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REVIEW

Trends in agroforestry research over 4 decades

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Agroforestry has a high potential to contribute to climate change mitigation and adaptation as a nature-based climate solution and is increasingly included as a climate strategy in international agreements and national plans. Yet, how to equitably increase and sustain agroforestry on the scale needed to meet these targets remains unclear. Examining broad trends in the existing 4 decades of agroforestry literature can highlight gaps and opportunities for future research that enables agroforestry transitions. Using text analytics and a full-text, corpus-based approach, we analyzed changes in word use in 9,664 agroforestry research articles and reports published between 1980 and 2020 with regard to 4 key themes of the social dimensions of agroforestry transitions: (1) agreements and policies; (2) scales and decision-making agents; (3) knowledge, culture, and equity; and (4) frameworks and methods. We then compared the frequency of these themes in research articles and reports. Despite the most frequently used terms across all 4 decades being primarily ecological (e.g., *forest*, *species*, *soil*), the lexicon of agroforestry literature has expanded to incorporate more social, economic, and political elements (e.g., *livelihood*, *knowledge*, *community*) over time, and as agroforestry has become more central to climate change adaptation and mitigation targets. Trends in the frequency of several terms (e.g., *biodiversity*, *development*, *climate*) corresponded with the signing of intergovernmental agreements, illustrating the responsiveness of the field to global priorities. Reports had a higher frequency of terms related to social themes than research articles. We discuss the implications of these emergent trends and opportunities for future research in support of sustainable and just agroforestry transitions.

Keywords: Nature-based climate solution, Agroecology, Policy, Decision-making, Text analytics, Social–ecological system

Introduction

In the face of urgent calls for climate action, nature-based solutions provide critical pathways for climate change mitigation and adaptation (Griscom et al., 2017). Agroforestry is one such nature-based solution, comprising a suite of land uses that integrate components of agriculture and forestry (van Noordwijk et al., 2018). Evidence of the multiple benefits of agroforestry systems—including their ability to contribute to both climate change mitigation and adaptation as well as a suite of co-benefits such as increased food security, biodiversity, and ecosystem services (Tschora and Cherubini, 2020)—has led to the emergence of agroforestry as a nature-based solution to climate change. Agroforestry contributes to climate change mitigation through increased above-ground carbon sequestration compared to annual cropping and livestock systems. For example, increasing trees on cropland and pastures, one pathway to agroforestry, has the potential to store up to 9.39 petagrams of carbon globally (Chapman et al., 2020). Additionally, agroforestry systems can contribute to climate change adaptation by reducing vulnerability and increasing adaptive capacity of systems to climate risks (Quandt et al., 2023) and enhancing other components of social–ecological resilience to climate change (Quandt et al., 2017; McGuigan et al., 2022).

Due to this potential, numerous nationally declared contributions, international agreements, and local adaptation plans now name agroforestry as a strategy for mitigating or adapting to climate change. For example, out of 148 Nationally Declared Contributions to the United Nations (UN) Framework Convention on Climate Change assessed in a recent study, 40% ($n = 59$) explicitly

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mentioned agroforestry as a strategy for mitigating or adapting to climate change (Rosenstock et al., 2019). A recent report published by the United Nations Environment Programme boasts the potential of forests to absorb 1 Gt of emissions by 2025 (United Nations Environment Programme, 2022), and a recent Intergovernmental Panel on Climate Change (IPCC) report highlighted the importance of agroforestry as an adaptation strategy (Bezner Kerr et al., 2022). Agroforestry is also included as a strategy in local and national adaptation and resilience plans (Nguyen et al., 2013; Mbow et al., 2014). Recent focus on agroforestry as a climate solution has spurred renewed attention to the importance of increasing agroforestry on landscapes (van Noordwijk et al., 2018) and conserving existing agroforestry systems (Ticktin et al., 2018).

Agroforestry has been viewed as a solution to social and environmental challenges since the term was coined, although integrated forest-agriculture systems have a much longer history. Indigenous communities developed and stewarded locally adapted, integrated forest-agriculture systems around the world for centuries prior to the coining of the term *agroforestry* (Olofson, 1983). Colonization and the dispossession of land from Indigenous peoples, along with a suite of political-economic factors, gave rise to biologically simplified, industrial agriculture (Kremen et al., 2012). By the 1970s, the failure of the Green Revolution to benefit low-income farmers (Evenson and Gollin, 2003), escalating land management problems such as erosion, and increased awareness of the relevance of Indigenous land management practices led to the coining of the term *agroforestry*, in a report commissioned by Canada's International Development Research Centre, to describe land management systems that simultaneously increase the productivity of landscapes while also reducing environmental degradation (Bene et al., 1977). Soon after, the International Centre for Research in Agroforestry (ICRAF) was established, which formalized agroforestry as a research discipline. Since then, 4 decades of agroforestry research have broadened and deepened our understanding of how agroforestry systems function and the ecosystem services they provide (Miller et al., 2020; Castle et al., 2022), how to optimize system design for production and environmental benefits (Clough et al., 2011), what are the drivers of and constraints to agroforestry adoption and persistence (Pattanayak et al., 2003; Mercer, 2004; Amare and Darr, 2020), and numerous other topics within this interdisciplinary field.

