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Forest restoration with agroforestry model in Krong Bong District, Viet Nam. Photo: Phan Thi Thuy Nhi, Tropenbos Viet Nam

Designing agroforestry systems for greater economic viability and resilience

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"In practice farmers' decisions are based on their perceptions of costs, benefits and risks, and these may differ substantially from the perceptions of outsiders or from the costs and benefits incorporated in models."

Introduction

The evidence base for the ecological benefits of agroforestry in general is solid (Jose 2009), particularly in relation to the potential to contribute to climate change mitigation (Köthke et al. 2022) and adaptation (Verschot et al. 2007). The potential of agroforestry for achieving the Sustainable Development Goals (SDG) is therefore also increasingly recognized. Several governments, multilateral organizations, civil society organizations and agro-commodity companies now promote agroforestry practices, after decades of encouraging high-yield, sun-loving crop varieties. Governments, for example, can address the perceived need for initial investments when converting an existing land-use system into an agroforestry system through tax rebates or payments for environmental services schemes (Kay et al. 2019). Despite these efforts, and the potential benefits of agroforestry, the uptake is lower than expected (Glover et al. 2013; Mukhlis et al. 2022), possibly due to gaps in people's understanding of the socioeconomic costs and benefits of these systems (Gosling et al. 2021).

The decision on whether to adopt agroforestry is influenced by a complex mix of factors (Kusters 2023). For individual farmers the reasons for carrying out agroforestry practices are diverse, including home consumption of tree products, lower requirements for inputs and the monetary benefits from the sale of products. Reported barriers to adoption of agroforestry include unclear tenure, farm size and labour requirements (Glover et al 2013). In addition, farmers' risk aversion under uncertain conditions may affect adoption of agroforestry (Jahan et al. 2022).

Knowledge, skills and experience seem to be particularly relevant factors for the adoption of agroforestry (Pathania et al. 2021; Jahan et al. 2022). Due to local differences and complex interactions between plants within the agroforestry mix, it requires stronger local knowledge management capacities than conventional farming practices do (Mercer 2004). While individual farmers make their decision on whether to adopt agroforestry based on a variety of factors, several studies found that although the perceived economic performance of the practices may not have been the most important factor, it was the one factor recurring among the most farmers (Louman et al. 2016).

This article addresses the question of how better knowledge of economic performance (costs and benefits) can contribute to more informed decision making by farmers on whether to adopt agroforestry. First, the article describes the main variables that directly influence the economic viability of agroforestry, such as benefits, costs, availability of and need for labour and land, productivity, production time, and farmers' risk profile. Then an example from Viet Nam explains the implications of different crop combinations and management practices on these variables.

Main economic variables that influence the economic viability of agroforestry

Benefits

Many benefits have been attributed to agroforestry, including income, food security, provision of firewood and carbon sequestration (Willemen et al. 2013). Moreover, a major economic benefit of agroforestry is its relatively high land equivalent ratio. In other words, the yield of a major crop may be lower in agroforestry than under monoculture, but the overall yield in agroforestry can be higher due to the additional products cultivated (Bowart and Logan 2020; Köthke et al. 2022). In case studies in Viet Nam, for example, three different coffee agroforestry combinations resulted in a higher net income per hectare (ha) than monocultural coffee yielded under similar conditions (Figure 1). This is especially relevant for smallholders and areas under pressure from other land uses.

Agroforestry contributes to food security and strengthens economic resilience, as crops provide multiple sources of income at different times throughout the year. This is achieved through spatial or inter-temporal intercropping of trees and other species, and through the mix of

