Agricultural Systems 224 (2025) 104235

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy

The bittersweet economics of different cacao production systems in Colombia, Ecuador and Peru

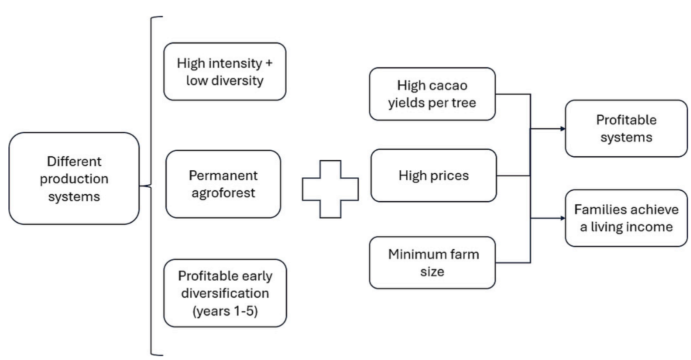
Andrés Charry [a], Carolay Perea [a], Karen Ramírez [b], Guillermo Zambrano [b], Fredy Yovera [c], Adriana Santos [b], Tito Jiménez [c], Miguel Romero [a], Mark Lundy [a], Marcela Quintero [a], Mirjam Pulleman [a,d,*]

[a] *International Center for Tropical Agriculture (CIAT), Km 17, Recta Cali-Palmira, Colombia*
[b] *Escuela Superior Politécnica del Litoral, ESPOL, Facultad de Ciencias de la Vida, Campus Gustavo Galindo Km 30.5 Vía Perimetral, P.O. Box 09-01-5863, Ecuador.*
[c] *Bioversity International, Centro Internacional de la Papa, Av. La Molina 1895, La Molina Lima 12, Peru*
[d] *Soil Biology Group, Wageningen University and Research, the Netherlands*

HIGHLIGHTS

- We compare the financial performance of fifteen cacao production systems from three South American countries.
- Using consistent parameters and assumptions, we evaluate which factors are more relevant for farm's economic success.
- Different systems can generate a living income, but a combination of various favorable conditions is required.
- High prices, high yields, diversification and minimum farm size are critical for generating a living income

GRAPHICAL ABSTRACT



ARTICLE INFO

Dataset link: Financial models of cacao production systems in Colombia, Ecuador and Peru (Original data)

Keywords:
Smallholder farming
Living income
Typical farms
Cost benefit analysis
Diversification
Financial assessment

ABSTRACT

CONTEXT: Cacao production takes place in diverse environments and agricultural systems, with its performance and income generation potential depending on multiple contextual factors. The crop has been promoted among smallholders in South America as a driver for sustainable rural development, but a systematic comparison of the economic performance of diverse cacao production systems in this region was missing, which led to a lack of consistency and clarity on the conditions that enable the crops' success in terms of profitability and income generation for farmers.
OBJECTIVE: We aimed to understand the economic performance of different cacao production systems from Colombia, Ecuador and Perú, and the factors that affect their profitability and income generation potential with regards to poverty and living income benchmarks under varying contexts.
METHODS: We employed the 'typical farm approach' to perform a comparative analysis of fifteen different cacao production systems from six distinct agroecological regions from Colombia, Ecuador and Perú.
RESULTS AND CONCLUSIONS: Eight out of the fifteen systems analyzed were found to be economically viable, while the remaining systems generate considerable losses. Positive outcomes depend on a combination of factors

* Corresponding author at: International Center for Tropical Agriculture (CIAT), Km 17, Recta Cali-Palmira, Colombia.
E-mail address: mirjam.pulleman@wur.nl (M. Pulleman).

https://doi.org/10.1016/j.agsy.2024.104235
Received 6 June 2024; Received in revised form 19 November 2024; Accepted 2 December 2024
Available online 10 December 2024
0308-521X/© 2024 The Author(s). Published by Elsevier Ltd. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

including sufficient prices, yields and land availability, adequate labor allocation, timely diversification, subsidies and low costs of productive factors. Considering those factors, we identified minimum conditions for achieving profitability and living incomes.

SIGNIFICANCE: Our findings provide essential information to decision makers on the limitations of cacao productive systems for achieving a living income, as well as the type of diversification, minimum prices, area and yields that could enhance their economic sustainability. Based on our findings, we discuss the relevance of subsidies for improving the system's performance. Finally, we suggest the use of different indicators and standardized assumptions to allow more reliable comparisons between cacao production systems.

1. Introduction

Over the last decades, numerous initiatives have been undertaken to strengthen cacao supply chains and improve the livelihoods of smallholder farmers around the world. These have focused on increasing productivity, promoting good agricultural practices, diversifying production, linking producers to higher-value markets, and more recently, monetizing carbon offsets and other ecosystem services (Hütz-Adams et al., 2022). Yet, recent studies indicate that these strategies have not sufficiently improved the production and living conditions of the farmers (Fountain and Hütz-Adams, 2022; Ingram et al., 2018). For example, in Ivory Coast and Ghana, between 30 % to 58 % of the farmers earn incomes below the extreme poverty line, and 73 % to 93 % do not receive a living income (Van Vliet et al., 2021). Similarly, Andersen et al. (2022) estimated the living income benchmark for cacao farmers in Peru and compared it with the incomes reported in a study from Alianza Cacao Peru, finding that most cacao smallholder farmers do not earn a living income from cacao production. No such studies were found for Colombia and Ecuador, but national statistics indicate a high prevalence of rural poverty and extreme rural poverty in the three countries, with 45 % and 19 % respectively in Colombia (DANE, 2022); 49 % and 28 % in Ecuador (INEC, 2021); and 41 % and 15 % in Peru (INEI, 2023). This does not specifically reflect the poverty levels of the cacao farmers but suggests that high poverty rates may also apply for the nearly 260 thousand families involved in cacao production in these countries.

In the long term, the situation for smallholder farmers is not likely to become easier. While international cacao prices have more than tripled during 2024, these spikes have been generally linked to supply changes rather than increases in production costs (Fountain and Hütz-Adams, 2022). For instance, the 2024 price increase has been attributed to major supply deficits in West Africa due to increasing pests and diseases, extreme weather events and chronic underinvestment in the plantations, all exacerbated by investors' speculation (J.P. Morgan, 2024; Kimball, 2024). Prices may descend with future supply changes, but farmers are likely to continue facing increasing costs of labor, inputs, consumer goods, and more climate-related challenges.

Several studies have analyzed the costs and benefits of cacao production systems, but few have been carried out for the Latin American context. Moreover, a systematic comparison of their results has proven to be challenging due to differences in methodologies and insufficient information about the assumptions employed. Caicedo-Vargas et al. (2022) evaluated organic and conventional cacao agroforestry systems (AFS) in the Ecuadorian Amazon region, finding that both systems had an equally low profitability even though the costs of household labor were not included. Pérez-Neira (2016) analyzed four production systems in Guayas, Ecuador (traditional, semi-intensive, intensively managed and organic), finding that all four systems were profitable with net margins ranging from 484 to 2323 USD/ha/yr. Nevertheless, the authors did not include the opportunity cost of land nor specify if it accounted for household labor. Pérez-Zuñiga et al. (2021), analyzed the profitability of AFS with different cacao densities in southwestern Colombia, finding net profits for systems with cacao tree densities between 625 and 800 trees/ha and yields above 700 kg/ha/yr. Yet the study does not mention if opportunity costs of labor and land were included, nor presents the income from associated crops. Cerda et al. (2014), analyzed the financial performance of 179 cacao AFS in five countries in Central America, finding that all systems generated positive household incomes (net income, plus in-kind income and household labor), but only 35 % obtained positive net cash incomes. The study accounts for family labor and provides extensive information on the parameters employed for cacao and associated crops, but it does not include land costs nor the depreciation costs of biological assets. Moreover, as the information was collected from a single point in time, it fails to capture the dynamic nature of the production system and thus the financial costs over time. Lastly, Riar et al., 2024; Rüegg et al. (2024) and Armengot et al. (2018) assessed the profitability of monocrops and AFS with conventional and organic management in Bolivia, as part of a long-term system comparison trial. They found comparable production costs and gross margins between conventional and organic systems. Additionally, they found that monocultures showed higher cacao yields, but the sale of plantains/bananas in the AFS overcompensated for the lower cacao revenues. These results offered key insights on the comparative performance of cacao production systems but were limited to only one landscape and did not include the opportunity cost of capital and land, which makes comparison with other contexts more difficult. In conclusion, it's still unclear under which conditions cacao production could be profitable and provide a living income in this region, especially considering the large diversity of production systems, yields, prices, and agroecological and macroeconomic conditions.

In this study, we evaluate the financial performance of fifteen different production systems from Colombia, Ecuador and Peru. We employ standardized assumptions and calculate multiple indicators to facilitate comparing their performance vis-a-vis the interests of different actors. We also include poverty lines, minimum wages and living income benchmarks to assess the systems potential for poverty alleviation.

2. Methodology and data collection

The methodological framework used to analyze the production systems (Table 1) is based on the principles of the "typical farm" methodology (Feuz and Skold, 1992) and the *Agri Benchmark* Standard Operating Procedures (Benchmark, 2005). This is a methodology that analyzes the operations of empirically grounded "virtual" farms,

Table 1
Regions and cacao production system typologies studied.

Country / Region	Typology name
Colombia / Boyacá	Conventional - Low yield (CB-LOW) Conventional - Average yield (CB-MID) Conventional - High yield (CB-HIGH)
Colombia / Putumayo	Conventional - Low yield (CP-LOW) Conventional - Average yield (CP-MID) Conventional - High yield (CP-HIGH)
Ecuador / Guayas	Conventional (EG-CON) Organic (EG-ORG)
Ecuador / Napo	Conventional (EN-CON) Amazonian Organic Kichwa Chakra (EN-OKC)
Peru / Piura	Organic Blanco de Piura (PP-OB) Organic Blanco de Piura + Mango (PP-OBM)
Peru / Ucayali	Conventional - No inputs (PU-MID) Conventional - Intensive (PU-HIGH) Organic (PU-ORG)

drawing from quantitative and qualitative data collection methods, such as desk research, focus group discussions, and farm observations, among others (Lasner et al., 2017).

Although this approach dates back to the 1920's (Elliott, 1928), it has become increasingly popular to establish benchmarks and analyze the effects of policy and technological changes in production systems (Chibanda et al., 2020). It is especially useful for analyzing systems with multiple periods, input and output flows, nevertheless, it also has some limitations to consider: i) The information required is usually not well documented, therefore, the method relies heavily on expert knowledge and in-depth discussions with farmers making the selection of data-points non-random (Chibanda et al., 2020). While the goal of the approach is not statistical representativeness, this must be considered when interpreting the results. ii) The inherent subjectivity of the information derived from expert interviews and focus group discussions makes the outcomes difficult to replicate and potentially biased.

To strengthen the validity of the results, we followed the following steps proposed in the *Agri Benchmark* Standard Operating Procedures (Benchmark, 2005), which includes triangulation with experts and data validation with secondary sources at various stages of the process.

