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REVIEW ARTICLE

# Farmer strategies for tree crop diversification in the humid tropics. A review

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**Abstract** Many tree crop farms in the tropics are in a process of crop diversification, even in regions that have traditionally been dominated by a single tree crop species. Here, we review the factors that drive diversification and that influence farmer choices. We analyze recent literature from tropical Latin America, Africa, Asia, and the Pacific Islands, with emphasis on West and Central Africa. We use a framework that distinguishes farmer objectives in diversifying; the opportunities and constraints caused by environmental, technological, market, and policy factors; and farmer characteristics. Our main findings are: (1) Farmers diversify to increase their income by adding more lucrative crops. They diversify also to spread their income to lean times between the harvests of their traditional crops. In addition, farmers diversify to maintain or increase their food security especially while young tree crops are maturing and to reduce their vulnerability to environmental, market, and policy shocks. (2) Famers take advantage of opportunities and are subject to constraints. These include: heterogeneous site characteristics; the legacy of previous forest vegetation; emergent market opportunities from growing urban centers; a diversity of products and market outlets for some crops that reduces marketing risks; government policies; labor constraints that favor certain crops; the availability of investment capital that influences particularly the timing of diversification decisions; and access to improved planting material. (3) Diversification decisions also depend on farmer characteristics such as their age, education, financial situation, and farm and family size. Young farmers are not always more active in diversification than older farmers, although diversification and crop change are often related to generational change. Returning urban migrants have often had a positive effect in terms of diversification and innovation. (4) Diversification is often a response to structural environmental degradation caused by decades of tree crop monocultures. We conclude with a list of areas where government and non-government organizations can support farmers in their diversification decisions.

**Keywords** Boom-and-bust cycles · Environmental degradation · Forest rent · Global climate change · Landscape · Livelihood security · Risk avoidance

Contents



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## 1 Introduction

Household diversification can be defined as "the process by which households construct increasingly diverse livelihood portfolios, making use of increasingly diverse combinations of resources and assets" (Niehof 2004). During the last decade, studies about diversification in rural areas have often focused on the combination of farming with non-farm activities (Winters et al. 2009; Barrett et al. 2001). In this review, however, our focus is on the diversification of farming itself, especially in the humid tropics where tree crops often dominate.

Millions of smallholder farmers in the humid tropics depend on tree crops such as coffee (*Coffea* spp.), cocoa (*Theobroma cacao*), coconut (*Cocos nucifera*), oil palm (*Elaeis guineensis*), and rubber (*Hevea brasiliensis*) for their livelihoods. Growers of tree crops cannot revise their land use decisions on a year-to-year basis as can, to some extent, those of annual crops. They are, therefore, particularly exposed to risks of environmental and market shocks, including sudden price fluctuations of international commodity markets, as well as changing government policies (Malézieux and Moustier 2005a). The history of tropical countries abounds with cases of boom-and-bust cycles, where phases of high prices and rapid expansion of certain tree crops were followed by economic decline caused by price crashes, newly arrived pests and diseases, or degrading soil and climate conditions affecting the dominant crop (Ruf 1995a). Examples include the long recession of the Amazon region after the end of the rubber boom caused by competition from Asian plantations at the beginning of the twentieth century (Dean 1987); the decline of coffee-dependent communities and countries from the late 1980s due to the fall of the international coffee prices (Malézieux and Moustier 2005a); or the continuing crisis of the main Brazilian cocoa region, southern Bahia, starting in the 1990s when the introduction of the witches' broom fungus (*Moniliphthora perniciosa*) of cocoa coincided with increasing economic difficulties (Alger and Caldas 1996). As we will show below, such boom phases of expanding tree crops are often characterized by quasi-monoculture systems that strongly rely on the natural resources that they inherited from the previous forest, that is, the "forest rent." These include relatively fertile soil, low pressure from weeds and pests, and micro-climatically protected conditions. Such boom phases are often followed by phases of environmental degradation and production decline that make subsequent bust phases more likely. For example, periodic production shifts of cocoa both within and between countries have been explained with environmental and social changes related to the exhaustion of the forest rent (Ruf 1995b). However, besides driving such periodic production shifts, the structural changes of aging frontier regions may also trigger diversification to other crops which rely less than cocoa on the environmental conditions of recently cleared forest land (Ruf 1987; Léonard and Vimard 2005).

Adding to these "traditional" processes and risks to which tropical tree crop farmers are exposed is now the risk of global climate change. Severe impacts of global warming on temperature-sensitive quality coffee have been predicted for mountain regions of Mesoamerica, made worse by likely increases in the frequency and severity of extreme weather events in this already hurricane-prone region (Schroth et al. 2009; Eakin et al. 2012). Similarly, West African cocoa farmers in marginal production areas near the forest–savannah boundary will increasingly be affected by a further drying of the climate through increased evaporation within the next decades (Läderach et al. 2013).

Since such structural changes and shocks—whether they are caused by droughts, diseases, or market instability—tend to affect different crops differently, producers of a portfolio of tree crops, who "do not put all eggs into one basket," tend to be less vulnerable than producers who are largely dependent on a single crop (Fig. 1). In this sense, diversification can be understood as a form of "self-insurance" (Barrett et al. 2001).

Tree crop diversification also allows farmers to gradually adapt to a changing environment (progressive decline in soil fertility, slow build-up of weeds, pests and diseases, decreasing rainfall and less protected microclimate, etc.) through a stepwise transition process from one dominant crop to another. In other words, it increases farmers' flexibility and adaptive capacity. Diversification has therefore become a common component of climate change adaptation strategies, as well as strategies to make farmers more resilient in general (Schroth et al. 2009; Pelling 2011).

Of course, diversification of tree crop systems also has its downsides in a market-oriented production system (Ruf and

**Fig. 1** This farm in southern Sulawesi, Indonesia, demonstrates the ancient principle of diversification that has recently attracted renewed interest as a strategy of self-insurance and adaptation to insecure and changing environmental, market, and policy conditions. The dominant crop in the fore-ground is cocoa (*T. cacao*); other crops include areca nut (*Areca catechu*) and coconut (*Cocos nucifera*) palms; food crops (cassava, *Manihot esculenta*; bananas, *Musa* sp.) and timber trees (photo: G. Schroth)

Schroth 2013b). Where one crop is clearly the most profitable at a given site and point in time, any dedication of land, labor, and capital to other crops will necessarily reduce total revenues, at least on the short term. Diversification may reduce economies of scale (e.g., from efficient use of processing or drying infrastructure) and may increase the cost of marketing small quantities of produce, especially in remote locations. Such economic realities set limits to farm diversification. It is therefore important for tree crop farmers, their advisers, and agricultural policy-makers to find the right balance between specialization on what farmers "do best" and is currently most profitable, and diversification to hedge risks and dispose of a portfolio of options on which to base gradual adaptation decisions, be it in response to environmental, economic, or other changes (Norton et al. 2006; Ruf and Schroth 2013b).

If farmers find that they would be better off by allocating some of their land, labor, and capital to an additional crop (i.e., to diversify), they have several options to do so. Instead of filling gaps in an old coffee or cocoa plantation with new seedlings of the same species, they may add another crop (say, bananas, fruit trees or timber trees), resulting in plot-level diversification or intercropping. They could replant their oldest and least productive plots with rubber trees or pasture grass, resulting in diversification at the farm level. Finally, different farmers in a village or watershed could specialize in different crops, resulting in diversification at the scale of the landscape, with individual farms forming specialized patches within a diversified land use mosaic. Several of these diversification options may take place simultaneously (Ruf and Schroth 2013a).