While strides have been made in understanding many aspects of agroforestry systems and transitions to agroforestry, how to equitably increase and sustain agroforestry on the scale needed to meet climate commitments globally remains a challenge. This is in part because agroforestry systems are complex social–ecological systems (SES) that interact with and are influenced by political-economic contexts and decision-makers at community, institutional, national, and international scales (van Noordwijk et al., 2018). At the farm or site scale, agroforestry transitions are a multiyear process of changing active or fallow simplified agriculture or non-native species dominant forest to biologically diverse systems that incorporate trees or shrubs with other tended and harvested plants and/or animals for harvest (Ollinaho and Kröger, 2021). These transitions often involve a succession of different financing mechanisms, labor sources, and plant and animal species over a number of years.

Understanding the social dimensions of transitions to agroforestry is particularly important for translating large-scale climate goals and plans into on-the-ground land use change. Research on the social dimensions of agroforestry transitions is especially valuable for examining barriers and opportunities for agroforestry transitions, which can inform policy and programs targeted at expanding agroforestry adoption. For example, social dimensions research has shown that barriers such as insufficient access to secure, long-term land tenure (Lawin and Tamini, 2019), high start-up costs, longer-term return on investment (Buttoud, 2013), lack of financial incentives and marketing opportunities (Sollen-Norrlin et al., 2020), supply chain limitations (Lillesø et al., 2018), and contested values between practitioners and institutions (Hastings et al., 2021) all can constrain agroforestry transitions. This research has also produced actionable recommendations for addressing these constraints such as guidelines for institutional investment in farmer incentives (Bettles et al., 2021) and for designing interventions to address unequal power dynamics (Schroeder and Suryanata, 1996; Smith and Dressler, 2017). In general, social dimensions of agroforestry are underrepresented in the global literature (Liu et al., 2019), yet the extent to which different social concepts (e.g., policy, scales, culture, livelihoods) have been investigated and their relative use over time is unknown. Because agroforestry literature is highly diverse, spread across hundreds of disciplines, and rapidly growing, the synthesis of broad trends in the social dimensions of agroforestry is critical to inform research that supports equitable agroforestry transitions to meet global climate targets.

Therefore, we tracked how word use in English language agroforestry publications has changed with regard to the social dimensions of agroforestry transitions over the 4 decades since the term *agroforestry* was coined. Our team's interdisciplinary expertise—in agroforestry, agroecology, sociology, social psychology, decision theory, and political ecology—provides a new and requisitely diverse look at this cross-cutting field. In this review, we drew on the discipline of culturomics, or the quantitative analysis of large bodies of text, as a framework for tracking the evolution of a field over time (Michel et al., 2011; Ladle et al., 2016). We used a full-text approach, which allows for the investigation of topics that would not appear in titles or abstracts and presents a proxy for tracking realized versus perceived importance of concepts (e.g., Anderson et al., 2021). Additionally, we investigated the frequencies of a curated list of terms to develop a deeper understanding of a dimension of agroforestry research that is essential for scaling and known to be understudied in the literature compared to ecological dimensions (Liu et al., 2019). Importantly, we also tracked the relative frequencies of terms over time, rather than presenting only the most frequent terms over the whole corpus, which is essential for identifying use patterns across terms and themes; linking changes in term use with historical context, as in for example, the signing of an international climate agreement; and identifying future research opportunities in response to current trajectories.

