CGIAR
RESEARCH PROGRAM ON
Forests, Trees and Agroforestry

FTA HIGHLIGHTS OF A DECADE
2011–2021

# Trees on Farms to Improve Livelihoods and the Environment

Ten years of
forests, trees and agroforestry
research in partnership for
sustainable development

## About the FTA Highlights series

This publication is part of a series that highlights the main findings, results and achievements of the CGIAR Research Program on Forests, Trees and Agroforestry (FTA), from 2011 to 2021 (see full list of chapters on the last page).

FTA, the world's largest research for development partnership on forests, trees and agroforestry, started in 2011. FTA gathers partners that work across a range of projects and initiatives, organized around a set of operational priorities. Such research was funded by multiple sources: CGIAR funders through program-level funding, and funders of bilateral projects attached to the programme, undertaken by one or several of its partners. Overall this represented an effort of about 850 million USD over a decade.

The ambition of this series is, on each topic, to show the actual contributions of FTA to research and development challenges and solutions over a decade. It features the work undertaken as part of the FTA program, by the strategic partners of FTA (CIFOR-ICRAF, The Alliance of Bioversity and CIAT, CATIE, CIRAD, Tropenbos and INBAR) and/or with other international and national partners. Such work is presented indifferently in the text as work "from FTA" and/or from the particular partner/organization that led it. Most of the references cited are from the FTA program.

This series was elaborated under the leadership of the FTA Director, overall guidance of an Editorial Committee constituted by the Management Team of FTA, support from the FTA Senior Technical Advisor, and oversight of the FTA Independent Steering Committee whose independent members acted as peer-reviewers of all the volumes in the series.

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**Trees on Farms to Improve Livelihoods and the Environment**

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CGIAR Research Program on Forests, Trees and Agroforestry
CIFOR Headquarters
Jalan CIFOR
Situ Gede, Sindang Barang
Bogor Barat 16115 Indonesia

T +62-251-8622-622
E cgiarforestsandtrees@cgiar.org

foreststreesagroforestry.org

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FTA HIGHLIGHTS OF A DECADE
2011-2021

# Trees on Farms to Improve Livelihoods and the Environment

**Lead authors:** Eduardo Somarriba

**Contributing authors:** Arlene López-Sampson,
Norvin Sepúlveda, Edwin García and Fergus Sinclair

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*The final content remains the sole responsibility of the authors.*

# Table of contents

**Executive summary............................................................ 4**

**1. Introduction....................................................................... 6**

**2. Forests, TOF, TonF and agroforestry systems.................... 9**

**3. TonF are a valuable resource............................................ 11**

**4. Realizing the potential of TonF in Honduras and Nicaragua........................................................................ 20**

**5. Conclusions and recommendations.................................. 36**

**References.......................................................................... 39**

## List of acronyms

| | |
|---|---|
| AFOLU | Agriculture, Forestry and Other Land Use |
| CATIE | Centro Agronómico Tropical de Investigación y Enseñanza |
| CBD | United Nations Convention on Biological Diversity |
| CIRAD | French Agricultural Research Centre for International Development |
| DIBIO | Direccion General de Biodiversidad/Biodiversity Directorate of the Ministry of Environment and Natural Resources |
| GHG | Greenhouse gas |
| ICF | Instituto Nacional de Conservación y Desarrollo Forestal/National Institute for Conservation and Forest Development, Protected Areas, and Wildlife |
| LULUCF | Land use, land-use change, and forestry |
| MNGS | Mesa Nacional de Ganadería Sostenible /National Platform for Sustainable Livestock |
| MRV | Monitoring, Reporting and Verification |
| NAMA | Nationally Appropriate Mitigation Action |
| NBSAP | National Biodiversity Strategies and Action Plan |
| NDC | Nationally Determined Contribution |
| RPAS | Remotely piloted aircraft system |
| SIGMOF | Sistema de Información para la Gestión y Monitoreo Forestal/National information system on forests and tree resources |
| TOF | Trees outside forests |
| TonF | Trees on farms |

# Executive summary

Trees are found in forests and outside the forest. Trees outside the forest are located in urban areas, on farms, and in natural plant formations that do not conform to the definition of forest (e.g. those in arid environments that do not meet minimum tree cover thresholds). Trees on farms (TonF) are dispersed in pastures or crop fields, in linear features (live fences, windbreaks, farm boundaries and internal divisions, on the sides of roads and watercourses), in patches or in regular plantation arrangements, solitary or in groups, with regular or variable density. Numerous studies have documented the abundance and importance of TonF to farmers' livelihoods and to the environment. However, TonF are: 1) "invisible" to and absent from the legal/institutional/policy/value chains/education/rural extension frameworks of most countries; and 2) suboptimally designed and managed. These factors prevent farmers, the private sector, and governments from fully realizing the potential of trees on farms.

This publication shows how the advances achieved by the joint work of FTA and the Trees on Farms for Biodiversity project in Nicaragua and Honduras were used to: 1) increase the visibility of trees in live fences on cattle ranches in the Honduran national information system on forest resources, and in both national reporting systems and sectoral development programmes for the cattle ranching sector; and 2) develop the knowledge and science-based tools needed to improve the design and management of trees in the shade canopy of agroforestry systems for cocoa and coffee. Increasing the visibility of trees on farms, and mainstreaming them in public policies and development initiatives, require that salient, science-based knowledge be generated, shared

and thoroughly discussed with key personnel in public institutions (Ministries of Environment, Forestry, and Agriculture) and private-sector organizations (sectoral governance platforms, financial institutions, etc.), and included in educational (national universities, extension service, and farmer field schools) and reporting systems.

Dispersed trees around house compounds and in pasture lands, Peñas Blancas, Matagalpa, Nicaragua. *Androanthus chrysanthus* tree in yellow blossom.

Photo by Norvin Sepúlveda

# 1. Introduction

In 2012, CGIAR's Research Program on Forest, Trees and Agroforestry (FTA) established a network of Sentinel Landscapes (SLs).[1] The goal was to conduct long-term research using standardized methodologies in order to understand (and improve) the temporal and spatial dynamics of land use, trees and forests in selected areas. The SL initiative included eight observatory landscapes around the globe that represented widely different biophysical and socioeconomic contexts. The SL initiative spanned 10 years, from 2012 to 2021.

Four central research questions were addressed in each SL, using standardized methodologies and datasets:

1. What drivers and processes determine/influence the presence of trees and forests in the landscape and on farms?
2. What is the magnitude of forests and TonF stocks and of their rate of change in the landscape?
3. What are the consequences to the provision of ecosystem services from changes in forests and TonF stocks in the landscapes and on farms?
4. What new concepts and models are needed to optimize the presence of forests and TonF in the landscape and on farms, and to secure the sustainable provision of ecosystem services?

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[1] https://doi.org/10.17528/CIFOR/DATA.00021.

The Nicaragua-Honduras Sentinel Landscape (NHSL) is a mosaic of forests, agricultural land, cattle ranches and crop fields covering 68,000 km$^2$, including two biosphere reserves and 13 protected areas (Figure 1). This landscape contains the largest remaining primary forests in Central America. Four study sites (each 10 km × 10 km), representing a forest transition curve from the forest frontier to intensive agriculture, were chosen for detailed studies. A summary of the information generated in the NHSL is available, including studies on land use, communities and households, farming systems, tree inventories on farms, and governance and management of protected landscapes, as well as more specialized, in-depth studies on sectors such as cocoa and coffee (Sepúlveda et al. 2020).

## The Nicaragua-Honduras Sentinel Landscape (NHSL): land use and vegetation

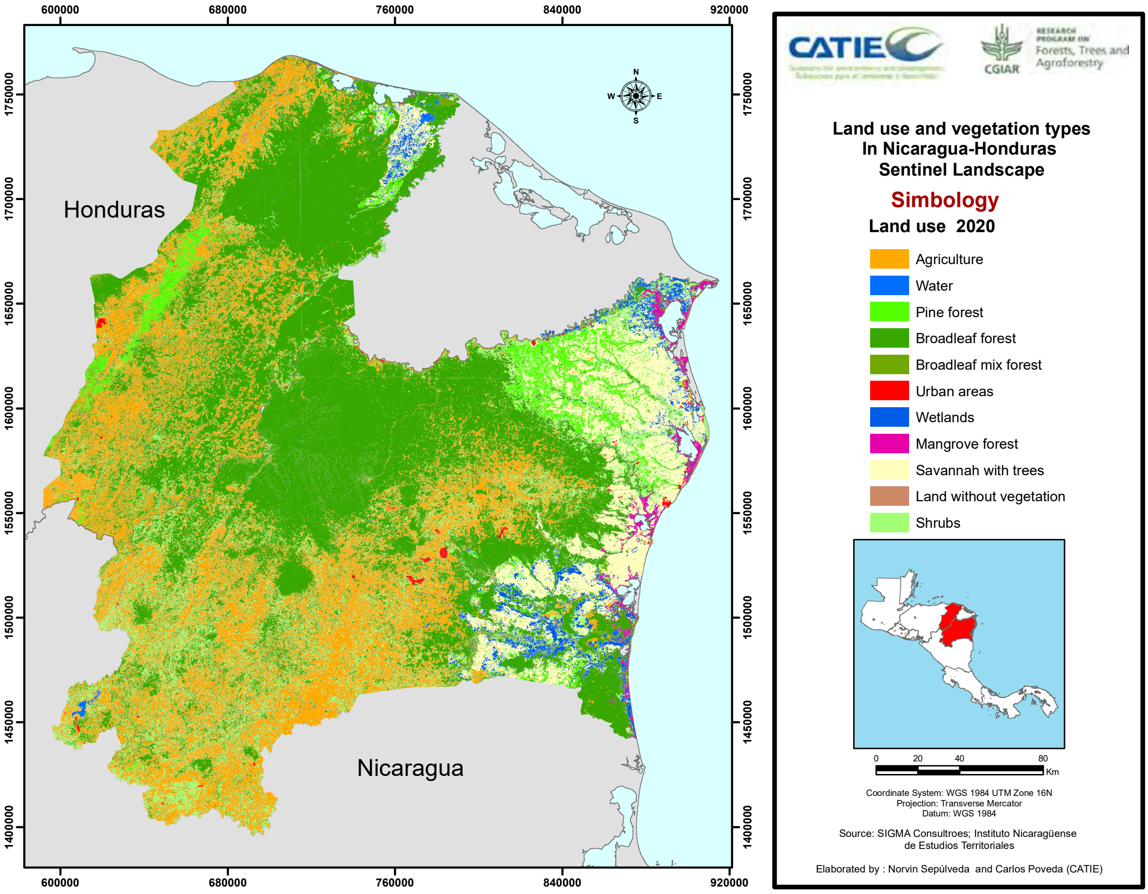
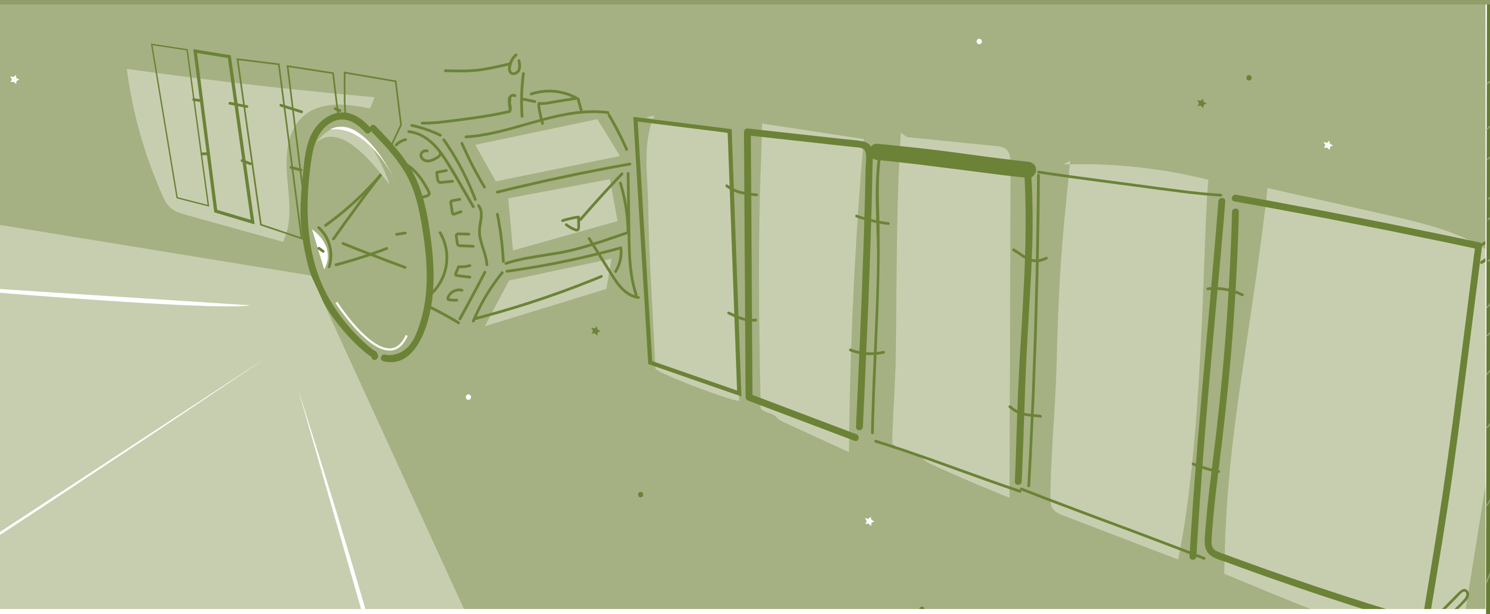