The objective of this paper is to contribute to our understanding of diversification decisions of tropical smallholder tree crop farmers. We review recent research on the processes and drivers of diversification in tree crop farms, including material from a recent volume about the topic (Ruf and Schroth 2013a) but do not intend to provide an exhaustive review of the voluminous literature on agricultural diversification. Although we consider information from Latin America, Africa, Asia, and the Pacific, our own background implies a certain bias toward West and Central Africa, and to cocoa, coffee and rubber. We also discuss some broader questions of the role of tree crop diversification in the evolution of tropical agricultural landscapes, emphasizing the point that the structural biophysical and social changes that are associated with tree crop boom-and-bust cycles may be important drivers of regional crop diversification. We conclude with a list of ways to support tropical tree crop farmers in their diversification decisions.

## 2 A framework for analyzing tree crop diversification

We use the simple framework for analyzing diversification decisions that is outlined in Fig. 2. Diversification decisions are understood as resulting from the interaction of three groups of variables: (1) the objectives of diversification, (2) opportunities for and constraints to diversification, and (3) farmer characteristics. In subsequent sections, we discuss four main objectives that guide tree crop farmers in their diversification decisions: (a) to increase revenues, (b) to stabilize income over the year, (c) to maintain food security especially during phases when the tree crops are not fully productive, and (d) to reduce risk. We then discuss a larger set of opportunities and constraints that influence how and when farmers pursue these objectives. Tree crop farmers are of course not a homogeneous group, but differ with regard to the relative weight they give to certain objectives and the ways how they are affected by and respond to opportunities and constraints (Fig. 2).

## 3 Objectives of diversification

### 3.1 Increasing revenues

As would be expected, there is strong evidence that tropical tree crop farmers make diversification (and more generally, land use) decisions in order to increase their revenues. In numerous cases, farmers have adopted additional tree crops because of their more favorable prices compared with their previous crops, leading to diversification. For example, in Côte d'Ivoire, the government's pricing policy deliberately favoring cocoa at the expense of coffee from the mid-1970s on together with the world price decline of coffee played a major role in a country-wide diversification process. It led coffee farmers often to first intercrop coffee with cocoa, then switch over to cocoa entirely (Ruf 2013). The resulting cocoa boom made the country the leading cocoa producer in the

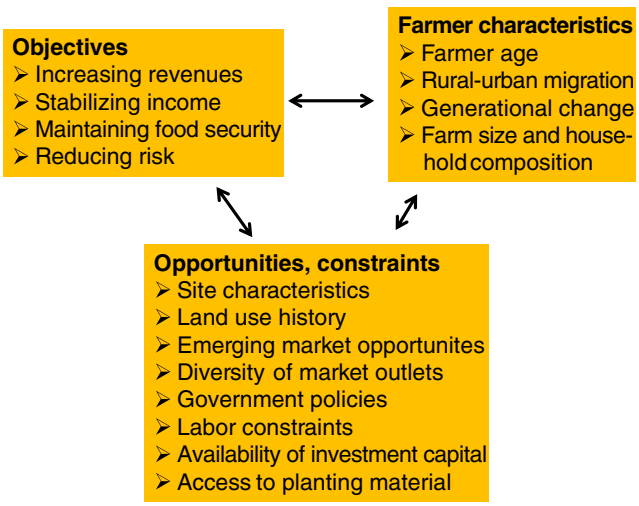


**Fig. 2** Objectives, opportunities/constraints, and farmer characteristics influencing diversification in tropical tree crop systems

world. The collapse of the government's price stabilization scheme in 1988 and declining cocoa producer prices in the 1990s and 2000s then played a role in the diversification toward oil palm and more importantly, rubber (Fig. 3) (Sayam and Cheyns 2013; Fiko and Yao 2013). More locally, farmers also diversified into fish ponds (Léonard and Oswald 1996). Diversification of cocoa farms into rubber, which currently enjoys favorable producer prices (Fig. 4) and is also more tolerant than cocoa of somewhat degraded environmental conditions, has recently become a common trend across West and Central Africa (Chambon and Mokoko 2013; Ruf 2013). Similarly, the low producer prices for cocoa in Ghana in the 1970s and 1980s, caused by government pricing policies, played a role in the emergence of diversified farms cultivating oil palm and citrus without completely abandoning cocoa (Michel-Dounias et al. 2013).

As in West Africa, low coffee prices also encouraged coffee farmers in Indonesia in the last decade to switch to cocoa (Paul et al. 2013). Similarly, clove (*Syzygium aromaticum*) producers in Sulawesi responded to a declining clove-to-cocoa price ratio during the 1980s and 1990s with diversification into cocoa (Fig. 5). Cocoa also became the diversification choice for farmers who had previously depended mostly on the production of irrigated rice. In Sulawesi, the increase of the cocoa-to-rice price ratio from 2 to 3 in the early 1980s contributed to launching a wave of diversification into cocoa. Many paddy farmers either sold their paddy fields or left them under sharecropping contract and migrated to upland areas to plant cocoa. Some partially irrigated rice fields were even drained and planted with cocoa. The same has happened in rice farms in southern Thailand with rubber instead of cocoa (Ruf et al. 2013). In 1992, when the cocoa-to-rice price ratio in Sulawesi had fallen back to around 2, Ruf et al. (2013) asked farmers at which point they would expect to give up cultivating cocoa and received as a response that this would happen at a price ratio of around 1. However, these farmers' estimates were based on the yields and production conditions of the time. After the 1997 drought and the outbreak of the cocoa pod borer (*Conopomorpha cramerella*) in Sulawesi, cocoa yields started to decline. Despite higher cocoa prices, many farmers started to switch back to rice and shift to oil palm in the late 2000s and early 2010s, contributing to a stagnation of cocoa production in Sulawesi.

### 3.2 Stabilizing income

Besides trying to increase their total revenue, tree crop farmers also show a desire to increase the stability of their income during the year and among years. While producers of crops such as coffee and cocoa face several months per year without any harvest, a feature of rubber that has attracted many cocoa farmers over the past 20 years to this crop is that it provides revenue almost throughout the year and for a long period of up to 30 years. This apparently offsets the disadvantage of its later entry into production, which is around 7 years as compared with 3–4 years for cocoa (Chambon and Mokoko 2013). In south-western Côte d'Ivoire, 54 % of rubber adopters cited the continuous revenue as principal motivation for adopting rubber, as compared with only 15 % for the increase in revenue (Fiko and Yao 2013). Oil palm is another crop that offers farmers the advantage of year-round production (Chambon and Mokoko 2013). Even where individual crops only produce one or two harvests per year, crop diversification can improve the income distribution over the year. For example in farms in southern Ghana, the combination of different perennial (cocoa, oil palm, orange (*Citrus sinensis*)) and annual crops allows farmers to obtain a more regular income (Fig. 6) (Michel-Dounias et al. 2013).