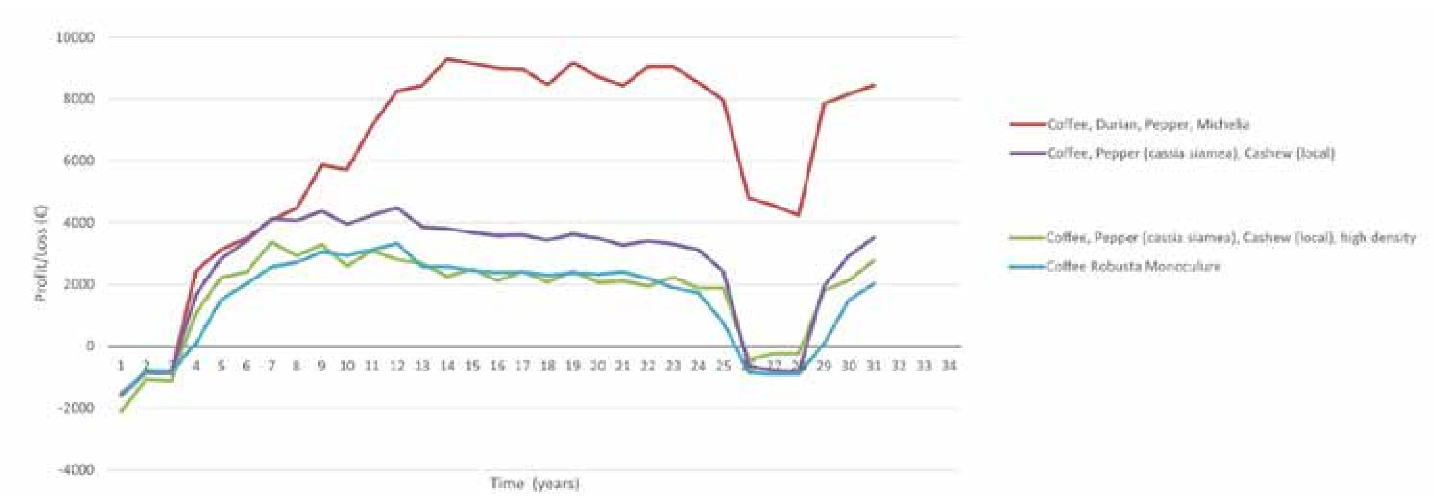

Figure 1. Projected annual net income per hectare of four different crop combinations in Viet Nam
Based on Farmtree tool projections (FarmTree 2023), calibrated with real farm data of 2023 (FarmTree bv 2023).

production of timber, fruits, rubber, latex, nuts, oils and fodder for livestock or other crops. Stability of income from multiple products provides resilience against yield losses of any one product due to severe adverse weather conditions. Diversity also contributes to more stable incomes, as a loss of market value due to sharp fluctuations in commodity prices can be compensated for by higher prices for other products.

Broadening income opportunities — both by expanding markets for a basket of products and by providing incentives for the provision of ecosystem services such as carbon sequestration — is essential for sustaining and expanding agroforestry (Kay et al. 2019) and for strengthening farmers' economic resilience. An important condition to achieving this is developing and implementing value chains to connect farmers' products to markets that adequately reward the products and benefits generated by agroforestry production. For example, niche markets that require a lower social, territorial and chemical footprint for agro-commodity production (such as coffee or cocoa) tend to pay higher prices. Agroforestry systems seem well placed to meet these requirements, provided that farmers are trained to meet market requirements and that control and certification procedures take into account the special conditions of smallholders.

At the same time, many of agroforestry's benefits are often seen as secondary and sometimes unintended. For example, farmers may be able to work under cooler conditions due to shade trees, or produce fruits for household consumption and local markets. Many such benefits do not have a market value or their market value is limited in relation to the value of the main crop (e.g., coffee or cocoa). Being aware of such secondary benefits may, however, shift farmers' decisions to adopt more diverse farming solutions, even though they may not be as profitable as monocropping.

Agroforestry provides various ecosystem services and environmental benefits such as climate mitigation. Upstream markets or companies can reward these benefits through payments for environmental services. In practice, agrocommodity prices typically fail to integrate the hidden social and environmental costs of conventional agriculture, while the benefits of diversified production systems such as agroforestry are not integrated.

