AC, Salecker J, Kisel Y, Meyer KM, Auliya M, Barnes AD, Corre MD, Darras K, Faust H, Hess B. 2017. A review of the ecosystem functions in oil palm plantations, using forests as a reference system. *Biological Reviews* 92(3):1539–1569.

Dove M. 2011. The banana tree at the gate. a history of marginal peoples and global markets in Borneo. *Human Ecology* 40(1):165–166.

Ekadinata A, Van Noordwijk M, Budidarsono S, Dewi S. 2013. Hot spots in Riau, haze in Singapore: the June 2013 event analyzed. ASB Policy brief No. 33. Bogor, Indonesia: World Agroforestry Centre - ICRAF, SEA Regional Office. p.6.

Ekadinata A, Vincent G. 2011. Rubber agroforests in a changing landscape: analysis of land use/cover trajectories in Bungo district, Indonesia. *Forests, Trees and Livelihoods* 20(1):3-14.

Elmhirst R, Siscawati M, Basnett BS, Ekowati D. 2017. Gender and generation in engagements with oil palm in East Kalimantan, Indonesia: insights from feminist political ecology. *The Journal of Peasant Studies* 44(6):1135-1157.

Euler M, Krishna V, Schwarze S, Siregar H, Qaim M. 2017. Oil palm adoption, household welfare, and nutrition among smallholder farmers in Indonesia. *World Development* 93:219-235.

[FAO] Food and Agriculture Organization. 2020. http://www.fao.org/faostat/en/#data/QV

Filer C, Mahanty S, Potter L. 2020. The FPIC Principle Meets Land Struggles in Cambodia, Indonesia and Papua New Guinea. *Land* 9(3):67.

Galudra G, van Noordwijk M, Agung P, Suyanto S, Pradhan U. 2014. Migrants, land markets and carbon emissions in Jambi, Indonesia: land tenure change and the prospect of emission reduction. *Mitigation and Adaptation Strategies for Global Change* 19(6):715-731.

Gatto M, Wollni M, Asnawi R, Qaim M. 2017. Oil palm boom, contract farming, and rural economic development: Village-level evidence from Indonesia. *World Development* 95:127-140.

Gillison AN, Bignell DE, Brewer KR, Fernandes EC, Jones DT, Sheil D, May PH, Watt AD, Constantino R, Couto EG et al (2013) Plant functional types and traits as biodiversity indicators for tropical forests: two biogeographically separated case studies including birds, mammals and termites. *Biodiversity and Conservation* 22(9):1909-1930.

Gouyon A, De Foresta H, Levang P. 1993. Does 'jungle rubber' deserve its name? An analysis of rubber agroforestry systems in southeast Sumatra. *Agroforestry systems* 22(3):181-206.

Guillaume T, Holtkamp AM, Damris M, Brümmer B, Kuzyakov Y. 2016. Soil degradation in oil palm and rubber plantations under land resource scarcity. *Agriculture, Ecosystems & Environment* 232:110-118.

Hidayat NK, Glasbergen P, Offermans A. 2015. Sustainability Certification and Palm Oil Smallholders' Livelihood: A Comparison between Scheme Smallholders and Independent Smallholders in Indonesia. *International Food and Agribusiness Management Review* 18(3):25-48.

Hidayat NK, Offermans A, Glasbergen P. 2016. On The Profitability of Sustainability Certification: An Analysis among Indonesian Palm Oil Smallholders. *Journal of economics and sustainable development* 7(18):45-62.

Hidayat NK, Offermans A, Glasbergen P. 2018. Sustainable palm oil as a public responsibility? On the governance capacity of Indonesian Standard for Sustainable Palm Oil (ISPO). *Agriculture and human values* 35(1):223-242.

[ICRAF] World Agroforestry. 2020. https://www.worldagroforestry.org/blog/2020/07/15/coconut-bashing

[IFC] International Finance Corporation. 2013. Diagnostic Study on Indonesian Palm Oil Smallholders: Developing a better understanding of their performane and potential. Washington DC, USA: International Finance Corporation. p. 96

Jelsma I, Schoneveld GC, Zoomers A, van Westen ACM. 2017 Unpacking Indonesia's independent oil palm smallholders: An actor-disaggregated approach to identifying environmental and social performance challenges. *Land Use Policy* 69:281-297.

Jelsma I, Woittiez LS, Ollivier J, Dharmawan AH. 2019. Do wealthy farmers implement better agricultural practices? An assessment of implementation of good agricultural practices among different types of independent oil palm smallholders in Riau, Indonesia. *Agricultural Systems* 170:63-76.