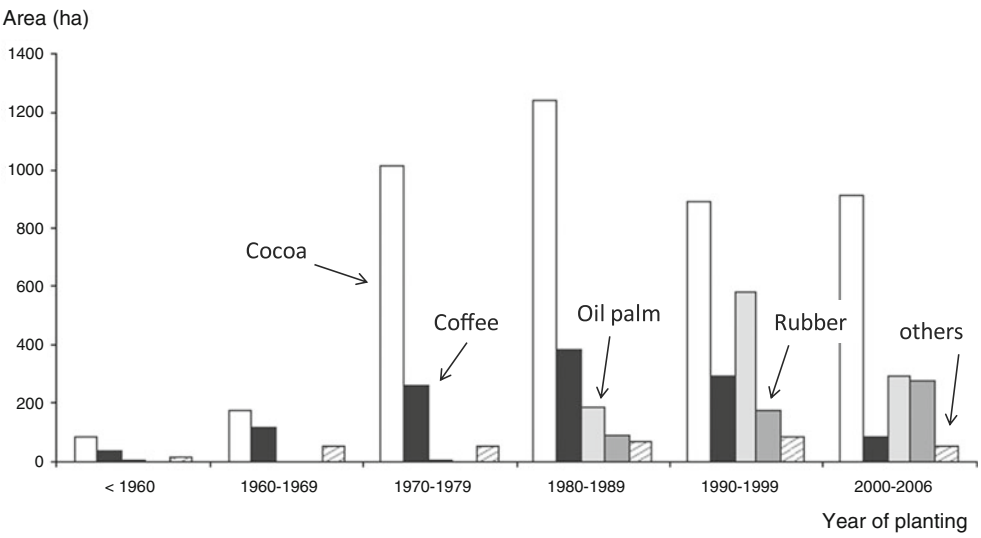


**Fig. 3** Planting periods of different tree crops in Côte d'Ivoire as recorded in 2005/2006 show the progressive country-wide diversification from a rural economy dominated by coffee (*Coffea canephora*) and cocoa (*T. cacao*) to a more diversified economy including oil palm (*Elaeis guineensis*) and rubber (*H. brasiliensis*) as well as some minor tree crops (after Ruf 2013, with permission from Editions Quae)

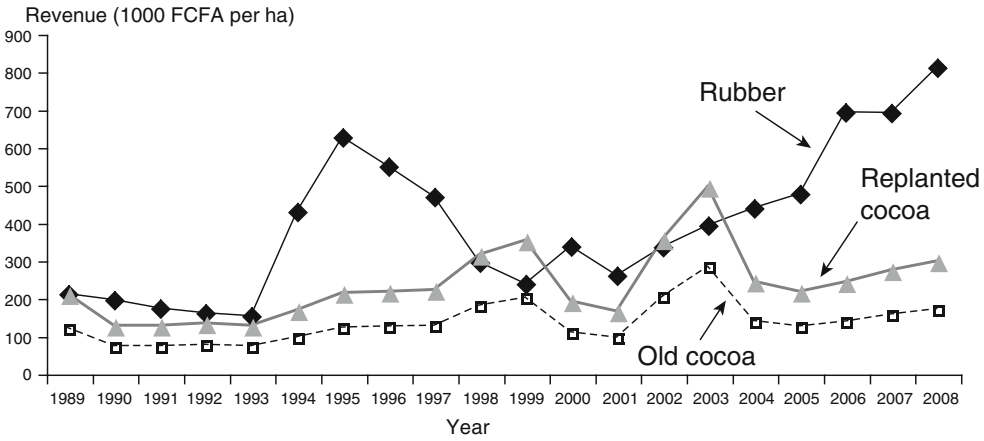


**Fig. 4** Estimated mean revenues per hectare of cocoa (*T. cacao*) and rubber (*H. brasiliensis*) in Côte d'Ivoire from 1989 to 2008. Together with the greater resistance of rubber to somewhat degraded environmental conditions and the almost year-round income, these help explain the increased adoption of rubber by cocoa farmers especially during the last decade (after Ruf et al. 2013, with permission from Editions Quae)

### 3.3 Maintaining food security

Tropical tree crop farmers usually prefer to establish their tree crops in mixed plantings with food crops. This is generally the most economical way of caring for the young tree crop as long as the tree seedlings do not fully occupy the site. It also increases food security during the first years before the trees come into production and generate cash revenue (Chaléard 1996; Gouyon 1995). Interplanting tree crops such as cocoa, coconut, and rubber with food crops such as plantains during these initial years allows small and migrant farmers to subsist during this unproductive period of their plantation. For example, in the Tapajós region of the Brazilian Amazon, rubber trees are generally planted into plots of cassava and other food crops (Schroth et al. 2003). This strategy of initial association of tree crops and food crops can be so important for farmer livelihoods that the gradual occupation of the landscape by tree crops with long life cycles, where little new or re-planting takes place, can lead to an increased risk of food insecurity. This has been reported for cocoa farmers in Côte d'Ivoire (Ruf 1996). When asked about this risk, rubber farmers in Côte d'Ivoire responded that their future income from rubber would allow them to buy rice, suggesting that increased and relatively secure income (and thus access to food) was valued higher by these farmers than "food sovereignty" (the ability to produce their own food) (Owusu and Ruf 2013).

Besides increasing food security, intercrops can play crucial ecological roles for the young tree crop. For example, it is during the seedling stage that cocoa trees are most in need of shade, and this temporary shade is often provided by bananas or plantains (*Musa* sp.). The ground cover provided by intercrops and the tillage and weeding afforded to them help suppress weeds that would delay the establishment and increase the mortality of the tree crop seedlings. A remarkable case of this nursing role of temporary intercrops for a tree crop was described from the forest–savannah boundary of Cameroon where farmers establish cocoa—usually considered an archetypical forest crop—on savannah land by initially suppressing competitive *Imperata* grass through tillage and planting of a succession of annual and pluri-annual food crops, then introducing the cocoa seedlings after 5–6 years (Jagoret et al. 2012). Another strategy found in the same area is to sow oil palms, sometimes interspersed with mango trees (*Mangifera indica*), at high density to suppress the savannah grasses, then

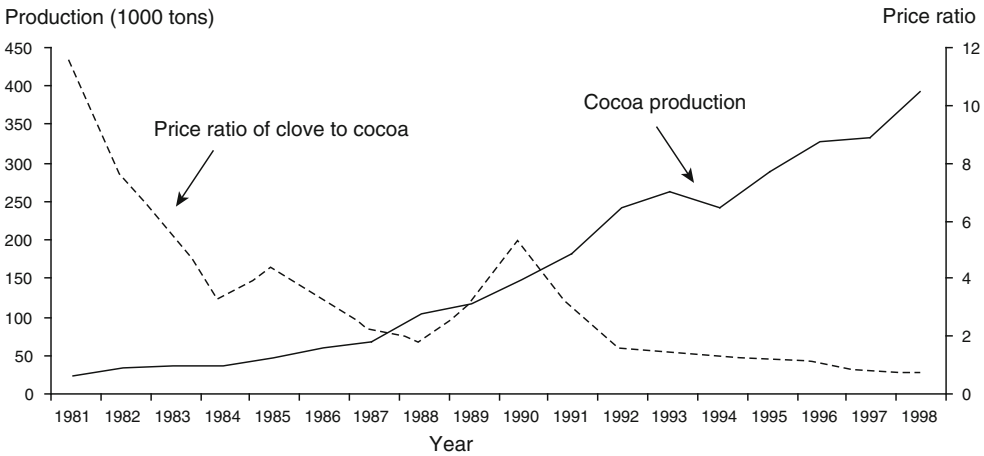


**Fig. 5** Falling clove-to-cocoa price ratio in Sulawesi, Indonesia, explain increasing adoption of cocoa (*T. cacao*) by clove (*S. aromaticum*) farmers during the 1980s and 1990s (after Ruf and Schroth 2013b, with permission from Editions Quae)

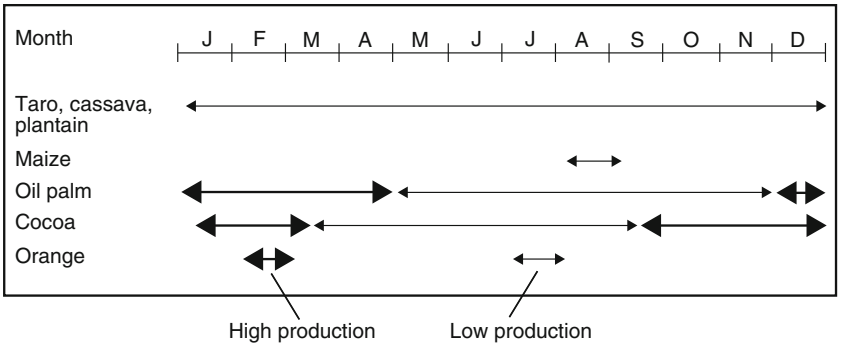


**Fig. 6** Annual phases of high and low production of various tree and food crops in Ghana, showing that associating several different crops can help to achieve more regular farmer incomes (after Michel-Dounias *et al.* 2013, with permission from Editions Quae)

after 8–9 years fell part of the palms for palm wine production and introduce the cocoa seedlings as an understory. Fruit and timber trees are then also planted or allowed to regenerate to form a permanent shade canopy and contribute to maintaining soil fertility and provide a range of products beside cocoa (Fig. 7) (Jagoret et al. 2012).

