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Evidence of agroecology's contribution to mitigation, adaptation, and resilience under climate variability and change in Latin America

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ABSTRACT

Agroecology is highly promoted in research and development discourse as a holistic and effective response to climate change. The objective of this study is to contribute to the analysis of the existing evidence that agroecology enables climate change (CC) adaptation and mitigation in the agricultural systems of Latin America, a region known for pioneering the development of this science, praxis, and movement. We applied the PRISMA method to analyze the existing literature providing such evidence. Stakeholder interviews were used to obtain in-depth perceptions of agroecology's contributions to CC adaptation and mitigation from a wide range of actors and development practitioners based in Colombia, Ecuador, and Peru: farmers, NGO representatives, researchers, university program leaders, and public officials. From a total of 1821 initially identified articles, 62 were screened, and 24 case studies analyzed for methods and evidence provided. Twenty-six stakeholders were interviewed. Combining quantitative and qualitative assessment methods, the scientific literature shows that agroecological systems are appreciated for addressing resilience in a systemic way hence not just climate change per se. Mitigation was generally assess by quantitative approaches. Integrating stakeholders' discourse to our analysis highlighted their knowledge of underlying processes contributing to farm CC resilience, where crop and animal diversification and integration of trees into farming systems are central. Stakeholders attributed agroforestry and less use of synthetic fertilizers as important roles for mitigation. Our study highlights the pertinence of combining systematic analyses of the evidence and perceptions drawn from a plurality of stakeholders to recognize the positive contribution of agroecology to climate change adaptation and resilience. However, it also pointed to future research that further assesses the specific trade-offs and synergies between agroecological practices, mitigation, and resilience at multiple scales. This will be important to mobilize and

KEYWORDS
Agroecological systems; systematic literature review; stakeholder interviews; Colombia; Ecuador; Peru

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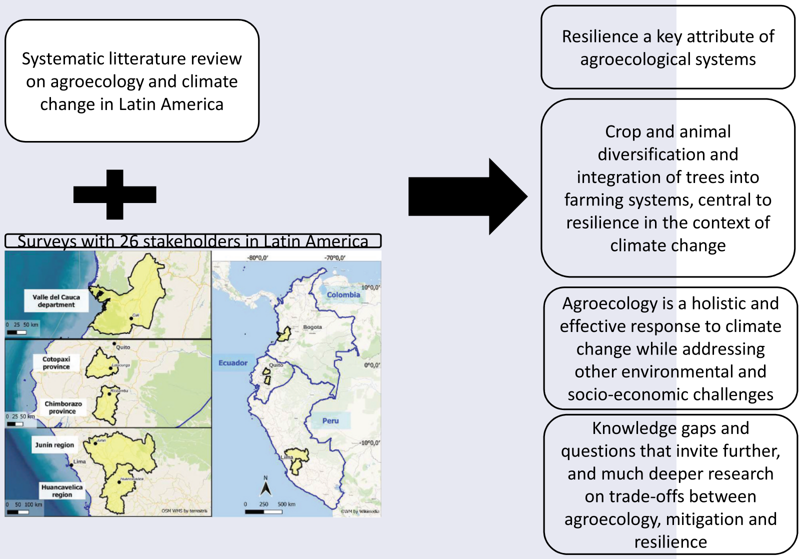
better orient the support from public institutions and donors that remains lacking on the ground.



Introduction

Agroecology is widely recognized as an alternative paradigm to industrial agriculture (Altieri 1989; Duru, Therond, and Fares 2015; Wezel et al. 2020) and as a scientific discipline anchored on a set of principles and practices that draw from the local know-how of traditional smallholder farmers and indigenous communities (Altieri and Toledo 2011). In its early stage of development, agronomic and ecological principles were emphasized: 1) enhancing recycling of biomass; 2) strengthening the immune system of soils, crops, and animals; 3) providing optimal soil conditions for plant growth; 4) minimizing losses of energy, water, and nutrients through conservation and regeneration; 5) diversifying species and genetic resources; and 6) enhancing beneficial biological interactions and synergies (Altieri 1983, 1999; Nicholls, Altieri, and Vazquez 2016). Yet, and most recently, agroecology also stands for a social movement with manifold political vindications worldwide (Wezel et al., 2020). By addressing concurrent issues like environmental conservation, social justice, and economic rural development systemically and at multiple scales, agroecology is also at the forefront of the shift toward sustainable food systems (Gliessman 1993).

Various authors make the case for agroecology as a response to climate change (Altieri et al. 2015; Saj et al. 2017; Sinclair et al. 2019). In terms of adaptation in the face of extreme climate events, smallholder farmers have historically deployed agroecology-based practices that draw from their local, traditional knowledge systems (Goland 1993; Altieri and Nicholls 2017; Baldinelli 2014; Holt-Giménez 2002). While the capacity of agroecology-based farming systems to buffer the effects of climate change through carbon sequestration and the reduction of greenhouse gas (GHG) emissions has been investigated, albeit not amply (Betancourt 2020; Machado-Vargas, Nicholls-Estrada, and Ríos-Osorio 2018; Turbay et al. 2014). Indeed, although agroecology is high on the development agenda, knowledge gaps remain that warrant a closer look at the specific benefits that agroecology brings to agricultural systems.

In Latin America, agriculture makes a significant contribution to climate change. Practices focused mostly on monocropping, which include large extensions and applications of synthetic fertilizers, insecticides, and fungicides, lead to almost 50% of GHG emissions and the consumption of 75% of the freshwater sources in the region (Smith et al. 2014). On account of drastic changes in land use (i.e. deforestation), soil degradation, and exacerbated climatic variability, Latin America currently shows one of the highest rates of biodiversity loss on the planet (94%), and along with it the degradation of ecosystems (De Sy et al. 2015; WWF 2022). The region is also one of the worst performers in terms of rural poverty reduction, access to land, and land distribution, which poses significant repercussions on its future prospects of economic prosperity and development (Berdegué and Fuentealba 2014; Bauluz, Govind, and Novokmet 2020). The expansion of agroexport crops and biofuels prevails in Latin America – the result of policies that incentivize productive performance based on economies of scale and yield maximization with synthetic inputs and conventional practices (Casimiro 2016; Rosset 2009). Despite this, agroecology continues to be widely promoted by grassroots networks and development institutions as *the* alternative, wary of agriculture's dependence on oil, and advocating for food system sustainability.

The foundations of agroecology in Latin America lie on the heritage of its ancient civilizations, with indigenous farming practices such as *chinampas* in Mexico, *waru warus*, and terracing systems in the Andes kept alive to this day and, with them, their provision of key ecosystem services (Deaconu et al. 2021; Fonte et al. 2012). Today, this legacy of cultural diversity and socioecological heterogeneity can be appreciated in its smallholder farmers across approximately 16.5 million farms (FAO 2014). Meanwhile, as a movement that challenges the *statu quo*, agroecology has been most visible and advanced by farmer organizations in Brazil, the Andes, Central America, Cuba, and Mexico (Altieri and Toledo 2011). Despite advances in its conceptualization, definition, and institutional support of agroecology through field experimentation and replication with smallholders (Chappell et al. 2018; SIFOR 2013; Olivera and Popusoi 2021; McNight Foundation 2022), the lack of systematic evidence pertaining to the benefits of agroecological practices is purportedly the greatest limitation to support their implementation and scaling through policy commensurate with its demonstrated potential (Snapp et al. 2021). On the other hand, as some have argued, the scant economic resources that have been historically devoted to research in this domain have done little to alleviate this situation (Tittonell 2014).

In view of the urgent need, in Latin America and beyond, to effectively address climate change and food system sustainability, assembling the evidence on the contributions – or limitations – of agroecology in the face of climate variability and change can help identify future areas of research and development in support of smallholder farmers and communities of practice in Latin America. This is also important to inform and orient decision makers at the pertinent scales in the region. Therefore, the objective of this paper is to systematically gather and analyze the existing evidence that agroecology makes a significant contribution to climate change (CC) adaptation and mitigation in the agricultural systems of Latin America.

Firstly, we applied a systematic review of the scientific literature to unearth the evidence of agroecology – as principles and practices applied to farming systems – contributing to climate change adaptation and mitigation in Latin America. Secondly, we undertook stakeholder interviews to investigate perceptions of agroecology's benefits in three study sites: Valle del Cauca department in Colombia, Chimborazo province in Ecuador, and Junín region in Peru. Farmers, researchers, NGO representatives, and municipal and regional government officials from each site were interviewed to complement the review findings by providing an additional layer of context-specific and experiential information.