**Figure 1.** The Nicaragua-Honduras Sentinel Landscape (NHSL): land use and vegetation.

This publication shows that forests, trees outside the forest (TOF), trees on farms (TonF), and agroforestry systems are part of the same continuum. Sometimes this is a zero-sum situation, with deforestation increasing the presence of both TOF and TonF. Research shows (Somarriba et al. 2017) that TonF are ubiquitous and very important for livelihoods and the environment, but  are "invisible" in the sense that they are absent from the legal, institutional, policy and education frameworks of most countries.

The results and knowledge presented in this publication combine outputs from the work directly supported by FTA, complemented by results from related work in the Trees on Farms for Biodiversity project (TonF), and from other projects of Centro Agronómico Tropical de Investigación y Enseñanza (CATIE) and French Agricultural Research Centre for International Development (CIRAD) located in the NHSL. The TonF project was designed under the framework of FTA's Sentinel Landscapes initiative. Both CATIE and CIRAD are members of the consortia of both the FTA and TonF initiatives. The knowledge generated by these partners is accompanied by current scientific information published by other authors working on the same themes in other geographies.



# 2. Forests, TOF, TonF and agroforestry systems

Trees are found in forests and outside the forest (Figure 2). Trees outside the forest (TOF) are located in urban areas, on farms, and in natural plant formations (e.g. those in arid environments) that do not conform to the definition of forest (de Foresta et al. 2013). The assessment and monitoring of TOF has significantly increased in the last decades (Baffetta et al. 2011; de Foresta 2017; Liknes et al. 2010; Wani et al. 2020). TOF are increasingly being included in national forest and landscape inventory systems (Schnell et al. 2015b; see Schnell 2015a for the contribution of TOF to national tree biomass and carbon stocks on three continents). The use of high-resolution satellite imagery and remote sensing, coupled with automated post-processing techniques, has improved the ability to map TOF at a large scale (Bolyn et al. 2019; Yadav 2019; Kattenborn et al. 2021). For example, a recently published study in *Nature* (Brandt et al. 2020) mapped all trees (>3 $m^2$ crown size) in an area in Africa covering 1.3 million $km^2$ using machine learning applied to high-resolution (<1 m) satellite imagery. Similarly, in Haryana State, India, very-high-resolution satellite imagery data was used to map TOF resources in a complex landscape (Kumar et al. 2021). More work is needed to harmonize and standardize definitions, methods and approaches across countries and forest institutions.

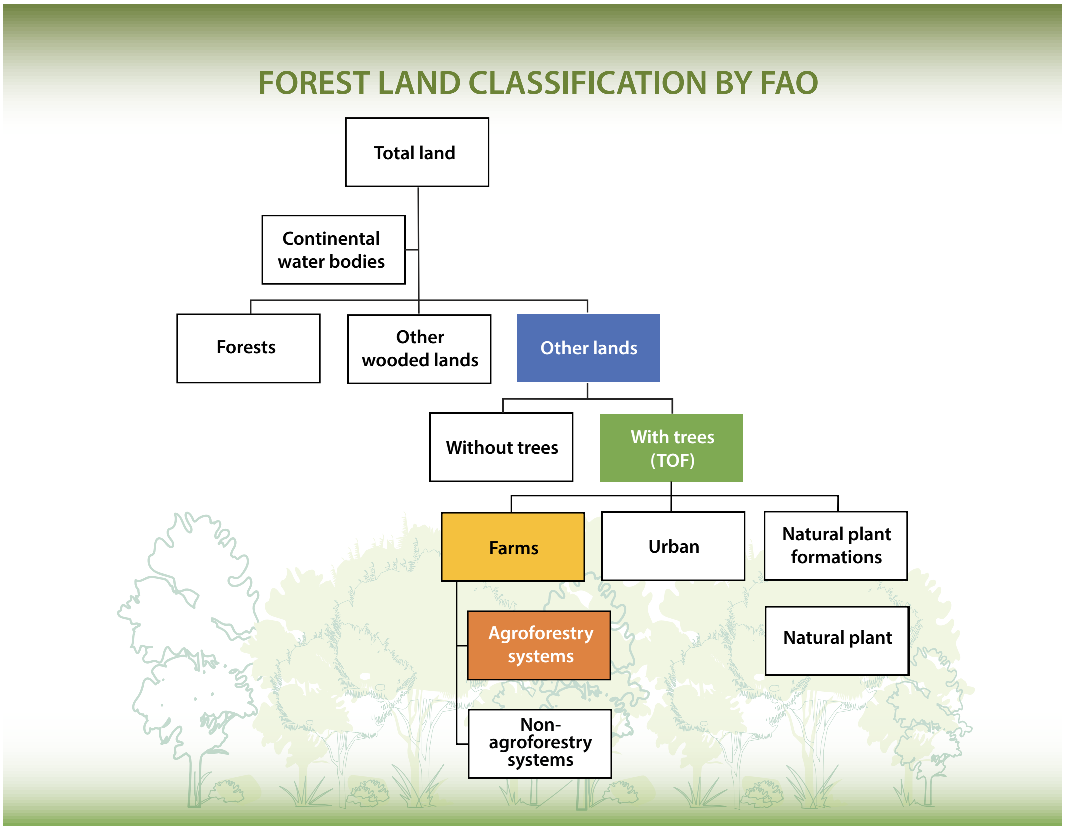


**Figure 2.** Forest land classification by FAO

# 3. TonF are a valuable resource

## 3.1 TonF for livelihoods

Trees on farms (TonF) are ubiquitous, contributing to the well-being of more than one billion people (Agrawal *et al.* 2013). In Central America, for instance, 54% of agricultural land has up to 30% tree cover (Zomer *et al.* 2009, 2014). TonF are dispersed in pastures and crop fields, in linear features (live fences, windbreaks, farm boundaries and internal divisions), on the sides of roads and watercourses (Chacón and Harvey 2008), in patches or in regular plantation arrangements, solitary or in groups, with regular or variable population density. Trees on farms are the result of three processes: (1) retention of residual trees from the original natural forest (Harvey and Haber 1998); (2) selection (and protection) of valuable trees from natural regeneration (Pinoargote *et al.* 2016; Somarriba 2011); and (3) active planting of selected species at specific locations on farms (Somarriba and Beer 2010; Somarriba et al. 2016).

Farmers retain, recruit or plant trees on farms because they are useful. TonF contribute to food and nutritional security (Almendarez et al. 2013; Saenz-Tijerino 2012; Thapa et al. 2021); generate income (Cerda et al. 2014); and provide ecosystem services as well as aesthetic and cultural benefits. In Latin America, half of the rural population use TonF for subsistence and income (Dewees 2013). For instance, shade trees in cocoa plantations provide energy, vitamins and micronutrients that improve family nutrition (Figure 3) and help families to avoid seasonal food shortages (Somarriba et al. 2017).