Farmers in Côte d'Ivoire have adapted their traditional intercropping practices used with young cocoa also to new tree crops such as rubber, even if this practice was long discouraged by extension services. According to standard recommendations, rubber trees should be established with leguminous cover crops, but farmers often prefer food crops, for the afore-mentioned reasons. Research has shown that the initial intercropping of rubber and other tree crops with food crops is agronomically sound and has no negative effect on subsequent rubber yields (Schroth et al. 2001).

Food or other short-cycle crops may again play an increasing role at the end of a rotation of tree crops as yields decrease and gaps form in the aging canopy, as shown for coconut groves in Vanuatu (Feintrenie et al. 2010, 2013). Sometimes, farmers can benefit from an attractive market for their short-rotation crops to bridge two tree crop cycles. For example in Indonesia, chilli (*Capsicum* sp.), ginger (*Zingiber officinale*), and, more recently, patchouli (*Pogostemon cablin*) often play the role of paying for the replanting of coffee or cocoa (Ruf and Lançon 2004). In West Africa, plantain and a shade-tolerant variety of yam (*Dioscorea* sp.), the "kokoassie," can also play these multiple roles as provider of food and cash between successive cycles of cocoa or cocoa followed by another tree crop (Temple and Fadani 1997). The kokoassie yam offers one of the rare agroforestry showcases where an annual food crop can be continuously associated with a tree crop even during the mature phase (Ruf 1995a).

### 3.4 Reducing risk

The objective of reducing risk is not easy to separate from the related objective of increasing income, since risk avoidance becomes most apparent where farmers move out of crops that have come under unpredictable environmental or economic pressures and adopt crops that seem to be relatively free from such pressures. As discussed before, producers of commodities such as cocoa, coffee, rubber, oil palm, clove, or pepper are subject to volatile international markets, including boom-

**Fig. 7** Successions of annual and tree crops used by farmers in Central Cameroon to suppress competitive *Imperata* grasses and establish cocoa (*T. cacao*) on savannah land. On the *left* photo, cocoa seedlings were planted in the shade of *Ceiba pentandra* trees and food crops (plantains, *Musa* sp.; cocoyam, *Xanthosoma sagittifolium*). The *right* photo illustrates the transition from savannah grasses in the front to farmer-made forest in the background, with planted oil palms (*E. guineensis*) and fruit trees (African plum or safou (*D. edulis*) to the left) shading cocoa seedlings in the center (photos: P. Jagoret/CIRAD, with permission)

and-bust cycles that are common with tropical tree crops (Cashin et al. 2002; Malézieux and Moustier 2005a; Ruf 1995b). The spectacular increase in cocoa production (including its adoption by many coffee farmers) during the second half of the twentieth century in Côte d'Ivoire, where farmers were effectively insulated from the fluctuations of world market prices by the national marketing board, suggests that this quasi-absence of market risks provided an effective stimulus for new planting. This worked until 1988, when the system went bankrupt and exposed producers suddenly to the vagaries of the world market, with real prices of cocoa and coffee falling by 70 % within 2 years. This price shock contributed to the present trend of diversification into rubber and oil palm (Fig. 3).

A risk avoidance strategy is also inherent in farmers' flight out of crops that are affected by new and (at least initially) poorly understood diseases and pests into crops that are not affected by such incalculable biological factors. The recent, partial shift from coconut to oil palm and orange in southern Ghana was driven by the spread of lethal yellowing disease on coconut especially since the 1970s interacting with a generational change of the farmer population (Ollivier et al. 2013). In Indonesia in the 1980s and 1990s, diseases affecting clove played a role in the diversification toward cocoa while in the early 2000s, the outbreak of the cocoa pod borer was a key factor encouraging farmers to diversify towards oil palm and rubber (Paul et al. 2013). On the other hand, swollen shoot virus, the main cocoa disease in Ghana, was apparently not an important factor in the diversification into oil palm in that country (Michel-Dounias et al. 2013). The witches' broom disease (*M. perniciosa*) of cocoa was brought in the late 1980s from the Amazon to the cocoa region of southern Bahia, Brazil, and there was initially no adequate response by the research and extension service. The ensuing cocoa crisis resulted in a certain level of diversification with expansion of Robusta coffee and rubber, the latter often planted into existing cocoa, although the region remains highly dependent on cocoa today (Schroth et al. 2011b).

A more general risk factor resulting from the progressive replacement of forests by farms and prolonged farming, often without nutrient replacement or other soil conservation measures, is a general degradation of environmental conditions, as seen in declining soil fertility, increased pressure of weeds, pests and diseases, and a drier microclimate that may aggravate the difficulties of the replanting of sensitive crops such as cocoa (Ruf and Schroth 2004). In parts of West Africa, this general degradation of ambient conditions has interacted with a decrease in rainfall during the 1970s and 1980s (Léonard and Oswald 1996). This drying trend caused by increasing temperature and evaporation with approximately constant rainfall is predicted to continue during the next several decades, increasing climatic risks especially near the forest–savannah boundaries (Läderach et al. 2013). The present trend of diversifying from drought-sensitive cocoa into rubber is partly caused by the considerable risk of replanting failure of cocoa in a more degraded and often drier environment, compared with several decades ago when cocoa was first planted on recently cleared forest land (Ruf 2013).

## 4 Opportunities for and constraints to diversification

### 4.1 Site characteristics

In their diversification decisions, tree crop farmers derive opportunities from and are constrained by the environmental conditions on their farms. Heterogeneous site conditions on a farm often result in crop diversification, although cases where even unsuitable sites are planted with the currently preferred crop are also common. For example, low-lying sites—where not used for rice or vegetables—are often reserved for tree crops that are water demanding and somewhat tolerant of water logging, such as oil palm (Owusu and Ruf 2013 for the Western Region of Ghana). In the Eastern region of Ghana, farmers arranged their tree crops on a topo-sequence according to slope positions and soils, with cocoa and orange on the upper and mid-slopes and oil palm on the lower slopes (Michel-Dounias et al. 2013) (Fig. 8). In southern Ghana, orange trees were planted on hill sites while oil palms and coconut palms occupied valleys and plains, before the lethal yellowing disease eliminated many of the coconut palms (Ollivier et al. 2013). Even on relatively flat terrain, local variation of soil fertility can be a strong determinant of crop diversification. For example, many farms on the Transamazon highway in Pará state, Brazilian Amazon, an area of current cocoa expansion, are composed of patches of fertile, basaltic *terra roxa* soils and soils with more sandy texture and lower fertility. While the former are often being used for cocoa, sometimes replacing sugarcane (*Saccharum officinale*) and often interplanted with timber trees, the latter are often under pasture (G. Schroth, personal observation).

The suitability of a site for a certain tree crop is also influenced by its location relative to settlements. In southwest Cameroon, farmers preferred to plant oil palm on plots close to their village because of the frequent harvesting, the difficulty of transporting the relatively large quantities of harvested fruit over long distances, and the increased risk of theft of the ripe fruits on more distant plots. More distant plots, on the other hand, were often planted with cocoa (Chambon and Mokoko 2013).