Methods

Systematic literature review

A compilation and progressive filtering analysis of scientific publications was conducted with the PRISMA exploratory methodology. English, Spanish, and Portuguese articles were included using the bibliographic databases: ScienceDirect (19–, 2021), Scopus (19–, 2021), SciHub (19–, 2021), Springer (19–, 2021), and Google Scholar (19–, 2021). To be selected, articles had to be (i) peer-reviewed publications and (ii) could include any year up to the

Table 1. Terms applied to the article search on agroecology as evidence of climate change mitigation and adaptation in Latin America.

Main search terms	1. Resilience	4. Agroecology	8. Latin America	11. Indigenous
	2. Adaptation	5. Agroecological practices	9. South America	12. Peasant
	3. Mitigation	6. Agroecological farming system	10. Central America	
Combination of terms	1 or 2 or 3	4 or 5 or 6	8 or 9 or 10	11 or 12

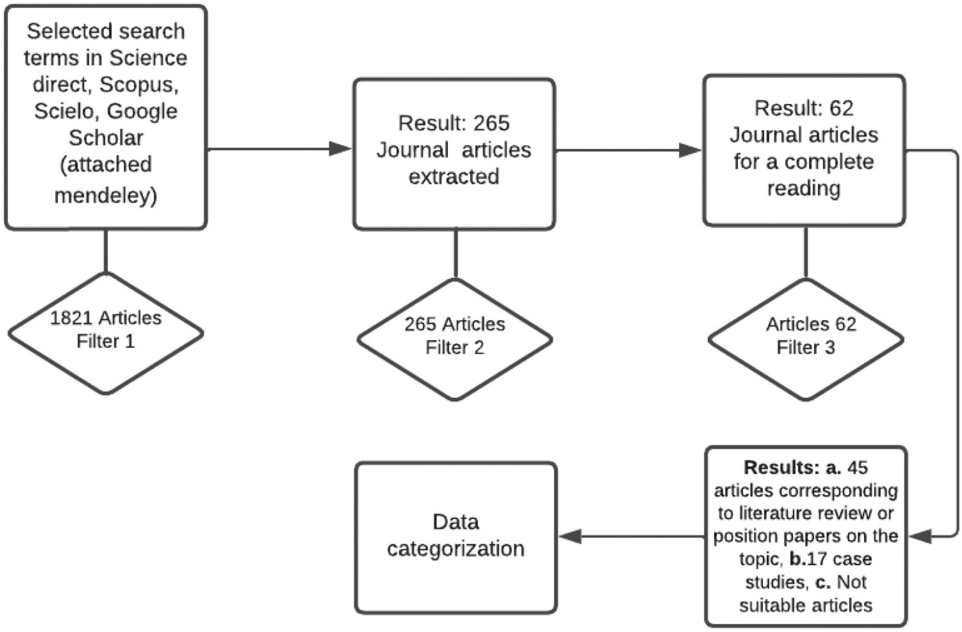


Figure 1. Article selection process using PRISMA exploratory methodology.

current year (2021). The search terms used were: (1) Agroecology, (2) Adaptation, (3) Mitigation, (4) Resilience, and (5) Latin America, with possible variations (Table 1).

The first filter (Filter 1: $n = 1821$, Figure 1) consisted in identifying articles based on the search terms.

The second filter (Filter 2: $n = 265$, Figure 1) consisted in revising each title and abstract to determine if the articles resulting from the main search were pertinent or impertinent. Only studies that delivered the main search terms or their variants and studies on Central and South America were considered.

The third filter (Filter 3: $n = 62$, Figure 1) consisted of fully reading the identified articles to determine whether they were indeed relevant to the research per the terms originally defined for the search. The information of interest was located and extracted while reading each of these articles. At this stage, additional studies were considered on the basis of expert suggestion. These studies did not explicitly mention the term agroecology (or its possible variations) into the abstract or title but rather agroforestry or silvopastoral systems.

To analyze and compare the content of the articles selected following Filter 3 ($n = 62$) we used two main variable domains: (1) specific practices or agroecological systems considered; (2) outcomes of these practices and systems in terms of CC adaptation and mitigation (Table 2). Below we break down each domain into its specific variables.

Table 2. Variables and subvariables used to analyze the selected 17 articles following Filter 3.

Bibliometric Variables	Practices	Agroecosystems	Climate resilience	Climate mitigation
	Subvariables	**Subvariables**		
Authors	Biodiversity Management	Crop, Livestock & Integration	Existing evidence on the link between agroecology and climate resilience	Existing evidence on the link between agroecology and climate mitigation
Title	Water management	Integration with Trees		
Year	Soil Fertility Management	Intercropping (Association)	No evidence	No evidence
Volume & Page	Pest & Diseases Management	Urban & Periurban Agroecology		
DOI	Carbon Storage			
Journal				
Key Words				

Agroecological practices

Agroecological practices inhabit systems, are context-specific, and are typically not conceived and applied in isolation. Importantly, these practices sustain interactions and ecological processes that facilitate ecosystem services at scales beyond the field. While there is not a fixed set of practices, techniques such as crop rotations, intercropping, mulching, hedges, and ecological corridors are common. These, among others, are based on the management of local resources to enhance soil fertility, optimize water resources, and break pest and disease cycles whilst maintaining the capacity to produce food (Snapp and Pound 2008; Tittonell 2014).

Agroecosystems

Agroecosystems include both a spatial and temporal arrangement of domesticated plants and animals that are intentionally included by farmers and interact with the associated diversity of fauna and flora colonizing the agroecosystem (Altieri 1999; Power 2013; Scow 1997; Tixier et al. 2013). It is at this scale that the structure and function of agricultural systems is typically designed following agroecological principles (Gliessman 1993).

Climate adaptation, resilience

We analyzed whether or not the paper produced qualitative or quantitative data on the contribution of agroecological systems to the adaptation or resilience of agroecosystems to climate change.

Climate mitigation

We analyzed whether or not the paper produced qualitative or quantitative data on the contribution of agroecological systems to climate change mitigation.

To better describe the methods and tools used to generate the evidence on the link between agroecology and climate change, we broke down each variable (i) to (iv) above into sub-variables corresponding to their various forms of implementation (Table 2).

Each article resulting from Filter 3 (62 articles eligible) was categorized according to the defined variables and sub-variables, where the article in question could address one or more variables and sub-variables. For example, an article could contribute to biodiversity management and soil fertility management (sub-variables under "Practices").

Stakeholders' perceptions of agroecology's contributions to CC adaptation and mitigation

Site selection

We identified local partners in Colombia, Ecuador, and Peru based on their experience in agroecology as determined by five main criteria: (a) NGO or farmer organization with track record practicing agroecology, (b) proximity to intermediary cities and markets, (c) institutional articulation (e.g., with universities, communities of practice, consumer networks, movements), (d) potential to scale agroecological practices, and (e) interest to participate in the study (Figure 2).

The NGOs EkoRural in Ecuador and Centro de Apoyo Rural (CEAR) in Peru, and the smallholder association Red de Mercados Agroecológicos Campesinos del Valle del Cauca (REDMAC) met these criteria, with each representing a distinct geography with agricultural production zones and specific sites in Chimborazo and Cotopaxi provinces (Ecuador); Huancavelica and Junín regions (Peru); and Valle del Cauca department (Colombia). In most of these sites, the pattern of rainfall has changed in the last 10 years compared to the one observed between 1964 and 2020. For example, at the site of Chimborazo, the annual rainfall decreased by 20% and the coefficient of variation increased by 15% (Navarro-Racines et al. 2021). In Colombia, no major changes have been observed but the variability of the average rainfall remained high with a coefficient of variation of 20%.