2.1. First – Region definition

Because the data collection was part of two Research for Development projects, the study regions were defined as the intervention areas of the projects. The first project is called "Sustainable Amazon Businesses", funded by the International Climate Initiative (IKI) and led by the Alliance of Bioversity International and CIAT. It sought to curb deforestation and reduce GHG emissions in the department of Ucayali, Peru, by promoting sustainable business models in the cacao and oil palm value chains. The second project is called "Clima-LoCa", funded by EU-DeSIRA and implemented by a consortium led by Bioversity-CIAT. The project has the goal of fostering climate-smart innovations to mitigate the impacts of the EU food safety regulation for cadmium on the cacao value chains of Colombia, Ecuador, and Peru. Clima-LoCa prioritized a few regions in each country, based on the effects of the regulation, on contrasting agroecological conditions for conducting field trials, and on synergies with existing initiatives. In Colombia, data was collected in the departments of Boyacá and Putumayo; in Ecuador, in the provinces of Guayas and Napo; and in Peru, in the department of Piura (See Fig. 1).

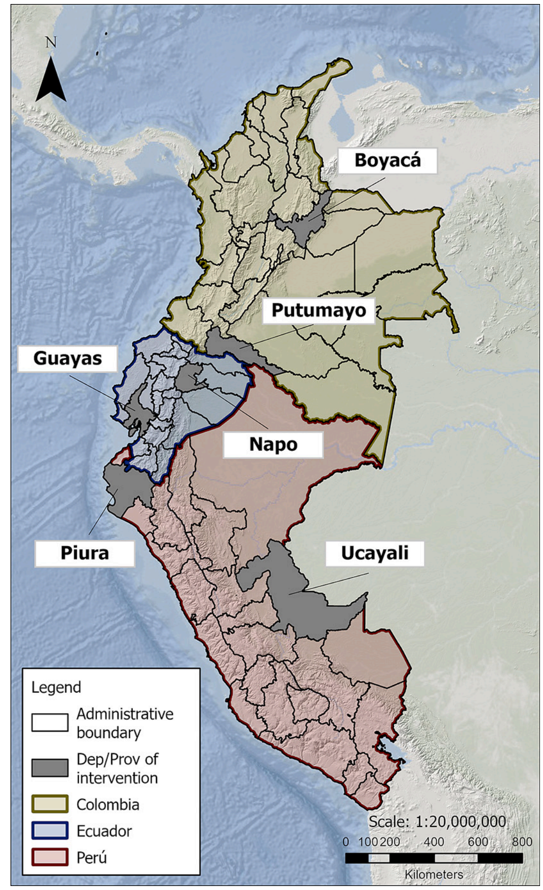


Fig. 1. Map of the selected regions.

2.2. Second - Define relevant and representative production systems

The research team defined the systems in collaboration with local experts (cooperative representatives, producer representatives, extension service providers) based on site specific criteria. The main differentiating factors within the Colombian regions were the yield levels, plant densities and management practices, as other characteristics were relatively homogeneous. In Ecuador and Peru, we found a larger diversity in terms of management practices, contrasting arrangements (e.g. AFS, monocrops), cacao varieties and market segments (e.g. conventional, organic) (Table 1).

2.3. Third - Data collection

For each typology, the research teams conducted workshops with groups of four to eight producers with the relevant characteristics. Participants were selected through snowball sampling with the support of local producer organizations and project partners. For Piura, data was collected only from local producers and experts using an in-depth interviewing format.

The data collected included general farm characteristics, and all the activities, inputs and outputs related to cacao and the associated crops. Farm characteristics included household composition, total farm area, area under cacao, ages of the cacao plots, other land uses, farm assets, land tenure, share of income from cacao and access to support services (e.g. credit, technical assistance, subsidies, government programs). We did not collect specific information on income from crops outside of the cacao production system or other non-agricultural activities. For the cacao production system (with its accompanying crop species), in-depth information was captured using one hectare as the unit of analysis. This included previous land uses, activities, yearly input and output flows, and prices, from the stages of land preparation and establishment, up to harvest and post-harvest at the age of peak productivity for the cacao trees. The information for each parameter was a result of consensus between the workshop's participants, which were later reviewed for potential inconsistencies and validated with the help of local experts.

Prices of inputs, products and services for each production system were set at the average values of the first semester of 2023 using secondary information from official data sources and consultation with local experts.

2.4. Fourth – Data processing and validation

A tool in Microsoft Excel was developed to model diversified cacao production systems. The tool generates a cash-flow model, a profit and loss statement (P&L) for one hectare in a year of peak production, and various performance indicators. As suggested by Chibanda et al. (2020), the results of the models were reviewed, adjusted, and validated with the support of local experts until these were realistic and consistent.

2.4.1. Assumptions and indicators

To allow for comparability between typologies and with other farming enterprises, we used some consistent assumptions among typologies and calculated standard indicators. Mahrizal et al. (2012) used a total life cycle of 25 years for cacao plantations in Ghana, with productivity peaking at year 12 and decreasing gradually until year 25. We did not find reliable studies assessing the productivity curves of cacao plantations in the regions of interest, but the experts interviewed agreed that peak productivity is reached in years 7 to 9 (depending on the variety and management) and that it could be sustained during the life cycle of the production system. For simplification, we assumed that peak productivity was sustained until year 20 followed by linear gradual decreases until year 25, where labor and input costs were reduced proportionally. We excluded the costs and revenues related to timber trees for the AFS that included these species, as a high premature removal of timber trees was reported for various typologies, and there were no reports of timber sales from any of the farms in the studied regions.

For the opportunity cost of land, we employed the rental cost of land in the region for comparable and substitute uses. Similarly, for the opportunity cost of household labor, we employed the price paid for a day of hired agricultural labor in each region. We also included a line for administrative costs, corresponding to 5 % of the system's direct costs and accounted for them as household labor.

Farm assets were depreciated in straight-line using the lifespans reported by farmers. The value of biological assets was calculated as the total costs of establishing and maintaining the system until the 3rd year, as it is not always possible to disaggregate the input and labor costs by crop in these production systems, and most of the accompanying crops were no longer present after this year. Biological assets were depreciated in straight-line for 25 years and included as a fixed cost in the P&L statement. Similarly, income generated from associated crops and cacao in the maintenance phase was distributed evenly for 25 years. This was included as a negative fixed cost in the P&L statement.

Most producers in the three countries reported receiving some inputs and seedlings from development projects, nevertheless, we included all input costs in the calculations as this represents the real cost of production. As very few farmers declared using credit for the establishment or management of their crops, all costs were assumed to be covered using the producer's own capital (i.e. no financing costs were included). Costs for technical assistance were not included because the service is usually not paid for by the farmer, is not accessible to all farmers, and its effects on yields are unknown.

Using the cash-flow model, we calculated Net Present Value (NPV), Internal Rate of Return (IRR), Land Expectation Value (LEV) and benefit-cost ratio (BCR). For the discount rates, we employed the average interest rates of agricultural loans for small-holder producers in 2023 in each country.

Using the information of the P&L statements, we calculated the net profit per hectare, breakeven cacao prices (BEP) and volumes, and the household incomes per hectare and farm by adding net profits, and opportunity costs of land and household labor. Labor productivity was calculated using Kg of cacao produced per day of labor, and the household income per day of labor. The latter allowed us to estimate the value captured by the household after subtracting production costs.

To estimate the prices that could support farmers in the short and long term, we calculated BEP at peak productivity and estimated the cacao price for which the NPV = 0, which we called the Minimum Feasible Price (MFP). BEP considers the total costs of production for a given year, while MFP integrates the financial costs of capital and the productivity curve of the plantation, reflecting better the long-term dynamics of the system.

We also compared the household income generated by each system with the countries' poverty lines, minimum wages and living income reference values reported in ALIGN (n.d.). While achieving living incomes can be considered the goal of the sector, poverty lines and minimum wages are closer to the reality of rural communities in Latin America and can be used as reference values to determine the poverty alleviation potential of these systems. As the share of hired labor differed substantially among typologies, and this influences the total household income, we included a scenario where all the activities were covered using household labor. This allowed us to compare the systems' potential productivity per day of labor (household income per day of labor), per hectare (household income per hectare), and the minimum area necessary for generating a living income, regardless of the labor composition.

Finally, we assessed the effect of subsidies on the financial performance of the systems by evaluating scenarios including a payment of 30 % of the establishment and maintenance costs of the system, disbursed in the first year of operations. This payment is aimed at reflecting some of the development projects that supported the expansion of cacao in the three countries, mostly in the form of inputs, seedlings and technical assistance.

3. The cacao supply chains in the three countries

In the 2021/22 season, world cacao production was estimated at 4.8 million tons (ICCO, 2023), coming from 5 to 6 million farmers of which nearly 90 % are smallholders with less than 5 ha (Bermudez et al., 2022). Latin America and the Caribbean account for about 20 % of global production, mostly concentrated in Ecuador, Brazil, Peru, Dominican Republic and Colombia (ICCO, 2023).

In 2020, an estimated 260,000 farmers from the three Andean countries (Colombia, Ecuador and Peru) produced over 584,000 tons of cacao beans on 950,000 ha (Table 2) (Agronet., 2023; FEDECACAO, 2023; MAG, 2022; MIDAGRI, 2023). Cacao production in these countries has grown substantially during the last decade, yet due to different historical, sociopolitical, environmental, and economic conditions, each country has followed a different pathway and produced diverse farming systems.

Ecuador has a cacao export tradition dating back to the late 1700s, with varieties that would be later known as "Arriba" or "Nacional" (Anecacao, n.d.). Today it is the largest player in the Americas with nearly 330 thousand tons of cacao beans produced in 2022, and exports surpassing USD 1 billion in the form of beans (around 90 % of the exported value), semi-elaborated products and chocolates (Charry et al., 2023). The country supports two contrasting models: the most prominent is aimed at bulk markets and employs the CCN-51 variety due to its high yield and resistance; the other one employs "Nacional" varieties, considered Fine or Flavor (FoF), which are mostly oriented towards specialty markets and have been promoted under more diverse AFS (Sánchez et al., 2019; Hütz-Adams et al., 2022).

Most of the production takes place in the coastal provinces, on relatively larger and more intensively managed farms, usually as irrigated monocultures or with low shade levels. But production in the Amazonian region has been growing, where both settlers and indigenous groups have undertaken cacao production. The former have followed a similar model to the coast, while the latter opted for a "Chakra" model, which is more diversified, with fewer cacao trees per hectare, and

Table 2
Cacao sector indicators for Colombia, Ecuador and Peru in 2020.

Indicators	Colombia	Ecuador	Peru
Sown area (ha)	189,000	590,579	177,000
Production (t)	63,416	327,393	158,944
Farmers	52,000	120,000	90,000
Average farm size (ha)	2.9	< 5 = 52 % 5,1–10 = 26 % > 10 = 22 %	1.96
Cacao varieties	Fine or Flavor; CCN-51	CCN-51; Nacional/ Fine or Flavor	Fine or Flavor; CCN-51
Average yield (Kg/ha)	~ 400	CCN-51 > 1000 Nacional ~200	840
Prevailing production systems	Conventional agroforestry systems	Conventional monocrops and agroforestry systems.	Conventional and organic agroforestry systems

Source: Charry et al., 2023; Hütz-Adams et al., 2022.

regularly under organic management (Zambrano et al., 2022).