Site conditions can change over time particularly in response to land use and drive further diversification decisions. Immediately after forest conversion, site conditions are typically favorable, with high nutrient availability in the soil, low weed and pest pressure, and a protected microclimate through surrounding standing forest. Throughout the tropical world, such recently cleared forest sites have been the preferred sites for planting cocoa (Ruf and Schroth 2004). As this forest rent

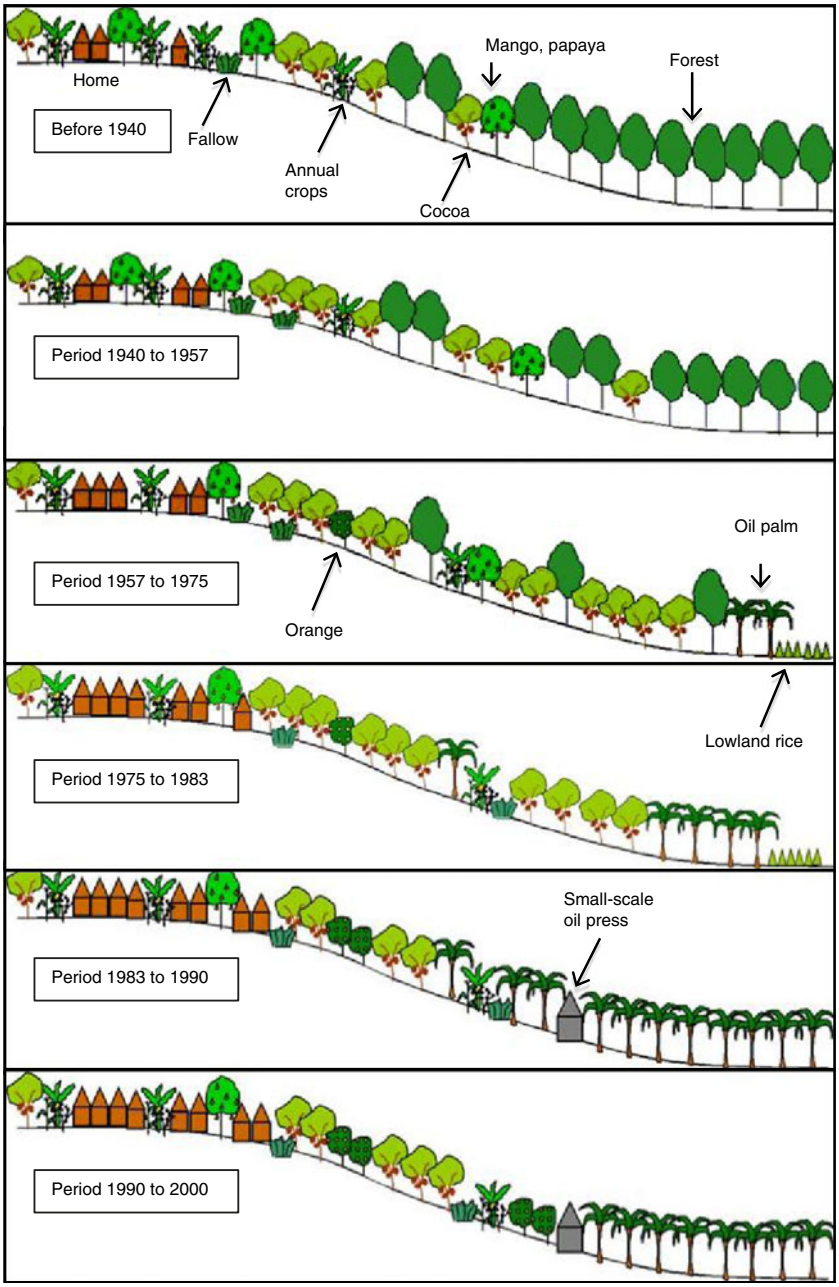


**Fig. 8** Evolution of the occupation of a slope transect by different crops in the Eastern Region of Ghana, illustrating the interaction of spatial and temporal dynamics of land uses in a mosaic landscape (after Michel-Dounias *et al.* 2013, with permission from Editions Quae)

is used up through years of land use and further forest clearing, declining site conditions often oblige farmers to adjust their land use decisions and diversify into less demanding crops. An example for this process was seen in the Moyen Cavaly region in western Côte d'Ivoire (Ruf 2013) (Fig. 9). Although the ferralitic soils are not very suitable for cocoa, farmers moving into the area in the 1970s initially planted mostly cocoa after forest clearing. During the 1980s and 1990s, as cocoa trees started dying at a young age, their interest shifted to the less demanding Robusta coffee, against the trend of decreasing coffee area elsewhere in the country. Finally, in the late 1990s and early 2000s, they increasingly settled on rubber as a highly profitable cash crop that is adapted to infertile and degraded site conditions. Through this process, the farmed landscape became more diversified and less dominated by the first pioneer crop, cocoa. Throughout Côte d'Ivoire and Ghana, the wildfires affecting many cocoa farms in the drought years 1983/1984 triggered a wave of adoption of oil palm and rubber as cocoa was difficult to replant in the already degraded environment (Michel-Dounias et al. 2013; Ruf et al. 2013; Sayam and Cheyns 2013).

### 4.2 Land use history

Where tree crops were planted on primary or secondary forest sites, some diversification is often inherited from the previous

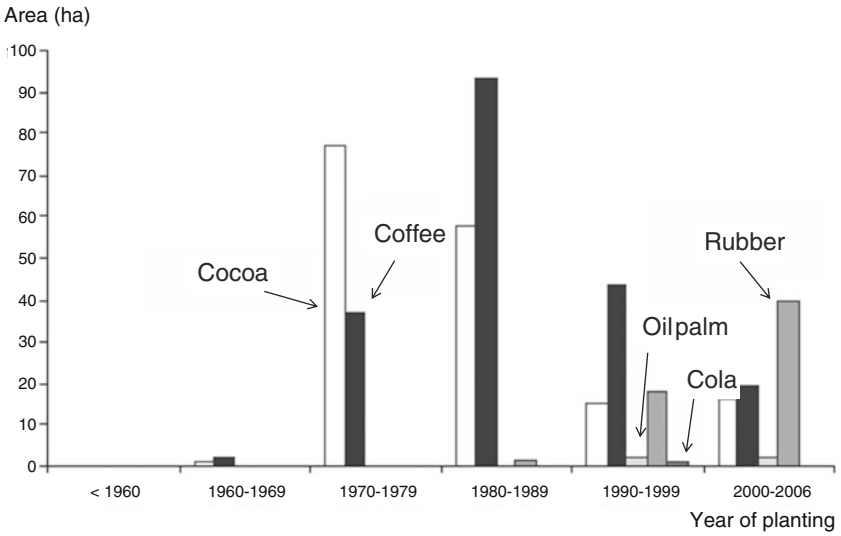


**Fig. 9** In the Moyen Cavaly region of Côte d'Ivoire, low soil fertility drove a process of tree crop diversification that progressively replaced the demanding cocoa (*T. cacao*) through less demanding coffee (*C. canephora*) and then rubber trees (*H. brasiliensis*). The data were recorded in 2006 (after Ruf 2013, with permission from Editions Quae)

forest vegetation that often includes some useful tree species as well as trees that were difficult or expensive to fell (de Rouw 1987; Schroth et al. 2004a). If a farm was established by partially clearing forest and underplanting remnant trees with tree crop seedlings, as has often been the case with cocoa and coffee and sometimes with tea, then some native fruit and timber trees remain in the overstorey. The former can be used for subsistence and the latter for income, although the sale of such forest remnant trees by farmers is illegal in many countries. For example, in Bahia, Brazil, many timber trees in cocoa farms were illegally sold during the cocoa crisis caused by disease and low prices in the 1990s in an attempt to compensate for the loss of cocoa income (Alger and Caldas 1996). In most cases, such trees are not being regenerated. Cases where remnant forest trees in tree crop farms are sustainably managed for continuous production and revenue are relatively rare in the tropical world. However, in several countries of Central America, including Costa Rica and Guatemala, coffee and cocoa farmers have adopted the planting of timber trees as a diversification option (Vaast et al. 2013; Beer et al. 1998).