Stakeholder interviews

For each study site, we aimed to include a diversity of experiences and perceptions on the contributions of agroecology to CC adaptation and mitigation. Stakeholders included in these interviews fell under one of the following categories: 1) Farmers (individual or representing an association), 2) NGO or foundation representatives, 3) Researchers or

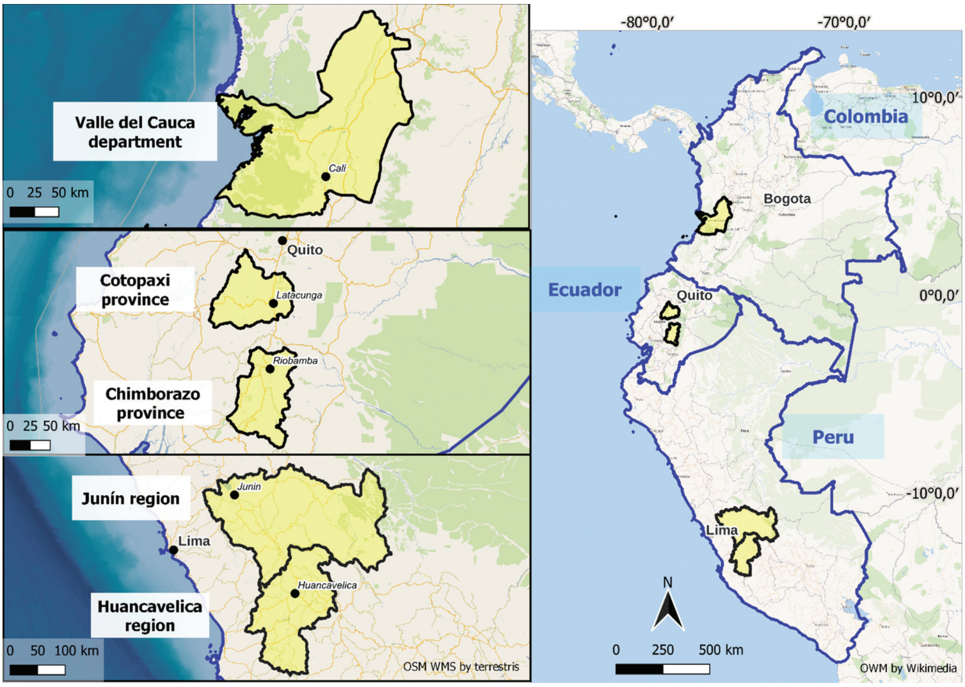


Figure 2. Location of the study sites.

Table 3. Categories of interviewed stakeholders per study site.

	Perú (Junín) *N*=7	Colombia (Valle del Cauca) *N*=10	Ecuador (Chimborazo) *N*=9
Farmers	1	3	2
NGOs, Foundations	3	3	2
Researchers or university program leaders	2	2	3
Public officials	1	2	2

university program leaders, and 5) Public officials (Table 3). Each interview was arranged with prior informed consent, following the approval and ethical procedures of the Institutional Review Board of the Institutional Review Board of the Alliance Bioversity-CIAT (Reference #2021-IRB05).

Twenty-six interviews were carried out virtually between July and August of 2021 through the Zoom platform. Each interview lasted between 1 h and 2 hand included voice recording. During the session, information was collected by the interviewer on an Excel template.

The interviews included open-ended questions. Interviewees were prompted to mention any economic, social, and environmental outcomes of these agroecological practices, and then specifically in terms of CC adaptation and mitigation. Stakeholder responses were categorized and analyzed as to potential differences across stakeholder categories and study sites.

Table 4. Main characteristics of the case studies analyzed.

AUTHORS	LOCATION	PRACTICES	AGROECOLOGICAL SYSTEMS
Acosta-Alba, Chia, and Andrieu (2019)	Colombia	Soil fertility management, Biodiversity management	Intercropping, Tree integration
Acosta-Alba et al. (2020)	Colombia	Biodiversity management	Intercropping, Tree integration
Baldinelli (2014)	Bolivia	Biodiversity management	Intercropping
Betancourt (2020)	Cuba	Soil fertility Management	Intercropping, Crop-livestock Integration
Bielecki and Wingenbach (2019)	Centro América	–	Intercropping, Tree integration
Calleros-Islas (2019)	México	Soil fertility Management, Water Management, Biodiversity Management	–
Cuartas et al. (2014)	Colombia, Mexico	Biodiversity management	Tree integration
Cerda et al. (2017)	Costa Rica	Biodiversity management	Tree integration
Do Carmo Loch et al. (2020)	Amazonas	Biodiversity management	Intercropping, Tree integration
Falkowski, Chankin, and Diemont (2020)	Mexico	Biodiversity Management	Intercropping, Tree integration
Hergoualc'h et al. (2012)	Costa Rica	Biodiversity Management	Tree integration
Hochachka (2021)	Guatemala	-	Tree integration
Holt-Giménez (2002)	Nicaragua	Soil fertility Management, Water Management, Biodiversity Management	Intercropping, Tree integration
Kearney et al. (2019)	El Salvador	Soil fertility Management, Water Management, Biodiversity Management	Intercropping, Tree integration
Machado-Vargas, Nicholls-Estrada, and Ríos-Osorio (2018)	Colombia	Soil Fertility management, Biodiversity management	Intercropping
Murgueitio et al. (2015)	Colombia, México	Biodiversity management	Tree integration
Notaro et al. (2022)	Nicaragua	Biodiversity management	Tree integration
Velasco Palacios et al. (2023)	Honduras	-	Intercropping, Tree integration
Rodríguez et al. (2017)	Colombia	Soil Fertility Management	–
Rogé et al. (2014)	México	Soil Fertility management, Biodiversity management	Intercropping
Rogé and Astier (2015)	México	Soil Fertility management, Biodiversity management	Intercropping
Rossing, Modernel, and Tittonell (2014)	Argentina, Brazil, Paraguay, Uruguay	Biodiversity management	Natural grassland-based livestock farming
Somarriba et al. (2013)	Nicaragua, Honduras, Guatemala, Costa Rica, Panama	Soil Fertility Management	Intercropping, Tree integration
Turbay et al. (2014)	Colombia	Biodiversity Management, Soil Fertility Management	Tree integration

Results

Number and types of articles reviewed

Filters 1 and 2 generated 1861 and 265 articles, respectively. Sixty-two of these articles were considered relevant following the defined criteria and proceeded to the next stage of full reading and application of Filter 3 (Figure 1). Most of these 62 articles were published in the last 5 years (Figure 3). Of these, 73% were review papers. These were mainly focused on the conceptualization of

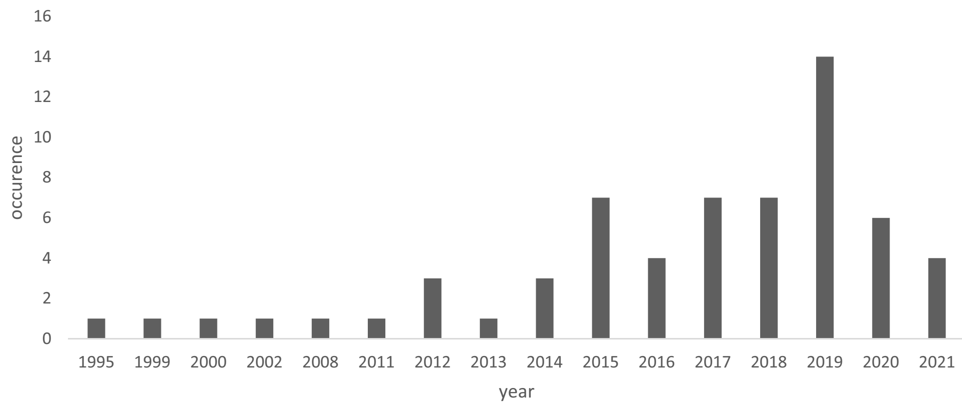


Figure 3. Year distribution of the articles (*n*=62) at Filter 3 of the literature review.

agroecology and the identification of lock-ins and actions to upscale its principles across food systems in the face of climate change and social inequity.

Many of these review papers alluded to the strategies used by smallholder farmers to adapt to risks and events including economic crises, pests and diseases, and climatic shocks such as floods, droughts, or hurricanes (e.g. Altieri and Toledo 2011; Anderson et al. 2020; Fonte et al. 2012; Holt-Giménez, Shattuck, and Lammeren 2021).

Seventeen of the 62 articles were case studies focusing on specific quantitative or qualitative databases in Latin America (e.g. Betancourt 2020; Calleros-Islas 2019; Machado-Vargas, Nicholls-Estrada, and Ríos-Osorio 2018; Turbay et al. 2014) on agroecological systems with 17 analyzing their relevance to address climate change issues. Seven additional studies were included at this stage. They corresponded to studies that analyzed how agroforestry or silvopastoral systems were allowing addressing climate change issues in Latin America but that were not captured in the filters. These 24 studies are analyzed in the subsequent section (Table 4).