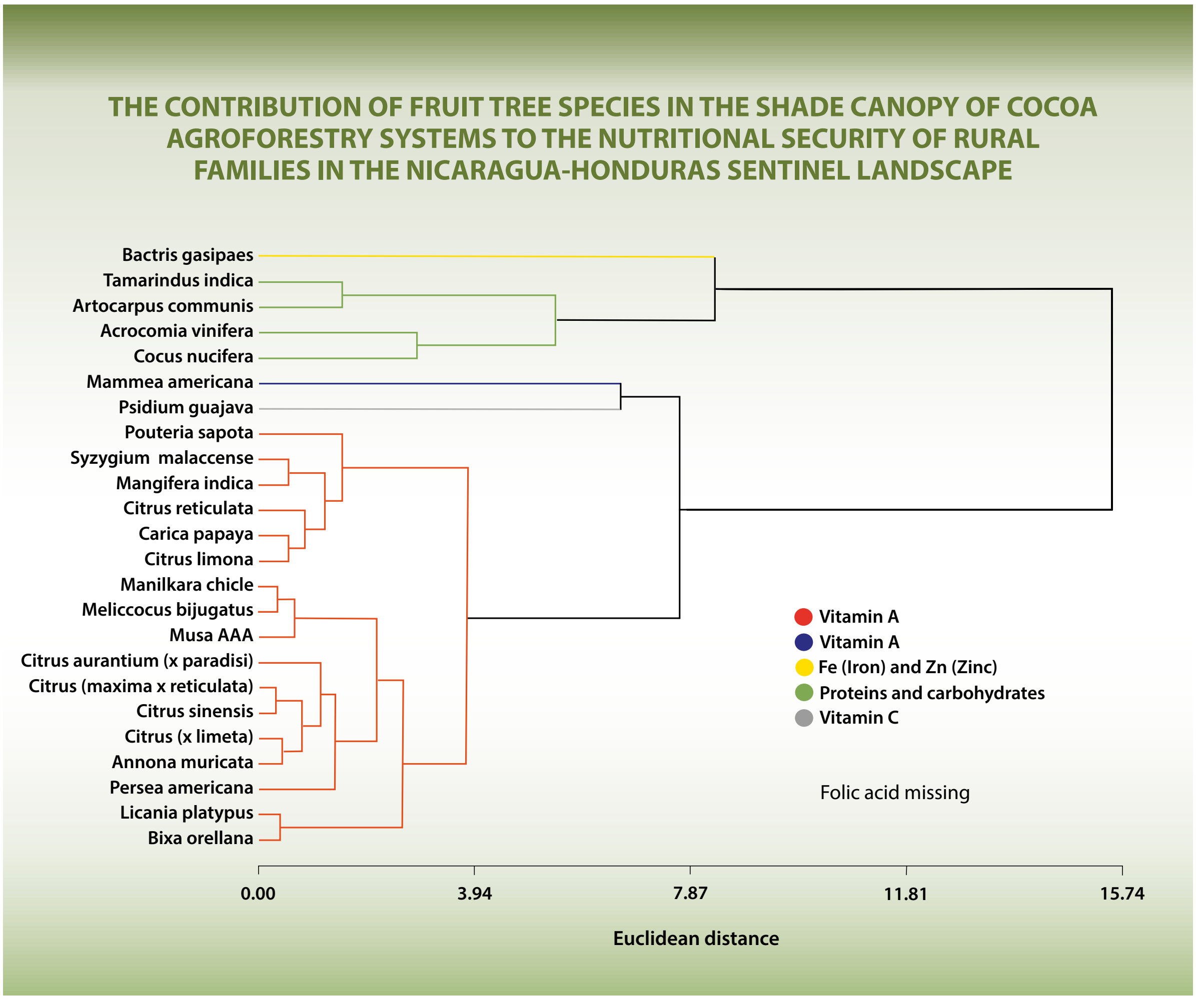


**Figure 3.** The contribution of fruit tree species in the shade canopy of cocoa agroforestry systems to the nutritional security of rural families in the Nicaragua-Honduras Sentinel Landscape (NHSL), Waslala, Nicaragua.

Adapted from Sáenz-Tijerino 2012

Shade canopy trees contribute 30% or more of the value of all the goods (cocoa, coffee, fruits, timber, firewood, posts, etc.) produced by a cocoa/coffee agroforestry plantation (Pinoargote et al. 2016; Cerda et al. 2014; Jezeer et al. 2017, 2018). The relative contribution of trees to farmers' livelihood depends on the design of the agroforestry system (Figure 4). Evidence supports the benefits of the intermediate-density hypothesis put forward by researchers in cocoa and whole farming systems in Africa (Ilstedt et al. 2016; Ruf 2011). According to those authors, optimal agroforestry production is achieved in agroforestry systems that are neither too simple nor too complex in terms of botanical composition, plant density, and vertical and horizontal spatial complexity.

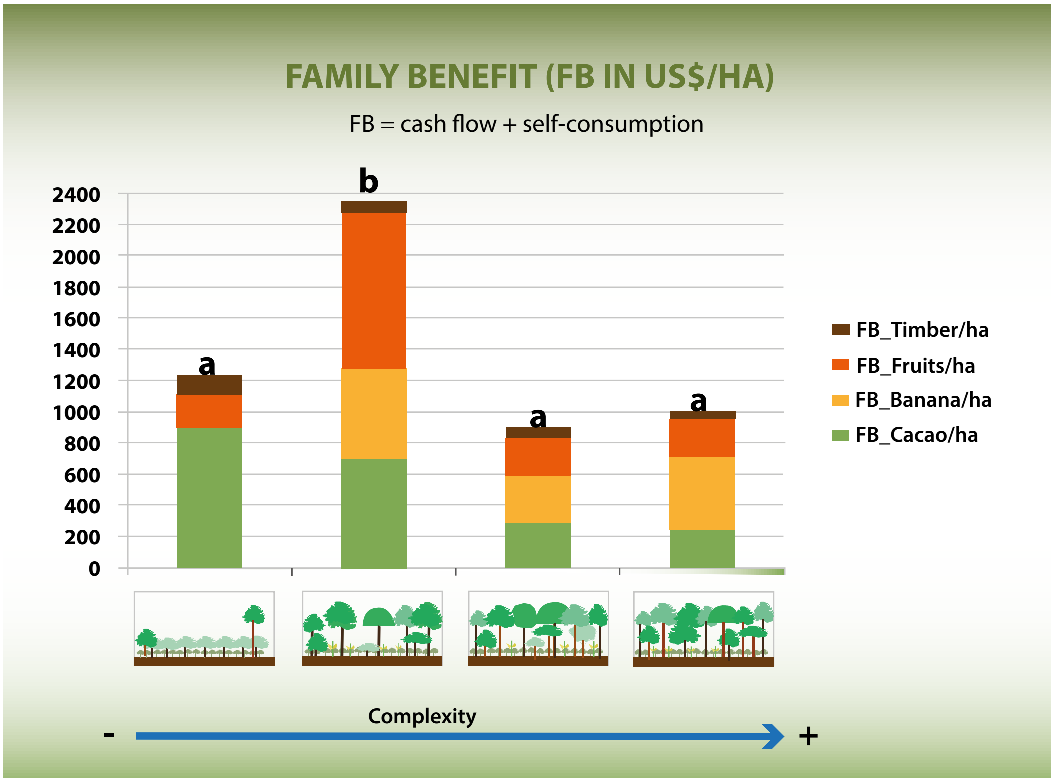


**Figure 4.** Family benefit (FB) from cocoa agroforestry systems with different shade canopy complexity in Central America

Note: Adapted from Cerda et al. 2014; columns with different letters are statistically different

Mixed cropping vegetables and food crops under scattered fruit trees in Jamaica

Photo by Eduardo Somarriba

TonF are a common feature in the Nicaragua-Honduras Sentinel Landscape (Figure 5). A complete inventory of trees (dbh>10 cm) on 781 ha of farmland in two sites (El Tuma-La Dalia and Waslala municipalities, Nicaragua) found 220 tree species and variable densities, depending on land use (Figure 6). Species richness also varied with land use, with a total 197 species in coffee plantations, 189 species in pastures, 169 species in cacao plantations, 152 species in homegardens, and 138 species in maize and bean crop fields (Amores Contreras 2015). Botanical composition also varied according to land use. For instance, most fruit tree species were found in homegardens, and naturally regenerated timber species were prominent in cocoa plantations (Somarriba et al. 2017).

*Cedrela odorata* – cocoa agroforestry in Turrialba, Costa Rica.

Photo by Eduardo Somarriba

**Figure 5.** Trees on farms in the Nicaragua-Honduras Sentinel Landscape (NHSL), El Guabo, Waslala municipality, Nicaragua

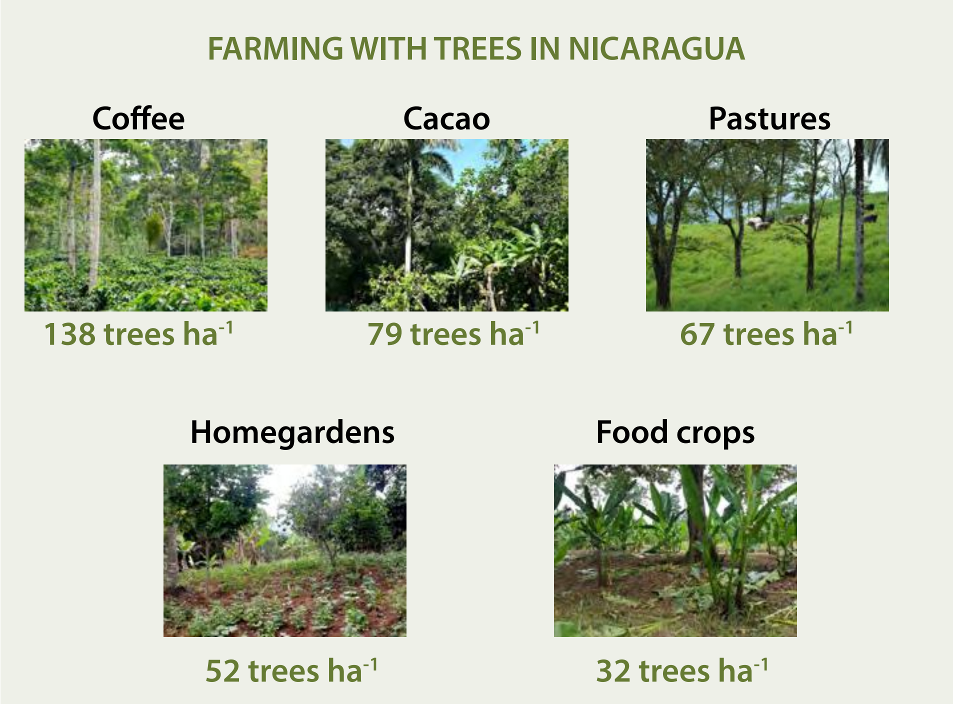


**Figure 6.** Average tree density by land use in farms in the El Tuma–La Dalia and Waslala municipalities, Nicaragua-Honduras Sentinel Landscape (NHSL), Nicaragua

Adapted from Amores Contreras 2015; Somarriba et al. 2017

Trees reduce the financial vulnerability of rural families. For instance, standing timber, worth USD 4,910–7,473 per ha, is an asset that can help families cope with unexpected needs or in times of hardship, providing a financial safety net (Amores Contreras 2015). Firewood, and a variety of fruits, for home consumption or sale, add to the diversified, low-risk strategy of smallholder farmers (Table 1).