Peru is the second largest producer in the Americas and the second exporter of organic cacao in the world (MIDAGRI, 2021). While cacao has been commercially promoted in the country since the 1930s, the largest "boom" took place starting in the mid-2000s as part of the coca substitution programs in the Amazonian regions (Hütz-Adams et al., 2022). Nowadays, most of the country's cacao exports are in the form of beans (around 54 % of the total exported value), but the exports of cocoa butter and powder are growing at accelerated rates (Charry et al., 2023).

The country has a large share of its cacao area with the CCN-51 variety, aimed mostly at bulk and bulk-certified markets. Nevertheless, the country holds a great diversity of local genetic groups (Thomas et al., 2023), some of which are globally recognized for their quality and profile (e.g., "Blanco de Piura" and "Chuncho"). In the last decade, native and other FoF varieties have been increasingly promoted through programs such as Alianza Cacao Peru, which introduced a FoF technological package for the Amazonian region in the early 2010s (Charry et al., 2023; Gómez et al., 2014; Hütz-Adams et al., 2022).

In Colombia, two large processing companies of national origin have consolidated the market since the beginning of the 20th century (Londoño Vélez, 2017), driven by a considerable local demand for hot chocolate beverages and confectionery products. Commercial production dates back as far as the 17th century and was concentrated mostly in the central regions of the country (Barrios Nieves, 1981). However, over the past 20 years the crop has undergone expansion in peripheric territories as a part of illicit crop substitution and alternative development programs (Abbott et al., 2018). Currently, Colombia produces over 60 thousand tons of cacao beans per year, and it is estimated that nearly 80 % is bought by the two national companies (Abbott et al., 2018). Around 11 thousand tons are exported as beans, while the rest is consumed domestically or exported mainly as confectionery products (Charry et al., 2023). The country's production systems are relatively homogeneous, as most development initiatives have promoted similar technological packages. The variety CCN-51 is prevalent in many regions, but trinitarian and other locally developed varieties have gained prominence over the last decades, as the national federation of cacao growers (FEDECACAO) works at positioning the country in the FoF segment.

4. Results - Description of regions and typologies

4.1. Boyacá, Colombia

This research area covers the western municipalities of the department of Boyacá located in the Andean Region of Colombia. The area presents a precipitation between 2000 and 3000 mm, and cacao is produced between 500 and 1300 m.a.s.l. The predominant soil types are Inceptisols and Entisols with an average slope of 42 % (IGAC (Instituto Geográfico Agustin Codazi)., 2004). With an estimated of 4500 ha, the department supplies 2 % of the total national production (FEDECACAO, 2023; Agronet., 2023). Nevertheless, it shares similar agroclimatic conditions and production systems with the department of Santander, where most of the Colombian cacao is produced.

Most of the cacao was established as AFS in the mid and late 2000s, including short cycle crops in the first year, plantain (as temporary shade) and cacao trees planted at 3 m × 3 m, and various tree species like avocado (*Persea americana*), abarco (*Cariniana pyriformis*), cedar (*Cedrus spp*) and melina (*Gmelina arborea*) at densities of nearly 200 shade trees per hectare. Some of these trees have been removed over the past decade. Death of cacao trees has also reduced the average cacao tree densities to ~1000 per ha in all typologies. The dominant cacao variety is CCN-51, but FoF varieties are also common.

4.1.1. Typologies in Boyacá

Conventional - Low yield (CB-LOW): Families with two hectares of cacao and an average yield of 200 kg/ha. Management practices are minimal, with no fertilization, and scarce pruning, pest and disease control. Includes a production of 300 kg of maize in the first year and 15 tons of plantain during the first two years.

Conventional – Average yield (CB-MID): Families with three hectares of cacao and an average yield of 450 kg/ha. Management practices include one fertilization every 2 to 3 years, occasional pruning, and some weeding. Includes a production of 1750 kg maize and 1500 kg of cassava in the first year, and 15 tons of plantain during the first two years.

Conventional – High yield (CB-HIGH): Families with three hectares of cacao and an average yield of 800 kg/ha. Management practices include two fertilizations per year, weed controls, one pruning, chemical pest management, and monthly manual pest and disease management. Includes a production of 1875 kg of maize and 200 kg of beans in the first year, and 15 tons of plantains during the first two years.

4.2. Putumayo, Colombia

This department is located in the Amazon region, and cacao production is concentrated in the southern and central areas of the department at altitudes between 320 and 680 m.a.s.l. Annual precipitation ranges between 3000 and 4400 mm. The predominant soil types in cacao production areas are Inceptisols and Andisols, with an average slope of 28 % (IGAC (Instituto Geográfico Agustin Codazi)., 2004). Cacao production is relatively recent, mostly resulting from illicit crop substitution programs. The department produces 3 % of the total national cacao production on nearly 5.400 ha (FEDECACAO, 2023; Agronet., 2023).

The crop has been promoted as AFS. Due to the climatic conditions, the cacao trees are planted at a relatively low density (4 m × 4 m). The system includes plantain for temporary shade and timber trees for permanent shade, yet a substantial share of these trees has been removed progressively through the past years. The most common cacao varieties are CCN-51, ICS-95, and more recently "*Súper Árbol*", introduced from Ecuador.

4.2.1. Typologies in Putumayo

Conventional – Low yield (CP-LOW): Families with one hectare of cacao and an average yield of 250 kg/ha. Management is very limited, with no fertilization and scarce pruning, weeding and pest and disease management. Includes a production of 300 kg of maize in the first year, and of 1.25 tons of plantain in the first two years (60 plants per hectare).

Conventional – Average yield (CP-MID): Families with two hectares of cacao and an average yield of 400 kg/ha. Management practices include one soil amendment application, foliar fertilization, pruning, weeding and monthly manual pest and disease management along with harvest. Includes a production of 7 tons of plantain during the first two years (625 plants per hectare).

Conventional - High yield (CP-HIGH): Families with three hectares of cacao and an average yield of 800 kg/ha. Management practices include two fertilizations and two prunings per year, continuous weed control and integrated pest and disease management. Includes a production of 4.25 tons of maize during the first three years and of 3.6 tons of plantain during the first six years (50 plants per hectare).

4.3. Guayas, Ecuador

Located in the coastal region with an altitude mostly below 5 m.a.s.l., this province has a temperature of 20 °C to 28 °C. The yearly precipitation (900–1800 mm/yr) is concentrated in the first half of the year. Soils have developed in sedimentary parent materials of alluvial and volcanic origin (Prefectura de Guayas, 2021), and are mostly flat. This province is the second largest cacao producer in the country, with nearly 68 thousand tons in 2022, representing 21 % of the national production (MAG (Ministerio de Agricultura y Ganadería)., 2023). It is estimated that 98 % of the cacao varieties planted in Guayas consist of CCN-51 and that the remaining 2 % are of the Cacao Nacional variety (Guilcapi, 2018).

4.3.1. Typologies in Guayas

Conventional (EG-CON): Families with three hectares of cacao, nearly 1200 trees per hectare and an average yield of 1587 kg/ha. Over 50 % of the labor is hired and due to its location, the opportunity cost of the land and labor is high. Management practices include high fertilizer application, chemical and manual weed controls, chemical pest and disease control, pruning and irrigation. Includes a production of 12.5 tons of plantain during the first three years (600 plants per hectare).

Organic (EG-ORG): Families with five hectares of cacao, with 840 trees per hectare (640 Nacional and 200 CCN-51) and an average yield of 680 kg/ha. Production of cacao Nacional reaches 363 kg/ha, which receives a substantial organic and quality price premium. Management practices are done mostly by the family and include foliar applications of organic fertilizer, weeding, pruning, and manual pest and disease control. The system includes a production of 1 ton of papaya in the second year, and 15.8 tons of banana and plantain combined (840 plants per hectare) during the first four years.

4.4. Napo, Ecuador

Located in the northern Amazon region, this province has an average temperature between 24 °C and 26 °C and monthly precipitations between 150 and 270 mm (Prefectura de Napo, 2020). Around 71 % of the soils in the province are Andisols, and nearly 48 % of the terrain has slopes greater than 70 % (GAD Napo, 2015). In 2022, production reached 3713 tons, with average yields of 610 kg/ha (MAG (Ministerio de Agricultura y Ganadería)., 2023). The Nacional varieties represent 79 % of the cacao planted in the region. About 65 % of the province's inhabitants self-identify as indigenous and produce cacao in a traditional system called the Kichwa chakra (Guilcapi, 2018). This system is managed mainly by women, applying ancestral knowledge and focusing on the sustainable use of natural resources (MATE and GIZ, 2020). Simultaneously, settlers migrating from the coastal and Andean regions have introduced more intensive production systems (Sellers and Bilsborrow, 2019). In general, the chakra system tends to be more diversified, with greater use of household labor and organic practices, while settlers employ monocultures with the CCN-51 and "*Súper Árbol*" varieties. Due to the local climatic conditions, the typical planting density is lower than in other regions, with 625 individuals per hectare.

4.4.1. Typologies in Napo

Conventional (EN-CON): Families with five hectares of cacao and an average yield of 1360 kg/ha. Management practices include high fertilizer application, pruning, multiple chemical and manual weed, pest and disease control. Nearly 60 % of the labor is hired. The system includes 11.3 tons of maize production per year during the first two years.

Organic Kichwa chakra (EN-OKC): Families with two hectares combining nearly 600 Nacional trees in AFS with production of maize in the first year (2.2 tons), and annual production of cassava (900 kg), plantain (1.1 ton) and guayusa (450 kg). Cacao yields are low, at 180 kg/ha, and is sold wet for a substantial premium for its quality and organic certification. All labor is carried out by the families, and the management practices for cacao are limited to weeding, pruning and harvesting. In this system, nearly 32 % of the income (adding cash and in kind) is derived from cacao.

4.5. Piura, Peru

This department is located in the north-western coastal region. The region is characterized by low precipitation, with around 700 mm per year and an average temperature of 23 to 26 °C. The farms are usually located in flat or slightly inclined terrains (slopes of 10 to 20 %) and soils are mostly of loam, clay loams and sandy loam texture. Around 2 % of the country's cacao is produced in this department on nearly 1500 ha. Cacao from Piura has positioned itself in specialty niches thanks to the varieties "Blanco de Piura" and "Gran Blanco", which are usually sold to cooperatives with organic and fair-trade certifications at high price premiums (Acero, 2020). It's important to note that a considerable share of farmers do not receive these premiums, since over 30 % of the farmers do not belong to the cooperatives, and some farmers have ceased to sell to niche markets due to the high cadmium contents in their beans (Villar et al., 2022). Cacao plantations are always irrigated and managed as a monocrop combined with banana for temporary shade during its establishment phase, or as permanent AFS with fruit trees (often mango, carambola or a mixture of trees). Due to the department's low precipitation, the incidence of pests and diseases is relatively low.