A high density of "companion trees" in tree crop farms may also reflect periods of abandonment or extensive management for economic reasons, during which these trees regenerated spontaneously. For example, the high density of jackfruit (*Artocarpus heterophyllus*) and caja (*Spondias mombin*) trees in Bahian cocoa plantations, both introduced fruit trees that are preferred by farm workers and regenerate easily, is partly a result of the cocoa crisis of the past 20 years (Sambuichi et al. 2012). The same process has occurred 50 years earlier on cocoa estates on São Tomé (Clarence-Smith 1993). Similarly, in West African cocoa farms, the wild oil palm emerges spontaneously especially during phases of extensive management or abandonment and can become an important source of additional revenue (Ruf 2013; Sayam and Cheyns 2013).

Even where tree crops were planted in slash-and-burn fields of annual crops where all vegetation was felled and burnt, native trees may be allowed to regenerate either because they are useful or because their suppression is not considered worth-while. For example, in the Tapajós region of the Brazilian Amazon, farmers traditionally plant rubber seeds into slash-and-burn plots with cassava and some other food crops. Owing to extensive management and frequent abandonment, these rubber groves evolve into diverse agroforests that provide a number of products beside rubber (Schroth et al. 2003, 2004b). A similar practice with rubber and rice as annual crop has been developed in Indonesia (Michon 2005; Feintrenie and Levang 2009).

### 4.3 Emerging market opportunities

New or growing market outlets may induce farmers to diversify into additional land use activities, or eventually to change their crops. The growing cities across Africa have created an increasing demand for food products, including staple foods, legumes, and fruits, and farmers with sufficient access to these urban markets have responded to these opportunities by modifying their traditional land use systems. For example, cocoa farmers in the relatively densely populated southwest of Cameroon have included further perennial crops (citrus, safou (*Dacryodes edulis*), oil palm), food crops (cassava, plantain), and also horticultural crops such as tomatoes and other legumes in their land use systems (Temple and Nzié 2013). Sonwa et al. (2007) showed that cocoa farmers in the proximity of Yaoundé, Cameroon, have increasingly replaced native forest tree shade in their cocoa farms with planted fruit tree shade in a process of economic diversification to take advantage of the increased market opportunities. Unfortunately, this economic diversification process goes in parallel with biological simplification of the traditional cocoa agroforests.

### 4.4 Diversity of market outlets

Being aware of the volatility of markets, farmers often show a preference for crops that offer a range of market outlets. One of the attractions of oil palm as a diversification option has been that the fruits can be sold either to nearby factories or on the local market as a basic ingredient of local dishes, or even be used for subsistence. In addition, at the time of renovation, palm wine can be obtained from the felled palms for sale and consumption, helping to finance the next crop or rotation (Ruf 2013; Sayam and Cheyns 2013). Coconut palm is another tree crop that stands out for its many uses, including food and building material (Feintrenie et al. 2013).

### 4.5 Government policies

Government policies create opportunities and constraints to diversification and the adoption of new tree crops. As mentioned previously, the shielding of cocoa and coffee farmers in Côte d'Ivoire from the volatility of international market prices has had a major stimulating effect on cocoa adoption but proved ultimately unsustainable. In Ghana in the 1970s and 1980s, on the other hand, the low producer prices paid by the government marketing board were on the way to kill the cocoa industry (Bateman 1990) and played a role in the emergence of diversified farms cultivating oil palm and citrus without completely abandoning cocoa (Michel-Dounias et al. 2013). Another case where poor policies have driven diversification away from the affected crop was the hold-up of the clove value chain in Indonesia in the 1980s by one of President Suharto's sons setting up a "clove marketing board" under his direct control (Ruf 2000). Clove farmers who had already been affected by declining prices responded by diversifying into cocoa (Paul et al. 2013) (Fig. 4).

Governments have also stimulated the adoption of new tree crops through specific projects, such as the oil palm and rubber smallholder schemes in Côte d'Ivoire (Colin 1990; Ruf 2013; Sayam and Cheyns 2013), Ghana (Michel-Dounias et al. 2013), and Cameroon (Chambon and Mokoko 2013). These provided planting material, technical assistance, and a guaranteed market outlet to the local farmers and induced many to diversify their cocoa farms with these tree crops. Where such experiences with new crops were perceived as successful, they were often copied by other farmers outside the group of direct project beneficiaries. This has happened with oil palm and orange in Ghana (Michel-Dounias et al. 2013), rubber in Côte d'Ivoire (Ruf et al. 2013), and rubber, oil palm, and citrus in Cameroon (Chambon and Mokoko 2013). Conversely, in south-western Cameroon where difficulties in the marketing of rubber have caused delays in payment to the farmers, this has triggered a regain in interest for cocoa and increased interest for oil palm for which marketing options are more diversified (Chambon and Mokoko 2013).

In Côte d'Ivoire and Ghana, policies claiming state ownership over naturally grown forest trees are an important impediment to planting native timber trees in cocoa farms because farmers would later have to prove that they have planted the trees to be able to commercialize their timber legally. Exotic trees are not subject to such restrictions and are therefore preferred by farmers (Ruf 2011). Restrictions and bureaucratic complications of the use of timber from native trees have also encouraged the planting of exotic tree species, such as eucalypts, rather than native species on cocoa farms in Brazil (G. Schroth, personal observation). They have also been a disincentive to tree planting and occasionally even an incentive to remove tree regeneration on tree crop farms in India (Guillerme et al. 2011).

Failure of governments to provide tenure security to tree crop farmers can also be a constraint to diversification. In Côte d'Ivoire, local farmers have in some cases questioned the right even of long-established immigrant farmers to plant rubber trees on land that they had bought (or rented, depending on the point of view) decades ago for planting cocoa, which was then the dominant pioneer crop (Colin and Ruf 2011).

### 4.6 Labor constraints

Given the limited possibilities of mechanization in tree crops, the adoption of new or additional tree crops is very often constrained by the availability of labor. Labor constraints have benefited the recent diversification into rubber among tree crop farmers in West Africa. Once established, rubber is a crop with relatively low labor demands that are also relatively evenly spread over the year. Moreover, cocoa farmers in Côte d'Ivoire who diversify into rubber can usually contract the rubber tapping out to share-croppers, with cocoa being managed mainly by family labor (Owusu and Ruf 2013).

There are also cases where different tree crops are managed by different members of the family. For example, in the 1980s in Madagascar, coffee farms became intercropped with bananas, with the coffee owned by the older generation and the bananas owned by the younger generation of farmers. This was a deliberate attempt by the old farmers to keep their sons on the farm without having to hand the farm over (Blanc-Pamard and Ruf 1992).

Whether or not such a division of tasks is possible, diversification is easier if the labor demands for the additional crop are complementary in time to those of the existing crops. Feintrenie et al. (2010) showed this to be the case in the association of coconut palms and cocoa in Vanuatu, with the exception of September when harvest times for the two tree crops coincided. Together with falling coconut prices (Malézieux and Moustier 2005b), this complementarity helps explain why the underplanting of old coconut groves with cocoa has become a common practice throughout the Asia–Pacific region (Fig. 10).

