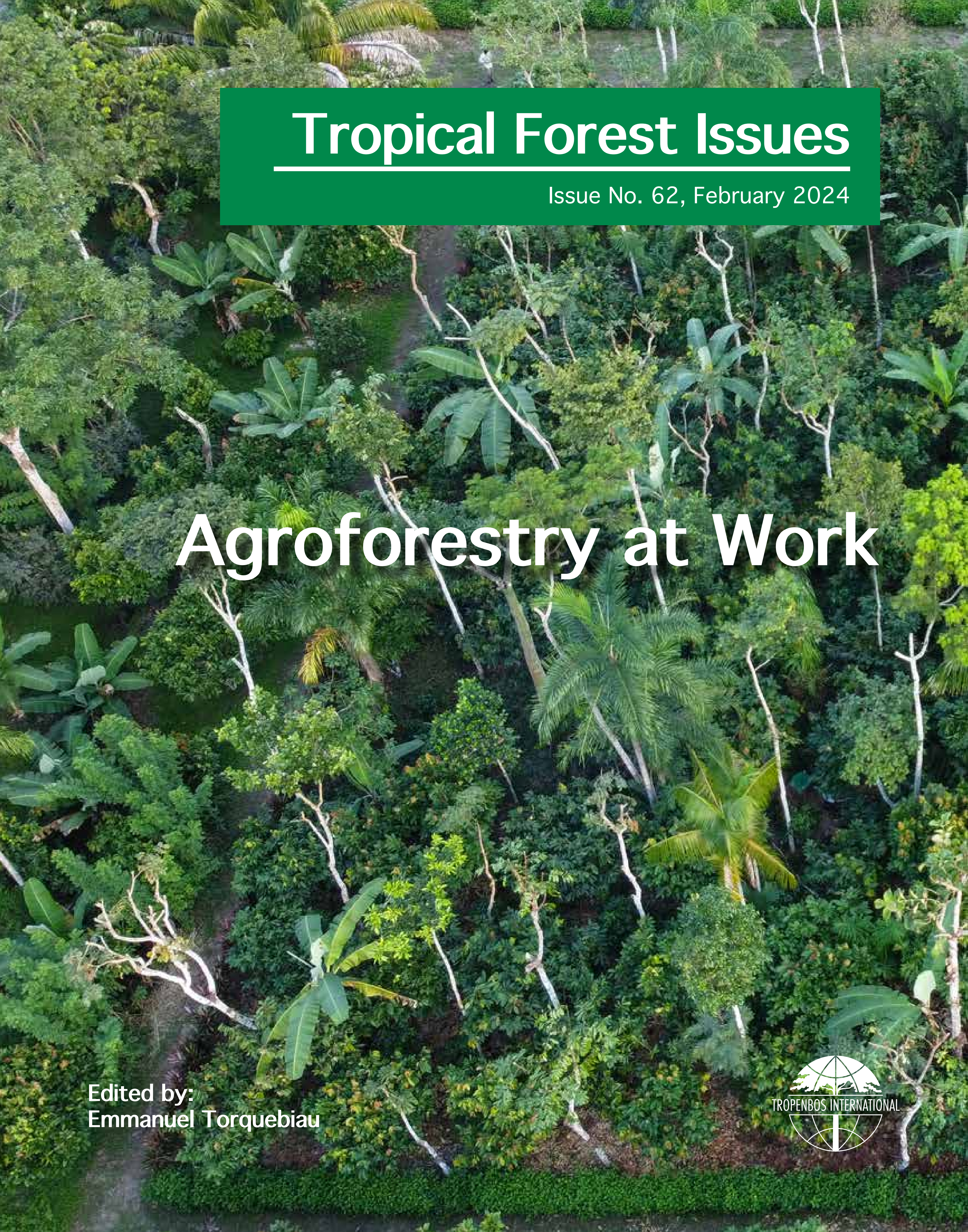

Tropical Forest Issues

Issue No. 62, February 2024

Agroforestry at Work

Edited by:
Emmanuel Torquebiau

TROPENBOS INTERNATIONAL

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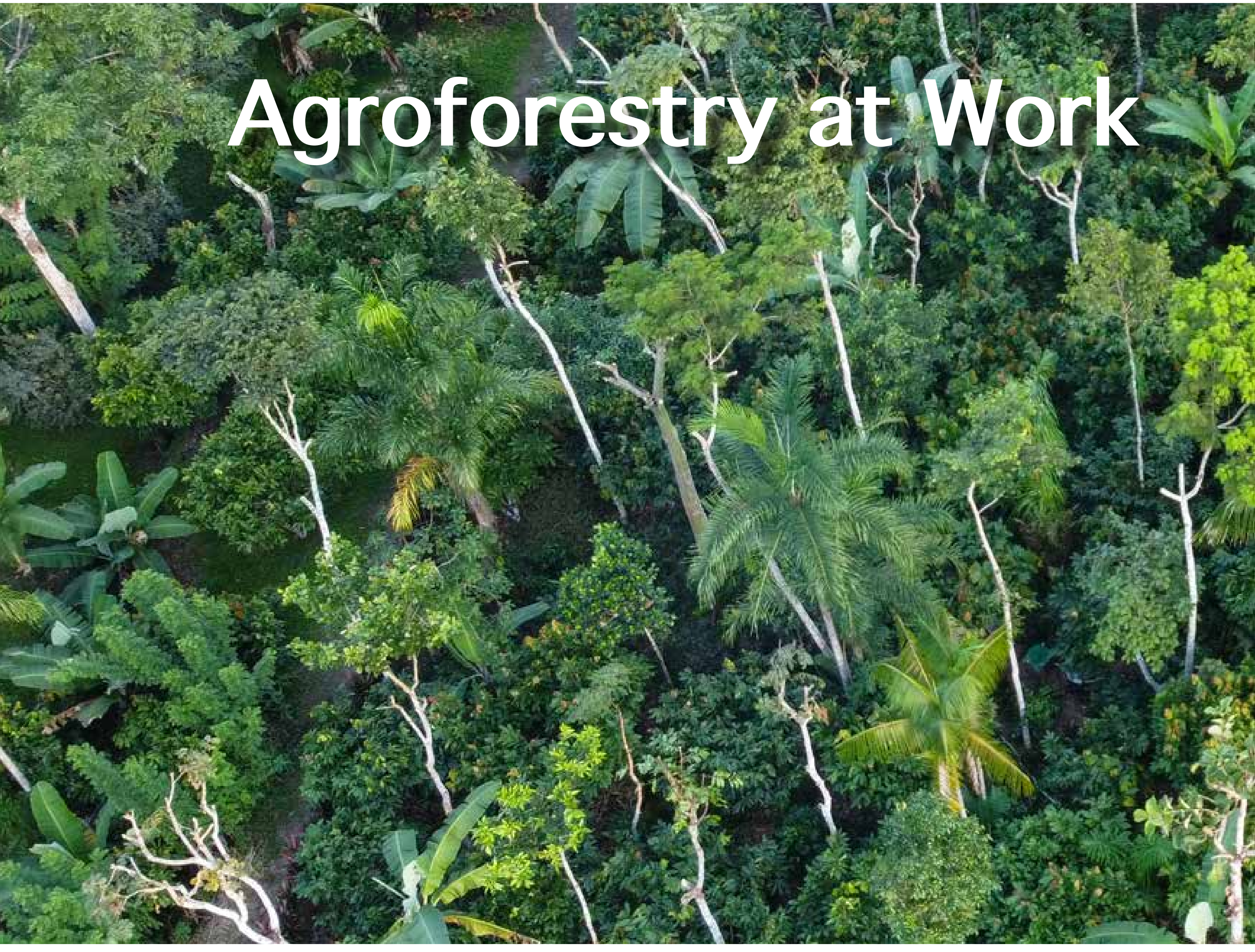

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Cover photo:	Aerial photo of a dynamic agroforestry plot that was part of the SysCom trial in Bolivia; shade trees are pruned twice a year. Photo: Erick Lohse, ECOTOP/FiBL

TROPENBOS INTERNATIONAL

Tropenbos International
Horaplantsoen 12, 6717 LT Ede, the Netherlands
+31 317 702020
tropenbos@tropenbos.org
www.tropenbos.org

Contents

Preface

Forests and trees play a crucial role in agricultural frontier landscapes, regulating climate and water cycles, and providing protection against drought and erosion. Despite their importance, deforestation and unsustainable land use persist globally, with negative effects on biodiversity, climate and water resources. The food and agriculture sector has significant negative impacts. It is responsible for 70% of water withdrawals and 60% of biodiversity loss, and generates up to a third of anthropogenic GHG emissions, which further exacerbates these impacts. Biodiversity loss and climate change increasingly disrupt agricultural production systems worldwide, threatening food security and perpetuating poverty and inequality. This especially affects communities and smallholders, who play a pivotal role in global food production. Worldwide, about 600 million smallholders, each working on less than two hectares of land, are estimated to produce 30–34% of our food supply.

There is an increasing international awareness of the need to transition to a climate-resilient, sustainable agricultural sector that is built on locally owned solutions and initiatives. Smallholders can play an important role in this transition.

Tropenbos International focuses on landscapes at the frontier between dry and humid tropical forests and agriculture. It is our ambition that by 2030, the production of agrocommodities and forest products no longer drives deforestation and biodiversity loss, but instead provides food security and diversified livelihoods for smallholders. Locally owned solutions such as agroforestry will play an important role in achieving this goal. It is essential to identify and remove barriers and strengthen incentives for agroforestry systems in order to fulfil their promise to benefit local communities and contribute to resilient and thriving landscapes and sustainable global food production.

Both traditional and formal knowledge and evidence are needed to bolster these locally owned solutions and drive the transition of the food system towards sustainability; e.g., by supporting collaborative learning among stakeholders to collectively address the barriers that currently delay the widespread adoption of agroforestry. Tropenbos plays a key role as a convenor and catalyst at various levels, ranging from the landscape to international dialogues.

This edition of *Tropical Forest Issues* (TFI) compiles and analyzes the evidence from across the world on how farmers make agroforestry work in support of this transition. The articles showcase the socioeconomic and environmental benefits of agroforestry, and how practitioners are addressing the barriers that limit agroforestry's full potential in terms of productivity and adoption to scale.

This issue of TFI showcases the diverse stakeholders engaged in the development, promotion and implementation of agroforestry. The cases serve as a vivid reminder to all stakeholders to join forces, to collaborate and to build strategic partnerships in order to realize the full potential of agroforestry for thriving and climate-resilient landscapes.

My thanks are extended to Emmanuel Torquebiau as the editor of this *Tropical Forest Issues*, Patricia Halladay for copy-editing and assistance with layout, Nick Pasiecznik, who initiated this process, and the members of the Sounding Board (Susan Chomba, David Ganz, Dennis Garrity, Sara Scherr and Eduardo Somarriba), who provided guidance throughout the process, as well as to the colleagues involved in the production of this issue. A special word of thanks goes to all of the authors who contributed their knowledge and insights to this issue. I also want to express my appreciation to the Ministry of Foreign Affairs of the Netherlands for funding this initiative as part of the Working Landscapes programme.

I encourage you to read the articles and challenge each other to take collective action with concrete steps towards sustainable and locally owned solutions that contribute to a transition towards a climate-resilient, sustainable agricultural sector.

Joost van Montfort
Director, Tropenbos International

Foreword: Nurturing Tomorrow's Harvest – A Global Odyssey in Agroforestry

In the vast tapestry of sustainable agriculture, agroforestry emerges as a beacon of hope, weaving together the wisdom of ancient practices with the demands of a modern, interconnected world. As the President of the International Union of Agroforestry (IUAF), it is both an honour and a responsibility to introduce this compendium of knowledge — a collection of 26 studies meticulously curated by Tropenbos International. This tome not only showcases the manifold advantages of agroforestry but also serves as testimony to the transformative potential it holds for our planet and its people.

The journey through the pages of this book mirrors the global trajectory of agroforestry, its roots deeply embedded in regions as diverse as Latin America, sub-Saharan Africa and tropical Asia. At the heart of our exploration lies the growing evidence of agroforestry's prowess in addressing critical global challenges — carbon mitigation, soil rejuvenation, biodiversity conservation and climate resilience. It is a story of trees and crops working in harmony, demonstrating that sustainability can be not only a lofty ideal but a pragmatic and rewarding reality.

In the initial chapters, we embark on a voyage through the major benefits and challenges of agroforestry, unravelling the intricate tapestry that links tree cover to agricultural productivity. The studies presented here span the spectrum, delving into the agronomy of diverse agroforestry systems worldwide. They illuminate the soil beneath our feet, the air we breathe, and the ecosystems that sustain life, providing invaluable insights into how agroforestry is more than a mere agricultural technique — it is a holistic approach to land use.

As we traverse through the regional sections dedicated to Latin America, sub-Saharan Africa and tropical Asia, a kaleidoscope of experiences unfolds. Each study acts as a window into the lived realities of farmers, their families and communities. These investigations, conducted at scales ranging from the familial to the global market, paint a nuanced picture of agroforestry's successes and challenges. Crucially, they underscore the importance of gender dynamics, revealing how the benefits of agroforestry flow through diverse channels, fostering resilience and prosperity among both men and women.

What unites these studies is an unyielding curiosity—an earnest exploration fueled by the promise that agroforestry holds. A promise not only to boost incomes and protect against life's uncertainties but also to confront some of the most formidable challenges of our time. The hope that permeates these pages is palpable — slowly but surely, agroforestry is gaining acceptance among farmers, policymakers, and private-sector players alike. The challenge before us is to accelerate its adoption, mindful of the multitude of agroforestry variations and the imperative to tailor them to local contexts, ensuring they fulfill the promise they bear.

In the following chapters, we will delve into the rich tapestry of studies that comprises this compendium, exploring the agronomic intricacies and real-world impacts of agroforestry. Each page turned is a step towards a more sustainable and resilient future, where the harmonious coexistence of agriculture and forestry paves the way for a world in balance. May this book inspire, inform, and ignite the flame of agroforestry's promise, illuminating the path towards a future where nature and agriculture dance in tandem, nurturing tomorrow's harvest.

Patrick Worms
President, International Union for Agroforestry (IUAF)
Vice-President, European Agroforestry Federation (EURAF)
Trustee, Savanna Institute
Senior Science Policy Advisor, CIFOR-ICRAF

Sorghum under *Faidherbia albida*, Senegal. Photo: E. Torquebiau

What makes agroforestry work?

Emmanuel Torquebiau, Nick Pasiecznik and Jinke van Dam

With contributions from Susan Chomba (WRI), David Ganz (RECOFTC), Dennis Garrity (GEA/CIFOR-ICRAF), Sara Scherr (EcoAgriculture partners) and Eduardo Somarriba (CATIE).

"As the world turns its attention towards nature-based solutions, agroforestry and community forestry, historically undervalued for their local impact, are seen as global assets. They are surely gaining momentum as scalable, bankable solutions — a pathway indeed to more sustainable solutions to environmental challenges, especially the climate and biodiversity crises."

Why do many farmers still resist adopting and scaling agroforestry? Are the economic benefits not enough, or not perceived to be enough? Or are there other reasons? These are the questions that were asked when work began on *Tropical Forest Issues* 62.

The ecological benefits of agroforestry are well proved and documented, and there is no shortage of technical knowledge. However, while agroforestry is an age-old practice in many countries, its widespread adoption on both small and large farms, and its improvement where already practised, remain limited. The practice is often characterized as too small to benefit from economies of scale. But is that really the case?

This issue contextualizes agroforestry in four introductory articles in terms of economic viability and resilience [1.1], gender inclusiveness [1.2], interactions with climate change and biodiversity [1.3] and barriers to adoption [1.4].* We then present 22 case studies that show the clear and tangible benefits from the adoption of agroforestry.

Convincing cases

These 22 examples of agroforestry at work, from a range of developing countries, all show that agroforestry provides direct and indirect benefits to farming families and the wider economy. The well-documented case studies show that agroforestry "works" — it contributes to improved livelihoods (including direct cash income), subsistence activities, employment and other community benefits. In highlighting the reasons for its success in a range of contexts, we hope to demonstrate that agroforestry can spread, encouraging other farmers to develop and expand more diversified, productive and resilient farming systems. Depending on the local context and individual traditions and perceptions, different farmers will have a preference for different agroforestry practices. This shows the importance of developing locally owned agroforestry production systems in order to achieve the full range of benefits.

The articles in this issue describe a wide range of agroforestry practices from an array of environments and socioeconomic conditions. Nine come from Africa, eight from Latin America and five from Asia. They can be classified into four categories:

- crops under trees or intercropped with trees;
- annual crops under multispecies tree cover;
- perennial crops under multispecies tree layers; and
- agroforests.

Crops under trees or intercropped with trees

In perhaps the most common type of agroforestry around the world, crops are grown under trees or with scattered or planted trees in fields or around fields. These cases are typically characterized by a two-layer arrangement, with trees occupying an upper storey, more or less dense and sometimes diffuse, and crops cultivated in the understorey. In the simplest cases, there is only one tree species and one crop species at a time beneath the trees. In Honduras, the *Inga* tree agroforestry model shows good adaptation to climate change and has contributed to halting land degradation and supporting food security [2.3]. In Cameroon, *Faidherbia albida* agroforestry parklands provide significant direct benefits to rural populations, such as firewood and fodder, and improve the productivity of associated crops [3.5]. In Burkina Faso, the development of hedged farmland (known as "bocage") has led to well-functioning landscapes where runoff and erosion are reduced, water is stored and overgrazing is controlled, giving rise to improved yields and better livelihoods [3.3]. In Brazil, intercropping oil palm with native species of various life cycles (annual, perennial) and production objectives (wood, fruits, etc.) proved efficient in meeting the criteria of plant diversity, agroecological function and economic diversity [2.5]. In South Africa, intercropping groundnuts with eucalyptus trees contributed to increasing food security and improving community livelihoods [3.9].

Annual crops under multispecies tree cover

Many two-layer agroforestry arrangements have tree or crop layers composed of several species. In some cases, the associated crops are annual plants (e.g., maize, beans) or semi-perennial, non-woody plants (e.g., pineapple, aroids, spices). In Burkina Faso, agroforestry parkland has an upper layer of scattered trees from an array of different species providing multiple non-timber tree products [3.2]. In Bangladesh, pineapple, aroids and spice plants are grown under a range of trees that provide firewood or fruits [4.2]. In a similar situation in India, cardamom is cultivated under nitrogen-fixing alder trees [4.1]. The milpa agroecosystem of Mexico is comparable, with maize and other crops such as beans and pumpkins growing in the impressive biodiversity of native trees and fruit trees [2.2].

Perennial crops under multispecies tree layers

In this category, the lower layer consists of a perennial crop, typically coffee or cocoa. In the Democratic Republic of the Congo, efforts are underway to popularize the cultivation of cocoa and plantain bananas combined with trees from degraded forests and fallows [3.6]. In Brazil, cocoa is grown along with other commercial crops such as banana and açaí palm under trees that provide shade as well as timber and non-timber products [2.6]. In Argentina, yerba mate, another perennial crop, is planted in araucaria timber tree plantations, where it finds a cool and humid environment [2.8]. In Bolivia, cocoa is planted with several companion crops (e.g., banana, coffee, ginger, avocado) in highly diverse ecosystems that favour the natural regeneration of trees [2.4]. With its very diverse trees, this last example actually looks like a case from the next category, with the tree component being a dense, mixed, multilayer, fully developed part of the plots.

**Please note: numbers in square brackets are cross-references to articles in this issue.*

Agroforests

In this category, trees are found in dense, mixed, often multilayered arrangements, with crops or livestock occupying various niches that can change in time and space. The resulting agroforests are agroecosystems that frequently resemble natural forests. They certainly represent a promising approach now and for the years to come. In Mexico, ancestral native agroforests are extremely diversified, with several dozen tree species, and they harbour a notable shade-tolerant variety of pineapple [2.1]. In Lao People's Democratic Republic, ethnic minorities who have decided to stop practising shifting cultivation instead plant coffee in mixed seasonal tropical forests, maintaining a protective and diversified vegetation cover, which is particularly useful on hill slopes [4.4]. On the east coast of Madagascar, agroforests with clove trees and other export crops have become a major feature, also providing a wealth of subsistence commodities [3.8]. In Zanzibar's Spice Islands, in Tanzania, polyculture spice agroforests with clove trees, turmeric and black pepper — as well as resilient sources of food and firewood — allow families to eat a nutritious diet while generating income [3.7]. In Ghana, the application of agroecological principles has been found to boost the productivity of cocoa agroforests thanks to farming practices that favour crop diversity, crop rotations, biomass management and biological pest control [3.4]. In Indonesia, rubber agroforests are profitable business ventures with strong traditional importance in spiritual life, including respect for ancestors, and also function as social spaces for gatherings and collective fruit harvesting [4.5]. In Sri Lanka, forest gardens provide ecosystem services similar to those of nearby forests, such as watershed rehabilitation, and have been shown to improve livelihood security and contribute to poverty alleviation [4.3]. In Ethiopia, multispecies agroforestry homegardens around dwellings are a source of staple food to replace crops from remote fields during a time of conflict [3.1]. In Brazil, improved shade-tolerant pastures planted under native araucaria trees have proved to remain productive for most of the year and to support cattle-raising while protecting forest remnants [2.7].

Conditions for tangible benefits

All the 22 case studies presented here mention the positive effect of agroforestry on farmers' income; 15 report actual, quantified economic data. They represent factual, data-based cases of "agroforestry that works" and of money-making agroforestry initiatives. Direct financial benefits are often realized by those farmers who have market access, whether formal or informal. Indirect benefits — such as improved subsistence, firewood and fodder security, increased savings and lower risks — are also among the tangible advantages that tree-based farming provides to farmers. Increased options for risk mitigation are also important. Greater stability of income from multiple products provides resilience against yield losses of any one product due to adverse weather or other unfavourable conditions. Diversity also contributes to more stable incomes, since loss of market value due to fluctuations in commodity prices can be compensated by better prices for other products.

However, these benefits should always be analyzed in the context of factors that may be hampering the uptake of agroforestry innovations, and thus from reaching its full potential in terms of productivity and adoption. Economic modelling based on actual field data [1.2] shows that there are four main categories of limiting factors: (1) lack of clear market opportunities for tree products other than the major crop; (2) perceived short-term costs at the time of converting to agroforestry; (3) additional perceived labour costs; and (4) lack of information on the positive environmental impacts of trees.

What then are the conditions that must be in place for these benefits to be realized? What steps have been taken by the farmers featured in this volume to demonstrate that agroforestry can indeed "work"? Based on recommendations formulated by the authors of the articles, some major trends emerge. They can be grouped in seven broad categories.

Improve social and human capital

The social and human capital necessary for the development of agroforestry are not always sufficient. Social relationships, as they exist through farmers' networks, often face constraints. More emphasis is required on innovative farmer agroforestry training, based on real-world agroforestry techniques; for example, to realize greater productivity. Criteria such as farmer happiness, well-being and the satisfaction of working on a pleasant farm in harmony with nature are seldom — if ever — taken into account, although they are mentioned by farmers as being important.

Pay attention to women

Failing to address women's needs and interests will limit the adoption of agroforestry. Women practitioners deserve more attention, as key stakeholders in monitoring and maintaining gender equality, as agents of change in the adoption of agroforestry, and because they often play a significant role in agroforestry management. In spite of these contributions, gender disparities hinder women's adoption of agroforestry and their participation in decision-making processes, which calls for gender-disaggregated policies and practices [1.1].

Align priorities

The priorities of experts, NGOs and institutions and farmers do not always align in terms of farming choices; e.g., some may advocate agroecology while others will recommend increasing the use of agrochemicals. Achieving congruence is crucial for increasing acceptance by farmers because some existing agroforestry practices do not correspond to conventional farming patterns and because agroforestry innovations often require drastic changes in farming practices. Support from institutions or extension services sometimes focuses exclusively on just one commodity, or on yield objectives, when it would be more effective to focus on the entire system and the opportunity to diversify crops, or to make farmers aware of specific benefits such as improved agroecology, and the potential for risk reduction, climate resilience or biodiversity conservation. Agroforestry development requires an ongoing iterative and participatory process that involves a broad range of stakeholders, including smallholder farmers, government at all levels, NGOs and the private sector.

Provide technical assistance and capacity strengthening

There is a great need for technical assistance and capacity strengthening at all levels, from farmers to farmer organizations, municipalities and government officials. Many small-scale farmers have limited agroforestry knowledge and are not confident about embarking on a new practice. There is also a widespread lack of skilled and unskilled labour to assist farmers. Most extension services are still focused on monoculture, and agroforestry rarely gets much attention. On-farm learning to share agroforestry best practices (e.g., pruning of companion trees), as well as experience and knowledge, can be extremely useful. Model farms can be local hubs for training and for disseminating genetic material from nurseries of native trees and seeds. "Champion" farmers can play a key role in solidarity and knowledge sharing in their communities and provide a critical mass of innovators and a social licence for innovation. At the village and landscape level, success is more likely if many people implement similar innovations.

Enable legal, institutional and policy frameworks

Policymakers must work to develop enabling legal, institutional and policy frameworks, including increased availability of public services, appropriate financing, access to credit and incentives, and insurance schemes specific to agroforestry. Legal steps may be necessary to modify laws or bylaws to make them more appropriate for agroforestry. Issues such as tenure regulations, timber-cutting permits and the right to use tree products must be enshrined in law and enforced by officials.

Expand economic research

Research institutions need to publish results that are based on multiyear and long-term data, and are convincing to non-specialists. Research must assess and address gaps, such as insufficient information about the use of multipurpose trees, the costs of establishing an agroforest, how to grow lesser-known crops in agroforestry associations, low-cost methods in terms of labour and inputs, disappearing Indigenous agroforestry knowledge, and agroforestry techniques that are well adapted to local agriculture. And high-yield agroforestry practices should not be neglected, as this is probably one of the best options to make sure that agroforestry farms benefit from economies of scale (i.e., by spreading costs over large areas). Research institutions must also acknowledge that complex systems such as multilayer agroforests require long-term financial resources and a multidisciplinary approach.

Develop value chains

Value chains for agroforestry products need to be developed in order to broaden income opportunities, and must take into account a variety of existing challenges: fluctuations in world prices, scattered and sometimes remote production, competition from other cash crops, the need to create access to new markets, transport costs and lack of transport. Institutional markets and niche markets for farm produce can provide important support for diversified agroforestry farms. Rewarding farmers for environmental services (e.g., carbon sequestration by trees), possibly linked with farm certification, can also contribute to strengthening farmers' economic resilience.

Conclusions

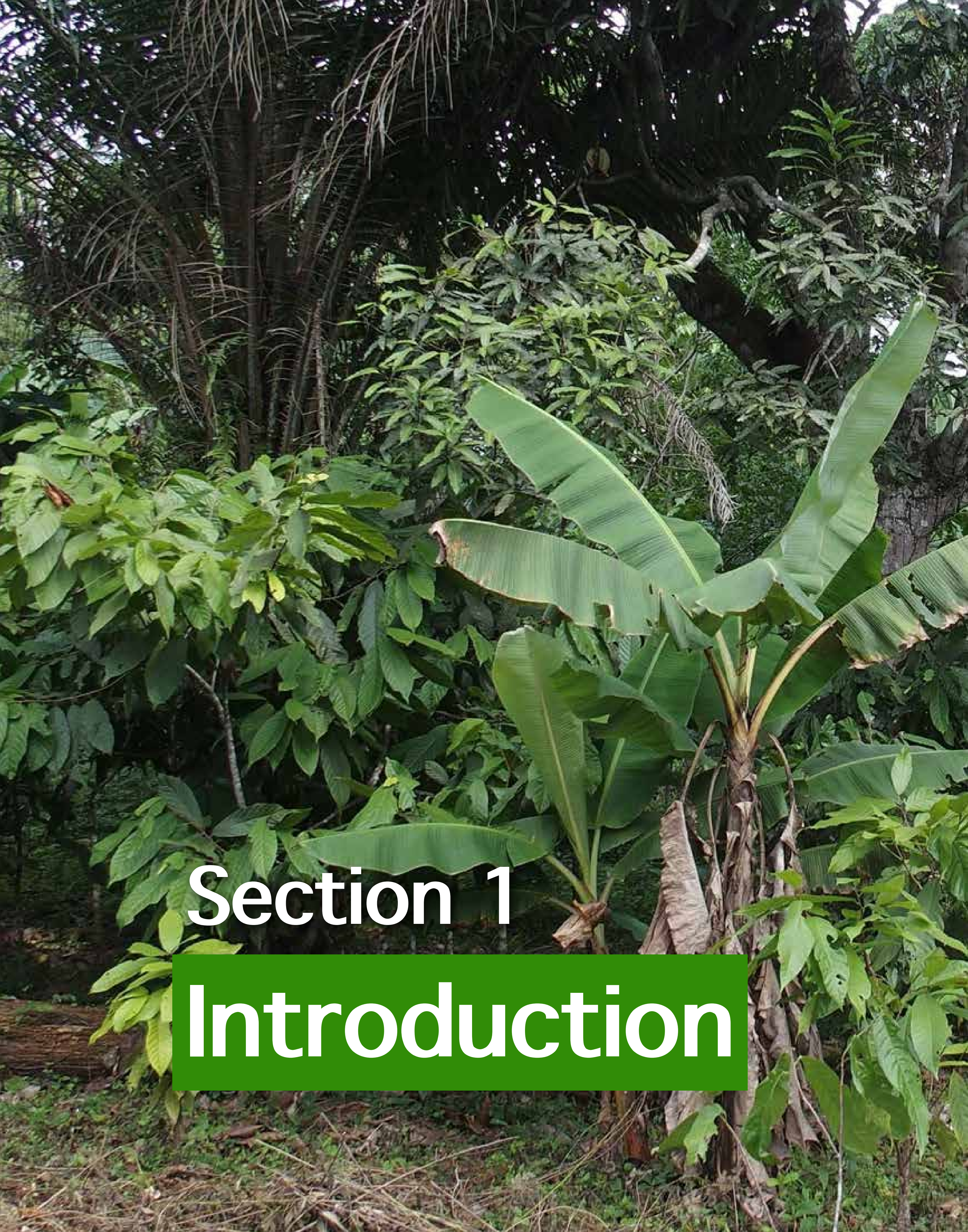
If the above conditions are met, as a function of local circumstances and taking the farmers' priorities as an entry point, of course, the co-benefits that agroforestry can bring — in terms of increased resilience to environmental and climate changes and to social and economic challenges — can be realized at a large scale and reach millions of farmers. Yet, for impact and adoption at scale to actually happen, a wide audience needs to be mobilized, including policymakers and all stakeholders responsible for development/environment/food system programmes — as well as those advising them. Companies, governments and knowledge and financial institutions are encouraged to collaboratively strengthen the enabling environment to support the required changes. It is hoped that the testimonies presented here will help reach this audience and spread the message that yes, "agroforestry works!"

Author affiliations

Emmanuel Torquebiau, Scientist emeritus, French Agricultural Research Centre for International Development/CIRAD (etorquebiau@outlook.com)

Nick Pasiecznik, Communications lead, World Vegetable Center (nick.pasiecznik@worldveg.org)

Jinke van Dam, Associate thematic lead, diversified production systems, Tropenbos International (jinke.vandam@tropenbos.org)



Section 1

Introduction

Previous page: Cocoa agroforest in Cameroon. Photo: E. Torquebiau

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

Bas Louman, Juan Manuel Moya, Jinke van Dam, Gabija Pamerneckyte, Tommaso Comuzzi, Tran Huu Nghi, Tran Nam Thang, Rosalien Jezeer and Maartje de Graaf

"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

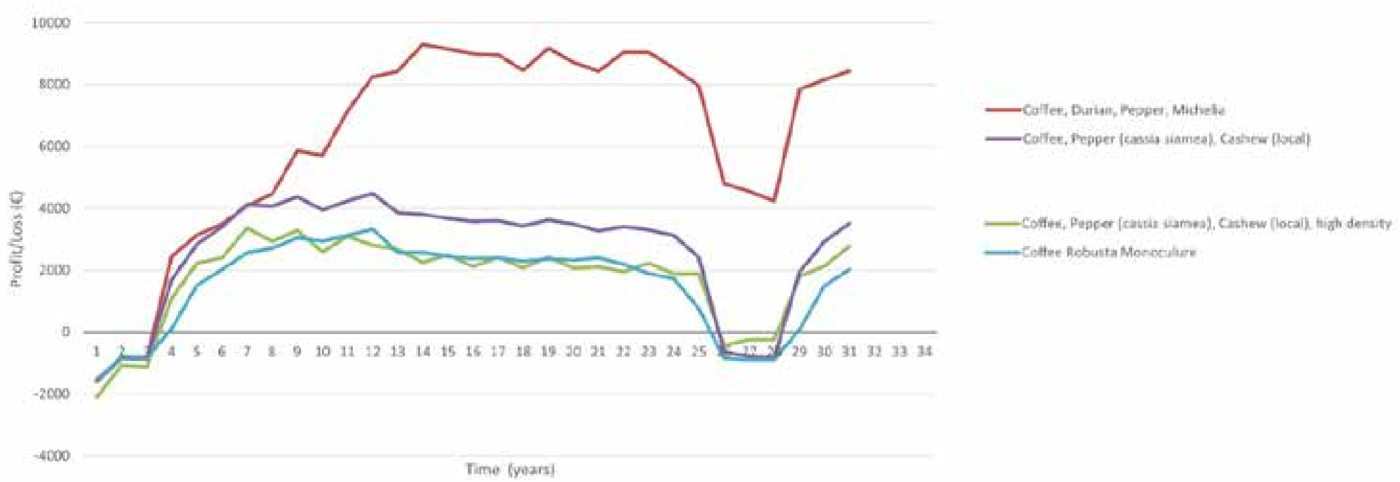


Figure 1. Projected annual net income per hectare of four different crop combinations in Viet Nam
Based on Farmtree tool projections (FarmTree 2023), calibrated with real farm data of 2023 (FarmTree bv 2023).

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

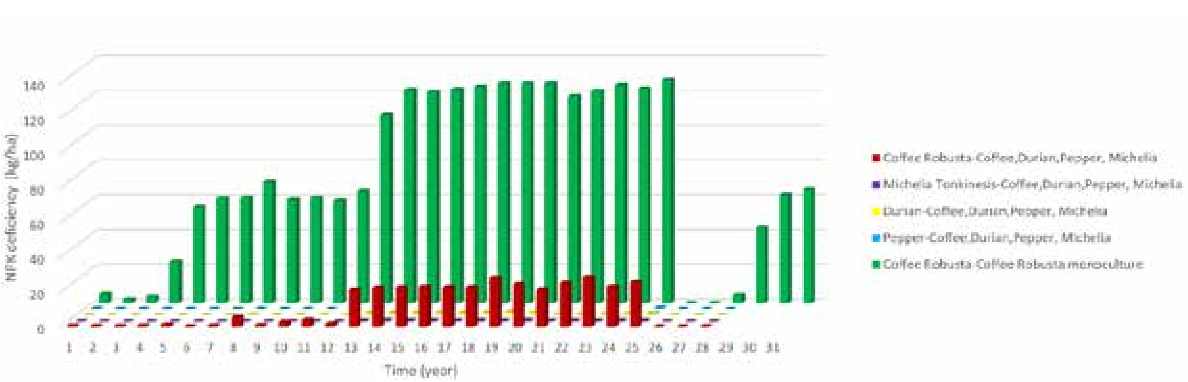


Figure 2. Need for fertilizer (kg/ha) in soils for coffee under monoculture (green bars) and agroforestry regimes (red bars)
As projected based on data from case studies in Viet Nam (FarmTree bv 2023). In both cases, NPK fertilizer was applied during the first ten years. The lower need for fertilizer 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

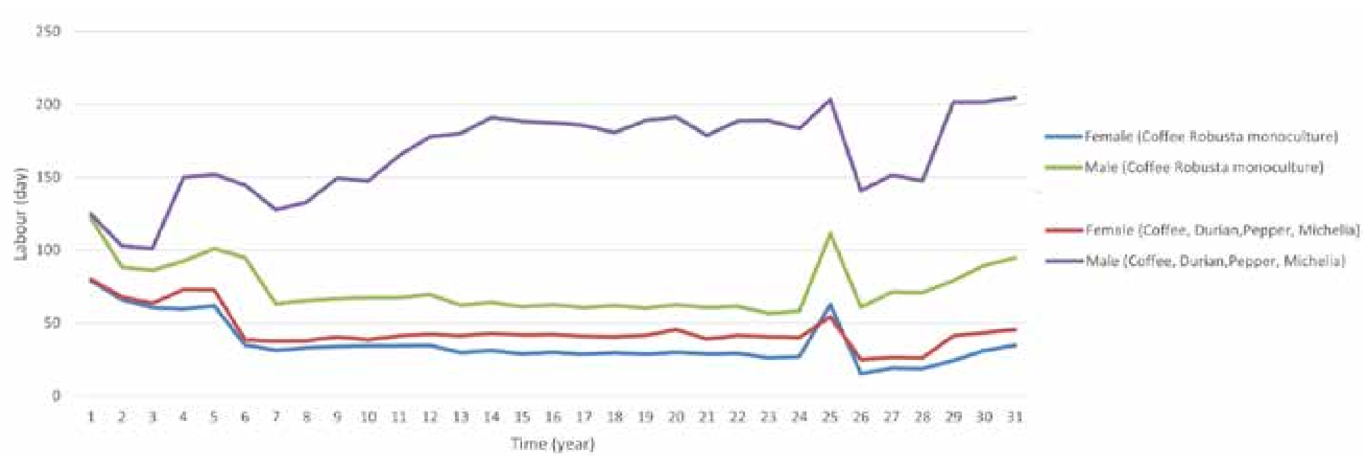


Figure 3. Labour needs (number of days) and division by gender for two crop combinations in Viet Nam

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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Author affiliations

Bas Louman, Programme coordinator, MoMo4C; country advisor, Viet Nam, Tropenbos International (bas.louman@tropenbos.org)
Juan Manuel Moya, Expert on business and finance, Tropenbos International (juan.moya@tropenbos.org)
Jinke van Dam, Associate thematic lead, diversified production systems, Tropenbos International (jinke.vandam@tropenbos.org)
Gabija Pamerneckyte, Expert, agroforestry impact quantification (gabija.pamerneckyte@farmtree.earth)
Tommaso Comuzzi, Student intern from Wageningen University and Research at TBI (tom-comuzzi@hotmail.com)
Tran Huu Nghi, Director, Tropenbos Viet Nam (nghi@tropenbos.vn)
Tran Nam Thang, Technical advisor, Tropenbos Viet Nam (thang@tropenbos.vn)
Rosalien Jezeer, Programme coordinator, Green Livelihoods Alliance (GLA) and Fire-smart landscape governance, Tropenbos International (rosalien.jezeer@tropenbos.org)
Maartje de Graaf, Thematic lead on community forest management and conservation; country advisor, Ghana and the Philippines, Tropenbos International (Maartje.deGraaf@tropenbos.org)

A female farmer in Pattaneteang village harvesting coffee.
Photo: RECOFTC Indonesia

1.2

Transforming agroforestry through gender practice: challenges and opportunities

Gamma Galudra, Nerea Rubio Echazarra, Reny Juita and Chandra Shekhar Silori

"Initiatives that aim at empowering women — recognizing their contributions and addressing the constraints they face — can lead to increased adoption of these agricultural practices."

Introduction

The global agriculture sector relies heavily on women, who constitute a significant portion of the workforce, especially in developing countries (FAO 2014). Despite their crucial role, women face inequalities in access to essential resources (FAO 2011), which results in lower agricultural productivity and increased poverty (Kiptot and Franzel 2011). Research in the agriculture sector estimates that if women had equitable access to education and other resources, production would increase by 10 to 20% (Quisumbing and Pandolfelli 2010). And as climate change threatens food systems (Steiner et al. 2020), addressing these gender gaps becomes even more urgent.

Agroforestry, as a climate-smart agricultural practice, offers promise by increasing land productivity, improving socioeconomic outcomes and promoting climate change mitigation and adaption (Bose 2015; Haeggman et al. 2020). Agroforestry is a broadly defined term that involves the cultivation of a diverse mix of trees, shrubs and crops, and, in some cases, their integration with livestock farming. This dynamic system of natural resource management, rooted in ecological principles, effectively incorporates trees into various landscapes, including farms and ranches (Kitalyi et al. 2013). Regarded as a sustainable land-use practice, agroforestry contributes to agricultural productivity, delivering economic, ecological, social and cultural benefits (Awazi and Tchamba 2019). Agroforestry significantly reinforces smallholder farmers' climate resilience, supporting food security, health benefits, environmental stability and reduced vulnerability to natural hazards (Haeggman et al. 2020).

In agroforestry systems across the globe, women play a significant role, (Debbarma et al. 2015). However, agroforestry systems are not gender-neutral (FAO 2013; Degrande and Arinloye 2014; Haeggman et al. 2020). Despite their pivotal role, women experience more disadvantages compared to men due to a complex net of socioeconomic, cultural and institutional factors (Kiptot and Franzel 2012). Gender disparities persist, and social norms influence how men and women engage with natural resources, affecting the adoption of agroforestry (Kiptot and Franzel 2012). Barriers such as restricted access to land, education, decision-making processes and finance hinder women's participation (Nguyen et al. 2021). Yet, empowering women to adopt agroforestry can lead to increased household well-being, food security and community development (Nguyen et al. 2021; Jamal 2023).

Gender roles in agroforestry management

Gender dynamics in agroforestry play a crucial role in community life. Gender roles, which consist of the expected behaviours and responsibilities of individuals based on their gender (Blackstone 2003), significantly influence how both men and women engage with forests, agroforestry and trees as vital resources for their livelihoods. Unfortunately, especially in rural areas there are notable disparities in the roles, rights and duties assigned to women and men. These inequalities are evident in various aspects of daily life, including decision-making, access to benefits from forest and tree resources, and experiences in forest and tree-based environments (Kiptot 2015).

Research conducted by Pasaribu et al. (2019) in Sungai Langka village, Indonesia, shows the tangible manifestation of these gender roles. Findings from this study reveal that women's contributions extend beyond household chores, with several households actively involving women in various agroforestry management activities (Figure 1).

The study highlights a prevailing gender divide in agroforestry management activities, with men primarily handling these responsibilities due to their role as primary earners for their families. This finding aligns with Suwardi's (2010) research, which also observed that men tend to invest more time in community forest management tasks due to their greater familial financial responsibilities. In addition, the division of labour between men and women in agroforestry is often influenced by the perception of physical strength and abilities. Men are typically assigned tasks perceived as physically demanding or requiring greater strength, such as land preparation, planting, plant maintenance and transportation. These gender-based roles have historical roots and are reinforced by cultural norms and expectations (Elias 2016).

Consequently, this gender-based division of labour in agroforestry can have significant implications for women's participation in decision-making processes and their access to and control over critical resources (Kinasih and Wulandari 2021). When women are primarily engaged in tasks seen as less physically demanding, they may have limited influence over decisions related to agroforestry practices, resource allocation and household expenditures.

Constraints faced by women in agroforestry adoption

Barriers to these five key aspects have significant impacts on women's engagement in agroforestry.

Land access

Securing land tenure rights is a crucial factor in agroforestry investment. However, women often find themselves in a less favourable situation than men when it comes to securing land access (Benjamin et al. 2021). For instance, in many land tenure systems of sub-Saharan Africa, women are largely excluded from obtaining permanent and secure land rights (Kiptot and Franzel 2011; Benjamin et al. 2021), due to the prevailing pattern of land inheritance (i.e., patrilineal), whereby land is typically passed down to male offspring (Kiptot and Franzel 2011).

Women's ownership of agricultural land remains limited (Kiptot and Franzel 2011; Chiputwa et al. 2021), with only 13% of agricultural landowners worldwide being women (UN Women 2018). This percentage varies across regions, with female heads of households and farm operators accounting for an average of 15% of agricultural landholders in sub-Saharan Africa, more than 25% in Latin America and less than 5% in Asia (FAO 2011).

Literacy and extension services

In certain cultures, girls are withdrawn from school earlier than boys and assigned to household and economic activities (Catacutan and Naz 2015). This results in lower literacy rates among women (Kiptot and Franzel 2011) and consequently, in their lower participation in extension activities and services (Catacutan and Naz 2015). The latter is further exacerbated by the time constraints faced by women due to their role as caregivers (Diawuo et al. 2019; Chiputwa et al. 2021).

Educational disparities hinder female adoption of innovative agricultural practices and cultivation methods that could help them achieve greater efficiency and profitability in farming (Kumase et al. 2010). Inadequate extension services further impede women's farming practices, as programmes often fail to address their specific needs (Nguyen et al. 2021).

While women's participation in educational programmes enhances agroforestry adoption and empowerment, restricted access to knowledge through farmer groups, controlled by socially higher-ranked males, poses challenges for female farmers (FAO and CARE 2019). This leads to many women preferring local, informal training and learning from other women (Nguyen et al. 2021), which emphasizes the need for accessible, culturally relevant and women-centric extension materials and methods.

Decision-making

Another important constraint is the imbalance in the power that women and men have in decision-making processes within the household and the community. As explained above, traditional social norms have long considered agriculture, including agroforestry, as a domain of men. These norms are deeply rooted at both the household and community level (Wiyanti et al. 2022), and they associate agricultural activities and responsibilities with male participation (Catacutan and Naz 2015; Wiyanti et al. 2022). This leads to a prevailing belief that men possess superior knowledge and expertise in agriculture (Wiyanti et al. 2022). As a result, men are typically deferred to when it comes to making decisions about agricultural and agroforestry-related processes (Catacutan and Naz 2015).

Decision-making bodies with gender imbalance within the community may intentionally or unintentionally increase gender biases and reinforce existing power dynamics. Men may dominate discussions and decisions (Catacutan and Naz 2015), which can limit the inclusion of gender-sensitive approaches and policies. Such situations may disregard issues that are crucial to women, such as access to land and credit. When women's insights and experiences are overlooked, it can result in missed opportunities to develop the innovative solutions needed to address complex challenges in agroforestry and rural development (Catacutan and Naz 2015; Wiyanti et al. 2023).

Labour

Limited access to labour is a major challenge for female farmers. Women allocate more time to family and child-rearing tasks compared to men, which reduces the amount of time they can dedicate to farm work (Kumase et al. 2010). Agroforestry demands careful planning and management, which can be hindered by time constraints.

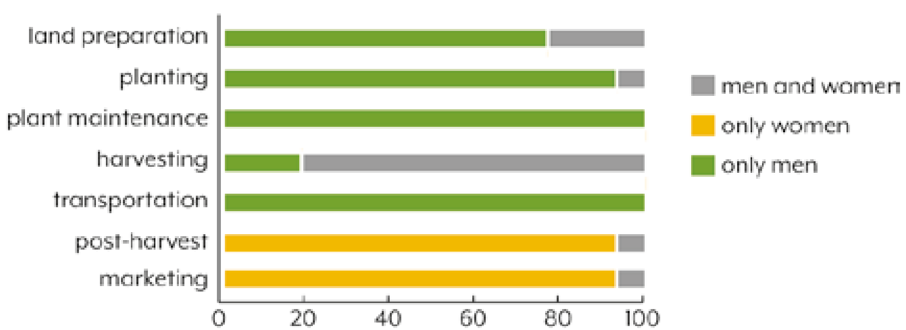

Figure 1. Gender roles (%) in agroforestry management activities of farmer households in Sungai Langka village, Indonesia. Based on: Pasaribu et al. (2019)

Female farmers in Bantaeng harvesting coffee. Photo: RECOFTC Indonesia

Evidence shows that women often rely on hired labour, while men invest more of their own or family labour in their farms (Ayodele 2020). This labour constraint can increase women's production costs, reduce profits and discourage agroforestry adoption. Poor women with limited financial resources are especially affected, and the shortage of labour resources in female-headed households can lead to reduced productivity and efficiency (Kiptot and Franzel 2011).

Financial resources

When it comes to finance, women can face constraints in many forms, such as limited access to credit, loans or investment capital. Female farmers often lack secure land rights and collateral assets (Catacutan and Naz 2015), which are frequently required as prerequisites for securing loans or credit (Hill and Vigneri 2011). Establishing an agroforestry system often requires initial investments in tree seedlings, equipment and other resources (Shennan-Farpón et al. 2022); therefore, the inability to access credit impedes female farmers from adopting this agricultural practice (Chiputwa et al. 2021). Moreover, cultural norms and societal expectations can restrict women from engaging in certain economic activities or controlling their capital (Fletschner and Kenney 2014).

Additionally, women possess less knowledge about marketing in comparison to men, and have minimal influence in transactions involving the buying and selling of agricultural products and farm equipment (Armbruster et al. 2019). This lack of financial literacy can be a significant barrier to adopting agroforestry practices (Chiputwa et al. 2021).

Women as agents of change

The Sustainable Development Goals (SDGs) set by the United Nations recognize the key role of women as agents of change, and gender equality in policy development is now deemed essential for sustainable development (UN 2015). Women's potential as agents of change for the adoption of agroforestry is evident, given their capacity for building social capital, their greater sense of community (UNDP and UN Women 2022) and their extensive knowledge of tree and forest species diversity, management and range of uses (Catacutan and Naz 2015).

In many projects, the involvement of women has been proven to be essential for success. In southern Chile, Peredo Parada et al. (2020) highlighted the key role of peasant women in the establishment of agroforestry due to the importance of the knowledge they hold. This was also observed by Singh (2023), who noted that the knowledge possessed by women in male-headed households regarding seeds, compatibility of crops used in intercropping and mixed cropping, manure and pest management was crucial for the adoption of a successful practice. Nevertheless, men continue to dominate the

A female farmer in Campaka village harvesting coffee. Photo: RECOFTC Indonesia

practice of agroforestry on a global scale. This imbalance is evident in various regions, as revealed by research conducted by Jahan et al. (2022) in Bangladesh, along with similar findings by Kiyani et al. (2017) in Rwanda and Kouassi et al. (2021) in Côte d'Ivoire.

Interestingly, Bourne et al. (2015) discovered that despite women valuing and preferring agroforestry as a potential form of land use more than men do, the lower number of trees in their lands showed that their capacity to adopt this practice is constrained. In line with this, Catacutan and Naz (2015) found in Viet Nam that, while women placed a higher priority on agroforestry than men did, female-headed households had fewer tree species in their homegardens. This gender disparity can be attributed to a multitude of factors; deeply entrenched social norms are among the main ones. As explained above, these norms contribute to women's lower wealth levels and restricted access to land, labour and extension services, as well as limitations imposed by inheritance systems, and the lack of rights for women to grow trees (Kiptot and Franzel 2011; Bourne et al. 2015; Diawuo et al. 2019; Hemida et al. 2022).

Female farmers' willingness to adopt agroforestry

In a recent study conducted by Agúndez and colleagues (Agúndez et al. 2022) in Niger, the findings showed that women, mainly those who were heads of household, were more willing to adopt climate change adaptation programmes or agroforestry systems than men were. In Uganda, Bourne et al. (2015) found that, in male-headed households, both men and women expressed similar preferences for new land uses, whereas female-headed households preferred agroforestry. Two main reasons can explain this phenomenon.

First, as explained above, men and women have different roles (Chiputwa et al. 2021), which leads to a difference in knowledge of natural resources and a difference in preferences (Gumucio et al. 2017). In El Salvador, Kelly (2009) found that women, whether as heads of household or as members, valued agroforestry fruit systems significantly more than men did because these systems provide food and access to additional markets, as well as ecosystem services such as soil enrichment. Similarly, Blare and Useche (2015) found that, on average, women placed a considerably higher value on cocoa agroforests than men did. In Viet Nam, women in male-headed households prioritized agroforestry more than men did (Catacutan and Naz 2015).

Second, as a consequence of resource degradation, men often opt for seasonal migration as a means to diversify their labour activity, a phenomenon that occurs in countries of the Sahel (Agúndez et al. 2022), and is also prevalent across the globe (Kelly 2009; Kiptot and Franzel 2011; Paudel et al. 2022). Consequently, this migration pattern results in households being led by women and exposed to greater vulnerability (Agúndez et al. 2022), which might influence the willingness of women to adopt agroforestry practices (Paudel et al. 2022).

Therefore, in contexts where women express a greater appreciation for agroforests than men do (Kelly 2009; Agúndez et al. 2022), the inclusion of women, both household heads and members, in land-use decision-making is likely to result in increased adoption of agroforestry systems (Blare and Useche 2015).

Conclusion and recommendations

Agroforestry plays a vital role by promoting sustainable forest management, empowering local communities, enhancing livelihoods and conserving biodiversity. Importantly, agroforestry has the potential to devolve forest management rights to communities while addressing their socioeconomic needs and contributing to environmental sustainability.

However, gender plays a significant role in agroforestry management, reflecting sociocultural expectations assigned to individuals based on their sex category. While both women and men contribute to forest- and tree-based livelihoods and management, gender disparities persist, hindering women's adoption of agroforestry. These inequalities stem from social norms deeply rooted in cultural expectations, which perpetuate gender biases and restrict women's access to education and vital resources, as well as their participation in decision-making processes.

Despite these challenges, women have the potential to be powerful agents of change in the adoption of agroforestry. Their complex knowledge of natural resources and their greater sense of community make them valuable contributors to agroforestry initiatives. Initiatives that aim at empowering women — recognizing their contributions and addressing the constraints they face — can lead to increased adoption of these agricultural practices, ultimately fostering more sustainable and resilient agricultural systems.