Analysis of case studies according to variable domains

Agroecological practices and systems

The practices under study in these cases included mostly fertility management (i.e. compost, earthworm humus, cover crops, manure, fallows, biopreparations) and biodiversity management (i.e. intercropping, crop rotation, conservation of native species and seeds) (e.g. Do Carmo Loch et al. 2020; Turbay et al. 2014; Calleros-Islas 2019). These practices were implemented as part of agroforestry systems: coffee systems (e.g. Bielecki and Wingenbach 2019; Machado-Vargas, Nicholls-Estrada, and Ríos-Osorio 2018; Turbay et al.

2014), systems mixing crops like cassava (*Manihot esculenta*) or pineapple (*Ananas comosus*) with trees such as cashew (*Anacardium occidentale*), açai palm (*Euterpe oleracea*), cacao (*Theobroma cacao*), or black pepper (*Piper nigrum*), among others (Do Carmo Loch et al. 2020), or livestock systems corresponding to intensive silvopastoral systems (Cuartas et al. 2014; Murgueitio et al. 2015) or to natural grassland-based livestock farming (Rossing, Modernel, and Tittonell 2014).

Agroecological practices and systems contribute to a systemic resilience

The studies highlighted how the resilience of agroecological systems is a key outcome of agroecological systems expected to address various economic and environmental risks including climate change. Rogé and Astier (2015) used a general resilience perspective to explore changes in Mixteca Alta cropping systems. Based on 29 in-depth interviews and 20 months of participant research with farmers from the communities, they inquired about the dynamics of abandonment and persistence of a traditional management system known as cajete maize. They highlighted how farmers' strategies were associated to multiple outcomes including social outcomes. In the same area, based on various workshops with farmers, Rogé et al. (2014) showed how the impacts of climate were interwoven with other drivers of changing agricultural practices. They also highlighted that farmers were more interested in stabilizing fluctuations in yields over time rather than maximizing yield potential. Their stabilizing practices included soil management to increase soil organic, matter, agricultural diversification, and landscape complexity, agroforestry practices (intercropping, soil conservation, and integrated pest management), renewing coffee cultivars, transitioning to more resistant coffee varieties, and crop diversification.

Similarly, Machado-Vargas, Nicholls-Estrada, and Ríos-Osorio (2018) proposed the Risk Index methodology (RIH) to assess the socio-ecological resilience of systems undergoing different stages of the agroecological transition. The index was based on an assessment of threats (water availability, sale prices of coffee, fertilizer prices), vulnerability to these threats (coffee productivity, food self-sufficiency and level of internal inputs use), and the response capacity of farms (based on indicators such as the percentage of shade trees, the diversity in the production systems, the autonomy from markets, the level of organization) and consequently allowed linking climate risk with other risks and challenges at farm scale. The authors associated resilience to climate variability to the more advanced stages of those transitioning farms.

In Colomba-Quetzaltenango, Guatemala, Bielecki and Wingenbach (2019) assumed that the analysis of the management of coffee leaf rust by farmers helps understanding how farmers manage environmental crisis such as climate change. The authors used semi-structured interviews, focus groups, and a livelihood framework analysis to examine how coffee leaf rust affected food security, vulnerabilities, livelihoods, coping mechanisms, and livelihood strategies of farmers of a coffee farming cooperative. Bielecki and Wingenbach (2019) showed that coffee leaf rust crisis is perceived as one more crisis of many and underscored coffee cultural identity as a key factor in smallholders' decision-making, as they struggled to preserve their livelihoods.

Dimensions of agroecological systems favoring climate adaptation and resilience

Baldinelli (2014) analyzed the specific role of agrobiodiversity in response to climate change. Based on observations of two Aymara communities of the Northern Bolivian Altiplano, Baldinelli showed the strategic use of the numerous crop varieties that many Aymara farmers still own according to their resistance to drought or frost.

Holt-Giménez (2002) compared the levels of resistance on "sustainable" farms using agroecological practices (such as contour plowing, contour ditches, cover crops, live fences), with neighboring, "conventional" farms (lacking those practices) over a large area of Hurricane Mitch disturbance. The author compared 880 plots paired under the same topographical conditions. He found that agroecological plots consistently have more topsoil, less erosion, more vegetation and lower economic losses than conventional plots.

Bielecki and Wingenbach (2019) in their analysis of farmers' management practices of coffee leaf rust crisis highlighted that crop diversification is used as a limited or short-term coping strategy to maintain their coffee identity, seasonal off-farm employment being preferred. These tensions between off-farm employment and crop and tree diversification were also highlighted by Do Carmo Loch et al. (2020) in a study conducted in the eastern Amazon of Brazil based on surveys with 41 farmers.

Based on semi-structured interviews with women and men coffee farmers of the Honduran dry corridor, Velasco Palacios et al. (2023) investigated possible gendered adaptation strategies, gender equity being a key principle of agroecology. Velasco Palacios et al. (2023) identified four common on-farm adaptation strategies implemented by farmers such as agroforestry, new cultivars, variety replacement, and crop diversification. However, they found gender differences with women having less access to information or tension with their domestic roles and responsibilities constraining their adaptation capacities.

Turbay et al. (2014), in a study carried out in Chinchina, Colombia, highlighted the linkages between the various technical and organizational dimensions of agroecology and the various dimensions of climate adaptation. They surveyed 70 coffee farmers, collecting information on farm size, use of labor, and residence. In addition, they used participant observation, workshops, and interviews of rural extension technicians to categorize farm exposure, vulnerability, and adaptation strategies to climate variability. The authors attributed a buffering role to practices such as agroforestry, plant cover crops, use of organic fertilizers, and crop associations, but also to social (group membership), economic (reduction of external inputs, certification), and political (organized mobilization) mechanisms.

In coffee farms of Guatemala, Hochachka (2021) underscored the importance of assessing the various subjective and objective dimensions of adaptation. They proposed an integral conceptual framework that considers four types of adaptation – personal, practical, critical-structural, and co-generative, in order to explore a balanced integration of subjective and objective adaptive capacities, in individuals and collectives. Based on key informant interviews, site visits, participant-observation, and focus groups, Hochachka (2021) found that the four quadrants of adaptation were present: practical adaptations (e.g. pruning, retaining soil humidity, and maintaining the shade or diversifying income generation), critical-structural adaptations (e.g. credit advances, donations, and grants), co-generative adaptations (e.g. creation of a cooperative), and personal adaptations (e.g. personal convictions, faith). Hochachka (2021) invite policy makers and practitioners to consider all these dimensions.

Agroecological practices and systems contribute to climate mitigation

The mitigation outcomes of agroecological systems were mostly assessed using quantitative data.

Betancourt (2020) applied the concept of "metabolic rift" to describe the extraction and movement of resources (i.e. nutrients) from the countryside to the city, asserting that agroecology helps mitigate the erosion and degradation of rural territories while reducing GHG emissions. The study was based on a regressive and comparative analysis of datasets recorded from 1961 to 2015 in Latin America, calculating average agricultural and forest land-use change, synthetic fertilizer use, and yield of associated maize and beans as a function of time.

Somarriba et al. (2013) quantified carbon stocks in 229 cocoa agroforestry systems in six cocoa growing areas in five Central American countries and local forest patches. They found that Central American cocoa-based agroforestry systems stocked, on average, 117 Mg ha^{-1} of total carbon with 51 Mg ha^{-1} in the soil and 49 Mg ha^{-1} in aboveground biomass (cocoa and canopy trees). They found differences between growing areas and highlighted that it is possible to minimize tradeoffs between carbon stocks and yield optimizing shade canopy design. Hergoualc'h et al. (2012) compared a monoculture of coffee and coffee shaded by the N2-fixing legume tree species *Inga densiflora* in research plots in Costa Rica and demonstrated that C storage rate in the phytomass was more than twice as large in the shaded coffee compared to the monoculture system (4.6 ± 0.1 and 2.0 ± 0.1 Mg C ha^{-1} year^{-1}, respectively).

Agroecological systems can favor synergies between mitigation and adaptation

Some studies jointly assessed adaptation and mitigation outcomes. This is the case of the studies of Cuartas et al. (2014) and Murgueitio et al. (2015) that analyzed the contribution of intensive silvopastoral systems to adaptation and mitigation of climate change based on a synthesis of various case studies that included Colombia and Mexico. These intensive silvopastoral systems are a specific modality of livestock agricultural forestry systems following agroecological principles. They are characterized by the combination of species from different strata from tropical or subtropical grasses, forage shrubs in high density, and woody tree species such as palms or fruit trees. The authors highlighted the positive impacts of these systems on animal health permitted by decrease in animal parasites and disease vectors, an improved regulation of solar radiation and temperature permitted by trees, and an increase in water quality and quantity due to increased vegetation cover compared to treeless pastural systems. In these systems, the adaptation capacity lies in the reduction of plant and animal production seasonality, making animal production less vulnerable to climate change. The authors also described positive effects on mitigation permitted by a better N digestibility and higher CO2 fixation in trees (Cuartas et al. 2014; Murgueitio et al. 2015).