The curated list of terms we analyzed represents important themes and subthemes of agroforestry transitions. We first examined the trends in terms related to agroforestry types and ecological benefits to contextualize the corpus. Then, we explored trends in 4 key domains of the social dimensions of agroforestry transitions. First, we investigated agreements and policy-related terms within 2 subthemes: (1) international agreements and goals related to 2 important drivers of agroforestry research and implementation over time—development (Bene et al., 1977; King, 1987) and climate (Liu et al., 2019); and (2) policy and economics, which influence farmer decision-making (Akamani and Holzmueller, 2017) and interventions to support increasing agroforestry on landscapes (Buttoud, 2013). Second, we explored the theme of scales and decision-making agents since transitions to agroforestry are multiscalar: they fundamentally involve changes in practices and levels of biodiversity at the individual, household, and community levels, yet the political-economic context of these local decisions and decision-making at larger scales, including within government and other institutions, are critical for enabling agroforestry transitions (e.g., Binam et al., 2017). Understanding the frequencies of these terms over time could help illuminate, for example, if the framing of agroforestry as a climate solution shifts the scale and importance of institutional drivers. Third, we investigated trends in terms related to knowledge, culture, and equity because understanding who can participate, who benefits, and whose knowledge is valued in agricultural transitions can inform interventions to improve equity in scaling (e.g., Gyau et al., 2014). Fourth, we examined trends in frameworks and methods, or how authors conceptualize the problem of adoption or transformations in agricultural systems and the prevalence of qualitative and quantitative methods, which affect the utility of the knowledge produced to stakeholders in scaling efforts (Coe et al., 2014; Dumont et al., 2019). Finally, we compared the relative frequency of these themes in research articles and in reports to identify areas of alignment or disconnect between these 2 publication types. Our analysis reveals important trends in the literature and illuminates future opportunities for research in support of sustainable and just transitions to agroforestry.

Methods

Data collection

We collected *n*-grams and metadata for all English language research "articles" and "reports" in the JSTOR corpus that included the term *agroforestry* ($n = 12{,}479$ articles; $n = 409$ reports) using Constellate, a text and data analytics service (JSTOR, 2022), to create our corpus. Constellate classifies "articles" as documents that came from a scientific journal and "reports" as documents that came from the JSTOR research reports collection. Articles include both articles with empirical data and review articles. Reports include policy briefs, case studies, and project reports from policy institutes around the world who contribute to the JSTOR collection, including nongovernmental organizations (NGOs), such as the Center for International Forestry Research (CIFOR) and CGIAR, foundations, and university-affiliated institutes (JSTOR, 2023). *N*-grams are a sequence of terms separated by a space. For example, *agroforestry* is a 1-gram and *alley cropping* is a 2-gram. We calculated the frequency of *agroforestry* in each document (number of mentions of the term in a document divided by the number of words in the document) and excluded publications that had an *agroforestry* frequency of less than 3 to avoid examining trends in research outside of the discipline that only mentioned agroforestry once or twice in the framing of the article. This left us with a total of $n = 9{,}358$ research articles and $n = 306$ reports in our corpus. We kept the minimum frequency of *agroforestry* low to account for the fact that the term is often abbreviated (e.g., AFS) and/or used in conjunction with other terms representing the many types of agroforestry (e.g., silvoarable, multistory systems, food forests). Although we recognize that many people practice and research systems that could be classified as agroforestry using different terms, like those listed above, we only used the term *agroforestry* to filter articles because we were most interested in trends in that body of literature and use of the term in research articles and reports.

N-gram analysis

We used a 2 stage process to select terms of interest. First, we curated a list of terms that were relevant to the 5 themes of agroforestry research and practice described in the introduction. We then referred to the list of most frequently occurring 1-grams in the corpus and selected terms that had more than 200,000 counts and were included in our list of terms relevant to agroforestry research or practice from step one. For analysis, we included synonyms and different forms of words where appropriate (e.g., plural, alternate spelling). The corpus is not case-sensitive. We grouped the terms into logical subthemes (**Figure 1C**). A full list of included terms and term groupings can be found in the supporting information (Table S1).

Using this set of key terms and their synonyms and alternate forms ($n = 265$), we queried our entire corpus of articles and calculated the frequency of each key term grouping ($n = 88$) in each document (number of times the term comes up in a given document divided by the number of words in the document). We maintained metadata on the article "type" ("research article" or "report") and year of publication. We then visualized the term frequencies by subtheme using the tidyverse (Wickham et al., 2019) and corpus (Perry, 2017) packages in R version 4.2.0.