This article describes several ways in which gender mainstreaming can enhance the effectiveness and sustainability of agroforestry initiatives. The following are key recommendations:

Collect gender-disaggregated data

Investing in robust data collection and analysis will help researchers and organizations better understand gender disparities and dynamics within agroforestry contexts. Accurate gender-disaggregated data will inform evidence-based policies, programmes and interventions, enabling tailored approaches that address the specific needs of and challenges faced by women and men in order to promote gender equity and sustainability in agroforestry.

Support equal access to resources

Policies and initiatives by governments and organizations that provide equal access to land, financial resources, agricultural inputs and extension services for women and men can help level the playing field and enable both genders to fully participate in agroforestry activities.

Promote gender-inclusive training and education

Gender-sensitive training programmes and educational initiatives developed and implemented by governments and organizations can challenge traditional perceptions and stereotypes. By focusing on increasing women's and men's knowledge and skills in agroforestry initiatives can empower both genders to participate effectively in decision-making processes.

Implement gender-responsive policies

Advocacy by organizations and individuals for the incorporation of gender-responsive policies at all levels of government includes enforcing regulations that ensure a minimum representation of women in decision-making bodies, such as the introduction of a quota for women in farmers' groups.

Foster women's leadership and participation

Women have proven to be effective agents of change due to their ability to nurture social connections, trust and community networks. Their greater sense of community enables them to share valuable information through informal channels, which plays a significant role in promoting agroforestry and time-saving practices within the community. The Weaving Leadership for Gender Equality (WAVES) programme by RECOFTC, for example, conducted from 2019 to 2022, focused on building women's leadership skills and increasing their participation in agroforestry and rural development initiatives. It created an effective network of 36 gender leaders across seven countries, fostering their engagement in decision-making processes and amplifying their work through collaborations. This initiative contributed to reshaping the gender agenda, emphasizing inclusion and social justice in the respective societies.

Raise awareness and challenge social norms

Awareness campaigns and community dialogues conducted by organizations and governmental bodies can challenge deeply ingrained social norms that reinforce gender inequalities in agroforestry. In addition, engaging with communities can help change perceptions about women's expertise in and contributions to agriculture and agroforestry.

Acting on these recommendations will help mainstream gender in agroforestry by addressing the root causes of gender disparities and promoting inclusivity. They will challenge traditional gender roles, empower women, and create an environment where both women and men have equal opportunities to engage in decision-making processes, benefit from agroforestry resources, and contribute to sustainable rural development.

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Author affiliations

Gamma Galudra, Regional Community Forestry Training Center for Asia and the Pacific (RECOFTC), Bogor, West Java, Indonesia (gamma.galudra@recoftc.org)

Nerea Rubio Echazarra, Graduate of Environmental Biology from Utrecht University (UU), Utrecht, the Netherlands (nrubioechazarra@gmail.com)

Reny Juita, Regional Community Forestry Training Center for Asia and the Pacific (RECOFTC), Bogor, Indonesia (reny.juita@recoftc.org)

Chandra Shekhar Silori, Regional Community Forestry Training Center for Asia and the Pacific (RECOFTC), Bangkok, Thailand (chandra.silori@recoftc.org)

1.3

Agroforest in Krui, Sumatra, Indonesia. Photo: E. Torquebiau

The agroforestry-biodiversity-climate change nexus

Emmanuel Torquebiau

"Agroforestry is a nature-based solution — by combining perennial plants (trees and shrubs) and annual, herbaceous plants (crops) and sometimes animals, it basically mimics nature."

"Biodiversity loss and climate change are inseparable threats to humanity that must be addressed together. They are also deeply interconnected in ways that pose complex challenges to effective policy-making and action." These are the words of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES 2020, para.1).

In a coordinated work between IPBES and the Intergovernmental Panel on Climate Change (IPCC), the two world-recognized organizations declared that "the functional separation between climate change and biodiversity creates a risk of incompletely identifying, understanding and dealing with the connections between the two, and, in the worst case, may lead to taking actions that inadvertently prevent the solution of one or the other, or both issues" (Pörtner et al. 2021: 4).

Due to climate change and biodiversity loss, land becomes less suitable for agriculture. This has severe consequences for food security. When land becomes degraded and there is an increasing demand for food, pressure on land increases, further exacerbating the risk of forest and land degradation.

This state of affairs brings us to a point where it seems to make sense — in fact, it is urgent — to look for initiatives that can simultaneously address the problems of the changing climate and decreasing biodiversity. As far as the climate is concerned, these initiatives must address both adaptation (i.e., adjusting to today's or tomorrow's climate and its consequences) and mitigation (i.e., decreasing sources or increasing sinks of greenhouse gases, or GHGs). In terms of biodiversity, solutions must take into account that plant and animal wildlife (including insects and microorganisms) is disappearing at unprecedented rates, and that agro-biodiversity (i.e., the part of biodiversity that includes useful plants and animals and their wild relatives) has been strongly affected by human activities and represents today only a minute portion of what it used to be at the origin of agriculture, around ten thousand years ago.

The land-use sector (agriculture, forestry and other land uses) has intimate connections with climate change and biodiversity. The sector is victim, cause and solution. Victim, because worsening climatic conditions (e.g., heat, drought, extreme events, etc.) strongly influence the primary productivity of both plants and animals, which must consequently adapt, be they wild or domesticated. Cause, because the sector emits 23% of total net anthropogenic emissions (Shukla et al. 2019). Agriculture is among the top emitters (artificial fertilizers, carbon release through ploughing, emissions by ruminants, etc.), together with land-use changes due to deforestation. Solution, because the sector can mitigate climate change through increasing CO_2 capture via photosynthesis, supporting carbon content in soil and biomass, and by reducing emissions through ecologically sound practices.

Regarding biodiversity, the land-use sector is also at the heart of the debate. The variety of land uses on the planet harbour innumerable species and — perhaps more importantly — provide an array of ecological niches and landscapes where those species can thrive, reproduce and disseminate. Both natural and human-made landscapes have made Earth what it is: a planet where environmental conditions are compatible with human life. The biodiversity loss in recent decades is unprecedented in human history and represents a diminishing not only of today's environmental wealth but also of the world's evolutionary history and its potential to further evolve (DeClerck and Martínez-Salinas 2011). In other words, biodiversity is both a resource and a dynamic process that allows ecosystems to function.

And the number one human activity that explains biodiversity loss is agriculture, for four main reasons: the conversion of natural ecosystems into farms and ranches; the intensification of management in long-established cultural landscapes; the release of pollutants, including GHGs; and the associated impacts from value chains, including those from energy, transportation and food waste (Dudley and Alexander 2017).

Agroforestry is one of the most promising initiatives that can simultaneously address both climate change and biodiversity. The main reason for this is the fact that agroforestry is a land-use system that is based on so-called nature-based solutions — "a concept of vital and urgent significance" — one that "means more than you might think," according to an editorial in *Nature* in 2017 (Nature 2017). Why is agroforestry a nature-based solution? Because by combining perennial plants (trees and shrubs) and annual, herbaceous plants (crops) and sometimes animals, it basically mimics nature.

Take tropical agroforests: these dense, mixed, multi-layer agroforestry associations, with a diversity of planted trees and crops, are often found around households and villages and sometimes cover entire landscapes; for instance, in Sri Lanka and Indonesia. At first glance, they resemble natural forests, with which they are sometimes confused (see photo, previous page). Although agroforests are dense, the large number of associated species means that each plant appears in small numbers. Spontaneous bio-diversity co-exists with planted species, and multiple ecological interactions characterize these agroforests, which require no intensive agricultural management. Fruit, wood, fodder, vegetables, honey, eggs, etc. are harvested all year round. In the face of climate change, these human-made forests behave like natural forests, adapting to seasonal hazards while capturing carbon.

Take shade-tolerant crops cultivated under tree cover, such as coffee (see photo , facing page), cocoa, yerba mate and rustic pineapple varieties. Here, trees provide the climate buffering role that they originally played in the natural environment where the wild relatives of those crops were initially found. There's not much difference, actually, between the dense forests of Ethiopia were wild coffee was first

Coffee growing under shade trees, Usa, Tanzania. Photo: E. Torquebiau

domesticated and the tree-shaded plantations of Bolivia or Brazil; between the wild cocoa bushes of the Amazonian rainforest undergrowth and today's shaded cocoa fields in DRC or Ghana; between the araucaria forests of South America and raising cattle or growing yerba maté under those same trees; between the wild pineapple of the Amazon and the varieties grown nowadays under Mexican trees.

Take scattered trees in parkland (see photo, next page), a ubiquitous farming practice in semi-arid and subhumid Africa. Here, the model is the African savanna, carefully mimicked by millions of African farmers who practise farmer managed natural regeneration (FMNR). Among sorghum, cowpea or millet crops, farmers protect hundreds of naturally growing tree species and tend them for their multiple benefits. This amazing agrobiodiversity performance includes plenty of tree-delivered services such as soil improvement, wind erosion control, temperature buffering, and shelter for people and animals. It also encompasses multiple tree products such as food, fodder, wood, fibre, medicinal substances, gums, oils and handicraft material.

Take homestead agroforestry as it exists in Bangladesh (see photo, page 26), Ethiopia and India, among other places. Around dwellings, a variety of useful trees provide shelter for people and a supportive climatic environment for poultry, fish ponds and small ruminants. An array of understorey shrubs and nutritious herbaceous crops complement the starchy diet obtained from rice or other cereals. The high agrobiodiversity of these areas is a source of commodities that can be harvested throughout the year. Homestead agroforestry plots have also a key social role, as they are a place for community life and interactions at the village level.

The list can go on. When compared to the monocultures of industrial agriculture and forestry, most agroforestry systems have higher biodiversity or better responses to the climate change challenge, if not both. Several recent scientific papers confirm this. In 2019, Udawatta et al. published a worldwide review analyzing 110 articles covering the period 1991–2019. Their results show that that floral, faunal and soil microbial diversity are significantly greater in agroforestry as compared to monocropping on adjacent croplands. Other studies have shown the contribution of agroforestry to biodiversity at the landscape scale (Schroth et al. 2004). In heterogeneous landscape mosaics, agroforestry trees influence ecological processes such as the movements of animals, the dispersal of plants, the microclimate and the fluxes of water or soil nutrients, as well as the dynamics of both pests and useful auxiliary species.

Agroforestry parkland in Senegal. Photo: L. Leroux

As far as climate change is concerned, several articles confirm the positive role than agroforestry can play. Tropical agroforestry is an important sink for atmospheric carbon, particularly due to the presence of tree biomass, but also from reduced soil erosion, improved soil structure and increased soil organic matter (Gupta et al. 2017). Agroforestry therefore has much potential to become an important climate change mitigation strategy that can underpin various national and international policies. In a study in Africa, where 15% of farms had a tree cover of more than 30%, Mbow et al. (2014) show that agroforestry can simultaneously achieve both mitigation and adaptation goals. A meta-analysis of soil carbon sequestration in agroforestry (De Stefano and Jacobson 2018) indicates that soil carbon is higher in agroforestry fields when compared to agriculture or pastures (but not when compared to forestry). A recent perspective article in the journal *Nature Climate Change* (Terasaki Hart et al. 2023) describes agroforestry as the largest agricultural natural climate solution opportunity, comparable to other prominent natural climate solutions such as reforestation and reduced deforestation.

It is thus not surprising to find that prominent international organizations have included agroforestry as an option worth considering to address the challenges faced by today's industrial agriculture. In its 2019 *Summary for Policymakers*, a Special Report on Climate Change and Land, the IPCC states: "Solutions that help adapt to and mitigate climate change [...] include inter alia: water harvesting and micro-irrigation, restoring degraded lands using drought-resilient ecologically appropriate plants; agroforestry and other agroecological and ecosystem-based adaptation practices (high confidence)" (Shukla et al. 2019: 22). In the section on sustainable land management, the same IPCC report states: "The following options also have mitigation co-benefits. Farming systems such as agroforestry, perennial pasture phases and use of perennial grains, can substantially reduce erosion and nutrient leaching while building soil carbon (high confidence)" (Shukla et al. 2019: 23). The recently published *Global Sustainable Development Report 2023* (UN DESA 2023), which takes stock of progress achieved so far towards the 2030 Sustainable Development Goals, has identified a series of key shifts to accelerate progress under entry points such as economy, food and energy. Agroforestry is noted twice as a recommended intervention, under food systems and nutrition patterns, and under global environmental commons.

Project Drawdown, a well-regarded nonprofit think tank that "advances effective, science-based climate solutions and strategies," cites several agroforestry options among quantitatively significant solutions to climate change: multistrata agroforestry (layered trees and crops), silvopasture (the integration of trees, pasture and forage into a single system) and tree intercropping (combining trees and crops); see Project Drawdown 2023. All three options are described as having "co-benefits" — i.e., they can both mitigate climate change through carbon sequestration and contribute to improved biodiversity and resilience.

Interestingly, similar conclusions are reached by the authors of the IPBES-IPCC report (Pörtner et al. 2021), who warn the world about the risks caused by the connections between biodiversity loss and climate change. They write in the sustainable agricultural and forestry practices section: "Measures such as the diversification of planted crop and forest species, agroforestry and agroecology enhance biodiversity and nature's contributions to people in landscapes focused on the production of food, feed, fibre, or energy. These measures can also reduce climate-induced losses of food or timber production by increasing adaptive capacity" (Pörtner et al. 2021: 17).

A synergy in response to biodiversity and climate change thus seems to be a recognized strength of agroforestry. Several recent studies nevertheless point to the fact that knowledge gaps and structural or functional shortcomings remain. For example, Quandt et al. (2023) note that helping farmers reduce climate risk and understand the adaptation benefits of agroforestry to specific climate hazards suffers from a lack of integrated biophysical-socioeconomic research spanning different geographic areas. Several studies (e.g., Cardinael et al. 2018) highlight the fact that the potential of agroforestry in mitigating climate change depends on the land-use type it replaces. For example, the carbon balance is mostly negative when converting from forests to agroforestry, but is positive when converting croplands to agroforestry. Some systems are more effective for above-ground carbon sequestration (e.g., improved fallows), while others perform better for soil carbon sequestration (e.g., agroforestry with animals).

And in order to realize the full potential of agroforestry for climate change mitigation, other GHGs, such as methane and nitrous oxide, should also be considered (Feliciano et al. 2018). A meta-analysis addressing patterns of shade plant diversity in agroforestry across Central America (Esquivel et al. 2023) reveals that this diversity is highly skewed towards secondary forest species and tree species that are useful for farmers, and that its conservation value is much lower than that of natural forests.

Last but not least, although agroforestry exists in many forms, it is often absent from policy documents and not recognized in the relevant national statistics, documents and plans (Mulyoutami et al. 2023; Buttoud et al. 2013).

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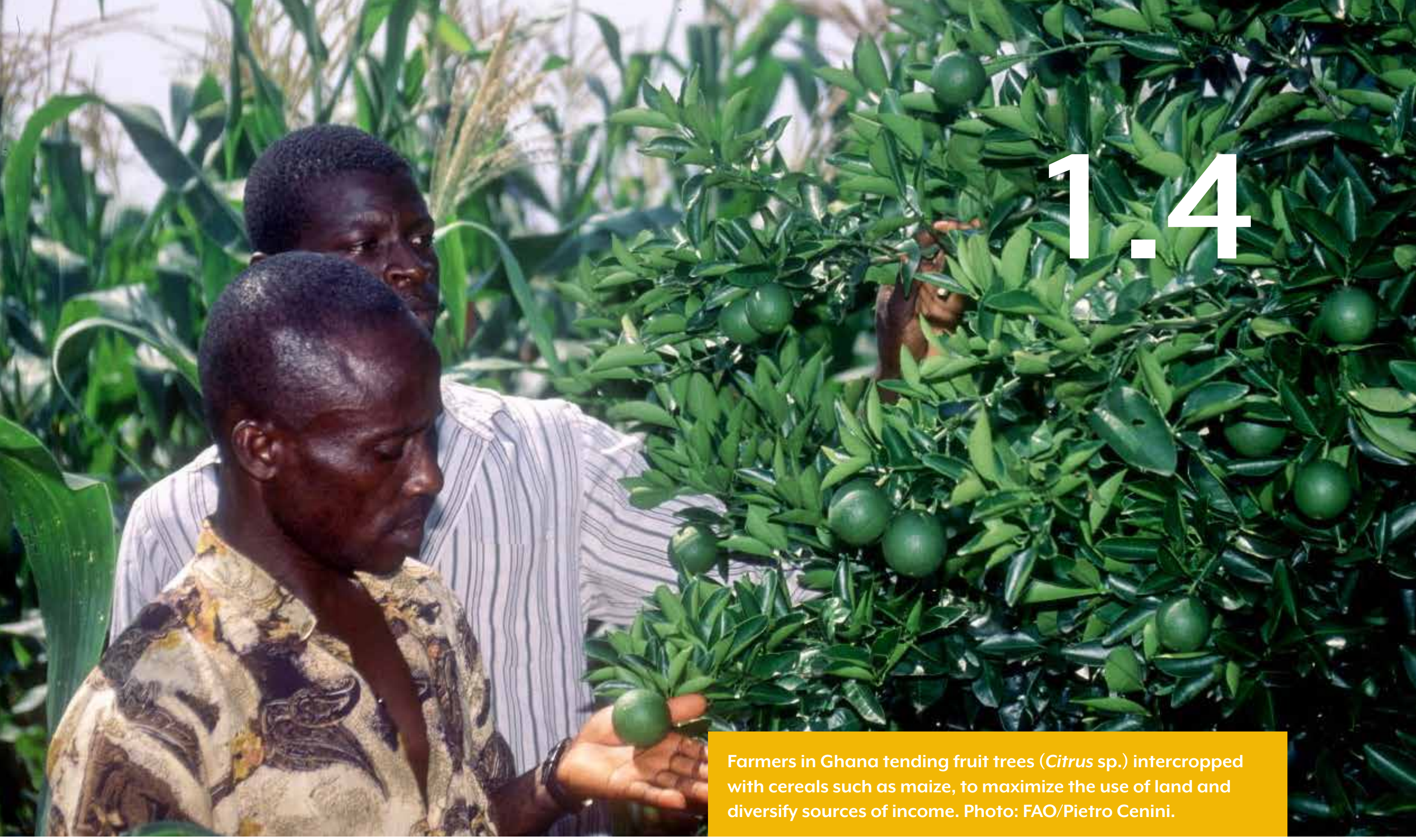
Author affiliation

Emmanuel Torquebiau, Scientist emeritus, French Agricultural Research Centre for International Development/CIRAD (etorquebiau@outlook.com)



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Farmers in Ghana tending fruit trees (*Citrus* sp.) intercropped with cereals such as maize, to maximize the use of land and diversify sources of income. Photo: FAO/Pietro Cenini.

Breaking barriers to agroforestry: FAO's global capacity needs assessment

Elaine Springgay and Priya Pajel

"Fortunately, the agroforestry community is getting bigger with time […] Yet, the major challenge is implementing, developing and managing agroforestry in a way that aligns with the interests of stakeholders, mainly smallholder farmers."

Introduction

The Food and Agriculture Organization of the United Nations (FAO) implemented a Global Agroforestry Capacity Needs Assessment (CNA) over the course of July and August 2022, which received extensive responses from a variety of agroforestry stakeholders. The findings reflected known barriers to agroforestry adoption and scaling up and provided nuanced insights into priority areas of work to address these barriers.

In recent years, agroforestry has gained renewed attention within global policy processes. It is often promoted as a strategy for conserving and restoring the environment; contributing to climate change adaptation and mitigation; and improving livelihood resilience and food security for smallholder farmers. The ecological and biophysical aspects of agroforestry are well documented, and its potential benefits have been repeatedly demonstrated. This is the case not only in the last 50 years — since the term

Women workers weed and clean around cocoa trees, Brazil. Photo credit: FAO/K. Boldt

first made its appearance in research and development efforts — but over the hundreds of years that smallholders have successfully been practising various forms of traditional agroforestry around the world.

Despite the longstanding experience with agroforestry and recognition of its benefits, it has struggled to become a widespread practice and still faces challenges in transitioning and scaling up from scientific understanding to widespread implementation. Popular enthusiasm alone is not enough to ensure sustainable agroforestry practices; broad support, at both the policy and technical level, is required. This calls for greater efforts across the globe on improving enabling environments, developing contextually adapted solutions, and strategically strengthening the capacities of all those involved in agroforestry on the ground.

To contribute to these efforts, FAO's Global Agroforestry Capacity Needs Assessment aimed to establish a baseline of existing agroforestry capacities throughout the world and to identify gaps where capacity support may be most beneficial. The global survey was carried out during the summer of 2022 and was completed by 1,572 people working on agroforestry in 145 countries, including governmental officials, researchers, practitioners, donors, community groups and farmers.

The survey assessed individual capacities and access to capacity development in agroforestry research, design and implementation; it also explored reasons for working on agroforestry and opinions on priority areas for future global efforts. What emerged was a broad picture of ongoing and emerging trends in agroforestry; in particular, three major action areas where further capacities could be developed:

1. transforming agroforestry into an economically viable production system;
2. strengthening enabling environments through agroforestry policies and strategies; and
3. improving agroforestry extension for more biodiverse and agroecological systems.

Global agroforestry capacities: strengths, gaps and opportunities

Barriers to agroforestry adoption and scaling up have been widely discussed in the literature. Many of the barriers relate to the lack of enabling environments for agroforestry, including secure land tenure, supportive policies, and access to markets and value chains (Buttoud et al. 2013). A lack of incentives for farmers is also recognized as a key issue, due to a delay in returns on investment from tree products versus annual crops. The historical division between agriculture and forestry and the lack of coordination between sectors has also adversely affected policy, land-use planning and extension services for agroforestry. Additionally, agroforestry research has predominately focused on biophysical studies at the farm level, paying limited attention to socioeconomic information (Karlsson 2018). Many of these barriers and gaps in knowledge were reaffirmed by the CNA.

The CNA was designed as a capacity self-assessment, and six main stakeholder groups involved in agroforestry responded: 1) governmental entities; 2) national and international non-governmental organizations (NGOs); 3) land users and community groups; 4) research and academia; 5) private-sector entities; and 6) investors and donors. Most respondents belonged to NGOs, followed by researchers/academia and government.

Survey respondents generally asserted a high level of agroforestry expertise, particularly in agroforestry planning and implementation, along with a strong dedication to and belief in the importance of agroforestry as a sustainable land management system. This was especially true for those in the NGO, government and land-user stakeholder groups. Their environmental capacities, as well as community engagement and inclusion, and training and extension services, were strongest. Further analysis revealed that respondents had more confidence in tree and forest management than in crop management and agriculture.

The main capacity gaps were related to socioeconomic aspects and strengthening enabling environments, namely business planning, policy analysis and implementation, and improving land tenure and resource use rights. Economic capacities, such as creating a market-based strategy, developing a value chain, and mobilizing finance, consistently ranked as weakest across most survey respondents.

The survey revealed stronger capacities within certain stakeholder groups. **Governmental stakeholders** featured community engagement, inclusion and capacity support as key strengths, along with providing technical assistance and extension services. The principal capacity gaps related to the enabling environment and the farm-level support needed to ensure the economic viability of agroforestry, including facilitating access to markets, mobilizing finance and developing business plans. They also identified strengthening formal and traditional rules and regulations governing land ownership, resource tenure and use rights for local communities as capacity gaps. Since governmental stakeholders are theoretically the main actors who can contribute to addressing structural barriers related to access to markets and tenure, this gap is significant and may explain why the enabling environment continues to be a major barrier to wider agroforestry adoption. It is important to note, however, that the respondents in this group may be technicians rather than policymakers, which could also explain the gap.

The **NGO respondents** claimed similar strengths to the governmental stakeholder group. The strongest capacities related to community engagement and inclusion, knowledge sharing, and capacity development. For instance, the group had expertise related to engaging youth, women, Indigenous peoples, and other marginalized groups in agroforestry-related decision-making processes and ensuring gender sensitivity. Meanwhile, strengthening enabling environments and ensuring the economic feasibility of agroforestry were this group's weakest capacities, including measures such as facilitating access to markets and value chains, strengthening tenure and use rights, developing market-based strategies and engaging with the private sector.

The **land user group**, which included smallholder farmers, pastoralists, community leaders and other local-level interest groups, demonstrated high capacity levels across the range of activities related to the successful planning and implementation of agroforestry, especially in terms of sustainably managing agroforestry systems and collaborating with their community. As with the other stakeholder groups, the main areas with capacity gaps were economic: developing a market-based strategy, assessing the costs and benefits of agroforestry interventions, and mobilizing finance.

Research and academia were well-represented in the survey results and their expertise lay mostly in identifying benefits, barriers and linkages related to agroforestry and environmental services, and in communicating this knowledge through various means. Self-identified gaps were generally linked to cost-benefit analyses, modeling and policy analysis. Interestingly, despite being confident in engaging with decision-makers, they identified the assessment of how policies influence implementation and agroforestry intervention outcomes as a weaker capacity.

The remaining stakeholder groups (the private sector, investors/donors, research and academia) showcased a range of capacities given the varied nature of their involvement with agroforestry. Perhaps unsurprisingly, the **private-sector group** had economic expertise in many of the areas that represented capacity gaps in the other groups; including, for instance, the development of profitable business models, facilitating access to funding, and value chain development. Selecting investments was a strength for this group, while developing risk mitigation

Local farmers, also known as *Sempre-vivas* flower gatherers, have developed an effective agricultural system that combines flower gathering, agroforestry gardening, livestock grazing and crop cultivation, Southern Espinhaço Mountain Range, Minas Gerais State, Brazil. Photo: FAO/Joao Roberto Ripper

measures and securing long-term funding commitments were areas with capacity gaps.

Investors and donors were not only the stakeholder group with the lowest response rate, but also self-assessed a low level of agroforestry-related capacities, identifying more gaps than strengths. Their strengths were linked to selecting agroforestry investments and facilitating access to funding. The main gaps included developing risk mitigation measures, establishing long-term innovative financing solutions, and value chain development.

The results of the CNA clearly reaffirmed how socioeconomic considerations are lacking in both agroforestry knowledge and practice. This includes gaps in farm-level support (including business planning and system design), enabling environments related to supply and to value chain development, access to markets, and design of incentives. Policy design and implementation were also repeatedly flagged as areas that need additional support. Although respondents had much expertise in community engagement and capacity development, they nonetheless called for further capacity support in developing agroforestry systems that maximize their potential to sustainably produce food. Based on these identified gaps and experiences shared by respondents, the three action areas — economically viable agroforestry, agroforestry policies/strategies and agroforestry extension — represent priorities that all those in the global agroforestry community can contribute to by leveraging their comparative advantages.

Action area 1. Transforming agroforestry into an economically viable production system

At the core of success is making agroforestry economically attractive to and feasible for farmers. Many agroforestry interventions are not successful in the long-term, or are not even adopted in the first place, because of insufficient recognition that they are production systems that need to ensure livelihoods and generate a sustainable cash flow (Gosling et al. 2020). Agroforestry should be promoted not only to address environmental, social or governance issues, but also in terms of business development and financial considerations. Therefore, addressing the capacity gaps that can transform agroforestry into an economically viable production system is crucial.

This involves improving the collection of economic data and supporting holistic cost-benefit analyses to address some of the information gaps related to the economics of agroforestry. Developing business models, case studies and guidance to showcase and increase the financial viability of agroforestry is also crucial. As one survey respondent working at a research institute in Uganda put it: "Agroforestry will remain a theoretical practice unless we strive to exhibit more and more successful case studies." Another goal is to enhance the capacities of practitioners to develop market-based strategies and investment proposals to finance their agroforestry businesses. At the market level, there is a need to improve access to financing, and to further develop sustainable value chains and markets for agroforestry products.

Risk perception and risk management are two of the main barriers to agroforestry uptake. Farmers, especially smallholders, perceive the longer-term investment of growing trees as riskier than agriculture with annual crops, or even unfeasible (Jerneck and Olsson 2014). Financial incentives — when well-designed, with short-, medium- and long-term outlooks — can play an important role in addressing this challenge. For instance, the popular topic of payments for ecosystem services, including carbon finance, is increasingly being discussed in the context of agroforestry. However, these incentive mechanisms should be implemented only as a supplementary source of income for farmers, especially in the start-up phase; the agroforestry system needs to be economically viable and sustainable without these additional payments.

Action area 2. Strengthening enabling environments through agroforestry policies and strategies

In order to successfully scale up agroforestry, holistic agroforestry policies and strategies to strengthen enabling environments are needed. Although many countries mention agroforestry in their sustainability and climate strategies, and advocacy for agroforestry is on the rise, only two countries — India and Nepal — have national policies for agroforestry in place, and more such policies are needed. Meanwhile, the CNA revealed that the lack of an enabling environment was a major gap for all stakeholders, including those working in governance-related institutions. As one survey respondent working as a researcher in Germany mentioned: "The major bottlenecks [in agroforestry support] really seem to be about policy and scaling up."

Addressing this policy gap has historically proven complex given agroforestry's position at the intersection of multiple sectors, including agriculture, forestry, environment and rural development; this has often resulted in agroforestry falling into jurisdictional cracks (FAO 2013). Therefore, improving cross-sectoral collaboration across government agencies and leveraging various types of expertise will be necessary to develop effective agroforestry policies. This is no easy task, but inter-regional knowledge exchange can help countries learn from the experiences of others in developing and implementing these kinds of policies. Design of effective incentives also needs to be addressed at the policy level. This can include adapting agricultural and tree growing subsidies to agroforestry systems and developing innovative ways to incentivize uptake through improved tenure and use rights.

Action area 3. Improving agroforestry extension for more biodiverse and agroecological systems

In order to maximize the regenerative and sustainable potential of agroforestry, perspectives need to shift towards a more holistic understanding of agroforestry as a food production system, and to emphasize its nutritional and agricultural benefits. Agroforestry systems should be designed and promoted in a way that is contextually appropriate, and that ideally strives to be as agroecologically diverse and biodiverse as possible. The need to mainstream biodiversity in agroforestry design and implementation was repeatedly mentioned by survey respondents, as expressed succinctly by an NGO officer working in Cameroon: "Agroforestry landscapes need to incorporate biodiversity conservation strategies." When effectively implemented, agroforestry can also contribute to halting deforestation and improving tree cover loss, particularly in critical areas where there may be competing land uses by agriculture and forestry (dos Reis et al. 2023).

Attaining these larger objectives requires recognizing agroforestry as a complex system where synergies need to be supported and competition minimized through active management. Although the CNA results showed a high level of individual expertise in capacity development and extension services, respondents expressed a need for further technical and capacity support. Knowledge and management of both crops and trees are two of the main factors that make agroforestry more difficult to practise than other forms of agriculture. This context can become even more complex when designing for improved biodiversity outcomes and applying agroecological practices. Therefore, improved data and ecological specifications on common agroforestry tree and crop species and interactions, and greater efforts in sharing relevant information through more effective means, is needed.

Two young men selling charcoal along the roadside, Cambodia. Photo: FAO/J. Koelen

Overall, overlapping expectations of environmental benefits and economic gains make agroforestry extension and capacity development especially important. Although the global agroforestry community is well equipped in this domain, capacity support is still needed to adapt to the shift towards more biodiverse and agroecological systems. A crucial element that also bears re-emphasizing is that farmers' knowledge, needs and aspirations should be at the core, not only of agroforestry design and implementation, but also of capacity development. This involves continuously ensuring that local and Indigenous knowledge is strengthened and is integrated into all levels of agroforestry interventions, increasing peer-to-peer learning opportunities, and facilitating collective organization. Moreover, addressing barriers to adoption can entail improving research on the sociocultural and behavioural considerations that influence agroforestry uptake, including gender issues and social inequality, social perceptions and cultural norms (Meijer et al. 2014). Eventually, a systematic approach to quantifying and understanding social, economic and environmental cost-benefit trade-offs for and with farmers will be an important step forward.

Conclusion and recommendations

Overall, the capacity needs assessment showcased a widespread, diverse and motivated global agroforestry community. Many respondents acknowledged that agroforestry is — rightly — being promoted and linked to global sustainability goals, but that the challenge remains in connecting global priorities with the realities of those working on the ground. The issue of farmers needing to receive their just benefit was present throughout the survey results; the lack of tangible benefits and of successful, relevant and contextual examples remain some of the main reasons for non-adoption.

Creating accessible agroforestry models and systems that achieve the balance of being profitable for farmers, agroecological and biodiverse is a central challenge. The three action areas — improving economic capacities, establishing effective incentives and policies, and strengthening extension — are critical parts of the solution. This information is not new; the results of the CNA confirmed well-known barriers to the widespread adoption of agroforestry. These barriers have persisted for decades. In order to see successful, scaled-up agroforestry there is a need to effectively address these gaps and build stakeholder capacities.

Each of the various stakeholders involved in agroforestry can contribute in working towards the goals of these action areas. The research community and practitioners can contribute to improving data on the socioeconomics of agroforestry, including economic feasibility, sociocultural factors that influence adoption, and case studies and examples of systems that have worked and those that have not. Policymakers can work with the private sector to improve enabling environments, through efforts to develop sustainable value chains and markets for agroforestry products.

A cross-cutting solution is to strengthen peer-to-peer knowledge exchanges at local, regional and global levels, and showcase successful agroforestry models and strategies. This can entail strengthening inter-regional connections and collaborations to share experiences between areas with similar ecological and socioeconomic conditions, establishing global and local communities of practice and peer-to-peer knowledge-sharing opportunities, and creating innovation centres and demonstration farms of successful agroforestry models. National NGOs can further contribute to highlighting and integrating local and Indigenous agroforestry knowledge.

In the transition to more sustainable agroforestry, it is imperative to leverage collective strengths to close gaps in agroforestry capacity. The successful scaling up of agroforestry — to contribute to a range of local, national and international goals — depends on different stakeholders with different expertise collaborating on farmer-centred agroforestry. FAO can support countries in developing holistic agroforestry policies and strategies, and can provide guidance and facilitate the implementation of good practices on the ground.

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Author affiliations

Elaine Springgay, Forestry Officer (Agroforestry), Food and Agriculture Organization of the United Nations (FAO), Rome, Italy (elaine.springgay@fao.org)

Priya Pajel, Agroforestry Specialist, Food and Agriculture Organization of the United Nations (FAO), Rome, Italy (priya.pajel@fao.org)

Section 2

The Americas

Previous page: Peasant women return home from the farm. Vereda Cabañitas, Solano, Caquetá, Colombia. Photo: Magali Guzmán

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Pineapple agoforest in El Cerro, Villa de Purificación, Jalisco.
Photo: Jesús Juan Rosales-Adame

2.1

Pineapple cultivation under tree canopies of ancestral agroforests in Mexico

Jesús Juan Rosales-Adame and Judith Cevallos-Espinosa

"The Indian pineapple or matzatli (Nahuatl word from Mesoamerica), is a plant which grows in warm regions and hilly places in these territories of the New World."

Translated from *La Historia Natural de la Nueva España*, 1571

Introduction

Pineapple (*Ananas comosus* var. *comosus* [L.] Merr.) is widely known. Due to its shape and popularity, it is considered the king of tropical fruits, and its production and consumption place it at the top of the world's acceptance rankings (Botella and Smith 2008). Despite this, the average consumer knows very little about its origin and production methods. The species is native to South America, particularly the Amazonian rainforests. There it was domesticated, diversified and disseminated millennia ago by local populations, as they did with other plant species, animals and ecosystems (Coppens d'Eeckenbrugge et al. 2011; Levis et al. 2018). In various regions of the continent, including Mesoamerica, the management of landscapes by local cultures generated primary agroecosystems that were probably

Weed and bush clearing with a *casanga*. Photo: Jesús Juan Rosales-Adame

indistinguishable from native forests or jungles (González-Jácome 2016). However, over time they developed productive management systems, some of which have recently become known as agroforests.

Agroforests, also known as modified forests or forest agroecosystems, are systems where human beings have managed the composition of the plants (native and introduced) according to their needs, but preserved the structural characteristics and ecological processes and functions that exist in ecosystems considered natural (Moreno Calles et al. 2016). In Mexico, these agroforestry systems include cocoa plantations, coffee plantations, multi-strata home gardens, *te'lom* (a Huastec agroforestry system, where the forest is managed and agriculture is included), silvopastoral systems and pineapple agroforests (Rosales-Adame and Cevallos-Espinosa et al. 2019; Fisher-Ortiz et al. 2020).

Pineapple agroforests are a form of land use where woody species (trees and shrubs) of the subdeciduous tropical forest (STF) have been associated with a *criollo* or *castilla* (*roja Española* complex) variety of pineapple since ancestral times (at least three centuries, but possibly millennia). This was long before the introduction of the improved varieties in the early 20th century that now dominate the national pineapple market (Rosales-Adame et al. 2016).

Pineapple is cultivated in Mexico under two production models. The conventional model is characterized by intensive monoculture, use of improved varieties, pest and disease control and chemical fertilization. This model relies on the elimination of biodiversity and has important negative implications from an environmental and human health point of view. The other production model is an agroforestry or "ecological" approach (Rosales-Adame et al. 2016). It is characterized by maintaining and respecting the natural forest cover of the region and including a significant investment in terms of ecological energy (higher light use efficiency due to several layers of foliage) and biological cultivation (manual labour with small tools rather than use of phytochemicals, and incorporation of litter from tree canopies). The pineapple variety grown in agroforestry is quite shade tolerant. It grows on sites with tree cover similar to or greater than that found in shaded coffee and cocoa systems; its canopy cover ranges from 75% to 88% of natural forest cover.

Shaping the pineapple agroforest

The Indigenous and mestizos inhabitants of the Pacific slope of Mexico, particularly in the west-central region in the states of Jalisco and Nayarit, have managed, conserved and treasured this agroecosystem for years. Agroforestry has also been practised in the state of Guerrero, where it is known as mountain pineapple.

This agroecosystem is almost unknown at the national and international level, despite its benefits in terms of sustainability, resilience and conservation of agrobiodiversity, and its role in the preservation of native

Photo 2. A pineapple agroforest in Jalisco.
Photo: Jesús Juan Rosales-Adame

diversity in marginalized areas of Mexico. Pineapple is deliberately associated with forest components only once, at planting, and is self-perpetuating (with management), which means that costs are low. Management is extensive, with minimal use of inputs and machinery, but with maximal use of traditional knowledge and local technologies, such as curved machetes or *casangas* , and harvesting baskets or *petacas*.

Pineapple agroforests are found in the lowlands of humid tropical regions, from flat land to steep slopes, at altitudes of 60 to 850 masl, and sometimes higher. Although pineapple is the most important crop, the system also yields about 20 other products that strengthen food sovereignty and self-sufficiency for the owners. This includes fruits (avocados, *mamey* (*Pouteria sapota*), bananas); coffee; wood for tools; and fodder. Goods are harvested or collected throughout the year, providing a regular source of food; some of them are traded in local and regional markets when there are surpluses. Pineapple production is seasonal and coincides with the rains (June to September). Timber production is not an objective. However, recently some timber species have been harvested, with negative impacts on the agroforest. A similar situation is observed with the deforestation of areas surrounding agroforests, which generates stress due to the edge effect when the temperature increases and the area dries out. The rural exodus of young people is another increasingly common problem.

In Jalisco, the oldest agroforest has a current area of about 15 ha, while in Nayarit it covers approximately 950 to 1,000 ha. In both states, there are also fragments (relicts) of agroforests in other sites.

Left: Close-up of a pineapple in Villa Purificación, Jalisco; Right: pineapple fruit harvesting baskets in Nayarit, Mexico.
Photos: Jesús Juan Rosales-Adame

About 70 species of woody plants are maintained in these agroecosystems, most of them native and a few domesticated. All the woody species are important, above all, for providing shade. However, the species that measure the highest on the importance value index (IVI) are *parota* or *guanacastle* (*Enterolobium cyclocarpum*) and *cuapinol* or *guapinol* (*Hymenaea courbaril*) which have forage, food (animal and human), timber and nitrogen-fixing values (Table 1). IVI measures how dominant a species is in a certain forest area.

Table 1. Importance value index (IVI) of pineapple agroforests in west-central Mexico

Species	Family	Importance value index (IVI)					
		R	C	V	Z	P	A-C
Astronium graveolens	*Anacardiaceae*	0	0	0	2.86	0	4.62
Mangifera indica [a]	*Anacardiaceae*	2.92	1.98	4.63	2.77	0	2.33
Spondias mombin	*Anacardiaceae*	0	0	0	8.48	1.3	0
Annona reticulata	*Annonaceae*	0	0	1.67	0	0	0
Thevetia ovata	*Apocynaceae*	0	0	2.22	0	0	0
Dendropanax arboreus	*Araliaceae*	0	0	6.68	0	0	0
Acrocomia aculeata	*Arecaceae*	0	0	4.61	0	0	0
Attalea cohune	*Arecaceae*	5.85	0	0	0	0	0
Sabal rosei	*Arecaceae*	0	0	1.26	0	0	2.26
Tabebuia donnell-smithii	*Bignoniaceae*	**59.67**	0	0	0	0	0
Tabebuia palmeri	*Bignoniaceae*	0	0	2.70	0	0	0
Tabebuia rosea	*Bignoniaceae*	3.12	3.16	4.96	1.34	5.63	1.18
Cochlospermum vitifolium	*Bixaceae*	0	1.45	0	0	0	0
Bourreria superba	*Boraginaceae*	0	0	2.91	1.25	0	0
Bursera simaruba	*Burseraceae*	4.68	1.51	14.64	3.91	2.50	0
Calophyllum brasiliense	*Calophyllaceae*	0	0	1.33	3.80	3.12	0
Carica papaya	*Caricacaceae*	1.67	0	0	0	0	0
Couepia polyandra	*Chrysobalanaceae*	0	0	14.38	0	8.18	2.22
Licania retifolia	*Chrysobalanaceae*	0	1.79	8.36	2.22	1.86	3.79
Clethra hartwegii	*Clethraceae*	0	11.17	7.51	6.27	0	0
Sloanea terniflora	*Elaeocarpaceae*	0	0	0	0	2.19	0
Gymnanthes sp.	*Euphorbiaceae*	0	0	1.17	0	0	0
Acacia polyphilla	*Fabaceae*	0	0	2.46	0	0	8.15
Andira inermis	*Fabaceae*	1.45	0	0	0	0	0
Ateleia pterocarpa	*Fabaceae*	8.85	0	3.87	0	0	0
Bauhinia ungulata	*Fabaceae*	0	1.38	0	2.39	0	0
Enterolobium cyclocarpum	*Fabaceae*	**107.45**	0	0	0	0	0
Gliricidia sepium	*Fabaceae*	0	0	3.44	0	0	4.10
Hymenaea courbaril	*Fabaceae*	0	**111.20**	**62.27**	**74.76**	**154.28**	**195.79**
Inga laurina	*Fabaceae*	**24.83**	1.57	0	**31.59**	4.51	0
Inga vera subsp. eriocarpa	*Fabaceae*	0	9.17	1.36	6.93	0	3.28
Lonchocarpus salvadorensis	*Fabaceae*	0	3.83	**15.10**	6.93	**25.40**	**12.68**
Platymiscium trifoliolatum	*Fabaceae*	0	1.37	12.27	6.62	17.41	3.83
Quercus aristata	*Fagaceae*	0	1.28	0	**15.46**	0	0

cont. Table 1.

Species	Family	Importance value index (IVI)					
		R	C	V	Z	P	A-C
Quercus glaucescens	*Fagaceae*	0	9.11	0	2.90	0	0
Carya illinoinensis	*Juglandaceae*	0	0	2.91	0	0	0
Cinnamomum sp.	*Lauraceae*	0	**24.76**	0	3.59	0	**15.17**
Persea americana [a]	*Lauraceae*	3.78	1.74	0	0	8.76	0
Persea hintonii	*Lauraceae*	0	3.37	0	11.82	0	5.47
Byrsonima crassifolia	*Malpighiaceae*	0	1.42	0	2.77	0	0
Heteropterys laurifolia	*Malpighiaceae*	0	0	1.15	0	0	0
Malpighia sp.	*Malpighiaceae*	0	5.93	0	2.65	0	0
Guazuma ulmifolia	*Malvaceae*	1.84	0	5.78	0	0	0
Trichospermum insigne	*Malvaceae*	0	7.20	12.90	0	0	0
Miconia sp.	*Melastomataceae*	0	18.51	3.32	0	0	0
Cedrela odorata	*Meliaceae*	**19.21**	0	1.77	5.45	9.15	0
Guarea glabra	*Meliaceae*	0	0	0	0	0	1.86
Trichilia americana	*Meliaceae*	2.17	0	0	0	0	0
Brosimum alicastrum	*Moraceae*	7.49	0	8.43	2.76	2.40	0
Ficus cotinifolia	*Moraceae*	0	0	16.31	4.90	0	0
Trophis racemosa	*Moraceae*	0	1.66	0	0	0	0
Musa cavendishii [a]	*Musaceae*	0	5.53	0	0	0	0
Eugenia sp.	*Myrtaceae*	0	2.73	**17.30**	11.34	2.40	11.53
Psidium sartorianum	*Myrtaceae*	4.22	0	2.26	**19.99**	0	0
Piper tuberculatum	*Piperaceae*	1.66	0	0	0	0	0
Coccoloba barbadensis.	*Polygonaceae*	0	0	1.28	0	0	0
Myrsine juergensenii	*Primulaceae*	0	1.87	0	5.49	0	0
Coffea arabica [a]	*Rubiaceae*	7.30	13.20	2.17	**25.27**	0	0
Citrus aurantifolia [a]	*Rutaceae*	1.66	0	1.10	0	0	0
Citrus limon [a]	*Rutaceae*	1.72	0	0	0	2.12	0
Citrus sinensis [a]	*Rutaceae*	3.45	0	0	0	0	0
Casearia arguta	*Salicaceae*	0	0	5.63	0	0	3.23
Xylosma flexuosum	*Salicaceae*	0	0	1.28	0	0	0.00
Xylosma sp.	*Salicaceae*	0	0	1.11	0	0	0
Cupania dentata	*Sapindaceae*	0	3.34	**28.13**	**14.90**	**31.77**	5.76
Pouteria sapota	*Sapotaceae*	**14.62**	0	0	0	0	0
Sideroxylon sp.	*Sapotaceae*	0	1.43	0	0	0	0
Cecropia obtusifolia	*Urticaceae*	1.66	11.32	3.29	1.23	0	0
Citharexylum sp.	*Verbenaceae*	0	0	0	0	0	3.86

R = La Rinconada (Jalisco); C = Cordón del Jilguero; V = El Venado; Z = El Zopilote; P = Puerta de Platanares; A-C = Acatán de las Piñas-El Cantón (Nayarit). See Rosales-Adame et al. (2014).

[a] Domesticated species incorporated into the agroforest to provide fruit.

Bold numbers indicate higher IVI values. IVI is calculated as relative frequency plus relative density plus relative dominance.

Tree density ranges from 130 to 850 individuals per ha depending on locality (Table 2). The subdeciduous tropical forest (STF) is the main forest type providing shade, but pineapple agroforests are also found in low-elevation deciduous *Quercus* forests and in vegetation assemblages with coffee. The richness (number of different species) and diversity (Shannon's diversity index) of woody species are similar to and in some cases higher than those recorded in shaded coffee systems in Central America (Costa Rica and Nicaragua), and in native lowland rainforests and montane cloud forests of the region.

Table 2. Richness, diversity and structure of woody vegetation in pineapple agroforests

Locality	Plot	Veg	D ind. ha^{-1}	BA m^2 ha^{-1}	AH (m)	S	H´
La Rinconada	El Cerro	STF–Coffee	260	73.2	18	6	1.28
	El Grande	STF–Coffee	310	72.0	11	9	1.84
	El Mamey	STF–Coffee	370	48.6	11	9	1.82
	El Morado	STF–Coffee	350	61.2	13	10	1.85
	Las Guámaras	STF–Coffee	190	35.0	16	5	1.02
Cordón del Jilguero	Campo de Fútbol	STF	200	21.9	13	3	0.39
	C. Salas	STF–Coffee	720	16.1	8	10	1.31
	F. Alemán	STF-*Quercus*	460	14.6	7	12	2.07
	Rodolfo	STF	200	18.2	11	5	1.40
	Los Chinos	STF–Coffee	640	30.0	7	13	1.92
El Venado	Los Zapotillos II	STF	240	20.1	11	3	0.54
	Los Zapotillos	STF	130	17.7	13	3	0.54
	M. Rosales	STF	470	36.5	10	18	2.42
	C. Cruz	STF–Coffee	800	28.2	9	15	1.94
	El Paranal	STF	850	21.8	7	24	2.72
El Zopilote	El Limón	STF–Coffee	510	21.4	12	13	2.20
	El Panteón	STF–*Quercus*	410	29.3	6	12	2.05
	P. Venado	STF	610	15.0	5	7	1.14
	P. Rosales	STF–Coffee	550	30.3	8	17	2.11
	R. Rosales	STF–Coffee	440	16.0	7	8	1.51
Puerta de Platanares	C. Ayón	STF	280	20.5	11	6	1.59
	E. Alemán	STF	230	22.4	12	5	1.21
	Exiquio	STF	180	21.0	15	3	0.73
	Puerteña	STF	380	29.5	8	8	1.25
	German	STF	250	32.1	10	6	1.67
Acatán de las Piñas-El Cantón	El Abril	STF	330	25.9	13	9	1.31
	Las Correras	STF	410	11.7	9	5	0.61
	P. Galana	STF	390	17.7	9	13	2.22
	Los Llanitos	STF	240	16.3	14	2	0.29
	Joel Rivera	STF	210	18.3	13	4	0.78

Veg = vegetation type; D = density; BA = basal area; AH = average height; S = species richness; H' = Shannon index. See Rosales-Adame et al. (2014). STF = subdeciduous tropical forest.

Agroforest work basically consists of removing weeds, bushes, branches and fallen trunks and preparing for harvesting. The density of adult pineapple plants varies according to the site, ranging from 8,700 to more than 25,300 per ha, while juvenile individuals range from 2,600 to 8,000 per ha. The production volume reaches 6.5 to 7 metric tonnes per ha per year, which is about 10% of what is harvested from improved, full-sun modern varieties. This low yield is compensated for by very low handling costs. Fruits are generally small but of outstanding quality. The plant is twice the height of the improved varieties and has thorns on the leaves and crown of the fruit. Pests and disease are minimal, due to the biodiversity of the system.

Cost to establish pineapple agroforests

Very little is known about the costs of establishing these agroforests. Information provided by producers in 2015 indicated that the maintenance cost was between MXN (Mexican peso) 12,740 and 17,200 per ha, depending on the region, in addition to the time and use of inputs, if required. The plots can be rented for a lump sum, depending on the condition and area. Production costs, updated for the year 2023, are estimated in Table 3.

Table 3. Estimated cost per ha in MXN (Mexican pesos) of establishing pineapple agroforests in Mexico, 2023

Item	Jalisco			Nayarit		
	No.	Cost	Subtotal	No.	Cost	Subtotal
Land preparation (hand labour wages)	15	400	6,000	15	300	4,500
Seed (pineapple plant shoots) including freight	10,000	[a]4.50	45,000	10,000	1.00	10,000
Labour for sowing seedlings	15	400	6,000	15	300	4,500
Labour for fence rehabilitation	4	400	1,600	4	300	1,200
Fuel for work on the plot	15	100	1,500	15	100	1,500
Total			**60,100**			**21,700**

[a] The cost of seed for Jalisco is higher because of the transfer from Nayarit.

Conclusions

Pineapple agroforests were the area's first ecological, sustainable and resilient systems and they have been cultivated to maintain the conservation of native vegetation and agrobiodiversity. The production of this tropical fruit on the Mexican Pacific coast was practised centuries before the establishment of today's prevailing conventional production model.

The considerations presented in this article are useful to decision-makers at the political level to value, defend, conserve and promote the maintenance of this ancestral form of agroforestry.

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Author affiliations

Jesús Juan Rosales-Adame, Departamento de Ecología y Recursos Naturales, Centro Universitario de la Costa Sur, Universidad de Guadalajara (jesus.radame@academicos.udg.mx)

Judith Cevallos-Espinosa, Departamento de Ecología y Recursos Naturales, Centro Universitario de la Costa Sur, Universidad de Guadalajara (jcevallo@cucsur.udg.mx)

Milpa agroforestry system. Photo: José Espinoza-Pérez

The milpa agroecosystem: a case study in Puebla, Mexico

José Espinoza-Pérez, Oscar Pérez-García, Cesar Reyes and Petra Andrade-Hoyos

"The management of multiple crops has allowed the milpa to coexist with native ecosystems and has supported the conservation of natural resources."

Introduction

One of the emblematic agroecosystems practised since ancient times in the biocultural regions of Mexico is the milpa system (Pérez-García and del Castillo 2016, 2017). It is composed of multiple native crops of importance for food security and agriculture. One of its characteristics is the association of maize with leguminous plants (beans), cucurbits (pumpkins), chillies and tomatoes, edible greens (*quelites*) and various perennial woody species.

Crop and/or land rotation is a crucial component in the sustainability of this agroecosystem. The management of multiple crops has allowed the milpa to coexist with native ecosystems and has supported the conservation of natural resources. The milpa is considered a sustainable production system because it supports high productivity through the efficient use of natural resources.