4.5.1. Typologies in Piura

Organic Blanco de Piura (PP-OB): Families have an average of 0.8 ha with cacao and reach yields of 875 kg/ha. Farmers in this typology belong to cooperatives to whom they sell wet cacao at high prices. Management practices include one application of (organic) fertilizer per year, one foliar application of bio protectors, one pruning, frequent clearing, manual pest and disease control, flood irrigation and drainage management. This typology includes yields and management practices slightly above the regions' average, but it represents an adequate yet achievable and growing model according to the experts consulted. Unlike other varieties, Blanco de Piura reaches its peak productivity in year 9 (instead of 7). This typology produces 1275 boxes of 100 plantains during its first three years.

Organic Blanco de Piura + Mango (PP-OBM): Families with one hectare combining 450 cacao trees in AFS with mango (50 trees per hectare). Cacao production at its peak reaches 420 kg/ha and is sold to cooperatives at high prices. Mango reaches its peak productivity of 8.75 t/ha in year 15. From this year onwards, cacao production represents 40 % of the total revenues of the system, and mango becomes the main source of revenues. Management practices for cacao include one yearly fertilization (organic), one foliar application of "*Bouillie Bordelaise*", one pruning, weeding, manual pest and disease control, flood irrigation and drainage management. The system produces 4 tons of maize in the first year and 440 boxes of 100 bananas in the first three years.

4.6. Ucayali, Peru

The department is located in the Amazonian region. Production takes place in various agroecological regions, but mostly in the hills and flatland areas, with average temperatures of 26 °C and a yearly precipitation of 1200 to 3000 mm (CIMA, 2017). Ucayali has the third largest production in the country, with over 22,000 tons, 25,000 ha and 5300 producers (MIDAGRI, 2023). Since the crop was promoted using standard technological packages, most producers present very similar arrangements i.e. AFS with short cycle crops during the first year, plantain as temporary shade and cacao trees planted at 3 m × 3 m, some fruit trees for household consumption (nearly 10 per hectare) and nearly 200 timber trees combining native species such as bolaina, (*Guazuma crinite*), shihuahuaco (*Dipteryx micrantha*), and capirona (*Calycophyllum spruceanum*), as well as mahogany (*Swietenia mahagoni*) and cedar (*Cedrus spp*). Nevertheless, most producers have removed most or all of these trees, leaving between 10 and 20 trees per hectare. The most common cacao variety is CCN-51 but FoF varieties have also been promoted.

4.6.1. Typologies in Ucayali

Conventional – No inputs (PU-MID): Families with five hectares of cacao and an average yield of 600 kg/ha. There is no fertilization in these systems, and management practices include three yearly weed control, one pruning, and manual pest and disease management along with harvesting. Includes a production of 2 tons of maize in the first year and 17.5 tons of plantain in the first three years.

Conventional – Intensive (PU-HIGH): Families with ten hectares of cacao and an average yield of 1500 kg/ha. These farmers are more business oriented and hire over 70 % of the farms' labor. Management practices include three fertilizer applications per year, regular weeding, two prunings, and both chemical and manual pest and disease control. Includes a production of 3 tons of maize in the first year and 31.3 tons of plantain in the first four years.

Organic (PU-ORG): Families with three hectares of cacao and an average yield of 800 kg/ha. Management practices include one yearly application of fertilizer (organic) and soil amendments, pruning, weeding, and regular manual pest and disease control. Includes a production of 3 tons of maize in the first year and 17.5 tons of plantain in the first three years. Organic price premiums are nearly 5 % above conventional price.

4.7. *Comparison of farm characteristics and financial performance*

In this section we present a set of indicators of farm characteristics and financial performance, together with selected indicators for two scenarios; (i) assuming that all activities are carried out using household labor and (ii) including a subsidy of 30 % of the establishment costs (Table 3).

We found large variations in the prices of cacao and production factors, leading to considerable differences in financial performance even among similar typologies. Labor costs in 2023 varied between and within countries, ranging from 12.6 USD/day in Piura to 20 USD in Guayas. Similar variations can be observed for the land costs, with the lowest values in Amazonian regions and the highest in the coastal regions of Ecuador and Peru. Price differences in the production factors are mainly related to accessibility, productive infrastructure, land and labor markets.

Labor accounted for 45 % to 70 % of the total production costs among the typologies, followed by land costs and in some cases, input costs. Depreciation of biological assets accounted from 8 % to 29 % of the total costs, nevertheless, most were compensated for by the distributed revenues from associated crops accrued during the maintenance phase.

On average, the opportunity cost of labor in the three countries was USD 15.9 per day, and the opportunity cost of land was USD 312 per hectare. The share of hired labor ranged from 0 % to 73 %, with a median of 35 %. Input expenditure per hectare ranged from USD 0 to USD 682 and USD 1141 for the most productive typologies in Ecuador and Peru respectively. Both typologies reported yields near 1500 kg/ha using the CCN-51 variety. The median annual input expenditure for all systems was 127 USD/ha.

Considerable price differences were found for conventional cacao, even within the same country. These were mostly related to ease of access to the regions. The median farmgate price was 2.68 USD/kg, with the lowest prices for conventional cacao in Ecuador, followed by Putumayo and Boyacá, Colombia. Ucayali, Peru reported the highest farmgate prices for conventional cacao among the three countries. Price premiums within the same regions for organic-FoF cacao ranged from 5 % to 67 %.

In Colombia, only one typology (CP-HIGH) was financially viable, with a BCR > 1 and an IRR of 20.5 %. This can be attributed to lower establishment costs (lower cacao density), lower cost of land, steady revenues from associated crops in the initial years, and high yields (1.43 kg/tree). In Boyacá, the system with average yields showed a slightly higher NPV than the higher yield system. This was due to lower accumulated losses during the initial years, and a lower share of hired labor. It's important to note that Colombia presents the highest discount rate, affecting NPV and BCR substantially. The lowest MFPs were 2.4 USD/kg in Putumayo and 3.44 USD in Boyacá. The lowest BEP on a farm at its peak productive age was 2.0 USD/kg.

In Ecuador, the two typologies from Guayas presented poor financial performance. Despite having high yields and labor productivity, EG-CON presented the lowest NPV of all systems. This is explained by its high opportunity costs of land and labor, high establishment and maintenance costs, and limited revenues from associated crops in the initial years, leading to a large accumulation of financial losses during this period. EG-ORG receives high prices for organic Nacional cacao, but it's also unprofitable due to low productivity per tree, and high labor and land costs. Nevertheless, due to lower management costs and higher income from associated crops in the initial years, it shows a better financial performance over time than EG-CON.

On the contrary, the two systems from Napo present very positive financial results. EN-CON has the highest productivity per tree, and the second highest labor productivity and IRR among all typologies. EN-OKC has very low yields but presents the highest cacao prices among all typologies. This system is highly profitable with the highest NPV and IRR among all typologies. Nevertheless, most of the income is derived from the associated crops, not from the cacao. When separating activities by crop, the analysis reveals that cacao production generates losses, indicating that other crops are subsidizing cacao. EN-CON had the lowest BEP and MFL among all typologies, with 1.8 and 1.97 USD respectively.

In Peru, all systems were financially viable with IRRs ranging from 10 % to 15 %, and profits ranging from 337 to 929 USD/ha/yr. Ucayali had the typology with highest revenue, NPV and IRR (PU-HIGH) but Piura had the typology with the highest net profits in a year of peak production (PP-OBM). Nearly 60 % of the revenues of PP-OBM come from mango sales, however, due to the long period for the mango trees to reach peak productivity, PU-HIGH shows better financial indicators. The lowest MFP among the Peruvian cacao systems is 2.63 USD/kg, and the average is 2.81 USD. The average BEP in Peru is 2.45 USD.

Under the subsidy scenario, all typologies experienced large performance improvements, nevertheless the low performing typologies in Colombia and EC-CON remained with BCR below 1. The subsidies ranged from 1017 to 3188 USD/ha depending on the systems' early capital needs.

When comparing systems by management type, the conventional monoculture from Napo showed higher profits than the organic Kichwa chakra, but considerably lower NPV and IRR. This was due to lower costs and higher profits during the initial years for the organic Kichwa chakra, which are less affected by the discount rate. Similarly, in Guayas, the organic system showed a better performance mainly due to the non-cacao component. In Piura, the AFS performed better than the monoculture, and in Ucayali the conventional high intensity system outperformed the others, but the organic system showed a better performance than the low intensity conventional system, as in this case, the higher prices and yields overcompensated for the higher costs.

4.8. *Household income*

For the Colombian typologies, household incomes range from 180 to 1590 USD/ha/yr. These income variations are highly related to the share of hired labor. None of the typologies achieve incomes above the poverty line, except for CP-HIGH (Fig. 2). Assuming 100 % of household labor, CP-HIGH is the only typology that could generate an income above the minimum wage. Nevertheless, the household income per day of labor for CB-MID, CB-HIGH and CP-HIGH are above the minimum wage and close to the country's living wage, revealing that these systems have the potential of generating decent living conditions for household members and hired labor, if they had more farmland available. To obtain 100 % of a living income from cacao under these scenarios, the best performing systems in Boyacá and Putumayo would require a minimum area of 5.3 and 4.1 ha respectively.

In Ecuador, household incomes range between 1303 and 1818 USD/ha/yr. EG-ORG and EN-CON have 5 ha and are close to reaching the living income. For EN-OKC and EG-CON, this drops to below 45 % as these typologies have considerably less land. Despite the good financial performance of EN-OKC, land limitations suggest that farmers belonging to this typology would be below the poverty line, unless they have

Table 3
Farm characteristics, cost structure and performance indicators by producer typology.