**Table 1. Tree products and value (USD, mean ± standard deviation) from trees on farms in El Tuma – La Dalia and Waslala municipalities, Nicaragua – Honduras Sentinel Landscape (NHSL), Nicaragua**

| Tree product | Tuma-La Dalia | Waslala | Pooled | p-value |
|---|---|---|---|---|
| Standing timber ($m^3$ per ha) | 12 ± 7 a | 19 ± 8 a | 16 | 0.08 |
| Value timber (USD per ha) | 4,910 ± 1325 a | 7,473 ± 1,554 a | 6,192 | 0.08 |
| Firewood (mg per ha) | 11.1 ± 2.3 a | 11.7 ± 2.8 a | 11.4 | 0.8 |
| Oranges (units per ha per year) | 3,324 ± 475 b | 5,468 ± 601 a | 4,486 | 0.03 |
| Other fruits (1) (units per ha per year) | 5,997 ± 690 a | 3,824 ± 486 b | 4,910 | 0.03 |
| Other fruits (2) (per kg per ha per year) | 162 ± 45 b | 314 ± 70 a | 238 | 0.03 |

Adapted from Amores Contreras 2015

Note: Fruits (1) are fruit species (other than oranges) sold by unit. Fruits (2) are fruit species (other than oranges) sold by weight. Means with different letters in the same row are statistically different.

## 3.2 TonF for the environment

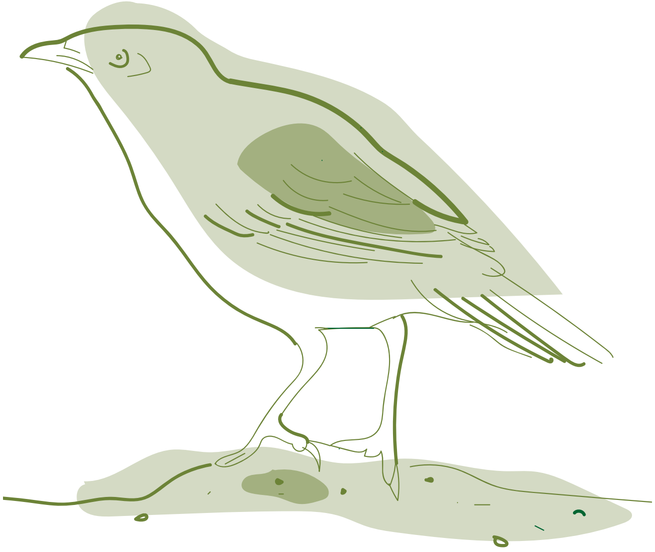
Trees on farms are also good for the environment, helping to conserve soil and water (Ilstedt et al. 2016), sequester atmospheric carbon (Griscom et al. 2017; Thapa et al. 2021; Zommer et al. 2014), and contribute to the conservation of threatened and ecologically valuable and wild biodiversity (Table 2).

**Table 2.** Bird species richness and abundance in a cattle-ranching landscape in the Nicaragua- Honduras Sentinel Landscape (NHSL), Catacamas, Honduras

| Land use | Number of plots | Species richness | Abundance | % abundance |
|---|---|---|---|---|
| Forest | 10 | 124 | 3,299 | 26.88 |
| Forest fragments | 24 | 115 | 1,468 | 11.96 |
| Rustic[2] coffee plantations | 4 | 153 | 2,616 | 21.32 |
| Crop fields | 20 | 130 | 4,190 | 34.14 |
| Pastures | 28 | 97 | 700 | 5.70 |
| Total | 86 | 209 | 12,273 | 100.00 |

Note: M= migratory, R=resident, T=transient

- 47 families
- 209 species / 759 [McKewy-Mejia M and Zelaya-Alberto CA (2005)]
- 28% of all bird species in Honduras
- 160 R (76.56%)
- 35 species M (16.75%)
- 12 species R + M (5.74%)
- 2 species T (0.96%)



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[2] This is coffee planted under heavily thinned natural forest.

TonF also help conserve agrobiodiversity by providing habitat and early colonization sites (Harvey and Haber 1998), connecting fragmented wild habitats, and providing steppingstones between protected areas in the agricultural landscape. Agroforestry systems (a formal conceptualization of the structure and function of TonF) are among the most popular nature-based solutions recommended for both the conservation of biodiversity (Dobie et al. 2019) and coping with climate change (Figure 7).

Mixed shade canopy over cacao in Haiti.

Photo by Eduardo Somarriba

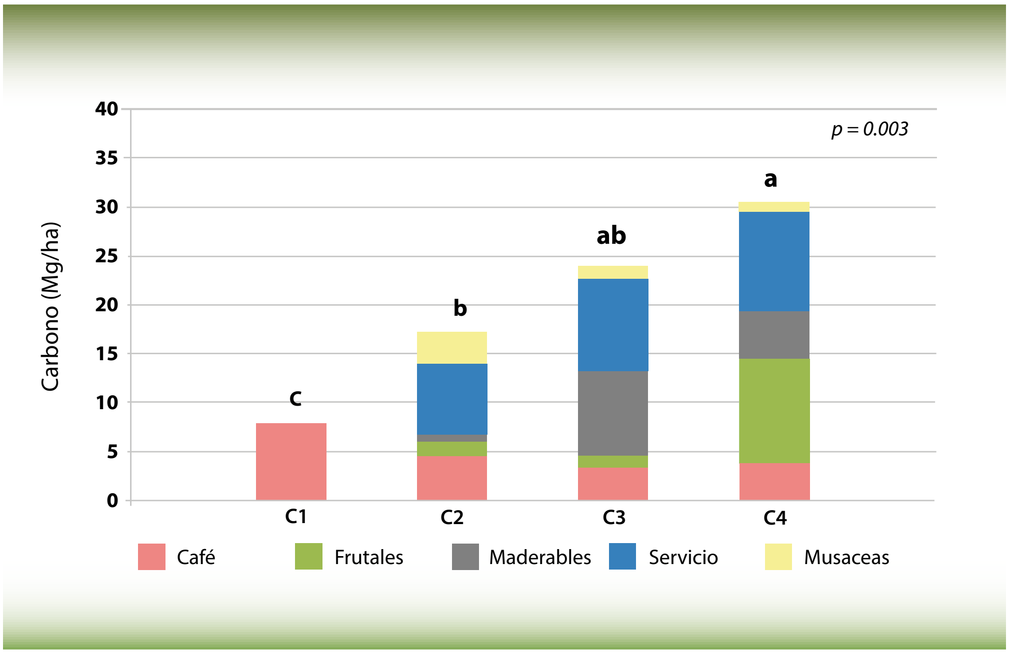

**Figure 7.** Carbon in aboveground biomass in open-sun (C1) and various types of coffee agroforestry systems (C2-C4), El Tuma – La Dalia and Rancho Grander municipalities, Nicaragua – Honduras Sentinel Landscape (NHSL), Matagalpa, Nicaragua

Adapted from Pinoargote et al. 2016; columns with the same letter are not statistically different

*Erythrina poeppigiana* and bananas as shade over *Coffea arabica* in Turrialba, Costa Rica.

Photo by xxxxx

## 3.3 TonF: the invisible resource

The abundance of TonF and the important roles that they play in rural livelihoods and environmental management are increasingly being recognized (Yadav 2019; Schnell et al. 2015a; Thapa et al. 2021; Thomas et al. 2021; Bolyn et al. 2019). However, TonF are still largely absent from global initiatives (such as REDD+, FAO/FRA, UN conventions on biological diversity and on water) and in national agendas.

At the global level, 40% of non-Annex I countries[3] recommend agroforestry for adaptation or mitigation; however, few national policies show the contribution of agroforestry to the Agriculture, Forestry and Other Land Use (AFOLU) sector (Rosenstock et al. 2019). Suber et al. (2020) point out that despite the opportunity offered by tree-based farming practices (i.e. silvopastoral systems) to mitigate greenhouse gas emissions — and hence contribute to the targets of Nationally Determined Contributions (NDCs) and Nationally Appropriate Mitigation Actions (NAMAs) of all Latin American countries — there is still limited data/information about these practices in the field and therefore, they are not included in national monitoring, reporting and verification (MRV) systems. The extent of TonF is unknown in most

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[3] Non-Annex 1 countries under the Kyoto Protocol are developing countries that do not have legally binding emission reductions targets.

instances because trees on farms are generally not included in inventories of tree and forest resources (Perry et al. 2008; Sloan and Sayer 2015), although this is changing.

TonF are also missing from national agendas. For instance, TonF are poorly represented or superficially treated in the legal, institutional, policy and development frameworks of most countries. In addition, TonF are missing from the curricula of national universities, technical institutes, and farmer field schools. TonF information is rarely included in the training curricula of rural extension agents, and consequently is missing from their technical advice to farmers (Somarriba et al. 2017). TonF are also absent from most National Biodiversity Strategies and Action Plans (NBSAPs).

This invisibility of TonF, and their absence from legal, institutional, policy, development, educational and business frameworks, may be the main reason for the poor development of the value chains of farm tree products (notably, farm timber and fruits), and the suboptimal design and management of TonF on most farms. The unrealized potential of TonF production also reduces the impact of many sustainable rural development initiatives.

Section 4 illustrates how the joint efforts of FTA partners and other associated partners within the TonF project,[4] especially the CATIE-led component in Nicaragua and Honduras, contributed to realizing the potential of trees on farms along two major impact pathways.

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[4] The TonF project is funded by the German International Climate Initiative (IKI) and implemented by World Agroforestry (ICRAF), the Center for International Forestry Research (CIFOR), CATIE, the International Union for Conservation of Nature (IUCN), and the Leibniz University of Hannover.

# 4. Realizing the potential of TonF in Honduras and Nicaragua

## 4.1 Impact pathway 1: Linear tree features in Honduran cattle ranches

Cattle ranching is of paramount economic importance in Honduras. Recent estimates (Canu et al. 2018) include 1.5 million head of cattle, 2.9 million hectares (ha) of pastures (26% of the total land in Honduras, and 50% of all agricultural land), 53,000 farms, 250,000 people directly involved, 150,000 jobs (33% of all employment in the agriculture sector), and 13% of the country's agricultural GDP. On average, Honduran cattle ranches are 29 ha in size (although 46% of all farms are <5 ha in size), with 72% of the land dedicated to pasture, 15% to crop fields, and 13% to forests (ibid.). Cattle ranching contributes 9.46% of the country's total greenhouse gas (GHG) emissions and is the most important driver of deforestation, contributing to emissions related to land use, land-use change, and forestry (LULUCF). In 2015 the LULUCF sector accounted for 30% of Honduras's total GHG emissions (Canu et al. 2018).

The use of trees as fences to demarcate property and resource-rich areas began during the Neolithic Period (Hayward and Kerley 2009). Today, these "live fences" are conspicuous features on farms around the world (Harvey et

Cattle grazing under scattered trees in Matiguás, Nicaragua.