Results and Discussion

General trends

Publications on agroforestry grew exponentially since the term was coined in the late 1970s (**Figure 1A**). Across the 4 decades, the top 10 most frequent terms in the corpus represented both fundamental ecology (i.e., *forest*, *species*, *soil*, *land*, *water*) and research applications

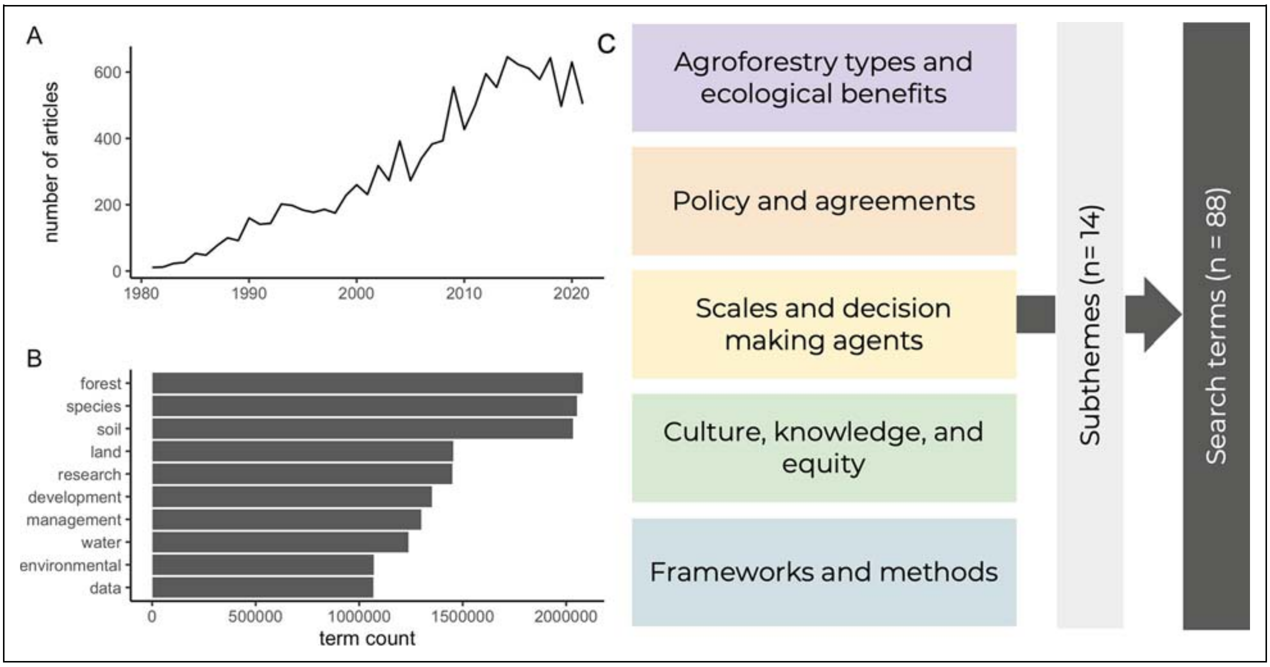

Figure 1. Characteristics of the corpus and conceptual diagram of the word frequency analysis. The corpus analyzed in this study included 9,664 research articles ($n = 9{,}358$; 97%) and reports ($n = 306$, 3%) extracted from the JSTOR corpus that were published between 1980 and 2020 and mention the term *agroforestry*. (A) The number of publications in the corpus over time. (B) The top 10 most frequent terms in the 4 decades of research. (C) Conceptual diagram of themes, subthemes, and search terms explored in the word frequency analysis.

(i.e., *development*, *management*) (**Figure 1B**). *Forest* was unsurprisingly the most frequent term since it is a root word of the term *agroforestry* (Bene et al., 1977; King, 1987), agroforestry systems are designed to mimic the structure and function of forests to varying degrees (Altieri and Nicholls, 2004; Malézieux, 2012; Young, 2017), and a significant body of research uses native forests as a reference for understanding biodiversity and ecosystem services in nearby agroforestry systems (e.g., Valencia et al., 2016). *Forest* was followed in frequency by *species*, *soil*, and *land*, further indicating that ecological themes have dominated agroforestry research over the past 4 decades. These fundamental ecology terms were followed by *research*, *development*, and *management*, which reinforces that agroforestry literature is largely applied in nature, continuing a trend that started when the term *agroforestry* arose in a research for development context (Bene, 1977; King, 1987) and was previously documented in the early 2000s (Nair et al., 2005). *Water*, *environmental*, and *data* were the least frequent of the top 10 terms. *Agroforestry* did not appear in the top 10 terms, potentially because studies may reference *agroforestry* in combination with other terms for types of agroforestry practices that have been used in the literature longer and/or are more locally relevant (e.g., tree intercropping, homegardens) and/or because of the tendency for the term to be abbreviated (e.g., AGF, AF). Terms related to the social dimensions of agroforestry systems were noticeably absent from the top 10 terms.