Farm indicators	CB-LOW	CB-MID	CB-HIGH	CP-LOW	CP-MID	CP-HIGH	EG-CON	EG-ORG[a]	EN-CON	EN-OKC	PP-OB[b]	PP-OBM	PU-MID	PU-HIGH	PU-ORG
Yield (kg/ha - dry)	200	450	800	250	400	1000	1587	680	1360	180	700	420	600	1500	800
Price (USD/kg)[c]	2.68	2.68	2.68	2.5	2.5	2.5	2.2	2.79	2.2	3.31	3.09	3.01	2.97	2.97	3.11
Cacao production area (ha)	2	3	3	1	2	3	3	5	5	2	0.8	1	5	10	3
Trees per ha	~1000	~1000	~1000	625	625	700	1200	840	625	625	850	450	~1000	1111	~1000
Labor (days/ha)	32	46	69	39	45	72.6	80	62	72	55	81	101	54	109	72
Share of hired labor (%)	34	52	58	19	4	36	51	8	60	0	29	35	28	73	46
Cost of labor (USD/day)	15.9	15.9	15.9	15.9	15.9	15.9	20	20	15	15	12.2	12.2	16.2	16.2	16.2
Cost of land (USD/ha)	227	227	227	193	193	193	700	500	500	300	432	297	216	270	216
Expenditure on inputs (USD/ha)	0	127	428	0	57	301	683	31	498	0	120	152	50	1141	456
Yield per tree (kg)	0.2	0.45	0.8	0.4	0.64	1.43	1.32	0.81	2.18	0.29	0.82	0.93	0.6	1.35	0.8
Cacao production per day of labor (kg)	6.3	9.8	11.6	6.4	8.9	13.8	19.8	11	18.9	6.4	8.6	4.2	11.1	13.8	11.1
Revenues and cost structures (for 1 ha in year of peak productivity)															
Revenue (USD/ha)	536	1207	2146	625	1000	2500	3492	1898	2993	1854	2162	3161	1784	4459	2487
Total costs (USD/ha)	943	1285	2090	1262	1307	1955	3775	2112	2392	1265	1784	2232	1382	3629	2150
Net profit (USD/ha)	−407	−78	56	−637	−307	545	−283	−214	601	589	378	929	402	830	337
Variable costs (as % of total costs)															
Labor	60	61	57	58	57	61	42	68	45	70	58	56	66	51	55
Inputs	0	10	21	0	4	15	18	2	21	0	7	7	4	32	21
Transport	1	2	2	7	5	5	2	0	2	0	0	12	2	4	4
Other variable costs	6	4	2	3	5	2	4	1	3	0	1	1	1	1	1
Fixed costs (as % of total costs)															
Depreciation of biological assets	33	29	18	11	15	8	11	18	17	14	14	10	21	12	13
Distributed income of associated crops	−33	−30	−17	−3	−11	−9	−6	−18	−15	−13	−10	−6	−17	−11	−12
Depreciation of equipment	6	3	4	5	6	4	4	2	3	2	2	2	4	1	4
Land costs	24	18	11	15	15	10	19	24	21	24	24	13	16	7	10
Administrative costs and management services	3	4	4	3	4	4	6	5	4	4	5	4	4	4	4

Performance indicators	CB-LOW	CB-MID	CB-HIGH	CP-LOW	CP-MID	CP-HIGH	EG- CON	EG-ORG[a]	EN-CON	EN-OKC	PP-OB[b]	PP-OBM	PU-MID	PU-HIGH	PU-ORG
Breakeven price (USD/kg)	4.7	2.86	2.61	5.05	3.3	2	2.38	N/A	1.8	N/A	2.57	2.29	2.3	2.42	2.69
Minimum feasible price (USD/kg)	7.2	3.76	3.44	8.18	4.77	2.4	2.88	N/A	1.97	N/A	3.08	2.63	2.78	2.65	2.9
Breakeven production (kg/ha)	352	479	779	505	523	782	1716	757	1087	N/A	578	335	465	1221	692
Household Income (USD/ha)	222	567	861	180	481	1590	1303	1670	1618	1818	1900	2126	1294	1745	1268
Household income from cacao (USD/farm)	444	1702	2583	180	963	4770	3908	8351	8089	3636	1606	2126	6469	17,447	3805
Share of living income from cacao (%)	5.4	20.6	31.2	2.2	11.6	57.6	45	96.1	93	42	20	26.5	80.6	217.4	47.4
Net Present Value	−2606	−1404	−1749	−4094	−2612	283	−8771	−1336	2554	5148	53	1120	874	3684	1285
Land Equivalent Value	−2648	−1427	−1777	−4160	−2654	287	−10,680	−1626	3110	6269	63	1324	1034	4359	1522
Internal Rate of Return (%)	N/A	N/A	N/A	N/A	N/A	20.5	N/A	N/A	15	30.4	N/A	10	10.2	15.2	12.9
Benefit Cost Ratio	0.75	0.89	0.88	0.37	0.68	1.03	0.79	0.95	1.09	1.36	1	1.06	1.05	1.1	1.06
Scenario - 100 % Household labor															
Household Income (USD/ha)	415	976	1552	328	684	2016	2134	1788	2263	1818	1900	2577	1580	3091	1812

(*continued on next page*)

Table 3 (*continued*)

Performance indicators	CB-LOW	CB-MID	CB-HIGH	CP-LOW	CP-MID	CP-HIGH	EG- CON	EG-ORG[a]	EN-CON	EN-OKC	PP-OB[b]	PP-OBM	PU-MID	PU-HIGH	PU-ORG
Household income per day of labor (USD)[d]	13	21.5	21.86	8.41	15.33	27.77	26.8	28.6	31.5	33	23.3	25.47	29.5	28.3	25.3
# of hectares to reach living income	19.9	8.5	5.3	25.2	12.1	4.1	4.1	4.9	3.8	4.8	3.4	3.1	5.1	2.6	4.4
Scenario – Subsidy															
Total subsidy (USD/ha)	2347	2839	2743	1017	1421	1218	3189	2818	3115	1333	1803	1702	2.17	3343	2.082
Net Present Value	−617	1000	575	−3232	−1408	2346	−5795	1295	5462	7708	1730	2700	2888	6787	3218
Internal Rate of Return (%)	N/A	N/A	N/A	N/A	N/A	74.1	N/A	N/A	67.9	109.9	N/A	15.5	21.5	33.9	33
Benefit Cost Ratio	0.94	1.08	1.04	0.51	0.83	1.14	0.86	1.05	1.19	1.45	1.1	1.13	1.17	1.18	1.15

[a]The yield of Nacional cacao is 363 kg/ha and was sold at a price of 3.1 USD/kg. The yield of CCN-51 cacao is 317 kg/ha and was sold at 2.2 USD/kg. The price displayed corresponds to the weighted average.
[b]The values for this typology correspond to 0.8 ha, except for the indicator of household income per hectare, where it was adjusted to 1 ha for comparison purposes.
[c]Prices for cacao, inputs, land and labor correspond to average local prices between January and July 2023.
[d]Household income per day of labor = Household income per hectare / labor days per hectare.
*Discount rates: Colombia = 18.05 %, Ecuador = 7.13 %, Peru = 7.75 %.
**Exchange rates: Colombia COP/USD = 4400; Peru PEN/USD = 3.7.
***Daily living wage equivalent (240 working days per year) in USD: Colombia = 24.3, Ecuador = 24.5, Peru = 26.5.
****For all typologies, the available household labor days were set at 384 (1.6 full time workers per household).

additional income sources. Assuming 100 % household labor, EG-ORG and EN-CON would stand above the minimum and living wages, which are very similar for Ecuador in 2023. In this scenario, all the typologies could generate daily revenues per day of labor substantially higher than the country's living wage. Between 3.8 and 4.9 ha of land would be needed to generate 100 % of the living income.

In Peru, household incomes range between 1268 and 2126 USD/ha/yr. PU-MID stands above the minimum wage, while PU-HIGH greatly surpasses the living income due to the large area employed (10 ha). Assuming 100 % of household labor, all typologies in Ucayali would obtain household incomes above the minimum wage and PU-MID would approach the living income. Typologies in Piura were profitable, but since they have one hectare or less, their total household income would remain below the poverty line. All the typologies can generate a household income per day of labor close to or greater than the living wage, indicating that land is the main constraint to provide decent livelihoods for farmers and workers.

5. Discussion

5.1. Fair prices and land access are critical for achieving a living income

It has been widely advocated that if the cacao sector is serious in its commitment of improving the farmers livelihoods and long-term sustainability, it must establish cacao prices that reflect production and living costs (Fountain and Hütz-Adams, 2022). Our results reconfirm that price premiums from specialty markets can have a substantial effect on profitability (Gockowski et al., 2013; Gockowski et al., 2011). Certified cacao farms may also enjoy additional competitive advantages, as these have more robust monitoring systems which would facilitate compliance with the most recent European legislations on deforestation and due diligence in supply chains. But premium segments are small (Gaia Cacao, 2021), thus highlighting the relevance of minimum fair prices for conventional cacao.

Fairtrade (2022) estimated Living Income Reference Prices for cacao in Ghana and Cote d'Ivoire in 2022 at 2.12 and 2.39 USD/kg respectively. This was done by using virtual model farms with "sustainable yields" (800 kg/ha), representative farming areas (3.3 and 4.4 ha), household sizes (6 to 8 people), and production costs according to good management practices. In this study we suggest using the average BEP and MFP for the systems that generated net profits or that reported yields above 800 kg/ha, as these could serve as additional benchmarks. As shown in Table 4, conventional prices at the time of the study were below the MFP in Colombia and Ecuador.

Seven of the fifteen typologies generated less than 40 % of the living income, including two profitable typologies. Only the typologies with five or more hectares achieved 80 % or more of the living income, and only five typologies with yields above 600 kg/ha and large areas approached or surpassed the minimum wage. Assuming 100 % of household labor, the profitable typologies from the three countries required an area of 3 to 5 ha to achieve a living income. With a more realistic share of 30 % hired labor, these values rise to 3.5 to 6 ha.

The possibility of expanding the farms is limited for many farmers and may imply considerable environmental risks, as land costs tend to be lower in remote areas with forest cover. Moreover, the results from Ecuador indicate that profitability is greatly affected by land opportunity costs, putting the sector in a situation with complex trade-offs between livelihood and environmental goals. These findings reconfirm that land availability is critical for poverty alleviation and highlights the need for including living income and farm size indicators, as financial performance alone fails to capture the producer's economic condition.

5.2. What is the right mix for success?

We found that different cacao systems have the potential to generate revenues and improve living conditions. These systems shared different combinations of favorable conditions such as: good yielding trees (>0.8 kg/tree on average), high cocoa prices (> 3 USD/kg), land access (3.5 to 6 ha), high labor productivity, high income from associated crops during the first years or during the productive lifespan of the system, low proportion of hired labor, and low costs of land, labor and capital.

Overall, we found that the systems' economic performance was highly sensitive to the results in the initial years. We suggest four complementary strategies with considerable potential to improve the financial sustainability of cacao farming: i) maximize revenues during the initial years through association of short cycle crops, ii) subsidize establishment costs, iii) introduce precocious varieties and management practices that allow for faster productivity curves, iv) emphasize crop rehabilitation and renovation to reduce establishment costs and speed up production times. Here we discuss the first two strategies.