More extensive livestock systems corresponding to natural grassland-based livestock farming (Rossing, Modernel, and Tittonell 2014) showed that moderate grazing and seasonal modulation of stocking rates allowed increasing animal live weight, carbon sequestration, and diversity index.

In Colombia, Acosta Acosta-Alba, Chia, and Andrieu (2019) assessed the synergies between mitigation, adaptation, and food security of various types of coffee-based-farming systems that differed according to the type of cropping and livestock systems using life cycle assessment (Acosta-Alba et al. 2020).

Agroecological systems also contribute to synergies between climate and other environmental challenges

In coffee systems of Colombia, Acosta-Alba et al. (2020) attempted to jointly assess carbon sequestration with other environmental indicators. They used life cycle assessment to compare sun coffee systems to coffee agroforestry systems with various types of shade. They showed the positive effects of permanent shade coffee systems on most of the environmental indicators assessed, highlighting the potential of agroforestry systems to address various environmental challenges.

Similarly, Cerda et al. (2017) attempted to jointly assess the various ecosystem services of coffee agroecosystems in Costa Rica. In 69 coffee agroecosystems belonging to smallholder farmers across a range of altitudes, they quantified four major ecosystem services (regulation of pests and diseases; provisioning of agroforestry products; maintenance of soil fertility; and carbon sequestration). They did not find trade-offs among the different ecosystem services studied or between ecosystem services and biodiversity, and that both low and highly diversified coffee agroforestry systems had better ability to provide ecosystem services than coffee monocultures in full sun. Notaro et al. (2022), in 82 coffee plots in Nicaragua, analyzed the synergies between four ecosystem services (coffee production, water quality preservation, carbon sequestration, and biodiversity conservation). They highlighted the importance of selecting adequate shade trees at moderate densities to achieve joint synergies between ecosystem services.

In a study conducted in El Salvador, Kearney et al. (2019) also assessed the various ecosystem services (including climate regulation) supplied by agroecological systems. In five farms, they compared a conventional management of maize intercropped with beans, organic management where synthetic inputs are substituted by organic inputs, "slash and mulch" agroforestry system established from a plot previously under conventional management (that included native leguminous and timber species and a mix of native and localized fruit-bearing species) and a "slash and mulch" agroforestry system established from a forest fallow. They found that when multiple indicators were evaluated simultaneously, both the "slash and mulch" agroforestry system treatments outperformed conventional and organic management.

Stakeholder interviews

Perceived social, economic, and environmental benefits of agroecology

Fifteen respondents, including farmers, NGO representatives, teachers, researchers, and public officials, emphasized the revaluation of agroecological products through prices that differentiate them and their appreciation by consumers as free of chemicals and friendly to the environment. In addition, six farmers related the positive effects of agroecology to cost reduction, better quality products, and ties of trust with consumers. As farmers explained, costs are reduced once purchased chemical inputs are replaced with the farm's resources. In this regard, three respondents (farmer, teacher, public official) acknowledged the beneficial function of agroecological practices for nutrient cycling and fertility of the productive soil matrix in the long term. Self-consumption was mentioned by six respondents (farmers, NGO representatives) as a further contribution of agroecology. Four respondents (public officials) associated these economic benefits to better access to financial resources (i.e. credit unions and savings cooperatives), local markets, and rapport with consumers and to organizations helping farmers gain access to land. Researchers and NGO representatives perceived additional contributions in this domain in terms of: economic resilience (three respondents); wellbeing, education, and poverty reduction (four respondents); more favorable cost-benefit ratio (three respondents); better social networks (one respondent);

decreased dependence on external inputs (one respondent), and women's empowerment (one respondent).

Researchers and NGO representatives (six respondents) saw the empowerment of farmers as an important social benefit of agroecology. Once they gain autonomy from the demands imposed by conventional markets, their decision-making power over what and when to plant is enhanced and this way "they feel more confident." Benefits in terms of women and youth's empowerment (women in charge of maintaining orchards and apiaries or the production of minimally processed goods for sale) (six respondents) and organizational bonds (five respondents) among farmers (*minga* or shared labor and associations) and between farmers and consumers were raised. Two farmers mentioned that women now represent about 70% of all sellers in the local agroecological markets in Valle del Cauca, Colombia. Such leadership from women in agroecology has led to a change in perception within families and communities, granting them respect and admiration, and in cases of domestic violence, the self-confidence to abandon their abusers. Other social benefits, perceived mostly by farmers (4), are the strengthened intra-family bonds, values, and ties to the community as a whole: "it creates bonds between families;" "with agroecology families come together and think and project into the future;" "families focus on coexistence and values;" people become more accepting of you;" "solidarity and camaraderie."

Environmental benefits of agroecology were generally seen by respondents at the landscape or global scales. All interviewed farmers (6) mentioned the positive effects of agroecological practices on fauna: "birds for biological control and seed dispersal;" "diversity of birds;" "songs of frogs and bees." Researchers (6) mostly expressed the benefits of agroecological systems in terms of regulating services: "conservation of soils so they maintain their nutritional characteristics;" "soil biodiversity;" "carbon sequestration and protection of fragile ecosystems such as the paramo;" "regulation of biota;" "water conservation systems;" "community-level water conservation campaigns;" "soil covers, padding;" "wild animals, armadillos, birds;" "carbon is captured and GHGs are mitigated." Lastly, public officials (4) highlighted the benefits of agroecology as enabling biodiversity and water management at the landscape and community scales (e.g. water quality, water access for the community), while NGO representatives (6) detailed them in terms of management practices like "water harvesting" and "living fences." The latter also mentioned reduced pollution as a salient contribution of agroecology.

Stakeholders' perceived benefits in terms of adaptation and mitigation to climate change

Half of the interviewed stakeholders asserted that agroecological systems support farm resilience in the face of extreme weather events (i.e. flood or drought), thus minimizing any economic (production lost) or biological constraints (pests and diseases) driven by climate change. They mentioned various agroecological practices such as genetic, crop, or animal diversity, the production and use of organic inputs through biomass recycling, crop rotation, mulch, use of legumes, water conservation practices, and agroforestry. However, they emphasized crop and animal diversification and the integration of trees in farming systems as critical to crops' recovery phase following an extreme weather event, thus conferring resilient qualities to the system as a whole. As a researcher and NGO representative from Ecuador explained: "Producers observe that frosts and floods affect crops, but that agroecological or diversified crops in the area recover faster". "Reforestation as part of agroecological systems is key as an adaptation strategy to optimize and conserve resources such as water" (NGO representative, Peru).

While farmers detailed the processes supporting such adaptation (e.g. creation of a microclimate, conservation of soil humidity with trees), researchers honed in on the effect that climate change is having on agricultural systems, as in "climate change has led to crops having to rise in meters above sea level." One of the five public officials interviewed expanded on agroecology's contribution to climate change adaptation, emphasizing the long-term and trial-and-error nature of adaptation as a process that is fundamentally borne by farmers: "The first to feel climate change and to be resilient are farmers. Initially, more agrochemicals were applied, generating resistance to pests and diseases that proliferated with changes in temperature. Then, they began to include agroecological practices that work in the medium and long term for adaptation. Farmers need to be trained to understand that the processes are medium and long term. Adaptation has cost the farmer" (public official, Ecuador).

Three farmers and one researcher from Peru noted that agroecological systems tend to show lower temperatures than those recorded in surrounding conventional production farms. Farmers attributed this difference to having created a diversified landscape with different types of trees and cover that generate shade and result in a more temperate microclimate. Two farmers from Colombia further mentioned having taken the temperature with a thermometer on several occasions and registering up to 10°C less on their farm than on nearby farms.