Attempts to modernize traditional agriculture by government agri-food and environmental policies and programmes have threatened the milpa system (Pérez-García and del Castillo 2016, 2017). However, the adoption of modern agricultural practices by farmers and Indigenous peoples has not been widespread. Basically, they have adopted some components of commercial agriculture, such as continuous production on the same land, use of synthetic fertilizers and agrochemicals, and maize monocropping. Despite these changes in the milpa system, local populations continue to use native maize seeds.

Due to the country's diverse and contrasting biocultural regions, the persistence of the milpa system in the face of maize monocropping requires study, particularly in terms of the socio-ecological context. This is necessary in order to identify the socio-environmental factors that support or hinder the permanence of the milpa.

This article discusses the agroforestry milpa and maize fields of the Totonacapan region in the northeastern highlands of Puebla, Mexico. Totonacapan farming families in the highlands cultivate one of two maize production systems: the milpa and the maize field, or *maizal*. The milpa is oriented to the production of food for self-consumption, and the latter is a system recently adopted in the region for commercial purposes. The following questions were posed: Why does the milpa system persist over the maize field in the same cultural and environmental space? What direct and intangible benefits do families obtain from both systems? To answer these questions, work was carried out with 32 farming families (16 milpa farmers and 16 maize field farmers) to document the direct benefits (food and income) and intangible benefits (food security and food sovereignty). In addition, the costs and benefits of the milpa and *maizal* systems were explored.

The role of useful plants in the milpa and in the maize field

The milpa

The milpa is sown once a year (December to June) and 69 useful species are cultivated in it (see photo a, next page). Among the basic food crops are maize, beans, tomatoes and chillies as well as complementary food sources such as *quelites* and fruit trees. Maize and beans are the most important crops in the milpa, given that they provide food security at the family level in the face of rising prices for maize and tortillas, due to the impact of climate change and food shortages caused by Covid-19. Maize is the preferred crop, being the main and most significant product for farming families. The growing of other crops and fruit trees in this system contributes to the family economy by diversifying the diet and occasionally generating monetary income through the sale of surplus products. The use and consumption of *quelites* also contribute to the diversification and provision of food for farming families. From maize, families are self-sufficient for an average of nine months of the year, while other crops sustain the family for a few months (Figure 1).

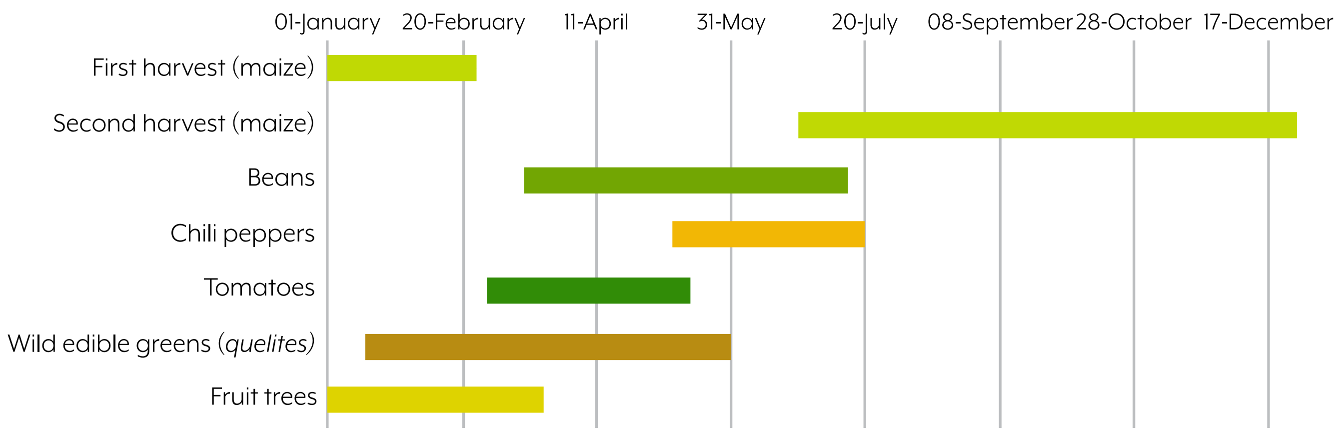

Figure 1. Self-consumption food produced in the milpa and period of consumption during the year

Of the shrub and trees in the milpa, seven species were identified as having a food use. The most important were gásparo (*Erythrina caribaea*) and *equizote* (*Yucca aloifolia*), which had the greatest presence in the plots and highest frequency of consumption in the families' diets (Espinoza-Pérez et al. 2023). In addition, shrub and tree species are used as firewood. *Inga* sp. is also considered useful for the control of weeds and for strengthening soil fertility (because it is a nitrogen fixer) and it contributes to lower doses of synthetic fertilizers being required in the milpa. Another species that contributes to this function is *higuerilla* (*Ricinus communis*), which is useful for weed control and, because it has a high density in the milpas, for fuel too (see photo b, below).

Farmers commented that material from the milpa, especially the leaves of the *higuerilla*, when incorporated into the soil, generates a natural mulch, favouring soil conservation and control of weeds. In addition, in the milpas, perennial woody species are often left standing or as live stumps due to their use as stakes/supports for beans (see photo c, below). Therefore, it is common to observe a high number of individuals of species that fulfil this function: *timbirillo* (*Acacia angustissima*), *mujut* (*Conostegia xalapensis*) and *capulín* (*Parathesis psychotrioides*). See Table 1. In addition, *timbirillo* is a nitrogen-fixing shrub, which forms islands of fertility, increases soil organic matter and prevents soil erosion (Reyes-Reyes et al. 2003), while the other two species are useful as food, and in hot maize-based beverages (*atole*) and wine production at the local level.

In other rural regions of Mexico, some non-woody species are used to delimit milpa plots, such as *nopal* (*Opuntia* spp.) and *maguey* (*Agave* spp.). These species serve multiple purposes, including providing edible and medicinal products. In addition, it is locally recognized that the woody cover of the milpa favours soil fertilization through the leaves, branches and trunks that are incorporated for decomposition. On sloping land with poor soil retention, fruit trees and woody perennials are used to stabilize banks or serve as retaining walls or windbreaks, and as sources of organic matter, firewood and charcoal. The fruit species commonly found in borders and plot boundaries are *capulín* (*Prunus capuli*), *durazno* (*Prunus persica*), *tejocote* (*Crataegus mexicana*), *manzana criolla* (*Malus domestica*) and *ciruelo* (*Prunus*

Milpa production method, including a) sowing; b) milpa agroforestry system; c) shrubs as bean supports; d) storage of maize cobs; e) tortilla production.
Photos: José Espinoza-Pérez

domestica). Timber species are also found: *encino* (*Quercus* spp.), *pino* or *ocote* (*Pinus* spp.), *sabino* (*Juniperus deppeana*) and *tepozán* (*Buddleja americana*); see Pérez-Sánchez 2012; Moreno-Calles et al. 2013.

The maize field (maizal)

In the northeastern highlands of Puebla, the maize system is being used for commercial purposes. In addition to maize, peasant families incorporate other crops for commercial purposes: *pipian*, tomatoes, tree species such as *pimienta* (*Pimenta dioica*), and commercially valuable timber trees: *cedro* (*Cedrela odorata*) and *caoba* (*Swietenia macrophylla*). In addition to these commercial species are *chaca* (*Bursera simaruba*) and *cocuite* (*Gliricidia sepium*) trees, used to delimit boundaries and as living fences and sources of firewood. The difference in crops and the density of shrub and tree species between the milpa and the maize field is notable (Table 1). In the maize field, farmers grow an improved maize variety, *hojero* (*Zea mays*). The farmers' rationale for growing this variety is that it produces mature ears that are 25 to 30 centimetres long and soft-grained, with leaf cover up to eight centimetres above the cob. Such characteristics mean that the improved variety has been outperforming the native *tuxpeño* maize, but growers recognize that it has less resistance to storage pests than the native maize does (see photo d, previous page). As a result, the crop has to be sold within the first two months after harvest (Andrés-Meza et al. 2014).

Table 1. Density and function of shrub and tree species in milpas and maize fields

		Density / ha		
Scientific name	**Common name**	**Milpa**	**Maize field**	**Function**
Yucca aloifolia L.	*Equizote*	4	0	Boundary and food
Pimenta dioica (L.) Merr.	*Pimienta*	2	4	Cash crop
Cedrela odorata L.	*Cedro*	2	3	Cash crop
Swietenia macrophylla King	*Carboncillo*	2	0	Cash crop
Citrus sinensis (L.) Osbeck.	*Naranja*	2	4	Food
Ricinus communis L.	*Higuerilla*	23	0	Helps control the growth of weeds
Heliocarpus appendiculatus Turcz.	*Jonote*	2	0	Firewood
Acacia angustissima (Mill.) Britton & Rose	*Timbirillo*	31	0	Stakes for beans
Conostegia xalapensis (Bonpl.) D. Don ex DC.	*Capulin*	12	0	Stakes for beans and food
Eugenia capuli (Schlecht. et Cham.) Berg	*Capulincillo*	1	0	Tool
Diospyros nigra (J. F. Gmel.) Perr.	*Zapote negro*	2	0	Food
Inga vera Willd.	*Chalahuite*	7	0	Shade, weed control and soil fertility
Mangifera indica L.	Mango	1	2	Food
Parathesis psychotrioides L.	*Capulin*	7	0	Stakes for beans and food
Pouteria sapota (Jacq.) H. E. Moore & Stearn	*Zapote mamey*	1	0	Food
Prunus persica (L.) Batsch	*Durazno*	4	2	Food
Citrus x limon (L.) Burm. F.	*Limón*	0	4	Food
Bursera simaruba (L.) Sarg.	*Chaca*	4	12	Fence
Gliricidia sepium (Jacq.) Kunth ex Walp.	*Cocuite*	0	14	Fence
Erythrina caribaea Krukoff & Barneby	*Gásparo*	3	0	Boundary and food

Production costs and benefits of milpa and maize fields

The milpa system

In the milpa, clearing and weed management are carried out three times during the growing season. During the same period, the family gathers firewood from fallen branches and trunks. The main agricultural tool used for clearing is the *azadón*, an instrument consisting of a wide, thick blade, sometimes curved, inserted into a wooden handle made from the tree known locally as *capulincillo* (*Eugenia capuli*), which is grown in the milpa. Weeding is done with the *azadón*, or occasionally with a machete, and there is no use of herbicides. No incidence of insect pests was reported in the milpas. However, most of the farmers agreed on one problem: the damage to maize and other plants by birds and small mammals (rats, gophers, squirrels, opossums, white-nosed coati). Farmers nevertheless recognize that these animals are part of the agroecosystem and that although they cause problems, they do not have serious impacts on production and it is possible to manage these effects.

In one growing season, to cultivate 1 ha of milpa, families invest an average of MXN 43,750 (Mexican pesos; USD 2,581), which includes clearing the cultivation area, sowing, fertilizing and transporting the harvest. However, because of the fertilizer support they receive from the state government and the prevalence of community labour (*mano vuelta*) among the farmers, they save on average MXN 16,500/USD 974 per hectare. From the sale of maize and beans, they earn MXN 13,500/USD 797, which implies a loss of MXN 3,000/USD 177. This, however, does not consider that the consumption of their own maize (tortillas) by the families during nine months involves a saving of MXN 21,900/USD 1,293; otherwise, this would be an expense.

Herbicide application in the maize fields.
Photo: Francisco Ramos López

Maize fields

Maize fields are cultivated twice a year. For one season and 1 ha, farmers invest an average of MXN 15,150/USD 894, which involves digging an *acahual* (fallow), planting maize, buying and applying herbicides (see photo above) for weed control as well as insecticides and foliar fertilizers, paying wages and transporting the harvest. From the sale of maize cobs for tamales, grain, *pipian*, tomatoes and peppers, the families generate an average total income per season of MXN 25,300/USD 1,493. This means a profit of MXN 10,150/USD 599. However, these families spend an average of MXN 6,500–7,250/USD 384–428 for the purchase of tortillas in six months. See Table 2.

Table 2. Costs and income/savings (+) per hectare (USD), milpa and maize fields

Cost	Milpa	Maize field
Clearing, planting, transport, etc.	2,581	894
Fertilizer support	* + 974	—
Average income	+ 797	+ 1,493
Purchase of tortillas	* + 1,293	384–428
Net income per ha	**+ 483**	**+ 171–215**

* The cost of fertilizer is saved as the government provides it for free.
* As noted above, milpa farmers save this amount because they can consume their own maize/tortillas for nine months of the year.

Packets of dry bracts of maize which are marketed in Mexico City and the capital of Puebla. Dry bracts are used to wrap tamales (a typical Mexican dish). Photos: Francisco Ramos-López

The families who cultivate maize fields recognize that it is difficult to return to the milpa system, largely because of the degradation of the soil; restoring it means leaving the cultivated area in *acahual* for at least seven years. Similarly, they are no longer willing to use the *azadón* as a substitute for herbicides to eliminate weeds in the cultivated areas.

Conclusions

The milpa agroforestry system persists over maize fields for several socio-environmental reasons. The milpa provides basic and traditional foods (maize, beans, chillies, tomatoes), generates savings and economic income, and also produces environmental benefits. The milpa produces native maize, which is locally preferred for reasons of adaptation and culinary traditions. In addition, the milpa allows people to diversify their diet and generate monetary income from the sale of surpluses, mainly beans and sporadically grain. Perennial woody plants fulfil several functions such as soil conservation and the production of firewood and timber. And by employing collective community labour, known as *mano vuelta*, production costs are relatively low.

In contrast, families who adopt the maize system think that cultivating milpa generates economic losses and requires a lot of effort. However, floristic simplification in the transition from milpa to maize fields directly affects the presence of locally used staple crops and beneficial shrubs and trees for soil fertility and pest control. The elimination of the bean crop in the maize field leads to the low presence of shrubs used as stakes/supports. In addition, the farming families who cultivate the maize fields recognize that they have lost the capacity to produce their own food, specifically maize, which is used to make tortillas and has a very high cultural value in Mexico.

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Author affiliation

José Espinoza-Pérez, Doctorante de El Colegio de la Frontera Sur (jep.espinozajose@gmail.com)

Oscar Pérez-García, Profesor investigador, Universidad Intercultural del Estado de Puebla. Lipuntahuaca, Huehuetla, Puebla, México (osperegrow@gmail.com)

Cesar Reyes, Desarrollo Sustentable. Universidad Intercultural del Estado de Puebla, México. Lipuntahuaca, Huehuetla, Puebla (cesar.reyes@uiep.edu.mx)

Petra Andrade-Hoyo, Investigador titular. Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias. Zacatepec, Morelos (andrade.petra@inifap.gob.mx)

Las Flores, Cuero catchment, June 2013. *Inga edulis* hedgerows, seven months after being planted. Photo: Inga Foundation

Inga tree agroforestry in Honduras

Mike Hands and Lorraine Potter

"Inga agroforestry halts devastating slash-and-burn practices and replaces them with regenerative agroforestry"

Introduction

Slash-and-burn agriculture is a critical problem in Honduras and across the tropics. It is environmentally devastating, damaging communities and making them more vulnerable to natural disasters. It is currently used by 200 to 500 million people in the tropics as they have no alternatives (Stief 2021). For generations, subsistence farmers have clear-cut and burned patches of rainforest to create plots of fertile soil for basic food crops. As a result, soil fertility does not last; in addition, crop failure and subsequent erosion force families to keep clearing new plots of rainforest every few years just to survive. Large areas of rainforest are destroyed worldwide every day, releasing huge quantities of carbon. The climate crisis exacerbates the problem, causing poverty, drought, floods and heat. Millions of people in the global south do not just face malnutrition — over 20% of the children in Honduras have poor diets that stunt their growth — but possible starvation, with no other option than to become climate refugees.

Agroforestry is an ancient agricultural practice. Cultures such as that of the Lenca people of Honduras call it "traditional technique" (Pelliccia 2018); it provides food, firewood and cash crops along with other benefits as farmers grow coffee and crops in between the trees. The tree genus *Inga* in Central and South America takes this technique to high levels of sustainability and resilience. A specialized agroforestry system developed by the Inga Foundation uses several species of the tree to support organic farming livelihoods, environmental protection, and resistance to climate shocks. The model saves rainforests from slash-and-burn practices, regenerates steep degraded land, and — by providing food security — prevents families from becoming climate refugees.

Established in 2007 and based on more than 20 years of research, the Inga Foundation is led by an all-Honduran team of foresters/agronomists and nursery and field technicians. One foundation member, who collaborates with regional NGOs and with the Royal Botanic Garden in Kew, UK, demonstrated that an agroforestry model using the nitrogen-fixing genus *Inga* spaced tightly in rows provides food, shade, fertilizer, firewood and soil and water protection. The foundation's Land For Life Project was designed to demonstrate, at the landscape scale, that a viable alternative to slash-and-burn is capable of truly sustainable agriculture.

Smallholders are feeding the world — they just are not recognized for it, nor do they receive any of the massive subsidies that industrial agriculture gets. Small-scale farmers in developing countries already bear the brunt of the climate crisis, yet they have received little of the promised funding to help them adapt to degraded land, drought, floods and heat. In tropical regions with little to no technology or infrastructure, few resources such as water for irrigation, and widespread food insecurity, there is a growing need for low-input solutions like the *Inga* model.

Features of the model

The foundation assists the families with their *Inga* seedling planting and they plant their own basic grain crops of their choice (maize or beans). A total of about 50,000 grain seeds are sown in a 1-ha plot to secure a family's basic needs. The planting density of the *Inga* trees in an alley plot is 5,000 per ha. *Inga* tree seedlings are planted 50 cm apart in rows and along contours on steep slopes, with rows about 4 m apart; they require no agrochemicals, chemical fertilizers, fossil fuels, heavy equipment, herbicides or pesticides.

The trees establish quickly, including on sites with invasive grasses, with a survival rate of 98%. Only small amounts of inexpensive mineral rock phosphate and magnesium/ sulphur are needed as supplements (no chemical

Alley of *Inga edulis* at two years' growth and ready for the first pruning. No herbicides have been used. The aggressive grasses that dominated the site have been eliminated by shade alone. Photo: Inga Foundation

First pruning of an *Inga* alley plot. Deep, tough mulch will protect the soil surface from erosion and sun. Weed growth is suppressed and moisture is retained beneath the mulch. Photo: Inga Foundation

fertilizers). Maize or beans are planted between tree rows, at the same time as the tree seedlings. After 18 to 24 months, the *Inga* trees are pruned, to reduce their height from about 6 m to 1.5 m. Branches and pruned material supply firewood and the stripped leaves provide a soil-protecting mulch. Crops are planted again between the rows in the mulch and the *Inga* trees regrow. After the crops have matured, they are harvested and the cycle repeats.

The other three parts of the *Inga* tree model are cash crops, hardwood trees for future income, and citrus tree plots. The *Inga* trees are interplanted with these crops and serve as nurse trees: improving the soil by providing all the needed fertilizer and by providing shade (for crops such as vanilla, cocoa and turmeric) and mulch. The *Inga* seedlings are planted at a rate of 200–2,000 trees per ha. Smallholder families make their own decisions about whether to plant a cash crop, fruit trees or hardwood trees.

The strategy for the model has been developed from the starting point of the functioning of the tropical rainforest itself, together with in-depth studies into the impact of slash-and-burn on forest ecology and with long-term studies into possible alternatives. The strategy addresses the deep causes of historical and present-day environmental degradation and is both remedial and regenerative. By regenerating historically degraded soil fertility on these long-deforested hill slopes the model positively addresses 12 of the Sustainable Development Goals without negative impact.

Approach

This agroforestry model is being implemented in two river valleys in northern Honduras and has now reached more than 450 subsistence farming families. Now in its twelfth year, the model allows families who planted their basic grain crops with the *Inga* model to have food when their neighbours who were still using slash-and-burn saw their crops either dry up or wash away. By allowing families to stay on one plot of land, the model helps address the socially destructive rural-to-urban and out-of-country migration that results from the failure of slash-and-burn to sustain subsistence agriculture.

The *Inga* approach works with nature, builds crop diversity, and empowers marginalized farmers. Rural subsistence families provide the land, labour and care and the foundation provides the training, native seeds and assistance with planting and the first pruning. The model yields abundant firewood for household needs; excess firewood can be traded or sold. Standing trees are no longer cut down. The thick mulch obtained when the leaves from the pruned branches are stripped has strong fertilizing and protecting effects, along with the nitrogen-fixing effect of the *Inga* trees.

Benefits of *Inga* agroforestry

The model is a socially and ecologically sustainable solution that benefits rural smallholder farmers and the planet. According to Project Drawdown, a think tank working on climate solutions, agroforestry can achieve carbon sequestration rates comparable to those of afforestation and forest restoration, with the added benefit of producing food (Rainforest Alliance 2021). The *Inga* agroforestry model's subsistence farming families have planted more than 6 million native trees; these anchor, enrich and regenerate land, even steep, depleted land. The system contributes to reducing CO_2 emissions and provides up to 100% food security; it also allows families to grow organic cash crops (vanilla, rambutan, cocoa, turmeric, allspice, black pepper and pineapple).

Economic and integrated benefits

IUCN's 2019 report on Honduras, an economic analysis of 11 restoration actions in the country (Nello et al. 2019), used 14 financial indicators, four environmental indicators and two social indicators to compare restorative techniques using multiple criteria. It reported that one of the most effective actions to generate income and environmental benefits was the restoration of degraded lands for the production of basic grains through the implementation of the *Inga* agroforestry system.

In Ixcán, Guatemala, an NGO trained by the Inga Foundation had its Inga project analyzed by researchers from the Inter-Institutional Agreement for Valle del Cauca Agricultural Production (CIPAV). Results (Climate CoLab 2012) showed that Inga plots yielded approximately 350 kg more maize per ha than traditional monocrop plots, a value of approximately USD 558 per harvest. The measure of extreme poverty in Guatemala (the amount needed for an individual to meet basic nutritional needs), is approximately USD 569 per year.

The benefits of the foundation's activities in Honduras since 2012 can be summarized as follows:

- CO_2 emissions avoided or sequestered— the foundation's carbon model predicts total avoidance or sequestration of 611,187 tonnes of CO2 (Hands 2021);
- avoidance of air pollution from not burning 3,960 ha of fallow vegetation;
- 5,840 ha of total land restored to agroforestry since the program began in 2012;
- increased biodiversity through standing trees not being cut for firewood and by biological corridors being created;
- sustainable food security;
- avoidance of slash-and-burn agriculture;
- regeneration of steep, highly degraded land;
- improved nutrition;

Long-term experimental *Inga* alleys about two weeks after tree pruning and maize sowing. This is a demonstration site in an ideal flat location. The realities for subsistence farming families are very different. The site does, however, show how the system looks and works. No herbicides are used in these plots. The trees (15 species) in the background were planted within a matrix of *Inga* in 2000.
Photo: Inga Foundation

Pepper (*Piper nigrum*) on living stakes of *Gliricidia sepium* within I*nga edulis* alleys. The pepper is interplanted with developing turmeric (*Curcuma longa*) and plantain (*Musa* sp.). Photo: Inga Foundation

- protection of watersheds, with no agrochemical run-off;
- improved rural livelihoods, including for women and young people;
- no debt or loans;
- prevention of erosion and mudslides;
- provision of renewable firewood without harvesting standing trees;
- reduced out-migration;
- elimination of herbicides, fungicides and pesticides; and
- elimination of chemical fertilizers, fossil fuels, GMO seeds and heavy equipment.

The Inga Foundation has facilitated its agroforestry model in 15 countries with farmers, NGOs and government agencies by providing training and native seeds at no cost. Its nurseries have provided more than 400,000 cacao plants and 85,000 pepper plants (for cash crops) along with tens of thousands of rambutan, avocado, pineapple, vanilla and other cash crop plants that families may choose at no cost.

Families are able to harvest beans and maize with no irrigation and little rain due to the thick leaf mulch from the pruned trees in the alleys, which cools the soil and retains moisture. Even in this region, which is experiencing severe climate shocks, it provides what farming families need most: food security.

Families can achieve self-sufficiency and food security within two years and they in turn can assist neighbours and relatives to do the same. It is a solution for the tropics that is owned and driven by communities through demonstration and farmer-to-farmer sharing. *Inga* agroforestry offers local solutions for climate resilience that empower local economies.

The model has proven to be a regenerative system that supports rural populations and natural resources. It is environmentally and economically sound in achieving both short- and long-term goals of climate resilience, food security, environmental protection, economic viability, and quality of life.

Resilience and replication

Adaptation to climate change needs local acceptance and community development at its core. The *Inga* tree model was set up in a way that allows families to choose to participate and puts them in full control of their plots. They determine what to plant as their basic grains and later, cash crops, and whether to plant fruit trees and hardwood trees. The foundation's nurseries provide the cultivars.

The status quo is the greatest barrier to a transformative food system that is localized and responsive to the needs of the people. The 54 leading countries of the world spend roughly $700 billion a year on farm subsidies, equal to 12 percent of gross farm revenues, according

Young cacao developing beneath the shade of *Inga edulis*. Weeds are largely controlled here by shade. Previously this site had been dominated by invasive grasses. Photo: Inga Foundation

to the Organisation for Economic Co-operation and Development (Abbott 2020). La Via Campesina also makes the case for overhauling humanity's destructive relationship with nature (La Via Campesina 2021). They are an international farmers' group founded in 1993, with 182 organizations in 81 countries.

The need for agroforestry in subsistence farming is an urgent priority, especially in the equatorial regions predicted to experience severe climate shocks of heat, drought and hurricanes. Smallholders have shown how the *Inga* agroforestry model can be replicated across entire landscapes. It is hoped that this will convince decision-makers in international institutions that such massive transformations in the rural economies of tropical countries are possible, economical and highly effective. The model needs to be self-replicating so it will require no further input from the foundation to spread from farmer to farmer. Because it is novel and revolutionary, however, the model now requires a concentration of effort and resources to achieve a critical mass of families.

Costs

The current all-in cost of USD 0.75 per tree will decrease as the model is replicated, more nurseries are established, and more training hubs are created. Although different countries have different land tenure, capabilities and community needs, there are many similarities that will make scaling efficient. The design of the model addresses barriers so that it can function as a systematic, low-input, integrated effort. The team is committed to seeing it replicated widely, with the demonstration farm becoming a full-time teaching centre.

The total cost of the project since its inception in January 2012 through to December 2021 is USD 1.68 million.

This includes all capital items such as vehicles, land, permanent equipment, etc., and works out to about USD 3,500 per family, given that some capital expenditure has already taken place.

Conclusions

The *Inga* agroforestry model allows governments in the humid tropics to fulfil their tree-planting initiatives while transforming lives for the rural poor. The foundation cannot change policies that favour and fund industrial agriculture. What it can do is gain visibility and showcase successes at the landscape level, and the possibility of replication with training hubs and nurseries for native seeds and trees. It is hoped that more achievements will create a critical mass that leads to additional funding and that the system will eventually spread on its own. The foundation works to attract mainstream environmental and capacity-building funding—to get the stories of resilience out to a wider audience and show people what is possible.

In a biological corridor, a 14-year-old *Terminalia oblonga* emerges from the *Inga* canopy. Left: *Inga vera*; right: *Hymenaea courbaril* and *I. vera*. Photo: Inga Foundation

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Videos

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Author affiliations

Mike Hands, Founder and Director, Inga Foundation (mhands400@btinternet.com)

Lorraine Potter, USA Board, Inga Foundation (ingatrees@gmail.com)

Cocoa pods. Photo: Johanna Rüegg

Dynamic cocoa agroforestry: 25 years of experience in Alto Beni, Bolivia

Johanna Rüegg, Walter Yana, Ascencia Yana, Beatriz Choque, Consuelo Campos and Joachim Milz

"Agroforestry plots can produce a range of foods for consumption and sale, contributing to income diversification and long-term resilience, food security and food sovereignty."

Introduction

Cocoa is traditionally cultivated under agroforestry. This production system is still common on the Latin American continent, although today the largest producing countries are Côte d'Ivoire and Ghana in Africa, where most cocoa is grown in monocultures.

Cocoa agroforestry is gaining more and more interest globally for its benefits in providing some of the functions of tropical forests, such as biodiversity and regulation of the water cycle and temperature extremes, as well as carbon sequestration. Cocoa, similarly to coffee, is very suitable for production under agroforestry. It is a species originating in riparian forests in the Amazon and Central America, where it occupies the lower middle stratum and therefore tolerates shade. Cocoa yields in agroforestry tend to be lower than in monocultures, although total system yields, including companion crops, are higher (Niether et al. 2020).

In Alto Beni, Bolivia, in the foothills of the Bolivian Andes, there has been experience with organic cocoa production under agroforestry for several decades. The systems employed by the smallholders differ in their design and diversity, but in general they are characterized by relatively high density and diversity of companion trees compared to other producing regions in the world (Figure 1).

Figure 1: A typical mature dynamic agroforestry system in Bolivia; trees are not yet pruned

Some systems can be characterized as dynamic agroforestry (see Box 1), which may include timber, fruit and native trees as well as palms, banana and other crops in addition to the main cocoa crop. Often, the large canopies of the trees are not pruned, leading to highly shaded systems (Esche et al. 2023); this was the case for the nine producers described in this article at the time they were interviewed. Today, there are programmes in the region that offer shade tree pruning as a service, in order to better maintain these highly dense and diverse agroforestry systems.

In 2008–2009 the Farming Systems Comparison in the Tropics project (SysCom) initiated a long-term study in the region to compare the agronomic, economic and ecological performance of two different cocoa production systems: conventional and organic cocoa production in monocrop (full sun) and agroforestry (shaded) (Schneider et al. 2017). The SysCom trial also included a dynamic agroforestry system, in line with the longstanding experiences of farmers in the region. The project was established on land that was fallow for 20 years and covered with secondary forest. The companion trees in the SysCom dynamic agroforestry plots are pruned twice a year (see photo, next page) to increase the light input to the cocoa and companion crops and to increase nutrient cycling. The system operates without external inputs.

This article provides economic results from a case study of a mature model plot under dynamic agroforestry in the region, with data from 2017 and 2020. It compares these results with information obtained in 2017 from other smallholder plots in the region that combine cocoa with fruit trees in agroforestry systems and with results from the dynamic agroforestry and organic monoculture plots that are part of the long-term SysCom trial.

Box 1. Dynamic agroforestry

The principles of dynamic agroforestry were formulated by Ernst Götsch, a Swiss producer and researcher who developed this form of production in Brazil in the 1970s (Götsch 1995). In 1995 he was invited to visit El Ceibo in Alto Beni, an umbrella organization of cocoa producers cooperatives. His visit introduced this form of agroforestry in the region, which has since been promoted by Ecotop. Among the principles are the combination of species, according to their life cycles and the strata they occupy in natural forests, the use of natural regeneration of species, and the high density of trees, especially at the beginning, which are then constantly thinned over time, leading to irregular spacing between trees of different heights (Andres et al. 2016).

Aerial photo of a dynamic agroforestry plot that was part of the SysCom trial; shade trees are pruned twice a year. Photo: Erick Lohse, ECOTOP/FiBL

Methodology

From 2017 to 2020, nine agroforestry plots of smallholder farmers, who grow cocoa together with a diversity of fruit trees, were selected in Alto Beni for a study at the regional level, including the model plot of Walter and Asencia Yana, which is described in more detail below. Not all of these plots can be characterized as dynamic agroforestry, but they certainly include elements of it. All companion trees — forest species as well as fruit and palm species — were inventoried. Through interviews with the farmers, information was obtained on the year of establishment, cocoa yields, income and use of fruit trees. The areas of the plots were recorded using GPS.

The following fruit tree species were found: *achachairú* (*Garcinia macrophylla*), *arasá* (*Eugenia stipitata*), *asaí* (*Euterpe precatoria*), banana (*Musa* sp.), starfruit (*Averrhoa carambola*), peach palm (*Bactris gasipaes*), *cherimoya* (*Annona cherimola*), citrus (*Citrus* sp.), *copoazú* (*Theobroma grandiflorum*), guava (*Psidium guajava*), *majo* (*Oenocarpus bataua*), mango (*Mangifera indica*), inga (*Inga* sp.), avocado (*Persea paradisiaca*), rambutan (*Nephelium lappaceum*) and jackfruit (*Artocarpus heterophyllus*). Among the inventoried trees, about 25 precious (i.e., high-value) timber species have a market in the region. Their standing value was estimated based on local prices, adjusting for the fact that 40% of the timber is lost during processing (Brönnimann 2017). The most common precious species were *Swietenia macrophylla, Amburana cearensis, Myroxilon balsamum* and *Hymeanea courbaril*.

Detailed data for the year 2020 from the model plot of Walter and Ascencia Yana, who recorded their labour and monetary investments, as well as their income from cocoa and companion crops, are included in this article. Expenses included equipment, maintenance, fuel and tools. Their 1.96-ha agroforestry system is one of the longest established examples in the region and also one of the most diverse and dense, including a high variety of fruit tree that are in the productive stage. Therefore, the plot is often visited in training sessions. The plot was established more than 25 years ago and was based on the principles of dynamic agroforestry (see Box 1).

Results

The model plot

In Walter and Ascencia Yana's model plot most of the companion trees were planted by seed, a common practice in dynamic agroforestry. Natural regeneration was respected and species of less interest or in competition with others were thinned and additional species were incorporated over time. Because of this type of management, which resembles natural forest processes, the layout of the plot is irregular, and there are places in the plot where companion trees are up to 1 metre apart. The cocoa density is 487 trees/ha.

An example of a dynamic agroforestry plot of a farmer in the region of Alto Beni, Bolivia. Photo: Johanna Rüegg

A total of 54 species were inventoried in the model plot, including 21 precious species and 13 fruit species. Including shrub and palm species whose fruits are not used brings the total number of species to 72.

From the fruit trees, six products were sold in 2017: *achachairú* (*Garcinia macrophylla*), starfruit (*Averrhoa carambola*), peach palm (*Bactris gasipaes*), *copoazú* (*Theobroma grandiflorum*), rambutan (*Nephelium lappaceum*) and *ocoró* (*Garcinia madruno*). Ginger (*Zingiber officinale*) was also harvested and sold. Rambutan, *achachairú* and *copoazú* are the most economically important crops and are sold every year. In addition, eight species were used for self-consumption.

In 2017 cocoa yields were 280 kg/ha, bringing an income of USD 1,116 per ha. Fruit trees contributed an income of USD 2,332 per ha, for a total income of USD 3,448 per ha. To date, no timber has been harvested; however, in 2017, the standing value of timber was estimated at USD 3,307 per ha, representing a long-term capital accumulation.

According to more recent (2020) data from the model plot (see Table 1), cocoa production has increased to approximately 430 kg/ha, with an income of USD 1,762 per ha. At the same time the sale of companion crops in 2020 was lower than in 2017, with a contribution of USD 1,174 per ha. With recorded costs of USD 294 per ha, and 54 working days/ha of labour invested, this results in a net income per working day of USD 49.

Table 1. Economic data (USD per ha) recorded on Walter and Ascencia Yana's model plot, 2020

Cocoa dry bean yield (approximate; kg/ha)	430
Income, cocoa	1,762
Income, companion crops	1,174
Total income	2,936
Costs	294
Labour time (days/ha)	54
Net income per working day	49

The results show that income from companion crops can vary from year to year due to fluctuations in yields or demand. In addition, fruit species come into production only after several years, and the market changes over the years. One of the challenges of agroforestry is to foresee and plan for long-term market developments. In the case of the Amazonian fruits *copoazú* and *asaí*, for example, there was not much interest in these crops when the model plot was planted in 1997. Since then, however, a very strong market for them has developed, contributing significantly to the family's economy.

Recently, companion trees in the model plot and in the region have been pruned, especially the high-stratum timber trees and the middle-stratum fruit trees, as too little light was reaching the cocoa stratum. This resulted in an increase in a mean cocoa yield from 138 to 506 kg/h, measured as part of a trial in farmers' fields (Esche et al. 2023). An estimated increase in fruit tree production of about 30% was also recorded in Walter and Ascencia Yana's model plot. The organic material from the pruning also serves to recycle nutrients. Currently, local advisory services recommended that producers have their trees pruned by a specialist every three years.

Together with the improvement of genetic material, the pruning of companion trees has increased dry bean cocoa yields in the model plot from approximately 280 kg/ha in 2017 to approximately 430 kg/ha in 2020 (Table 1) to approximately 480 kg/ha in 2022. The yields of companion crops were also increased by pruning and thinning. And as the cocoa grafts mature, a further increase in production is expected.

Comparison with other producers

Table 2 shows the characteristics of smallholder plots in the region as assessed in 2017; all were focussed on organic cocoa production in agroforestry with timber and fruit species. Half of the plots had an area less than 0.98 ha. However, this does not always represent the area cultivated with cocoa, but refers to the total size of the inventoried plot. The plots were between 10 and 20 years old, representing mature systems in terms of cocoa, but young in terms of timber, which isn't harvested before 25–50 years of age. Densities of companion trees between 84 and 517 trees/ha could be observed, which shows that these plots are quite complex and dense systems. Fruit species, including banana, are of high importance as additional crops, with an average of 125 individuals/ha. In the region, there are also plots focused on timber that do not include fruit trees (these were not included in the selection of plots for this study).

Table 2. Characteristics of plots producing cocoa together with fruit and timber species in 2017

	Area (ha)	Age (years)	Density, cocoa/ ha	Density, timber trees/ha	Density fruit trees and others/ha	Density companion trees/ha	Total number of tree species	Number of timber trees
Minimum	0.54	10	455	79	39	150	27	14
Maximum	4.38	21	543	333	280	517	67	25
Mean	1.51	16	483	188	125	313	40	18
Median	1.00	17	483	184	87	271	36	18

Cocoa yields vary between 190 and 1,015 kg/ha, with a mean of 514 kg/ha (Table 3).

The two agroforestry components — timber as well as fruit trees and other crops (such as ginger) — contribute substantially to the economic performance of the plots. Farmers mentioned selling between one and seven companion crops, with half of the farmers marketing more than three additional products. These sales contribute between 3 and 68% of farmers' income, with a mean of USD 899 per ha per year. In comparison, cocoa contributes a mean of 68% of income, with a mean of USD 2,089 per ha per year.

The timber component represents a substantial capital accumulation, with a mean standing value of USD 5,565 per ha in 2017. Given that the plots can probably remain productive for up to 25–50 years, this can make a strong contribution to the income of the families if the timber is sold in the future.

Table 3. Cocoa yields, income, species for self-consumption and capital accumulation from the plots in 2017

	Cocoa dry bean yield kg/ha	Cocoa income USD/ha	Income sale fruit USD/ha	Number of crops for sale	Number of crops for self-consumption	% cocoa income	Total income USD/ha	Standing value USD/ha (60%)*
Minimum	190	773	148	1.00	2.00	32	998	2,955
Maximum	1015	4,126	2,389	7.00	10.00	97	4,274	8,682
Mean	514	2,089	899	3.44	5.78	68	2,988	5,565
Median	437	1,778	945	3.00	5.00	67	3,533	5,129

*Note: As mentioned on page 59, 40% of the timber is lost during processing (Brönnimann 2017).

Comparison of smallholder plots with results of the 2017–2019 SysCom long-term trial

The SysCom Bolivia trial in 2017–2019 compared the production and economic performance of two cocoa production systems: organic monoculture and dynamic agroforestry at the age of 9 to 11 years. In both systems, the cocoa density was 625 trees/ha. The dynamic agroforestry systems had a density of approximately 800 companion trees/ha during this time, substantially higher than in all the smallholder plots inventoried above. One of the reasons for this is that the farmers' plots in the 2017 study were older; thus, density has reduced over time. The companion crops that were harvested and sold were banana, coffee, *chima*, *copoazú*, ginger, *palillo* (*Curcuma longa*) and avocado.

Table 4 shows mean labour time and yields from the SysCom trial collected for the years 2017–2019. Income was calculated using local prices. Costs were estimated based on tools and inputs purchased during that time. All values were converted from BOB (boliviano) to USD with an exchange rate of 6.95125 BOB/USD (average exchange rate in 2017).

Table 4: Average cocoa yields (kg/ha) and economic data (USD/ha) for the SysCom project, Alto Beni region, 2017–2019

	Organic monoculture	Dynamic agroforestry
Cocoa dry bean yield	1,170	590
Income, cocoa	3,670	1,857
Income, companion crops	0	1,498
Total income	3,670	3,355
Costs	456	147
Labour costs (day/ha)	113	145
Net income per working day	28	22

The dynamic agroforestry system forming part of the SysCom trial is 2.8 times more labour intensive than that of Walter and Asencia Yana, and income is also higher in the SysCom trial. This is due to intensive management; for instance, the accompanying trees are pruned twice a year, so productivity is higher. With this more intensive management, yields of 590 kg/ha can be achieved in dynamic agroforestry, a promising yield but far from the 1,170 kg/ha of dry beans that were achieved in organic monoculture during the same time (Table 4). However, total productivity has to be considered. In agroforestry systems almost 45% of total income comes from companion crops, in the SysCom trial and in the model plot. However, the return on labour (net income per working day) recorded in the model plot (USD 49; see Table 1) was considerably higher than either the monoculture (USD 28) or the dynamic agroforestry system (USD 22) of the SysCom trial (Table 4), indicating that although income is lower, the farmers have found efficient ways to manage their plots.

Conclusions

Although there was a high return on labour in the model plot, there was high variability in cocoa yields. A few farmers achieved similar yields as monocultures in the region, while others showed a considerable share of income from crops, indicating the potential of dynamic and multipurpose agroforestry systems. Agroforestry plots can produce a range of foods for consumption and sale, contributing to income diversification and long-term resilience, food security and food sovereignty. A whole range of possible combinations is possible — each system has to be adapted to the specific circumstances, market opportunities and preferences of those who work on it.

Achieving economic profitability — while maintaining a high diversity of timber trees and native species for biodiversity conservation, efficient micro and macro climate regulation, water cycle regulation and carbon sequestration — is a great achievement. In addition, the "happiness" — the well-being and satisfaction — of working on a diversified plot of land in harmony with life is often mentioned by farmers. The importance of agroforestry systems in resilience to climate change, and its positive perception by farmers in the region, has also been shown (Jacobi et al. 2015).

Furthermore, the results show the importance of good practices such as the improvement of genetic material and the pruning of companion trees, and demonstrate that there is potential to further improve efficiency in the management of dynamic agroforestry systems. Actors in the Alto Beni region are contributing effectively to this process, offering pruning services and technical assistance such as providing seeds and seedlings of companion species and locally selected cocoa, as well as investing in long-term research and training.

Finally, for research and to evaluate the economic performance of agroforestry systems, it is important to obtain multiyear and long-term data, as agroforestry systems are also an investment for future generations.

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Author affiliations

Johanna Rüegg, Research Institute of Organic Agriculture (FiBL), Switzerland (johanna.rueegg@fibl.org)

Walter Yana, Producer, Fundación Ecotop, Bolivia (w.yana@ecotop-consult.de)

Ascencia Yana, Producer, Bolivia (w.yana@ecotop-consult.de)

Beatriz Choque, Fundación Ecotop, Bolivia (betina1423@hotmail.com)

Consuelo Campos, Fundación Ecotop, Bolivia (c.campos@ecotop-consult.de)

Joachim Milz, Fundación Ecotop, Bolivia (j.milz@ecotop-consult.de)

Aerial view of the oil palm agroforestry Expansion Pilot site. Photo: Natura Cosméticos

2.5

Criteria for scaling up oil palm agroforestry in northeastern Pará, Brazil

Camila Costa, Iguatemi Costa, Mauro Costa, Bruno Lima, Gizele Souza and Raoni Silva

"Ensuring regeneration performance and environmental benefits while promoting inclusive economic benefits for different farmer profiles is the goal."

Introduction

The global scenario of oil palm monoculture produces several social and environmental conflicts, mainly regarding conversion of logged tropical forests, loss of biodiversity and insecure land rights (Goh et al. 2017). In Brazil, science-based evidence has emerged in recent years on the positive impacts of oil palm agroforestry (Ramos et al. 2018; Castellani et al. 2011), showing that the conservation of biodiversity allied to the oil palm chain is possible. When well realized, this approach includes oil palm — a pioneer forest species that before being domesticated existed naturally in a forest environment — as part of a diversified production system. The system promotes farmers' livelihoods, guarantees future income from timber production and supports food security, as well as soil improvement and carbon capture and storage.

The municipality of Tomé-Açu, in the northeast of the state of Pará, encompasses more than 200 agroforestry systems (with different arrangements of plants) tested by the Mixed Agricultural Cooperative of Tomé-Açu (CAMTA), which has achieved international recognition for agroforestry practices (Piekielek 2010). Founded by Japanese immigrants more than 90 years ago (1931), the cooperative was once the world's largest producer of black pepper, but disease in the 1960s in the monoculture areas decimated the pepper plantations. After a period with monoculture and many lessons learned, the cooperative realized that the backyard agroforestry gardens of riverside dwellers did not face significant agronomic difficulties. The cooperative saw the opportunity to work from the perspective of diversification. Today, with the support of agro-industry, it is one of the largest examples of agroforestry production and commercialization in the Amazon, acting as an important disseminator of agroecological practices and an essential partner for agroforestry research and the pilot scale-up of the SAF Dendê oil palm agroforestry system.

This article reports on part of the activities carried out in Tomé-Açu by Natura, a cosmetics company, and CAMTA, which build on former research activities that also included the Brazilian Agricultural Research Corporation (Embrapa) and the World Agroforestry Centre (ICRAF). These pilot activities, called the Expansion Pilot, aim to mobilize developing low-risk business models for farmers.

Challenges to the expansion of oil palm agroforestry

There are four main challenges in scaling up oil palm agroforestry in the Brazilian Amazon:

1. environmental and land tenure regularization, both in time frame and costs of legalization;
2. effective implementation of financing systems with disbursements that align with the agricultural calendar, as well as financial mechanisms for various types of farmers;
3. labour demand — including mechanized alternatives and involvement of a diversity of farmers (family farmers, small and medium farmers); and
4. market connections and agreements for various agroforestry products — internal purchasing agreements with the cooperative, with the subsequent involvement of other companies.

It is important to emphasize that socio-environmental benefits must be linked to farmers' needs. This requires access to qualified technical assistance for guidance on agroecological system management and productivity, on the agroecological inputs available, and on guarantees of complex relationships such as land-use rights. One essential aspect is that no planting should take place in areas with illegal deforestation after 2008.

As for market certification related to sustainable oil palm practices, the requirements of the Roundtable on Sustainable Palm Oil (RSPO) have been used. And, since oil palm agroforestry includes other crops, it is important to consider all components. In this context, the Union for Ethical Biotrade (UEBT), which certifies the ethical sourcing system of natural ingredients and is guided by the principles of fair trade, biodiversity conservation and a trusting relationship with supplier communities, can guide practices.

As mentioned above, a specific challenge is land tenure regularization. Although the legalization process generates management benefits and greater visibility for local restoration and recovery initiatives, the necessary documentation, the applications for authorizations for site preparation and the planting licences all need to be taken into account into the budget and schedule, as they can be complex and time consuming.

Brandão et al. (2018) observed with small integrated producers in northeastern Pará that the ability to hire labour has been a more important determinant of labour allocation in plantation management than the availability of family labour. Labour is very important in the initial phase of the system, and its scarcity has been worsened by the fact that farmers are also involved in cocoa harvesting and maintaining good practices for the production of cocoa beans.

There is a need to release funds on a schedule that is adjusted to the agricultural calendar, as there was no specific credit line for the implementation of agroforestry systems.

Importantly, carbon was also considered as a product of the system. And along with the market created for it, a question arose: can carbon generate financing for a transition from oil palm monoculture to more ecological production systems?

Oil palm agroforestry research site in Pará, Brazil. Photo: Natura Cosméticos

Unprecedented solutions for a revolutionary production system

In 2007 Natura, CAMTA and Embrapa started what would become the largest research project in duration and investment ever carried out by the companies, with the third-highest number of scientific publications. The first demonstration plots were planted 15 years ago. Thanks to the choice of inputs in the production process, and to agroecological management and arrangements that are well-adapted to the ecological functions of the species, the project has shown excellent results in terms of productivity per hectare and environmental benefits, such as increased carbon storage (Ramos et al. 2018), soil fertility, nutrient cycling and biodiversity.

All the knowledge and learning by the cooperative was incorporated in the structuring of the Expansion Pilot. This learning, combined with the natural demands of the scaling process, brought with it the understanding of the need to develop parameters that would meet the interests of the various farmers without losing the guidance and essence of the work already done. It is in this context that the SAF Dendê guiding principles for oil palm agroforestry emerged, seeking to quantify the new productive areas through three key performance indicators (KPIs): plant diversity, functionality, and economic diversity. The guiding principles also provide inputs for the monetization of positive impacts in the scaling phase.

Guiding principles

It was necessary for the guiding principles to address five factors:

a. reliability, by proposing technical-scientific robustness combined with transparency and simplicity in obtaining data;
b. eligibility, from the use of more than one criterion per KPI, and where criteria can be used simultaneously or prioritized as appropriate;
c. scalability, by considering agility and ability to adjust to different areas and contexts through the use of remote sensing tools for field measurements;
d. replicability, by adapting the criteria to different landforms, climate and agricultural activities; and
e. impact, by correlating each key performance indicator to an ecosystem service, considering the scope of the impacts and extrapolating the results in a context beyond the borders of the analyzed property.

It is important to reaffirm the basic requirements of effective oil palm agroforestry: comply with RSPO and UEBT specifications; have a range of tree species in the system; address ecological succession among species and the presence of at least two strata at the end of the cycle; carry out more than one regenerative practice, in addition to the non-use of fire and the use of service species; have at least 50% native species in the system throughout its existence; and achieve a minimum of 5 of the 12 criteria of the KPIs.

There are three KPIs. Each of the three indicators has four criteria, and each criteria receives a score of either 0 (absence) or 1 (presence). Therefore, there is a possible score of up to 4 points per KPI and a total possible score of 12 points.

KPI Plant diversity assesses the abundance and number of species in the production system and is directly interconnected with other ecosystem services and the presence of micro, meso and macrofauna. It confers nutritional and phytosanitary health and resilience to the system. These are the four criteria:

- at least two of the three main functional niches: forest species (long cycle), intermediate species (medium cycle), and agricultural crops (short cycle);
- at least three forest species native to the biome throughout the system cycle, at least two of which are perennial;
- support soil health, increased use of organic inputs throughout the cycle, replacing chemical fertilizers;
- support native biodiversity in the system by eliminating pesticide use throughout the cycle.

KPI Functionality assesses the harmonious functioning of the system; i.e., how well the production system ecologically and architecturally mimics natural forest processes. Functionality supports intensification of ecosystem services and greater climate resilience of the system. These are the four criteria:

- active ground cover in and between the rows throughout the entire system in the early and middle stages;
- at least 50% of the area has some canopy cover by the middle stage of the system;
- at least two species (annual, perennial, semi-perennial) in the system have provide an environmental service; e.g., nitrogen fixation and provision of organic matter;
- in terms of land cover density the number of individuals of perennial species per hectare is greater than 600 in the most advanced period of succession.

KPI Economic diversity assesses the economic and market resilience of the system, as well as food security, product diversity and management effectiveness. Reducing risks through diversification confers possibilities for various products and price premiums as well as robustness in production. These are the four criteria:

- at least one species in the system provides non-timber forest products (NTFPs) as its main product at any time in the cycle;
- at least one species in the system is a fruit tree;
- at least one long-cycle timber species is present (no less than 20 individuals per hectare);

Left: Field workshop at an oil palm agroforestry scaling site. Right: Planting. Photos: Natura Cosméticos

- diverse agricultural species are present, with no less than two being annual or semi-perennial.

The minimum value of compliance should be five of the 12 KPIs criteria met (42%). The requirement for farmers is that the system should show continuous improvement with constant monitoring that reflects a higher and better score over the years. Farmers are now able to achieve 100% compliance from the middle stage of the system, between eight and nine years after the start (given that 50% canopy cover cannot be achieved before the middle stage). Five farms planted in 2022 and 2023 have areas ranging from 5 to 48 hectares.

The guiding principles were established for the micro scale of the production system, with the flexibility to be used at the macro scale of the landscape (depending on the local partners available), and with potential for use at a global scale, in terms of expansion of the intended impact. The involvement of a range of actors (farmers, associations, cooperatives, partner companies) emphasizes the importance of valuing all those who contribute significantly to the generation of positive impacts through proven ecosystem services. It also opens up the possibility of the principles themselves being adjusted in the future if necessary.

It is also important to reinforce the importance of considering the 12 criteria in the selection of production areas, so that ecosystem services are maximized. As shown in Figure 1, this includes areas' potential for contributing to six themes (T): conservation of genetic resources (T1), livelihood systems (T2), forest management and restoration (T3), investments, value chain and overall sustainability (T4), landscape dynamics (T5) and climate change and forest changes (T6). These six factors are intrinsically related to land use; i.e., in areas with annual crops or grasses, the contribution to climate change mitigation, conservation of genetic resources and forest management and restoration are practically nil. Therefore, such areas should be a priority for oil palm agroforestry.