Agroforestry types and ecological benefits

Intercropping was by far the most frequent term of the 9 agroforestry types that we analyzed, occurring more than 3 times more frequently than any other term (**Figure 2A**). This is likely because *intercropping*, meaning 2 or more crops grown together, was coined decades before the term *agroforestry* (Vandermeer, 1992). *Alley*, as in *alley cropping*, increased rapidly in frequency from the mid-1980s to the mid-1990s, at which point it slowly declined in frequency. This increasing trend coincides with the development of alley cropping as an agroforestry technology by the World Agroforestry (ICRAF) in the 1980s. Despite much research and development in the 1980s, technical difficulties designing systems and the high labor cost of managing crops and trees contributed to low levels of alley cropping adoption in the 1990s (Sanchez, 1995; Suryanata, 2016). This might have resulted in a decrease in alley cropping research reflected in the downward trend in *alley* starting in the 1990s. We also found a slight increase in *silvopasture*, the intentional integration of trees and pasture for animals, since the early 2000s. *Homegarden* remained at a relatively steady level over the 4 decades, although it had considerably lower frequency than intercropping. Homegardens are a traditional land use practice made up of diverse, multilayer systems of trees and other plants found near houses that have been a model for other, larger-scale agroforestry systems (Kumar and Nair, 2004). Interestingly, *multistory*, *agrisilviculture*, *agrisilvopasture*, *permaculture*, and *windbreak* were relatively absent from the corpus. While considerable research on these types of agroforestry exists, our analysis shows that these terms had low frequency within literature mentioning *agroforestry* in the last 4 decades, indicating that they may not be frequently associated with *agroforestry* in the literature.

Biodiversity and *conservation* were the most referenced ecological benefits in the agroforestry literature of any of

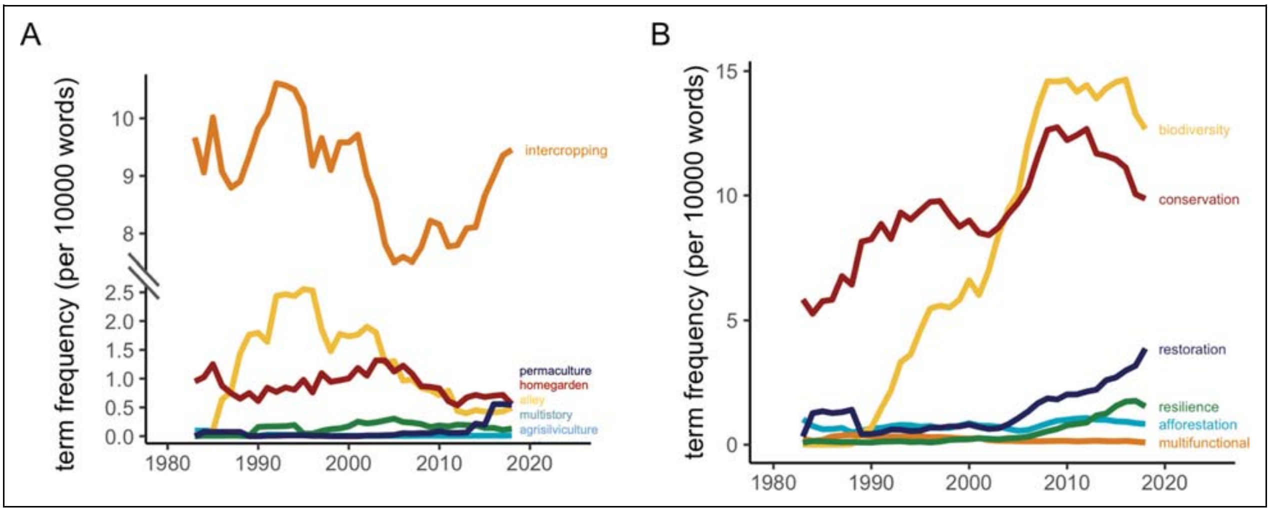

Figure 2. Frequency of curated sets of terms related to (A) agroforestry types and (B) ecological benefits. Note that the term labels sometimes represent multiple related terms. For example, *windbreak* also includes *shelterbelt* and *hedgerow*. For a full list of terms and nested, related words, see Table S1.