Moreover, two farmers defined the practices permitting CO_2 sequestration and lower GHG emissions as those that decrease the use of industrial inputs or combine several strata of cultivated plants. Three NGO representatives and two public officials also pointed to the decrease in GHG emissions through the minimal use of synthetic fertilizers as agroecological practices are implemented. One researcher from Colombia referred to her studies demonstrating that agroecology-based agroforestry systems in the foothills of Valle del Cauca, Colombia, increase carbon storage by a factor of 2 to 3 compared to conventional systems (i.e. coffee, lemon, and soursop monocrops) (Ángel 2016). According to these studies, the total carbon captured in soils and trees was

108 ton/ha in foothills with agroforestry versus 60 ton/ha in conventional systems (1200 m.a.s.l.), and N_2O emissions were 58.2 ug/m2/ha compared to 255.7 ug/m2/ha in conventional systems.

Discussion

Pinning down resilience to climate change

Based on a global review of abstracts, Saj et al. (2017) highlighted the growing interest on agroecology and climate that is evident in the scientific literature over the last 6 years. However, toward the objective to legitimate agroecology, Montenegro de Wit et al. (2016) suggest the need to articulate practical legitimacy coming from practitioners to scientific legitimacy.

Our study applied a systematic literature review and stakeholder interviews to gather and scrutinize the evidence of agroecology's role in climate change adaptation and mitigation in Latin America.

Agroforestry systems composed of coffee and mixtures of perennial and short-cycle crops were the main agroecological systems described in the case studies. These systems were found to be more resilient to climate and economic risks (Machado-Vargas, Nicholls-Estrada, and Ríos-Osorio 2018); to restore degraded tropical forests and to rely on knowledge exchange networks for their management (Hochachka 2021). Such preponderance of agroforestry systems may be explained by the location of the case studies, with few cases in the high Andes region.

Resilience was a central theme in the case studies that highlighted that climate change is only one of the objectives of the strategies implemented by farmers.

Interviewed stakeholders also presented resilience as a key attribute of agroecological systems. It was also addressed in a holistic manner through their perceptions of its environmental benefits. Stakeholders did not firstly dissociate climate change from other environmental issues. In particular, farmers interpreted agroecology as intricately linked to their surrounding environment.

The possibility that agricultural systems be resilient to any shocks can be questioned. One recent study has shown that agroecological practices aiming to improve the resilience of farming systems to pests and diseases may actually lead to adverse effects in terms of climate change (Fanchone et al. 2022). According to the authors, weed control practices relying on the introduction of bovine animals in cropping systems could increase GHG emissions due to emissions from enteric fermentation. More analyses are consequently needed to better understand such trade-offs at various scales.

Nonetheless, both the case studies examined and stakeholders' responses provided insights on the contribution of agroecology to resilience in the face of climate change. Crop and animal diversification and the introduction of trees in agroecological systems were mentioned by stakeholders as key aspects conferring farm resilience. Furthermore, food self-sufficiency, social networks, organization of production for commercialization, and political mobilization to claim benefits also contributed to farm resilience (Machado-Vargas, Nicholls-Estrada, and Ríos-Osorio 2018; Turbay et al. 2014). The protagonism of farmers, particularly of women (Velasco Palacios et al. 2023), and the recognition of their cultural identity and knowledge (Rogé and Astier 2015; Rogé et al. 2014), were important factors of resilience in agroecological systems.

Mitigation was also present in the literature analyzed that highlighted the positive role of trees for carbon sequestration but also of diversified silvopastoral system to improve animal diet and reduce enteric emissions. While stakeholders acknowledged the role of agroforestry and reduction of synthetic fertilizers in climate change mitigation, in some cases their statements confused the meaning of the term that was associated by farmers with the creation of a microclimate rather than to carbon sequestration or to the reduction of greenhouse gas emission. Indeed, the less tangible dimension of mitigation compared to adaptation, particularly for farmers, has been mentioned by various authors (Martinez Baron et al. 2018; Osorio-Garcia et al. 2020).

Limitations of the study

Our study is the first to provide a systematic review of the existing (formal) evidence that agroecology enables climate change adaptation and mitigation in some of the agricultural systems of Latin America. Nonetheless, this systematic literature review did not aim to be exhaustive. Some relevant papers may have been excluded from the analysis because emphasis was placed on peer-reviewed articles where the authors used the term “agroecology” either in the title, abstract, or key words. Yet, it was important for us to identify the concrete contributions of scientists to the research community in agroecology specifically. We also acknowledge that by limiting the literature review to published articles in the chosen academic search engines, we intentionally excluded gray literature from the analyses, which could have provided additional insights and rich contextual information on agroecology’s contribution to climate resilience in smallholder contexts. This limitation was balanced by the integration of stakeholder-perceived evidence of agroecology’s benefits in terms of adaptation and mitigation to climate change under contrasting lenses – that of academic production and testimony from a plurality of actors on the ground, such as in formal institutions, civil society networks, and farming communities. These perceived evidences were supported by their experiential knowledge combining observations (e.g. 70% of sellers in the local organic markets of Valle del Cauca are women) and their own informal (recording differences in temperature) or formal experiments (research conducted on the topic by local scientists). Yet, while stakeholder interviews provided a valuable range of in-depth perceptions from each of the study sites, their scope was constrained to only the viewpoints of those actors who were available to be interviewed from the larger pool of compiled actors for each site. It could also be argued that because these discourses were analyzed through the lens of the study authors, their interpretation is prone to bias.

Conclusions

Through applying the PRISMA methodology and intentionally focusing on published, peer-reviewed articles as a means for identifying and making visible the contributions of researchers to the agroecology community, specifically in Latin America, but also zooming in on Colombia, Ecuador, and Peru and shifting our attention to the perceptions of a diversity of stakeholders – farmers, NGO representatives, researchers, university program leaders, and public officials – we can harvest three main lessons.

The first lesson is that agroecological systems are appreciated and studied in terms of resilience to shocks – be they climatic, economic, or environmental. Specific agroecological arrangements and underlying processes are conferring resilience to climate change. Both literature review and stakeholder testimonies highlighted that crop and animal diversification and integration of trees into farming systems were central to resilience in the context of climate change. Combining both knowledge sources, we can conclude that agroecology can be a holistic and effective response to climate change while addressing other environmental and socio-economic challenges.

The second is that there remain knowledge gaps and questions that invite further, and much deeper, research, such as looking into the trade-offs and synergies operating at multiple scales between agroecological practices, mitigation, and resilience.

The third is that per the literature and perceptions analyzed, agroecology in research and practice is mostly supported by NGOs at the local and subnational level. This begs the question of the types and sources of evidence that will ultimately gain the attention and support from governmental institutions and donors for the scaling out, up and deep of agroecology.

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References

Acosta-Alba, I., J. Boissy, E. Chia, and N. Andrieu. 2020. Integrating diversity of smallholder coffee cropping systems in environmental analysis. *The International Journal of Life Cycle Assessment* 25 (2):252–66. doi:10.1007/s11367-019-01689-5.

Acosta-Alba, I., E. Chia, and N. Andrieu. 2019. The LCA4CSA framework: Using life cycle assessment to strengthen environmental sustainability analysis of climate smart agriculture options at farm and crop system levels. *Agricultural Systems* 171:155–70. doi:10.1016/j.agsy.2019.02.001.

Altieri, M. 1989 Agroecology: A New Research and Development Paradigm for World Agriculture Agriculture, Ecosystems and Environment 27: 37–46 doi:10.1016/0167-8809(89)90070-4

Altieri, M. 1999. Applying agroecology to enhance the productivity of Peasant farming systems in Latin America. *Environment Development and Sustainability* 1 (3/4):197–217. doi:10.1023/A:1010078923050.

Altieri, M. A. 1983. Agroecology: The scientific basis of alternative agriculture. In *Divison of biological control*, 162. Berkeley: University of California.

Altieri, M., and C. Nicholls. 2017. The adaptation and mitigation potential of traditional agriculture in a changing climate. *Climatic Change* 140 (1):33–45. doi:10.1007/s10584-013-0909-y.

Altieri, M., C. Nicholls, A. Henao, and M. A. Lana. 2015. Agroecology and the design of climate change-resilient farming systems. *Agronomy for Sustainable Development* 35 (3):869–90. doi:10.1007/s13593-015-0285-2.

Altieri, M., and V. M. Toledo. 2011. The agroecological revolution in Latin America: Rescuing nature, ensuring food sovereignty and empowering peasants. *The Journal of Peasant Studies* 38 (3):587–612. doi:10.1080/03066150.2011.582947.