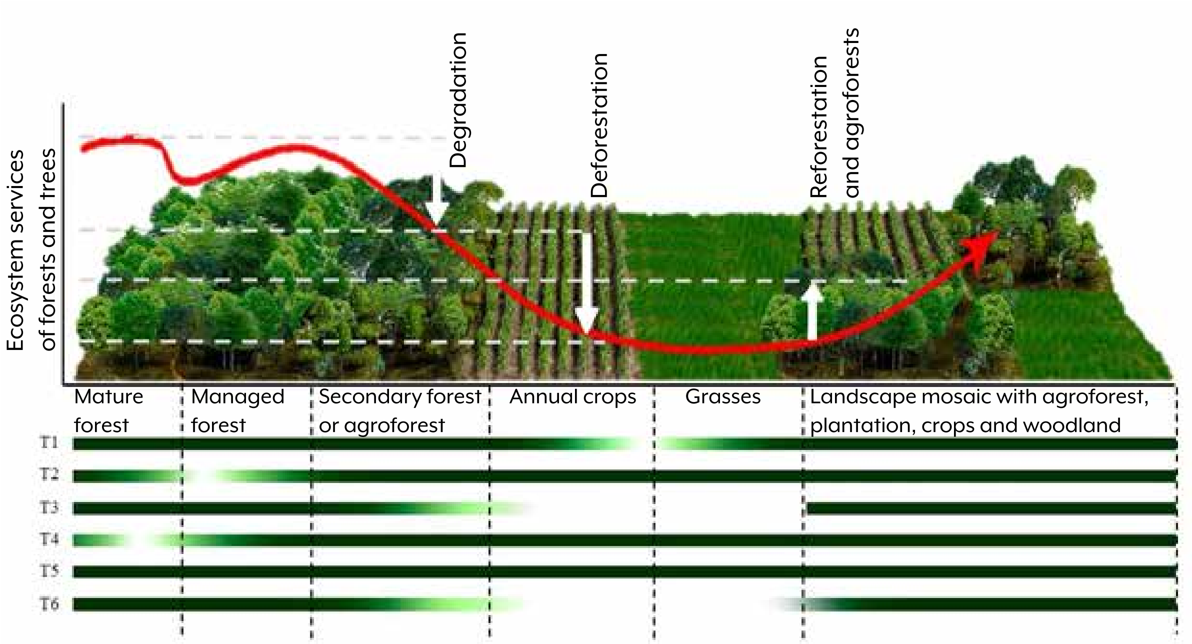

Figure 1. Forest and land use transition curve (red arrow), human intervention (white arrows) and the themes for each area of the landscape (the darker the green bar, the more pertinent the theme)

T1: conservation of genetic resources; T2: livelihood systems; T3: forest management and restoration; T4: investments, value chain and overall sustainability; T5: landscape dynamics; T6: climate change and forest change. Source: Costa (2018), adapted from CIFOR (2011).

Financing implementation

Assessing the research data for the oldest demonstration plots of oil palm agroforestry, the costs and management practices of the cooperative's technicians and farmers, and the bank's assessment of the species indicated for modelling, allowed Natura, along with a financial institution, to develop the first spreadsheets in Brazil for financing oil palm agroforestry. Previously, for the first three years, in which farmers have the greatest need for investments, there was no way for them to obtain financial resources through banks. Now, however, the financial institution has an investment line for setting up agroforestry systems with oil palm.

Two spreadsheets were created for analysis. They differ in fertilizer inputs during implementation; the organic model includes 100% organic fertilizer and the mixed model includes a combination of organic (40%) and chemical (60%) fertilizer. Farmers who opt for the mixed model frequently increase the use of organic inputs throughout the cycle.

Due to the high cost of chemical inputs in recent years, the two spreadsheets showed similar profitability. There were large areas implemented in 2022 (approximately 40 to 50 ha each), where farmers chose to finance implementation with their own resources. Table 1 presents the more conservative spreadsheet, with mixed fertilizers. The main crops considered were oil palm, cocoa, black pepper and *andiroba* (*Carapa guianensis*, a timber tree also grown for the oil content of its seeds), with guaranteed purchase of cocoa and black pepper by the cooperative and of palm and *andiroba* oil by Natura.

Oil palm seedling. Photo: Natura Cosméticos

Table 1. Costs (Brazilian real, or BRL) for soil preparation, demarcation and seedlings, year zero

Use of the product / service	Description of the product	Unit	Quantity	Unit price	Total
Planting	Oil palm seedlings	unit	109.00	15.00	1,635.00
Planting	Cocoa seedlings	unit	571.00	1.75	999.25
Planting	Agroforestry seedlings (propagules)	unit	300.00	1.00	300.00
Planting	Agroforestry seedlings (seeds)	unit	40.00	20.00	800.00
Planting	Pepper seedlings	unit	326.00	3.00	978.00
Planting	Forest species seedlings	unit	26.00	2.50	65.00
Liming	Dolomitic clay	kg	1,000.00	0.50	500.00
Phosphate	Natural phosphate	kg	439.60	2.03	892.39
Soil survey and analysis	Soil analysis	unit	1.00	220.00	220.00
Soil preparation for planting	Tractor	hourly rental	10.07	300.00	3,021.00
Removal of wood stakes (marking for planting)	Agricultural day labourer	daily wage	5.48	75.72	414.95
Demarcation and picketing	Agricultural day labourer	daily wage	1.00	75.72	75.72
Land surveyor	Surveyor's daily allowance	daily wage	0.10	1,000.00	100.00
Total					**10,001.31**

Given these costs, and the challenge of finding financing mechanisms that meet the various profiles of farmers, there is an opportunity to consider carbon as another element in the financing of a transition from oil palm monoculture to more ecological production systems such as oil palm agroforestry, once good management practices are adopted to incorporate carbon and promote soil health.

In addition, insurance specific to agroforestry is being developed with a global insurance company, so that farmers are covered, especially in the face of the growing impacts linked to climate change.

Ways forward

The learning accumulated over the years working with oil palm agroforestry brings confidence, but does not eliminate the possibility of new challenges.

Expediting land and environmental regularization requires a concerted effort with government agencies to ensure that investments meet broader business and government demands, and do not leave out interested smallholder farmers who can benefit from inclusive agreements.

For the mechanization cost challenge, given the diversity of farmers, it is appropriate to consider viable alternatives that meet the needs of small and medium farmers who are already involved, based on local partnerships. New technologies are emerging all the time and CAMTA's technical team, Natura and new partners are aware of them.

Although there are decades of research and agronomic experience in oil palm monoculture, compared to only one full decade of oil palm agroforestry, it is certain that increasing ecosystem services is the only possible path to improve the world's most important vegetable oil chain, still so tied to and associated with environmental and social harm.

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Author affiliations

Camila Brás Costa, Biodiversity Specialist in the Natural Ingredients and Socioproductive Systems team, Natura Brasil, Benevides, Pará (camila.bras.costa@gmail.com)

Iguatemi Costa, Scientific Manager in the Natural Ingredients and Socioproductive Systems team, Natura Brasil, Cajamar, São Paulo (iguatemicosta@natura.net)

Mauro Costa, Senior Manager in the Relationship and Supply Group of Sociobiodiversity, Natura &Co, Benevides, Pará (maurocosta@natura.net)

Bruno Lima, Coordinator at the Sociobiodiversity Supply and Relationship Group, Natura &Co, Benevides, Pará (brunolima@natura.net)

Gisele Souza, Coordinator in the Natural Ingredients and Socioproductive Systems team, Natura Brasil, Benevides, Pará (giselesouza@natura.net)

Raoni Silva, Manager in the Relationship and Supply Group of Sociobiodiversity, Natura &Co, Benevides, Pará (raonisilva@natura.net)

Renovated *cabruca* area at the Boa Sorte Farm in Uruçuca, Brazil.
Photo: Pedro Santos

2.6

Cocoa agroforestry in Brazil through a public-private partnership

Pedro Zanetti Freire Santos, Jens Hammer, Michele Santos, Noemi Siqueira and Rodrigo Mauro Freire

"Cocoa produced in carbon-positive, biodiverse and regenerative agroforestry systems can be a commodity that generates urgently required income for small-scale farmers while driving the restoration of large areas of degraded forest landscapes in Latin America."

Introduction

Historically, Brazil has been one of the most important cocoa-producing countries in the world, and is currently the sixth biggest producer. Initially, cocoa production was concentrated in the Amazon region, where the cacao species is native and cocoa consumption has a history of more than 5,000 years. Since the 1970s, the production of cocoa, promoted by the Brazilian cocoa research institute, the Executive Commission for Cocoa Cultivation Planning (CEPLAC) in the newly colonized areas along the Trans-Amazonian Highway, has been increasingly replaced by extensive livestock farming. The production of cocoa shifted mainly to the state of Bahia, where cocoa was cultivated under the trees of the highly biodiverse Atlantic Forest in a type of agroforestry system known as *cabruca*. This brought considerable prosperity to the region. However, the economic boom was abruptly halted in 1989 by a fungal epidemic, Witches' broom disease (*Moniliophthora perniciosa*). Thus, Brazil became a net importer of cocoa beans. Since 1997, the Brazilian chocolate industry has imported an average of 50,000 tonnes per year from countries such as Côte d'Ivoire, Indonesia and Ghana to meet demand (Coslovsky 2023).

In the wake of sustainable development programmes and, more recently, with the emergence of the bioeconomy, interest in cocoa cultivation has been renewed in Brazil, especially when carried out in agroforestry systems. In the expectation that cocoa could become an alternative to unsustainable cattle-raising or unsustainably produced agricultural crops, many initiatives sprang up, often with international funding. Funders and the large industrial chocolate manufacturers have also recognized the potential of cocoa agroforestry to generate income and restore landscapes, and the manufacturers are playing an increasingly active role in promoting cocoa production in agroforestry systems by small-scale farmers in Bahia, Pará and elsewhere in Brazil.

In 2020, the Brazilian branch of the international food company Mondelez — accompanied by the German Agency for International Cooperation (GIZ) within the public-private partnership programme, develoPPP.de, of Germany's Federal Ministry for Economic Cooperation and Development — started the Sustainable Cocoa Production from Agroforestry in the Amazon and Atlantic Forest project to promote sustainable cocoa production in the country. The project aimed to build on Mondelez's Cocoa life programme (see Box 1), which pays farmers premiums and provides technical assistance on the condition that they comply with environmental regulations and adopt good agricultural practices.

Box 1. The Cocoa Life programme

Cocoa Life, Mondelez International's global programme, was launched in 2012 to secure a supply of more sustainable cocoa beans. The programme seeks to support cocoa producers and their communities through an integrated approach in three areas:

- Cocoa production as a prosperous business
  - The focus is supporting producers to increase their productivity levels and family income.
- Empowered cocoa communities
  - This component focuses on capacity-building activities targeting children, youth and women within cocoa communities to boost development through the promotion of entrepreneurship and education.
- Conserved and restored forests
  - The focus is to protect and restore the cocoa production landscapes where Mondelez sources from, in partnership with suppliers and communities.

The cocoa agroforestry project

Based on this approach, the project partners designed specific strategies for two regions: Bahia and Pará. In Bahia, together with the Cocoa Innovation Center (CIC), the project aimed to rejuvenate cocoa crops in over-aged *cabruca* stands. In Pará, the partnership joined The Nature Conservancy (TNC) Forest Cocoa initiative. Since 2013 the TNC initiative has promoted cocoa agroforestry systems as an alternative to livestock raising, and as a way to restore degraded pastureland. To achieve these goals, a number of innovative strategies and tools have been developed; these are detailed below.

Rejuvenation of cabruca *systems in southern Bahia*

The first cocoa seeds were brought to southern Bahia from Pará state in 1746. In the Atlantic Forest of Bahia, the plant found favourable conditions that allowed it to flourish: appropriate soil, tropical hot weather and plenty of rain (Souza Júnior 2018). Throughout the next 270 years, the cocoa agroecosystem in the region expanded, based on the *cabruca*, a traditional agroforestry system where the cocoa is cultivated beneath the canopy of big native trees. Currently, there are more than 69,000 producers and around 420,000 ha covered with cocoa in the region (AIPC 2023), at least 40% of which is cultivated in *cabruca* systems (Mapbiomas Cacau 2020). Unfortunately, most of these *cabruca* areas were abandoned or left with very little management after the Witches' broom crisis, leading to extremely low productivity levels.

To contribute to overcoming this problem, 32 long-term experimental plots were established on small farms to generate empirical evidence on rejuvenation strategies, including the testing of various clones and management practices (planting, pruning, fertilizing, irrigating, mechanization). The experiments in the Renova Cacau project demonstrated that proper pruning technologies and light management and other agricultural practices during and after the rejuvenation process, in combination with replacing old cocoa plants with genetically improved ones, allowed farmers to not only effectively control the Witches' broom disease, but also to increase cocoa production. The data generated indicate the possibility of increasing cocoa production from 300 kg/ha, the Bahia state average, to over 1,500 kg/ha (Ahnert et al. 2021). Investments in the recommended technologies have proved to be economically viable, with an internal rate of return (IRR) above 12%; this corresponds to an average income of USD 1,000/ha/year (WCF et al. 2021). This income is attractive to the mostly poor small-scale farmers in the region and may help to bring them out of poverty. It may also convince young people to stay on the farms while conserving the *cabruca* system, with its rich biodiversity.

These experiments resulted in both technical guidelines and demonstration sites for training small-scale farmers in Bahia in the possibilities of rejuvenating their *cabruca* forests. These products have been used to illustrate the alternatives to 2,000 farmers who have participated in on-field courses. Another 2,400 families benefitted from technical assistance from the technicians of the Intermunicipal Consortium of Southern Bahia (CIAPRA), which provided training not only in technical aspects, but also in other areas relevant to small-scale farmers, such as restoration techniques, financing, crop diversification, participatory facilitation skills, commercialization, and environmental registration (*Cadastro Ambiental Rural*, or CAR); the latter included a partnership with the state government to expedite the process, which is complex.

Cocoa agroforestry to restore degraded land in the state of Pará

The state of Pará currently has around 150,000 ha covered with cocoa, more than 18,000 producers and an average productivity level of almost 1,000 kg/ha; it is the second biggest producer in the country (AIPC 2023). But, at the same time, the state accounts for 42% of the total deforestation in the Brazilian Amazon since 2008 (Assis et al. 2019). The municipality of São Félix do Xingu, where the TNC cocoa agroforestry project has been implemented since 2013, has the second highest deforestation rate in the Amazon, most of it to create pastureland for cattle.

Aiming to revert this critical scenario, TNC — in partnership with the project consortium — encouraged more than 300 farmers to adopt cocoa agroforestry systems to restore degraded pastureland. Unlike the *cabruca* system, these agroforestry systems are typically established on deforested land and combine cocoa with other commercial crops, native and not, such as banana and açaí palm. The farmers also plant tree species for shade and for the production of timber and non-timber forest products, in accordance with the specific environmental conditions and the needs and preferences of the farmers. The efforts showed that restoring degraded land is possible but challenging. Initial costs to improve soil conditions are high, the process takes a long time, and there is a scarcity of family labour. In these situations,

Field days for smallholders in southern Bahia at one of the experimental plots of the Renova Cacau project, where youth and women are actively encouraged to participate. Photo: Pedro Santos

therefore, farmers might not dedicate their scarce labour to restoration activities unless they are supported with sufficient funding and technical assistance.

The establishment of agroforestry systems on medium- to good-quality soils, however, showed attractive financial results, with an IRR of around 15% and an average yearly income between USD 1,000 and 1,500/ha from cacao alone (WCF et al. 2021). This is more than six times the USD 150/ha/year that can be earned from cattle (Braga 2019).

The project also supported four local farmer organizations with participatory workshops and ongoing mentoring activities to strengthen their management capacities, including developing a business model and exploring commercialization opportunities for both the private and public markets. Additionally, following a request from the producers, the project offered a full-time six-month computer course to train users in basic informatics and digitization skills.

A highly biodiverse agroforestry system in Pará state, where several tropical fruit species, as well as native timber trees and trees that provide non-timber forest products, are planted together with cocoa. Photo: Pedro Santos

To strengthen the diversification strategies of agroforest producers, the project also conducted capacity-building activities for the municipal and state technicians involved in the purchase of local produce for school meals. In Brazil, municipalities and state and federal educational institutions are legally required to purchase at least 30% of school meals from local farmers (federal Law no. 11.947/2009). As a result, in 2022 the Women's Fruit Pulp Producer Association of São Félix do Xingu sold for the first time USD 50,000 in fruit pulp to the São Félix municipality, and expects to earn USD 70,000 in 2023. Selling the wide range of tropical fruits cultivated in the agroforests, together with cocoa, not only generated important extra income for the women; at the same time, it provided agroecological nutrients for the local children: a win-win scenario.

Another important achievement resulted from the work that TNC conducted with the Pará state environmental agency to develop and approve the state-level Normative Instruction No. 07, from 2019 (Portal legislativo 2019), which allows the implementation of agroforestry systems with cocoa to restore legal reserve areas. This provides an important motivation for farmers to restore the environmental conditions on their farms, because it reconciles legal requirements with the possibility of earning a good financial return.

In Pará state cocoa cultivation is mostly done by small-scale farmers and within agroforestry systems, 70% of which are in degraded areas (Venturieri et al. 2022). The recent expansion of cocoa agroforestry systems indicates the great potential of this commodity to become an important driver of large-scale forest landscape restoration in biodiversity hotspots such as the Amazon rainforest.

Challenges

The project tackled a number of structural challenges that hamper the spread of sustainable cocoa agroforestry in Brazil. For example, many small-scale farmers suffer from limited access to technical assistance and credit, partly due to the low availability of public services, but also because of a high degree of informality. In fact, convincing farmers to join the project was not easy, because they feared that the required official registration

Due to the legal insecurity of harvesting valuable timber from trees more than 30 years old in cocoa agroforestry systems of the Trans-Amazonian Highway, producers are cutting down the trees to cultivate cocoa under direct sunlight in a monoculture system, a recent trend that is growing rapidly in the region. Photo: Anderson Serra

of the land (CAR) would involve costs and reprisals by government authorities due to existing environmental liabilities. Setting up a more integrated assistance service — that combines technical, environmental and financial expertise at the level of cooperatives and municipal organizations — emerged as a promising approach to overcome these problems. Such an approach, however, would require financial and institutional support by the state and the federal government.

Another problem that the project experienced was the strong and exclusive focus of many stakeholders, such as government, private companies and landowners, on just one plant: cocoa. In some cases, agroforestry systems are promoted more as a way to produce cocoa than as an opportunity to diversify or for their associated potential for income generation, risk reduction, climate resilience and biodiversity conservation. And paradoxically, trees planted in agroforestry systems are subject to legal insecurity; they can be legally harvested by the farmer under the existing forestry law, since the necessary steps to obtain a timber-cutting permit are unclear and confusing. This neglect of products other than cocoa encourages the current trend of growing cocoa in direct sunlight outside of agroforestry systems, resulting in a dramatic decrease in the environmental value of cocoa production.

Key lessons learned

The tools and strategies developed in this project have been adopted by several cocoa agroforestry initiatives in Bahia state and in the new cocoa-growing areas along the Trans-Amazonian Highway, where the number of cocoa farmers supported by different initiatives, including government and NGOs, will increase to more than 3,000 over the next year. However, this success should not obscure the fact that many challenges still need to be overcome in order for small-scale farmers in Brazil to establish and maintain financially attractive, biodiverse and sustainable cocoa agroforestry systems that generate income while restoring and maintaining soil fertility and biodiversity.

In addition to informality, lack of technical assistance, and difficulties in access to credit, there is a widespread lack of skilled and unskilled labour. Also, value chains for the other products from agroforestry systems need to be developed, and the necessary legal steps to obtain a licence to harvest the timber from trees in the agroforestry system need to be clarified by the government. Institutional markets, such as the one for school meals mentioned above, could be important in promoting diversification, but this requires systematic efforts in capacity building for municipalities as well as producers.

Cocoa agroforestry with açaí palm, rubber tree (*Hevea* sp.) and Brazilian mahogany in Pará, Brazil. Photo: Pedro Santos

Recently, new due diligence initiatives in Europe have increased the pressure for product traceability down to the plot level. Attributes such as no deforestation, no slave labour or child youth labour, fair wages for workers and a living wage for producers are all critical to the future of sustainable cocoa production. However, considering that 80% of Brazilian cocoa is still marketed informally by intermediaries, it is uncertain how or even if these new requirements can be implemented without putting further pressure on the weakest element of the value chain: small-scale farmers.

Conclusions

Harnessing the potential of cocoa production in agroforestry systems for sustainable local development in Brazil depends mainly on two actions:

- Valorizing the immense product diversity of cocoa agroforestry systems (firewood, timber, fruits, oils, nuts and seeds, fibres, cosmetics) to discourage farmers from cultivating cocoa in direct-sunlight monocultures.
- Establishing a support system (at the level of cooperatives and municipal organizations, or through the private sector) that assists farmers not only in the production of cocoa, but also in the other aspects of agroforestry, and in the entire set of legal, environmental and technical issues relevant to becoming successful and sustainable.

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Author affiliations

Pedro Zanetti Freire Santos, Technical assessor, GIZ Brazil, Ilhéus, Brazil (pedro.zanetti@giz.de)

Benno Pokorny, Director, GIZ Brazil, Brasília, Brazil (benno.pokorny@giz.de)

Jens Hammer, Cocoa Sustainability lead, Mondelez International, Curitiba, Brazil (jens.hammer@mdlz.com)

Michele Santos, Cocoa Life Brazil Program Supervisor, Mondelez International, Curitiba, Brazil (michele.Santos@mdlz.com)

Noemi Siqueira, Cocoa Florest Project Manager, The Nature Conservancy, São Paulo, Brazil (noemi.siqueira@tnc.org)

Rodrigo Mauro Freire, Brazilian Amazon Private Areas Lead, The Nature Conservancy, Belém, Brazil (rfreire@tnc.org)

General view of a traditional *caíva* area (without pasture management), in the northern region of Santa Catarina State, southern Brazil, in remnants of araucaria forest. Photo: Ana Lúcia Hanisch

Improving an agroforestry system with livestock in southern Brazil

Ana Lúcia Hanisch

"Caívas are areas where the remnants of araucaria forest have been conserved for the purpose of animal herding and harvesting of yerba mate (Ilex paraguariensis)."

Agroforestry systems around the world have been valued for their environmental and cultural importance, but there is still a large gap (almost a taboo) in the economic valorization of these systems, especially in terms of increasing their productivity.

In southern Brazil, a type of agroforestry called *caíva* has existed for more than a century. This is a rural property where the remnants of *araucaria* forest have been conserved for the purpose of animal herding and harvesting of yerba mate (*Ilex paraguariensis*; Mello and Peroni 2015; Lacerda et al. 2020; Tomporoski et al. 2022). As an agroforestry initiative that involves native trees, cattle herds and pastures, it is classified as a silvopastoral system (see photo above).

Although *caívas* occupy more than 100,000 ha in the northern region of Santa Catarina State and a similar amount of land in Paraná State, factors

***Caíva* after adoption of Epagri technologies to improve pasture production, Canoinhas, Santa Catarina, southern Brazil. This includes planting of the shade-tolerant perennial pasture *Axonopus catharinensis* overseeded with ryegrass.**

such as legal insecurity, low economic yield and difficulties in management have led to the loss of thousands of hectares of this system, with enormous costs to biodiversity. One of the limitations in the maintenance of these systems is low animal productivity, which in turn is associated with, among other factors, the inadequate management of the native pasture vegetation.

Despite being productive systems, with the almost constant presence of cattle, *caívas* contribute to maintaining a significant forest cover in the region, maintaining rare tree species and even some species threatened with extinction. Surveys conducted in *caívas* have confirmed high levels of tree species richness (an average of 40 species), with a density ranging from 220 to 1,300 adult trees per hectare (Hanisch et al. 2010; Mello 2013; Pinotti et al. 2018), which confirms the importance of this traditional silvopastoral system to forest conservation.

In these systems, livestock usually graze on native pasture vegetation that forms the herbaceous stratum, without grazing control or soil fertilizing. Consequently, pasture yields are low and cease completely during the autumn and winter months, which results in a low stocking rate of 0.35 animal unit/ha (Hanisch et al. 2014). Such a situation is not economically attractive to smallholders, resulting in pressure on *caíva* landowners to replace this system with more profitable alternatives, such as reforestation with exotic species or annual commodity crops (Lacerda et al. 2020).

To address this situation, the Agricultural Research and Rural Extension Company of Santa Catarina State (Epagri), in partnership with several other entities, has been conducting research since 2006 on *caívas*. The results of the technologies that developed from this research have already shown that it is possible to increase animal production by up to 400% in this system, with maintenance of the tree stratum, active forest regeneration, and legal certainty over properties, all of which mean a significant increase in income for families (Hanisch et al. 2021). Environmental benefits occur because the first phase of adopting the technology is to set aside permanent preservation areas and prevent livestock from having access to them.

The technologies developed by Epagri are based on five activities:

1. selection of perennial pastures adapted to shaded areas, so as not to have to cut down native trees;
2. planting of improved pastures adapted to shaded areas (*Axonopus catharinensis*) without soil disturbance, in order to maintain the stock of organic matter and avoid the germination of the seed bank, with the use of herbicides only in the initial phase;
3. soil liming and annual fertilizing of the pasture with applications of organic and mineral sources (top dressing);

4. rotational grazing with pasture height control for animal entry and exit;
5. in the autumn/winter period, overseeding with ryegrass and clover — the areas thus remain productive for more than 300 days each year, with a capacity to support two animal units/ha and to conserve the tree stratum of the forest remnants.

A key step prior to the adoption of these technologies is the selection of a suitable area for *caiva*. In this regard, the main factor is shade provided by the trees. Only *caivas* that naturally have little shade are selected. It is important to realize that, as agroforestry systems in remnants, *caívas* have heterogeneous forest covers. They are classified according to the openness of the canopy: forest, closed *caívas*, open *caívas*, very open *caívas* and *potreiros*, or native pasture vegetation with a few native trees (Marques et al. 2019; see Figure 1).

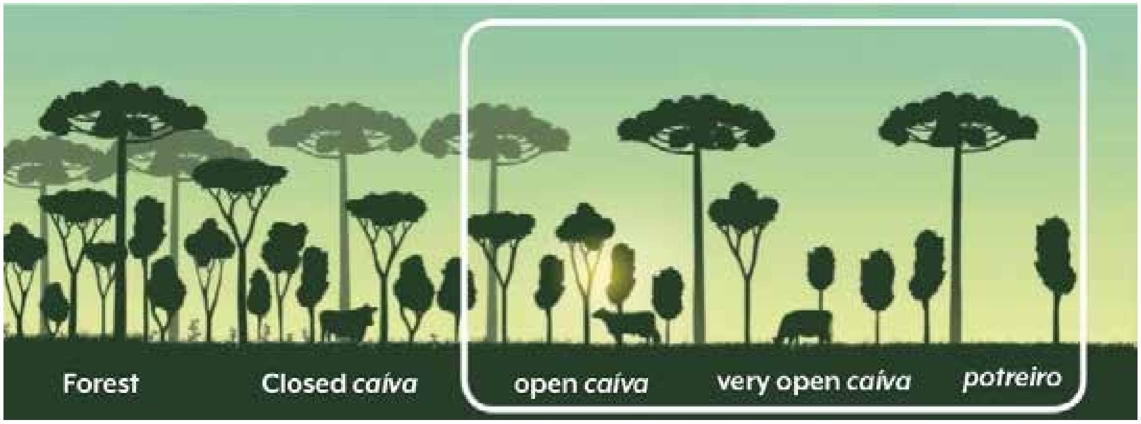

Figure 1. Gradient of shading in *caivas* with different forest covers, from a forest area (with many trees) to an open pasture area with few trees (*potreiros*)

Adopting the strategies of pasture improvement, soil liming and annual fertilization with rotational grazing can occur only in the open and very open *caívas*. This will bring significant results in increasing pasture production and, consequently, in animal production (Hanisch et al. 2022). In other types of *caívas*, it is suggested that they be used for the preservation and provision of ecosystem services.

Research on *caivas* improvement is helping to show that it is possible to conserve forests and generate income with increased productivity. A question that is always asked when the results of increased animal production are presented is: But don't animals eat forest seedlings, compromising forest conservation? First, it is important to remember that the animal has been part of the system for dozens of years, and its presence is important to keep the areas clean of weeds. This facilitates the harvesting of the yerba mate that grows in these systems. And second, with the increase in forage availability that results from the adoption of Epagri's technologies, it is possible to increase the animal load without compromising forest regeneration (which is very active in the fallow areas). This is because animals do not consume tree shoots when there is pasture available (Pinotti et al. 2020; Hanisch et al. 2021).

Epagri is completing 17 years of continuous research, with increasingly encouraging results and with its practices already adopted by dozens of families. Its work has been published in national and international journals and has received several awards and recognitions. Research will continue to face many challenges, but also have many achievements.

Research is based on the premise that the country's research and development sector needs to develop technologies for the farming families who have conserved the forest remnants through utilization. Much has been done and researched on how to recover degraded areas, but very little is invested in agroforestry systems with conservation potential. These now need to be adapted to the purposes of increased production in order to generate income for families.

Research on complex systems such as agroforestry requires medium- and long-term financial resources, as well as multidisciplinary teams, with a focus on productivity and environmental conservation. There is a great demand for the generation and diffusion of technologies for farmers who conserve their forests through using them as agroforestry systems. It is hoped that this technology for pasture improvement in *caívas* will be an important aid in the process of valorization of these systems, and that it will contribute to the generation of income, better working conditions and environmental conservation in rural properties in southern Brazil.

Finally, it is essential to ensure that the valorization of the *caívas* as areas of environmental use and conservation through strategies for their productive improvement does not contradict the need to maintain permanent preservation areas and to create areas for the exclusive purpose of conservation of the mixed *ombrophilous* forest landscapes.

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Author affiliation

Ana Lúcia Hanisch, PhD, Agricultural Research and Rural Extension Company of Santa Catarina (Epagri), Experimental Station of Canoinhas, Santa Catarina, Brazil (analucia@epagri.sc.gov.br)

Yerba mate field, Argentina. Photo: Marcelo Javier Beltran

2.8 The Argentinian experience with yerba mate in agroforestry

Luis Colcombet, Paola Gonzalez, Sara Barth, Marcelo Javier Beltran and Guillermo Arndt

"Due to this multitude of positive environmental and ecosystem services, agroforestry practices may directly contribute to the achievement of a number of United Nations Sustainable Development Goals."

Introduction

Climate change mitigation and food security are two of the main challenges in today's societies. Agroforestry — defined as the presence of trees on cropland, as external and internal boundaries and on any other available niche of farmland — can provide both food and climate change mitigation. As an agroecosystem that combines trees with farming practices, agroforestry has the potential to increase both biomass and soil carbon while maintaining agricultural production (Cardinael et al. 2017). There are several types of agroforestry systems, with different rates of above-ground and soil carbon sequestration (Corbeels et al. 2019). Agroforestry also contributes to water quality improvement, biodiversity enhancement, erosion control and nutrient cycling and availability (Dordel 2009; Varah et al. 2013).

Left: Yerba mate nursery; right: Yerba mate adult plants in production. Photos: Marcelo Javier Beltran

Due to this multitude of positive environmental and ecosystem services, agroforestry practices may directly contribute to the achievement of a number of United Nations Sustainable Development Goals (SDGs): 2 (no hunger), 7 (renewable energy), 11 (sustainable cities and communities), 12 (responsible consumption), 13 (climate action), 15 (life on land), and — often neglected — 17 (partnerships for the goals). It may also benefit other SDGs indirectly (Hübner et al. 2021).

Yerba mate

Yerba mate, or YM (*Ilex paraguarensis*) is a tree species approximately 15 metres (m) tall native to South America. It occupies the medium stratum of the continent's Atlantic Forest. The tree is endemic to eastern Paraguay, Misiones Province in Argentina and the southern Brazilian states of Rio Grande do Sul, Santa Catarina and Paraná (Giberti 2011). It is found in natural association with *Araucaria angustifolia* and *Ocotea* sp. The soils in the region are acidic (pH 5–6) old oxisols, and actual fertility depends greatly on the availability of organic matter.

The dried YM leaves are used for a traditional infusion that is sipped with a straw; this goes back to pre-Hispanic times. Jesuit priests learned how to grow the trees and planted them in plantations as far back as 1704. The infusion can be drunk with hot water (*mate*) or cold water (*terere*). The infusion can also be prepared as a tea.

During the last decades, new products have emerged, such as dehydrated powder to prepare "instant mate."

The small branches and leaves of YM are traditionally harvested during the southern hemisphere's fall and winter, between April and August. The drying process typically involves two stages. The first consists of passing the leaves and small branches (less than 10-mm diameter) through direct flames. This stage, known as "cracking," decreases moisture to 33% and sterilizes the leaves. The second stage consists of conventional drying at temperatures between 90 and 120°C for 2.5 to 4.5 hours under direct heat (hot air with smoke) or indirect heat (heated air through a heat exchanger). This is followed by maturation and finally by grinding and packaging. In Brazil, most YM is ground, packaged and marketed immediately after drying and must be consumed within two months. In Paraguay and Argentina, the leaves are matured in a dry dark building for a minimum of six months and, ideally, 12 to 18 months. During this period an oxidation process occurs, adding a golden yellow colour to the leaves and resulting in a less strong taste, which consumers in these countries especially appreciate.

There are two main strategies for YM production: a) large-scale farms based on the use of fertilizers and economies of scale (mechanical harvest, intensive management); and b) niche markets involving diverse special tastes, blends, sustainability and agroforestry landscapes.

Traditionally, YM was harvested by climbing the trees every two to three years in forest stands with naturally high proportions of trees and cutting the ends of branches with leaves. Cultivation of the trees increased during the 19th century in agroforestry arrangements that included *Araucaria* trees, and in association with cattle-raising in the Santa Catarina, Río Grande do Sul and Misiones highlands. In 1924, seeking higher productivity and easier ways to harvest the leaves, large-scale "open sky" monoculture plantations were established. Managing 1.5 m–2.5 m bushes instead of the native trees, which are approximately 15 m tall, eliminated the need to climb the trees to harvest the leaves, which could be dangerous. And by observing leaf-sprouting patterns, researchers and farmers have also found ways to increase the proportion of thin branches and leaves to be harvested. Initially, 600–1,200 bushes per ha were recommended. During the late 1970s and 80s, however, the recommended density increased to 2,200 bushes per ha. The last two decades have seen a slowly increasing interest in mechanized harvesting, with a recommended density of 2,700–4,000 trees per ha to facilitate a very high proportion of leaves in the harvest.

During the last two and a half decades, there has been increasing interest in high-quality YM grown in more natural, sustainable and shaded conditions, and in developing energizing beverages. Today, in Misiones Province, 16,000 farmers cultivate 182,000 ha of YM yielding 276,000 tonnes of dry leaves yearly; this is their main source of income. Of the farmers, 85% are smallholder who manage only 10% of the total crop volume. Of the dried YM, 10% is exported to a growing market in Europe, the USA and the Middle East. In the first two markets, consumption is boosted by South American expatriates and by the growing interest in healthy drinks. In the Middle East, where the culture of sipping mate is surprisingly blending in, Syria is the country with the highest YM imports.

Yerba mate agroforestry in Argentina's Misiones Province

Back in the 1930s, the immigrant farmer Alberto Roth, who admired the Swiss naturalist Moisés Bertoni (who had emigrated to the Upper Paraná river region in Paraguay,) observed that YM under naturally occurring *Araucaria angustifolia* trees grew better than under open-sky conditions. This was the start of promoting an agroforestry practice for YM. Later, in the 1980s, Juan Kozarik, Santiago Lacorte, Florencia Montagnini and other researchers working in the region noted the contribution of trees in agroforestry and silvopastoral arrangements to maintaining soil fertility and carbon sequestration, and even to sustaining and increasing crop and animal yields, when properly managed. Later, other researchers (Fernández et al. 1997) demonstrated that the level of some soil nutrients in YM plantations can be higher under trees than under conventional open-sky plantations. Julia Dordel (2009), working with nurse (shelter) trees in mixed tree plantations, demonstrated that *Grevillea robusta* doubles the availability of phos-

Left: Mate *bombilla* (drinking straw), package of dried Yerba mate leaves and ready-made drink; right: Argentinian woman sipping mate. Photos: Marcelo Javier Beltran

Left and right: Santo Pipó agroforestry trial; centre: views and farmers' visit. Photos: P. Gonzalez

phorus in the soil and in the leaves of the sheltered species *Toona ciliata*. A silvopastoral demonstration plot in Tres Capones, Misiones, also showed a 50% increase in forage from *Axonopus catarinensis* grown under *Grevillea robusta* trees compared to traditional open-sky pastures (Colcombet et al. 2019).

The effect of shading on YM yield and quality was studied in a trial growing YM under the trees *Grevillea robusta, Fraxinus* sp. and *Peltophorum dubium* (Prat Kricun and Kuzdra 2011). Results showed a 15% higher YM yield under *Grevillea robusta* after seven years. This seems to reject an initial hypothesis that YM needs to be grown under deciduous trees, since *Grevillea robusta* is an evergreen species. The trial also pinpoints the possibility that YM is benefiting from the *Grevillea robusta* effect on soil phosphorous, which may offset the depressive yield effect from possible excess shading.

A YM trial plantation simulating 0, 30, 50 and 70% shading indicated a tendency to reduced yield under increased shading. However, no clear statistical relationship between shading and YM yield was found in a YM trial under the tree species *Peltophorum dubium, Cordia trichotoma, Parapiptadenia rigida, Balfourodendron riedelianum, Handroanthus heptaphyllus, Grevillea robusta, Toona ciliata, Araucaria angustifolia* or *Paulownia tomentosa* on the farm of Luis Comoli, Santo Pipó, Misiones Province (Munaretto et al. 2019).

Shading could also influence YM leaf quality. As a rule, plants tend to intensify the production of secondary metabolites and essential oils when subject to shading; this can affect flavour. Although a few YM processors affirm that shaded YM has a preferred taste that consumers recognize by paying a higher price, chemical analyses have not revealed any clear tendency.

Tree shading is also said to facilitate fungi development in situations where ventilation is poor, resulting in high relative humidity. However, the years 2021 and 2022 provided climatic conditions that tell a different story. From February 2021 to January 2022, rainfall was less than 900 mm in the Misiones area; it is normally about 1,900 mm. These dry conditions were exacerbated during the November 2021 to February 2022 period by record high temperatures combined with record low (under 30%) relative humidity. During this period, up to 70% plant mortality associated with leaf burn was reported in open-sky YM plantations under eight years of age, while there was next to no mortality in YM under agroforestry (Colcombet et al. 2019).

Conclusions

According to the experiences in Misiones Province, no significant negative effects of shading were observed, either direct or indirect (i.e., leading to a greater proliferation of diseases) in YM yield. Moreover, in some cases, a positive effect of the shade trees was observed, in protecting the YM from extreme hot and dry conditions, and generating up to a 15% yield increase compared to full-sun conditions. This is likely due to the sheltering effect of the trees in the integrated environment of the YM-trees agroforestry association. This supports the argument that YM can grow sustainably in agroforestry systems. Nevertheless, a good understanding of these interactions is still necessary to support YM sustainable management in agroforestry. This could also lead to innovative marketing strategies, in a market valued at USD 270 million per year in Misiones Province alone.

The I 049 Agroforestry project from the National Institute of Agricultural Technology (INTA), which started in July 2023, will include a statistical trial with four repetitions to study the effect of trees on soil fertility and YM yield, sanitary status and leaf properties and taste, in paired agroforestry arrangements with or without *Araucaria angustifolia* shading trees. This should allow the institute to build capacities and generate better recommendations for YM agroforestry farming in Argentina and the region.

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Author affiliations

Luis Colcombet, National Institute of Agricultural Technology (INTA), Agricultural Experimental Station of Montecarlo, Misiones, Argentina (colcombet.luis@inta.gob.ar)

Paola Gonzalez, National Institute of Agricultural Technology (INTA), Agricultural Experimental Station of Montecarlo, Misiones, Argentina (gonzalez.paola@inta.gob.ar)

Sara Barth, National Institute of Agricultural Technology (INTA), Agricultural Experimental Station of Montecarlo, Misiones, Argentina (barth.sara@inta.gob.ar)

Marcelo Beltran, INTA, Soil Institute, Castelar, Buenos Aires, Argentina (beltran.marcelo@inta.gob.ar)

Guillermo Arndt, INTA, Agricultural Experimental Station, Misiones, Argentina (arndt.guillermo@inta.gob.ar)

Section 3
Africa

Previous page: Agroforestry with cocoa field in Bafwapada village, Bafwasende territory, DRC. Photo: Annie Beko

Homestead agroforestry and storage of animal feed in Hawzen.
Photo: Relief Society of Tigray (REST)

Contributions of homestead agroforestry during the war in Tigray, Ethiopia

Mitiku Haile, Desta Gebremichael, Halefom Gebrekidan, Dawit Gebregziabher, Girmay Darcha and Woldemariam Gebreslassie

"Through homestead agroforestry, households can meet their energy needs, enhance food production, generate cash income, produce animal feed, and enhance agrobiodiversity, thereby improving their livelihoods."

Introduction

Forest and land degradation is among the major problems in Ethiopia's Tigray Region. Forest degradation is caused by conversion of natural vegetation to agricultural lands; this is driven by rapid population growth and unplanned settlement and resettlement. Land degradation contributes to the decline of agricultural productivity and to food insecurity and rural poverty. It also affects the type of plants grown, the availability of surface and subsurface water, and biodiversity.

To address these problems, governmental and non-governmental organizations over three decades have established exclosures (closed off areas) in degraded forests and communal grazing lands to allow natural regeneration. The aim of the exclosures was to minimize human

Homestead agroforestry activities with trees at Abreha We Atsbeha, Ethiopia. Photos: Relief Society of Tigray (REST)

activities through implementing a range of physical and biological soil and water conservation structures and by mobilizing communities for massive tree planting in various watersheds. These concerted efforts significantly enhanced environmental recovery and the regreening of degraded landscapes, reduced soil erosion and increased the recharge of surface and subsurface water. Despite such measurable and verifiable achievements, however, several challenges remain. They include low survival and growth of transplanted seedlings, minimal economic gain and scarce equity, with biased benefit sharing and ownership. These factors undermine landscape restoration success in Tigray. And in addition to these challenges, the war that began in Tigray in early November 2020 has created human catastrophe and massive destruction of forest resources for firewood and for military purposes (Deckers et al. 2020).

As a result, it was not possible to implement watershed-level communal plantations in Tigray. As an alternative option, farmers established homestead agroforestry in the area near their residences. Homestead agroforestry is an integrated tree-crop-animal production system that is established on small parcels of land surrounding homesteads and managed by family labour (Kumar and Nair 2004). In Tigray, several farmers who practise agroforestry have been traditionally managing their homesteads through various efforts, such as planting trees, cultivating naturally growing trees and shrubs through farmer managed natural restoration (FMNR), improving soil management through soil and water conservation, planting vegetable and fruit gardens, keeping livestock, and beekeeping. Most of these farmers have benefitted from the products from their homestead, such as firewood, construction wood, nutritious food, animal feed and cash income. However, there is no strategy document, guide or manual for homestead agroforestry available to farmers.

Assessing homestead agroforestry

The Relief Society of Tigray (REST) established a team of experts from Mekelle University's College of Dryland Agriculture and Natural Resources, Tigray Agricultural Research Institute and REST to conduct an assessment of farmers' experience with homestead agroforestry practices. Financial support to conduct the assessment was provided by the Development Fund of Norway. The team was provided with a terms of reference prepared by REST. Project coordinators gave an orientation to team members on the objectives of and ways to conduct the assessment.

A desk study by the team members reviewed literature on homestead agroforestry and developed a survey questionnaire. The questionnaire covered issues such as the contributions of homestead agroforestry, including income, food and energy. It also covered the strengths of and challenges to the implementation of homestead agroforestry, and the remedies to address these challenges. A checklist was also developed for group discussions with farmers and experts. To build consensus, validation of the questionnaire and checklist was conducted by the relevant sectors within REST. To gather the required information, 32 beneficiary households, including model farmers, were included in the assessment survey. Model farmers are those who introduce new crops, techniques and technologies to other farmers in the village. Model farmers were included in the assessment because they are believed to have the most experience with homestead agroforestry in the region.

Contributions of homestead agroforestry

If farmers' crops are looted or damaged and their livestock are looted or slaughtered, it is difficult for them to maintain their livelihood. Farmers needed to search for other sources of livelihood. Homestead agroforestry has greatly contributed to addressing this problem. The various types of tree species found in homestead agroforestry provide a range of benefits that include food, charcoal, firewood, construction material and farm implements; they also provide ecosystem services, supporting soil health and soil fertility and reducing soil erosion. Homestead agroforestry can contribute to improving the microclimate and enhancing beautification, and has the potential to increase carbon sequestration. It also promotes agrobiodiversity. Some contributions of homestead agroforestry are specific to times of war, such as shelter from shelling and to hide valuable household items from looters. However, this article focuses on the contribution of homestead agroforestry to income, food and energy during the war in Tigray.

A source of cash income

In addition to their home consumption of agroforestry goods, homestead agroforestry practitioners generate significant income from selling firewood, charcoal, irrigated crops, vegetables, spices and fruits (irrigated and not). *Eucalyptus camaldulensis* and *Eucalyptus globulus* are the well-known introduced species used for generating income from the selling of firewood and charcoal. Fruits from *Mangifera indica* (mango) and *Ziziphus spina-christi* (known as *geba*) are consumed by farmers and sold to generate income at the farm gate or in nearby markets. Most of the farmers visited during the assessment were growing fruits and vegetables at their homesteads for earning cash income. Income was also generated from selling the leaves of *Rhamnus prinoides* for local beverage making and social gatherings. The income generated from these products ranges from none (i.e., farmers use them only for home consumption) up to ETB 455,000 (Ethiopian birr; USD 9,100) per year, in the case of a model farmer. The average yearly income of the surveyed households who practise homestead agroforestry was ETB 33,882 (USD 678).

The tree that saved lives

In times of war, coupled with sieges and blockades, communities are displaced, or move to protect themselves from attack. By the time they come back to their residence they do not find what they left. Goods have been looted, burned or taken away. As a result, it becomes difficult to sustain a livelihood in the original

Homestead agroforestry activities with vegetable crops and livestock at Abreha We Atsbeha, Ethiopia.
Photos: Relief Society of Tigray (REST)


Homestead agroforestry products include firewood. Photos: Relief Society of Tigray (REST)

residence. Farmers had two options: either to move to another area to find food, or if they remained in their residence, to depend on food items considered as famine food or wild food. Items not commonly eaten before, such as the fruits of *Ziziphus spina-christi* (*geba*), can become staple foods. This tree species can thus be considered a risk management option for individuals affected by war. For many people who were forced to remain in their residence because of uncertainties if they moved to another place, the fruit of *Ziziphus spina-christi* saved their lives. It was also frequently given as a gift to relatives elsewhere. As a result, people named it "the tree that saved lives."

Many stories are available about the tree. A farmer from Seharti Samre District who was displaced from his residence came back when the place became safer. However, his house was damaged, and three tonnes of maize and sorghum had been looted. Fortunately, his house was surrounded by an area of homestead agroforestry with many *Ziziphus spina-christi*. His entire family could be fed, and their lives saved.

A source of energy

The effects of war resulted in extreme poverty for many farmers. This forced farmers to sell firewood and charcoal as a coping strategy. In addition, urban residents who relied on electricity were frequently cut off from the electricity grid. This forced them to shift to biomass energy sources such as firewood and charcoal. Eucalyptus trees, which are commonly grown in homestead agroforestry, became one of the major sources of biomass energy for urban dwellers.

The conflict in Tigray has created human devastation and massive destruction of forest resources for firewood (Deckers et al. 2020). Moreover, despite local bylaws and regulations against cutting vegetation in exclosures, communities that were greatly affected by the war and cut off from alternative energy sources such as electricity for cooking turned to local sources of wood. Remote satellite sensing images confirmed the pressures that this energy crisis put on trees and shrubs (Schulte to Bühne et al. 2022). However, a large part of this biomass energy came from trees grown in homestead agroforestry gardens, thus reducing the pressure on forests.

Major supports for homestead agroforestry

Homestead agroforestry is not new in Ethiopia. It is a well-known practice in several regions of the country. This means the development of homestead agroforestry in war-affected Tigray can rely on several positive factors:

- government's previous experience with homestead agroforestry;
- support from NGOs;
- committed leaders and community members;
- availability of research and higher education institutions;
- availability of roads and electricity;
- extension support through skilled experts;
- experience of farmers with homestead agroforestry;

- a suitable agroecological zone;
- existing linkages with microfinance providers; and
- availability of private nursery sites.

Major challenges to homestead agroforestry

Nevertheless, some challenges will have to be faced by farmers and other stakeholders when developing homestead agroforestry:

- trauma at all levels as a result of war;
- shortage of water and free grazing areas;
- shortage of agricultural inputs such as seeds, fertilizer and chemicals;
- shortage of an active labour force in some households;
- insufficient technical support, monitoring and evaluation;
- shortage of funds for private homestead agroforestry; and
- absence of a strategy document, guide or manual for homestead agroforestry.

Remedies to address the challenges

These challenges can be addressed with the following initiatives:

- provide training in war trauma healing at all levels;
- improve the supply of agricultural inputs to farmers;
- together with stakeholders, develop a strategy document, guide or manual for homestead agroforestry;
- develop alternative water-harvesting structures such as water tanks, and harvest rainwater;
- strengthen technical support, monitoring and evaluation; and
- plant drought-resistant seeds and seedlings.

Recent advancements

Homestead agroforestry has been practised in the region for many years. During two years of war, it was impossible to implement soil and water conservation or watershed-level seedling plantations in areas distant from homes, mainly because of security problems. Homestead farming was considered not only an option, but mandatory. As part of this, REST implemented the Food Security and Livelihood Recovery Support for War-affected Communities in Tigray project, funded by the Development Fund of Norway. The project was implemented in five districts affected by war. One of the options was establishing a homestead woodlot plantation as an alternative livelihood strategy. Compared to the previous watershed-level communal plantation, this practice has contributed to resolving the ownership problem (i.e., farmers did not own the trees in the plantation) because in this project, tree seedlings were chosen and selected by the farmers and were planted in their homesteads. This practice, coupled with proper pit preparation, moisture-conserving structures,

Adjacent households with (left) and without (right) homestead agroforestry in Hawzen, Ethiopia. Photos: Relief Society of Tigray (REST)

post-planting management (such as fencing, manuring, watering, continuous monitoring and other measures), contributed to improved growth of the multipurpose seedlings.

As part of the project, two cluster workshops were organized with district leaders, natural resource management experts, researchers and farmers. These workshops enabled farmers to share their experience. The district leaders clearly supported homestead agroforestry and showed their commitment to consider it as their priority agenda. Moreover, the concept was presented to the regional Agricultural Task Force at the Bureau of Agriculture and Natural Resources. The presentation focused on the importance of homestead agroforestry and the need to support it by developing a good strategy document and a guide or manual, together with stakeholders.

Conclusions

No household should fail to adopt agroforestry practices. There are several reasons why this should be a priority among stakeholders engaged in homestead development in Tigray:

- Through homestead agroforestry, households can meet their energy needs, enhance food production, generate cash income, produce animal feed, and enhance agrobiodiversity, thereby improving their livelihood.
- It is important to develop a regional strategic document on family-based integrated homestead development in order to contribute to policymaking.
- Practising homestead agroforestry can reduce pressure on communal forest resources and curb deforestation.

These efforts could be assisted through providing technical support, appropriate financing and capacity strengthening, as well as enabling legal, institutional and policy frameworks. The strategic document (or a guide or manual) should be disseminated to the stakeholders in homestead agroforestry in order to support successful implementation.

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Author affiliations

Mitiku Haile, Professor of soil Sciences and Sustainable Land Management, Mekelle University, Mekelle, Tigray, Ethiopia (gualmitiku@gmail.com)

Desta Gebremicheal, Director of Natural Resource and Agricultural Development, REST, Mekelle, Tigray, Ethiopia (destagbr@gmail.com)

Halefom Gebrekidan, Natural Resource Management Program Manager, REST, Mekelle, Tigray, Ethiopia (Gebrekidan_halefom@yahoo.com)

Dawit Gebregziabher, Assistant Professor of Forest and Resource Economics, Mekelle University, Mekelle, Tigray, Ethiopia (dawitom35@gmail.com)

Girmay Darcha, Researcher in Forestry and Agroforestry, Tigray Agricultural Research Institute, Mekelle, Tigray, Ethiopia (girmaydarcha2007@gmail.com)

Woldemariam Gebreslassie, Bureau of Agriculture and Natural Resources, Mekelle, Tigray, Ethiopia (Weldeg612@gmail.com)

FMNR *Faidherbia* parkland in Baribsi.
Photo: Jean Charles Bambara

Farmer managed natural regeneration to reconstitute agroforestry parklands in Burkina Faso

Jean Charles Bambara

"Farmer managed natural regeneration offers agronomic, environmental and socioeconomic benefits."