the benefits we analyzed (**Figure 2B**). *Conservation* was the most frequent term before the early 2000s and steadily increased over the 4 decades. This aligns with the historical context of *agroforestry* as a tool for achieving both conservation and development goals (King, 1987), and *conservation* was likely linked with *soil* (i.e., soil conservation) prior to the rise in *biodiversity*. *Biodiversity* started with much lower frequency than *conservation*; however, it increased rapidly beginning in 1990, surpassing the frequency of *conservation* in the mid-2000s. This timing follows the signing of the Convention on Biological Diversity in 1993 (UN, 1992). *Restoration* increased in the early 2000s, corresponding with the growth of the Society for Ecological Restoration (SER, 2004) signaled by the publication of the International Primer on Ecological Restoration, and has since led to a growing body of work on restoration through agroforestry (Zahawi, 2005; Vieira et al., 2009; Moreno-Calles and Casas, 2010; de Oliveira and Carvalhaes, 2016; Park et al., 2018; Miccolis et al., 2019; Padovan et al., 2022). Shortly after, *resilience* increased, surpassing *afforestation* in the early 2010s, yet remaining lower than *restoration*. The relatively low frequency of *resilience* in the agroforestry literature in the most recent decade is somewhat surprising considering the term is often associated with climate change and studies have documented how agroforestry systems support social–ecological resilience to climate change (Lasco et al., 2014; Quandt et al., 2017; McGuigan et al., 2022). *Multifunctional* was virtually absent from the literature.

Policy and agreements

Over the past 4 decades, agroforestry literature has shifted focus from the global goal of development to the goal of climate change mitigation and adaptation; yet, the policy mechanisms for translating these goals and agreements into increased agroforestry on the ground remain underrepresented in the literature. Since the mid-2000s, the frequency of *climate* tripled, surpassing *development* around 2010 (**Figure 3A**). This leap coincides with the 2007 Nobel Peace Prize awarded to the IPCC for their Fourth Assessment Report, which described the physical basis of climate change, as well as impacts, adaptations, and mitigation (IPCC, 2007). For instance, the implementation of agroforestry is estimated to sequester as much as 43.4% of all European agricultural emissions, depending on the type of agroforestry (Kay et al., 2019). Both *adaptation* and *mitigation* have increased since 2010 while *development* decreased in relative frequency during the same period. *Adaptation* was correlated with *mitigation*, suggesting that the heightened interest in climate change throughout the agroforestry literature is focused on both adaptation and mitigation, whereas interest in agroforestry for development has declined over the last decade. However, *adaptation* slightly surpassed the frequency of the term *mitigation* in recent years, suggesting that the contribution of agroforestry for climate change adaptation may be more heavily emphasized than the potential for mitigation. *Agreement* was infrequently used in the corpus, and *SDG* (i.e., Sustainable Development Goals) and *IPCC* were mostly absent.

While *economy*, *policy*, and *markets* were frequently mentioned in the agroforestry literature, policy mechanisms for supporting agroforestry adoption and persistence (i.e., *incentives*, *taxes*, and *subsidies*) occurred infrequently (**Figure 3B**). *Economy* had a higher term frequency than *policy* or *market*, suggesting a strong emphasis on the economics of agroforestry systems and the economic drivers of agroforestry transitions. The frequencies of *economy*, *policy*, and *market* increased from the mid-1990s to the early 2000s, which may coincide with the Second Assessment Report published by the IPCC in 1995 (IPCC, 1995). This report contained the first edition of the section, "Economic and Social Dimensions of Climate Change" which may have spurred research in this focus area. Other research on *economy*, *policy*, and *markets* in agroforestry literature has analyzed how state, country, and regional level policies affect agroforestry practices