Photo by Eduardo Somarriba

al. 2005). Cattle ranches in Honduras are no exception (Otárola et al. 1985). Live fences divide pastures and regulate the movement of animals; rotational grazing is one of the most important management practices to intensify cattle ranching. Live fences produce posts (to rehabilitate existing fences or create new ones), fodder, firewood, timber, fruits, habitat for wildlife and structural connectivity in the landscape (Harvey et al. 2005; Chacón and Harvey 2007). Live fences play an important role in landscape restoration, especially in restoring connectivity among forest fragments in agricultural landscapes (Francesconi et al. 2011). For more information about research work on forest and landscape restoration conducted within FTA, see FTA Highlight No.4 in this series (Guariguata et al. 2021).

Cattle ranchers in Catacamas, Honduras, can improve the productivity of their farm by effectively designing and managing their live fences (Figure 8).

An inventory of linear tree features in 25,000 ha in the Catacamas landscape (Figure 9) identified 10,239 fence segments spanning 1,730 km (linear density = 69.21 m/ha) and covering 6.36% of the land (Table 3). Live fences in cattle ranching landscapes in Costa Rica, Nicaragua and Guatemala have similar characteristics (Chacón and Harvey 2007; Harvey et al. 2005; Solis et al. 2019).

*Vochysia guatemalensis* in line planting for timber production, Turrialba, Costa Rica

Photo by Eduardo Somarriba

**Figure 8.** A typical scenario in the Catacamas landscape, Honduras. Live fences are common features in valleys and hills in both pasture lands and crop fields.

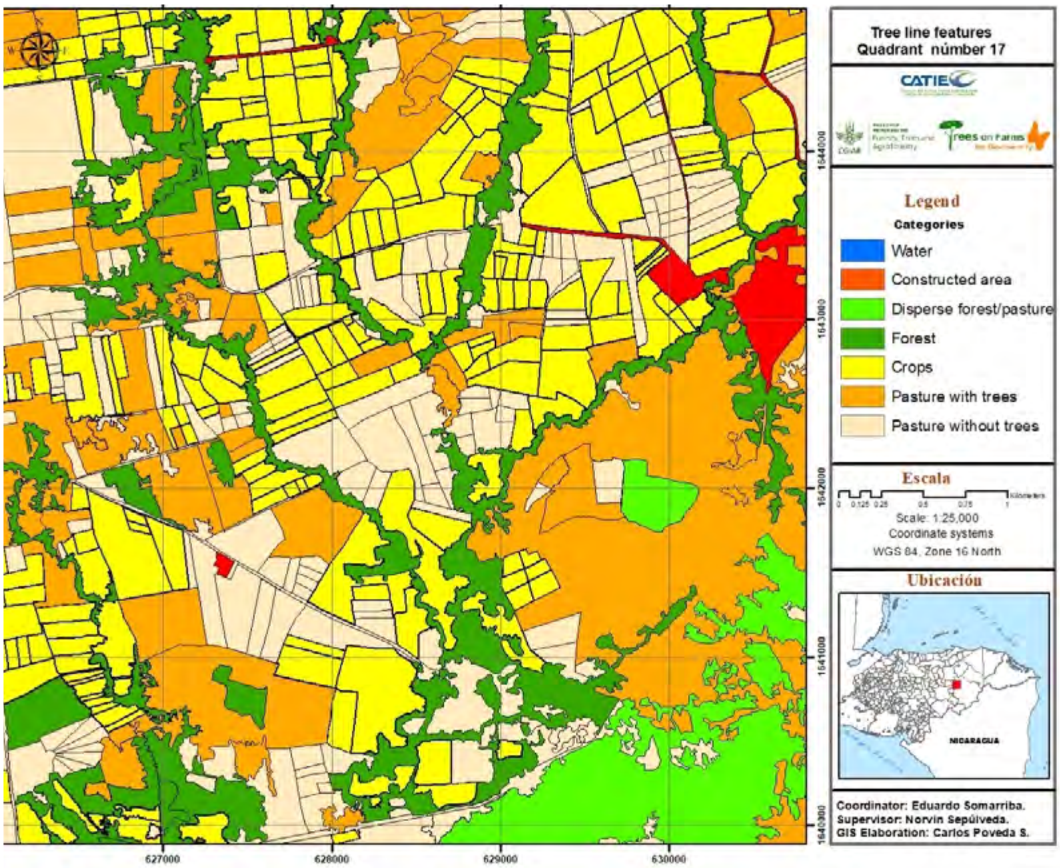

**Figure 9.** Tree line features in one (5 km x 5 km) sample quadrat in the Catacamas landscape, Olancho, Honduras.

The production potential of live fences is enormous. It has been shown that the timber yield from 1 km of live fence is equivalent to the yield of 1 ha (or more) of a pure, block, timber plantation (Somarriba et al. 1999). The potential for timber production from live fences in the 2.9 million ha of pastures in Honduras, with a linear density of 69.21 m/ha, is equivalent to 200,709 ha of pure, block, timber plantations. Fencing allows farmers to regulate grazing and thus to control pasture growth and animal yield. Fencing is expensive, but live fences are cheaper to establish than dead-post fences. Including live fences in national inventories and official data repositories can help governments develop policies and official reports and reinforce the private sector by supporting farmers and other value chain actors.

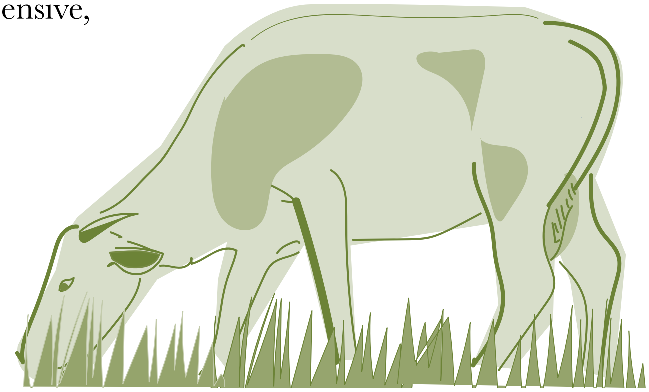

**Table 3.** Linear tree features in the agricultural landscape in the Nicaragua-Honduras Sentinel Landscape, Catacamas, Honduras

| Element | Length (m) | Cover (ha) | Linear density (m/ha) | Canopy cover (%) |
|---|---|---|---|---|
| Urban | 49,057 | 2 | 1.96 | 0 |
| Roads | 26,368 | 3 | 1.05 | 0 |
| Dead post fence | 571,301 | 0 | 22.85 | 0 |
| Live fence | 902,837 | 1,014 | 36.11 | 4.06 |
| Water course | 154,870 | 521 | 6.19 | 2.08 |
| Forest strip | 3,886 | 15 | 0.16 | 0 |
| Tree line | 21,976 | 35 | 0.88 | 0 |
| Total | 1,730,295 | 1,590 | 69.21 | 6.36 |

Source: Unpublished data, ongoing joint research by FTA and TonF project

Realizing the full potential of live fences requires innovations by farmers, government, the private sector and academia. Fortunately, well-designed innovations in live fences are likely to be adopted by cattle ranchers. Although cattle ranchers have a low tolerance for trees inside pastures, removing trees when canopy cover reaches 20%, they actively plant trees in live fences.

This joint FTA-TonF-CATIE effort provided science-based evidence of the extent, current value and potential of live fences to both government and the private sector in Honduras and facilitated the inclusion of live fences in a four-pronged approach:

1. increased inclusion of live fences and other linear tree features (such as gallery forests)[5] in SIGMOF, the national information system on forests and tree resources;
2. inclusion of live fences in national reports of the Ministry of Environment and Natural Resources (the Biodiversity Directorate, or Dirección Nacional de Biodiversidad/DIBio) to UN conventions (biological diversity and climate change, and the Decade on Landscape Restoration), and national government reports;
3. introduction of farm-level innovations on live fences in the list of best practices supported by the livestock NAMA programme, to be implemented starting in 2022;
4. engagement with other projects and government initiatives to scale up innovations on live fences developed in the Catacamas landscape to other cattle ranching regions and sectors in Honduras.

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[5] A gallery forest is a forest that grows along a watercourse.

A theory of change for these developments is shown in Figure 10. For more information about theory of change conducted within FTA, see Highlight No. 17 in this series (Belcher et al. 2021). A group of FTA, TonF project and CATIE scientists, in close consultation with their academic counterparts (CATIE´s graduate school, national universities, and research groups, notably Universidad Nacional de Agricultura and Universidad Zamorano) and with political support from leaders in the government and private sector, developed the methodologies and tools to scientifically assess the extent of forests, trees on farms, and bird biodiversity (as an indicator) in the Catacamas landscape. Live fences were assessed using remote sensing and drone-based methods and software specifically designed for this initiative, complemented by farm-level field inventories. Science-based biophysical knowledge — coupled with expert knowledge and a behavioural economic tool, COMMOD, an agent-based modeling environment (Étienne 2014) — was used to design innovations using participatory methods in live fences, to be included in the livestock NAMA initiative.

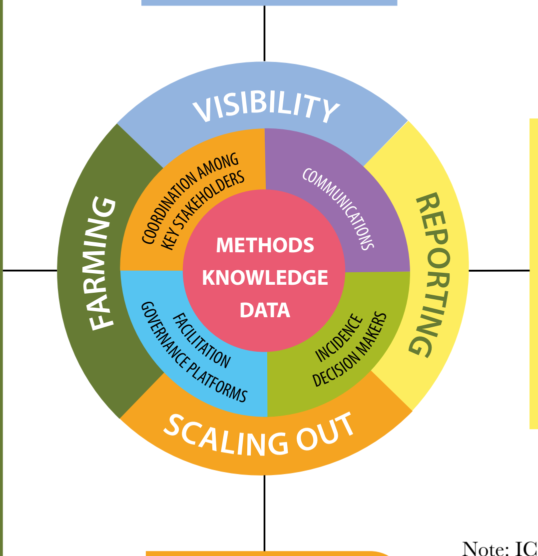


**Figure 10.** Elements of impact pathways to enable farmers, government, and the private sector in Honduras to fully realize the potential of treed live fences on cattle ranches.