Introduction

Burkina Faso faces accelerated degradation of its natural resources as a result of the combined effects of natural and human-caused factors (inappropriate farming practices, bush fires, wood cutting, extension of agricultural areas, etc.). The province of Passoré, in the Nord Region of the country, is in an arid zone and regularly experiences food insecurity. Climate change impacts are exacerbated by strong anthropogenic pressures, overexploitation of land, deforestation, rural exodus and poverty (Kaboré et al. 2019). The successive droughts of the 1970s and 1980s that affected the Sahelian countries left their mark on this province, including a negative impact on the soil. Rainfall — around 600 to 900 mm annually — is insufficient and irregular (Conseil régional du Nord 2018). Very low agricultural yields expose populations to the spectre of famine (INSD 2022). Vegetation is severely degraded as a result of over-exploitation.

To address these problems, farmers have for many years been developing initiatives based on local knowledge and traditional practices. These include traditional agroforestry systems, known as agroforestry parklands (scattered trees in cropland) and water and soil conservation techniques such as stone barriers, *zaï* (pits to catch water and concentrate nutrients) and half-moons. Many specialists advocate a return to these ancient agroforestry practices (e.g.,Torquebiau 2022), which are seen as a way of bridging the gap; i.e., reconciling agriculture and the environment. For a long time public agricultural policies considered trees an obstacle to mechanization (Dupraz and Liagre 2011). But the adoption of these local practices requires high levels of conviction and motivation (Akrich et al. 2006). Some NGOs are involved in promoting these practices, as a project manager at Solidarité et Entraide Mutuelle au Sahel (SEMUS), a local development association based in Yako, explains:

> *"In the project, we encourage agroforestry because it also helps to safeguard certain species that were on the verge of extinction. It's the only way to safeguard these species. Otherwise, here in the village, we're going to reach a point where our children won't even know what our forest species are, compared to the ancestral practice we used to know."*

Among these initiatives, which in part rehabilitate farmers' knowledge of nature, is farmer managed natural regeneration, or FMNR. FMNR is an ancestral agroforestry practice that consists of protecting and tending spontaneous stump sprouts or natural seedlings of useful trees and shrubs in agricultural fields. This article analyzes the contribution of FMNR to the reestablishment of agroforestry parklands and its socioeconomic impact.

This qualitative study was carried out from March to June 2022 in the province of Passoré, in the communes of Gomponsom, Lâto-den and Yako. It is based on diverse information sources and on various criteria such as the size of the farm, the species found in the plots and their condition. Data was collected using semi-structured interviews, informal interviews and an ethnobotanical survey. These techniques were combined with direct observation to determine any discrepancies between discourse and practice. The study involved 68 people — 45 men and 23 women — of varying socio-demographic characteristics. This article presents some of the perceptions that emerged from the empirical data and that are cited by local people (farmers) as reasons to adopt FMNR. Insecurity due to persistent attacks by armed terrorist groups, which foster a climate of terror and suspicion among the population towards actors from outside their environment, caused some people to refuse to take part in the study and often hindered the fieldwork.

Farmers' perceptions and adoption of FMNR

A low-cost agroforestry practice

One of the reasons why farmers are so keen to adopt FMNR is that it is a low-cost practice that everyone can afford. Other options, such as reforestation, vegetated stone barriers and nutrient gardens, all require a certain amount of money and considerable physical effort. Planting a tree is seen as a good initiative, but it requires money to buy the plant and to protect it (with fencing) from browsing by animals. FMNR, however, requires fewer technical and financial resources.

A way to circumvent customary prohibitions

Sociocultural and metaphysical beliefs surround trees and local species. The traditional species found in agroforestry parklands are seen as a gift from God and cannot therefore be planted. For some farmers, planting these trees on an agricultural plot could be interpreted as defiance of ancestors and gods, and therefore as a transgression of ancestral rules. However, several of the people interviewed felt that FMNR is a "discreet" technique that offers room for manoeuvring and avoids transgressing social norms. For the animist stakeholders who share these beliefs, by practising FMNR they avoid attracting the wrath of the ancestors, as they have not planted the tree but rather tended it.

A strategy for getting around land restrictions

Some agroforestry practices also involve planting trees on cultivated plots. Given the customary land laws in force in the country, this planting could be seen as a sign of ownership of the plot (Levasseur et al. 2008; Colin et al. 2023). As a result, it is likely that migrants, people from other villages and women could be excluded from agroforestry, as they have limited rights to land. Nevertheless, these stakeholders recognize the advantages and benefits of trees in the fields and are developing strategies to this end. Since FMNR does not involve any tree planting, it becomes a way of getting around these land restrictions.

The farmers surveyed indicate that the young trees that are ubiquitous in the plots are the fruits of the FMNR that they have practised. Field data also show that FMNR is a practice encouraged by landowners. This view is linked to the customary laws governing land tenure. Indeed, one of the restrictions on land transactions is the prohibition on the lender cutting down trees on the agricultural plot. Failure to comply with this explicit rule results in the withdrawal of the plot.

In this context, practising FMNR denotes good intentions on the part of the user of the plot, who instead of destroying the trees to enlarge the field, develops initiatives to increase their number on the farm. This does not contradict the customary system, where the planting of a tree is quickly interpreted by the owner as a sign of land appropriation. This is what a 63-year-old Indigenous farmer in Gomponsome had to say:

> *"If someone applies for a plot of land to cultivate and then wants to plant a tree, they must inform the owner first. If, after discussions, you all agree, so much the better. The owner will say that he gave you his land to cultivate. Now if you want to plant a tree, you should know that I offered you the land but you didn't buy it. How many years can a tree live? At some point, you'll want to take over the land because you've planted trees. But after a certain length of time, the owner is going to want to reclaim the land, and that's complicated."*

It is not only foreign men who appreciate and adopt FMNR. Women are also excluded from owning land under customary law. They are regarded as foreigners not only in their own families but also in their husband's family. They work the land only with the permission of their husbands and are not allowed to plant trees, on pain of repudiation by a family council.

In view of its relatively effective results, FMNR therefore appears to be an agroforestry practice capable of meeting the threefold challenge of restoring land, reducing exclusion from projects involving tree planting, and reducing food insecurity by increasing the cash income of vulnerable households. Its practice has led to significant changes in the province of Passoré.

Social dynamics and changes

FMNR has become a systematic practice that farmers have integrated into their farming systems. This is partly due to the failure of projects to disseminate techniques to combat desertification, implemented in the Sahel in the post-drought periods of the 1970s and 1980s. More importantly, it is because FMNR generates visible and concrete results and does not require any financial investment on the part of the farmer. It can be described as a success story (Olivier de Sardan 2021).

Left: A young *bangandé* (*Piliostigma reticulatum*) from FMNR in a field at Gomponsom; Right: A more established *bangandé* (*Piliostigma reticulatum*) from FMNR. Photos: Jean Charles Bambara

Towards hybridization of agroforestry parklands

The gradual decline in indigenous species in agroforestry parklands, combined with the scarcity of firewood for energy, has prompted farmers to introduce other species into their fields, such as *Piliostigma reticulatum* (*bangandé*). The rehabilitation of this species is the result of women's desire to meet their energy needs, as firewood is the most widely used energy source in the province. According to data from the Institut National de la Statistique et de la Démographie (INSD 2019), wood is the main source of energy for cooking (82.9%), followed by gas or biogas (6.2%). Practising FMNR has made it possible to reintroduce species that had fallen into disuse. This has helped to reduce population pressure on species commonly found in agroforestry parklands.

This hybridization of agroforestry parklands — by integrating and tending *bangandé* — is in line with the farmers' approach, which consists of avoiding the restrictions of the forester and the constraints linked to the exploitation of certain trees. This relates in particular to protected local species, for which the farmer must contact the departmental environmental service, which is the sole state guarantor of the preservation of flora and fauna. The photos on the previous page illustrate the importance that the people of Gomponsom attach to FMNR in their fields and the interest that *bangandé* represents.

An opportunity to restore the forest landscape

Another merit of FMNR is that it has improved the density of plant cover. Among the species favoured are shea, *Faidherbia* (formerly *Acacia) albida*, *néré*, *Lanea microcarpa*, *Balanites* sp. and lianas. In an area where sociocultural beliefs are still very much alive and can have a negative influence on reforestation and landscape regreening activities, FMNR is becoming the practice that makes it possible to meet the challenge of land degradation by restoring clearings (*zippélés*). In addition, various species have improved the livelihoods of local people through the commercial opportunities they offer. In the province of Passoré, FMNR has made it possible to regenerate 430 ha of forest, mainly made up of local species such as *Vitellaria paradoxa, Parkia biglobosa, Lannea microcarpa, Balanites aegyptiaca, Acacia macrostachya, Bombax costatum* and *Piliostigma reticulatum*. See photos below.

Empowering women

The empowerment of women is one of the major changes brought about by the practice of FMNR. To reduce rural poverty, which disproportionately affects women, the non-timber forest product (NTFP) sector has been promoted by development agents, in conjunction with FMNR. NTFPs provide commercial opportunities, with the result that processed NTFPs can be found in shops and

Left: Tolia communal forest; right: Young shea shoots in Kouni. Photos: Jean Charles Bambara

other businesses in the country. The international market is also being explored, and processed products (shea butter, *soumbala*, monkey bread (baobab), tamarind, etc.) can now be found in various forms, with packaging stamped with the Burkina Faso flag. The growing demand for NTFPs on the international market is a boon for local people. With this in mind, since 2011 the NGO Tree Aid has been promoting agroforestry practices and local governance of forest resources through the Weoog-Paani ("New Forest") project in the Nord Region. The project has strengthened the capacity of women members of forest management groups in techniques and technologies for processing non-timber forest products. For example, to help women process shea butter, Tree Aid and its partners have set up a semi-industrial unit to help women process shea kernels into shea butter in the commune of Gomponsom (see photo, right).

Through providing NTFPs, farmer managed natural regeneration has therefore helped to increase women's income and strengthen their autonomy within the household. Many women are increasingly investing in the exploitation, processing and sale of NTFPs such as shea, *néré*, *Balanites* leaves, *Lanea microcarpa* and lianas (see photos next page), which enables them to participate more fully in the household economy and cover expenses such as children's clothing and supplies, medicine, and condiments for the family meal. This has helped to change the status and perception of women in society.

Women at the shea processing unit said that thanks to FMNR the sale of products from agroforestry parklands meant that they were no longer as dependent on their husbands and could play a full role in accordance with the gender division of labour (Kergoat 2001). These women stated that they had an annual income of between XOF 60,000 (West African CFA franc; EUR 91.60) and XOF 100,000 (EUR 152.67) from the sale of NTFPs. They invest these sums in other income-generating activities; in particular, the rearing of small ruminants, with a twofold objective: to provide fertilizer for their plots of land, and to sell products during the lean season to meet emergencies. Some of the women save their money in the Caisse Populaire.

Conclusion

This article shows that ecological and environmental crises, and their adverse effects on local populations in Passoré Province, have encouraged the rehabilitation of ancestral practices such as FMNR. Supported since the late 1970s by external players, this practice has become re-established in this region of Burkina Faso.

A group of women at the shea processing unit at Gomponsom. Photo: Jean Charles Bambara

Farmers' renewed interest in FMNR is linked to its products and to the agronomic, environmental and socioeconomic benefits that it offers. Local people do not just adopt a technique; they assess the benefits, costs and consequences in terms of improving their livelihoods. In view of the positive changes that FMNR has brought about in reducing socioeconomic insecurity, and thanks to the commercial opportunities offered by non-timber forest products, FMNR now appears to be an essential practice for reconstituting agroforestry parklands in the face of the many failures of reforestation projects and ongoing land ownership dynamics. FMNR also makes it possible to increase biodiversity in areas affected by climate change. Because of its potential for rapid reconstitution of tree and shrub cover at a low cost, this agroforestry practice should be disseminated more broadly to prevent the degradation of forest resources. It could also be replicated in other localities in Burkina Faso to prevent and combat the degradation of natural resources.

Processing and sale of NTFPs: a) making shea butter at Gomponsom; b) crushing *balanites* nuts at Zoungoungou; and c) *balanites* leaves for sale. Photos: Jean Charles Bambara

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Author affiliation

Jean Charles Bambara, PhD student in socio-anthropology at Joseph Ki-Zerbo University, Burkina Faso (bam_jean80@yahoo.fr)

Bocage hedge at the Filly pilot farm. Photo: Terre Verte

3.3

Wégoubri, an innovative agroforestry solution for rain-fed agriculture in the Sahel

Nassirou Yarbanga

> ***"Sahelian bocage has made it possible to reshape rural areas and create a new living and working environment."***

Introduction

The degradation of the Sahelian rural environment has worsened over the last few decades, particularly as a result of local agricultural practices, endangering rural populations. In response to this challenge, the NGO Terre Verte was set up in 1989 to support the Guiè pilot farm, located around 60 km north of Ouagadougou in Burkina Faso (Baudin 2017).

The NGO is promoting bocage (hedged farmland, or *wégoubri* in Moré), a rural development concept practised by the Guiè pilot farm in the 1990s and subsequently adopted by other Burkina Faso pilot farms (Filly, Goèma, Barga and Tougo) belonging to inter-village associations. A pilot farm relies on six technical teams supervised by a director (see Table 1). The pilot farm is the linchpin in implementing the bocage concept in an area.

Aerial view of the Tankouri bocage in Guiè. Photo: Terre Verte

A bocage is defined as a rural landscape of meadows and/or fields surrounded by living hedges that form a continuous network — a "linear forest" where trees, crops and livestock are combined.

In the Sahel, the primary purpose of hedges is to store rainwater during the monsoon season (mainly June to September). The hedges, combined with bunds (embankments), reduce runoff and soil erosion, and encourage biodiversity in this very fragile environment. The hedges also help to address the problems associated with extensive agriculture, which is still widely practised in the Sahel, particularly overgrazing and roaming by animals, slash-and-burn farming and excessive cutting of firewood.

Bocage areas are created at the request of landowners. They are organized with customary co-ownership, comprising individual plots and common land, managed by a land-owning group of beneficiaries. The result is a restored environment where agriculture is no longer synonymous with erosion, where livestock farming is no longer synonymous with overgrazing, and where trees and shrubs are integrated into agriculture. The principles of agroforestry are fully integrated in this new farming practice.

The increase in yields achieved after only a few years of soil restoration appears to be a real solution to the degradation of Sahelian environments and is helping to improve the living conditions of farmers and the rural population as a whole.

The Guiè pilot farm

The bocage of the Guiè pilot farm has been implemented to incorporate three components: experimentation with new bio-ecological farming and rural development techniques (applied research), training, and advice and support for the farmers involved.

Experimentation with new techniques was based on processes already used in the region, in particular earth bunds, to which was added hedges and water reservoirs. The living hedges alone proved insufficient to stem the damage to vegetation and crops by roaming cattle. Fencing was therefore essential to supplement the enclosure effect of the hedge. The "mixed hedge" therefore combines wire fencing with the shrubs of the living hedge (*Cassia sieberiana, Combretum micranthum, Diospyros mespiliformis*). The different species are produced by the nursery section of the pilot farm using several techniques, including nursery sowing, layering, grafting and cuttings, depending on the requirements of the species. Through these various processes, the nursery contributes to the maintenance of local species, the return of species thought to be extinct and the adaptation of new species to local environmental conditions. In order to ensure the development of bocage areas on a large scale, the pilot farms have developed the technique of direct sowing of shrubs, which consists of planting the seeds in trenches in the bocage (i.e., not in the nursery) and then watering them until the first rains.

Training in these new techniques was provided by taking on young apprentices on the farms and by holding sessions in the fields for adults. Participants were also encouraged to learn about other agro-environmental experiences in Burkina Faso and neighbouring countries, and even in Europe, where ancient bocages offer a wealth of lessons.

Bocage development is used to **advise and support farmers** to practise sustainable agriculture. After studying the site to be developed and drawing up the project, the beneficiaries clear the necessary paths, which are marked by the pilot farm's technicians. The site is managed on the principle of "paid labour-intensive work" (*travaux à haute intensité de main d'œuvre*). This system makes it possible to involve rural populations in major works that are usually entrusted to mechanized companies, in particular for the construction of earth bunds and the digging of ponds. Paid contract workers acquire real know-how, and all sections of the working population (young people, men and women) are involved. This approach is part of the support for the region's socioeconomic development and is financed by technical and financial partners.

Once completed, the bocage area is managed by a customary land-owning group, which is responsible for maintaining the common areas and ensuring compliance with the three basic rules for preserving the Sahelian environment: control of livestock, of fire and of wood cutting.

The three work components are organized in six sections, each with a team supervised by a director (Table 1).

Table 1. Sections of work

Nursery	• testing new plants and new horticultural techniques • producing the plants needed for planting • meeting the needs of local populations • safeguarding local species that have become rare
Livestock farming	• experimentation with rational grazing (control of grassland and fallow land, making hay and silage) • improving herd management • support for farmers with grazing fallow land
Technical support	• training, technical support and monitoring and evaluation for farmers in the use of bocage areas • development of new expertise
Agricultural equipment	• logistical support for work on the pilot farm • development of targeted mechanization to facilitate large-scale tasks
Land management unit	• creation of bocage areas, rain gardens, *bullis* (large water reservoirs) and rural tree-lined roads • site surveys • supervision of labour-intensive paid work • fencing and reforestation
Bocage maintenance	• development of environmental management skills (tree pruning and maintenance) • maintenance of hedges and roadside trees

***Combretum micranthum* (*randga*) plant in nursery, Filly pilot farm. Photo: Terre Verte**

The concept of the bocage

The principle behind the management of bocage areas is that of "informal co-ownership" organized around the beneficiaries' customary land use and comprising individual plots and common areas. The precise legal status of this type of rural co-ownership has yet to be worked out.

Commons

The commons are the areas and structures that are the responsibility of everyone; they form the physical foundations of the bocage, from the outside in:

1. The firebreak — a cleared perimeter zone that surrounds the entire area and protects it from the ever-present risk of fire during the long dry season (October to May).
2. The mixed hedge — made up of a wire fence between two lines of shrubs, which blocks access to the cultivated fields by roaming livestock.
3. The openings — four "cattle grids" to prevent livestock from accessing to the site and allow only pedestrians and bicycles, with a main gate that gives access to livestock and tractors.
4. The main and secondary paths serving each plot, with each plot comprising four fields.
5. A *bulli* (large reservoir) to collect water from the paths and help water the livestock.
6. Plots, some of which are shared (woods, pastures, communal fields).

Related facilities (diversion channels, large *bullis*) are sometimes required upstream of the site to protect it from runoff from undeveloped areas.

Individual plots

These plots benefit from the advantages of the commons in improving agriculture and livestock farming, while preserving individual ownership. Each owner receives one plot of 2.56 ha (160 x 160 m), divided into four fields, each 0.64 ha (160 x 40 m), depending on the slope of the land.

Each field is accessed by a path and surrounded by double protection: an earthen bund and a hedge. At the lowest point of the field is a small pond (*banka*) to infiltrate excess runoff water. Along the edges of each field are large trees next to a strip of grass, two metres wide, to slow runoff and limit erosion.

The integrated organization of the commons and individual plots provides an excellent approach for working, enabling yields two to three times higher than traditional yields, in sustainably productive conditions.

Zaï *cultivation*

Zaï cultivation is a traditional cereal-growing technique, originating in Yatenga Province in the northwestern region of Burkina Faso; it involves concentrating water and nutrients around a cultivated plant. During the dry season, *zaï* (pits) 30 cm in diameter and 15 to 20 cm deep are dug. As soon as the first rains fall in May-June, which are insufficient for irrigation, compost is placed in the *zaï*, covered with a small quantity of soil, and the cereal (millet, sorghum or maize) is sown.

By concentrating the water, soil and compost, this technique allows early planting of crops, which can then take full advantage of the monsoon and withstand the short dry spells between rains.

This technique also helps to regenerate the soil and restore degraded land, while producing a good harvest even in the first year. It is also a way of ensuring that the crop will provide enough to live on, whatever the vagaries of the weather. At Guiè, good results were obtained with an annual rainfall of just 428 mm! However, a lack of compost remains an obstacle to the development of *zaï*. In some cases, large quantities of compost have been obtained thanks to livestock farming with crop rotation; during the dry season, this includes a fallow area grazed by the animals and protected by a solar-powered electric fence.

Trees in the bocage

In the Sahelian environment, where there is a long dry season, the presence of trees in the bocage is essential to encourage biodiversity. The majority of trees and shrubs have fertilizing functions, thanks to their roots and the decomposition of biomass. Acacias, for example, help to enrich the soil through symbiotic root associations with nitrogen-fixing bacteria. They can also help to desalinate soils, unclog crushed soils and fix loose soils, while their decomposed foliage produces good compost. In addition, as the biomass produced by trees decomposes, it encourages the proliferation of microfauna, which helps to increase the soil's agronomic potential. This biomass provides mulch for the fields and protects the soil from splash erosion (the impact of raindrops).

Thanks to the trees in the bocage, a natural ecosystem is gradually being reconstituted, encouraging biodiversity. The bocage creates a microclimate favourable to flora and fauna. Evapotranspiration from tree vegetation emits water vapour, which helps to recharge clouds and maintain rainfall.

The trees in the bocage provide many other services, but the most important is the maintenance of the bocage. After a few years, hedges become rows of trees or shrubs that produce large quantities of firewood and fodder. Fast-growing trees need to be trimmed and pruned (every three years, in March–April, for hedges that are five to ten years old), to allow the hedge to thicken and to facilitate the growth of other species. Maintained in this way, hedges remain productive and continue to provide environmental and productive services.

The fruits of several of these tree species are part of the diet of local populations. For example, the seeds of *Acacia macrostachya* (*zamné*, or *kardga*, an endangered species

Close-up of a field within the bocage, Guiè. Photo: Terre Verte

Trimmed mixed hedge, Filly pilot farm. Photo: Terre Verte

commonly planted in hedges), are a favourite food at major ceremonies in urban areas. *Parkia biglobosa* (*néré*, planted preferentially as a line in the centre of fields), has highly prized fruits (powdered, eaten directly or its seeds transformed into *soumbala*). *Sclerocarya birrea* (*nobga*) grows mainly on the edges of ponds and produces fruit whose juice and nuts are highly prized. These few examples illustrate that the bocage plays a very important role in the conservation of these species, which are regularly collected in the natural environment and may be on the verge of extinction.

The leaves and roots of several species are part of the medical practices and cultural traditions of local societies. *Néré* is used to combat female sterility, ulcers and stomach aches; the leaves of *Combretum micranthum* (*randga*) are used to treat hepatitis; the roots of *Cassia sieberiana* (*koubrissaka*) are used to treat stomach aches. The fibrous outer bark of *Piliostigma reticulatum* (*bangandé*) is used to make *secco* (fences), mats and beehives.

Testimony from a family farmer of the Zamtaoko bocage in Filly, on biodiversity and increasing resources (source: Terre Verte 2021: 13; translated from French):

> *"As I said earlier, this land was really unproductive! Some 36 years ago, the land was ploughed with a tractor and andropogon transplanted to cover it with grass, but the work was a failure! The andropogon couldn't last a year and died before the first rains of the following rainy season. When this area was being developed, we used to say in our hearts that simple bunds and ponds couldn't bring this land back to life. If only these developers had known that other actors who preceded them had used greater resources than this without succeeding, they wouldn't be bothering with such works. But I'm personally amazed by what I see now! Valuable plants like andropogon, shrubs and trees here, I'm really amazed! Come along and let me show you some extraordinary things. I have a lot of red-flowered kapok trees (*Bombax costatum*), which have brought me an average of two 100-kg bags of kapok over the last few years.*
>
> *I also have a lot of andropogon. This has enabled me to make 6 seccos [fences] for my needs and to sell 30 bundles of this andropogon, which brought me CFA 28,500 (West African francs)/EUR 43.*
>
> *Many species that had disappeared from these areas have reappeared in my fields and are a real treasure for me. There's lamboèga (*Capparis corymbosa*), andga (*Vitex doniana*), the tamarind tree (*Tamarindus indica*), bangandé (*Piliostigma reticulatum*), wèdga (*Saba senegalensis*), tipoèga (*Bauhinia rufescens*) and even termite mounds!..."*

The spread of bocage

Sahelian bocage has made it possible to reshape rural areas and create a new living and working environment, ensuring high and diversified production and promoting biodiversity in a pleasant landscape.

The experimental plots in the Guiè/Tankouri bocage, after a four-year rotation (sorghum in *zaï*/grazed fallow/groundnuts-sesame-bean-bissap/millet-beans), achieved sorghum yields of 2.7 tonnes in 2006 and 3.2 tonnes in 2007: two to three times the yields achieved by the best farmers in the region!

Developing a hedged bocage costs between EUR 600 and 800 per hectare (ha), and increasing sorghum yields is valued at EUR 150 to 300 per ha, less EUR 50 per ha for mechanizing the zaï. A farmer would therefore be able to make a profit of around EUR 100 to 250 per ha cultivated with cereals each year. It is conceivable that this sum could be used to repay a loan to finance a hedge. However, a financial return of this kind is out of the question for the time being, as the changes in attitudes and farming practices that it would entail are taking place very slowly. The NGO Terre Verte remains fully committed to creating new hedged farmland and training farmers, however, in order to demonstrate its effectiveness and profitability. To date, 1,581 ha have been developed, benefiting 541 families.

Conclusions

Any action in the context of the environment must take place over time and be confined to a well-defined area, in order to gain in-depth knowledge of the problems and to implement effective solutions. This is what the NGO Terre Verte is trying to do through its pilot bocage farms in the Sahel. Its teams are at the service of the farmers, helping them to restore their living environment by adapting agroforestry techniques to local agriculture, within a bocage area that enables them to increase their resources while promoting biodiversity.

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Author affiliation

Nassirou Yarbanga, Director of the Barga Pilot Farm, Yatenga Province/Burkina Faso (info@eauterreverdure.org)

A farmer proudly shows off his trees in the bocage area of Filly. Photo: Terre Verte

A cocoa agroforest in the JBL. Photo E. Kumeh

How agroecology can help build dynamic cocoa agroforests in Ghana

Eric Mensah Kumeh

"Policymakers, researchers, extension services, NGOs and the private sector must join forces to provide comprehensive support for agroecological cocoa farming."

Introduction

In the heartland of Ghana, where lush landscapes once boasted vibrant and diverse forests and cocoa agroforests, a disheartening trend has taken hold. Once-thriving ecosystems teeming with life and cultural richness have gradually transformed into cocoa monocrops devoid of companion crops, biodiversity and the intrinsic nature that once defined cocoa farming in the region. The race for high cocoa yields underpinned this process and disrupted the intricate balance between nature and agriculture, giving rise to a cascade of social, ecological and economic challenges.

This article describes the transformative potential of agroecology as a beacon of hope for reestablishing balance in Ghana's cocoa-forest mosaic landscapes. Agroecology — rooted in the principles of ecological harmony and sustainable agriculture — offers a way to revive and restore biodiversity, empower farmers and ensure a resilient and thriving future for cocoa farms.

Full-sun cocoa in the JBL. Photo: E. Kumeh

This article draws on a case study of local innovation that was identified through in-depth ethnographic fieldwork in Ghana's Juabeso/Bia Landscape (JBL). It articulates a vision of how the adoption of agroecological principles can breathe life back into cocoa farming, enable food security, nurture vibrant ecosystems, preserve cultural heritage, and empower cocoa farmers.

Promising start, bleak outlook

Cocoa remains a cornerstone of Ghana's economy, with immense social, cultural and economic significance. Many cocoa farmers in the country clear forest to establish cocoa, while reserving established beneficial trees or tending their saplings for shade, food and cultural benefits. These farmers integrate cocoa seeds or seedlings with companion crops such as cocoyam, yam and plantain, ending the planting of most of these crops as the cocoa achieves canopy closure. Wild yam (*Dioscorea villosa*) was typically an exception; farmers continued to tend it even after the cocoa canopy closes since it is well adapted to growing in shade and contributes to household food security.

Many institutions, including the Ghana Cocoa Board (COCOBOD), NGOs and cocoa-buying companies, have over the years invested significant resources in the JBL to promote farmers' uptake of cocoa agroforestry. These actors supply cocoa farmers with hybrid cocoa seedlings, tree seedlings such as T*erminalia ivorensis/superba, Melicia excelsa, Entandrophragma angolense* and *Cedrella odorata*. In addition, COCOBOD supplies agrochemicals to the farmers. The institutions train farmers in various skills, such as agrochemical application and shade management, aimed at improving the effectiveness of the cocoa agroforests. Although these investments initially boosted cocoa production in the area for most of the 2000s, cocoa production in the JBL has declined significantly in recent years and farmers' uptake of cocoa agroforestry has been stymied.

Barriers to cocoa agroforestry

The decline of cocoa production in the JBL and the poor uptake of cocoa agroforestry lie mainly at the intersection of three key issues:

- full-sun cocoa;
- tenure insecurity; and
- food insecurity.

Full-sun cocoa

With the emergence of full-sun, monoculture cocoa, touted to improve cocoa bean productivity, practitioners and researchers persuaded cocoa farmers to do away with old-growth, large-canopy trees that formed the overstorey layer on their farms. This development occurred on the back of genetic improvements in cocoa and along with expanded fertilizers and pesticides supplied by the Ghanaian government to cocoa farmers. The main rationale was to bridge "the yield gap," as cocoa farmers' outputs were believe to be subpar (Amponsah-Doku et al. 2022; Asante et al. 2022).

Drawing on outputs from full-sun cocoa on experimental stations and in other countries, COCOBOD and many other cocoa-sector stakeholders convinced cocoa farmers in the JBL that they could double their yields with full-sun cocoa. What many of these stakeholders failed to consider was that simulations on experimental stations, including water stress management, are often not replicable or feasible on farms. Meanwhile, cocoa monocultures have proved to be less resilient than cocoa agroforestry to climate variability and pests. As a result, COCOBOD and other actors that influenced farmers to adopt cocoa monoculture are now racing to influence them to revert to cocoa agroforestry. Thus, the shift in promoting cocoa agroforestry needs to be interpreted within the context of redressing an ill-advised policy in the country rather than as an innovation.

Further, some proponents of cocoa agroforestry encourage approaches that are ill-suited to farmers' operational environment. For example, the Cocoa Research Institute of Ghana recommends planting 18 shade trees per hectare of cocoa farm; this, however, is argued to often be inadequate for achieving shade levels that provide optimal economic and environmental benefits, due to differences in the crown size of various tree species (Blaser et al. 2018; Niether et al. 2020; Richard and Ræbild 2016). Additionally, whereas one strand of the literature argues that the benefits of cocoa agroforestry add up over time at all levels, others assert that cocoa agroforestry is inimical to farmers' economic interests at the farm level but beneficial at the landscape level. Cocoa farmers in the JBL end up trapped in the politics of knowledge and incongruence in policy and practices.

Tenure insecurity

Until 1962, cocoa farmers effectively held ownership rights to the trees on their farms, with traditional authorities sanctioning associated claims. This changed considerably when the Nkrumah administration passed the *Concessions Act*, 1962 (ACT 124, Section 14.4), vesting the rights over naturally regenerated trees to the state. This act is largely recognized as the result of the president's aim to curb the power of traditional authorities as punishment for supporting the colonial administration, and to consolidate government control over rural areas. The change empowered the state to issue timber rights to private companies for logging on cocoa farms, creating multiple conflicts.

In the JBL, timber companies continue to fell trees on cocoa farms without the consent of farmers and without paying compensation for the damages inflicted on such farmers. This has discouraged many farmers from maintaining old-growth trees such as mahogany, *Melicia excelsa, Terminalia* spp. and *Ceiba pentandra* on their farms. Some farmers proactively debark trees, apply

Farmer on a food crop farm that encroaches on the Krokosua Hills Forest Reserve, JBL. Photo: E. Kumeh

Box 1. Grassroots voices on cocoa agroforestry

Grassroots voices are essential in conveying farmers' perceptions and sense of justice about cocoa agroforestry. Focus group discussions on cocoa agroforestry with farmers across the JBL were often tense, charged and heated.

For example, in discussing support systems for agroforestry in Kunkumso, JBL, a farmer who had been engaged in cocoa production for over 25 years observed that: "COCOBOD and stakeholders miseducate us — cocoa farmers. One moment, they tell us to cut the trees on our farms; another time, 'plant trees,' they tell us. I personally don't understand or listen to them anymore because their knowledge is just theoretical. We are farmers, constantly on the farm. We know what works and doesn't work."

Other cocoa farmers such as this one were concerned about the complexities of tree registration: "What annoys me most is NGOs are frequently telling us to go and register our trees at the district office. So, if I don't have transport fare to go there, I cannot register my trees. What is that?" "I am challenging you to come with us and look at how timber contractors have destroyed our cocoa with their logging activities. Contractors, district officials and you researchers don't hold us in any regard at all; you don't value us. You're always telling us to plant trees in our cocoa. Come with me, let's go and see for yourself. I will never plant any tree seedlings," lamented another cocoa farmer, whose trees had been destroyed by a logger without his consent or any form of compensation.

A recurring theme in farmers' narratives is an apparent stifling of their agency. With stakeholders having largely failed to address cocoa farmers' concerns and grievances pertaining to trees on farms, farmers' resisting cocoa agroforestry, in multiple ways, is likely to continue in the JBL.

agrochemicals or set fire to destroy trees and eliminate the risk that timber contractors will damage their farms. Other farmers prefer to preserve less economically viable species and slender crown trees such as *Newbouldia laevis*, while still others desist from planting shade trees altogether due to the complexities in establishing ownership rights over them (see Box 1).

Food insecurity

Permanent food production is critically marginalized in debates about cocoa agroforestry in Ghana (Kumeh et al. 2022). Those debates that do take place are pixelated, asymmetrical and biased towards tree planting on cocoa farms. Policymakers and practitioners discuss food production only during the establishment phase of cocoa, either in new areas or through the rehabilitation of old or diseased farms. The latter problem has been particularly topical in the JBL, which is losing its lead position in national cocoa exports due to surging climate shocks, and a high incidence of Cocoa Swollen Shoot Virus Disease (CSSVD) and Black Pod disease.

Indeed, COCOBOD is implementing a multimillion-dollar cocoa programme to rehabilitate old and diseased farms in the JBL and elsewhere. Cocoa rehabilitation does not consider long-term food production, even though cocoa farmers cannot eat cocoa. Under the programme, COCOBOD pays farmers a fixed rate: GHS 1,000 (USD 86) per ha of cut cocoa farm. It also supplies them with inputs — hybrid seedlings, tree seedlings and plantain suckers — and technical advice to establish their cocoa. The plantain is meant to shade the cocoa seedlings and provide food during the initial phase of farm establishment. Thus, the programme largely entices farmers to lock up their lands under full-sun cocoa, leaving them exposed to food insecurity once their cocoa establishes itself. Often farmers have to wait for "gaps" in their cocoa to produce food crops. Some studies have found that food insecurity is on the ascendency in cocoa-growing communities, even among farmers certified by the Rainforest Alliance, because income from cocoa alone is insufficient to meet their food needs. In the JBL, cocoa farmers are forced to encroach into forest reserves to produce food, leading to deforestation conflicts with forestry authorities (see Kumeh et al. 2022).

These cases indicate that the adoption of cocoa agroforestry in the JBL depends on the interaction of social, cultural and policy issues, and not just economic returns. Together, these factors not only militate against the adoption of cocoa agroforestry, but are increasingly driving a trend where cocoa farmers — in some cases, entire communities — shift from cocoa agroforestry completely, trading their cocoa farms for illegal surface gold mining (Eberhard et al. 2022; Snapir et al. 2017). The consequences are staggering. Once-vibrant cocoa-

Cocoa farms being converted to surface gold mining in the JBL. Photo: E. Kumeh

forest landscapes, alive with the symphony of countless species, are being reduced to barren expanses. This loss of biodiversity not only disrupts the delicate ecological balance but also threatens the long-term viability of cocoa production. In this challenging landscape, agroecology emerges as a solution that promises to restore the balance between productivity and sustainability in cocoa farming.

Agroecology as a path to dynamic cocoa agroforests

Agroecology encompasses an assemblage of farming practices that engender crop diversity, rotations, biomass and residue management, and biological pest control. Although it recognizes and aims to improve yields, its broader aim is to increase overall system resilience, and to provide diverse social, economic and environmental benefits over the long term.

At its core, agroforestry is an agroecology practice. The challenge, however, is that agroforestry in the JBL is practised in a way that neglects many of the agroecological principles that underlie it. Such principles include: i) reducing nutrient losses while improving nutrient cycling; ii) cultivation and use of locally adapted food crops while building on local knowledge and culture; iii) diversified production with the utmost respect for the inherent capability of soils over time; and iv) optimizing beneficial biological interactions to increase the efficiency and resilience of farming systems.

An overlooked, underexplored and unpolished gem

Deep in the land of a community in Ghana, where several hectares of cocoa farms have been devastated by illegal mining, Farmer X (he is not named here to protect his identity) was found to have implemented dynamic cocoa agroforestry that respects many agroecology principles.

While the lush overstorey canopy of diverse trees on his cocoa farm is noticeable from a distance, it is what he does beneath the understorey that is fascinating. Each year, he uses the off-season period to dig pits, about 50–70 cm wide and deep, on his cocoa farm, planting wild/bush yam in them. Bush yam, he notes, is notoriously difficult to dig up as the tubers can be very irregular. Having dug the pits, he fills them with cocoa litter from his farm and with dried cocoa placenta that is extracted and aggregated while drying his cocoa beans. He plants yam setts in the cocoa litter-placenta mixture, dressing it with some soil to provide additional support. Farmer X pointed out that this technology makes harvesting the matured yam tubers fairly easy, significantly reducing the losses from digging up the yam in a conventional planting approach (see photos next page), while meeting a significant part of his household food needs.


Left: Wild yam harvested from an ordinary cocoa farm, December 2019. Right: Wild yam harvested from Farmer X's farm, January 2020. Photos: E. Kumeh

The relative success of this farmer also indicates the potential of agroecology to improve biodiversity and ecosystem services in cocoa. By using cocoa litter and placenta to amend soils, cocoa farmers could reduce the risk of fire on their farms, and improve nutrient cycling, biodiversity and soil carbon sequestration. The rejuvenation of soil health and the reduction of chemical inputs can lead to enhanced resilience, minimizing the risks posed by pests and diseases. This newfound ecological balance may bring not only intrinsic value but also tangible benefits to farmers' livelihoods.

Building the foundations for a giant leap

While Farmer X's success provides inspiration and motivation, other challenges may hinder the scaling of agroecology principles in cocoa agroforestry in Ghana. In addition to the barriers such as tree ownership and inconsistent or inappropriate technical support discussed earlier, actors need to find ways around issues such as limited empirical information on options to optimize food production in mature cocoa agroforests, poor investment in wild yam germplasm development, and policy and institutional shortfalls that impede bottom-up learning from farmers. Also, the growing threat of illegal mining on cocoa farms in the JBL cannot be discounted.

To overcome these challenges, a collaborative effort is paramount. Policymakers, researchers, extension services, NGOs and the private sector must join forces to provide comprehensive support for agroecological cocoa farming. Investment in farmer programmes, particularly at the community level, can enhance knowledge co-creation, yielding pragmatic solutions. The development of robust market systems, with fair pricing and certification schemes, can incentivize and reward farmers for their sustainable practices.

The role of government in this transition is pivotal. Policymakers must recognize and prioritize the integration of agroecological principles into cocoa sector development policies and strategies. This requires aligning incentives, regulations and support mechanisms to create an enabling context for agroecology to flourish. A starting point would be to give back control over trees on farms to farmers while exploring ways to overcome the governance challenges that led to the abuse and misuse of pesticides in cocoa agroforests. These efforts require a long-term vision that transcends political cycles and ensures sustained commitment to agroecological principles.

Conclusions

This article provides a critical reflection on how the co-optation of cocoa agroforestry — and neglect of the agroecological principles that underlie it as a practice — led to cocoa monocropping. It demonstrates how state failure to guarantee farmers' rights to trees and secure permanent food production in cocoa agroforests undermines the spirit of functional agroforestry and frustrates farmers' efforts. This not only limits their uptake of dynamic agroforestry but creates negative spillover effects such as encroachment into forest reserves to secure food and the transition to illegal mining on cocoa farms.

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Author affiliation

Eric Mensah Kumeh, postdoctoral researcher at Leverhulme Centre for Nature Recovery, School of Geography and the Environment, University of Oxford, UK (eric.kumeh@ouce.ox.ac.uk)

Faidherbia albida agroforestry parkland with cowpea crop, North Region, Cameroon. Photo: Régis Peltier

Three decades of *Faidherbia albida* agroforestry in Far North Region, Cameroon

Amah Akodéwou, Oumarou Palou Madi, Faustin Ambomo Tsanga, Romain Rousgou and Régis Peltier

"The bundle of wood no longer comes carried on our heads, it has come above our heads, from the tops of the trees!"

Introduction

In the semi-arid and subhumid regions of Africa, agroforestry plays an important economic and ecological role. It makes a significant contribution to the livelihoods of rural populations and to the response to climate change through carbon storage and improved adaptation to climatic hazards. Agroforestry is also a solution to land degradation caused by poor farming practices and can meet the growing need for food and firewood.

In the context of the Sahelian (semi-arid) climate, which is not very favourable to reforestation through tree planting, one of the appropriate agroforestry practices is farmer managed natural regeneration (FMNR). When farmers clear and prepare fields or grazing areas, FMNR includes selecting, protecting and managing spontaneous tree saplings and the natural regrowth produced by tree and shrub stumps (Abasse et al. 2023).


Left: At the end of the dry season, a clump of *Faidherbia albida*. Right: The same clump after the farmer selected four shoots; the following year he will keep only two shoots, then one in year 3. Photos: Faustin Ambomo Tsanga

Faidherbia albida, formerly known as *Acacia albida,* is a member of the legume family. It is one of the most suitable and the most recommended tree species for FMNR in areas that are favourable for it, in particular, those with sandy alluvial soils and a shallow water table in the dry season (10–50 m). Where it is not naturally present, planting it is possible, but is much more expensive: at least XAF 1,000 (Central African franc; EUR 1.50) per tree planted instead of XAF 100 per tree (EUR 0.15) protected by FMNR.

This article looks at some of the benefits derived by Sahelian populations from agroforestry parklands with this tree, using the example of Far North Region, Cameroon.

Agroforestry support over a 30-year period

In Far North Region, Cameroon, from 1994 onwards, the *Développement Paysanal et Gestion de Terroir* (DPGT) project encouraged the restoration of *Faidherbia albida* agroforestry parklands. In subsequent years, the Cameroonian (IRAD) and French (CIRAD) agricultural research institutes joined forces to study the restoration dynamics of these areas (Gautier et al. 2002). This work was continued by the *Ecole Nationale du Génie Rural, des Eaux et Forêts* (ENGREF) with support from the *Pôle Regional de recherche Appliquée au développement des Systèmes agricoles d'Afrique Centrale* (PRASAC) (Smektala et al. 2005). It was taken over by CIRAD and IRAD in 2021 (Akodéwou et al. 2022).

Support for farmers

Thanks to a deduction from the sum paid by *Société de Développement du Coton du Cameroun* (Sodécoton) to Village Associations of Agricultural Producers, the DPGT project paid a subsidy of XAF 100 per tree (EUR 0.15) over three years, from 1997 to 2000, to farmers protecting trees in their fields (XAF 50 the first year, then XAF 25 in years 2 and 3 provided the trees are effectively protected). From 2000 to 2004, the subsidy was XAF 75 per tree, half paid by the DPGT and half by the cotton producer groups; the same amount was paid by the *Eau Sol Arbre* (ESA1) project from 2004 to 2008. As of 2009, the ESA2 project abolished the subsidy and financed only the paint for marking the trees to be protected and the bonus paid to the person responsible for marking, amounting to XAF 10 per tree.

Project impacts

In the 2000s, the DPGT project declared that more than one million *Faidherbia albida* trees had been preserved in fields in the Far North Region. In 2020, adding the North Region, an evaluation indicated that an additional 900,000 trees had been conserved since 2010, including other species. However, in two test villages, it was noted that tree protection had "run out of steam" when subsidies ceased.

The diameter at breast height (DBH, at 1.3 m from the ground) of the *faidherbia*, measured in 2012, shows an over-representation of the 11–20 cm and 21–30 cm diameter classes (Marquant 2012). The annual diametric growth being around 2 to 2.5 cm, it is possible to estimate that trees less than 30 cm in diameter were protected after the start of the DPGT and ESA projects, which tends to prove the impact of these projects' conservation policies. The diameter class of young trees (1–10 cm) has a lower density than the larger diameter classes (i.e. trees assumed to be older), indicating a slight decline in the conservation dynamic over the four years preceding the 2012 inventory (subsidies stopped in 2008). In 2022, this trend was confirmed by a remote sensing study (Akodéwou et al. 2022), which shows that there are few young *faidherbia*, even though the projected crown area has more than doubled between 2009 and 2018, increasing from 2.5% to around 5.9% of plot area, due to the increase in crown size of the trees selected during the 2000s (Figure 1).

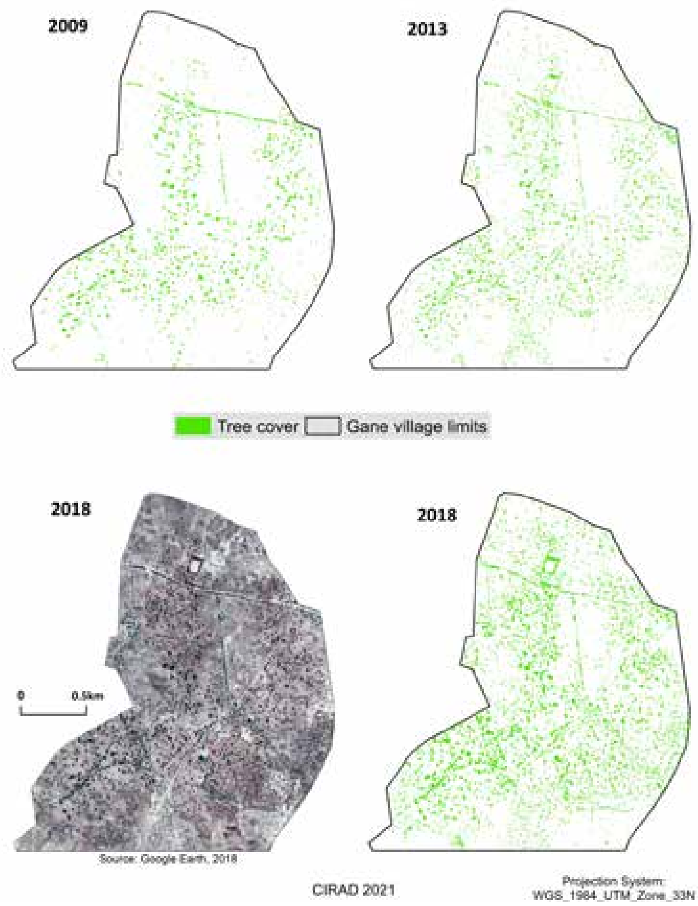

Figure 1. Tree cover change, 2009–2018, Gané, Far North Region, Cameroon. Source: CIRAD

There seem to be many reasons for the decline in interest in selecting new plants by FMNR in recent years. Insecurity of land tenure remains a problem, although some people thought it had been minimized by the fact that they were able to conserve trees with the support of projects and therefore of the state. Formal and informal harassment and fines by state agents persist when farmers want to prune the trees they have protected (as if they were not the real usufructuaries of these trees); this reduces their motivation to practise FMNR. In addition, production (fruit, fodder, wood) and services (improved fertility, microclimate improvement, etc.) are long-term gains, whereas the subsidy, however modest, provided immediate income.

Fortunately, the trend of FMNR running out of steam following the end of subsidies (also observed in central-western Niger; see Boubacar et al. 2022), is not a general one. Studies (e.g., Abasse et al. 2023) have shown that FMNR has expanded as people become aware of its benefits. In south-central Niger, for example, there has been spontaneous adoption of FMNR, promoted and disseminated by non-governmental organizations, and large-scale regreening of the landscape (Toudou et al. 2020).


Left: *Faidherbia* trees, 10 years old, selected by FMNR in rows spaced 4 m apart, to enable cotton to be cultivated with animal traction (ploughing and ridging), in rotation with sorghum associated with cowpea. Right: Aboubacar Njiémoun, an engineer with IRAD, shows a ten-year-old *faidherbia* plant, the base of which has been trimmed of shoots and low branches. Photos: Régis Peltier

Significant economic impact

Faidherbia albida boosts crop yields, especially in situations of poor fertility. It has long been recognized that the species has a positive effect on associated crops. Analyses carried out in Far North Region, Cameroon, on the productivity of associated cotton crops show that there is a strong correlation between the soil fertility of the site and the presence of *faidherbia*, especially in young parklands (around 15 to 50 years old) with poor soil fertility. Under tree crowns, greater vegetative development and a higher average cotton weight were observed. In old parklands with very large trees, however, shade can become a limiting factor in cotton production. Even though *faidherbia* has an inverted phenology (leafing out in the dry season and defoliating in the rainy season), all the branches intercept some of the sunlight. It is therefore recommended that large crowns be pruned and old trees replaced by young seedings selected by FMNR.

Cotton growing in a *faidherbia* parkland. Photo: Régis Peltier

Sorghum just before harvest, in a *faidherbia* parkland at the end of the rainy season (October) on the Fadaré Dune, Far North Region, Cameroon; the *faidherbia* trees have just regained their foliage, but the shade will not reduce the upcoming harvest. On these poor sandy soils, but well supplied with deep water, only millet can be grown in treeless plots, while sorghum, which is more demanding in terms of fertility, can grow only under the trees. Photo: Régis Peltier

Similarly, in a recent updated review of the sustainability of *Faidherbia albida*-based agroforestry in sub-Saharan Africa, Sileshi et al. (2020) showed that maize and sorghum productivity increased by 150% and 73% respectively under the *faidherbia* canopy compared with the canopy-free zone.

Faidherbia *parklands and firewood*

A study of firewood consumption (Marquant 2012) showed that in 2012, the *Faidherbia albida* parkland provided one-quarter of the domestic firewood needs of the villages of Gané (2 kg/capita/day) and Sirlawé (0.9 kg/capita/day); the trees were pruned every six to eight years. *Faidherbia* wood is an excellent fuel, with a calorific value of 4,720 kcal/kg of anhydrous wood (BFT 1989). The parklands therefore provide relief for the women who collect the wood, who otherwise might need to harvest several hours away from their village. As one woman put it: "The bundle of wood no longer comes carried on our heads, it has come above our heads, from the tops of the trees!" The weight of a bundle of firewood in Cameroon's Far North Region varies from 4 to 8 kg and costs XAF 365 (EUR 0.56; Folefack and Abou 2009). Assuming an average of 6 kg per bundle, and bearing in mind that wood is two to three times more expensive in towns than where it is produced, the parklands can generate savings of around XAF 5,900,000 (around EUR 9,000) to XAF 6,600,000 (around EUR 10,000) per year in Gané and Sirlawé respectively.

A fodder and feed supplement

Faidherbia albida parklands also play a very important role in providing supplementary fodder (leaves from pruned branches and pods) in the middle of the dry season, when bush fodder is scarce and not easily digestible. Because of the species' inverted phenology, its fodder and pods are produced at a time that allows livestock to bridge the gap. *Faidherbia* fodder also provides the necessary nitrogen supplement to dry grass fodder. This nitrogen is not available through the consumption of groundnut, cowpea and millet, which are all in short supply. In urban centres in Niger, *Faidherbia albida* pods are expensive (just less than cowpea byproducts and groundnut haulms), and on average have the highest digestible nitrogen content (Dan Gomma et al. 2017).

Conclusions

In the current context of food insecurity and climate change in the Sahel, it is necessary to assess the direct economic and ecological benefits of agroforestry. This article presents some of the benefits derived by Sahelian populations from agroforestry parklands.

This summary shows that *faidherbia* agroforestry parklands provide significant direct benefits to rural populations, such as the production of firewood through pruning, the production of animal fodder and the improved productivity of associated crops.

By storing carbon, agroforestry parklands also contribute to the process of mitigating climate change. When they are well diversified, they enable the conservation of biodiversity that is directly useful for the yield of non-timber forest products.

However, to guarantee sustainability, certain conditions must be met. These include security of tenure; the right to use all tree products through sustainable management techniques (pruning) enshrined in law and effectively enforced by local forestry officials; support from projects, development companies and the government; publication of research results that are convincing to the government; regular payment of small incentives and confirmation of support from government and international organizations; and the use of simple, low-cost methods in terms of labour and inputs.

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Author affiliations

Amah Akodéwou, French Agricultural Research Centre for International Development (CIRAD), Research Unit Forests and Societies, Montpellier, France and Institut National de la Recherche Agronomique du Niger (INRAN), Niamey, Niger (amah.akodewou@cirad.fr)

Oumarou Palou Madi, Agricultural Research Institute for Development of Cameroon (IRAD), Maroua Centre, Maroua, Cameroun (paloumadi17@gmail.com)

Faustin Ambomo Tsanga, Center for International Forestry Research- World Agroforestry (CIFOR-ICRAF) project UE-DESIRA INNOVACC Garoua and University of Maroua, Cameroon (F.ambomo@cifor-icraf.org)

Romain Rousgou, Center for International Forestry Research- World Agroforestry (CIFOR-ICRAF) project UE-DESIRA INNOVACC Garoua and University of Maroua, Cameroon (R.Rousgou@cifor-icraf.org)

Régis Peltier, French Agricultural Research Centre for International Development (CIRAD), Research Unit Forests and Societies and University of Montpellier, Montpellier, France (regis.peltier@cirad.fr)

Cocoa, fast-growing trees and/or fruit tree system in the Bakumu Kilinga sector, Ubundu territory, DRC. Photo: Charles Mpoyi

Farmers' perceptions of agroforestry, Democratic Republic of the Congo

Alphonse Maindo, Charles Mpoyi, Sagesse Nziavake, Félicien Musenge, Théophile Yuma, Ben Israël Bohola and David Angbongi

"Building an agroforestry model requires a continuous, participatory and iterative process that involves all stakeholders."