Anderson, C. R., M. P. Pimbert, M. J. Chappell, J. Brem-Wilson, P. Claeys, C. Kiss, C. Maughan, J. Milgroom, G. McAllister, N. Moeller, et al. 2020. Agroecology now - connecting the dots to enable agroecology transformations. *Agroecology & Sustainable Food Systems* 44 (5):561–65. doi:10.1080/21683565.2019.1709320.

Ángel, D. 2016. Evaluación de Servicios Ecosistémicos Generados en la Agricultura Familiar Agroecológica Campesina (AFAC) del Centro del Departamento del Valle del Cauca. Universidad Nacional de Colombia Sede Palmira Facultad de Ciencias Agropecuarias. https://repositorio.unal.edu.co/handle/unal/57627.

Babin, N. 2015. The coffee crisis, fair trade, and agroecological transformation: Impacts on land-use change in Costa Rica. *Agroecology & Sustainable Food Systems* 39 (1):99–129. doi:10.1080/21683565.2014.960549.

Baldinelli, G. M. 2014. Agrobiodiversity conservation as a coping strategy: Adapting to climate change in the Northern Highlands of Bolivia. *Consilience* 11:153–66.

Bauluz, L., Y. Govind, and F. Novokmet. 2020. Global land inequality (halshs-03022360). HAL Open Science.

Betancourt, M. 2020. The effect of Cuban agroecology in mitigating the metabolic rift: A quantitative approach to Latin American food production. *Global Environmental Change* 63:63. doi:10.1016/j.gloenvcha.2020.102075.

Bezner Kerr, R., J. Liebert, M. Kansanga, and D. Kpienbaareh. 2022. Human and social values in agroecology: A review. *Elementa: Science of the Anthropocene* 10:1. doi:10.1525/elementa.2021.00090.

Bielecki, C. D., and G. Wingenbach. 2019. Using a livelihoods framework to analyze farmer identity and decision making during the Central American coffee leaf rust outbreak: Implications for addressing climate change and crop diversification. *Agroecology & Sustainable Food Systems* 43 (4):457–80. doi:10.1080/21683565.2019.1566191.

Calleros-Islas, A. 2019. Sustainability assessment. An adaptive low-input tool applied to the management of agroecosystems in México. *Ecological Indicators*. doi:10.1016/j.ecolind.2017.12.040.

Casimiro, L. 2016. Need of an agroecological transition in Cuba, perspectives and challenges. *Pastos y Forrajes* 39:150–59.

Cerda, R., C. Allinne, C. Gary, P. Tixier, C. A. Harvey, L. Krolczyk, C. Mathiot, E. Clément, J.-N. Aubertot, and J. Avelino. 2017. Effects of shade, altitude and management on multiple ecosystem services in coffee agroecosystems. *The European Journal of Agronomy* 82:308–19. doi:10.1016/j.eja.2016.09.019.

Cuartas, C. A., J. F. Naranjo, A. M. Tarazona, E. Murgueitio, J. D. Chará, J. Ku, F. J. Solorio, M. X. Flores, B. Solorio, and R. Barahona. 2014. Contribution of intensive silvopastoral systems to animal performance and to adaptation and mitigation of climate change. *Revista Colombiana de Ciencias Pecuarias* 27:76–94.

Deaconu, A., P. R. Berti, D. C. Cole, G. Mercille, and M. Batal. 2021. Agroecology and nutritional health: A comparison of agroecological farmers and their neighbors in the Ecuadorian highlands. *Food Policy* 101:102034. doi:10.1016/j.foodpol.2021.102034.

De Sy, V., M. Herold, F. Achard, R. Beuchle, J. G. P. W. Clevers, E. Lindquist, and L. Verchot. 2015. Land use patterns and related carbon losses following deforestation in South America. *Environmental Research Letters* 10 (12). doi:10.1088/1748-9326/10/12/124004.

Do Carmo Loch, V., D. Celentano, E. Gomez Cardozo, and G. X. Rousseau. 2020. *Towards agroecological transition in degraded soils of the eastern Amazon*. Forests, Trees and Livelihoods. doi:10.1080/14728028.2020.1863866.

Duru, M., O. Therond, and M. Fares. 2015. Designing agroecological transitions; a review. *Agronomy for Sustainable Development* 35 (4):1237–57. doi:10.1007/s13593-015-0318-x.

Falkowski, T. B., A. Chankin, and S. A. W. Diemont. 2020. Successional changes in vegetation and litter structure in traditional Lacandon Maya Agroforests. *Agroecology & Sustainable Food Systems* 44 (6):747–67. doi:10.1080/21683565.2019.1649784.

FAO. 2018. The 10 elements of agroecology: Guiding the transition to sustainable food and agricultural systems. https://www.fao.org/3/I9037EN/i9037en.pdf

Fonte, S. J., S. J. Vanek, P. Oyarzun, S. Parsa, C. Quintero, I. M. Rao, and P. Lavelle. 2012. Pathways to agroecological intensification of soil fertility management by smallholder farmers in the Andean Highlands. *Advances in Agronomy* 116:125–84. doi:10.1016/B978-0-12-394277-7.00004-X.

Gliessman, S. 2016. Transforming food systems with agroecology. *Agroecology & Sustainable Food Systems* 40 (3):187–89. doi:10.1080/21683565.2015.1130765.

Goland C. (1993). Agricultural Risk Management Through Diversity: Field Scattering in Cuyo Cuyo, Peru. *Culture & Agriculture* 13 (45–46):8–13. doi:10.1525/cuag.1993.13.45-46.8.

Hergoualc'h, K., E. Blanchart, U. Skiba, C. Hénault, and J.-M. Harmand. 2012. Changes in carbon stock and greenhouse gas balance in a coffee (coffea arabica) monoculture versus an agroforestry system with Inga densiflora, in Costa Rica. *Agriculture, Ecosystems & Environment* 148:102–10. doi:10.1016/j.agee.2011.11.018.

Holt-Giménez, E. 2002. Measuring farmers' agroecological resistance after hurricane mitch in Nicaragua: A case study in participatory, sustainable land management impact monitoring. *Agriculture, Ecosystems and Environment* 93 (1–3):87–105. 0167–8809/02/$. doi:10.1016/S0167-8809(02)00006-3.

Holt-Giménez, E., A. Shattuck, and I. V. Lammeren. 2021. Thresholds of resistance: Agroecology, resilience and the agrarian question. *The Journal of Peasant Studies* 48:715–73. doi:10.1080/03066150.2020.1847090.

Kearney, S. P., S. J. Fonte, E. García, P. Siles, K. M. A. Chan, and S. M. Smukler. 2019. Evaluating ecosystem service trade-offs and synergies from slash-and-mulch agroforestry systems in El Salvador. *Ecological Indicators* 105:264–78. doi:10.1016/j.ecolind.2017.08.032.

Machado-Vargas, M. M., C. I. Nicholls-Estrada, and L. A. Ríos-Osorio. 2018. Social-ecological resilience of small-scale coffee production in the Porce river basin, Antioquia (Colombia). *IDESIA* 36:141–51. doi:10.4067/S0718-34292018005001801.

Martinez Baron, D., G. Orjuela, G. Renzoni, A. M. Loboguerrero Rodríguez, and S. Prager. 2018. Small scale farmers in a 1.5°C future: The importance of local social dynamics as an enabling factor for implementation and scaling of climate-smart agriculture. *Current Opinion in Environmental Sustainability* 31:112–19. doi:10.1016/j.cosust.2018.02.013.

McNight Foundation. 2022. Accessed August 2022. https://www.mcknight.org/es_mx/programs/international/collaborative-crop-research/our-approach

Montenegro de Wit, M., A. Iles, A. R. Kapuscinski, and E. Méndez. 2016. Toward thick legitimacy: Creating a web of legitimacy for agroecology. *Elementa: Science of the Anthropocene* 4:000115. doi:10.12952/journal.elementa.000115.

Murgueitio, E., R. Barahona, J. D. Chará, M. X. Flores, R. M. Mauricio, and J. J. Molina2015The intensive silvopastoral systems in Latin America sustainable alternative to face climatic change in animal husbandry. *Cuban Journal of Agricultural Science* 49 4 https://cjascience.com/index.php/CJAS/article/view/500

Navarro-Racines, C., P. Álvarez-Toro, D. Ríos, R. Borja, G. Padilla, D. Montalvo, P. Oyarzún, P. Orrego, O. Renato, D. Taipe, et al. 2021. Servicios Integrados Participativos de Clima para la Agricultura (PICSA) en comunidades agroecológicas de Ecuador, Perú y Colombia. Experiencias y lecciones aprendidas durante la implementación de la metodología PICSA en las provincias de Cotopaxi y Chimborazo, Sierra Centro en Ecuador, en las regiones de Huancavelica y Junín en Perú y, en el departamento del Valle del Cauca en Colombia durante el año 2021. CCAFS Info Note. Programa de Investigación de CGIAR en Cambio Climático, Agricultura y Seguridad Alimentaria (CCAFS).