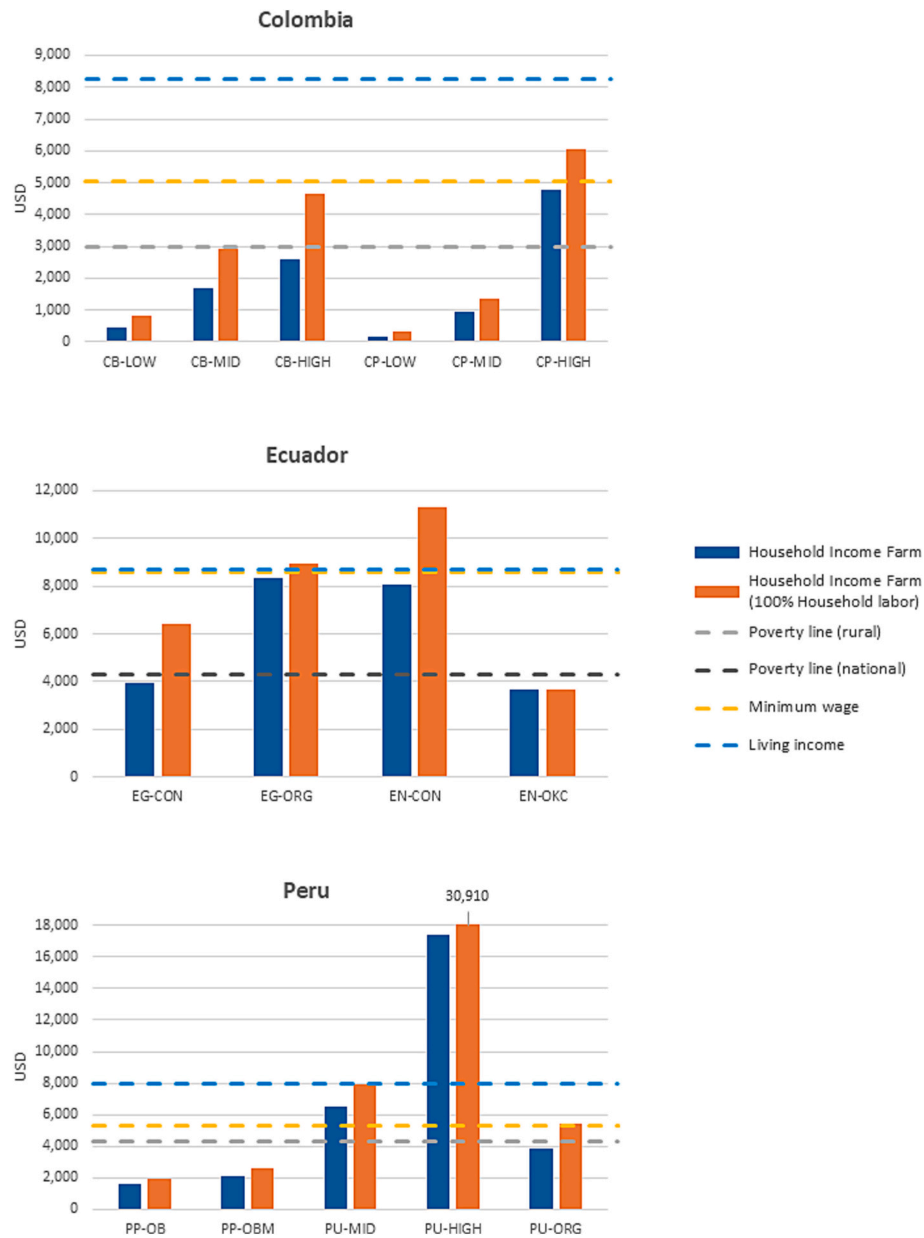


Fig. 2. Yearly household incomes per farm and country income benchmarks (poverty line, minimum wage and living income).
*Colombia and Peru report a rural poverty line, while Ecuador reports only a national poverty line.
**Minimum wage calculated for a household with 1.6 working persons.
***Yearly living incomes for a rural household per country in USD: Colombia = 8276, Ecuador = 8688, Peru = 8027 (ALIGN, n.d.).

Table 4
Cacao reference prices in the three countries (in USD/kg).

Indicator	Colombia	Ecuador	Peru
Breakeven price (BEP)	2.31	2.1	2.46
Minimum feasible price (MFP)	2.92	2.43	2.81
Conventional cacao price (CCP)	2.5–2.68	2.2	2.97
Premium cacao price (PCP)		2.79–3.31	3.01–3.11

Given the high establishment costs and the time required for reaching sufficient cacao yields, intercropping with short cycle crops during the first 3 to 6 years appears critical. We observed a good performance of contrasting systems, such as the permanent AFS (cacao-mango in Peru and the Kichwa chakra in Ecuador) and the more intensive monocultures (with some diversification during the first years). Nevertheless, our study does not allow identification of the most profitable crop mixes, as we lacked robust information on prices, yields, and behaviors of the associated crops throughout the lifecycle of the different cacao production systems in their respective contexts.

Our findings are in line with the current literature, which shows that profitability depends on minimum yield and prices levels, but there is also considerable diversity of successful strategies. Some studies found that diversified, shaded systems were profitable (Ramírez-Argueta et al., 2022) and could surpass monocultures when accounting for total output (Pérez-Neira et al., 2020; Armengot et al., 2018; Jezeer et al., 2017; Cerda et al., 2014). Others reported that management intensity is more relevant, regardless of species diversity (Blare and Useche, 2013; Pérez-Neira, 2016). Pérez-Neira (2016) found that organic systems were more profitable than semi-intensive systems but less than intensively managed monocrops (i.e. improved varieties, high fertilization doses, moder irrigation systems). In Bolivia, cacao yields and return on labor in conventional and organically managed AFS were similar, while lower yields were reported for organic monocultures than conventional monocultures albeit with similar return on labor due to higher costs of conventional management (Armengot et al., 2016).

We recommend further research on different species arrangements and plant densities that allow the introduction of more short cycle crops and/or other commercially interesting perennial species. The sector would also benefit from developing functional timber value chains in the production regions. Previous studies that analyzed cacao systems with diverse timber associations found that a major share of the revenues may come from the forestry component (Ramírez-Argueta et al., 2022), but we had considerable difficulties identifying functional timber markets in the study areas where farmers could sell these products at competitive prices. In that sense, we believe that attributing too much weight to the revenues from the timber or fruit components to cacao AFS could be risky if it does not consider the full market system in the cacao production regions. Moreover, as discussed by Fountain and Hütz-Adams (2022), diversification brings other challenges in the form of additional investments, technical and labor constraints, and as in the Kichwa chakra model, it may mask economic losses due to poorly managed or aged cacao. Innovative arrangements should be explored for different contexts, where cacao does not need to be the main crop, but at least covers its own production costs.

We observed that partial subsidies could substantially improve the financial performance of the systems. Combining subsidies and well-planned diversification would be particularly helpful for new plantations, as it would reduce risks and improve the cashflow during the initial years. Soft credits have been broadly recommended for addressing farmer's needs (Bonnieux, 2019; Effendy et al., 2019). Nevertheless, thin margins, increasing climate and market risks, low IRR, and high sensitivity of the cacao systems to early revenues suggest that, without sufficient protections (such as subsidies, insurances and/or adequate diversification), farmers would be in considerable risk of failing to repay loans even under low interest rates.

Governments and international cooperation may be persuaded to continue subsidizing the sector, driven by the environmental and social benefits of some cacao production systems (Andres et al., 2016; Franzen and Borgerhoff Mulder, 2007; Löhr et al., 2021; Obeng and Aguilar, 2015). Nevertheless, there might be other crops providing similar benefits at equal or lower costs (Pokorny et al., 2021). Considering that thousands of farmers remain in poverty after decades of support, the main beneficiaries of these subsidies may well be the cacao traders, grinders, chocolate manufacturers and consumers. These actors benefit from artificially lower prices due to subsidies, and at the expense of farmers that perceive land and labor revenues below the market value. We recommend that decision makers carefully analyze the impacts of the different cacao systems before deciding which production systems to support, where and how, prioritizing those with greater social and environmental benefits. Consequently, a larger share of support may come from the industry, as they benefit considerably from development programs, many of them funded by the national budgets of the producer countries.

Our results further highlight the importance of integrating multiple performance indicators, as the objectives of different actors do not necessarily converge. NPV, IRR, BCR, repayment periods and net profits are usually of higher interest for entrepreneurs, investors and other financial sector actors; yields, production costs and minimum prices may be more relevant for traders and the chocolate industry; LEV, minimum farm size and labor productivity are particularly useful for informing land policies and rural development programs, while household income may be of especial interest for farmers, workers and poverty alleviation programs. We also suggest incorporating risk assessments and environmental indicators, which were out of the scope of this study.

5.3. Who is losing?

Various typologies were unprofitable, raising the question why farmers in similar situations continue growing cacao. Seven out of fifteen typologies produced a negative NPV, indicating that they incur net losses (including the financial cost of the invested capital) over a period of 25. Six of them presented net losses in the year of peak production, meaning that the families under these conditions are obtaining labor revenues and land rents below the regional minimums. While these farmers might be better off allocating their labor and land to more profitable enterprises, their permanence as cacao growers may be explained by a mix of individual and contextual factors. Among the individual factors are the advanced age of the farmers and low education levels (Hütz-Adams et al., 2022; Pabón et al., 2016; Sánchez et al., 2019), which limit their capacity to manage more strenuous crops, adopt better practices or engage in other productive activities. Other factors could include the farmer's accrued knowledge of the crop, holding on to past investments (i.e. sunk cost fallacy), a sense of tradition and identification with the cacao culture, and a lack of resources for transitioning to other crops. They may also have additional sources of income and use their farm production only as a complement. On the other hand, it's important to note that cacao has various advantages for farmers, such as a low perishability, relatively less strenuous labor, consistent buyers, and some production throughout the year even with minimum investment in crop management.

Among the contextual factors, the promotion of the crop by the private sector, and a considerable support among public institutions, international cooperation and NGO's are likely to play an important role. This translates into high visibility and a positive perception of the crop, subsidized inputs (e.g. seeds, fertilizers, tools), greater participation in development programs, and greater access to markets, extension services, information, and other support services. The production regions may also have a low demand for agricultural labor, few job opportunities in other sectors, or lack of more profitable crops suitable for the region. Similarly, the land market may not be dynamic enough to allow farmers to rent out or sell their land at high enough prices. All these factors make it unlikely that farmers switch crops or leave agriculture (in the short term), even if their cacao farm is not profitable.

The share of farmers working under conditions similar to the unprofitable typologies included in our study is not known, but considering that average yields in Colombia, Ecuador and Peru are 450 (FEDECACAO, 2023), 610 (European Forest Insititute, 2021) and 966 kg/ha/yr (MIDAGRI, 2023) respectively, a considerable segment of cacao farmers likely experience a similar situation, especially in the first two countries.

5.4. Limitations

The models used were highly sensitive to labor parameters, as labor costs represent around 60 % of the production costs. Since labor intensity came from recalled values reported by farmers, the results could be biased. Moreover, the reported labor intensity varied substantially among typologies, even when discussing similar practices and technification levels. These variations may indicate subjectivity, but could also be explained by differences in topography, varieties, agroecological conditions, or the farmer's skills, age and farm equipment. As mentioned by Fountain and Hütz-Adams (2022), reliable public data on labor input is still absent. However, he found that labor in systems with low productivity ranged between 25 and 85 days/ha/yr. It ranged from 65 to 130 days in plantations with good agricultural practices, and up to 287 days in highly intensive systems. Similarly, Fairtrade (2019) estimated 125 days/ha to produce 800 kg in West Africa. The typologies in our study included between 32 and 110 labor days per hectare, which falls within the previous values.

It is possible that the opportunity costs of labor and land employed in this study are overestimated due to the factors discussed above, resulting in lower net losses and higher NPVs. Nevertheless, changes in these parameters would have a relatively minor effect on the household incomes presented, since these include the opportunity costs.