Introduction

The development of agriculture, particularly monocultures and extensive, land-consuming practices, to meet the growing needs of humanity poses serious problems for forests and biodiversity (Wu et al. 2010). The resulting deforestation and forest degradation are fuelling climate change. Forests are important carbon sinks; their destruction leads to significant greenhouse gas emissions. There is an urgent need to protect forests, and yet, the increase in the world's population and the spread of consumerism requires either improved production systems and techniques or the expansion of production areas. Reconciling the needs of forest populations with the preservation of forests and biodiversity in the context of resilience to the effects of climate change is becoming a priority for development players and public authorities.

Cocoa-plantain system in the community field of the Barumbi-Tshopo local community forest concession, Bekeni Kondolole sector, Bafwasende territory, DRC. Photo: Augustin Toiliye

Agroforestry, the association of trees with crops and/or livestock, is increasingly seen as a way of contributing to climate change resilience, and above all as an alternative to industrial agriculture and slash-and-burn practices. Agroforestry has a lot to offer: the protection of soil, water and biodiversity; maintaining agricultural production; mitigation of climate change or adaptation to it; multiple tree products, such as wood, fruit, fodder, medicines, etc. (Torquebiau 2022; Katayi et al. 2023).

Specialists can design agroforestry models that in theory increase farm resilience and crop productivity. However, these models, even those developed in research stations and those that work elsewhere in the world, face challenges. Models must be feasible in the local context in which they are implemented and must meet a range of needs; this often forces specialists to rethink and reinvent their approach in the face of in-the-field realities.

Agroforestry, like all innovation, must be a dynamic process involving both farmers and technical experts. It should follow a process of mutual learning; this requires constant questioning, reflection and updating of the approaches used, of the relationships between the stakeholders and understanding of the stakeholders themselves, in order to be feasible on the ground. This concerns the entire process: the choice of crops to grow, the selection of tree species to be planted in the fields, the choice of management methods for agroforestry systems (individual or community), land rights, and so on.

This article reviews the experience of Tropenbos DRC to support small forest and agricultural producers in agroforestry as part of Tropenbos International's Working Landscapes programme (Maindo and Kapa 2015). The study is based in the Bafwasende area of Tshopo Province. It illustrates how agricultural production systems designed by experts and implemented or popularized by development projects are often at odds with the perceptions and practices of local people in tropical forest areas, who are reluctant to engage in reforestation activities. For forest populations, forests were, are and always will be there; they are eternal. These farmers often equate agroforestry with reforestation. Thus, the participation of target populations in the design of agroforestry models does not necessarily guarantee their success. Local needs are not identical to those of the experts. This is certainly what Tropenbos DRC has been working to understand.

Integrating agroforestry into community forestry

Bafwasende covers an area of almost 47,087 km², with a sparse population (around 12 inhabitants per km²) living in very isolated villages where extreme poverty is widespread. The people traditionally practise slash-and-burn agriculture. There is 98% forest cover, but this has come under serious threat in recent years, particularly from uncontrolled logging (including opening up areas for agriculture) and the in-migration of people from North Kivu and Ituri provinces.

For Tropenbos DRC, promoting agroforestry as part of community forestry would reduce pressure on the forests while providing food, generating substantial income and increasing land security for local communities. Following a baseline study in 2019, a model was designed based on two pillars: a community field system and an agroforestry model combining cocoa and plantain (cooking bananas) with trees (forest and fruit species, etc.).

In 2019 three communities already involved in community forestry were selected: Bampaka of Bafwamogo, Bampaka of Bapondi and Barumbi-Tshopo. They received their Local Community Forest Concession (LCFC) titles one year later, in February 2020, covering a total area of 90,000 ha. To this was added 300,000 ha of 10 new community forestry initiatives. Each community created a community field at least 10 ha large in the wooded fallow land adjacent to the villages. The field would have cocoa and plantain. It was important to create small clearings in the fallow land in order to maintain some shade for the cocoa plants. Each community field is laid out in alternating strips of cocoa and plantain plants, 10 m wide, in order to maintain a good level of sunlight for the plantain. This gives a density of 555 cocoa trees per ha (with a planting density of 3 x 3 m) instead of the 1,111 grown in a cocoa monoculture.

Plantain is a traditional crop in Bafwasende, where it forms part of people's staple diet. Kisangani, around 100 kilometres from Bafwasende and with a population of 1.5 million, is a major outlet for plantains. Plantains are also a near-perennial crop: a plantation can last up to 25 years, according to Benoît Dhed'a Djailo, a Congolese plantain specialist at the University of Kisangani. The cocoa tree is little known in this region, but has significant economic potential: 2,000 kg of merchantable cocoa per ha per year, with 1 kg of merchantable cocoa worth USD 1.5. Yira migrants, who are familiar with cocoa growing and its commodity chain, are an asset for development of the sector in Bafwasende, where they are setting up cocoa farms. Growing perennial crops, as well as LCFCs and tree planting, make it possible to secure land for local communities and obtain an emphyteutis certificate (affirming property rights for a defined period), which is more secure than customary rights. Depending on the

Rehabilitation of an old palm grove with cocoa in the Babongombe area, Bakumu Obiatuku sector, Ubundu territory, DRC. Photo: Meschac Koy

Rehabilitation of an old palm grove with cocoa in the Basukwambao area, Bakumu Mandombe sector, Ubundu territory, DRC. Photo: Meschac Koy

number of trees in the field, people also plant useful forest species (host trees for caterpillars, for example) and fruit trees, in addition to leaving naturally occurring trees in place to shade the cocoa trees.

The failure of a communitarian ideology

The community agroforestry fields have not produced the expected results, despite the Working Landscapes programme's investment and Tropenbos DRC's technical support. From 2019 to 2021, only 4 ha of cocoa trees of the 30 ha expected were planted by the three communities: 1.5 ha by the Barumbi-Tshopo; 1.5 ha by the Bampaka of Bafwamogo; and 1 ha by the Bampaka of Bapondi. Members of the communities had no shortage of reasons for not taking part in the collective work. These reasons included the struggle for daily survival and the amount of work already required in the fields. An undisclosed reason, which was expressed later (Yee Wong et al. 2019) was concern about the sharing of the benefits of the community field. Among the Bampaka of Bafwamogo, for example, the community field was divided up into family plots, and each family looked after its own plot. This raises a real question of governance.

To work in the community fields, the members of the local communities asked for support in the form of food rations and farming implements. Surprisingly, the farmers claimed that they did not have the farm implements they needed to work in the community fields, even though they did not ask for them when they went to work in their own fields. Therein lies the rationale: it is up to the community to pay for work that is in the community's interest, and not up to individuals. What's more, the programme's technical assistants had to supervise the community work so that it could be carried out. Some might be tempted to see in this a lack of mutual trust and of true community spirit, where no one feels directly responsible for the community field, since the income from it belongs to everyone, even those who have not contributed. Contrary to popular belief, local communities are no more communitarian than any individual. Individualism and social fragmentation are indeed at work in Bafwasende, but they coexist simultaneously with a certain solidarity with others (Marie et al. 2008). The various circumstances (happy or painful) of life bear witness to this solidarity: birth, marriage, celebrations, funerals, schooling, illness, etc., are all opportunities to show solidarity with others and to exchange with them. Individuals are bound together by relationships of dependence. This is what makes them a community. The only activities that are community-based, however, are those linked to setting up and maintaining the cocoa and tree nurseries.

In a brainstorming session with the Tropenbos DRC team to evaluate and draw lessons from the programme, local community members clearly acknowledged this manifest lack of interest in community fields and expressed their preference for individual or family fields (Vautier 2016). This implied that a fundamental change of perspective was needed. In a new approach in 2021, each local community had to identify people interested in agroforestry to get support from the programme. This approach paid off. In six months, nearly 50 small producers signed up and planted 45 ha of cocoa trees; the community approach had stalled at 4 ha in three years. Four cocoa tree nurseries have been set up in the three LCFCs: two in Barumbi Tshopo, one in Bafwamogo and one in Bapondi. The three community fields, whose total area has now increased from 4 to 5.5 ha, have been converted to training fields. The average size of the farmers' fields is around 2 ha. The first cocoa fields are already producing fruit, and the beans have been sold since 2021.

Under the Programme Intégré REDD+ Oriental (PIREDD+O), taking place in Tshopo, Ituri and Bas-Uélé provinces, and which is based on an individual approach, around 600 additional ha of cocoa trees were planted in one year in the individual fields of the three LCFCs and the 10 community forest initiatives of Bafwasende. This cocoa is mainly planted in the shade of tree fallows and/or planted trees.

Economic factors

The agroforestry model — which combines cocoa and plantain with trees in degraded areas or in forest fallows — was designed to be economically and ecologically viable. For small producers, however, it does not appear to be economically viable. As a result, they refuse to practise it, either in community fields or individual plantations. They prefer not to combine plantain plants and cocoa trees, but do agree to keep or plant useful trees (forest and fruit species). For them, the aim is to maximize the number of cocoa trees in the fields and not plant plantain.

Commercial cocoa is more economically profitable than plantain: with 1 ha of well-tended cocoa trees, the 2,000 kg of beans produced each year can generate an income of USD 3,000. The first cocoa pods are harvested after 18 months. Plantains do not bring in as much, not to mention the difficulties of storing them for a long time when they are ripe. The risk of rot is too high and there are no plantain processing plants in the region. As a result, people plant the plantain trees in the traditional food crop fields, and not in the agroforestry fields.

In tropical forest areas, people believe that forests are eternal and do not imagine that they could one day disappear. This is why they do not reforest by planting trees, since they think natural regeneration will take

Nursery for cocoa, fruit trees and fast-growing trees in the Penekatanga area, Bakumu Kilinga sector, Ubundu territory, DRC. Photo: Charles Mpoyi

place despite the threats posed by excessive logging. However, they do leave or protect certain trees in their fields because of their cultural, medicinal or economic importance (pharmacopoeia, fruit, caterpillar-hosting, sacred trees, etc.).

To meet the economic needs of the farmers within the framework of agroforestry, the programme has worked closely with the communities to identify and select useful trees, to collect their fruit and to sow them in community nurseries. These include fruit trees, fast-growing forest species and species that host edible caterpillars. Examples are mandarin (*Citrus reticulata*), avocado (*Persea americana*), red apple (*Malus domestica*), bush butter (*Dacryodes edulis*), orange (*Citrus sinensis*), *lambortant* (*Triumfetta lepidota*), *Terminalia superba*, *Leucaena leucocephala*, *Albizia* sp., *Millettia laurentii* and *Treculia africana*. The total surface area of transplanted trees in cocoa fields is equivalent to 101 ha (with a theoretical spacing of 9 x 9 m).

Some farmers also include food crops (rice, maize, etc.) in their agroforestry field to provide food and income while waiting for cocoa plants and trees to produce. Most of the cocoa plantations were established in mid-2021. The first production was expected in 2024 (after 36 months). However, the hybrid variety of the *Institut National des Études et Recherches Agronomiques* in Yangambi is bearing fruit early, 18 or 20 months after planting.

Conclusion

The success of an agroforestry model depends on its acceptance by farmers. Their needs and interests do not always correspond to those of the experts and NGOs that support these models. Building a model therefore requires a continuous, participatory and iterative process that involves all stakeholders. Any model, even the best one, can fail if its designers are not flexible enough to adapt and reinvent it to serve its users/beneficiaries. “Who increases his knowledge increases his ignorance,” said Friedrich Schlegel.

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Author affiliations

Alphonse Maindo, Tropenbos RDC et Université de Kisangani (amaindo67@gmail.com)
Charles Mpoyi, Tropenbos RDC et Université Officielle de Mbuji Mayi (charlesmpoyimukolamoyi@gmail.com)
Sagesse Nziavake, Tropenbos RDC et Institut Supérieur d’Etudes Agronomiques de Bengamisa (sagessenziavake@gmail.com)
Félicien Musenge, Tropenbos RDC et Institut Supérieur de Commerce de Goma (felimusenge@gmail.com)
Théophile Yuma, Tropenbos International et Université de Kisangani (theophileyumakalulu@gmail.com)
Ben Israël Bohola, Tropenbos RDC et Institut Supérieur d’Etudes Agronomiques de Bengamisa (benisraelb@gmail.com)
David Angbongi, Tropenbos RDC (davidangbongi@gmail.com)

A Pemban farmer holds flowering clove buds. The buds are harvested green and dried for export. Photo: Zach Melanson, CFI

Zanzibar's spice forests: Restoring the Spice Islands

Rebecca Jacobs

"On the east coast of Tanzania, agroforestry farmers in the Zanzibar Archipelago are regenerating the region's spice economy while improving their economic and environmental resilience."

Introduction

Spice farming has long been an integral part of the Zanzibari peoples' culture, history and economy. But in the past few decades, the region's role in the global spice trade has declined rapidly, along with the diversity and resilience of its once thriving forests and fertile soils.

Since 2015, Community Forests International (CFI) and Community Forests Pemba (CFP) have been working in Zanzibar to re-establish diverse agroforest ecosystems called spice forests. Spice forests provide a number of benefits. First, they provide an economic incentive for farmers to make the transition from monoculture farming to more ecologically sustainable agroforestry systems. Second, they offer an important opportunity to increase women's equality in the agricultural sector and beyond. Third, these diverse agroforests have the potential to restore a resilient spice-farming economy across the islands, benefitting farmers and the wider community and re-establishing Zanzibar as a leader in the ecologically and socially sustainable spice trade.

A brief history

A thousand years ago, spice plants were brought to the islands of Zanzibar. As the global market grew, so did spice production across the islands, increasing the country's economic importance and making it a leader in the highly competitive global spice trade. Zanzibar became and continues to be known as the Spice Islands.

Since the 1950s, however, the expansion of global spice production, a decline in market prices, and increasing local demands for land have caused a sharp decline in spice farming. To compound the challenges facing Zanzibari spice farmers, the primary governmental organization exporting Zanzibari spices was dissolved in the early 2000s, leaving spice farming to the private sector. Tourism has become Zanzibar's primary economic priority, leaving the spice and agricultural sectors behind. Smallholder farmers on the island of Pemba have been the hardest hit. This trend, coupled with the pressures of a rapidly growing population, is driving farmers to expand annual cropping into hilly areas previously reserved for spice trees.

Cloves, more than any other spice, highlight this rise and fall. From the 1850s to as recently as the 1960s, Zanzibar was the world's largest clove producer, exporting 6,000 metric tonnes annually (Nayar 2009). However, in recent decades, persistent government interference and a government monopoly have meant low prices paid to farmers for cloves, resulting in a decline in the trade. Although Zanzibari cloves are still considered to yield the highest-quality oil, flavour and aroma, the number of clove trees on the islands is less than half what it was in the late 1950s, and production of the spice has dropped to less than 10% of the global market.

A living spice culture

For spice farmers, the decline in the spice market necessitated a change in their farming practices. In most cases, this meant converting their farms to grow monocrop staples such as cassava, primarily for self-consumption or to sell in local markets. These monoculture farms are less resilient to the changing climate, environmental risks and market changes, leaving farmers and their families vulnerable. Zanzibari farmers also face other constraints, including a history of poor soil conservation, irrigation and drainage practices, many of which are unlikely to improve in the absence of specialized agricultural extension services.

For over a decade, CFP has been working with farmers across the islands to restore their landscapes, their livelihoods, and Zanzibar's place in the global spice trade. To date, CFP has supported small-scale farmers to establish more than 89 hectares (ha) of thriving spice forests across Zanzibar, providing both ecological and economic benefits. Although Zanzibar's place in world clove production has decreased, traditional spice knowledge is still very much alive among the region's farmers and the islands' culture. Pemba Island supports the cultivation of an exceptionally diverse array of crops, originating both from the African continent and from more distant regions, including India, Indonesia and the Mediterranean. It's not uncommon to find more than a dozen varieties of fresh spices in a Zanzibari market, including cardamom, black pepper, vanilla, ginger, turmeric, coriander, lemongrass and cinnamon. By revitalizing their agricultural strategies and producing organic spices for the rapidly growing global market, Zanzibari spice farmers are supporting climate resilience and solutions, creative enterprise opportunities, and strong livelihoods.

Growing thriving agro-ecosystems

The concepts of agroforestry are rooted in local and Indigenous cultures from around the world, and the spice forests in Zanzibar are in many ways simply restoring these practices and positioning their benefits for a global market. In Zanzibar, the spice forest model draws specific inspiration and knowledge from the experienced Chagga homegardens ("banana forests") farmers of Kilimanjaro, in mainland Tanzania. This centuries-old system combines agriculture, forestry and animal husbandry so effectively that it sustains one of the highest population densities in rural Africa (FAO 2014). With inspiration and shared knowledge from the Tanzanian mainland, combined with their own longstanding knowledge and culture of spice production, Zanzibari farmers are growing productive spice-based agroforests.

By definition, agroforestry is based on the concept of mutually beneficial relationships between annual crops and tree species, creating a diversified farming ecosystem. The spice forests in Zanzibar include a mix of 16 main timber, fruit and nurse tree species combined with seven high-value spices, including vanilla, cinnamon, black pepper, cardamom, turmeric and cloves — and farmers often grow additional vegetable crops as well. This polyculture model promotes structural and ecological diversity that provides a multitude of natural habitats for insects, birds and animals, and regenerates a healthy soil ecosystem.

The potential of agroforestry for carbon change mitigation is well recognized, and increasing attention is being given to agroforestry as a "natural" climate solution. Tropical agroforestry systems, such as Zanzibar's spice forests, act as enhanced carbon stores, sequestering sizeable quantities of carbon each year (Albrecht and Kandji 2003).

Moreover, the spice forests offer tangible benefits to farmers, including increased crop yields, diversified income streams, and improved household nutrition. By cultivating a range of crops within the same plot, farmers are reducing the need for additional land — a key benefit on small island states such as Zanzibar, where fertile lands are limited. The crop diversity enhances farmers' adaptation and resilience to the increasing risks of climate change, including unpredictable rainfall, drought, floods and soil erosion. In 2019, 72% of agroforestry farmers indicated that their land fertility had increased after converting their annual agricultural plot to agroforestry (CFP 2019).

Beyond spices, these agroforests provide farmers and their communities with a resilient source of food, energy (over 90% of the energy consumed in Tanzania is biomass), and income security while restoring ecological function to the landscape.

Saidi's story

Saidi Khalifa is a farmer on Pemba Island who exemplifies this land restoration. When he first met CFP, Saidi was monocropping the island's most common crop, cassava (*mahogo* in Swahili). His fields were becoming less productive each year, likely due to the depleting nutrients in the soil. However, with one-on-one training, some initial trees from the community-run nurseries, and a lot of work in the fields, Saidi transformed his 3.7-ha, low-value cassava farm into a food and spice forest system.

He is now growing bananas, pineapples, turmeric, black pepper, corn, jackfruit, mango, coconut, casuarina, teak, pumpkin, sugarcane, and much more. Saidi has completely changed his landscape by changing how he farms. Following CFP's advice, he has built a simple but effective trench irrigation system to improve water management, and is restoring the health of his soil by planting a mix of permanent fruit and spice tree crops on his farm.

By replacing monoculture agricultural landscapes with polyculture spice forests, small-scale farmers such as Saidi are improving their economic prospects while building resilience to climate change and supporting global efforts to mitigate the effects of climate change. These spice forests serve as a model for sustainable agriculture, demonstrating the potential of farming practices that

Saidi Khalifa, an agroforestry farmer from Wingwi Mapofu, Pemba Island, with several new vanilla cuttings distributed by CFP. Photo: Zach Melanson, CFI

Bimajo Masoud Juma stands proudly with a flourishing vanilla vine in her small but thriving spice forest. Bimajo is now sharing her knowledge with other women in her community, supporting their spice farming efforts. Photo: Zach Melanson, CFI

produce food and income while also providing ecological benefits and enhancing climate resilience.

Expanding women's opportunities

Across Zanzibar, women bear the responsibility for providing food, water and energy for households in rural areas and are more dependent on natural resources than men are. What's more, women face multiple barriers to participating in the agriculture and trade sectors. Historically, men have dominated these sectors, and women's rights to land ownership have been limited. As a result, most women who farm in Pemba do so on land that they do not own or have any customary rights to. This lack of land tenure makes it challenging for them to invest in long-term production systems such as spice and tree crops, which are too high risk. Gender inequality and the associated lack of women's economic agency impede both women's rights to independence and the region's wider prosperity.

Yet women in Zanzibar often cultivate gardens and have a wealth of knowledge on agricultural best practices, including the importance of crop diversity. Over the years, CFP has helped share and refine this knowledge with hundreds of women, delivering hands-on training to help them increase and diversify their yields while increasing their income and economic independence through capacity-building support for enterprise and business development. For many women, this is their first independently earned income — in fact, 98% of women participating in agroforestry training indicated that they had control over the income they made from farming, a rate much higher than the 13% national average. What's more, over 65% of women have increased their annual income (CFP 2022).

Step into Bimajo's forest

Bimajo Masoud Juma is an inspiring agroforestry farmer and community leader from Pemba Island. Since 2017 she has been working with CFP to help grow her own thriving spice forest and inspire others in her community. Like many women in Zanzibar, Bimajo had relied on her husband to support their family financially. After separating from her husband, Bimajo was struggling to find a source of reliable income for herself and her children. Unlike many women, Bimajo was fortunate in having access to a small plot of land left to her by her father. Through vegetable farming, she was able to earn a little bit of money, and slowly but surely invest in her land. Soon after starting, she decided to enrol in CFP's agricultural training programme.

With the skills she learned, Bimajo transformed her small plot of land from a monoculture yam farm into a diverse spice forest, full of vanilla, cardamom, black pepper, cinnamon, cloves and more. In 2023, Bimajo has harvested almost 2 kilograms of vanilla pods to sell — and is selling vanilla vines to aspiring spice farmers as an additional small source of income, and also to encourage other women to practise spice farming. Bimajo is intercropping fruit and vegetable crops with her spices, allowing her family to eat a nutritious diet while providing them with an additional source of income. Women like Bimajo are forging new opportunities for themselves and their communities, shifting the culture and conversation for increased women's representation and gender equity across Zanzibar and beyond.

Restoring resilient livelihoods

The production of fruits, vegetables and high-value spice crops — including cloves, vanilla and cinnamon — increases farmers' adaptability and resilience to market fluctuations, all while providing a more steady and diversified source of income throughout the year. Although agroforestry systems may have lower yields for individual crops, the total system yields are often much higher, contributing to greater food security and resilience (Niether et al. 2020). In a 2019 survey of farmers in Zanzibar, over 95% of newly trained agroforestry farmers reported increased total yields on their lands after converting their plots to agroforests (CFP 2019). In 2022, a survey of participants showed increases between 40% for established spices such as cardamom, cinnamon and black pepper and 100% for new crops such as ginger and vanilla (CFP 2022).

These increases in yields also improve farmers' incomes. In the 2022 survey, 74% of new agroforestry farmers reported higher incomes (CFP 2022). CFP is working alongside farmers to create stronger cooperative models, allowing farmers to sell directly to markets and eliminating the cost and risk of working with resellers. In 2018, for example, farmers reported receiving between TZS 300,000 and 400,000 (Tanzanian shillings; EUR 114–151) for 1 kilogram of dried vanilla. Agroforestry farmers working with CFP have sold vanilla directly to international buyers at TZS 900,000 (EUR 341) per kilogram, a large increase in farmers' direct income.

Meet Kibano Omar Kibano

Kibano is a spice farmer from Mtambwe Kaskazini village in Pemba. For years, Kibano struggled to make ends meet, earning only TZS 150,000 (EUR 57) per month as a subsistence farmer. But everything changed when he turned to spice farming, cultivating vanilla, black pepper and cinnamon. After receiving extensive agroforestry training and support, he improved the quality and quantity of his spices.

"I've worked with CFP for two years, and I can say with confidence that the quality and quantity of my spices are much better now," Kibano said. "I've increased the number of my vanilla plants from 200 to 570, my black pepper plants from 7 to 15, and I now have 50 cinnamon and 15 cardamom plants."

Agroforest spice farmer, Kibano Omar Kibano next to a newly planted vanilla cutting supplied by CFP. This vine will start to produce high-quality beans in about three years. Photo: Zach Melanson, CFI

A spice forest farmer holds a handful of nutmeg in various stages of being dried. The red and orange outer veins are removed and ground into mace, while the nutmeg is typically sold whole. Photo: Zach Melanson, CFI

As a result of the growth in his crops, Kibano's monthly income has increased to TZS 200,000 (EUR 78) per month. He can now provide his family with three solid meals a day and send his eldest child to secondary school. His next goal is to invest further in spice farming by producing seedlings to sell. His long-term objective is to earn TZS 6 million (EUR 2,160) per year and send his children to university, by investing more in his spice farming. Kibano is now a teacher and role model for others in his community, and his farm has become a learning hub for aspiring agroforestry farmers.

Bridging the market

With a steady local demand for spices and their relatively high value compared to other farm products, there is a constant economic incentive for farmers to produce spice crops. But to unlock the full potential of agroforestry for economic and ecosystem benefits, farmers are looking to connect to more profitable international markets.

The global organic spice market was valued at over USD 38 billion in 2018, and the market is expected to surpass USD 40 billion by 2024 (The Exchange 2022). The variety of spices grown using sustainable and organic agroforestry practices is well-positioned to thrive in this expanding market. A market analysis conducted for Zanzibar spices identified several quickly growing market opportunities for spice forests. These include ecotourism, and natural and equitable consumer markets in the food, cosmetic and household sectors. Moreover, several trends point to an increasing future demand, including expanding global tastes for international and multiethnic foods; growing awareness of the health benefits of spices; and increasing populations of Hispanic and Asian backgrounds in major markets such as the United States and Europe.

CFP and CFI continue to build connections between small-scale farmers and export markets in order to ensure the long-term viability and economic success of spice production. On one side, assisting in the creation of farmer-owned and -operated cooperatives and associations helps build sales and marketing capacity. These collectives allow farmers to access new and bigger markets and to hold equitable decision-making power at the trade table.

At the same time, efforts are also being made to establish reliable and equitable trade opportunities for farmers through a network of regional and international export partners. These range from farmer representation at national trade shows to partnering with global buyers such as Lush Cosmetics for organic vanilla. In the past two years alone, more than 2,000 agroforestry spice farmers have connected with local and international markets.

Importantly, brands and individual consumers are becoming more aware of environmental and social impacts, resulting in a growing global demand for ethically and sustainably produced products. As this demand grows, so do the economic opportunities and potential for agroforestry spice farmers.

Towards a resilient future

A number of challenges remain to ensure the scalability of agroforestry across the Zanzibar islands and beyond. These include the changing climate and prolonged rainy season, as well as limited access to affordable financing and to technologies and extension services that support the transition to agroforestry systems. CFI and CFP are working in tandem with other local and international partners to overcome a number of these challenges, including creating connections to financial institutions and government bodies for increased support and establishing in-field learning hubs for farmers to share agroforestry best practices, experience and knowledge.

The spice forest project has the potential to be replicated in agricultural communities across the globe and adapted to local contexts and environments. In fact, the expansion of the spice forest model to Tanzania's mainland is already being planned. The regeneration of spice forests in Zanzibar demonstrates how agroforestry can improve economic stability for vulnerable farming communities while restoring ecosystems for long-term climate resilience. More than a decade of experience working to establish and grow spice forests has also demonstrated the need for greater structural support, to allow farmers the growth and stability to thrive. Together, CFP and CFI have developed a number of key recommendations for agroforestry professionals:

- Communities are more likely to engage in and uphold sustainable farming and land-use practices when provided with a shared framework and agreements to identify roles and responsibilities and hold all stakeholders accountable.
- The best outcomes for increasing gender equality through agroforestry projects will come from women practitioners. This is because women experts further catalyze empowerment and act as role models for local women. All practitioners must be well-versed in gender-based approaches and local culture and help women navigate any challenges within the family or community.
- Including loans or community finance programmes alongside agricultural extension support will improve long-term yields and sustainability.
- Lead farmers can be indispensable resources in their communities and provide important peer-to-peer solidarity and knowledge sharing. Their model farms can act as local hubs for training and distributing material. By establishing learning hubs in the communities, agricultural training opportunities are more likely to reflect local needs, knowledge and environment.

Through agroforestry, Zanzibar's spice farmers and their communities are growing far more than just spices. In the face of numerous structural, climate and market challenges, these farmers are regenerating the region's spice economy while improving their economic and environmental resilience — one spice tree at a time.

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Author affiliation

Rebecca Jacobs, Digital Communications Manager, Community Forests International (www.forestsinternational.org)

Hillside agroforests and lowland rice fields on the east coast of Madagascar. Photo: Julien Sarron

3.8

The agroforests of the east coast of Madagascar

Pascal Danthu, Julien Sarron, Eric Penot, Juliette Mariel, Vololoniriana Razafimaharo and Isabelle Michel

"Cash crops grown in agroforests on the east coast of Madagascar generate foreign currency for the country and help to ensure food security for farmers, but is this sustainable?"

Vanilla, cloves and cinnamon are indispensable ingredients in gastronomic traditions the world over, and also have numerous industrial, medicinal and agricultural applications. These crops have made Madagascar famous, but are they the source of its wealth? Are they profitable for farmers? What is their future in a context of great economic uncertainty on the international market and in the face of climate change?

Agroforests based on cash crops

In Madagascar, vanilla, cloves, lychees, black pepper and cinnamon are all grown along the east coast by thousands of small-scale farmers in agroforestry plots featuring a high level of plant biodiversity within complex arrangements. These cash crops are a part of the country's history, which for a long time during the French colonial era focused on exports.

Clove trees in a rainfed rice plot. Photo: Pascal Danthu

The introduction of these crops profoundly altered ancestral family farming, which was based on the practice of *tavy* (slash-and-burn cultivation) on the hillsides for the production of rainfed rice and other subsistence food crops. Now, irrigated rice is cultivated in the lowlands, and agroforestry plots for cash crops cover the slopes. These fall into three categories:

1. mono-specific plantations with a dominant crop (in particular, clove trees), although this type of plot is now in the minority;
2. parks, where a dominant tree crop is combined with one or more annual crops (for example, clove trees and rainfed rice, vanilla, maize or sugarcane), or with grazing; and
3. agroforests, which are more or less complex, and characterized by a wide diversity of associated plants (cultivated or not) forming a multistorey structure (for example, clove trees and lychees, or other fruit trees, timber trees, sugarcane, vanilla, pineapple).

Farmers who are also food processors

The markets for these products are in the hands of a few global giants of the food industry, and the structure of the commodity chains is relatively simple: collectors/buyers act as the link between farmers and exporters, who are generally based in Toamasina (also called Tamatave), the main export port. The farmers deliver a finished product to the collectors, ready for export.

Depending on the product, preparation is more or less complex and time-consuming.

Agroforest with young clove trees. Photo: Pascal Danthu

Preparing vanilla involves a series of stages requiring real expertise to give the finished product its quality and aromatic complexity. It starts with hand-pollination, followed by several post-harvest stages: scalding, steaming, drying, refining of the pods, and sorting and packaging of the black vanilla.

The clove tree is hardy and requires little maintenance, but the bud must be harvested before the flower opens, otherwise, "headless" cloves of lesser commercial value will be produced. De-clumping (separating the flower bud from the stalk) and drying in the sun take four or five days. The essential oil of cloves is obtained by distilling the leaves or cloves in stills (which are often archaic and consume a lot of firewood) for 12 to 24 hours, with a yield of around 5%.

The lychees have to be delivered very quickly for conditioning (sulphuring) and storage in the cold rooms of the refrigerated ships that transport them to Europe.

Plant products from agroforests in Madagascar's top three exports

Today, Madagascar is the world's leading producer of vanilla (around 70% of global production), the second largest exporter of cloves (behind Indonesia, the undisputed leader) and essential clove oil (20,000 and 2,000 tonnes respectively), and the leading exporter of lychees to the European market. In 2020, vanilla accounted for almost 22% of Madagascar's exports, while cloves and essential oils each accounted for 3% (Danthu et al. 2020; OEC 2020; BFM 2023).

However, this snapshot should not mask very significant interannual variations, as shown in Figure 1. The share of plant products from the east coast in total Malagasy exports dropped from a range of 20% to 30% in 1990–1995 to around 5% to 10% between 2005 and 2009, stabilizing at between 30% and 40% since 2016. Vanilla is by far the most profitable crop, although this has not always been the case; in the 2010s, it was cloves.

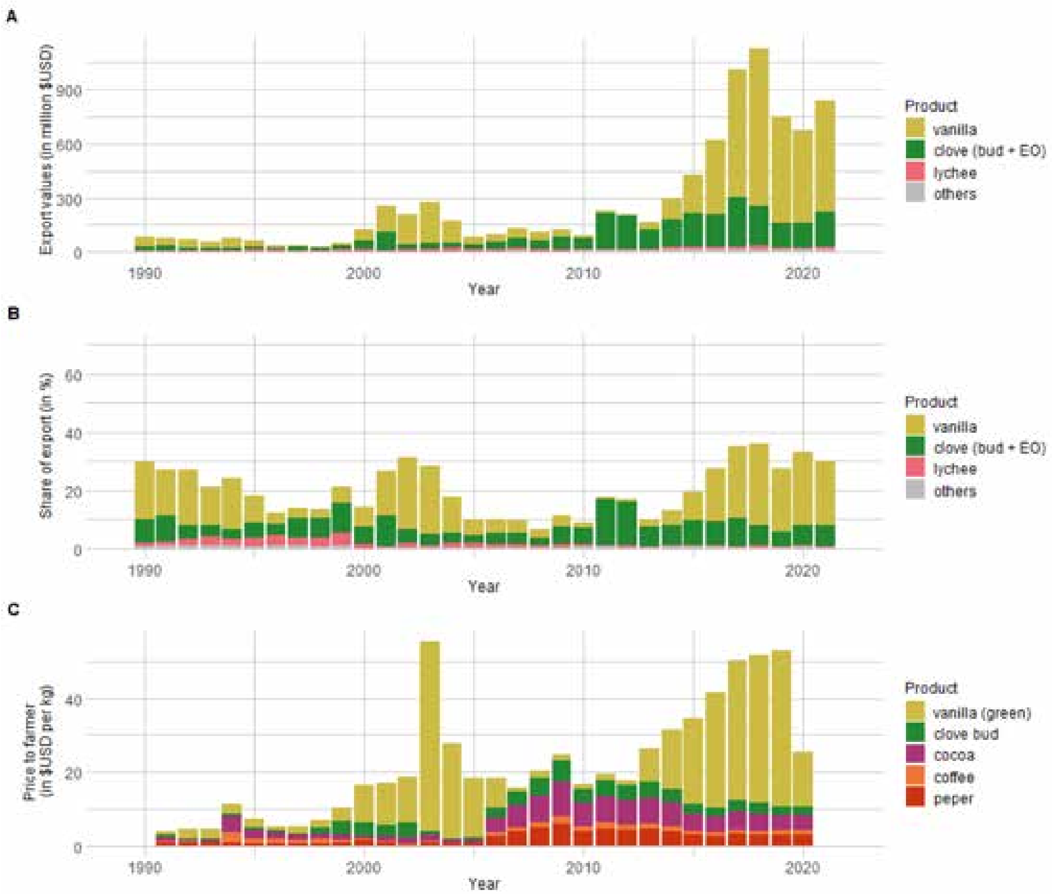

Figure 1. a) Exports (USD million); b) percentage of total exports; and c) farm gate price (USD/kg) of cash crops in Madagascar, 1990–2020. EO: essential oil. Source: BFM 2023; FAOSTAT 2023

Vanilla grower. Photo: Juliette Mariel

Vanilla has been subject to much speculation and uncertainty, and has experienced considerable price fluctuations for more than twenty years. The price of a kilogram (kg) of prepared vanilla ranged from USD 6 to USD 600 between 1999 and 2016, falling back to between USD 250 and USD 400 more recently (Veldhuyzen 2019). Some of these fluctuations are linked to the vagaries of weather, growing conditions and farmers' know-how. Added to this are local security conditions, with theft of green vanilla a real problem, as well as the speculative strategies of the main players in the industry. The setting of a minimum purchase price by the government drove buyers away when this turned out to be higher than the world price. This has been the case since 2020. These difficulties may have prompted some manufacturers to turn to other vanilla suppliers such as Indonesia, Papua New Guinea and Uganda, or even to... synthetic vanillin.

Indonesia, Tanzania (the islands of Zanzibar and Pemba), Comoros and Brazil are significant competitors in cloves, which have three main destinations: Indonesia, to supplement the Indonesian harvest and supply the *kretek* industry (a traditional cigarette made partially from cloves); India, and the Middle East, where spice blends (carry or massala) are produced — and in addition, the niche market in northern countries. The world price of cloves is less volatile than that of vanilla, but varied from USD 2 to USD 22/kg between 2001 and 2012, stabilizing today at between USD 7 and USD 9. For essential clove oil, the average price is around USD 10/kg; it has risen almost continuously since 1998, when it was USD 3 (BFM 2023; FAOSTAT 2023).

Lychee exports from Madagascar (by refrigerated ship) supply around 80% of the European market, and total around 17,000 metric tonnes (mt) a year (Jahiel et al. 2014). The industry is organized around the *Groupement des Exportateurs de Litchi*. Every November, the export campaign mobilizes 75,000 seasonal workers to harvest and pack the fruit. Prices have stagnated at around USD 1,300/mt for 20 years, and export volumes are tending to fall (from 24,000 mt in 2008 to 14,000 mt in 2022) (BFM 2023), in line with a loss of fruit quality and less interest on the part of European consumers.

The central role of cash crops in farm income and the sustainability of family farms

In 2021, around 1.3 million households were engaged in agriculture on the country's east coast, including 780,000 in cash crops, with the largest contingents in the Sava and Analanjirofo regions (INSTAT 2020). Cash crops grown in agroforests in these regions (mainly clove essential oil and cloves, vanilla and lychee) account for between 20% and almost 100% of cash income (Fourcin et al. 2015). As a result, farm households in these regions have higher incomes than those in the more isolated southern regions (southern Atsinanana and especially Vatovavy, Fitovinany and Atsimo Atsinanana), where cash crops are more rare.

In Analanjirofo Region (the heart of clove production), at least 50% of farm income comes from clove products. Farm households with the most clove trees are those that generate the highest annual farm income. In this region, where all the lowlands are cultivated with rice, 50% to 70% of households are unable to be self-sufficient in rice, the staple food in Madagascar. Income from cash crops is used primarily to buy additional rice, in order to achieve indirect food security.

The parks and agroforests provide income as well as self-consumed products (fruit, wood, medicinal plants), which represent a relatively significant saving — or rather, non-expenditure — for farm households. Some species, such as breadfruit, cassava and maize, are used to meet food requirements, particularly each year in April or May, when rice reserves are exhausted and the new harvest is not yet available (known as the hunger season). They also contribute to feeding livestock and poultry.

Sava Region, which produces vanilla, appears to be the richest. Vanilla is a source of high income, even if world market prices fluctuate (from USD 15 to USD 38 per kg of green vanilla between 2017 and 2020). Some boom years bring a substantial financial windfall, leading to spectacular buying sprees (mattresses, televisions, solar panels, etc.). However, the day-to-day reality remains marked by the poverty syndrome. Farmers are often forced to sell their green vanilla, sometimes below the minimum price set by the government, in order to ensure their food security.

Sale of lychees at a local market. Photo: Eric Malézieux

Diversifying crops and farm income: a way of adapting to volatile world prices?

For farm households involved in cash crops, cloves and vanilla account for a significant proportion of their income. But their strategy is characterized both by diversified production for export (cloves and essential clove oil, green and prepared vanilla, as well as lychees, pepper and cinnamon), and by production that is either self-consumed or sold in local markets (bananas, avocados, cassava, lychees, breadfruit, jackfruit, *noni* (*Morinda citrifolia*), soursop, pineapple and citrus), sometimes supplemented by livestock products. This diversification of cash crops is a protection against the high volatility of products on the world market, providing income over the long term.

These diversification initiatives also take into account, although often in a very reactive way, changes in international demand for high-quality products with high added value, as is currently the case for black pepper, pepper tree (*Schinus terebinthifolius*) and above all cinnamon, for which global demand is rising sharply.

A positive situation at present, but a questionable outlook

The export commodity chains of the east coast of Madagascar for crops grown mainly in agroforests are sources of wealth for the country, significantly consolidating its trade balance. They also support food security and limit the extent of poverty, or even ensure relative financial comfort for farming households, compared with those in other regions of the country.

However, long-term observations of these agroforests and their production highlight variations in production and farmers' remuneration, which ultimately raise questions about the role of cash crops in improving the living conditions and food security of farm households. In the past, these developments have led to periods of crisis or euphoria, raising questions about the future: what dynamics, what hazards, what resilience?

In addition to production fluctuations, it is possible, and even likely, that there will be more numerous and more violent shocks linked to climate change, which is already having a significant impact on Madagascar (drought, floods, cyclones, rising temperatures) and which could cause lasting disruption to crop yields. Similarly, the production of essential clove oil in highly inefficient stills consumes large quantities of firewood, which puts considerable pressure on wood resources. As a result, a

Cinnamon sticks. Photo: Eric Penot

major constraint has arisen in the supply of firewood to run the 5,000 to 8,000 stills of the east coast. Thought needs to be given to developing this production by, for example, promoting the inclusion of fast-growing trees in or near agroforests.

The economic outlook is no more reassuring, and some plausible developments could worsen the situation. In the short term, developments in green chemistry could offer synthetic eugenol or vanillin at such a low cost that these two compounds would replace essential clove oil or vanilla in many industrial applications. This threat is reinforced by competition from other emerging countries: Comoros, Zanzibar and Brazil for cloves, Indonesia, Mexico or Papua New Guinea for vanilla, Viet Nam and Réunion Island for lychee.

It is therefore difficult to be certain about the medium- and long-term sustainability of Madagascar's cash crop export sectors, and therefore about the resilience of the farmers who supply them.

Promoting income security through diversification

This overview of agroforests on the east coast of Madagascar, the place of the products they provide on world markets, the role they play in the resilience of farm households, and also the hazards that threaten them, raises the question of their sustainability and adaptation. The answer may lie in one word: diversification — not only of crops but also of land management practices, and of the uses of the products (sale, self-consumption, food or feed, other uses).

Diversifying the uses in agroforests makes it possible to combine cash crops, food crops for self-consumption and crops sold locally: rice, tubers and fruit, small livestock (zebus, as standing capital or labour, pigs, poultry). It could also lead to an increase in vegetable production, in order to reduce household dependence on purchased vegetables; these are often imported from the high plateaus in the centre of the country, and are therefore expensive and not widely consumed locally.

Diversification can focus more specifically on cash crops, combining cloves and vanilla, as well as other products with high added value or high demand on international markets, such as black pepper, cinnamon, pepper tree berries, ginger and cardamom. It can also involve a better valorization of resources, particularly clove trees, by combining the cultivation of cloves and the production of essential oil from the distillation of the leaves. This diversification can (and should) also involve reintroducing trees for firewood into agroforests and rehabilitating or improving stills to improve essential oil yields at a lower environmental cost.

Studies on the physiology of interactions between species in agroforests, and on the management of agro-biodiversity at different scales, from plots to farms and landscapes, will enable better crop diversification, improve product quality, and ensure the resilience of agroforestry systems through a better adaptation to climate hazards. But whatever the case, there are already many approaches being used by farmers, whose knowledge has enabled them to ensure the resilience of their farms and to overcome economic and ecological crises.

Conclusions

- A significant proportion of Madagascar's wealth is generated by the export of plant products from the agroforests of the east coast, mainly vanilla, cloves and lychees.
- The agroforests of the east coast, the cash crops they support and the products they produce help to reduce poverty among rural populations.
- These crops are grown by thousands of small farmers who also process the products (cloves, essential clove oil, vanilla), delivering finished products for the commodity chains.
- Farmers manage the diversity of their agroforestry plots and, more generally, of their farms, which also include rice paddies and livestock, in order to increase their financial income and food security.
- This necessary diversification of production needs to be strengthened in order to ensure the long-term resilience of farms in the face of possible future climatic and economic hazards.

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Author affiliations

Pascal Danthu, French Agricultural Research Centre for International Development (CIRAD), Research Unit Horticultural Systems, University of Montpellier, Montpellier, France (pascal.danthu@cirad.fr)

Julien Sarron, French Agricultural Research Centre for International Development (CIRAD), Research Unit Horticultural Systems, University of Montpellier, Montpellier, France and Centre National de Recherche Appliquée au Développement Rural (FOFIFA - CRR Est), Toamasina, Madagascar (julien.sarron@cirad.fr)

Eric Penot, French Agricultural Research Centre for International Development (CIRAD), Research Unit Innovation, INRAE, Institut Agro, University of Montpellier, Montpellier, France (eric.penot@cirad.fr)

Juliette Mariel, French Agricultural Research Centre for International Development (CIRAD), Research Unit Knowledge, Environment and Societies (SENS), French National Research Institute for Sustainable Development (IRD), Paul Valéry University, Montpellier, France (juliette.mariel@cirad.fr)

Vololoniriana Razafimaharo, Centre National de Recherche Appliquée au Développement Rural (FOFIFA - CRR Est), Toamasina, Madagascar (poussie.ignizine@gmail.com)

Isabelle Michel, French Agricultural Research Centre for International Development (CIRAD), Research Unit Innovation, National Research Institute for Agriculture, Food and the Environment (INRAE), Institut Agro, University of Montpellier, Montpellier, France (isabelle.michel@supagro.fr)

Groundnuts between rows of young eucalyptus trees.
Photo: Phokele Maponya

Agri-silviculture community growers in Mpumalanga Province, South Africa

Phokele Maponya

"Agroforestry can help bridge the gap between agriculture and forestry by creating integrated systems that fulfil environmental and socioeconomic goals and generate income."

Introduction

The important contributions of agriculture and forestry to the South African economy have the potential to support poverty alleviation and economic growth. According to Kotze and Rose (2015), about 32,000 commercial farmers account for 95% of the country's locally produced food, while the remaining 5% of food is produced by 220,000 emerging farmers (a category of farmers between smallholders and commercial farmers) and 2 million subsistence farmers. According to Agriculture, Forestry & Fisheries (2017), the forestry sector is a major contributor to the South African economy through its well-developed and diversified forest products industry. It supports manufacturing subsectors such as sawmilling and pulp and paper production, as well as mining and construction. In addition to its upstream and downstream impacts, the sector has strong potential for creating jobs and small businesses; it includes about 157,500 jobs across its entire value chain.

Groundnuts planted between eucalyptus rows at the MTO plantation. Photo: Phokele Maponya

Agroforestry is a land-use system that combines the use of woody perennials and agricultural crops and/or livestock to achieve beneficial ecological and economical interactions for food, fibre and livestock production. Structurally, according to Nair (1985), the system can be defined as agri-silviculture (crops plus trees), silvopastoralism (pasture/animals plus trees), or agrosilvopastoralism (crops plus pasture/animals plus trees). Properly managed agroforestry systems provide multiple benefits and contribute to improved livelihoods and income generation. Agroforestry practices are also specific to location and climate; it is key to develop systems that are locally relevant, and to consider the biophysical and socioeconomic context on a case-by-case basis. South Africa is a semi-arid country and is vulnerable to water stress, particularly drought.

Agri-silviculture combines and integrates crops and trees managed on the same farm. According to Bentrup et al. (2019) and Maponya et al. (2022) the main contributions of agri-silviculture are as follows:

- produce multiple products such as food/vegetables/fruits, fodder and forage for livestock, firewood, timber, and leaf litter for organic manure production;
- sustain and improve crop productivity, which increases income for the farmers;
- improve the nutritional value of animal feed by supplying green fodder;
- recycle soil nutrients, which also reduces the need to buy chemical fertilizers;
- improve farm-site ecology by reducing surface runoff, soil erosion, nutrient loss, gully formation and landslides;
- improve the local microclimate and enhance the farm's productive capacity;
- reduce pressure on community forests and other natural forests for fodder, firewood and timber; and
- help beautify the surrounding areas.

Agroforestry in Mpumalanga Province

A study by Maponya et al. (2022) in Limpopo and Mpumalanga provinces showed that including crop production in forestry plantations (intercropping groundnuts with eucalyptus trees) contributed to increasing food security and improving community livelihoods. The objectives of the study, which is summarized here, was to monitor the establishment and expansion of this type of agri-silviculture and to determine the food security status and socioeconomic characteristics of the community growers.

There is great interest in agroforestry among the smallholder farmers and community growers in the Ehlanzeni and Gert Sibande districts of Mpumalanga Province (Maponya et al. 2022). A total of 143 agri-silviculture community growers participated in the study in an area where annual rainfall is about 600–700 mm (range 400–1,000 mm), with cool to hot temperatures. The research employed both qualitative and quantitative methods concurrently; the aim was to establish the limitations, balance and strength of the data. The methods included participatory action research with closed and open-ended questionnaires and the option for participants to construct their own response about the subject matter. In October 2021, each of the 143 growers was allocated an area of 2,601 m^2 within a forestry plantation area to implement the agroforestry scheme; the total area was 37.2 hectares. The land was made available by Mountain to Ocean (MTO), a private forestry company. This agroforestry initiative is referred to here as the "intervention." The food security status of the growers was assessed before (October 2021) and after (June 2022) this intervention.

The socioeconomic characteristics of community growers in Ehlanzeni District are summarized in Table 1. It shows striking results about the gender of participants (68% women) and age distribution (60% were more than 60 years old, a worrisome indicator that the young generation needs to be attracted to agroforestry).

Weeding groundnuts between rows of young eucalyptus trees at the MTO plantation. Photo: Phokele Maponya

Table 1: Selected socioeconomic characteristics, agri-silviculture community growers, Ehlanzeni District, 2022

Variables	Details	Community growers	Percentage
Gender	Female	97	68
	Male	46	32
	Total	**143**	**100**
Age category	18 – 35	3	2
	36 – 45	3	2
	46 – 60	52	36
	> 60	85	60
	Total	**143**	**100**
Level of education	Less than Grade 7	113	79
	Matric	30	21
	Post-matric	0	0
	Other	0	0
	Total	**143**	**100**
Farming experience (years)	1 – 5	3	2
	6 – 10	3	2
	11 – 20	52	36
	21 – 49	85	60
	> 50	0	0
	Total	**143**	**100**
Training provided *	Yes	143	100
	Total	**143**	**100**

* The provider of training for all 143 participants was the Small Enterprise Development Agency, a division of the national government's Department of Small Business Development.

A glimpse of part of the 37.2 ha allocated to the nearby communities at the MTO plantation. Photo: Phokele Maponya

Food security

Before intervention

An evaluation of food accessibility before the intervention revealed that not all 143 community growers had land to grow or access food and that all were moderately food insecure. Problems such as monotonous diets and few or small meals or undesirable food were commonly mentioned.

Of the growers, 54% indicated problems in terms of food availability before the intervention, mentioning that food runs out before they get money to buy more, while 71% said that they cannot afford to eat enough food every day. 72% mentioned that they often feel hungry and that children cannot get enough to eat (28% sometimes and 72% always). According to Maponya et al. (2022), some of the coping strategies that community growers used to support food availability include buying food on credit from local shops, remittances, social grants, food parcels, food support from neighbours, etc.

In terms of food diversity, all the 143 community growers said they have access to the following foods: cereals, white tubers and roots, vitamin A-rich vegetables, fruits, dark green leafy vegetables, other vegetables, legumes, meat and fish, eggs and dairy products, as well as oil, fat and sugar, and spices, condiments and beverages.

After intervention

Food accessibility after intervention had strongly increased, with a whopping 88% of the community growers indicating that they could now access food on the land allocated to them. Only 12% indicated that they were still food insecure, in some instances because of the lack of transport money to monitor their land allocation and in some instances, because of damage by animals to their groundnut fields.

In terms of food availability after intervention, 59% of the participants indicated that their food never runs out before they get money to buy more; 40% said it sometimes runs out. 38% said that they can always (50% often) afford to eat enough every day. Most said that they can now buy or have enough food and 62% that they are never hungry anymore, including children.

Agri-silviculture community growers have access to both formal and informal markets. On the formal market, prices range from ZAR 200 to ZAR 650 per kg of groundnuts; 19 rand (ZAR) = USD 1. The harvest was transported from Mpumalanga to Pretoria by the processing facility at no cost. On the informal (local) market, prices range from ZAR 50 to ZAR 100 per five-litre bucket of groundnuts. This local market price resulted in a 42% increase in income, although exact figures are difficult to compare because of different marketing metrics (kg versus five-litre buckets). So, people obviously

An agri-silviculture community grower checking the progress of her upcoming harvest and the condition of her harvested groundnuts. Photos: Phokele Maponya

indicated that they prefer the informal market, since they got a good price for their harvest. In addition, it must be emphasized that community growers were reluctant to disclose the exact quantities sold to the formal and informal markets as they feared that future support could be compromised.