Once implemented and operational, agroforestry can also lead to savings; e.g., by reducing the costs of agrochemicals on farms, including pesticides, herbicides and fertilizers, and by reducing irrigation costs. Jezeer et al. (2018) found that for small-scale Peruvian coffee farms, for example, established shaded low-input coffee had a better economic performance (net income, cost-benefit ratio) than unshaded high-input coffee. Figure 2 illustrates how, in a specific case in Viet Nam (Farmtree bv 2023), michelia trees help reduce the need for nitrogen, phosphorus and potassium (NPK) fertilizer over time. Coffee in the agroforestry plot (red bars in Figure 2) requires hardly any fertilization after it has been fertilized with 400 kg/ha for the first ten years. This is not the case for coffee in monoculture (green bars in Figure 2).

Although trees do use water, in coffee agroforestry systems in the Central Highlands of Viet Nam it was found that trees also contributed to a better regulation of the availability of water by increasing soil organic matter, thus enhancing water storage capacity (FarmTree bv 2023). This may reduce the need for (and thus the

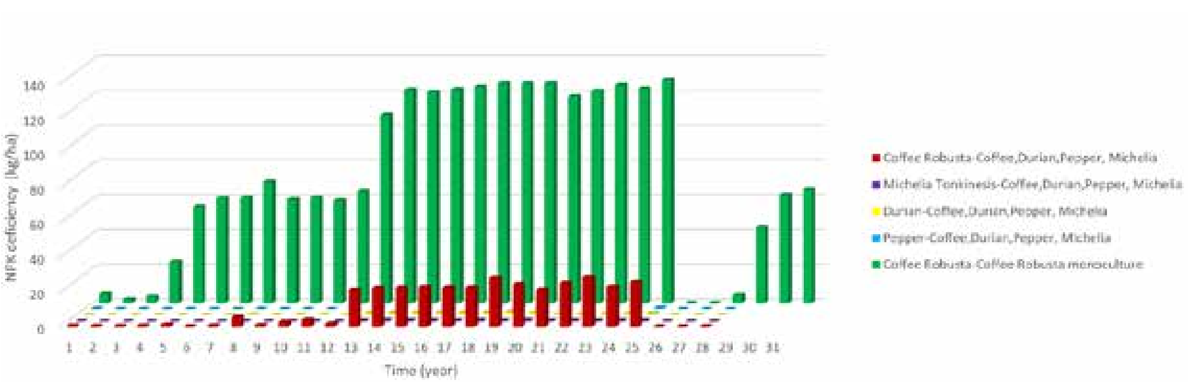

Figure 2. Need for fertilizer (kg/ha) in soils for coffee under monoculture (green bars) and agroforestry regimes (red bars)
As projected based on data from case studies in Viet Nam (FarmTree bv 2023). In both cases, NPK fertilizer was applied during the first ten years. The lower need for fertilizer for coffee after five years in agroforestry case is mainly due to inclusion of the tree *Michelia tonkinensis* in the plant mix.

costs of) irrigation. In addition, the Central Highlands experience very strong winds during the dry season, which negatively affect coffee production. These negative effects have been mitigated through the presence of trees in agroforestry systems.

Costs

Costs can be direct, indirect, fixed and variable. Direct costs are directly related to production, such as the purchase of raw materials or equipment. Direct costs can be fixed or variable. Examples of fixed costs are land, or equipment that lasts for several years. Examples of variable costs are tree seedlings or inputs such as fertilizer and pesticides. Indirect costs include loss of income due to competition between trees and the main crop. In practice, most farmers will deal with direct and variable costs, acquiring inputs that are directly and positively related to production. In general, increased inputs will lead to extra profit from yields. However, farmers often apply inputs without considering the recommendations for their application. This results in some farmers, for example, applying much more fertilizer than is required to grow a good crop, or applying it incorrectly or at the wrong time. In one case in Ghana, for example, cocoa farmers did not apply the recommended quantities of fertilizer on their farms because the achieved higher production was insufficient to compensate for the additional costs of the fertilizer. In other cases, they did not have the cash flow to be able to purchase sufficient fertilizer at the time in the production cycle when it was most needed (Lawrence and Louman 2021).