Additionally, other approaches discount the local wage using employment rates or other relevant variables to have an adjusted opportunity cost of labor. We decided to employ the local values for the opportunity costs as they reflect the rates used in the respective regions and facilitate a straightforward comparison of the crop's performance against other agricultural activities. We observed that some of these opportunity costs are omitted in other studies, as they may not be easily perceived by the farmers. Nevertheless, these are the farmers' most valuable assets. Their inclusion is fundamental for calculating the true cost of production, and in consequence, a fairer price for the sector.

Our models used prices from the first semester of 2023, therefore, the production costs and financial performance presented in this study do not accurately reflect the situation in the previous decades, when most of the plantations were established. Yet, they provide valuable insights into the general conditions of the sector during the most recent years, as international prices had remained at levels near 2500 USD/t in the period 2017–2022. At the price levels observed in the first quarter of 2024, all the analyzed typologies would be profitable, yet there is great uncertainty about the future of the sector, and while analyst predict that cacao prices may stabilize at relatively high levels (Blas, 2024; J.P. Morgan, 2024), a continuous increase in labor costs is also expected. The current crisis should warn chocolate manufacturers that fair prices that allow for a decent living and continuous reinvestments in the productivity and resilience of the plantations are necessary to mitigate similar shocks in the future.

6. Conclusions

Our results indicate that different production systems have the potential to be profitable enterprises and provide a living income. Nevertheless, seven out of the fifteen typologies presented considerable losses, effectively subsidizing cacao prices through land and labor revenues below the market prices. Several contextual and individual factors limit their implementation of better practices or the transition to more profitable enterprises.

Profitability depends on minimum yields, areas and price levels, but there is also considerable diversity of successful strategies. The well performing typologies had yields >800 kg/ha/yr, >3.5 ha of cacao, received considerable income from associated crops in the initial years of establishment, received premium prices for cacao, or perceived low prices for their production factors (mainly land and labor). Highly mixed systems like the Kichwa chakra also showed a good financial performance, but losses due to low cacao yields were masked by the revenues from other crops. Overall, we found that the systems' financial performance was highly sensitive to the results in the initial years, therefore we discussed two strategies that could derive in substantial improvements: exploring different associations with short cycle crops during the initial years and subsidizing establishment costs.

We recommend the use of a broad set of indicators in similar studies, as they offer information relevant for different interest groups. Their inclusion in large regional initiatives as CacaoFIT (Orozco-Aguilar et al., 2024) would provide key insights for the cacao sector in Latin America. Coupling these indicators with measurements of risk and environmental impacts will be especially useful for informing land use policies in the region.

Credit authorship contribution statement

Andrés Charry: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Carolay Perea:** Validation, Investigation, Formal analysis. **Karen Ramírez:** Writing – review & editing, Writing – original draft, Validation, Investigation, Formal analysis, Data curation. **Guillermo Zambrano:** Writing – review & editing, Writing – original draft, Validation, Investigation, Formal analysis, Data curation. **Fredy Yovera:** Validation, Investigation. **Adriana Santos:** Writing – review & editing, Validation, Resources, Investigation. **Tito Jiménez:** Validation, Investigation. **Miguel Romero:** Methodology. **Mark Lundy:** Writing – review & editing, Resources, Conceptualization. **Marcela Quintero:** Supervision, Resources, Project administration, Funding acquisition. **Mirjam Pulleman:** Writing – review & editing, Supervision, Resources, Project administration, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

This study was supported by the DeSIRA Initiative of the European Union (grant no. FOOD/2019/407-158) through the project "Clima-LoCa" (Fostering low cadmium and climate-relevant innovations to enhance the resilience and inclusiveness of the growing cacao sectors in Colombia, Ecuador and Peru); and by the International Climate Initiative (IKI), of the German Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety (BMU) through the project "Sustainable Amazon Businesses" (18_III_101_PER_M_Drivers of Deforestation). Both projects were coordinated by the Alliance of Bioversity International and CIAT. The contents of this document are the sole responsibility of the researchers and can under no circumstances be regarded as reflecting the position of the European Union. The authors acknowledge the continuous support of the producers, extensionists and representatives from the cacao value chains of Boyacá, Putumayo, Guayas, Napo, Piura and Ucayali, who contributed with their knowledge, time and expertise throughout this research.

References

Abbott, P.C., Benjamin, T.J., Burniske, G.R., Croft, M.M., Fenton, M., Kelly, C.R., Lundy, M., Rodriguez Camayo, F., Wilcox, M.D., 2018. An analysis of the supply chain of cacao in Colombia. United States Agency for International Development - USAID, Cali, CO, p. 208.

Acero, L.A.L., 2020. Sostenibilidad y cadenas agroproductivas de cacao en el Perú perspectivas desde las regiones Piura y San Martín. Nova Rev. Amaz. Bragança 8 (1), 179–189. https://doi.org/10.18542/nra.v8i1.8626.

Agronet., 2023. Estadísticas sectoriales [Database]. Colombia. Retrieved from. https://www.agronet.gov.co/estadistica/Paginas/home.aspx?cod=20.

ALIGN. (n.d.). Guidance Tool on Living Wages and Living Income. Retrieved from https://align-tool.com/ (in June 10, 2023).

Andersen, L.E., Andersen, N.N., Anker, R., Anker, M., 2022. Living Incomes Rural Areas and Small Towns of Coffee and Cocoa Growing Regions of Cajamarca, Cusco, Junin, and San Martin, Peru.

Andres, C., Comoé, H., Beerli, A., Schneider, M., Rist, S., Jacobi, J., 2016. Cocoa in monoculture and dynamic agroforestry. Sustain. Agric. Rev. 19, 121–153. https://doi.org/10.1007/978-3-319-26777-7_3.

Anecacao. (n.d.). Historia del cacao. Retreived from https://anecacao.com/cacao-en-el-ecuador/historia-del-cacao/.

Armengot, L., Barbieri, P., Andres, C., Milz, J., Schneider, M., 2016. Cacao agroforestry systems have higher return on labor compared to full-sun monocultures. Agron. Sustain. Dev. 36, 1–10.

Armengot, L., Barbieri, P., Andres, C., Milz, J., Schneider, M., 2018. Comparing productivity and profitability of agroforests and monocultures in Bolivia. In: 2017 International Symposium on Cocoa Research (ISCR), Lima, Peru, 13-17 November 2017.

Barrios Nieves, O., 1981. Origen, expansión y situación actual del cacao. ICA. Retrieved from. https://repository.agrosavia.co/handle/20.500.12324/13384.

Benchmark, Agri, 2005. Agri Benchmark Cash Crop A Standard Operating Procedure to Define Typical Farms. Braunscweig, Germany. Retrieved from. https://literatur.thuenen.de/digbib_extern/dk038513.pdf.

Bermudez, S., Voora, V., Larrea, C., Luna, E., 2022. Global Market Report. Cocoa Prices and Sustainability. International Institute for Sustainable Development. Retrieved from. https://www.iisd.org/system/files/2022-11/2022-global-market-report-cocoa.pdf.

Blare, T., Useche, P., 2013. Competing objectives of smallholder producers in developing countries: examining cacao production in northern Ecuador. Environ. Econ. 4 (1), 72–80.

Blas, J., 2024. The Meltdown in Chocolate is Coming as Prices Signal Supply Shortages. The Japan Times. https://www.japantimes.co.jp/commentary/2024/03/13/world/chocolate-meltdown/.

Bonnieux, G., 2019. Access to Finance for Cocoa Farmers. Access to Finance Working Group, Swiss Platform for Sustainable Cocoa, Bern, Switzerland.

Caicedo-Vargas, C., Pérez-Neira, D., Abad-González, J., Gallar, D., 2022. Assessment of the environmental impact and economic performance of cacao agroforestry systems in the Ecuadorian Amazon region: an LCA approach. Sci. Total Environ. 849, 157795. https://doi.org/10.1016/j.scitotenv.2022.157795.

Cerda, R., Deheuvels, O., Calvache, D., Niehaus, L., Saenz, Y., Kent, J., Vilchez, S., Villota, A., Martinez, C., Somarriba, E., 2014. Contribution of cocoa agroforestry systems to family income and domestic consumption: looking toward intensification. Agrofor. Syst. 88 (6), 957–981. https://doi.org/10.1007/s10457-014-9691-8.

Charry, A., Atkinson, R., Junca, J., Perea, C., Thomas, E., Pulleman, M., 2023. Effects of the EU Food Safety Regulation on Cadmium on the Cacao Value Chains of Colombia, Ecuador, and Peru. Briefing Note No. 4. International Center for Tropical Agriculture (CIAT), Cali, Colombia, p. 14.

Chibanda, C., Agethen, K., Deblitz, C., Zimmer, Y., Almadani, M.I., Garming, H., Rohlmann, C., Schütte, J., Thobe, P., Verhaagh, M., Behrendt, L., Staub, D.T., Lasner, T., 2020. The typical farm approach and its application by the Agri Benchmark network. Agriculture 10 (12). https://doi.org/10.3390/agriculture10120646. Article 12.

CIMA, 2017. Ucayali: Sinergias por el clima. Centro de Conservación, Investigación y Manejo de Áreas Naturales-CIMA Cordillera Azul, Lima, Perú, p. 28.

DANE (Departamento Administrativo Nacional de Estadística), 2022. Comunicado de prensa. Pobreza monetaria Año 2021.

Effendy, Pratama M.F., Rauf, R.A., Antara, M., Basir-Cyio, M., Mahfudz, Muhardi, 2019. Factors influencing the efficiency of cocoa farms: a study to increase income in rural Indonesia. PLoS One 14 (4), e0214569. https://doi.org/10.1371/journal.pone.0214569.

Elliott, F.F., 1928. The“ representative firm” idea applied to research and extension in agricultural economics. J. Farm Econ. 10 (4), 483–498.

European Forest Insititute, 2021. Diagnóstico de la cadena de valor del cacao, y mapeo de los indicadores y sistemas de información existentes. Resultado del diagnóstico participativo en Ecuador. Retrieved from. https://euredd.efi.int/wp-content/uploads/2022/09/Informe-1_Diagnostico-cadena-Cacao_Ecuador.pdf.

Fairtrade, 2019. Fairtrade Living Income Reference Prices for Cocoa An explanatory note (revised version 2019). Retrieved from. https://files.fairtrade.net/2019_RevisedExplanatoryNote_FairtradeLivingIncomeReferencePriceCocoa.pdf.

Fairtrade, 2022. Fairtrade Living Income Reference Prices for Cocoa update October 2022. Retrieved from. https://files.fairtrade.net/Fairtrade-Living-Income-Reference-Price-for-Cocoa-adjustment-update-1-Oct-2022.pdf.

FEDECACAO (Federación Nacional de Cacaoteros), 2023. Estadísticas nacionales. Retrieved from. https://www.fedecacao.com.co/economianacional.

Feuz, D.M., Skold, M.D., 1992. Typical farm theory in agricultural research. J. Sustain. Agric. 2 (2), 43–58.

Fountain, A.C., Hütz-Adams, F., 2022. 2022 Cocoa Barometer.