Conclusions

The findings of the study show that agroforestry can help bridge the gap between agriculture and forestry by creating integrated systems that fulfil environmental and socioeconomic goals and generate income. Furthermore, public-private partnerships — which involve collaboration between a government agency and a private-sector company — can be used to finance, develop and operate projects such as agroforestry/agriculture initiatives. In this case, the collaboration was between Mountain to Ocean (MTO), a private company, and the Agricultural Research Council (ARC), a government research agency.

The study showed that the agri-silviculture community growers were able to sell their products at both formal and informal markets. The study also indicated the various challenges faced by the growers, including high transport costs and lack of transport. This transport challenge should be prioritized as similar studies indicate that the influence of collaborations, and of increasing access to markets, road and transport, helped farmers shift from subsistence to market-based farming. Furthermore, a gradual increase in the production of crops and the raising of animals contributed to an increase in agroforestry for cash generation.

The current collaboration is growing from strength to strength. The agri-silviculture community growers were allocated a further 150 ha by MTO, given groundnuts seeds by the Department of Forestry, Fisheries and Environment, and the ARC continued with its socioeconomic study and market linkage. During land allocation to the communities, Kalinda Trading, a private company, also served the communities with peanut butter made from the previous growing season's groundnuts sold to the formal market. The agri-silviculture community growers emphasized that they moved away from their villages to the MTO plantation in search of its good climate, including rainfall, and because it would improve their livelihoods through income generation, job creation and food security. It is thus recommended that agroforestry should be intensified across South Africa, especially since it also contributes to Sustainable Development Goals 2 (Zero hunger) and 17 (Partnership to achieve the goal) of the United Nations.

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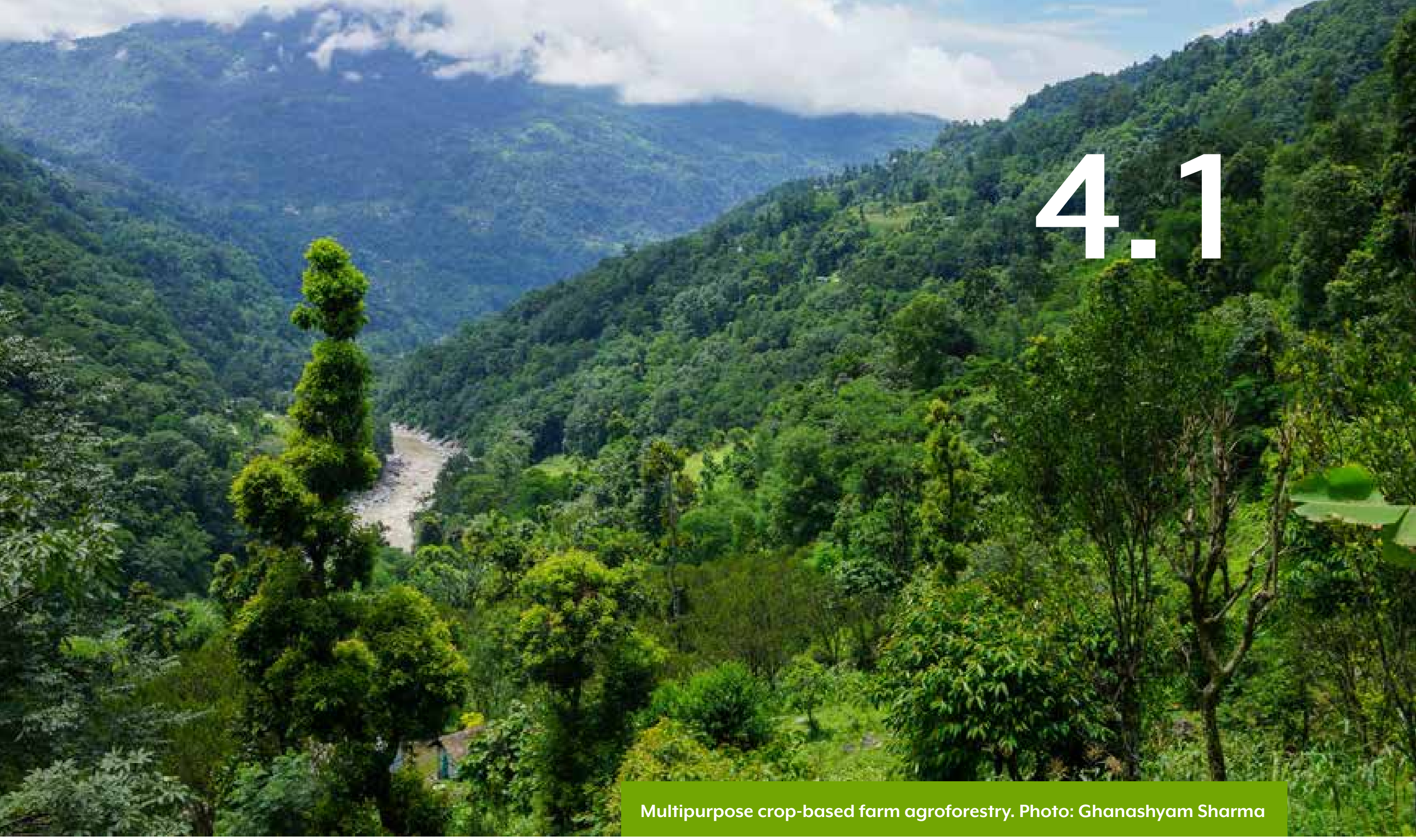
Author affiliation

Phokele Maponya, Agricultural Research Council-Vegetable, Industrial, Medicinal Plants, Pretoria, South Africa (maponyap@arc.agric.za)

Section 4

Asia

Previous page: A farmer shows her durian harvest at her *tembawang* agroforest in Sinar Kuri village, Ketapang, West Kalimantan, Indonesia. Photo: Irpan Lamago



Multipurpose crop-based farm agroforestry. Photo: Ghanashyam Sharma

Multipurpose, climate-resilient agroforestry in the Eastern Himalayas

Ghanashyam Sharma

"Agroforestry can improve the socio-ecological and socio-economic status of Indigenous populations and enhance mountain ecosystem services."

Introduction

Traditional farmers in various developing regions have passed down intricate farming systems that effectively manage challenging environments and climate variations while fulfilling subsistence requirements. These systems have been successful without relying on modern agricultural technologies such as mechanization, chemical fertilizers or pesticides. India's rich historical legacy of agroforestry practices continues to be acknowledged by contemporary ecologists and development agencies (Kumar and Sikka 2014).

India's National Research Centre for Agroforestry (NRCA) has conducted research that has contributed in many ways, such as identifying suitable tree species for the country's different agro-ecological zones. One of the outcomes of the 2014 World Congress in Agroforestry was the promulgation of Indian's National Agroforestry Policy.

Forest-based agroforestry around cultivated farms. Photo: Ghanashyam Sharma

The traditional farming systems in the Eastern Himalayas are a compelling example of small-scale agroforestry systems (including homegardens) that have been managed by Indigenous farmers for generations. These systems offer a range of socioecological, sociocultural and socioeconomic benefits. Their diverse array of multipurpose trees, shrubs, traditional crops and livestock (Sharma et al. 2016) promotes ecological sustainability. They are more diverse than monocropping, providing multiple services to households. The predominant land-use practices in the region include agroforests and other agroforestry systems, open cropped areas, and adjacent forests. This article discusses efforts to implement Indigenous agroforestry-based agricultural management in the Eastern Himalayan region.

Agroforestry diversity

During the early 17th century, Nepali farmers initiated terrace farming practices in Sikkim. Subsequently, they devised a variety of agroforestry systems within Sikkim and extended towards Bhutan and the northeastern Himalayas. These innovations were later adopted by other mountain farmers in the region. Traditional agroforestry practices in the region are classified into seven systems: farm-based, forest-based, large cardamom-based (with two subsystems: alder-cardamom and mixed trees-cardamom), mandarin based, crops/mixed trees-based, slash-and burn based, and tea-garden-based (Table 1). These systems possess the potential to improve livelihoods by providing farmers with a range of alternatives to increase both farm production and income. Furthermore, they support productive and protective roles for ecosystems, including promoting biological diversity, maintaining healthy ecosystems, preserving soil and water resources, storing terrestrial carbon, and enhancing resilience.

Farm-based agroforestry

In this system, farmers manage multipurpose tree species for fodder, firewood and timber within and around cultivable land, as well as in terrace risers to stabilize soil. They also practise intercropping under tree canopies (photo page 145). The system consists of *sukha-bari* (rainfed fields) with crops such as maize-potato and maize-ginger, as well as *pani-khet* (wet rice-based fields) where rice is followed by winter crops and vegetables. Effective management of fodder trees and food production is critical for maintaining livestock.

Forest-based agroforestry

This system integrates forested and farmed areas (see photo above), including bamboo groves. Farmers cultivate multipurpose trees (with social, ecological, economic and aesthetic functions), and safeguard timber species for construction and repairs. To regulate water and prevent flooding, erosion and slope instability, agroforestry plots are situated along ridges and furrows, vertically on slopes, and horizontally between slopes. Downhill drainage offers consistent irrigation and the terraced slopes are shielded by agroforests.

Large cardamom-based agroforestry

This system includes a diversity of multipurpose trees that include fodder trees and bushes, timber trees, fruit trees, etc. (see photo a, below). Large cardamom (*Amomum subulatum*) is a valuable cash crop cultivated in the northeastern states of India, Bhutan and Nepal between 600 and 2,300 metres above sea level (masl), in areas with mean annual rainfall of 1,500–3,500 mm. Its distinctive aroma and flavour make it highly sought after in the global market. Large cardamom production involves low volume per plant and requires relatively low labour inputs, which is advantageous for smallholder farmers.

Alder-cardamom agroforestry

Himalayan alder (*Alnus nepalensis*) is a naturally occurring tree that forms a beneficial association with cardamom, offering shade, nitrogen fixation and nutrient-rich litter (Sharma et al. 2008). This pioneer species thrives in challenging environments such as landslide soils, denuded habitats, rocky slopes, stream banks and natural areas. Farmers gradually establish an alder-cardamom association (see photo b, below) by planting cardamom saplings and maintaining tree density annually (Sharma et al. 2016). The system has economic viability, ecological adaptability, social acceptability, and considerable carbon sequestration potential (Sharma and Sharma 2017).

Mixed trees-cardamom agroforestry

Common shade trees used in large cardamom agroforestry systems include *Schima wallichii*, *Engelhardtia acerifolia, Eurya acuminata, Leucosceptrum canum, Maesa chisia, Symplocos theifolia, Ficus nemoralis, Ficus hookeri, Nyssa sessiliflora, Osbeckia paniculata, Viburnum cordifolium, Litsaea polyantha, Macaranga pustulata*, and *Alnus nepalensis* (see photo c, below). Large-cardamom agroforestry practices also conserve biodiversity elements in the region. This system promotes a more diverse range of tree species than other agroforestry systems in the

Diverse agroforestry systems a) large cardamom agroforestry; b) alder-cardamom agroforestry; c) mixed trees-cardamom agroforestry.
Photos: Ghanashyam Sharma

region. The trees also support birds and other wildlife, which contributes to the system's ecological structure and functioning.

Mandarin-based agroforestry

This system (which also includes *Albizia stipulata* and other tree species) intercrops high-value cash crops, such as Sikkim mandarin (*Citrus reticulata*) and ginger with maize, pulses, buckwheat, finger millet, oilseeds, taro and yam on non-irrigated *sukha-bari* land (see photo a, below). Large cardamom cultivation is also included in this system. The system is promising at lower elevations (250–1,700 m). *Albizia*, another nitrogen-fixing species, is commonly grown alongside other trees in this system to enrich soil fertility.

Crop/mixed-trees-based agroforestry (>300 m)

Riverbanks and terraced slopes contribute to the genetic diversity of traditional rice varieties, such as *krishna bhog*, *nuniya* and *kataka*. This agroforestry landscape (see photo b, below) demonstrates the importance of traditional ecological knowledge. Some dryland and wet-rice varieties have declined, while irrigated rice varieties, such as *attey*, *timmurey, jhapaka, bacchhi, mansaro, baghey-tulasi*, *champasari, sikrey* and *taprey*, are well-adapted to agroecological zones ranging from 300 to 1,800 m in elevation (Sharma and Sharma 2017). Tree-lined terraces protect upland rice cultivation, conserving water and providing nutrients.

Legumes, beans, maize, wheat, buckwheat, oilseeds and vegetables are cultivated during the winter. This agroforestry system also integrates large cardamom and forests, conserving water, controlling floods and providing nutrients and habitat for wild animals. The region supports agrobiodiversity, traditional irrigation practices, and diverse cropping systems. Numerous farmers practice agroforestry by allowing their animals to graze within these systems, while others opt for stall-feeding their livestock due to the scarcity of grazing areas within their agroforestry farms.

Slash-and-burn agroforestry

The Lepcha Indigenous community in Sikkim has devised agroforestry systems tailored to both valleys and steep slopes. Employing a technique referred to as *bhashmey-kheti*, they practise shifting cultivation in the Dzongu valley (see photo a, next page). This slash-and-burn technique involves a series of steps: in December, a considerable forest expanse is cleared. The resulting debris is set ablaze as a means of generating fertilizer, a practice conducted from mid-February to mid-March. Following this, at the advent of the monsoon season, crops are sown. After one or two crop cycles, the land is left fallow, while new areas are prepared. This labour-intensive process involves all family members; men engage in physically demanding tasks and women handle debris clearance, seed selection, sowing and harvesting. Farmers maintain the cultivation of traditional varieties of cereals, pulses, oilseeds, tubers, and lesser-known underutilized crops,


a


b

Diverse agroforestry systems a) Mandarin -based agroforestry; b) crop/mixed-trees based agroforestry. Photos: Ghanashyam Sharma

with women playing a crucial role in safeguarding and preserving the seeds.

This method relies on the soil fertility of cleared forests to cultivate a diverse range of crops, encompassing dry paddy, wet paddy, maize, wheat, hulless barley, buckwheat, millet, grain amaranths, oat, sorghum, Job's tears (*Coix lachryma*), ginger, turmeric, legumes and pulses, *chayote* (*Sechium edule*), domesticated and wild yams (*Dioscorea* spp.), cassava, colocasia (*Colocasia esculenta*), and a variety of cucurbits. The Dzongu region currently has a solitary upland dry paddy (*tuk-mor-zho*), an ancient practice of the Lepcha people. They also cultivate mandarin oranges, peas, pear, plum, avocado and large cardamom, as well as wild edibles, encompassing medicinal and aromatic plants.

Until the early 2000s, shifting cultivation (*sudyom prek shyon* or *sudyom hong shyong*) was the predominant agricultural method practised by the Lepcha on the steep slopes of the Dzongu area. Echoes of this approach still persist in the upper reaches of Dzongu, where a diverse array of crops are cultivated.

Tea garden

The Temi tea (*Camellia sinensis* L.) garden, established in 1969, encompasses an area of 176 hectares (ha) along steep hillsides ranging from 1,200 to 1,800 masl. This tea fetches a premium price in the international market. The first flush of Temi tea fetched record breaking price of INR 10,250 per kg (USD 124) in 2023. The garden is operated by the Government of Sikkim and produces approximately 100 metric tonnes of tea annually, which undergoes on-site processing and packaging. Recently, the tea garden has been certified as organic, leading to increased demand.

The Darjeeling Hills have a total area of 241,700 ha, of which an estimated 40% is covered by forests, 40% by *khasmal* (forests for community use) and municipalities, 2% by cinchona plantations, and 18% by tea plantations (see photo b, below). First planted in 1839, Darjeeling tea has a quality that is the result of climate, soil conditions, altitude and meticulous processing. About 10,000 metric tonnes are grown every year, spread over 17,500 ha of land. The tea has its own special aroma, a rare fragrance that fills the senses. Tea from Darjeeling has been savoured by connoisseurs all over the world. The first flush of this tea fetched around USD 278 per kg in 2023.

This integrated system offers ecological and economic advantages and promotes biodiversity conservation. It includes alley cropping (tea grown in between rows of woody/non-woody species), which benefits soil fertility, carbon sequestration and erosion control. Intercropping tea with ginger, turmeric or fruit trees diversifies income and improves pest management. Preserving natural habitats (streams, ponds, forests) within tea plantations promotes biodiversity and supports pollinators, birds and mammals.

Diverse agroforestry systems a) agroforestry based on slash-and-burn; b) tea garden-based agroforestry system, Teesta Valley, Darjeeling. Photos: Ghanashyam Sharma

Table 1. Stand dynamics in seven agroforestry systems

Parameter	Agroforestry system						
	1. Farm-based	2. Forest-based	3. Large cardamom-based	4. Mandarin based	5. Crop, mix-tree-based	6. Slash and burn-based	7. Tea-garden-based
Tree density (trees ha^{-1})	198 ± 25	843 ± 132	417 ± 17	280 ± 54	723 ± 124	153 ± 34	78 ± 34
Basal area (m^2 ha^{-1})	6.43 ± 1.21	21.36 ± 3.66	19.51 ± 3.43	5.10 ± 1.23	12.51 ± 1.49	3.87 ± 2.6	3.12 ± 0.5
Tree biomass (t ha^{-1})	12.84 ± 2.54	59.45 ± 3.25	64.61 ± 5.81	15.21 ± 26	23.42 ± 4.53	10.32 ± 31	6.32 ± 42
Net primary productivity (t ha^{-1})	4.65 ± 1.87	8.43 ± 2.39	12.61 ± 3.26	3.51 ± 1.26	5.13 ± 0.99	6.35 ± 24	Not estimated
Agronomic yield of crops (t ha^{-1} $year^{-1}$)	1.14 ± 1.65	0.21 ± 0.04	0.31 ± 0.10 1	1.25 ± 0.50 2	0.26 ± 0.12 1	2.18 ± 1.45	0.68 ± 0.51
Edible NTFPs collection (kg ha^{-1})	124 ± 24	207 ± 5.34	30.41 ± 6.91	50 ± 12	105 ± 20	2.76 ± 1.05	Not produced
Fodder collection (t ha^{-1})	2.36 ± 0.89	5.73 ± 2.54	0.21 ± 0.09	2.81 ± 1.35	3.57 ± 2.18	1.65 ± 0.65	Not produced
Stand litter production (t ha^{-1} $year^{-1}$)	9.35 ± 3.26 3	7.34 ± 2.17	10.25 ± 0.46	4.80 ± 1.81	6.93 ± 2.51	1.98 ± 0.35	Not collected
Crop residue (t ha^{-1} $year^{-1}$)	8.42 ± 2.47	0.17 ± 0.02	Not collected	3.24 ± 1.32	Not collected	1.53 ± 1.05	Not collected
Floor litter (t ha^{-1})	5.23 ± 25	8.23 ± 2.15	34.91 ± 1.24	4.76 ± 2.11	26.87 ± 3.86	3.78 ± 1.25	Not collected
Litter extraction (t ha^{-1})	0.21 ± 0.04	2.83 ± 0.85	1.21 ± 1.23	0.05 ± 0.01	1.56 ± 1.65	1.24 ± 0.52	Not collected
Firewood extraction (t ha^{-1})	0.37 ± 0.15	1.78 ± 0.96	1.95 ± 0.23	0.21 ± 0.05	1.47 ± .24	3.42 ± 1.35	Not collected

Note: Agronomic yield includes cardamom capsule (fruit), crops yield, mandarin fruit, tea leaves and crop residue.
Values are pooled from three site replicates. Source: updated from Sharma et al. (2016)

Costs and economic benefits

Traditional agroforestry systems have significant economic and social benefits for local communities. High-value cash crops provide farmers with income to support health care, education and social activities. Farm-based agroforestry systems also supply essential products for subsistence needs, such as food and nutrition. In addition to aesthetic and recreational benefits, agroforestry mountain ecosystems serve as important reserves of potable water and water for agriculture. Agroforestry practices provide a continuous supply of non-timber forest products, underutilized crops, and clean air, all of which improve the quality of life for mountain communities (Sharma et al. 2016). Table 2 shows that the costs associated with managing and maintaining traditional agroforestry systems differ, based on the system used.

Table 2. Monetary input and output (USD ha-1), and cost-benefit analysis of seven agroforestry systems

Input costs (USD)	1. Farm-based	2. Forest-based	3. Large cardamom based	4. Mandarin based	5. Crop, mix-tree-cardamom based	6. Slash-and-burn-based	7. Tea-based
Labour employed for land preparation	201	18	—	82	—	87	—
Weeding	28	—	20	40	27	46	10
Labour employed for harvesting	45	11	24	30	31	26	50
Post-harvest management	8	—	48	11	51	11	—
Gap filling and replantation	17	11	23	9	13	7	—
Firewood for curing	—	—	43	—	28	—	—
Total output benefits (USD)	**299**	**40**	**158**	**172**	**150**	**177**	**60**
Agronomic yield	545	—	1,761	1,136	1,140	561	37,500
Firewood extraction	25	121	123	14	74	10	—
Fodder (tree/ground) extraction	15	15	—	8	9	6	—
NTFP/wild edibles extraction	9	35	11	6	12	8	—
Total	**594**	**171**	**1,895**	**1,164**	**1,235**	**585**	**37,500**
Output: Input ratio	1.99	4.17	11.99	6.77	8.23	3.31	625.00

Note: Values are pooled from three site replicates. Source: updated from Sharma et al. (2016)

The output-to-input ratio was highest for tea-based agroforestry and lowest for farm-based agroforestry. These results indicate that the choice of agroforestry system can significantly affect both the costs and benefits of production. Therefore, careful consideration should be given when selecting the most suitable agroforestry system. These findings could be used to inform decision-making by stakeholders involved in agroforestry systems, including policymakers, farmers and researchers.

Functions and services of traditional agroforestry in Sikkim

The cultivated systems located adjacent to the protected area network in the eastern Himalayan region provide a vital biological corridor for the movement of wild animals designated as flagship species, along the Himalayas within India, and across the border towards Bhutan in the east, the Tibetan Autonomous Region of China in the north and Nepal in the west. Agricultural landscapes are crucial in supporting globally threatened and biologically restricted species, thus maintaining biological connectivity. In the region, wild biodiversity and traditional agroforestry are continuous landscape elements characterized by a close interaction between people and natural systems.

In the Himalayan watershed, conventional agriculture is associated with high overland flow and soil and nutrient losses. In contrast, traditional agroforestry practices conserve soil and nutrients, which helps to maintain ecosystem services and biodiversity (Pandey et al. 2013). These agroforestry systems provide diverse functions that support ecological sustainability: maintaining soil fertility, conserving resources, enhancing productivity, and reducing erosion. Operated by smallholders, they meet market demands through sustainable production. They suit marginal lands, and support impoverished and Indigenous people (Sharma et al. 2007). They also enhance resilience, providing forest cover and perennial cash crops.

Traditional agroforestry systems have a remarkable level of crop diversity (Table 3), including a significant number of varieties for rice (88), maize (31) (Sharma and Pradhan 2023) and pulses and legumes (34), among others. Furthermore, these systems support a diverse range of plant species, including more than 483 medicinal and aromatic plants, 216 weeds, more than 250 fodder crops, 150 timber species, and more than 290 multipurpose tree species, as well as 20 bamboo species. These agroforestry landscapes are agricultural heritage systems that play a vital role in preserving genetic resources and maintaining agrobiodiversity.

Table 3. On-farm species richness of crop varieties commonly grown in agroforestry systems of the Eastern Himalayas

Crop	Local name	Number of varieties
Rice (*Oryza sativa*)	*Dhan*	88
Vegetables	*Sabjiharu*	75
Fruits	*Falharu*	63
Eskush (*Sechium edule*)	*Eskush*	55
Spices	*Masala*	38
Pulses and beans/legumes (*Phaseolus* spp., etc.)	*Simbi-bori*	34
Tubers	*Tarul*	33
Maize (*Zea mays*)	*Makai*	26
Pseudo-cereals (lesser known crops)	*Geda-gudi*	21
Mustard (*Brassica* spp.) and other oil seeds	*Tori/Rayo*	18
Citrus (*Citrus* spp.)	*Suntola*	13
Banana (*Musa* sp.)	*Kera*	9
Finger millet (*Eleucine coracana*)	*Kodo*	8
Pumpkin (*Cucurbita* sp.)	*Pharsi*	8
Chilli (*Capsicum* spp.)	*Khorsani*	8
Taro (*Colocasia* sp.)	*Pindalu*	6
Ginger (*Zingiber officinale*)	*Aaduwa*	5
Buckwheat (*Fagopyrum tataricum*)	*Phaper*	4
Soybean (*Glycine max*)	*Bhatmas*	3
Barley (*Hordeum* spp.)	*Jau*	3
Wheat (*Triticum aestivum*)	*Gehun*	2
Total		**520**

Conclusion

Traditional agroforestry systems in the Eastern Himalayas offer a sustainable approach to balancing short-term food and livelihood needs with long-term environmental conservation. These systems exemplify how agroforestry can improve the economic status of rural populations and enhance mountain ecosystem services. Conventional agriculture's sustainability suffers due to production-focused interventions, which sideline agroecosystem maintenance and smallholder employment. In the northeast Himalayas, small-scale mixed-crop rainfed systems are rooted in traditional mountain wisdom. Indigenous agroforestry knowledge declines with socioeconomic shifts, mirroring other developing nations. Trends vary due to agroecology, demographics and market access. Research must assess gaps, especially related to multipurpose trees. This aligns with productive traditions, buffers climate change, and sequesters carbon for resilience.

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Author affiliation

Ghanashyam Sharma, The Mountain Institute India (banstolag@gmail.com)

Agroforestry on depleted Sal forestland in Bangladesh.
Photo: Kazi Kamrul Islam

Agroforestry for income and livelihood development of ethnic minorities in Bangladesh

Kazi Kamrul Islam

"The productivity of agroforestry on deforested land has greatly enhanced the livelihoods of ethnic minorities."

Introduction

Agroforestry on depleted forestland has made enormous changes compared to traditional forest management approaches in developing countries. The various tree, crop and animal products provided by agroforestry systems support the basic needs and uplift the livelihoods of millions of smallholders throughout the world. Bangladesh is a developing country with only 17% forest, which faces tremendous pressure from people who depend on forests for their daily living. Of the country's three major forest types, the moist deciduous Sal (*Shorea robusta*) forest (0.12 million ha), is the most deforested and degraded, with population pressure seen as the main cause of this. Of the original area of Sal forest, only 36% was left in 1985, falling to 10% by 2008 (Alam et al. 2008; Islam and Sato 2012).

Accordingly, people-oriented forest management approaches such as agroforestry have been practised in; e.g., the major Sal forest near the town of Madhupur since 1989 (Islam et al. 2022; Islam and Hyakumura 2021).

This article explains how agroforestry has affected income generation and livelihood enhancement for ethnic farmers in the Madhupur Sal forest of Bangladesh. In this area, more than 50,000 people — including 20,000 ethnic minorities (Garo and a few Koch) — practise agroforestry and their livelihoods depend on it. A livelihood comprises natural, physical, human, financial and social capital, as well activities and physical access, which together determine the level of living gained by the individual or household (DFID 2000). These types of capital are the building blocks of farmers' livelihoods and all of them are needed to achieve livelihood outcomes (DFID 2000). Previously, ethnic farmers were fully dependent on Sal forests to sustain their daily living; now, agroforestry could play a significant role in improving the communities' livelihoods.

Sal forests and agroforestry

The condition of the Madhupur Sal forest varies, from open, heavily used and degraded scrub to relatively dense Sal coppice regrowth and scattered trees (Islam et al. 2013; NSP 2008). See Figure 1. It is noteworthy that significant plant variety still exists, despite the fact that all places have had some degree of use. Huge wildlife species (e.g., tiger, leopard, elephant, sloth bear and spotted deer) have been eradicated from the forest (NSP 2008). It has been estimated that there are 176 species of woody plants (73 of which are trees) and 140 species of birds, 19 species of mammals, 19 species of reptiles, and 4 species of amphibians in the forest. The dominant tree species (more than 80%) is the commercially profitable Sal. Tangail and Mymensingh Forest Divisions have administrative jurisdiction over the forest.

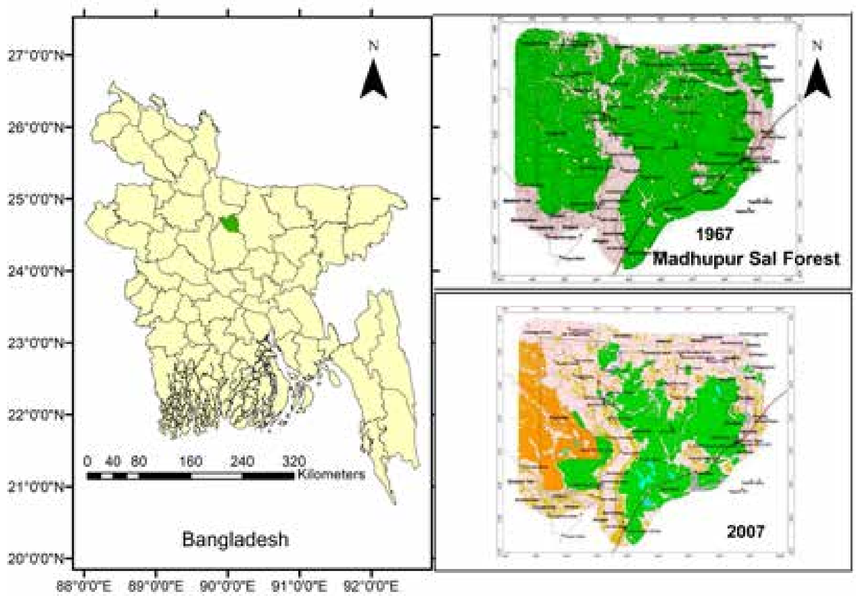

Figure 1. Location of Madhupur Sal forest of Bangladesh and the extent of forest in 1967 and 2007
Orange: rubber plantations; pink: agricultural practices; green: forest

Ethnic minorities have a long history related to the forest. Sal forest-dependent Garo (who comprise most of the communities) and a few Koch ethnic communities established themselves in the Madhupur Sal forest more than 200 years ago (Islam and Sato 2013). Due to the severe deforestation of Sal forests in the 1970s, the Bangladesh Forest Department started to carry out people-oriented forest management programmes in 1989. Agroforestry was part of this initiative. Each farmer gets 1 ha of deforested land to implement agroforestry and shares 50% of the income of the planted trees with the department after a 10-year cycle. Local farmers can cultivate seasonal crops in association with the planted trees, and the entire crop is the sole property of the farmer. Besides these government-run programmes, local people are also practising agroforestry on their own land, producing multiple crops in association with fast-growing trees such as *Acacia* spp. A previous study (Islam et al. 2022) found that more than 90% of local farmers were mainly using acacia (*Acacia auriculiformis*) trees with a few *minjiri* (*Cassia siamea*), *gamar* (*Gmelina arborea*), neem (*Melia azedarach*), jackfruit (*Artocarpus heterophyllus*) and eucalyptus (*Eucalyptus camaldulensis*) trees on their agroforestry lands. Except for jackfruit these

Acacia-turmeric (left) and Acacia-pineapple (right) agroforestry crops at Madhupur, Bangladesh. Photo. Kazi Kamrul Islam

are fast-growing tree species that are a potential source of firewood and income generation for local farmers. Various types of crops, in particular the shade-loving pineapple, ginger, aroids and turmeric, are the dominant crops. Pineapple is the most common crop.

Research approach

The local Forest Department made farmers' data available to the project before the study team randomly selected 90 ethnic farmers from five villages across the entire Madhupur Sal forest area (each farmer being a member of a single household). Both men and women are farmers, and all of them live in poverty. Both quantitative and qualitative data were gathered for the study, and the study team developed a semi-structured questionnaire for the farmers' interviews. Focus group discussions, opinions from the Forest Department staff, and practical observation methods were used to gather qualitative data. The questionnaire was created to gather comprehensive economic data regarding the agroforestry programme and the participants' socioeconomic information, and a preliminary survey was carried out to test it.

The harvesting time of the agroforestry crops varies among species; for example, pineapple provides a first harvest at 18 months, after the transplanting of suckers and continues to generate income for four years. This means that the crop outputs differ according to which type of agroforestry is practised. The study determined the crop production costs and yield/ha on a yearly basis, calculating the prevailing average unit market price in the local currency (Bangladeshi taka, or BDT), later converted into USD (United States dollars); BDT 85 = USD 1 at time of writing. In the case of mixed cropping, the team collected the data and carried out the conversion per hectare separately for each crop. Trees were harvested after ten years and the total output (firewood, timber, fodder) from them was determined and then calculated on a yearly basis. The study also determined the benefit-cost ratio (BCR) of each crop combination. With the support of two enumerators, the entire data collection process was completed from 2020 to 2022.

Types of agroforestry practices

The research team found five types of profitable agroforestry practices in Madhupur.

Acacia-pineapple-papaya

Acacia (*Acacia auriculiformis*) is a fast-growing species, planted by farmers along the boundaries of fields or inside the land in a scattered manner. The spacing of the acacia trees depends on the individual farmer's choice, but on average there were ±400 trees per hectare. Farmers transplanted pineapple suckers (30×40-cm spacing) between tree lines and included papaya sparingly in the pineapple lines. Around 22,000 pineapples and 600 papaya plants per hectare are planted. The acacia-pineapple-papaya agroforestry practice can produce for up to ten years. The pineapples produce for up to four years; after ten years, the acacia wood is harvested and sold in the market. Usually, pineapples start yielding at 18 months and the papaya trees provide a good yield for two to three years. Farmers earn their highest economic income in the second year of this agroforestry practice.

Acacia-pineapple-ginger

The acacia trees are planted in a scattered fashion, and the pineapple and ginger crops are planted in alternate rows, with one row of ginger between two rows of pineapple. Around 22,000 pineapples and around 600 kg (17 mounds) of ginger rhizomes are planted per ha. The soil type and climate of the area is suitable for growing shade-loving agroforestry crops such as ginger, which does well under these conditions. This agroforestry practice usually continues for ten years, after which the acacia trees are cut down and a new cycle starts.

Acacia-pineapple-turmeric

This practice follows the same planting techniques as for acacia-pineapple-ginger, with turmeric replacing ginger. The amount of turmeric seeds planted per ha is about 165 kg. Turmeric is a seasonal crop and is harvested before the pineapples ripen, allowing farmers to get an early income.

Jackfruit-pineapple-papaya

This is a popular and common practice in the Madhupur Sal forest area. Jackfruit is a traditional and evergreen fruit tree species that has been grown in this region for a long time. The jackfruit trees are planted along the boundaries of the cropland as well as inside it in a scattered manner, and various crops are grown in association with them. Ethnic farmers cultivate pineapple and papaya in association with jackfruit trees right at the beginning of their agroforestry practice. Farmers plant around 100 to 150 jackfruit trees, around 18,000 pineapple and 200 papaya plants per ha.

Acacia-pineapple-aroid

A range of varieties of aroids (*Colocasia esculenta*) were observed in the study area. Aroid tubers are very nutritious and shade-tolerant and require few inputs for production. They are planted between pineapple rows and around 450 kg of "seeds" (i.e., small pieces of the tuber) per ha are required, with 20,000 pineapple suckers and 400 acacia trees per hectare. Intercultural operations are minimum for aroid crops, while other operations are the same as in the other agroforestry practices.

Economic outputs of agroforestry

Economic analysis revealed that all five practices generated significant income for farmers. The acacia-pineapple-ginger association produced the highest output of USD 5,088 ha/year, followed by acacia-

Ethnic farmers participate in a range of agroforestry practices; left: turmeric; right: pineapple. Photo. Kazi Kamrul Islam

pineapple-aroid (USD 4,149), jackfruit-pineapple-papaya (USD 3,235), acacia-pineapple-papaya (USD 3,092) and acacia-pineapple-turmeric (USD 3,235). See Table 1. Tree (timber) income did not vary significantly across the five practices, as the total gross income of the agroforestry practices depends mainly on income from crops. The labour cost in all models was the highest cost, although farmers mentioned that labour requirements decreased with the age of the plantation. The total production cost was highest for the jackfruit-pineapple-papaya association (USD 2790/ha) and lowest for the acacia-pineapple-aroid system (USD 2,044/ha).

To measure profitability, all costs during the ten-year rotation period and the income from sales of both trees and crops were assessed. The net profit of the five different agroforestry systems showed that the acacia-pineapple-aroid model is the most profitable, as the market price of aroids did not vary, and costs of production were low. This practice has the highest benefit-cost ratio (BCR 3.03). Despite this, however, farmers in the Madhupur Sal forest area widely practise the pineapple-based production model because pineapple provides returns as soon as four years after initial planting, and there is a well developed pineapple marketing system in the area.

Table 1. Cost of production, total income and net income (USD) of agroforestry practices (ha/year)

	Agroforestry practice				
	Acacia-pineapple-papaya	**Acacia-pineapple-ginger**	**Acacia-pineapple-turmeric**	**Jackfruit-pineapple-papaya**	**Acacia-pineapple-aroid**
Production costs					
Tree seedlings	232	207	212	251	216
Land preparation	181	191	198	227	128
Planting material	335	369	349	325	314
Labour	642	802	733	757	515
Fertilizer and manure	311	326	251	205	158
Pesticide	77	92	232	263	76
Weeding/irrigation	112	146	132	158	158
Harvesting	299	393	314	311	288
Sticks to support plants	99	67	100	114	69
Transport	12	9	8	10	11
Miscellaneous	103	169	146	169	111
Gross income					
Timber income*	529	482	506	565	518
Thinning tree income	94	82	59	71	106
Firewood income	34	29	26	29	24
Fodder income	8	11	6	5	9
Crop income	4,829	7,253	4,534	5,355	5,537
Total gross income	5,495	7,858	5,131	6,025	6,193
Total production cost	2,404	2,770	2,675	2,790	2,044
Net income	3,092	5,088	2,455	3,235	4,149
Benefit-cost ratio (BCR)	2.29	2.84	1.92	2.16	3.03

*The income from timber shown here represents the 50% share received by the farmer; this was calculated on a yearly basis.

Livelihood development

Most agroforestry farmers in the Madhupur area are poor people from ethnic minorities. After being involved in the agroforestry programme, their livelihood assets improved. The literacy rate of farmers and their children gradually increased. Participating farmers got involved in various organizations to get loans and technical assistance to manage their agroforestry fields, thanks to the high number of NGOs and GOs present in the area. Participants' awareness of health care facilities improved, and a Christian missionary provided basic health care.

Local road infrastructure gradually improved; mud roads have been replaced by bitumen roads. Forest Department staff mentioned that people-oriented programmes and tourism have had an impact on improving road infrastructure. Farmers had received a good amount of money by selling timber at the end of the ten-year period, which they mainly used to improve their house structures with tin walls and roofs. Ethnic farmers were also able to buy chickens, pigs and cattle with the money they received from agroforestry. The available labour provided by the participants' family had decreased, however, due to the awareness of education and migration to the capital city for jobs in the garment industry.

Farmers received income from seasonal crops throughout the year, and this increased their food self-sufficiency rate for 11 months of the year. With the income from agroforestry, farmers can also manage their family health care and visit the local hospital/clinic for treatments. The most positive aspect of agroforestry was to increase the number of trees, both in farmers' households and in agroforestry fields.

Conclusions

Agroforestry is an effective approach to generating household income for poor ethnic farmers in the Madhupur Sal forest area. As a production system based on tree crops, aroid-pineapple-based agroforestry has numerous benefits that contribute to generating household income generation and improving the livelihoods of rural farmers. The results of this study showed that agroforestry based on aroid-pineapple increases farmers' total household income by maximizing the benefit-cost ratio of the farm. The study concluded that the impacts of agroforestry practices had strongly improved the financial, physical and natural assets of ethnic farmers. However, the development of social and human capital was still not satisfactory. The social relationships and networks of the farmers had not fully developed, or they faced constraints. More emphasis needs to be placed on the development of high-yield agroforestry practices, together with farmer training programmes, to further improve farmers' livelihoods and overall farm productivity.

Acknowledgements

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Author affiliation

Kazi Kamrul Islam, Professor, Department of Agroforestry, Faculty of Agriculture, Bangladesh Agricultural University, Mymensingh, Bangladesh (kamrulbau@bau.edu.bd)

Inside the canopy in 2013. Photo: Kamal Melvani

Watershed rehabilitation with forest gardens in Moneragala District, Sri Lanka

Kamal Melvani, Jerry Moles and Yvonne Everett

"All stakeholders in the landscape mosaic of a watershed must participate in and gain from land rehabilitation if it is to succeed."

Introduction

Forests in mountainous watersheds provide valuable ecosystem services, including sustaining water flows. Moss and leaf litter, for example, store precipitation like sponges and gradually release it into streams. This ensures dry season flow in rivers and provides a lifeline to people when there is no rainfall. Riparian forest vegetation is especially important, because tree roots bind soil on stream banks, prevent erosion and reduce sediment flow and nutrient loss into streams while also filtering water. Shade cast by forest canopies lowers stream water temperature and enhances water quality.

Forest destruction results in the loss of these ecosystem services, impoverishing inhabitants and diminishing watershed sustainability. Conversely, establishing forest gardens (FGs) in watershed rehabilitation restores ecosystem services, provides livelihood benefits to communities, and improves watershed sustainability. Having restored Sri Lankan watersheds for over 30 years, the Neo Synthesis Research Centre (NSRC) tested the practice of forest gardens with 52 farmers at Maragalakanda, Sri Lanka for four years, from 1999 to 2004. This article describes how rehabilitation in the landholding of one farmer (referred to here by the pseudonym *Rani*) increased household livelihood security, reversed forest loss, and sustained watershed health. Evaluations undertaken from 2012 to 2016 assessed changes that were then occurring in Rani's landholding, and their implications for practitioners and planners.

Context

Located in southeast Sri Lanka, Maragalakanda (a mountain in Moneragala District) receives 1,750–2,500 mm of rainfall annually in two separate monsoon seasons. It is the watershed of the Maragala Oya (see Figure 1) a river that feeds the Kumbukkan Oya. Maragalakanda has eight vegetation types: semi-evergreen, tropical wet evergreen, riverine and secondary forests, rubber plantations, grasslands, savannah and *chena* (traditional swidden agriculture with land rotation and extended fallow). The area is rich in biodiversity, encompassing 427 floral and 353 faunal species (IUCN 2018).

Watershed degradation first occurred here when forestland was cleared for plantations (tea, sugarcane, rubber) and continues through modern *chena* cultivation (non-traditional swidden agriculture without land rotation or extended fallow, referred to from now on as *chena*). With declining fertility, land is abandoned and returns to secondary forest. Estate Tamil communities who live in the upper watershed generate meagre incomes through *chena* cultivation (vegetables, sesame, finger millet, pumpkins, groundnut, bananas) or as labourers. They do not own land, and with little access to adequate housing, health facilities, potable water or sanitation, are impoverished. Sinhala farmers who reside in downstream areas do own land, but also clear forestland for *chena* cultivation. Unsustainable land management and high poverty rates, along with high biodiversity values and hydrological significance, made the Maragala Oya watershed an ideal choice for land rehabilitation.

Rehabilitation followed a successional process, using regenerative agriculture, analog forestry and conservation forestry. Regenerative agriculture promoted the cultivation of diverse annual and semi-perennial crops using biological inputs. Analog forestry established a tree-dominated ecosystem that was similar in structure and ecological function to the closest natural forest. These practices economically empowered rural communities through the use of marketable native and exotic crop species in landscape designs (Senanayake and Jack 1998). In parallel, conservation forestry, undertaken in buffer and riparian zones, sought to restore

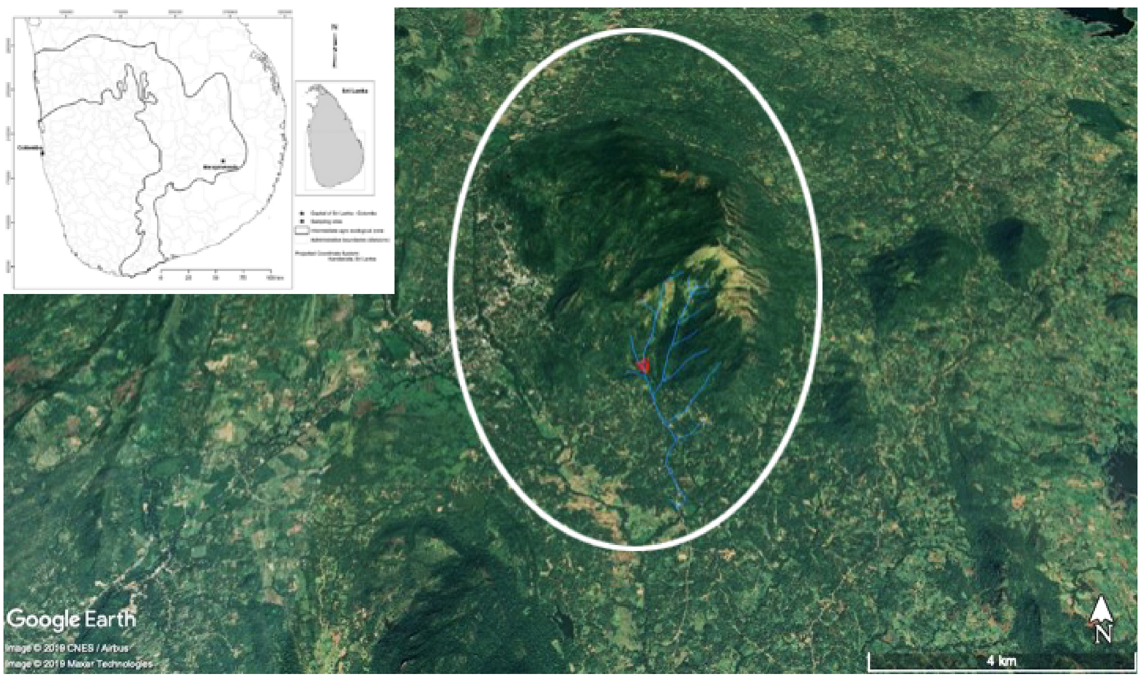

Figure 1. A 3D Google Earth image of Maragalakanda (white oval); the mountain rises from the lowland peneplain. Maragala Oya is in blue, and the project location is in red.

stream ecosystems while recreating habitat for faunal biodiversity using only native forest species. Once tree canopy was restored, these degraded areas would begin to conserve water and function like water towers.

Before rehabilitation began, preliminary discussions were held to identify households' issues, and how they would benefit from adopting forest gardens. Low and inconsistent on-farm income from *chena* cultivation, which in 2000 was USD 95, was their biggest problem. This allowed only one of Rani's five children to attend school, limited food purchases (cooking oil, sugar, and animal protein), and compelled household members to labour on other people's lands. The situation was acute in the dry season, when food stocks had been consumed, income from the past year's *chena* cultivation expended, and stream water was neither potable nor sufficient for cultivation.

Desperate and uncertain of how to resolve the situation, Rani's household welcomed the prospect of consistent income, food, medicine, firewood and timber from a forest garden. They decided to allocate the largest portion of their landholding to tree-dominated agriculture and the balance to cash crop and *chena* cultivation; cash income was essential to satisfy their immediate needs.

A base map (Figure 2) was drawn in 1999 that showed land use, topography, existing vegetation, wind, and water flows in Rani's 3.2-hectare landholding. Located at 216 masl, the landholding was part of a landscape mosaic comprised of undisturbed and disturbed natural forest remnants, feeder streams of the Maragala Oya, another farmer's (Raja's) landholding, an Estate Tamil village, and paddy fields. Land was sloping (~30%), rocky and eroded. Sparse vegetation provided minimal habitat for animals, birds and other pollinators. There was no water source except three dead gullies (i.e., gullies where the streams had dried up), which — along with open, hot and dry conditions — engendered unfavourable growing conditions.

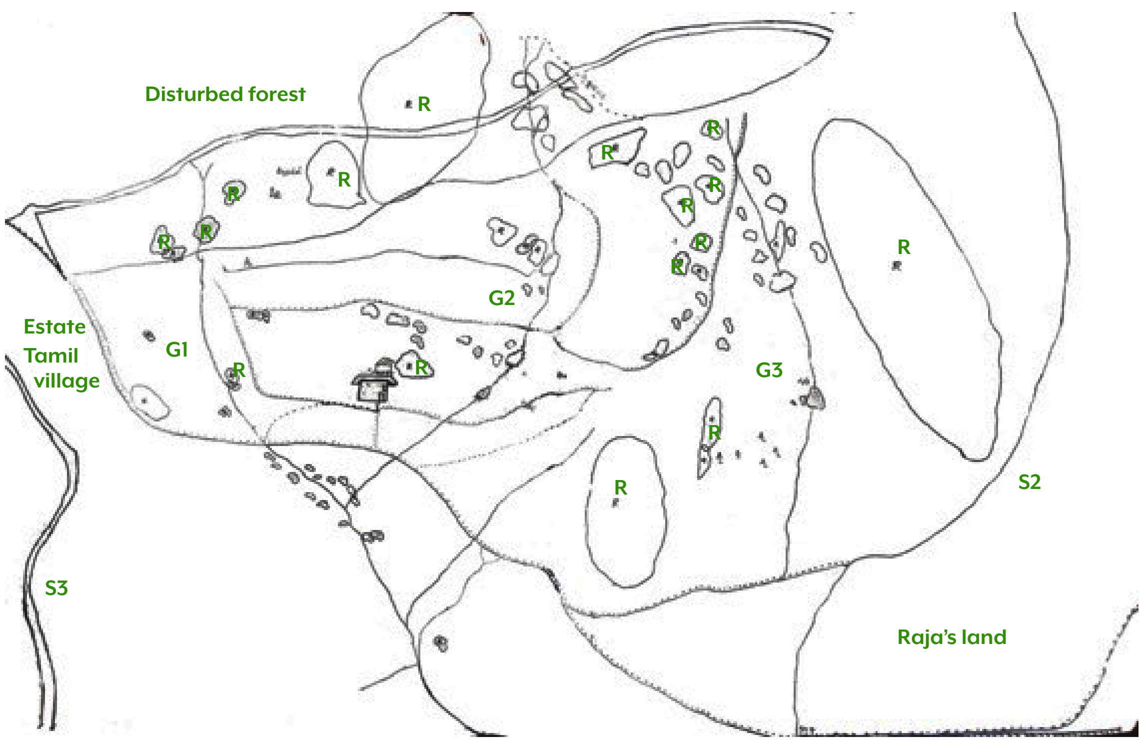

Figure 2. Base map of Rani's landholding on Maragalakanda in 1999
R: very rocky; G1, G2 and G3: dead gullies; S2, S3: major streams

The proposed forest gardens were modelled on the forest above Rani's landholding. Vegetation mapping (Küchler and Zonneveld 1988; Senanayake 1989) of this forest revealed that it mainly comprised broad-leaved and evergreen trees and shrubs across four strata (ground, low, mid and upper), as well as other growth forms, including forbs, climbers, grasses and lichens. A low density of species, 6–25% canopy closure, and the presence of exotic species signified that the forest was disturbed. This data provided context for the landscape design of the forest gardens.

The landscape design also considered topography, water, and wind flows. Drawn in accordance with household aspirations, it divided Rani's landholding into several land uses, including forest gardens, paddy fields, *chena* and cash crop areas, and a buffer zone between the disturbed natural forest and the landholding (Figure 3). Riparian vegetation was designed around ponds established in gullies. Forest garden vegetation mimicked the vegetation structure of the adjacent forest and aimed to provide the same ecological functions and services by using both crop and non-crop species.

Table 1 lists 175 species established in the forest gardens according to their height class and stratum. They provide a wide range of ecosystem services.

- 96 species (55%) provide food and medicine;
- 29 species (17%) provide riparian buffer and water filtration;
- 20 species (11%) provide shade and cover rocks;
- 10 species (6%) are ornamental;
- 9 species (5%) provide timber and firewood;
- 6 species (3%) provide biopesticides; and
- 5 species (3%) provide green manure.