Jezeer R, Slingerland MA, van der Laan C, Pasiecznik N. 2019. *Improving smallholder inclusiveness in palm oil production—a global review.* Wageningen, the Netherlands: Tropenbos International. xx + 166 pp. http://www.etfrn.org/publications/exploring+inclusive+palm+oil+production

Joshi L, Wibawa G, Beukema HJ, Williams SE, Van Noordwijk M. 2003. Technological change and biodiversity in the rubber agroecosystem. In: Vandermeer JH, ed. *Tropical Agroecosystems: New Directions for Research.* Boca Raton, Fl (USA): CRC Press, p.133-157.

Joshi L, van Noordwijk M, Sinclair FL. 2005. Bringing local knowledge in perspective: A case of sustainable technology development in jungle rubber agroforests in Jambi, Indonesia. In: Neef A, ed. *Participatory Approaches for Sustainable Land Use in Southeast Asia.* Bangkok, Thailand: White Lotus Press, p.277-289

Ketterings QM, Wibowo TT, van Noordwijk M, Penot E. 1999. Farmers' perspectives on slash-and-burn as a land clearing method for small-scale rubber producers in Sepunggur, Jambi Province, Sumatra, Indonesia. *Forest Ecology and Management* 120(1-3):157-169.

Khasanah NM, van Noordwijk M, Ningsih H. 2015a. Aboveground carbon stocks in oil palm plantations and the threshold for carbon-neutral vegetation conversion on mineral soils. *Cogent Environmental Science* 1(1):1119964.

Khasanah N, van Noordwijk M, Ningsih H, Rahayu S. 2015b. Carbon neutral? No change in mineral soil carbon stock under oil palm plantations derived from forest or non-forest in Indonesia. *Agriculture, ecosystems & environment* 211:195-206.

Khasanah N, Van Noordwijk M, Slingerland M, Sofiyudin M, Stomph D, Migeon AF, Hairiah K. 2020. Oil Palm Agroforestry Can Achieve Economic and Environmental Gains as Indicated by Multifunctional Land Equivalent Ratios. *Front. Sustain. Food Syst.* 3:122. doi: 10.3389/fsufs

Lehébel-Péron A, Feintrenie L, Levang P. 2011. Rubber agroforests' profitability, the importance of secondary products. *Forests, Trees and Livelihoods* 20(1):69-84

Markne M. 2016. Certifying sustainability: independent oil palm smallholders' experiences of the RSPO certification process in the Riau province, Indonesia. Available from: http://www.diva-portal.org/smash/get/diva2:898810/FULLTEXT01.pdf. Accessed 19-11-2020.

McCarthy JF, Cramb RA. 2009. Policy narratives, landholder engagement, and oil palm expansion on the Malaysian and Indonesian frontiers. *Geographical Journal* 175(2):112-123.

Meijaard E, Abrams JF, Juffe-Bignoli D, Voigt M, Sheil D. 2020. Coconut oil, conservation and the conscientious consumer. *Current Biology* 30(13):R757-R758

Meyfroidt P, Carlson KM, Fagan ME, H. G-VV, Macedo MN, Curran LM, DeFries RS, Dyer GA, Gibbs HK, Lambin EF, et al 2014. Multiple pathways of commodity crop expansion in tropical forest landscapes. *Environ Res Lett.* 9:074012

Miccolis A, Robiglio V, Cornelius JP, Blare T, Castellani D. 2019. Oil palm agroforestry: fostering socially inclusive and sustainable production in Brazil. In: Jezeer R, Pasiecznik N, eds. *Exploring inclusive palm oil production*. Wageningen, the Netherlands: Tropenbos International, p.55-62. http://www.etfrn.org/publications/exploring+inclusive+palm+oil+production

Mithöfer D, van Noordwijk M, Leimona B, Cerutti P. 2017 Certify and shift blame, or resolve issues? Environmentally and socially responsible global trade and production of timber and tree crop commodities. *International Journal of Biodiversity Science, Ecosystem Services & Management* 13(1): 72-85.

Miyamoto M. 2006. Forest conversion to rubber around Sumatran villages in Indonesia: comparing the impacts of road construction, transmigration projects and population. *Forest Policy and Economics* 9(1):1-12.

Morgan M. 2017. Women, gender and protest: contesting oil palm plantation expansion in Indonesia. *The Journal of Peasant Studies* 44(6):1177-1196.

Murdiyarso D, van Noordwijk M, Wasrin UR, Tomich TP, Gillison AN. 2002. Environmental benefits and sustainable land-use options in the Jambi transect, Sumatra. *J Veg Sci.* 13(3):429-438.

Pacheco P, Gnych S, Dermawan A, Komarudin H and Okarda B. 2017. *The palm oil global value chain: Implications for economic growth and social and environmental sustainability*. Working Paper 220. Bogor, Indonesia: CIFOR.

Papenfus MM. 2000. Investing in oil palm: an analysis of independent smallholder oil palm adoption in Sumatra, Indonesia. Southeast Asia Policy Research Working Paper 15. Bogor, Indonesia: World Agroforestry Centre (ICRAF).