Adoption of agroforestry practices may often be limited due to perceived opportunity costs and loss of income. An example is the opportunity cost of planting trees, where these trees take up space that was originally reserved for the main commodity or crop. The opportunity cost refers to the benefits that farmers perceive they could have obtained if they had planted a crop or commodity, instead of planting the trees, which generate returns over a longer period of time (i.e., farmers strongly prefer benefits now to benefits that occur later). Another example is the cost of having to attend training for specific agroforestry practices, instead of using that time for a crop that they are already familiar with.

Costs are usually higher at the beginning of the agroforestry cycle, partly due to the need to acquire and plant trees, but also because the ecological benefits of agroforestry usually take time to materialize. For example, on relatively degraded soils, well-designed agroforestry systems may still need fertilization for the first six to ten years to bring soil fertility to a reasonable level, but later they may provide sufficient nutrients and organic material to the soils and thus require less fertilization (see Figure 2). Over time, the financial benefit of reducing fertilization costs may be greater than the financial benefits of increased production. Incurring lower costs is particularly important for crops whose market prices fluctuate.

Later in the growing cycle, the initial costs may be compensated for by the production from the trees, or by the reduced need for fertilizers and pests. For the first four to seven years, however, this may not yet be the case. As shown in Figure 1 the annual balance becomes positive after year 4, and, in most options, break-even points (i.e., accumulated income equals accumulated costs) are reached in year 8 (for agroforestry combinations) to year 10 (for monoculture).

Some agroforestry projects provide financial support to compensate for the direct costs of acquiring and planting the trees, but not for the opportunity costs in the first years (in terms of lower income due to a lower density of the cash crop).

Labour

When including labour costs in the economic analysis of agricultural and agroforestry systems, it should be considered whether the activities are part of the main agricultural activity or are secondary activities that are contemplated as a side investment that will generate higher income. In the case of cocoa in Ghana, it has been seen that if cocoa farming is done as a secondary activity, farmers may not want to invest much of their time or hire labour to achieve optimal yields. In some cases, cocoa farmers are older farmers in retirement or those who focus more on income-generating activities (Bymolt et al. 2018).

Additionally, when calculating a benefit-cost ratio, using market prices for labour may often result in negative financial results, particularly for small-scale producers with labour-intensive agroforestry systems. Farmers in Viet Nam who were asked about their labour costs referred only to costs for hiring (temporary) labour. They saw their own labour as an investment, for which they received the net income from farming as a return. Whether this return is satisfactory appears to depend on the farmer's need for income and the objectives for farming, as well as on the opportunities to find alternative work elsewhere. An economic analysis to support farmers in making decisions on their (family-based) farming systems would therefore make more sense to them if labour costs are indicated in terms of time needed rather than monetary costs.

Agroforestry is often more labour intensive than conventional (monoculture) cropping. Although the impact of agroforestry on labour demand varies according to local conditions, it can be a limiting factor when there is a shortage of labour or when labour costs are high. For example, in cocoa farms in Bolivia labour demand was higher in agroforestry, although returns per labour unit were also higher (Armengot et al. 2016), while in Africa shade trees in agroforestry helped reduce labour requirements for weeding and pesticide application (Nunoo and Owusu 2017). Figure 3 indicates that in Viet Nam, adding a commercial crop to the agroforestry systems increases male labour requirements more than female labour requirements. This is, however, not always the case and will depend on the type of crops added and local labour distribution.

The demand for labour in agroforestry systems varies relative to monocultural systems. In addition, adding crops and complexity may also have implications for the type of labour to be contracted: different crops may require different management and harvesting techniques.

Farmer risks

Smallholder farmers face multiple future challenges: climate change, fluctuating prices, lack of market access, pests and disease. Strategies to alleviate these risks will be impeded if they are not based on an understanding of how farmers perceive risk (Eitzinger et al. 2018) and how they react to it (Mercer 2004). It is therefore important to identify and better understand the risks that farmers perceive when implementing farming practices that are intended to meet both economic and environmental expectations, while being resilient to current and future changes.