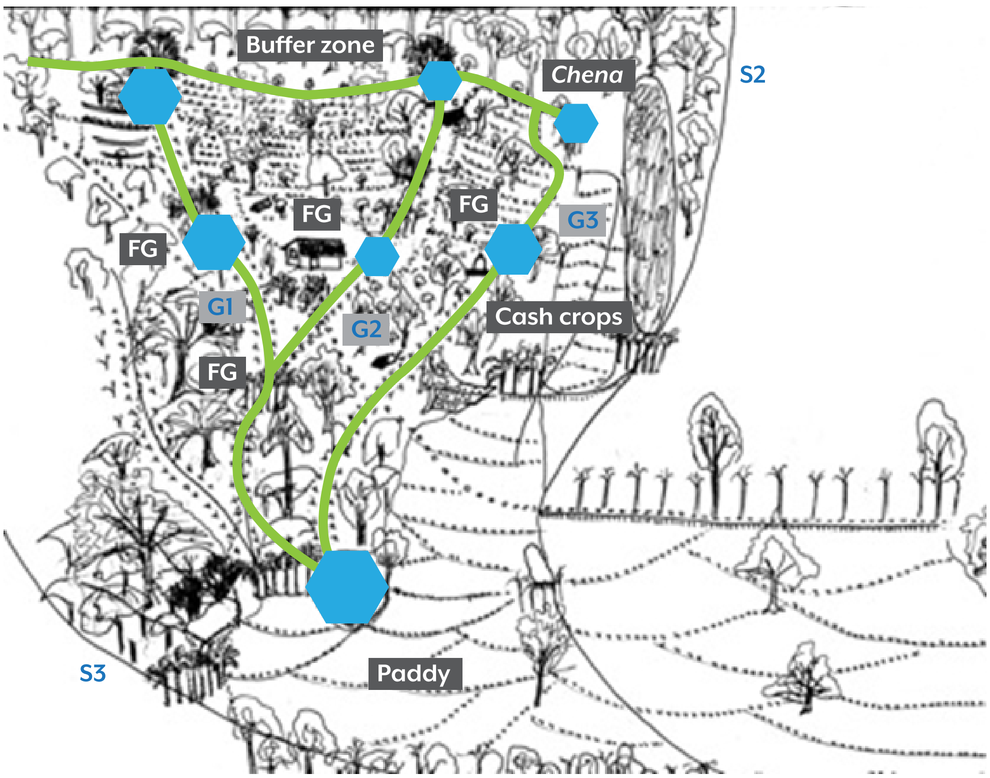

Figure 3. Landscape design of Rani's landholding. The green line indicates proposed riparian vegetation; the blue polygons are holding ponds.

FG: Forest Garden; G1, G2 and G3: dead gullies; S2 and S3: major streams

Table 1. Species established in forest gardens by stratum, height class and ecosystem services

Stratum	**Upper**	**Mid**	**Low or understorey**	**Forest floor or ground**	**Other growth forms across all height classes**
Height class	**> 20 m**	**2–20 m**	**0.5–2 m**	**0.1–0.5 m**	
Food and medicine	*Vateria acuminata*	Avocado, Bengal quince, breadfruit, brindleberry, cashew, Ceylon almond, Ceylon cherry, Ceylon date, Ceylon olive, cloves, cocoa, curry leaf, ice cream bean, Indian gooseberry, jak, King coconut, *Madhuca longifolia*, Malay apple, *Mangifera zeylanica*, mango, mangosteen, pebble tamarind, rambutan, sapodilla, soursop, tamarind, *Terminalia bellerica, Terminalia chebula*, woodapple	Banana, bilimbing, cardamom, cinnamon, coffee, custard apple, drumstick, guava, jam fruit, lemon, lime, mandarin, orange, papaw, pomegranate, pomelo, *Sesbania grandiflora*, starfruit, *Wrightia antidysenterica*	*Alternanthera sessilis, Amaranthus* spp., aubergine, bird chillie, bitter gourd, black gram, bottle gourd, bush bean, *Canna indica*, *Capsicum chillie*, cassava, *Cassia auriculata*, Cowpea, ginger, horse gram, *Lasia spinosa*, leafy cabbage, long bean, melon, okra, pineapple, pumpkin, purple yam, radish, red chillie, ridge gourd, snake gourd, squash, taro, tomato, *Trianthema portulacastrum*, turmeric, winged bean	**Palms:** *Caryota urens*, coconut **Climbers:** Ceylon spinach, *Cardiospermum halicacabum*, *gotukola*, kan kong, passionfruit, black pepper, *Piper betel, Piper longum, Salacia chinensis*, sweet potato **Grasses and tuft plants:** Lemongrass, *Pandanus amaryllifolius*
Riparian buffer and water filtration	*Calophyllum* sp., *Horsfieldia eriya, Madhuca longifolia, Mangifera zeylanica, Terminalia arjuna*	*Garcinia terpnophylla, Mesua nagarissum, Mimusops elengi, Myristica dactyloides, Nauclea orientalis, Pongamia pinnata*	*Alpinia calcarata, Alpinia nigra, Alpinia zerumbet, Clerodendron* sp., *Clerodendrum chinense, Dillenia retusa, Pagiantha dichotoma, Strobilanthes asperrima*	*Aponogeton crispus, Acorus calamus, Costus speciosus, Jussueia repens, Lagenendra* sp., *Nymphaea nouchali, Spathyphyllum pattini*	**Palms:** arecanut **Grasses and tuft plants:** *Pandanus kaiida*, yellow bamboo
Shade and covering rocks	*Alstonia scholaris, Ficus racemosa, Samanea saman*	*Adenanthera pavonina, Bridelia retusa, Dimocarpus longans, Ficus bengalensis, Mallotus phillipensis, Sterculia foetida,Syzygium assimile, Tetrameles nudiflora, Trema orientale*	*Ficus hispida*	*Munronia pumila*	**Palms:** *Calamus rotang* **Climbers:** *Anamirta cocculus, Pothos scandens* **Succulents:** *Aloe vera, Kalanchoe pinnata, Sansevieria zeylanica*
Ornamental	*Delonix regia*	*Cassia spectabilis, Lagerstroemia speciosa, Spathodea campanulata, Tabebuia rosea*	*Caesalpinia pulcherrima, Heliconia* spp., *Tecoma stans*	*Anthurium* spp.	**Epiphytes**: *Orchid* spp.

Table 1, continued

Stratum	**Upper**	**Mid**	**Low or understorey**	**Forest floor or ground**	**Other growth forms across all height classes**
Height class	**> 20 m**	**2–20 m**	**0.5–2 m**	**0.1–0.5 m**	
Timber and firewood	*Antiaris toxicaria, Berrya cordifolia, Melia dubia, Michelea champaca*	*Chloroxylon swietenia, Chukrasia tabularis, Diospyros ebeneum, Filicium decipiens, Vitex altissima*			
Biopesticide	Neem		*Vitex negundo*	*Andrographis paniculata*, marigold, *Sida spinosa*	**Grasses and tuft plants:** *Vetiver zianoides*
Green manure		*Ceiba pentandra*	*Cassia alata, Erythrina lithosperma, Gliricidia sepium, Pavetta indica*		

The majority (52%) of all crops grown in forest gardens were trees. Shrubs, forbs, climbers, herbs, grasses, tuft plants, epiphytes, and other growth forms, including succulents and palms, made up the balance. High floral diversity with varying reproductive phenologies allowed household members to harvest crops in the short and long term. The household was food secure because they had continuous access to food and income throughout the year, and for many years. This tree-dominated, highly agrobiodiverse landscape design also reduced the risk from stressors (e.g., climate variability, animal pests) and lessened livelihood vulnerability. Short-term, annual (vegetables, leafy vegetables) and semi-perennial (root vegetables such as turmeric) crops satisfied immediate needs for food, Ayurvedic medicine, and income.

Crops were cultivated across central open areas in raised beds (see Figure 4), using soil excavated from contour drains dug to prevent erosion and increase water infiltration. Since there was no water source, water from a wetland above the landholding was diverted through a canal and distributed along the same flow pathways as the dead gullies and into a series of holding ponds. These gley-lined ponds increased water-holding capacity in the landholding and allowed Rani to breed native freshwater fish. In time, pond water would percolate into the groundwater table and recharge dormant aquifers. An irrigation line was also installed from the upper reaches of the watershed to supply stream water for household needs. Planted in between short-term crops were small and large trees — fruit, nut, spice, timber, and firewood species for harvest in the long term. Once these perennial crops started to mature and semi-shade conditions had set in, annual crops were phased out and replaced with shade-loving crops (e.g., black pepper). Riparian species were densely planted to mitigate soil erosion, increase shade to reduce soil moisture evaporation, build root mass to increase infiltration and recharge dormant groundwater aquifers, and recreate habitat for biodiversity.

Ecosystem services

Over half of all species provided food, medicine, timber, firewood, ornament and biopesticides and were either used for household consumption or sold to generate income. While 96 species across all strata provided food and medicine, nine species confined to mid and upper strata were harvested for timber and firewood. Several plants had multiple values; e.g., jak provides food, timber and fodder while actively increasing soil organic matter owing to its voluminous leaf litter. While *Gliricidia* and coconut were used for firewood and harvested after a few years, timber harvests occurred in the long term. Some timber classified as super luxury (*Diospyros ebeneum*), luxury (*Berrya cordifolia, Chloroxylon swietenia*), Special Class Upper (*Chukrasia tabularis*) and Class 11 (*Melia dubia*) generated massive returns when sold, and were valuable biological assets of high Net Realizable Value (Melvani et al. 2020b). Several flowering trees, shrubs and annuals (e.g., *Anthurium* spp.) were ornamental, and beautified the homestead. Rani deliberately cultivated select annuals (e.g., *Andrographis paniculata*, marigold, *Sida spinosa*), and trees (e.g., *Vitex negundo*, neem) to make biopesticides.

Left: The Gully 1 area when restoration began in 1999; project staff and Rani's family planted Gliricidia sepium as a nurse crop. Right: The Gully 1 area in 2012, after riparian vegetation was established. Photos: Kamal Melvani

Species in forest gardens also contributed regulatory ecosystem services. Of these, 29 native forest species were planted in riparian areas to reduce erosion, stabilize streambanks, and regulate flows of surface and ground water through increased shade and infiltration. Trees (e.g., *Mangifera zeylanica*), palms (e.g., *Caryota urens*), shrubs (e.g., *Strobilanthes asperrima*) and grasses (yellow bamboo) were established along dead gullies (see photos above) and around ponds, while others (e.g., *Terminalia arjuna, Alpinia calcarata, Pandanus kaiida, Costus speciosus*) and water plants (e.g., *Nymphaea nouchali, Lasia spinosa*) filtered pond water. The use of native forest species in the buffer zone extended the range of the disturbed forest and created a biodiversity corridor between natural and disturbed forests (see photo, below). The microclimate in the landholding was regulated by shade created by 20 species of fast-growing trees (*Erythrina lithosperma, Vitex negundo, Gliricidia sepium*), palms (arecanut), climbers *(Pothos scandens)* and succulents (e.g., *Aloe vera*) planted around and between rocks.

Rani's forest gardens provides a biodiversity corridor between disturbed and undisturbed forest in the landscape mosaic of Maragalakanda, Moneragala, Sri Lanka. Photo: Kamal Melvani

Almost all floral species contributed leaf litter to soils. Leguminous (*Gliricidia sepium, Cassia alata*) and non-leguminous trees (*Ceiba pentandra*), shrubs (*Pavetta indica*) and grasses (lemongrass, *Vetiver zizanoides*) were grown as hedgerows on contours for soil conservation or used as green manure to make compost and liquid fertilizer, which are essential to regenerative agriculture. All these species supported the cycling of nutrients (e.g., carbon, nitrogen, phosphorous), and increased the soil fertility, productivity and profitability of FGs. The establishment of diverse floral species at different strata in FGs recreated biodiversity habitat, especially for pollinators and predators of insect pests.

Although traditional methods of pest management were used, habitat was also created for predators of rice pests by planting live fences of *Gliricidia sepium* and *Pavetta indica* on the bunds of paddy fields. Trees, including *Madhuca longifolia*, *Pagiantha dichotoma* and *Dillenia retusa*, were planted around the threshing floor, and arecanut palms along boundaries. The upper section of Rani's land was used to cultivate vegetables in *chenas*, while purple yam (*Dioscorea alata*) was grown as a cash crop in the lower section. Rani had two oxen that were used to plow the paddy fields.

Monitoring and evaluation

Project impacts were assessed in different ways and at various times. During the project's lifespan, planting records were monitored by mapping trees, shrubs and other vegetation planted annually (Figure 4 shows the area after the project ended). Also assessed were changes in shade, leaf litter, soil organic matter, and biodiversity: surface (butterflies, birds, mammals, ants, snails, reptiles, amphibians), soil (earthworms) and aquatic (fish). Results from these rapid assessments indicated that Rani's landholding was increasing in ecological maturity. Concurrent livelihood changes were also evident. Annual income increased from USD 95 in 2000 to USD 280 by 2004.

Figure 4. Map of Rani's landholding in 2004, after project activities ceased. Although trees and shrubs dominate the forest gardens, annual and semi perennial crops are cultivated in raised beds along contours. Dense planting of native trees is evident alongside gullies G1–3, in which holding ponds store water.

Two long-term evaluations of rehabilitation were undertaken after the project ended. The first assessed biodiversity changes after analog forestry at project closure in 2004 using bird species richness, diversity and community composition (Gunasekera 2004). Birds were selected as indicators of habitat quality, and Rani's forest gardens and adjacent forest remnants compared. Results revealed that bird species richness in Rani's FGs was nearly the same as that in the forest plots surveyed. The mean number of non-forest bird species in Rani's FGs was higher than the mean number of specialist forest bird species, however, signifying that habitats in these four-year-old FGs were not as ecologically mature as in the forest remnants.

The second evaluation was a doctoral study (Melvani 2019) that focused on why and how farmers valued forest gardens in 85 landholdings in 2012–2016. Maragalakanda was one among nine locations sampled, and Rani's landholding one of the sampling sites. By 2013, vegetation in Rani's landholding had matured into distinctive land-use areas, including four forest gardens, paddy fields, *chena* and cash crop plots (Figure 5). Canopy closure in FGs 1, 2 and 3 had increased, whereas FG 4 had open conditions because trees had been harvested for timber. In contrast, the previously open and very rocky *chena* cultivation area had greater vegetation and canopy closure. The cash crop area, however, still maintained semi-open conditions.

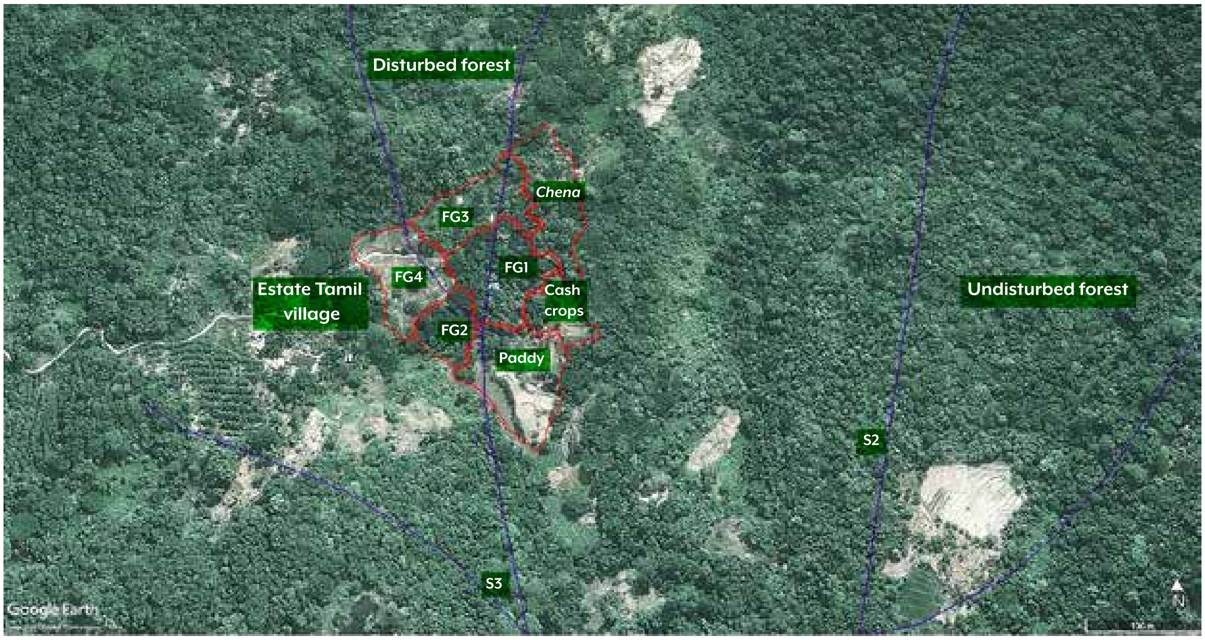

Figure 5. Google Earth image of Rani's landholding in September 2012, 13 years after rehabilitation in 1999. Shown are forest gardens, *chena* and cash crop plots, paddy fields, feeder streams of the Maragala Oya (in blue), and disturbed and undisturbed natural forests.

Although Rani cultivated a range of crops across her landholding, crop diversity was higher in forest gardens than in all other land uses. Most crops provided food and Ayurvedic medicine, while others provided firewood and timber (Melvani et al. 2020a). By 2013, more than half of Rani's landholding was under FG land use and had become a biodiversity corridor between the undisturbed forest and adjacent disturbed forest (see photo, page 24). More birds frequented the landholding. Rani confirmed, "I hear birds singing and realise that the value of my land has increased" (Melvani et al. 2022:8). Leaf litter increased in this tree-dominated environment that enhanced soil moisture retention, fertility and productivity. Consequently, by 2013, total income increased to USD 32,241, of which, almost 80% (USD 25,642) was from Rani's FGs. This massive income was generated from a) the sale of timber harvested from existing trees in FG4 (USD 22,918), and b) the value of household consumption and sale of pepper, coconut, fruits and vegetables (USD 2,724) obtained from FGs 1–3.

Over 60% of the total value of food and firewood consumed by Rani's household was grown in FGs. Moreover, average FG profit (USD 24,413) in Rani's landholding was higher than that of FGs in all other farmers' landholdings sampled at Maragalakanda.

In addition, with increased tree maturity over time, the estimated Net Realizable Value of potential timber and firewood stocks (biological assets) in Rani's landholding had grown to USD 3,308 by 2016. Having amassed considerable wealth, Rani educated all her five children, bought land and vehicles for them, and did not clear forests for livelihoods anymore. Despite these gains, Rani's livelihood was stressed by new challenges, including increasing rainfall variability, animal pests and the rising cost of purchases (e.g., fuel, electricity).

In 2014, Maragalakanda farmers acknowledged that deep-rooted trees increased infiltration, which, with the presence of holding ponds, recharged groundwater and facilitated aquifer recharge of dead streams in gullies (Oakes and Penna 2014).

Figure 6. Google Earth image of Rani's landholding in September 2023, 24 years after rehabilitation started in 1999. The image also shows expansion of the Estate Tamil village into the disturbed forest above Rani's landholding.

By 2023, a Google Earth image (Figure 6) demonstrated that further changes had occurred in Rani's landholding. While canopy closure increased in FGs 1, 2 and 4, *chena* and cash crop plot areas, FG3 now experienced open conditions because many trees had been harvested. Other dramatic changes included the shrinking area of disturbed forest owing to the upward expansion of the Estate Tamil village.

Conclusions

Watershed rehabilitation with forest gardens reversed forest loss, restored ecosystem services, increased livelihood security, and obliterated poverty in Rani's household. While all these gains improved watershed health and sustainability, there remain serious issues to consider. Here are some recommendations.

All stakeholders in the landscape mosaic of a watershed must participate in and gain from land rehabilitation if it is to succeed. Practitioners must however recognize that farming households can and will make changes in the landscape design of their landholdings depending on their short- and long-term needs, and when adapting to stress. This may result in dramatic changes to their landholdings and livelihoods, but is how stakeholders choose to do it. The changes that occurred over time in FGs 3 and 4 in Rani's landholding are a good example of this.

Policymakers and planners of landscape-level watershed restoration must also consider population growth as a critical factor in the sustainability of outcomes. At Maragalakanda in 2023, the emergence of new generations of people in the upper watershed resulted in more forests being cleared and increasing fragmentation. Planners must therefore allocate new lands for expanding watershed populations while strictly implementing laws that prevent forest destruction.

Acknowledgements

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Author affiliations

Kamal Melvani, Neo Synthesis Research Centre, Sri Lanka and Charles Darwin University, Australia (kamalmelvani24@gmail.com)

Jerry Moles, Neo Synthesis Research Centre, Sri Lanka and Blue Ridge Plateau Initiative, USA (molesjerry@gmail.com)

Yvonne Everett, Neo Synthesis Research Centre, Sri Lanka and Cal Poly Humboldt, USA (yvonne.everett@humboldt.edu)

Coffee bushes planted in natural forest. Photo: Andrew Bartlett

Environmental, social and economic sustainability in Lao coffee

Andrew Bartlett, Khamkone Nanthepha, Thongxay Yindalath and Jane Carter

"Growing coffee doesn't require a lot of hard work, so a woman like me can do it very easily," says Seaumkham Lertmanyphan. "I don't know to what extent forest cover has increased, but before [we cultivated coffee] we cut down trees before planting crops, especially when growing rice and maize in upland areas."

Introduction

Seaumkham Lertmanyphan is one of a growing number of Lao farmers, many of them women, who have taken up the cultivation of coffee in the understorey of the natural forest near their homes. This is a form of agroforestry that utilizes the shade of existing trees to grow high-quality speciality coffee that is in much demand on the market. The forest and its biodiversity are preserved, rather than being cleared for agriculture, and more importantly for the farmers of Khoun District in Xieng Khouang Province, they earn a significant and growing income. A project of the Swiss Agency for Development and Cooperation (SDC) has assisted the farmers in establishing two agroforestry learning centres, where farmers work on processing the coffee cherries, and test the means to "climate proof" their production. The project approach combines environmentally-friendly coffee cultivation with farmer-based training and action research, engagement with private companies in local processing, and scaling up the experience to national markets.

Previously precarious livelihoods

The northern hills of the Lao People's Democratic Republic (henceforward Laos) are home to many ethnic minorities whose traditional way of life is shifting agriculture. Typically, the landscape is made up of a patchwork of large plots at different stages in a cultivation cycle of some 5 to 20 years' duration. Under traditional tenure arrangements, the user rights for these plots belong to various families. In the dry season at the start of the first year of the cycle, trees and shrubs are felled and burned; upland rice is planted once the rainy season starts. Women often live in small shelters on the plots during the growing period, spending many hours weeding the crop by hand. The following year, the first plot is left fallow while a new plot is cleared and planted. Fallow plots produce a wide range of wild food, the mix of which changes over the years.

With increasing population pressure and competing demands on land use — including flooding for hydroelectric dams and intensive contract farming — this way of life is no longer sustainable. Although shifting agriculture still occurs, it is within a more confined area on a shorter rotation, with farmers often using herbicides to kill weeds. Farming families also need to supplement their income through labour migration; this is generally carried out by the younger generation, leaving the elderly to take care of the farms, along with young children. Opportunities for future farmers that respond to needs for income generation, social interaction and environmental sustainability are very limited in these upland areas. However, agroforestry coffee has shown that it is attractive enough to keep some young people, particularly women, in their home villages.

Coffee cultivation in Keoset

The work on coffee (*Coffea arabica*) that is detailed here began in Keoset, a community of roughly 500 households clustered in five rural villages in Khoun District, Xieng Khouang Province. The land of steep hills and valleys lies around 1,200–1,400 m above sea level; temperatures generally peak at 30°C during the hottest months, and rarely dip below zero (although, as indicated later, this is changing). There is one rainy season, May to October, and the average annual rainfall is around 1,500–2,000 mm.

The coffee is planted in mixed seasonal tropical forest with a height of 15 to 30 m. Much of this is secondary forest, having been cleared in the past during shifting cultivation. The dominant species are *Castanopsis hystrix* and *Castanopsis echninocarpa*. Other trees are *Nauclea orientalis, Quercus serrata, Pterocarpus macrocarpus* and species of the genus *Dysoxylum, Hopea, Lagerstroemia* and *Lithocarpus*. As noted in the Provincial Biodiversity Strategy (Department of Natural Resources and Environment 2013), the area is also home to *Aquillaria* spp. (agarwood) and *Dalbergia* spp. (rosewood), but the value of these trees has resulted in overharvesting. Various non-timber forest products are collected, including the nuts of *Castanopsis,* mushrooms and roots, some of which are used in traditional medicine, both locally and exported to China.

The farmers of Keoset began planting coffee in forested areas close to settlements some three decades ago under an International Fund for Agriculture Development project. This was combined with mixed farming, including some livestock and limited shifting cultivation. Coffee was seen as a new and promising opportunity, but most of the coffee farms were abandoned when the project ended in 2005 due to the lack of a market. Some bushes remained, however, and in 2010 an SDC project began to revive cultivation and develop a market. The Mueang Xieng (MX) Coffee Company set up in the area in 2012 and began buying coffee cherries to process in its factory. The District Agriculture and Forest Office (DAFO) provided broad support for coffee development, but lacked specific expertise. Gradually, however, the volume of production increased. A scoping study conducted by the SDC project Lao Upland Rural Advisory Service (LURAS) in 2016 recognized the considerable market potential. The project is implemented by the Swiss NGO Helvetas and works in close collaboration with the Department of Agricultural Extension and Cooperative under the Ministry of Agriculture and Forestry and with the district authorities (DAFO).

The coffee nurseries in the area were established with seeds brought from the Bolaven Plateau in southern Laos, where the crop was introduced a century ago during colonial times. Seedlings are planted in the forest at 6 to 12 months and a density of 2,000–2,500 per ha. The resulting bushes start to bear fruit in the third year, increasing in yield until the full production is reached between 5 and 7 years. Occasional pruning keeps the bushes at a manageable height of no more than 2 m.

Learning by doing

LURAS worked with coffee farmers to establish learning centres in two villages. Complete with mini-processing facilities, these centres serve as a hub for knowledge exchange on all aspects of coffee cultivation and processing. The development of processing and marketing has been key to success. In working on these aspects, the project has taken care to collaborate with two companies, thus avoiding a monopsony (a market situation in which there is only one buyer) and to ensure that the product is tailored to market demand.

Coffee cherries are harvested between November and February, with drying and grading extending through March. Everything must be finished by mid-April, in time for the Lao new year holiday, after which farmers are busy preparing their rice fields. Processing the coffee cherries is conducted using the wet method: first immersing them in water and separating off the immature and damaged ones (which float). The skin of the good cherries (those that sink) is then mechanically removed in a pulping unit, which still leaves some mucilage clinging to the beans. This is detached by fermentation for 24 to 36 hours. The resulting coffee beans remain coated by a middle layer known as parchment. They are spread on raised racks in drying sheds with transparent covers. Compared to drying on the ground or on exposed racks, this provides better control of moisture and temperature, and avoids contamination by dust.

Lao farmers refer to coffee at different stages of processing by its colour (see Table 1). Once the moisture has fallen to between 10 and 12%, the coffee is hulled to remove the parchment, leaving green beans; 5 to 6 kg of cherries produces 1 kg of green beans. These are then graded by hand to remove any defects that would reduce the sale value, such as immature or broken beans, or those that show signs of damage by insects or fungus. This primary processing ensures a significant value addition for the farmers. Further processing through roasting is a highly skilled operation and must be conducted outside the village. Another 15–18% of weight is lost during roasting. Nevertheless, there are ways to significantly increase the quality of the green beans and thus achieve a premium price.

Keoset coffee producers carrying out primary processing: picking, weighing, soaking and drying. Photos: Andrew Bartlett

Table 1: Prices in USD per kg for coffee from Keoset at the time of the 2022–23 harvest

Stage	Description	Price
Red	unprocessed coffee cherries	0.58
White *	semi-processed beans	2.75
Green	the traded product after hulling and grading	4.30
Brown	roasted beans	21.80

*Note: White is known in the industry as parchment (washed, pulped and dried, but still retaining the endocarp).

The first mini-processing centre was established in the village of Ban Pieng in 2017, when LURAS facilitated a contractual collaboration between the MX Coffee Company and a group of farmers. Working with the district authorities, the project also provided advisory support for the establishment of coffee nurseries in nearby areas. The following year, a second learning centre was established in the village of Ban Tan Tai; there, the project facilitated collaboration with the Comma Coffee Company. The company invited farmers to a cupping session, where the quality of different coffees was assessed. It then offered training in quality control and grading and signed a contract with the farmers for their green beans. LURAS meanwhile continued to facilitate further farmer interest, especially among youth, and collaborated with MX, Comma and international experts on improvements such as the design of drying beds, natural processing, and factors affecting the sugar content of beans.

The global Covid-19 pandemic of 2020 at first threatened all the progress made, as tourist numbers plummeted, and local demand for coffee dropped. Yet this also proved to be an opportunity, as MX, Comma and other companies started investigating international markets and found interested buyers. The roasted coffee beans are sold as a high-quality niche product, a reputation that was consolidated when Keoset coffee produced under contract to Comma was awarded first prize in the Washed Arabica category of the Taste of Laos competition in 2022. It achieved the very high cupping score of 84.29. This unusually high cupping score obtained for Keoset coffee may be due to the natural fertility of the forest soil, which has been supplemented with compost made by the farmers.

A decade ago, coffee farmers in the north of Laos often sold their unprocessed cherries to traders who came across the border from Viet Nam. More recently, producers have been able to sell parchment (semi-processed beans) to locally based companies, thereby gaining a higher price. The LURAS project has shown that farmers can go even further in adding value at the village level. By using a simple hulling machine and spending a few hours grading, they can sell green beans to roasting companies and exporters at prices determined by the international market for specialty coffee.

Profitable returns

In the period 2018–2022 the Keoset farmers sold approximately 31 tonnes of coffee and earned an income of some USD 115,000. This equates to an average income of about USD 575 per household per year, but averages are deceptive. There is a wide range in income from coffee among households in these villages; the largest household coffee gardens, about 2 hectares (ha) each, are now generating an income of approximately USD 2,400 per year, while the smallest gardens may each earn an annual income of less than USD 100. Within the area of Keoset there are now about 155 ha of coffee planted under natural forest, at a density of some 2,000–2,500 bushes per ha. Most of these bushes are young and have only just reached full production (which is from the fifth year onwards); they are likely to produce well for at least 20 years and probably more, given the favourable conditions. The average yield at present is 1.5–2 kg per bush, but this is expected to increase to up to 2.5 kg per bush as the bushes mature.

As commercial interest in north Lao coffee has increased, other actors have crowded in – sometimes tempting farmers to sell to them rather than honour contractual agreements with MX and Comma. The two companies have responded by offering credit at favourable rates and establishing benefit-sharing schemes.

Women at the forefront

As the quotation at the beginning of this article indicates, coffee is a "woman-friendly" crop. The coffee harvest takes place in the dry season when the weather is cool and there are fewer demands on women's labour. Picking coffee is relatively light work for those who are used to planting and harvesting rice. The forest is within a few hundred metres of the villages, and women can carry

A buyer from Comma Coffee Company provides advice on grading. Photo: Andrew Bartlett

out the processing as a collective enterprise beside their homes, where they can also take care of small children.

Of the some 2,900 Keoset farmers now engaged in coffee cultivation, the vast majority, around 90%, are women. The groups at both the learning centres are led by women. Not only are the women responsible for picking and processing, they also play a leading role in negotiating contracts and managing finances. Nevertheless, as interest and income opportunities have grown, so too has the engagement of men, some of whom have opted to remain at home rather than participate in seasonal labour migration. The timing of cherry harvesting and processing dovetails nicely with rice and maize cropping. Thus, while household members continue to cultivate food crops and keep a few livestock animals, coffee brings a significant additional income. In a few cases, such as that of Seaumkham Lertmanyphan quoted earlier, coffee has become the main household production system.

Coffee essentially allows rural livelihoods to rise above a level of wearying subsistence to one of dignity, with enough money to buy necessities. Through coffee, women have a greater voice in household decision-making and have their own source of cash without threatening food security. They also have the knowledge that they are maintaining the local environment for the next generation.

Risk management — building community and ecosystem resilience

The next generation will almost inevitably feel the effects of climate change even more strongly than the present generation does. Already the frequency of temperature extremes is increasing, and rainfall patterns are becoming more erratic. Whereas frost was rarely reported in the past, there have been recent sudden cold snaps when the temperature dropped to –3°C. Coffee is particularly sensitive to frost, but within the forest the bushes are protected; there, temperatures have not dropped lower than –1°C. Similarly, the forest provides protection against sudden intense storms.

The maintenance of forest cover helps to conserve soil organic matter and carbon, and farmers have further improved soil health by applying compost made from coffee waste and locally available animal manure. In addition, pests and diseases are more readily controlled by natural predators in the biodiverse forest ecosystem. This has special recent significance, given the discovery of the coffee cherry borer (*Hypothenemus hampei*) in the area in 2020. LURAS has worked with farmers to test various non-chemical methods to control this very serious pest; these have to date been largely successful, probably in part due to natural predators that thrive in the forest environment. For example, ants are described by Perfecto and Vandermeer (2015) as important agents in the control of coffee cherry borer, among the many other benefits of biodiverse production systems.

Seaumkham Lertmanyphan and other members of the Keoset producer group prepare coffee cherries for processing. Photo: Andrew Bartlett

Challenges

Although the story so far is very positive, a variety of challenges remain: institutional and legal context; world price fluctuations; remote and scattered production; geographical limitations; and competition from other cash crops.

Institutional and legal context

Within the government structure in Laos, as in many other countries, agroforestry occupies an uncertain position between different departments of the Ministry of Agriculture and Forestry. The Ministry of the Natural Resources and Environment could also claim responsibility, while commercial aspects, in principle, fall under the Ministry of Industry and Commerce. To date, LURAS has focused on building the relationship between farmers and private companies, which fortunately cooperate readily with each other. However, it is also important to build capacity within the government to guide and support this cooperation, especially given the potential for developing climate-resilient livelihoods and the legal ambiguity associated with agroforestry in the current *Forestry Law*.

World price fluctuations

Dramatic changes in the price of green coffee beans are a characteristic of the global coffee trade, meaning that the price Lao farmers receive is influenced by events in countries such as Brazil and Indonesia. Since Laos produces less than 1% of global coffee, it will always be a price-taker rather than a price-maker. It is therefore important that farmers continue to practise a mixed farming system and not rely solely on their income from coffee.

Remote and scattered production

Northern Laos is not ideal territory for export-oriented investment given the poor road system, scattered production, and the country's land-locked status. The strategy has therefore been to focus on specialty-grade coffee (i.e. cupping scores over 80), enabling buyers to export relatively small volumes of "single origin" coffee to independent roasters — and providing farmers with a premium price for their beans. This is currently working well, yet it remains to be seen how the market develops.

Competition from other cash crops

In a drive to boost production and farming incomes, the agriculture sector in Laos has experienced a rapid expansion in various commercial crops. Some of these, especially rubber and bananas, have enriched foreign investors. Others, most notably maize and cassava, have provided quick wins for small farmers, but at the cost of forest destruction and declining soil fertility. In the south of Laos, there have been several reports of farmers replacing coffee with cassava. While there is a risk that this might also happen in the north, it is hoped that growing awareness within government and among farmers of the environmental risks associated with cassava production will serve to curb short-term interests. Cassava production could be especially damaging on sloping lands, where soils are vulnerable to erosion; this demands stricter zoning and regulation over different production systems on the part of the government.

Conclusions

Alarm within the global coffee industry about the impact of climate change on production was sounded some time ago; indeed, a public-private venture for sharing information on the threat was established in 2010 (the Initiative for Coffee and Climate). The positive experience of Lao farmers with coffee in a relatively climate-resilient agroforestry system has potential significance for other countries with forested upland areas in similar agroecological zones. While such agroforestry systems are unlikely to ever compete seriously with large-scale coffee production at greater planting densities, they can be complementary to that production. Given their potential for promoting small farmers' incomes at the same time as resilience to climate change and the promotion of biodiversity, they deserve further attention.

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Author affiliations

Andrew Bartlett, Independent consultant, formerly International Adviser to the LURAS project based in Vientiane, Lao PDR (andrew.seedbed@gmail.com)

Khamkone Nanthepha, Provincial Adviser for the LURAS project, based in Xieng Khouang, Lao PDR (khamkone.nanthepha@helvetas.org)

Thongxay Yindalath, Senior Technical Officer for the LURAS project, based in Xieng Khouang, Lao PDR (thongxay.yindalath@helvetas.org)

Jane Carter, Senior Adviser, Natural Resource Governance at Helvetas head office, based in Bern, Switzerland (jane.carter@helvetas.org)

Smallholder farmer harvesting rubber near Laman Satong village, West Kalimantan, Indonesia. Photo: Irpan Lamago

Towards a sustainable business model for rubber agroforestry in Indonesia

Elok Mulyoutami, Dia Mawesti, Triana, Edi Purwanto and Atiek Widayati

"Our rubber plot is a mixed rubber garden, where many other valuable plants can grow and be harvested for home use and to generate additional income."

Ms. Rupina, Dayak rubber smallholder farmer, Mekar Raya village

Agroforests: traditional and functional

The significance of agroforestry systems to Dayak communities, particularly rubber (*Hevea brasiliensis*) agroforests, is deeply rooted in their social and cultural setting. For decades, this land-use system has provided economic benefits as well as other vital assets for their various livelihood elements.

In Simpang Dua sub-district, Ketapang District, West Kalimantan, Indonesia, agroforests have flourished for generations. There are two common types: *tembawang* and rubber agroforest. *Tembawang* is a traditional fruit garden, with illipe nuts (*Shorea* spp., or *tengkawang*) as the primary commodity and also including fruit and food trees such as durian (*Durio zibethinus*), *langsat* (*Lansium domesticum*), *cempedak* (*Artocarpus integer*) and *jengkol* (*Archidendron pauciflorum*). Smallholders usually establish *tembawang* after cultivating upland (rain-fed) paddy fields for a few years, or in homegardens that are planted with the various tree species. The second type is rubber agroforest, a mixed garden with rubber as the primary commodity and dominant tree (Michon et al. 2007). It is locally called *kebun karet*, literally "rubber garden."

In the past decades, *tembawang* and rubber agroforests have faced threats of conversion, due to the plunging rubber price at the farmers' level, from around EUR 900/ tonne in 2011 to EUR 300 in 2023 (Figure 1). With such a low rubber price, rubber smallholders can no longer rely on this commodity as their primary livelihood source. The oil palm boom in West Kalimantan since the early 2000s has made it even more difficult to resist land conversion. Although both agroforestry systems are threatened, *tembawang* is considered more resilient since it provides more socioeconomic benefits for local communities, and its tenure rights are better protected under local customary law.

Some Dayak communities maintain rubber agroforests more to respect their ancestors' clan and traditions than for tangible economic benefits. Traditional rubber agroforests are perceived as low-input and low-output systems and are economically marginal (Grass et al. 2020). However, for some other communities, rubber agroforestry is still valuable economically, since farmers can earn income from other commodities when the rubber price is low. Rubber agroforests can potentially reduce smallholders' vulnerability to volatile rubber markets, particularly if their income from other tree species is substantial (Huang et al. 2022).

Figure 1. Rubber price per tonne (EUR), 2000–2023
Source: Malaysian Rubber Board

***Tembawang* in Mekar Raya, West Kalimantan, Indonesia. Photo: Abdul Hadedi**

Rubber agroforest in Mekar Raya; rubber trees can be recognized by the scars on the bark from collecting. Photo: Abdul Hadedi

Values of agroforests to the communities

Sociocultural values

In rubber agroforests, individual ownership applies only to rubber trees, while other commodities belong to all and may be harvested by other members of the community. For instance, *bemban* (*Donax canniformis*), various species of rattan (*Calamus* sp.) and bamboo (*Bambusoideae*) are harvested for crafting materials. Conversely, *tembawang* is entirely communally owned and managed by the family clan. In addition, *tembawang* is a social space for annual collective fruit harvesting and gatherings. Overall, different agroforests of Kalimantan have strong traditional importance linked to spiritual life, respect for ancestors and other sociocultural values. In contrast, plots with oil palm and *jengkol* do not have such values (Table 1).

Table 1. Agroforest functions and sociocultural values

System	Functions	Collective action	Natural and spiritual values	Land-related property right
Rubber agroforests	Food, income, other locally used products	—	Ancestor reverence	Individual-semi-communal based
Tembawang	Food, income, other locally used products, identity, knowledge	Annual social and cultural events	Ancestor reverence	Communal
Oil palm with *jengkol*	Food, income	—	—	Individual-based

Adapted from Mulyoutami et al. 2023

Economic values

Rubber agroforests provide diversified income. Huang (2022) highlights that diversified farms have higher returns when rubber prices are low, but this depends on whether the commodities chosen provide good returns in terms of land and labour. In the current situation in Simpang Dua, where rubber agroforests are mostly intercropped with subsistence crops (see photos), market opportunities for secondary products such as *jengkol* and sugar palm (*Arenga pinnata*) exist only in the neighbouring villages.

A modelling study carried out in 2021 using the FarmTree Tool (DIBcoop 2021) showed that rubber agroforests

Oil-palm plot in Simpang Dua. Photo: Gusti Suganda

provide higher income than oil-palm plantations despite their higher labour requirements (Table 2). The model calculated the potential production of several commodities in different scenarios, assuming a 10% discount rate of the present price. The model assumes that all crops are sold on the market; therefore, results for the *tembawang* show high potential income, while in reality many crops are grown for subsistence and thus have a low market value. Rubber is intended for market use and is the most significant regular source of income.

Table 2. Potential revenue (IDR/EUR) from three agroforestry systems in Simpang Dua sub-district

System	Trees and commodities	Modelling result, 30-year life cycle			Production orientation
		Labour investment (per ha per year)	Net income (NPV @10% DR) per year	Input costs (NPV @10% DR) per year	
Rubber agroforests	Rubber, *jengkol*, sugar palm	EUR 331.4	IDR 12,048,000 (EUR 753)	EUR 931	Market
Tembawang	*Durian, langsat, cempedak, jengkol,* sugar palm, *Coffea robusta*	EUR 169.6	IDR 13,346,666 (EUR 834)	EUR 1,083	Subsistence
Oil palm	Oil palm	EUR 172.3	IDR 10,257,066 (EUR 641)	EUR 925	Market

Notes: Data source: DIBcoop (2021). NPV: Net present value; DR: Discount rate

In 2022–2023, however, primary data collection in Simpang Dua and Sinar Kuri sub-districts shows results that differ from the modelling results. Income from rubber agroforests was IDR (Indonesian rupiah) 12,921,600 (EUR 777) per ha per year, while oil palm monoculture generated a higher income of IDR 15,652,500 (EUR 941). So, modelling data and actual field data indicate that rubber agroforests and oil palm monocultures are both promising. While data showed that oil palm provides higher income in the short term, rubber agroforests can provide higher income over the entire system cycle. This difference is also due to the fact that oil palm requires more inputs such as fertilizers, particularly during the non-productive stage, which is accounted for in the DIBcoop model. More intensive economic analysis is needed to understand this further.

Financing agroforests: challenge and opportunity

In many countries, agricultural loans and investment portfolios are disproportionately low compared to the agriculture sector's share of gross domestic product. The financial sector, including banks and microfinance institutions, provides only minimal resources to the agricultural sector. A World Bank Brief (World Bank 2022) lists the reasons why more financial support is not provided: inability to manage the specific (e.g., climatic) risks of agriculture; high transaction costs in dealing with a large number of smallholders; the presence of micro, small and medium enterprises along agriculture value chains; limited effective demand for finance; and the lack of expertise of financial institutions in managing agricultural loans.

Long-term financing would be ideal for supporting smallholder rubber agroforests, improving yields and adding value to community livelihoods from secondary commodities. Unfortunately, obtaining this type of financing faces many obstacles related to the lack of productivity of agroforestry crops and the low attention on the part of investors, financiers and markets. Another form of support for small-scale agroforest products would be to link them to markets and communities of buyers, in order to help communities increase production from their agroforests.

A similar situation is observed in the case of cocoa agroforests in Côte d'Ivoire, where long-term financing is needed to target on-farm agroforest activities to sustain and improve profitability while transforming farming systems. Klein et al. 2021 recommends that funding be obtained through loans and that funders estimate a minimum level of cash flow generated by sales to cover producers' needs and ensure repayment of the loan without burdening family budgets.

Smallholder farmers who do not achieve adequate profitability need non-commercial financial support (i.e., support that does not to be repaid), including technical support, to strengthen their farming practices (Klein et al. 2021). In Central Sulawesi, Indonesia, incentive mechanisms such as carbon payments seem to have positive impacts on the income derived by cocoa smallholders for the households that have the fewest financial resources. In addition, carbon payments may reduce the need for smallholders to clear the forest and sell their land (Seeberg-Elverfeldt et al. 2009). Multiple market-based instruments (such as premium prices for eco-certification, carbon payments, and taxes on conversion processes) can stabilize farmer income and reduce income inequality among farmers (Djanibekov and Villamor 2017).

Non-financial incentives, such as for performance-based results, might also be considered, not only for smallholders but also for wider communities. Incentives for local people in Bungo District, Jambi Province, Indonesia, were not provided directly for agricultural businesses, but for measures such as the establishment of micro-hydro power plants, setting up rubber nurseries, and installing demonstration plots of improved rubber cultivation systems and seedlings (Joshi et al. 2011). In the case of Simpang Dua, payments for ecosystem services from the Gunung Juring Protection Forest, located in the sub-district, have been used to establish a mineral-water business. This effort was initiated by one village in the sub-district, Mekar Raya, with the support of the local forest authority. Both financial and non-financial support from local authorities can assist local business initiatives.

Will the rubber agroforest business model work?

The business model for rubber in Simpang Dua sub-district is currently managed by households. Financial support is necessary, although at the current stage, the most crucial support needed is for improving the quality and quantity of rubber production. Credit Union (CU) Semandang Jaya, a local financial institution, expressed little interest in further assisting rubber smallholders (Mawesti et al. 2021). The major reason was that production is low due to falling rubber prices, and yield is low due to the variety of rubber trees, which has low agronomic productivity. Other factors contributing to low production and/or productivity are poor seedling quality, dense spacing between trees, no pruning, no agricultural inputs, old unrevitalized trees, and inappropriate harvesting techniques. Another factor that deters involvement by the CU is the low quality of the latex produced. Smallholder farmers often mix dirt into coagulated rubber to increase its weight, but this stratagem does not work, because the rubber market demands good-quality rubber that is free of dirt.

CU Lantang Tipo did provide financing to rubber smallholders for replanting, with a four-year grace period for repaying the loan and a 14-year payback period. However, most local smallholder farmers hesitate to take such loans because rubber rejuvenation is a low priority. They maintain ancestral rubber plots without fertilizers or pesticides (i.e., low maintenance). Oil palm and fruit trees are more attractive than renewing rubber plots.

UPPB purchases *bokar* from rubber smallholders in Simpang Dua. Photo: Sulaiman

In four villages in Simpang Dua — Mekar Raya, Gema, Kamora and Batu Daya — at least 150 smallholders have been identified as active rubber tappers. For decades, these smallholder farmers have relied on local (village-level) buyers to purchase the raw rubber (*bokar*) and sell it to local agents at the sub-district level who have purchasing agreements with rubber factories. These different intermediaries in the rubber supply chain have put smallholder farmers in a vulnerable state: the farmers do not have the bargaining power to determine the selling price amid the steadily decreasing price of rubber. Smallholder farmers are not well informed about the rubber price at the factory level, and in addition, some of them are already in debt due to pre-financing from buyers for working capital and daily costs. Therefore, rubber smallholders have limited options to earn better and more fair prices.

Rubber smallholders thus face various types of difficulties. The lower global demand for natural rubber weakens prices and devitalizes the business process. Some factories are closed, some buyers are no longer purchasing rubber, and some smallholder farmers are reluctant to sell. The expansion of nearby large-scale oil palm plantations has shifted the rural labour force from rubber smallholders to plantation workers, especially the younger generation. The temptation to change land use to oil-palm farms is high, given the more stable and relatively high price of palm oil. Rubber smallholders also face other challenges that are part of locally controlled forest and farm businesses: insecure tenure; inadequate technical capacity; lack of business and market know-how; and limited cost efficiencies and bargaining power (Macqueen et al. 2018).

Aggregation as the key for market access

In Simpang Dua, although obtaining financing remains challenging, access to the market can be improved by establishing a rubber processing and collective marketing unit (*Unit Pengolahan dan Pemasaran Bokar* or UPPB). In 2022, farmers' groups in the four villages formed a UPPB and registered it with the Agriculture, Livestock, and Plantation Agency of Ketapang District. The unit would arrange collective marketing and provide technical capacity for farmers to meet the specifications of Standard Indonesia Rubber, a quality standard for *bokar*. By establishing the UPPB as a legal entity, farmers

UPPB sells *bokar* to PT NKP, a rubber-processing company. Photo: Triana.

can collectively sell rubber slabs (coagulated latex in thick sheets) directly to crumb rubber factories (which process natural rubber into rubber granules, mostly to supply tire manufacturers; see photo previous page), and earn prices up to 25% higher than they would get by selling as individual farmers.

> *"I am happy to sell* bokar *to UPPB. So far, the buying price from the middlemen is much lower than the UPPB, though we need to sell it collectively to reduce the transportation cost."*
> Ms. Heni, a rubber farmer from Kamora village

Being a newly established institution, Simpang Dua UPPB faces several challenges. Despite 80% of active rubber smallholders in the four villages being members, regular delivery to crumb rubber factories is still a challenge because of irregular supplies from farmers. The recent price is still far below the high price of the last decade, which demotivates farmers to tap their rubber trees. Among local smallholder farmers, rubber slabs that they sell to local traders are also kept at home instead of being sold and are commonly used as savings for urgent needs or when the rubber price picks up, even though the quality of the slab will deteriorate after three months of storage.

The actions and commitments that Simpang Dua UPPB must undertake can be summarized as follows:

- UPPB must gradually improve rubber slab quality to obtain a better price, thus unleashing the potential to get a premium price (Fair Rubber). Even so, 70% of all natural rubber production goes to car tire manufacturers, and convincing them to try Fair Rubber is tough. Hence, the Fairtrade label for rubber production involves a very narrow market (Kunz 2021). However, with direct links to rubber factories through UPPB, local smallholder farmers can also access private financial resources to improve their technical capacity in product knowledge and standard quality, as required by the industry.
- As a business unit, UPPB must also have a solid business case in which they remain profitable even without external support. Currently, there are various supports and facilitation options for local rubber smallholders in Simpang Dua, in the form of intervention strategies (Figure 2).

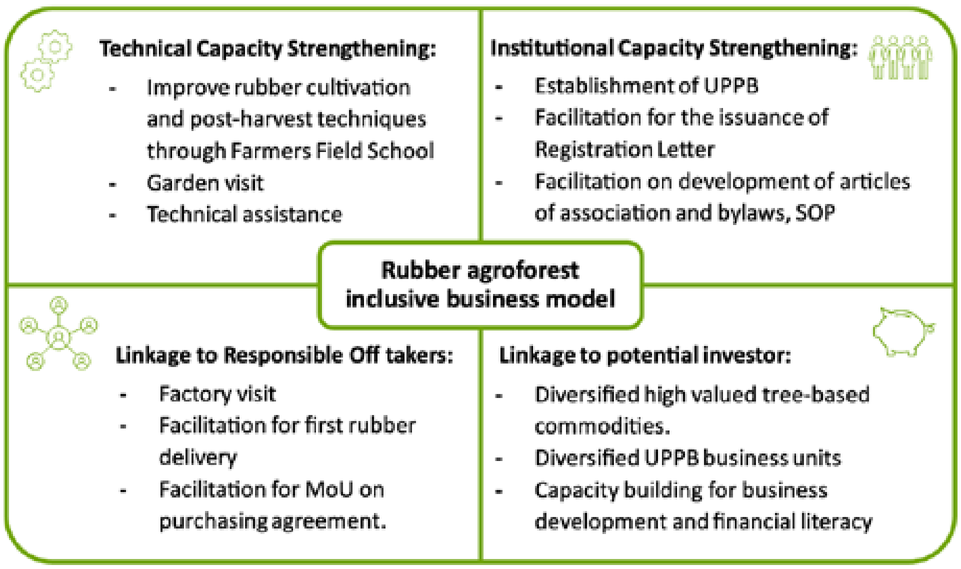

Figure 2. Intervention strategies for sustainable business model, rubber agroforestry

In the long run, these intervention strategies will lay the foundation for UPPB to be a strong farm producer organization running an inclusive business model for rubber agroforests. By improving their institutional and technical capacities, local smallholder farmers are expected to increase their production capacity and the quality of their rubber, which is their main or "anchor" commodity. Macqueen et al. (2018) found that many successful forest and farm producer organization (FFPO) business models started with a particular anchor value chain; they then diversify into various production lines because doing so will reduce the risk of failure. In this case, once the anchor product has a well-established market, UPPB can potentially facilitate market aggregation of diversified commodities to provide an additional source of income for local smallholder farmers from rubber agroforestry plots.

Conclusions

To promote sustainable and inclusive rubber agroforest businesses, commitment from all relevant stakeholders — including smallholder farmers, government at all levels, NGOs and the private-sector — is needed. Through regulatory support, the government can incentivize farmers to maintain agroforests. However, even with the current lack of interventions from the government, local farmers' groups have shown high resilience by organizing themselves to improve the system and to develop their business as well, with the support of NGOs. And as a vital part of the rubber supply chain, crumb rubber factories can also play an essential role in supporting rubber agroforests. With initial support from the government and through local collective actions, a rubber agroforestry business is expected to be established, and responsible financial institutions and investors can provide financial support to further develop this business.

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Author affiliations

Elok Mulyoutami, Tropenbos Indonesia (eloknco@gmail.com)

Dia Mawesti, Tropenbos Indonesia (dia.mawesti@gmail.com)

Triana, Tropenbos Indonesia (triana2802@yahoo.com)

Edi Purwanto, Tropenbos Indonesia (edipurwanto@tropenbos-indonesia.org)

Atiek Widayati, Tropenbos Indonesia (atiekwidayati@tropenbos-indonesia.org)

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Tropenbos International
Horaplantsoen 12, 6717 LT Ede, the Netherlands
tropenbos@tropenbos.org
www.tropenbos.org

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