Franzen, M., Borgerhoff Mulder, M., 2007. Ecological, economic and social perspectives on cocoa production worldwide. Biodivers. Conserv. 16, 3835–3849. https://doi.org/10.1007/s10531-007-9183-5.

Gaia Cacao, B.V., 2021. Global Cocoa Market Study. International Executive Service Corps. https://iesc.org/2021-global-cocoa-market-studies.

Gockowski, J., Afari-Sefa, V., Sarpong, D.B., Osei-Asare, Y.B., Dziwornu, A.K., 2011. Increasing income of Ghanaian cocoa farmers: is introduction of fine flavour cocoa a viable alternative. Quart. J. Intern. Agric. 50 (892–2016–65197), 175–200. https://doi.org/10.22004/ag.econ.155531.

Gockowski, J., Afari-Sefa, V., Sarpong, D.B., Osei-Asare, Y.B., Agyeman, N.F., 2013. Improving the productivity and income of Ghanaian cocoa farmers while maintaining environmental services: what role for certification? Int. J. Agric. Sustain. 11 (4), 331–346. https://doi.org/10.1080/14735903.2013.772714.

Gómez, R., García, R., Tong, F., González, C., 2014. Paquete tecnológico del cacao fino de aroma. Oficina de las Naciones Unidas contra la Droga y el Delito para el Perú y el Ecuador – UNODC.

Guilcapi, M., 2018. Análisis del estado actual de las cadenas de café y cacao. In: Producto 2: Cacao. In: https://procurement-notices.undp.org/view_file.cfm?doc_id=186105.

Hütz-Adams, F., Campos, P., Fountain, A.C., 2022. Barómetro del cacao - Base de referencia para Latinoamérica, 2022.

ICCO (International Cocoa Organization), 2023. ICCO Quarterly Bulletin of Cocoa Statistics, Vol. XLIX, No.2, Cocoa year 2022/23.

IGAC (Instituto Geográfico Agustin Codazi)., 2004. Mapa Digital de Suelos del Departamento de Boyacá, República de Colombia. Escala 1:100.000.

INEC (Instituto Nacional de Estadistica y Censos), 2021. Encuesta Nacional de Empleo, Desempleo y Subempleo 2021 (ENEMDU). Indicadores de Pobreza y Desigualdad.

Ingram, V., van Rijn, F., Waarts, Y., Gilhuis, H., 2018. The impacts of cocoa sustainability initiatives in West Africa. Sustainability 10 (11), 4249. https://doi.org/10.3390/su10114249.

Instituto Nacional de Estadística e Informática (INEI), 2023. Perú: Evolución de la pobreza monetaria 2011–2022. Informe técnico.

Jezeer, R.E., Verweij, P.A., Santos, M.J., Boot, R.G., 2017. Shaded coffee and cocoa–double dividend for biodiversity and small-scale farmers. Ecol. Econ. 140, 136–145.

Kimball, S., 2024. Cocoa Prices are Soaring to Record Levels. What it Means for Consumers and Why 'The Worst is Still Yet to Come'. CNBC. https://www.cnbc.com/2024/03/26/cocoa-prices-are-soaring-to-record-levels-what-it-means-for-consumers.html.

Lasner, T., Brinker, A., Nielsen, R., Rad, F., 2017. Establishing a benchmarking for fish farming – profitability, productivity and energy efficiency of German, Danish and Turkish rainbow trout grow-out systems. Aquac. Res. 48 (6), 3134–3148. https://doi.org/10.1111/are.13144.

Löhr, K., Aruqaj, B., Baumert, D., Bonatti, M., Brüntrup, M., Bunn, C., Weinhardt, M., 2021. Social cohesion as the missing link between natural resource management and peacebuilding: lessons from cocoa production in Côte d'Ivoire and Colombia. Sustainability 13 (23), 13002. https://doi.org/10.3390/su132313002.

Londoño Vélez, S., 2017. Industrialización del cacao en el siglo XX: de la artesanía a la gran industria. BANREPCULTURAL. Retrieved from. https://www.banrepcultural.org/biblioteca-virtual/credencial-historia/numero-130/industrializacion-del-cacao-en-el-siglo-xx.

MAG, 2022. Cifras agroproductivas. Sistema de Información Púbica Agropecuaria. Ecuador. Retrieved from. http://sipa.agricultura.gob.ec/index.php/cifras-agroproductivas.

MAG (Ministerio de Agricultura y Ganadería), 2023. Ficha del cultivo de cacao. Sistema de Información Pública Agropecuaria. http://sipa.agricultura.gob.ec/index.php/cacao.

Mahrizal, Nalley L., Dixon, B., Popp, J., 2012. Necessary Price premiums to incentivize Ghanaian organic cocoa production: A phased, orchard management approach. HortScience 47, 1617–1624. https://doi.org/10.21273/HORTSCI.47.11.1617.

MATE, GIZ, 2020. La chakra kichwa amazónica. Retrieved from. https://www.ambiente.gob.ec/wp-content/uploads/downloads/2020/07/La-chakra-kichwa-amazonica.pdf.

MIDAGRI (Ministerio de Desarrollo Agrario y Riego), 2021. Plan Nacional de Desarrollo de la Cadena de Valor de Cacao-Chocolate al 2030.

MIDAGRI (Ministerio de Desarrollo Agrario y Riego), 2023. Sistema Integrado de Estadística Agraria [Database]. Retrieved from de. https://siea.midagri.gob.pe/portal/.

Morgan, J.P., 2024, April 3. Will Rising Cocoa Prices Trigger a Chocolate Crisis? JPMorgan. https://www.jpmorgan.com/insights/global-research/commodities/cocoa-prices.

Napo, G.A.D., 2015. Plan de Desarrollo Provincial y de Ordenamiento Territorial. Gobierno Autónomo Descentralizado Provincial de Napo.

Obeng, E.A., Aguilar, F.X., 2015. Marginal effects on biodiversity, carbon sequestration and nutrient cycling of transitions from tropical forests to cacao farming systems. Agrofor. Syst. 89, 19–35. https://doi.org/10.1007/s10457-014-9739-9.

Orozco-Aguilar, L., Lopez-Sampson, A., Cerda, R.H., Casanoves, F., Ramirez-Argueta, O., Diaz Matute, J., Somarriba, E., 2024. CacaoFIT: the network of cacao field trials in Latin America and its contribution to sustainable cacao farming in the region. Front. Sustain. Food Syst. 8, 1370275. https://doi.org/10.3389/fsufs.2024.1370275.

Pabón, M., Herrera-Roa, L., Sepúlveda, W., 2016. Caracterización socio-económica y productiva del cultivo de cacao en el departamento de Santander (Colombia). Rev. Mexicana Agroneg. 38 (1345–2016–104520), 283–294.

Pérez-Neira, D., 2016. Energy efficiency of cacao agroforestry under traditional and organic management. Agron. Sustain. Dev. 36 (3), 49. https://doi.org/10.1007/s13593-016-0386-6.

Pérez-Neira, D., Schneider, M., Armengot, L., 2020. Crop-diversification and organic management increase the energy efficiency of cacao plantations. Agric. Syst. 177, 102711. https://doi.org/10.1016/j.agsy.2019.102711.

Pérez-Zuñiga, J.I., Rojas-Molina, J., Zabala-Perilla, A.F., 2021. Plant spacing assessment in cocoa (Theobroma cacao L.) agroforestry systems in the Colombian Pacific region. Agron. Colomb. 39 (3), 426–437. https://doi.org/10.15446/agron.colomb.v39n3.90131.

Pokorny, B., Robiglio, V., Reyes, M., Vargas, R., Carrera, C.F.P., 2021. The potential of agroforestry concessions to stabilize Amazonian forest frontiers: a case study on the economic and environmental robustness of informally settled small-scale cocoa farmers in Peru. Land Use Policy 102, 105242. https://doi.org/10.1016/j.landusepol.2020.105242.

Prefectura de Guayas, 2021. Plan de Desarrollo y Ordenamiento Territorial de la Provincia del Guayas. Retrieved from. https://guayas.gob.ec/wp-content/uploads/2021/08/2021-08-20-PDOT-Guayas.pdf.

Prefectura de Napo, 2020. Plan de Desarrollo y Ordenamiento Territorial de Napo. Prefectura de Napo. Retrieved from. https://www.napo.gob.ec/website/index.php/transparencia/plan-de-ordenamiento-territorial.

Ramírez-Argueta, O., Orozco-Aguilar, L., Dubón, A.D., Díaz, F.J., Sánchez, J., Casanoves, F., 2022. Timber growth, cacao yields, and financial revenues in a long-term experiment of cacao agroforestry systems in northern Honduras. Front. Sustain. Food Syst. 6. https://doi.org/10.3389/fsufs.2022.941743.

Riar, A., Goldmann, E., Bautze, D., Rüegg, J., Bhullar, G.S., Adamtey, N., Armengot, L., 2024. Farm gate profitability of organic and conventional farming systems in the tropics. International Journal of Agricultural Sustainability 22 (1), 2318933. https://doi.org/10.1080/14735903.2024.2318933.

Rüegg, J., Yana, W., Yana, A., Choque, B., Campos, C., Milz, J., 2024. Dynamic cocoa agroforestry: 25 years of experience in alto Beni, Bolivia. Agroforest. Work 62, 59.

Sánchez, V., Zambrano, J.L., Iglesias, C., Rodríguez, E., Villalobos, V., Díaz, F.J., Carrillo, N., Gutiérrez, A., Camacho, A., Rodríguez, O., 2019. La cadena de valor del cacao en América Latina y el Caribe. FONTAGRO, ESPOL, INIAP.

Sellers, S., Bilsborrow, R., 2019. Agricultural technology adoption among migrant settlers and indigenous populations of the northern Ecuadorian Amazon: are differences narrowing? J. Land Use Sci. 14. https://doi.org/10.1080/1747423X.2020.1719225.

Thomas, E., Lastra, S., Zabaleta, D., 2023. Catálogo de cacaos de Perú. Bioversity International y MOCCA, Lima Perú.

Villar, G., Yovera, F., Pezo, A., Thomas, E., Roscioli, F., Sandy Da Cruz, R., Jiménez, E., Lopez, A., Aguilar, F., Espinoza, E., Davila, C., Chavez Hurtado, C.R., Lastra, S., Zavaleta, D., Charry, A., Atkinson, R., 2022. Caracterización socioeconómica de las cadenas de valor de cacao con énfasis en la problemática de cadmio en Piura y Huánuco, Perú. Bioversity International, Lima (Perú), p. 72.

van Vliet, J.A., Slingerland, M.A., Waarts, Y.R., Giller, K.E., 2021. A living income for cocoa producers in Côte d'Ivoire and Ghana? Front. Sustain. Food Syst. 5, 732831. https://doi.org/10.3389/fsufs.2021.732831.

Zambrano, G., Ramírez, K., Santos, A., Charry, A., Chávez, E., 2022. Caracterización de tipologías de agricultores de cacao de los cantones Tena y Naranjal en Ecuador: indicadores financieros y modelos de negocios. Publicación CIAT No. 539. Centro Internacional de Agricultura Tropical (CIAT), Cali (Colombia), p. 58.