Although agroforestry brings potential benefits, farmers' decisions to adopt agroforestry or full-sun systems depends on the way they perceive risk, which in turn depends on their socioeconomic situation (Sanial 2019). This is confirmed by Alpizar et al. (2011), who found that coffee farmers in Costa Rica are highly risk averse, more so in conditions of great uncertainty. Examples in Ghana and Côte d'Ivoire [add sources for these?] portray how farmers might see conversion to agroforestry as a potential risk. They may fear an increase in negative environmental effects (e.g., pests), an increased threat of legal and illegal timber cutting, or be concerned about the physical dangers of having large trees on the farm (e.g., falling branches).

While farmers may perceive a range of different risks, production risks (such as those increasingly caused by climate change) and market risks appear to be most relevant, but farmers may not perceive them in the same way as extensionists, businesses or scholars do. Unpublished reports of interviews with cattle farmers used for the study of Louman et al. (2016) indicated, for example, that these farmers considered diversification to be a risk, because they did not have experience in cultivating anything else than cattle. This is contrary to the opinion of many local extension agents and scholars, who promote diversification as a means of risk mitigation.

Additionally, local conditions may not always be opportune for a farmer to transition to agroforestry, because enabling conditions may be lacking and the risks for the farmer may therefore be too high. Often, technical assistance, knowledge management capacities, and

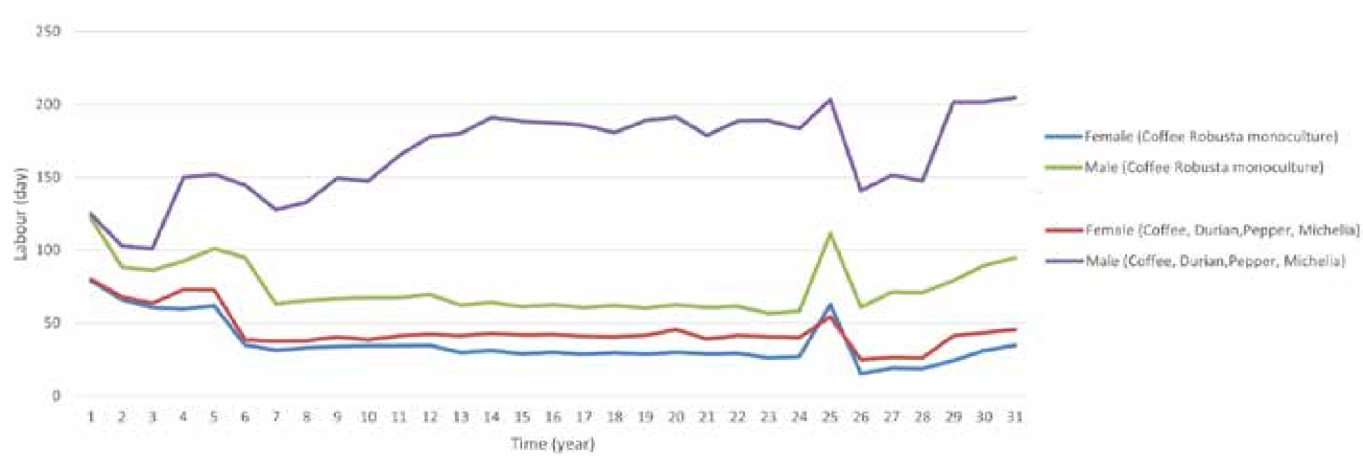

Figure 3. Labour needs (number of days) and division by gender for two crop combinations in Viet Nam

Pterocarpus macrocarpus, a timber species, planted with coffee in Hoa Le commune, Krong Bong, Viet Nam. Photo: Phan Thi Thuy Nhi

organizational support is needed to demonstrate that agroforestry systems work and generate benefits. And in many cases, local agroforestry systems have been abandoned because government policies, technical assistance and international value chains focused on a single crop, rather than on the range of products already locally produced.