## VISIBILITY

TonF visibility in Hondura's official national information system on forest and other natural resources:
- ICF-SIGMOF

## FARMING

NAMA-Livestock initiative includes:

**Extension Services:**
1. Zamorano University
2. UNAG - National University of Agriculture and Livestock
3. HEIFER International
4. Honduran Dairy Chamber (CAHLE)
5. Honduran Meat Chamber (CAFOGAH)
6. Livestock Federation of Southern Honduras (FEGASURGH)
7. Ministry of Agriculture, Directorate for Science and Technology in Agriculture (SAG-DICTA)
8. CATIE

**Financing:**
1. Public Bank (BANPROVI)
2. Private Bank (BANRURAL)
3. Foundation for Development (FUNDER)
4. CONFIANZA (financial mechanism for colateral, leverage funding )

**Policy and incentives:**
1. National Platform for a Sustainable Livestock Sector (PNGS, multi-sectoral, involves 16 institutions)
2. SAG (Ministry of Agriculture and Livestock)
3. MiAmbiente
4. FAO
5. FENAGH

**MRV:**
1. Ministry of Forestry (ICF-SIGMOF)
2. MiAmbiente (DNCC and DIBIO)
3. SAG
4. ZAMORANO University
4. CATIE

**Implementation in farms:**
- Agreement CATIE-DEITSUR project
- Agreement CATIE-ABC (American Bird Conservancy)
- Agreement ICF-FENAGH

## REPORTING

- Ministry of Environment, National Directorate for Biodiversity (DIBIO) report to CBD
- Presidency of the Republic of Honduras, Climate Change National Directorat (DNCC): report UN convention on climate change
- Both DIBIO and DNCC are members of Inter-Ministerial Committee of Honduras which also include the National Roundtable for Monitoring of Biological Diversity of Honduras. Decisions on the official position of Honduras on the various UN conventions are decided at this National Rountable.

## SCALING OUT

**1. Producers, organizations and sectoral institutions:**
- IHCAFE (coffee)
- PROCACAOH (cacao)
- PROSACAO (cacao)
- FENAGH (livestock)
- FEGASURH

**2. National Platform** for sustainable livestock sector (PNGS): design and promote policy for sustainable livestock sector

**3. Executive Secretary** Central American Agriculture-Livestock Council (SE-CAC): scaling out to other Central American countries

Note: ICF = Instituto Nacional de Conservación y Desarrollo Forestal/National Institute for Conservation and Forest Development, Protected Areas, and Wildlife; DIBio = Dirección Nacional de Biodiversidad (National Biodiversity Directorate), Ministry of Environment; IHCAFE = Honduras' national coffee institute; MNGS = Mesa Nacional de Ganadería Sostenible (Roundtable on Sustainable Livestock Production); NGOs = non-governmental organizations; SIGMOF = Sistema de Información para la Gestión y Monitoreo Forestal/National information system on forests and tree resources

*Pinus pinea* line planting in cattle ranches, Tuscany, Italy

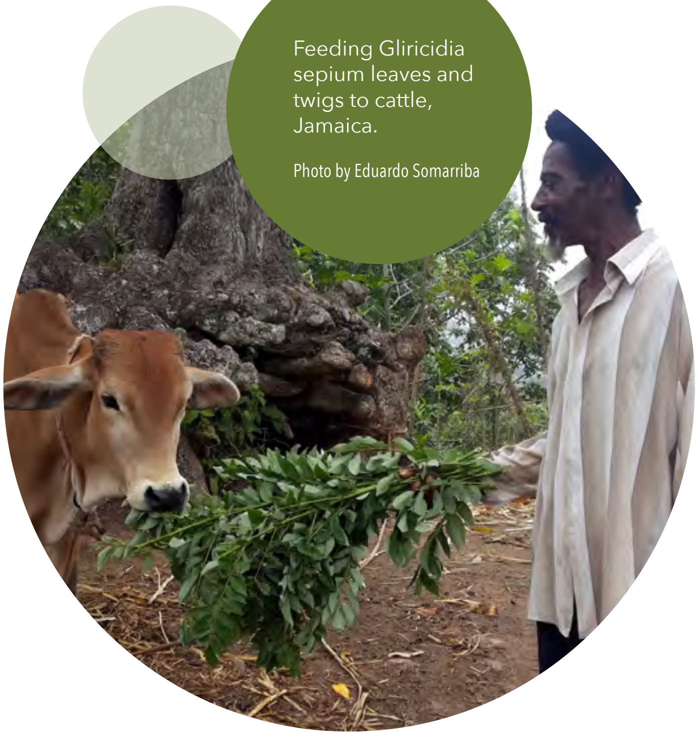
Photo by Eduardo Somarriba

Science-based results and information on tree stocks, biodiversity value, carbon storage and climate change mitigation, as well as agronomic and financial performance, were extensively communicated in a series of webinars, in targeted presentations to key groups of stakeholders (top government officials, technical staff, sectoral authorities and governance platforms, and academics) and at national conferences. A sustained effort to publish this research in policy briefs, technical documents and international journals was central to the communication strategy. Technical dialogue was accompanied by political dialogue with decision makers (ministries, vice-ministries, national directors; e.g. the Ministry of Environment and the national committee on biodiversity monitoring) to increase awareness of the importance of TonF and to create a more favourable mindset for the consideration of live fences in these groups' regular activities and reports.

The project specifically targeted the inclusion of TonF data from the pilot (Catacamas agricultural landscape, representing 2.9 million ha of pasturelands in Honduras) in the national information system on forests, biodiversity, and climate change (SIGMOF), and helped the National Institute for Conservation and Forest Development, Protected Areas, and Wildlife (ICF) staff to develop the software and code, modify the webpage, and include the inventory, storage, retrieval and reporting of TonF in SIGMOF. Training key ICF staff and purchasing software licences were also supported. In parallel, the project team increased the dialogue with key staff of DIBio to include substantial, verifiable indicators of the contribution of TonF to biodiversity conservation in the pilot landscape in the directorate's national report to the UN Convention on Biological Diversity (CBD). Following success with DIBio, similar processes are now underway to include TonF-Catacamas in reporting to both the UN Framework Convention on Climate Change and the national forest landscape restoration programme.

However, including TonF in both SIGMOF and national reports to UN conventions is not sufficient to firmly place it on national agendas. The long-term involvement of the private sector is mandatory, especially cattle ranchers, the financial system, and the agro-industry. To this end, the project targeted the country's national platform for sustainable, low-carbon livestock production: Mesa Nacional de Ganadería Sostenible (MNGS). MNGS is the most important national-level negotiation and decision-making platform for the livestock sector and is embraced by the most important farmers' organizations: the national federation of farmers and cattle ranchers of Honduras (FENAGH) and the most important organization for the dairy sector (CAHLE); and by key financial institutions (FICOSA); the Ministry of Agriculture (SAG); the Ministry of Environment (MiAmbiente); the National Institute for Conservation and Forest Development, Protected Areas, and Wildlife (ICF); and academia.

MNGS, with the support of a technical team (led by CATIE and including Carbon Neutral, an international NGO) is leading the formulation of the NAMA livestock initiative, which is partially funded by Germany's NAMA facility. Central to the implementation of NAMA at the farm level is a list of best practices to be supported, both technically and financially, by the NAMA initiative



Feeding Gliricidia sepium leaves and twigs to cattle, Jamaica.

Photo by Eduardo Somarriba

Cattle grazing under *Pinus elliottii* in Misiones, Argentina.

Photo by Eduardo Somarriba

and the national banking system. The project team succeeded in including innovations on live fences in the list of best practices supported by the NAMA initiative and developed (with some components still under development) the knowledge base on promising live fence designs and management that would increase financial returns from livestock and tree products while conserving wild biodiversity, storing significant amounts of carbon in woody biomass, and reducing emissions and the carbon footprint of livestock farming in Honduras. On-farm innovations will be implemented on 1,200 farms in the next five years, and an additional 10,000 farmers are expected to adopt similar innovations, with support from the NAMA initiative and funding from national financial institutions.

The momentum generated by ICF and SIGMOF, the Ministry of Environment, and the livestock NAMA has motivated government officials and actors in other sectors (e.g. the national coffee institute, several other projects funded by international donors, and important NGOs in Honduras) to consider replicating the work conducted in the Catacamas landscape in other territories and agriculture subsectors. Replication of the work in the coffee-growing region and in the dry corridor in southern Honduras is currently under preparation.

## 4.2 Impact pathway 2: Optimal design in cocoa and coffee agroforestry systems

The use of shade trees in cocoa cultivation varies widely among producer countries (Table 4). Cocoa agroforestry systems are classified in at least six broad typologies (Somarriba and Lachenaud 2013) that reflect the management objectives of the farmer:

- open-sun cocoa (farmer interested only in producing cocoa);
- shade-only trees (mostly leguminous trees such as Erythrina spp., Gliricidia spp. or Albizia spp.);
- simple productive shade (e.g. cocoa-timber, cocoa-banana, cocoa-coconut, or cocoa-rubber);
- mixed, multistrata shade canopies;
- very complex systems such as the cabruca system (cocoa under thinned natural forest) in Brazil;
- successional agroforests

**Table 4.** Use of shade in cocoa cultivation

| Country | Cocoa | | |
|---|---|---|---|
| | Area (ha) | Shade (%) | Sun (%) |
| Brazil | 720,053 | 93 | 7 |
| Cote d'Ivoire | 2,851,084 | 26 | 74 |
| Indonesia | 1,701,351 | * | 90+ |
| Ghana | 1,683,765 | 25 | 75 |
| Ecuador | 537,410 | 20 | 80 |
| Colombia | 173,016 | 75 | 25 |
| Dominican Republic | 152,261 | 100 | * |
| Peru | 125,580 | 90+ | * |
| Venezuela | 64,462 | 90+ | * |
| Mexico | 58,734 | 90+ | * |
| Haiti | 26,975 | 100 | 0 |
| Nicaragua | 9,310 | 90+ | * |
| Guatemala | 4,333 | 90+ | * |
| Costa Rica | 4,000 | 100 | — |
| Honduras | 1,889 | 90+ | * |
| El Salvador | 941 | 85 | 15 |

Adapted from Somarriba and López-Sampson 2018; Note: * = some uncertainty re data

Pollarded *Erythrina poeppigiana* trees used as shade over *Coffea arabica*, Turrialba, Costa Rica.

Photo by Eduardo Somarriba

Most cocoa agroforestry systems on smallholder farms are suboptimal in design and management. Poor silvicultural management, improper spacing and planting patterns, low yields of tree products, poor links of tree products to markets, and other socioeconomic constraints (e.g. poor legal and policy frameworks, lack of availability of funding, cultural values, etc.) are commonplace in coffee and cocoa farming. The reasons for this are poorly understood. A large fraction of on-farm fruit production is lost to rot, and most farm timber is traded illegally, reducing financial returns to farmers. For farmers to take full advantage of their coffee and cocoa agroforestry systems they need to improve and redesign the management of their shade canopies. However, most farmers lack the necessary knowledge of agroforestry design and management.