Purwanto E, Santoso H , Jelsma I, Widayati A, Nugroho HYSH, van Noordwijk M. 2020. Agroforestry as policy option for forest-zone oil palm production in Indonesia. *Land* 9(12):531.

Rahayu S, Pambudi S, Permadi D, Tata HL, Martini E, Rasnovi S, Nuroniah HS, Kindt R, Nugraha M, Dewi S, van Noordwijk M. 2021. Wood density and dispersal modes of trees regenerating in disturbed forests and agroforests in Indonesia. https://assets.researchsquare.com/files/rs-236533/v1/25fdedf5-dc00-4c5a-bb39-00550e076cea.pdf

Rahmanulloh A, Sofiyuddin M, Suyanto, Budidarsono S. 2013. Land Use Profitability Analysis (LUPA). In: van Noordwijk M, Lusiana B, Leimona B, Dewi S, Wulandari D, eds. *Negotiation-support toolkit for learning landscapes*. Bogor, Indonesia: World Agroforestry Centre (ICRAF), p.47-51.

[RSPO] Roundtable on Sustainable Palm Oil. 2017. Impacts. Available from: https://rspo.org/about/impacts. Accessed 19-11-2020.

Rutgers AAL. 1925. De toekomst van de bevolkingsrubber in Nederlandsch-Indië. (The future of smallholder rubber in the Dutch Indies) *Ind. Mercuur* 48:833.

Ruysschaert D, Salles D. 2014. Towards global voluntary standards: questioning the effectiveness in attaining conservation goals: the case of the Roundtable on Sustainable Palm Oil (RSPO). *Ecol Econ.* 107:438-446.

Schwarze S, Euler M, Gatto M, Hein J, Hettig E, Holtkamp AM, Izhar L, Kunz Y, Lay J, Merten J, Moser S. 2015. Rubber vs. oil palm: an analysis of factors influencing smallholders' crop choice in Jambi, Indonesia. EFForTS Discussion Paper Series, No. 11, GOEDOC, Dokumenten- und Publikationsserver der Georg-August-Universität, Göttingen, http://nbn-resolving.de/urn:nbn:de:gbv:7-webdoc-3954-4

Sheil D, Casson A, Meijaard E, Van Noordwijk M, Gaskell J, Sunderland-Groves J, Wertz K, Kanninen M. 2009. *The impacts and opportunities of oil palm in Southeast Asia: What do we know and what do we need to know?* Occasional Paper 51. Bogor, Indonesia: Center for International Forestry Research.

Slingerland MA, Khasanah NM, van Noordwijk M, Susanti A, Meilantina M. 2019. Improving smallholder inclusivity through integrating oil palm with crops. pp. 147-154. In: Exploring inclusive palm oil production. Wageningen: Tropenbos International. http://www.etfrn.org/publications/exploring+inclusive+palm+oil+production

Sofiyuddin M, Rahmanulloh A, Suyanto S. 2012. Assessment of profitability of land use systems in Tanjung Jabung Barat district, Jambi province, Indonesia. *Open Journal of Forestry* 2(4):252-256.

Suyanto S, Tomich TP, Otsuka K. 2001. Land tenure and farm management efficiency: the case of smallholder rubber production in customary land areas of Sumatra. *Agroforestry Systems* 52(2):145–160.

Suyanto, Dewi S. 2021. Can rubber agroforestry resolve the global issues on socio-economic dimensions? Presentation at RUBIS workshop, April 5th – April 9th 2021, Yogyakarta (Indonesia). https://www.rubis-project.org/project-events/rubis-international-workshop-2021/rubis-international-workshop-2021

Tata HL, van Noordwijk M, Werger M. 2008. Trees and regeneration in rubber agroforests and other forest-derived vegetation in Jambi (Sumatra, Indonesia). *Journal of Forestry Research* 5(1): 1-20.

Tata HL, van Noordwijk M, Ruysschaert D, Mulia R, Rahayu S, Mulyoutami E, Widayati A, Ekadinata A, Zen R, Darsoyo A, Oktaviani R. 2014. Will funding to Reduce Emissions from Deforestation and (forest) Degradation (REDD+) stop conversion of peat swamps to oil palm in orangutan habitat in Tripa in Aceh, Indonesia? *Mitigation and Adaptation Strategies for Global Change*. 19(6): 693-713.