Market price fluctuations

High market prices may be a great motivation for farmers to include certain species such as fruit trees in their crop mixture. Market price fluctuations, however, are one of the major risks that farmers face. In Viet Nam, farmers have been reacting to high market prices for products such as avocado by planting them extensively. As a consequence, the price dropped and no longer provided an incentive to plant avocado (FarmTree bv 2023). Farmers may diversify to create a buffer against fluctuating prices; Mexican farmers diversified their livelihoods when they perceived that coffee production had collapsed (Padrón and Burger 2015).

However, when diversifying merely for the sake of diversification, farmers may face production risks as well as market risks. They need to learn how to grow the new crops and how to manage crop interactions, and they also need to get acquainted with new, sometimes barely existing, markets.

Modelling: implications for economic viability

When smallholders adopt agroforestry, they consider socioeconomic, ecological and even political factors that may result in opportunities or constraints. These factors range from access to markets for a variety of products, and incentives for adoption that compensate for early costs, to environmental conditions such as climate and frequent droughts, among others.

This article used a numerical model for the configuration, planning and projection of scenarios based on farm data from Dak Lak Province in Viet Nam during 2023. This model helped illustrate the information found in literature and from Tropenbos International Network members on experiences in how various crop system designs affect costs, benefits and labour requirements and may affect economic viability (Figures 1–3).

Four economic factors seem to be hampering the uptake of agroforestry systems: (1) lack of clear market opportunities for tree products other than the major crop; (2) perceived short-term costs at the time of transforming the system; (3) perceived additional labour costs; and (4) lack of information on the positive impacts of selected tree species on, for example, soil fertility. In addition, risk perception, including the risk associated with fluctuating market prices, often affects the uptake of agroforestry practices.

The Farmtree Tool (Farmtree 2023) provides model that helps to make explicit these concerns and to analyze the effects of making adjustments in the design of an agroforestry system. For example, Figure 1 demonstrates how the value of additional products may increase the overall per-hectare value of the system. It also shows how combining crops with different economic life cycles (in this case, coffee with michelia) helps overcome the drop in income when a crop needs to be replaced.

Figure 1 further shows that initial establishment costs can be recovered after eight to ten years. If a farmer converts an existing plantation to an agroforestry system, such costs would be restricted to the direct costs of the tree seedlings and their planting, as well as the indirect costs of reducing the number of plants per hectare of the main crop. Whatever such costs are, in order to convince many farmers and to scale up agroforestry, they will need to be compensated for, or the future market opportunities will need to be so attractive that farmers are prepared to incur them. Apparently, the latter has been the case for pepper and avocado in recent years in Viet Nam.

In Viet Nam, michelia may be a promising tree crop, but it is not yet widespread. In addition, there is still insufficient market information to estimate its potential to increase income for a large number of farmers. However, unlike avocado and pepper, michelia also apparently contributes to maintaining soil fertility. Figure 2 shows that this possibly reduces fertilizer needs for the main crop (coffee) after the initial establishment, which considerably reduces the costs for maintaining coffee production and thus contributes to higher future net income (as shown in Figure 1). This shows the importance of being able to project the short- and long-term costs and benefits of the various species included in an agroforestry mix. Trees such as michelia may be as sensitive to market price fluctuations as other species, but they have the benefit of reducing future costs, thus lowering the risk of financial losses if market prices tumble.

Models like the one used in this article can help make explicit the expected costs and benefits of different species mixes and different management regimes. Extension agents could use this type of model with locally calibrated data to help farmers make more informed decisions about how to design their agroforestry systems. In this way, companies and farmers can step away from the standard agroforestry packages often promoted, which do not necessarily include the most appropriate crop and tree mixes for the conditions of individual farmers.

Studies and models are helpful to communicate experiences and experiments, and can be useful tools to inform farmers of the implications of the choices they make in designing and implementing their farming systems. However, experience shows (see for example article 4.5) that there is a need to be aware that in practice farmers' decisions are based on their perceptions of costs, benefits and risks, and that these may differ substantially from the perceptions of outsiders or from the costs and benefits incorporated in models. Taking this into consideration when implementing an agroforestry system will be critical in moving from model scenarios to reality and in scaling up agroforestry.

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