**Fig. 10** The underplanting of aging coconut (*C. nucifera*) groves with cocoa (*T. cacao*) has become a common practice in the Asia–Pacific region, here in Papua New Guinea (photo: G. Schroth)

### 4.7 Availability of investment capital

As discussed above, an expected increase in income is a main motivation in farmers' decisions to diversify their farming system by adopting new or additional tree crops (Trivedi 1992). However, the timing of diversification decisions does not always coincide with phases when the financial benefit from diversification would be greatest (i.e., when the prices of current crops are low and those of new crops high) but rather with phases when current earnings and savings allow such investments (Berry 1976). For example, over the past 15 years, the planting rate of rubber as main diversification crop for cocoa farmers in the department of Gagnoa, Côte d'Ivoire, tended to be positively correlated with current cocoa prices, and rubber adoption rates tended to be higher when the price ratio of rubber to cocoa—and thus the expected increase in income from rubber adoption—was relatively low. This suggests that new rubber planting was limited by investment capital, of which cocoa was the main source, and that revenue from cocoa was directly invested in new rubber plantings (Fig. 11) (Ruf et al. 2013). In southwestern Côte d'Ivoire, lack of capital or credit was, with 56 % of interviewees, the most frequently mentioned constraint for cocoa farmers for diversifying into rubber, followed by access to suitable land (20 %) and lack and/or high cost of labor (14 %) (Fiko and Yao 2013). Similarly, the annual rate of cocoa planting in Côte d'Ivoire in the 1970s and 1980s, which involved massive migrations to areas with available forest land, was strongly influenced by savings that migrants had accumulated just before moving to the western forest frontiers (Ruf 1995a). In eastern Côte d'Ivoire, farmers used revenues from vegetable sales to reinvest in their cocoa and coffee plantations, as well as the other way round, suggesting that more crops increased the flexibility of farmers to make investment decisions (Malézieux and Moustier 2005b).

### 4.8 Access to planting material

The extent to which access to improved planting material constrains farmers' diversification decisions seems to differ among crops. In Cameroon, oil palm was the only tree crop for which farmers made their planting decision dependent on the availability of improved planting material and of the cash to purchase it. For rubber, they recognized the superiority of grafted seedlings but would have also planted unimproved seedlings if the former were not available. Finally, for cocoa, the planting of unimproved local materials was the rule (Chambon and Mokoko 2013). In Indonesia, diversification toward oil palm may have also been hampered by limited

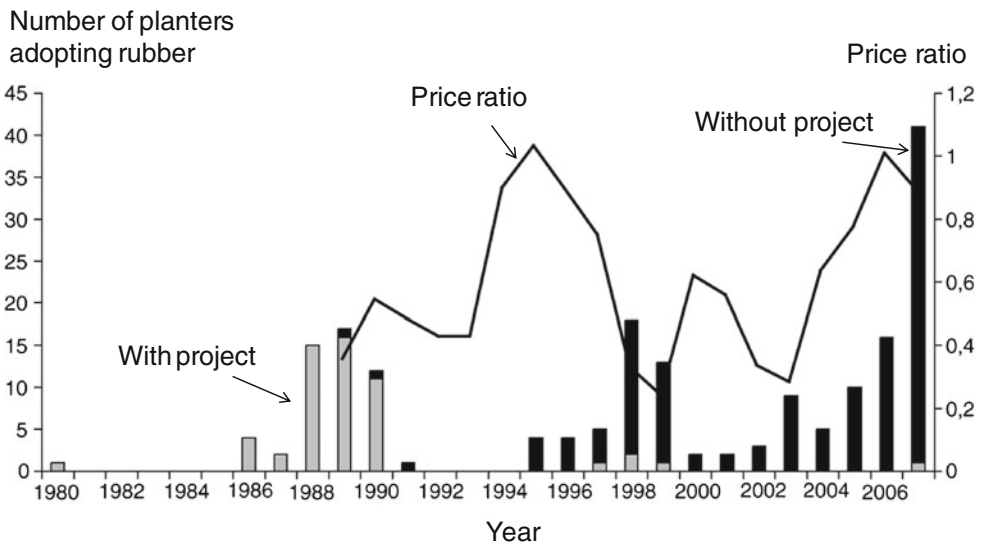


**Fig. 11** Rubber adoption by cocoa farmers in Côte d'Ivoire from 1980 to 2007 tended to be higher when cocoa prices were high, and thus the rubber-to-cocoa price ratio low, suggesting that investment capital, supplied by cocoa sales, was a main limiting factor for diversification into rubber. "With project" refers to rubber plantations that benefited from government funded projects, while "without project" refers to rubber adopters without government support (after Ruf et al. 2013, with permission from Editions Quae)

availability of hybrid material, since farmers were aware of its superiority (Paul et al. 2013). In Côte d'Ivoire, cocoa farmers have often delayed the diversification toward rubber in the (often vain) hope of receiving free clonal rubber material from the government (Ruf et al. 2013). In the Tapajós region of the Brazilian Amazon, the vast majority of rubber agroforests in the villages on the river banks have been planted with locally collected (i.e., cost-free) seeds, although only 24 % of the farmers expressed a preference for seed-grown trees which they considered more robust than grafted trees, while 47 % claimed lack of access to superior grafted clones at the time of planting (Schroth et al. 2003).

## 5 Farmer characteristics and diversification

### 5.1 Farmer age

It is often assumed that younger farmers are more innovative and thus more likely to diversify from their or their fathers' traditional crops into new crops. However, the evidence is mixed. In southern Ghana, older cocoa farmers tended to have less diversified farms than younger farmers who were the first to adopt orange and oil palm as additional crops (Michel-Dounias et al. 2013). In southwest Cameroon, on the other hand, older cocoa farmers tended to have more diversified farms than younger farmers, possibly because their farms were also older and more in need of improvement through replanting and this opportunity was used to introduce also new crops (Temple and Nzié 2013). Older farmers may also financially be in a better position to diversify than young farmers: In Côte d'Ivoire, retired people often invested their pensions in their farms, including for diversification (Sayam and Cheyns 2013). Finally, Chambon and Mokoko (2013) showed for Cameroon that both young and old farmers diversified but in different ways. For old farmers, diversification was driven by the aging of their cocoa farms requiring replanting, and this was sometimes done with additional crop species. On the other hand, young farmers arriving at or returning to the villages often started their farms by trying out alternatives to the traditional cocoa, such as rubber, oil palm, and citrus and often included cocoa later in their farming systems.

### 5.2 Rural–urban migration

The return of young people to the villages after a period in the city seems to have benefited the diversification of traditional farming systems. Throughout the developing world, young people leave rural areas to try their luck in the cities. Especially in times of economic crisis, many of them do not succeed and eventually return to their villages, bringing with them a better education, new information, and often more openness to change and innovation. Chambon and Mokoko (2013) suggest that, in Cameroon, when an increase in cocoa prices after the trade liberalization in 1996 attracted young people back to their villages, keen to create plantations for themselves, this brought a new dynamism to the old cocoa farms of their fathers and benefited the adoption of new crops such as oil palm and rubber. The same was the case in the 1990s in the Côte d'Ivoire (Sayam and Cheyns 2013).

### 5.3 Generational change

Generational change is often associated with diversification or a change in crops since the new generation, whether inheritors or buyers, may look for new portfolio characteristics and may benefit from new information. In southern Côte d'Ivoire, the diversification from coffee to cocoa was partially connected to a change in generation. Farmers in the 1950s and 1960s were often coffee farmers. They started to move to cocoa mostly by abandoning their old coffee farms and migrating to the forested western regions, followed by their sons and nephews who became cocoa farmers. As these cocoa farms age, a new generation of farmers, including young people returning from the cities, is again actively involved in the adoption of rubber and oil palm (Ruf 2013).