In a study in Bolivia (Ortíz-González 2006), farmers were asked 18 questions on factors that bear on the decision-making process regarding shade canopy design. Each question had one "right" answer. The study showed that more than 80% of farmers gave right answers to only 2 of the 18 questions; 28% gave the right answers to five questions; and less than 50% of farmers gave the right answers to 11 of the 18 questions (ibid.). This means that farmers (and extension agents alike) fail in shade canopy design (Figure 11). Similar results were found for cocoa farmers in Waslala, Nicaragua (Silva et al. 2013), and coffee farmers in Costa Rica (Linkimer 2001) and Mexico (Yepez-Pacheco 2001).

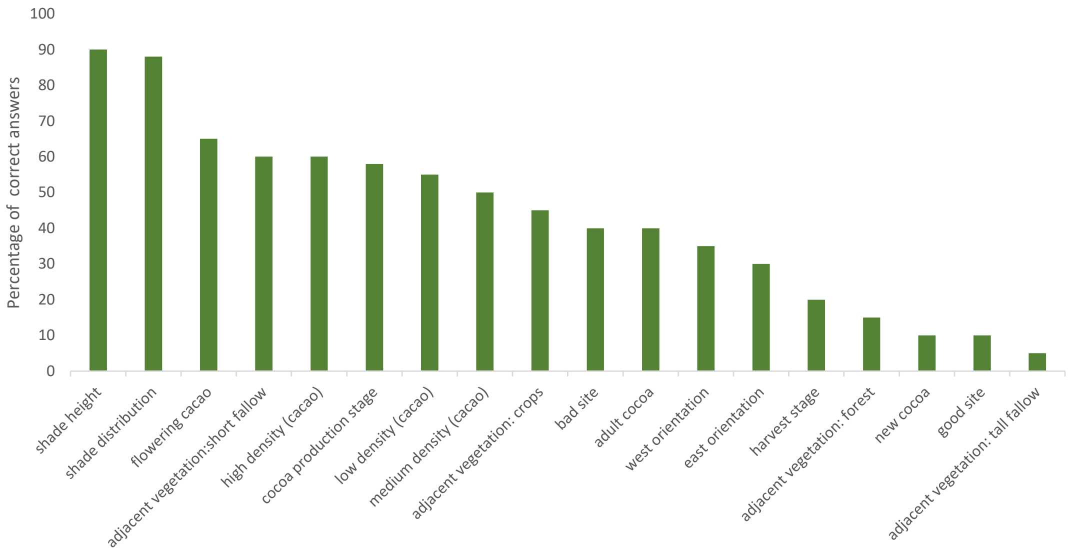


**Figure 11.** Percentage of cocoa farmers in Alto Beni, Bolivia, who gave the right answer to critical questions influencing decisions on the selection of the best shade level in a cocoa farm.

Adapted from Ortíz-González (2006)

The central goal was optimizing the design of the coffee or cocoa shade canopy to meet farmers’ production priorities. Success in achieving this goal can increase the prominence of coffee and cocoa agroforestry systems in farmers’ livelihood strategies and in global initiatives addressing climate change, biodiversity loss and degradation of natural resources (e.g. water and soil). The use of shade in coffee and cocoa cultivation is at risk due to both the current wave of crop intensification to achieve higher yields and the replacement of coffee and cocoa by other less ecologically friendly but more profitable crops (Harvey et al. 2021; Orozco-Aguilar et al. 2021; Somarriba and López-Sampson 2018).

Optimal design of a cocoa agroforestry system must incorporate biophysical as well as socioeconomic considerations. From a biophysical point of view, optimum agroforestry design requires the analysis of interactions and trade-offs between the various objectives

of the farmer's coffee/cocoa agroforestry system. Designing optimal shade canopies in coffee/cocoa agroforestry is a complex process (Somarriba et al. 2018). Research is underway on the mathematical optimization of an idealized coffee/cocoa agroforestry system (Figure 12). To achieve optimal design farmers must select the right species, tree population densities, planting arrangements, and management (e.g. crown pruning, thinning, filling gaps due to missing plants, etc.) to "fill up" the area containing the shade canopy. The shade canopy is a three-dimensional volume, not a two-dimensional shape on the ground (Somarriba et al. 2018). A more comprehensive approach to shade canopy design should include socioeconomic factors (e.g. labour requirements and availability). More research is needed to understand how socioeconomic variables interact with biophysical factors to determine the optimal design and management of a cocoa agroforestry system.

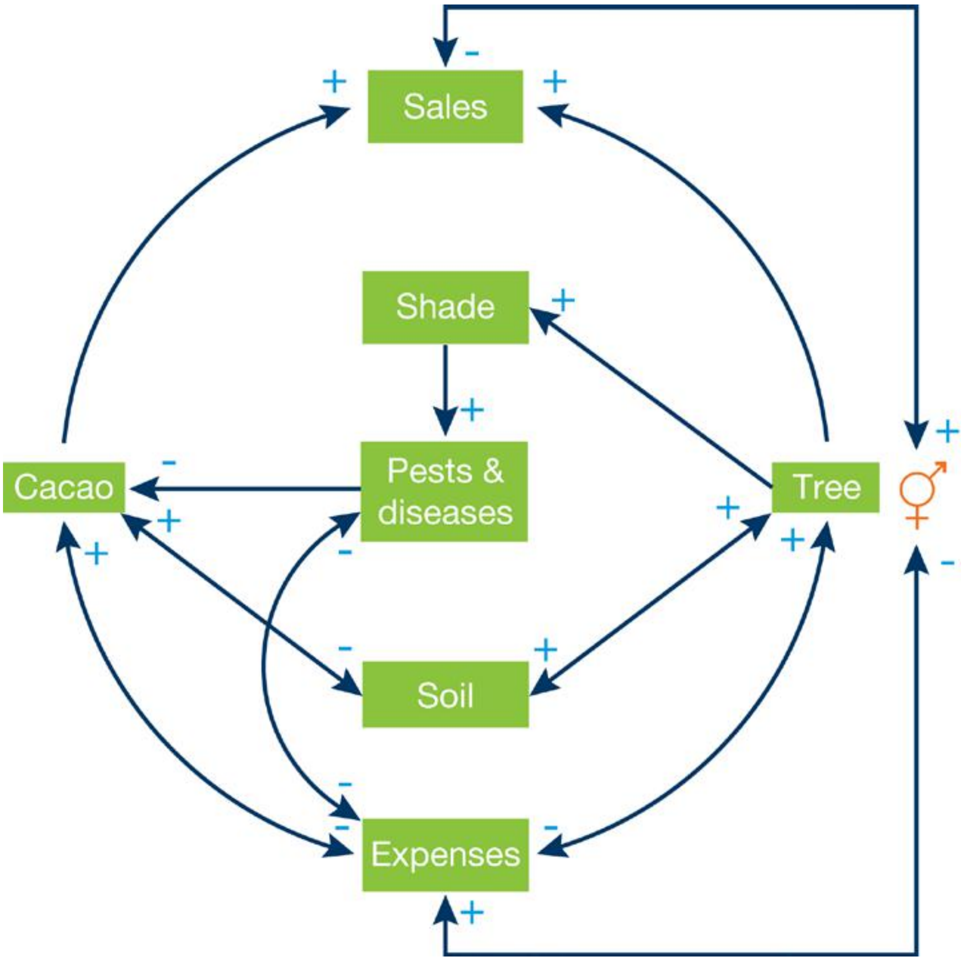


**Figure 12.** A schematic depiction of the components and interactions between components in an idealized cocoa agroforestry system model.

Trees are bigger and taller than coffee and cocoa plants, and tree crowns, in their privileged position, are the first to capture solar radiation, depriving the leaves of the crop in the understorey of light. Shading is a central interaction between trees and crops in coffee/cocoa agroforestry systems. There is no single recipe for the ideal shade canopy. A four-step methodology has been developed to systematically decide on the best course of action to achieve optimal shade (Somarriba et al. 2018). In this methodology, farmers (and extension agents) systematically evaluate almost 30 key variables (Table 5).

**Table 5.** Elements of the four-step methodology for the analysis of the best shade for a coffee/cocoa plantation

| Step | Action | Variables |
|---|---|---|
| 1 | Determine farmer's objectives | Products |
| | | Services |
| 2 | Evaluate status of plantation | Self-shading: age, spacing, variety, pruning |
| | | Crop phenology status: flushing, flowering, fruit filling, fruit ripening |
| 3 | Evaluate site conditions | Soil fertility level |
| | | Soil water availability |
| | | Latitude |
| | | Slope and exposure |
| | | Lateral shading: nearby vegetation and hills |
| | | Wind |
| | | Cloudiness |
| 4 | Evaluate shade trees | Crown characteristics: height, diameter, porosity, monthly leaf fall pattern |
| | | Canopy cover spatial homogeneity |
| | | Use and value |
| | | Botanical composition |
| | | Stand density: basal area, population density, stem diameter frequency distribution |

To evaluate the shade patterns of any shade canopy design, Somarriba et al. 2020 developed ShadeMotion,[6] a free software application that calculates the number of hours of shade that accumulate in each point (cell) of a plot due to the presence of any number of trees, with crowns of different shapes and sizes, anywhere on Earth. The software produces visual representations of the shade projected by the trees when they block the sun's rays, based on geometrical considerations and taking advantage of the accuracy of the formulas that determine the position of the sun at any time of the year and

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[6] www.shademotion.net.

in any place on Earth (Figure 13). This software allows users to simulate the entire life cycle of an agroforestry plantation (including changes in the populations and dimensions of the trees due to natural growth or pruning). It has a good 3-D visualization module, and offers new results and summaries of shade data (Somarriba et al. 2020).