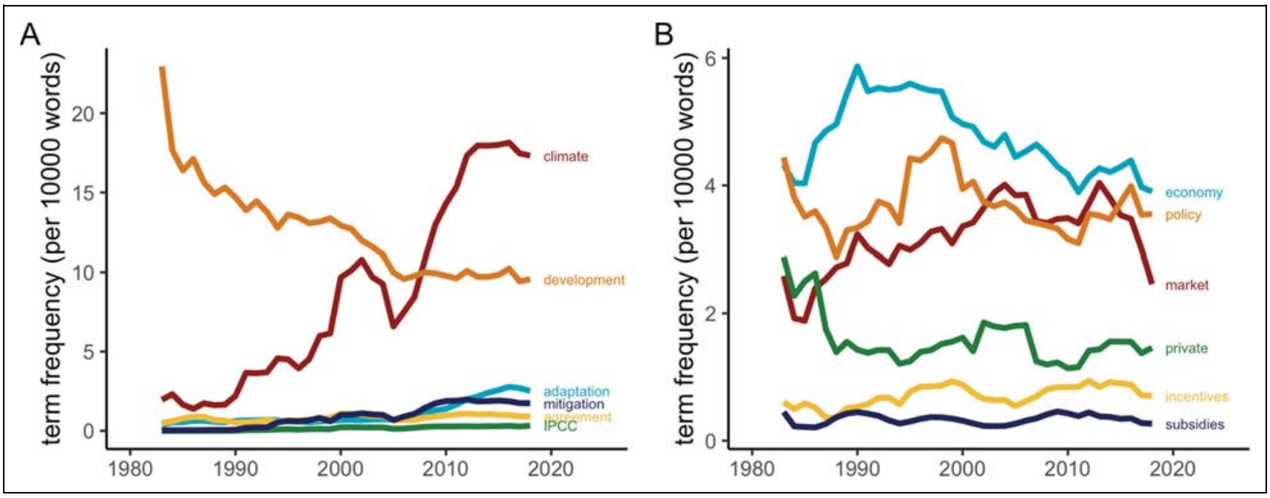

Figure 3. Frequency of curated sets of terms related to policy and agreements in an agroforestry corpus. Frequency of terms related to (A) agreements and societal goals and (B) economics and policy. Note that the term labels sometimes represent multiple related terms. For a full list of terms and nested, related words, see Table S1.

(Buck, 1995; Santiago-Freijanes et al., 2018; Ndlovu and Borrass, 2021). *Taxes*, *subsidies*, and *incentives* were less frequent in the agroforestry literature.

Scales and decision-making agents

The scales and decision-making agents of interest in agroforestry publications have become more diverse, with the most notable increase in *landscape* and *community.* In the most recent decade, *practices* and *households* were the most frequent terms at the farm scale, surpassing *farm* which was the most frequently used term until the early 1990s (**Figure 4A**). *Farm* and *practices* largely align with the ecological and agronomic foci of agroforestry literature; however, the increase in *household* suggests an increase in attention to the social dimensions of agroforestry systems, since decisions about farming practices are often linked with household dynamics, such as economics (Glover et al., 2013). Relatedly, *livelihoods* also increased steadily since the mid-1990s, which aligns with the first introduction of the sustainable livelihood concept, an integrated approach to poverty eradication, by the Brundtland Commission on Environment and Development and expanded in the 1992 United Nations Conference on Environment and Development (Krantz, 2001). The Millennium Development Goals (UN, 2000) and subsequent SDGs (UN, 2022) both modeled sustainable livelihood approaches, aligning with the continued increase in *livelihoods* in the corpus throughout the 2000s. *Farmer*—which in our analysis included the related terms *practitioner*, *producer*, *grower*, and *smallholder*—only increased slightly in frequency over the 4 decades and remained lower than *household* and *farm.* This reinforces that farmers remain important actors in the agroforestry literature. Since 2000, however, use of *stakeholder* has increased, which may indicate a broadening in scope to other decision-making agents in agroforestry such as landowners, buyers, support organizations, or policymakers, which has been proposed as an important change to ensure research supports scaling (Glover et al., 2019).

Social was the most frequent term in this theme, despite its decreasing use over the 4 decades (**Figure 4B**). This could indicate increasing attention to the social dimensions of agroforestry systems. *Rural* was more frequent than *social* in the early 1980s, but decreased by more than half by 2000, the largest decrease of any term in this theme, yet it remained one of the most frequent terms. *Community* rose steadily in frequency over the 4 decades. Usage of *local* and *urban* remained relatively consistent with an increasing trend. The term *network* increased starting around 2000, but remained relatively infrequently used despite studies showing the importance of farmer networks to increasing and sustaining agroforestry practices (Lin et al., 2021). *Labor*, often a constraint to agroforestry transitions (Pattanayak et al., 2003; Glover et al., 2013), occurred infrequently in the literature and experienced a slow decline in use over the 4 decades.

While *government* occurred frequently across the 4 decades, *infrastructure* had a considerably lower frequency in the 1980s and steadily increased after 1990 (**Figure 4C**). The frequency of *institution* remained stable. Terms which reference the type of governance, or degree of political centrality, such as *centralized* and *polycentric*, remained relatively infrequent, although engaging diverse community members in agroforestry transitions is important (Akamani and Holzmueller, 2017).