Tomich TP, Van Noordwijk M, Vosti SA, Witcover J. 1998. Agricultural development with rainforest conservation: methods for seeking best bet alternatives to slash-and-burn, with applications to Brazil and Indonesia. *Agricultural Economics* 19(1-2):59-174.

van der Vossen HAM, Umali E, eds. 2001. *Vegetable oils and fats*. Plant Resources of South-East Asia 14. Bogor, Indonesia: PROSEA.

van der Vossen HAM. 1974. Towards more efficient selection for oil yield in the oil palm (Elaeis guineensis Jacquin). Doctoral thesis, Wageningen: Wageningen University.

van Noordwijk M, Mulyoutami E, Sakuntaladewi N, Agus F. 2008. Swiddens in transition: shifted perceptions on shifting cultivators in Indonesia. Bogor, Indonesia: World Agroforestry Centre - ICRAF SEA Regional Office. 48p.

van Noordwijk M, Tata HL, Xu J, Dewi S, Minang PA. 2012. Segregate or integrate for multifunctionality and sustained change through rubber-based agroforestry in Indonesia and China. In: Nair PKR, Garrity D, eds. *Agroforestry-the future of global land use*. Dordrecht: Springer, p.69-104.

van Noordwijk, M, Bizard V, Wangpakapattanawong P, Tata HL, Villamor GB, Leimona B. 2014. Tree cover transitions and food security in Southeast Asia. *Global Food Security* 3(3–4):200–208.

van Noordwijk M, Khasanah N, Dewi S. 2016. Can intensification reduce emission intensity of biofuel through optimized fertilizer use? Theory and the case of oil palm in Indonesia. *Glob Change Biol Bioenergy*. Doi:10.1111/gcbb.12398 van Noordwijk M, Pacheco P, Slingerland M, Wibawa G, Dewi S, Khasanah N. 2017. Palm oil expansion in tropical forest margins or sustainability of production? Focal issues of regulations and private standards. Working paper 274. Bogor, Indonesia: World Agroforestry Centre (ICRAF) Southeast Asia Regional Program.

van Noordwijk M, Zomer RJ, Xu J, Bayala J, Dewi S, Miccolis A, Cornelius J, Robiglio V, Nayak D, Rizvi J. 2019. Agroforestry options, issues and progress in regional contexts. In: van Noordwijk M, ed. *Sustainable development through trees on farms: agroforestry in its fifth decade.* Bogor, Indonesia: World Agroforestry (ICRAF), p.97-120

Villamor GB, Le QB, Djanibekov U, van Noordwijk M, Vlek PL. 2014a. Biodiversity in rubber agroforests, carbon emissions, and rural livelihoods: An agent-based model of land-use dynamics in lowland Sumatra. *Environmental Modelling & Software* 61:151-165.

Villamor GB, Desrianti F, Akiefnawati R, Amaruzaman S, van Noordwijk M. 2014b. Gender influences decisions to change land use practices in the tropical forest margins of Jambi, Indonesia. *Mitigation and Adaptation Strategies for Global Change* 19(6):733-755.

Villamor GB, Pontius RG, van Noordwijk M. 2014c. Agroforest's growing role in reducing carbon losses from Jambi (Sumatra), Indonesia. *Regional Environmental Change* 14(2):825-834.

Vincent G, Joshi L, Susilawaty, 2011. Is flexibility or productivity the key to persistence of rubber agroforests in Jambi province (Sumatra)? *Forests, Trees and Livelihoods* 20(1):51-67.

Warren Thomas E, Nelson L, Juthong W, Bumrungsri S, Brattström O, Stroesser L, Chambon B, Penot É, Tongkaemkaew U, Edwards DP, Dolman PM. 2020. Rubber agroforestry in Thailand provides some biodiversity benefits without reducing yields. *Journal of Applied Ecology* 57(1): 17-30.

Wibawa G, Hendratno S, van Noordwijk M. 2005. Permanent smallholder rubber agroforestry systems in Sumatra, Indonesia. In: Palm CA, Vosti SA, Sanchez PA, Ericksen PJ, eds. *Slash-and-Burn Agriculture: The Search for Alternatives*. New York: Columbia University Press, p.222-232.

Williams SE, Van Noordwijk M, Penot E, Healey JR, Sinclair FL, Wibawa G. 2001. On-farm evaluation of the establishment of clonal rubber in multistrata agroforests in Jambi, Indonesia. *Agroforestry Systems* 53(2):227-237.

Woittiez LS, van Wijk MT, Slingerland M, van Noordwijk M, Giller KE, 2017. Yield gaps in oil palm: a quantitative review of contributing factors. *Eur. J. Agron.* 83: 57-77.

Wulan YC, Budidarsono S, Joshi L. 2008. Economic analysis of improved smallholder rubber agroforestry systems in West Kalimantan, Indonesia-implications for rubber development. In *Sustainable sloping lands and watershed management conference*. Luang Prabang, Lao PDR.

Yunta GA, Dede M. 2019. The application of concentration and stimulation techniques of polyetilene glycol on the production of rubber plant PB 260 clone. In: *IOP Conference Series: Earth and Environmental Science* 391(1):012012. IOP

Ziegler AD, Fox JM, Xu J. 2009. The rubber juggernaut. *Science* 324(5930):1024-1025.