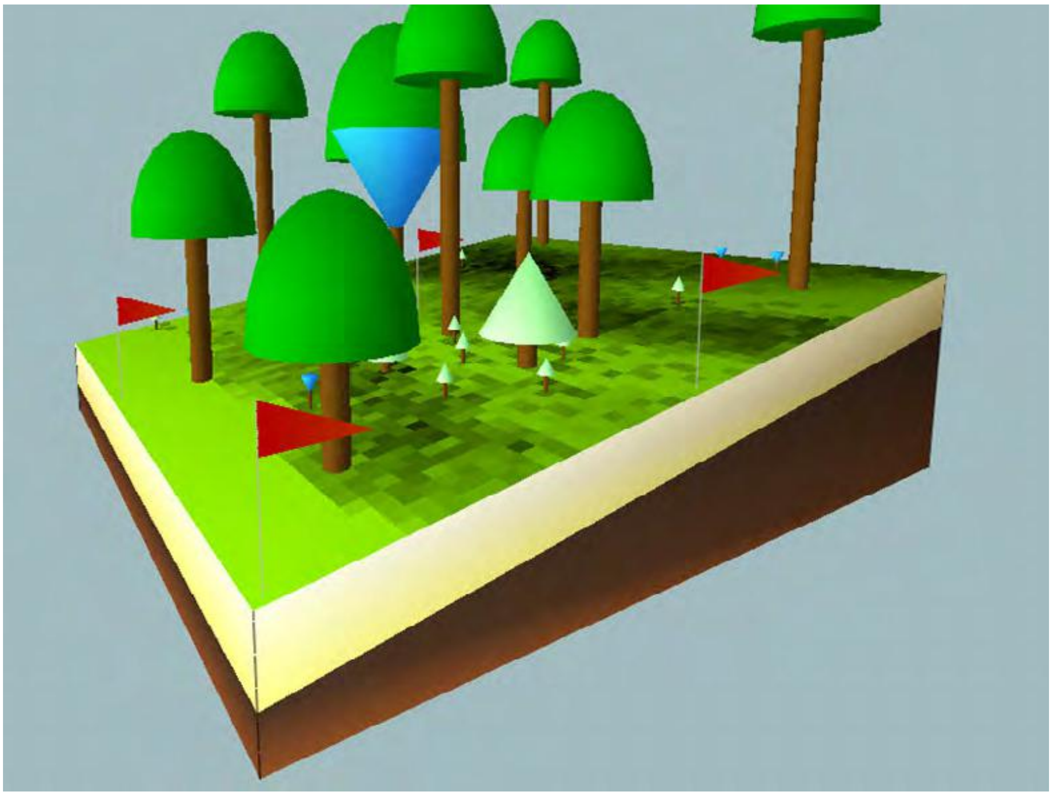

**Figure 13.** ShadeMotion software

Recognizing and counting trees in agricultural landscapes using remote sensing techniques and automated post-processing is becoming a common feature of tree measurement and tree inventory (Åkerblom et al. 2017). To aid in the analysis and redesign of coffee/cocoa shade canopies the project team developed TonFanalizer,[7] a tool that analyzes and extracts information on tree/vegetation cover derived from satellite images or images acquired using a remotely piloted aircraft system (RPAS). The tool is a software-based application that analyzes and extracts information on orthomosaic[8] tree/vegetation cover and digital elevation models in a simple and agile way (Arriola-Valverde et al. 2021a, 2021b; Rimolo-Donadío et al. 2021). It can handle raster and vector layers of different land uses with resolutions up to 1-cm pixels, with the aim of facilitating the analysis of high-resolution RPAS

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[7] https://gitlab.com/tonfanalyzer/tonf_analyzer.

[8] An orthomosaic is a large, extremely detailed image with high detail level obtained by combining many smaller images, called "ortophotos."

imagery. It is capable of computing RGB indices, recognizing crown shape, inspecting elevation models, extracting distances, areas, and estimating tree locations. The results can be exported as text-based, raster or vector files, which allows the calculation of RGB indices and extraction of tree heights and tree crown dimensions, as well as automatic tree detection using machine-learning techniques. The exported information is easy to interpret and use with other software tools (Figure 14).

**Figure 14.** TonFanalyzer, a drone-based tool to assess tree stands in cocoa agroforestry systems

High-resolution images from drones are used to generate the input data required to run a ShadeMotion simulation. The combination of TonFanalyzer with ShadeMotion is currently being used in farmer field schools in Honduras to redesign and optimize existing suboptimal cocoa shade canopies in a visual, realistic and participatory manner with cocoa farmers.

# 5. Conclusions and recommendations

FTA's and the German International Climate Initiative's TonF research-in-development project in the Nicaragua-Honduras Sentinel Landscape provided science-based evidence on the extent of trees in live fences and other tree linear features on cattle ranches and on their value to both livelihoods and the environment in Catacamas, Honduras. Engagement with key political and technical partners in government institutions (Ministry of Environment, and Ministry of Forestry/ICF), and with leaders in the livestock private sector, allowed the project to increase the inclusion of trees on farms (TonF) in the national information system on forests and tree resources in Honduras (SIGMOF) and convinced the Ministry of Environment and Natural Resources to include TonF in its national report to the UN Convention on Biological Diversity (CBD), emphasizing the role of TonF in the country's strategy for biodiversity conservation. Project team members supported negotiations with the private sector and succeeded in including innovations in live fences in the portfolio of technologies to be supported (both technically and financially) by the livestock NAMA initiative. Other Honduran stakeholders have shown their willingness to replicate the work conducted in Catacamas in other regions and production sectors (e.g. coffee and staple crops such as maize and beans). Scaling up the work in Catamacas will foster the intent of DIBio to use TonF as a sound strategy for the conservation of biodiversity in agricultural landscapes. The role of TonF in addressing climate change and forest landscape restoration programs is also being considered by the Honduran government.

Timber trees in crop fields, Heredia, Costa Rica.

Photo by Eduardo Somarriba

Most agroforestry systems on farm are suboptimal in design and yield, limiting their potential to improve livelihoods and provide ecosystem services. The work on this project provided new concepts, models and tools to optimize the design and management of cocoa and coffee agroforestry systems. These concepts, models and tools are applicable to other agroforestry systems as well. More effort is needed to test these tools in a range of biophysical and cultural contexts. Special attention should be given to including the new knowledge and tools in the university curricula (faculties of agronomy, animal production, forestry, agricultural economics, etc.), in the messages delivered by extension agents, and in farmer field schools.

To increase the visibility of TonF and to optimize the design and management of existing agroforestry systems on farms, several actions should be taken:

**Farmers:**

- Extension agents should aim to create a culture among farmers to consider TonF as crops

**Policymakers**

- Design and enforce supportive legislation (e.g. on tenure rights), policies and financial mechanisms to stimulate farmers to plant, tend and use/sell trees on their farms
- Simplify regulations and procedures to harvest, transport and use farm timber

**Value chain actors**

- Support certification schemes that promote the use of trees in agroforestry systems (e.g. bird friendly, sustainable, timber trees planted on the farm, etc.)
- Improve the value chains of fruit, timber and other tree products from trees on farms
- Certify farm production and increase family income through payment for the ecosystem services rendered by TonF

**Academia**

- Develop sustainable intensification approaches that preserve trees in the shade canopy
- Include trees on farms in the curricula of universities, extension agencies and farmer field schools

Heavily pruned *Grevillea robusta* trees in tea (*Camellia sinensis*) fields, Kenya.

Photo by Eduardo Somarriba

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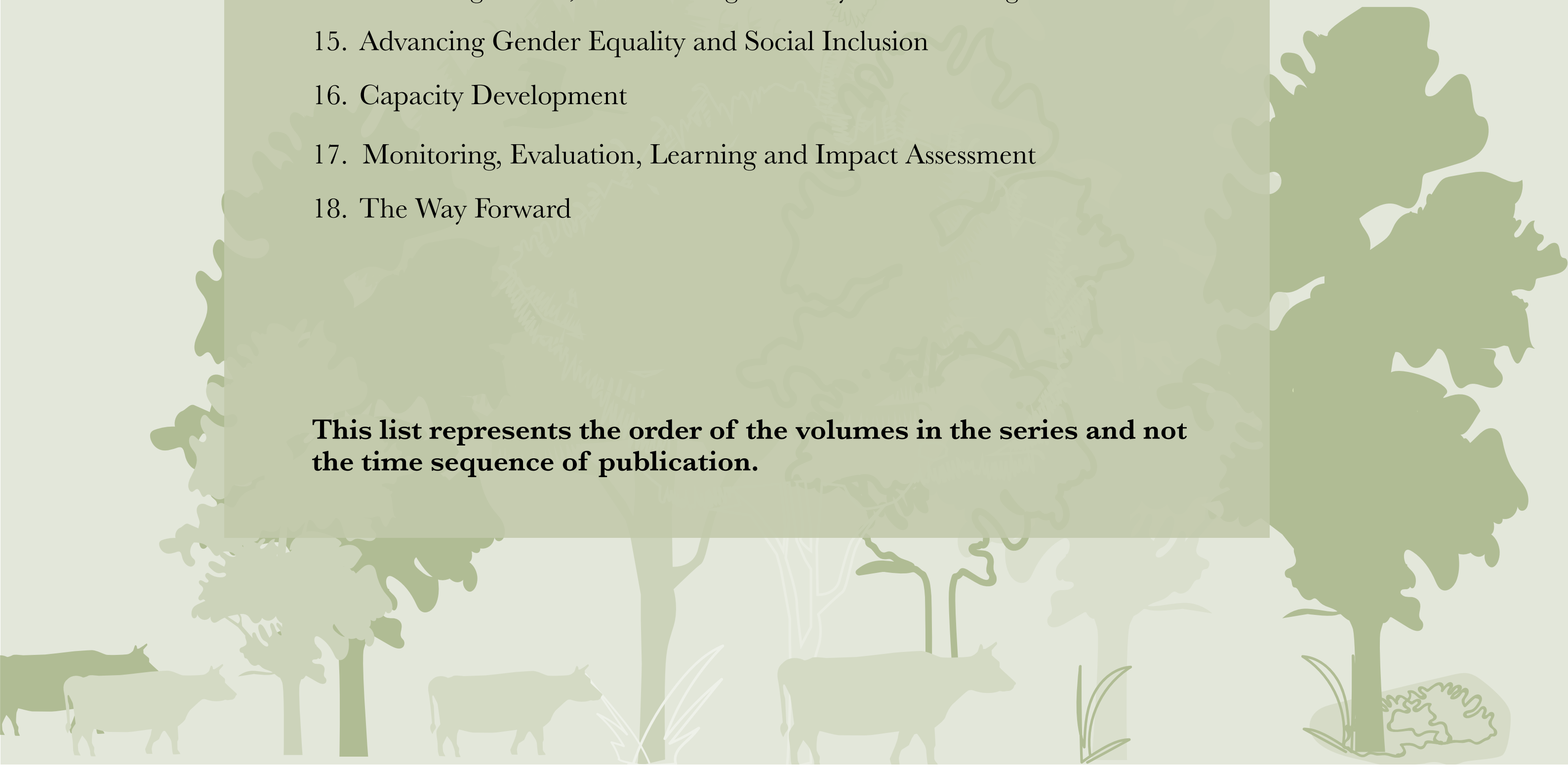

FTA HIGHLIGHTS OF A DECADE
2011-2021

# Trees on Farms to Improve Livelihoods and the Environment

Over the last decade, the CGIAR Program on Forests, Trees and Agroforestry (FTA) has undertaken innovative basic and applied research across different scientific disciplines on the importance of trees on farms (TonF) to farmers' livelihoods and to the environment. The goal was to support the inclusion of TonF in reporting systems and development programs, and to develop the knowledge base and science tools needed to optimize agroforestry systems. This publication presents key FTA outputs on trees on farms from 2011 to 2021.

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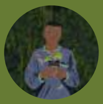
1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