Nicholls, C., M. A. Altieri, and L. Vazquez. 2016. Agroecology: Principles for the conversion and redesign of farming systems. *Journal of Ecosystem & Ecography*. doi:10.4172/2157-7625.S5-010.

Notaro, M., C. Gary, J.-F. Le Coq, A. Metay, and B. Rapidel. 2022. How to increase the joint provision of ecosystem services by agricultural systems. Evidence from coffee-based agroforestry systems. *Agricultural Systems* 196:2022103332. doi:10.1016/j.agsy.2021.103332.

Osorio-Garcia, A. M., L. Paz, F. Howland, L. A. Ortega, I. Acosta-Alba, L. Arenas, N. Chirinda, D. Martínez-Barón, F. O. Bonilla, A. M. Loboguerrero, et al. 2020. Can an innovation platform support a local process of climate-smart agriculture implementation? A case study in Cauca, Colombia. *Agroecology & Sustainable Food Systems* 44 (3):378–411. doi:10.1080/21683565.2019.1629373.

Power, A. G. 2013. *Ecology of agriculture*. Encyclopedia of Biodiversity (2nd Edition) 9–15. doi:10.1016/B978-0-12-384719-5.00006-X.

Rodríguez, N. R., E. Vázquez Bedoya, L. Restrepo, and S. M. Márquez Girón. 2017. Characterization and typification of coffee production systems (coffea arabica L.), Andes municipality. *Revista Facultad Nacional de Agronomía* 70:8327–8339.

Rogé, P., and M. Astier. 2015. Changes in climate, crops, and tradition: Cajete maize and the rainfed farming systems of Oaxaca, Mexico. *Human Ecology* 43:639–53. doi:10.1007/s10745-015-9780-y.

Rogé, P., A. R. Friedman, M. Marta Astier, and M. A. Altieri. 2014. Farmer strategies for dealing with climatic variability: A case study from the Mixteca Alta region of Oaxaca, Mexico. *Agroecology & Sustainable Food Systems* 38 (7):786–811. doi:10.1080/21683565.2014.900842.

Rosset, P. M. 2009. Food sovereignty in Latin America: Confronting the new crisis. NACLA Report on the Americas. 16–21. 10.1080/10714839.2009.11722233

Rossing, W. A. H., P. D. Modernel, and P. A. Tittonell. 2014. Diversity in organic and agroecological farming systems for mitigation of climate change impact, with examples from Latin America. In *Climate change impact and adaptation in agricultural systems [J]*, ed., P. G. Fuhrer. Wallingford, UK: CABI. doi: 10.1079/9781780642895.0069.

Saj, S., E. Torquebiau, E. Hainzelin, J. Pages, and F. Maraux. 2017. The way forward: An agroecological perspective for climate-smart agriculture. *Agriculture Ecosystem Environment* 250:20–24. doi:10.1016/j.agee.2017.09.003.

Scow, K. M. 1997. 11 - soil microbial communities and carbon flow in agroecosystems. *Ecology in Agriculture* 3: 367–413.

SIFOR. 2013. Smallholder innovation for resilience (sifor): Strengthening biocultural innovation systems for food security in the face of climate change. Asociación ANDES (Peru) and IIED. Workshop report.

Smith, P., M. Bustamante, H. Ahammad, H. Clark, H. Dong, E. A. Elsiddig, H. Haberl, R. Harper, J. House, M. Jafari. 2014. Agriculture, forestry and other land use (AFOLU). In *Climate change 2014: Mitigation of climate change. contribution of working group III to the fifth assessment report of the intergovernmental panel on climate change*, ed. O. Edenhofer, R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel, and J. C. Minx, 811–922. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Snapp, S., Y. Kebede, E. Wollenberg, K. M. Dittmer, S. Brickman, C. Egler, and S. Shelton. 2021. *Agroecology and climate change rapid evidence review: Performance of agroecological* *approaches in low- and middle- income countries*. Wageningen, the Netherlands: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).

Somarriba, E., R. Cerda, L. Orozco, M. Cifuentes, H. Dávila, T. Espin, H. Mavisoy, G. Ávila, E. Alvarado, V. Poveda, et al. 2013. Carbon stocks and cocoa yields in agroforestry systems of Central America. *Agriculture, Ecosystems & Environment* 173:46–57. doi:10.1016/j.agee.2013.04.013.

Tittonell, P. 2014. Ecological intensification of agriculture—sustainable by nature. *Current Opinion in Environmental Sustainability* 8:53–61. doi:10.1016/j.cosust.2014.08.006.

Tixier, P., N. Peyrard, J. N. Aubertot, S. Gaba, J. Radoszycki, G. Caron-Lormier, F. Vinatier, G. Mollot, and R. Sabbadin. 2013. Chapter seven - modelling interaction networks for enhanced ecosystem services in agroecosystems. *Adv Ecol Res* 49:437–80. doi:10.1016/B978-0-12-420002-9.00007-X.

Turbay, S., B. Nates, F. Jaramillo, J. J. Vélez, and O. L. Ocampo. 2014. Adaptation to climate variability among the coffee farmers of the watersheds of the rivers porce and Chinchiná, Colombia. *Investigaciones Geográficas, Boletín Del Instituto de Geografía, UNAM* 85:95–112.

Velasco Palacios, H., K. Sexsmith, M. Matheu, and A. Reiche Gonzalez. 2023. Gendered adaptations to climate change in the Honduran coffee sector. *Women's Studies International Forum* 9:102720. doi:10.1016/j.wsif.2023.102720.

Hochachka, G. 2021. Integrating the four faces of climate change adaptation: Towards transformative change in Guatemalan coffee communities. *World Development* 140:105361. doi:10.1016/j.worlddev.2020.105361.

Snapp, S., and B. Pound. 2008. *Agricultural Systems: Agroecology and Rural Innovation for Development*. 1st ed.

Chappell, M.J., A. Bernhart, L. Bachmann, A. Luiz Gonçalves, S. Seck, P. Nandul, A. C., and dos Santos. 2018. Agroecology as a Pathway towards Sustainable Food Systems. Misereor. https://www.misereor.org/fileadmin//user_upload/misereor_org/Publications/englisch/synthesis-report-agroecology.pdf.

Olivera, R., and D. Popusoi. 2021. Stock-take report on agroecology in IFAD operations. An integrated approach to sustainable food systems. *IFAD*. https://www.ifad.org/documents/38714170/39155702/PMI+Agroecology+assessment.pdf/d39e37dd-8c35-c909-669d-906bb3ad716f?t=1631019354584.

FAO. 2014. *The state of food and agriculture. Innovation in family farming*. https://www.fao.org/3/a-i4040e.pdf.

Fanchone A., L. Nelson, N. Dodet, L. Martin and N. Andrieu. 2022. How agro-environmental and climate measures are affecting farming system performances in Guadeloupe?: Lessons for the design of effective climate change policies. *International Journal of Agricultural Sustainability* 20 (7):1348–1359. doi:10.1080/14735903.2022.2136836.

Wezel, A., B. G. Herren, R. B. Kerr, E. Barrios, A. L. Gonçalves, and F. Sinclair 2020. Agroecological principles and elements and their implications for transitioning to sustainable food systems. A review. *Agron. Sustain. Dev* 40:6. doi:10.1007/s13593-020-00646-z.

Sinclair, F., A. Wezel, C. Mbow, S. Chomba, V. Robiglio, and R. Harrison 2019. "The contribution of agroecological approaches to realizing climate-resilient agriculture." Rotterdam and Washington, DC. Available online at www.gca.org

WWF. 2022. *Living Planet Report 2022 – Building a naturepositive society*. Switzerland: WWF, Gland.

Berdegué, J. A., and R. Fuentealba. 2014. The state of smallholders in agriculture in Latin America. In *New Directions for Smallholder Agriculture*, ed. P. B. R. Hazell and A. Rahman. Oxford: Oxford Academic. doi:10.1093/acprof:oso/9780199689347.003.0005.