In other cases, diversification of tree crops was in part motivated by the desire of parents to create opportunities for their sons on the farm and prevent them from leaving for the cities. In the early 1980s, in the region of Teluk Intan in Peninsular Malaysia, smallholders started to intercrop their coconut palms with cocoa to increase their revenues so that their sons could stay at home and help in the harvest of the coconuts (that requires climbing of the palms) rather than look for a job in Malaysia's rapidly industrializing economy (Dupraz and Lifran 1995; Dupraz and Morisson 2013). A similar motivation was behind the afore-mentioned diversification of coffee farms in Madagascar in the 1980s, where farmers retained ownership of the coffee bushes but allowed their sons to intercrop them with bananas (Blanc-Pamard and Ruf 1992).

### 5.4 Farm size and household composition

Diversification also seems to be related to farm size and composition of the household. In southwestern Cameroon, larger farms were more diversified than small farms, and the degree of diversification into food and horticultural crops was higher for households with a larger number of active women, probably because women were mainly responsible for these crops (Temple and Nzié 2013).

## 6 Diversification and the evolution of tropical landscapes

Although the public image of tropical tree crops is characterized by vast monoculture plantations of oil palm or rubber, the

reality is that a lot of tree crops are grown on smallholder farms and that diversification is an ongoing process on many of these farms. Diversification is not a new phenomenon on humid tropical farms where home gardens have been in existence for thousands of years (Kumar and Nair 2004). However, while specialization and quasi-monoculture practices have long been a characteristic of tree crop booms and were a hallmark of the Green Revolution, this new wave of diversification reverts to some extent the resulting overspecialization that brought with it risks for livelihoods and the environment (Malézieux and Moustier 2005a). We will now briefly reflect on the implications of this process for tropical landscapes.

Diversification can often be understood as a phase in the evolution of agricultural landscapes. In the humid tropics, these landscapes often arise from forest through the expansion of agricultural frontiers, driven by booms of cash crops such as coffee or cocoa that are cultivated almost in monoculture, except that they are associated with food crops during the first years and often interspersed with remnant trees from the previous forest vegetation (Dean 1995; Clarence-Smith 1996). As such frontier areas mature, their agricultural landscapes tend to become more diversified. New crops are added as market opportunities arise, for example, through better roads and improved access to urban centers and as the initial pioneer crops decline under increasing pest and disease pressures (such as the lethal yellowing of coconut in West Africa, or the cocoa pod borer in southeast Asia). Where such pioneer fronts were planted with demanding crops that are sensitive to environmental degradation such as cocoa, farmers are also often obliged to diversify after decades of farming into less demanding crops that are easier to establish on already exhausted soils, in a less protected climate, and under higher pressure from weeds, pests, and diseases. This is one of the reasons behind the recent expansion of rubber and oil palm—fairly adaptable crops that can be planted under a wide range of site conditions—in areas in West and Central Africa that used to be dominated by cocoa but have now used up their forest rent (Ruf 1987; Ruf and Schroth 2004).

Is the current trend towards increased diversification of tree crop systems then a "Malthusian" sign of progressive environmental degradation of aging agricultural landscapes that obliges farmers to adjust by switching to less demanding crops? Or is it better understood as a process of intensification and innovation in response to increased pressure on the land and new opportunities, as postulated by E. Boserup (1965)? The reviewed information suggests that it can have elements of both, but can mostly be characterized as "innovation to adapt to changed market, policy and environmental conditions, subject to constraints." These constraints include a wide range of biophysical, socioeconomic, and technological factors. In none of the cases we discussed were diversification and the adoption of new crops clearly steps in a downward spiral of progressive environmental and socioeconomic decline. In fact, farmers in Cameroon even succeeded through a process of tree crop diversification to introduce an archetypical forest crop—cocoa—into savannah, so arguably "improved" the site from an agro-ecological perspective and increased their range of crop options (Jagoret et al. 2012). Cases of "agro-forestation" of savannah land have also been reported for coffee based agroforests in Guinea (Correia et al. 2010) and cocoa in Sulawesi (Ruf and Lançon 2004).

On the other hand, cases where forest landscapes were converted into tree crop farms that then progressively degraded into cattle pasture are also common in the history of tropical agriculture. Examples include former coffee land in the Brazilian Atlantic forest (Dean 1995) or cocoa land in Mesoamerica (Clarence-Smith 2000). While this happened centuries ago, such a self-reinforcing process of progressive degradation of agricultural landscapes could still result where tree crop-based farming systems are coming under environmental and socioeconomic pressure, including pressures caused by climate change, and pasture or slash-and-burn agriculture are the only viable alternatives and diversification options. For example, in the highlands of southern Mexico, where Arabica coffee farms are interspersed with cattle pasture and forest, a quality and resulting price decline of the coffee through global warming, combined with increased weather risks in an already hurricane-prone area (Eakin et al. 2012), could lead to the expansion of pasture and food crops, with positive feed-back effects through the resulting increased risk of wildfire (Schroth et al. 2009). In this situation, support for shade coffee farms and their diversification with other tree crops that are less sensitive to temperature increase have been proposed as elements of an adaptation strategy (Schroth et al. 2009; Cortina-Villar et al. 2012). Similarly, in the lower Tapajós region of the Brazilian Amazon, a phase of low rubber prices has led to the abandonment of rubber tapping and the traditional practice of planting rubber seeds into slash-and-burn plots, turning cassava growing in slash-and-burn agriculture into the dominant land use activity even within inhabited protected areas. To create tree-based alternatives to slash-and-burn agriculture and reduce the use of fire especially in protected areas, techniques to intensify rubber agroforestry without completely breaking with the traditional methods have been developed (Schroth et al. 2004b). Furthermore, the planting of timber and non-timber trees into cassava plots, building on the old rubber agroforestry tradition, has been promoted with some success (Schroth et al. 2011a; Schroth and da Mota 2013).

## 7 Conclusion

Diversification is a reality and, in many cases, a necessity in tropical tree crop farming. Although it means that some economies of scale may be lost, this is often more than

compensated by the reduced vulnerability of diversified farms and regions to environmental, policy, and market risks and the increased flexibility to adapt to long-term environmental and market trends. An important insight of recent research is that tree crop diversification is in part a response to environmental change, especially the structural degradation of environmental conditions following progressive deforestation, that make ambient conditions increasingly unsuitable for sensitive “pioneer crops” such as cocoa. Understanding farmers' objectives, preferences, and constraints can help in devising strategies and policies to support farmers' diversification decisions. In accord with the reviewed information, the following components are of particular importance in such strategies.

Firstly, farmers need information about technical and marketing options of alternative crops, as well as risks involved, so that they can make informed choices. This also includes medium-term trends in environmental factors (such as downscaled climate change predictions at a given location) and trends in market demands, to the extent that these can be predicted. Secondly, farmers are very often constrained by a lack of capital to invest in alternative crops. Therefore, the availability of affordable credit is important, but it must be accompanied by technical and marketing assistance to avoid that farmers become indebted when their investments fail. Such technical advice should be flexible rather than prescriptive so that farmers can adapt their new crops to their specific conditions and practices. Thirdly, since marketing is such a critical factor in the success of a new tree crop, care must be taken that marketing channels are reliable and that there is preferably a range of marketing options. Fourth, since small farmers are typically labor-constrained, diversification options whose labor demands are complementary to those of the existing crops, rather than increasing total labor needs during phases of peak demands, are preferable because they do not proportionally increase the dependence on hired labor that may be expensive or unavailable. Fifth, in some regions, addressing land tenure insecurity enables migrant farmers to make investment decisions without having to fear that they might weaken their hold over their land. Finally, improved planting materials should be made available to ensure that newly established tree crops are productive, pest- and disease-tolerant, and their products of good quality.

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