Scales above the state or country level (i.e., *landscape*, *regional*, *global*) increased over the last 4 decades (**Figure 4D**). Notably, the frequency of *regional* and *global* surpassed *country* around 1990. The increasing trend in the use of *global* may suggest advances in data availability and statistical analysis methods, as well as the changing focus on the potential of agroforestry practices to contribute to carbon storage on a global scale to combat climate change. The frequency of *landscape* tripled, the most significant increase of any scale term, with the steepest increase occurring in the 2000s. This increase corresponds with an increase in literature on landscape approaches to restoration and conservation, or frameworks for balancing

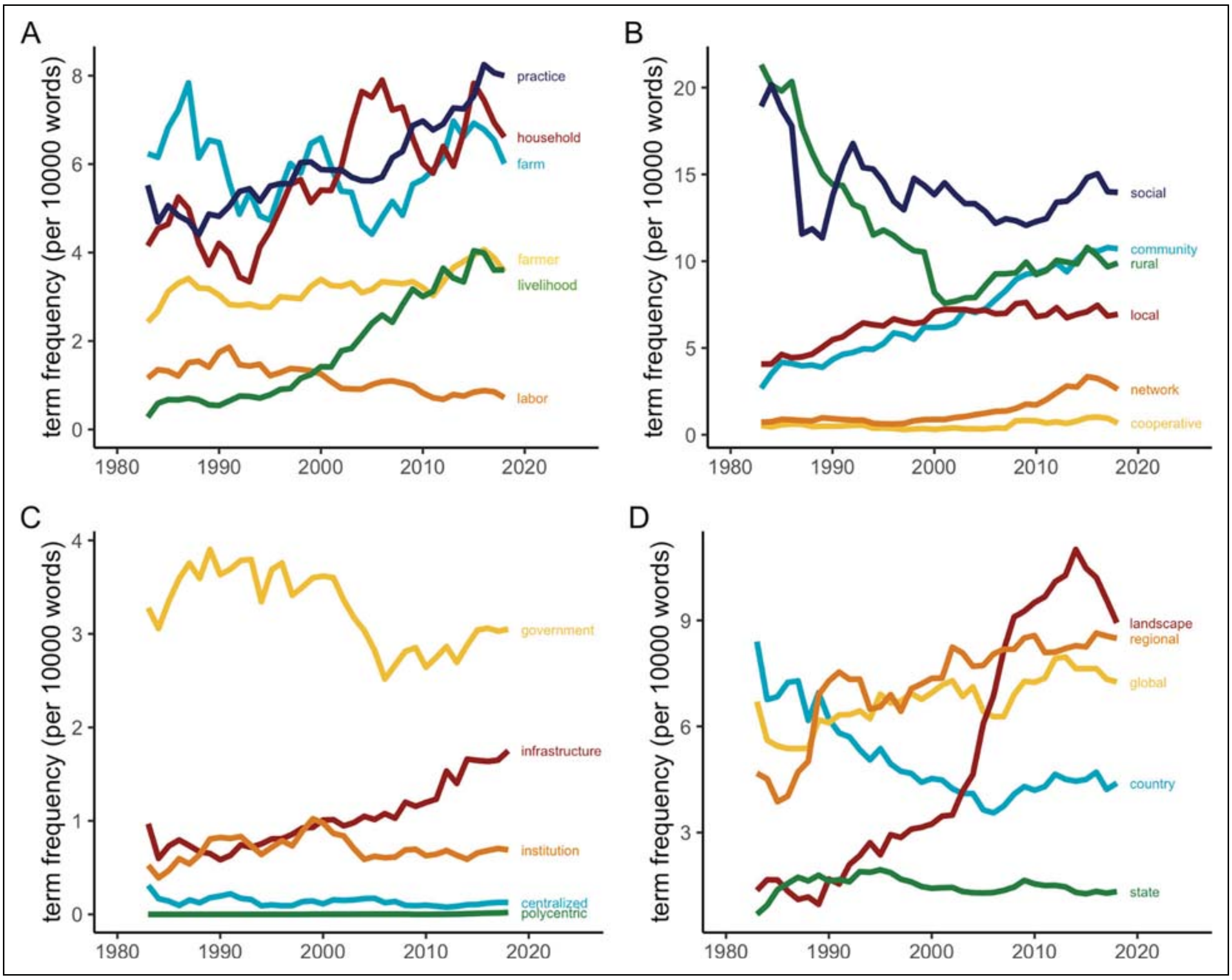

Figure 4. Frequency of curated sets of terms related to scales and decision-making agents in an agroforestry corpus. Frequency of terms related to scales at 3 levels within a state—(A) site/farm, (B) community, and (C) government, and (D) spatial scales at and above the state level. Note that the term labels sometimes represent multiple related terms. For a full list of terms and nested, related words, see Table S1.

multiple land uses in a given area through integrated policy and practice (Arts et al., 2017).

Knowledge, culture, and equity

Use of the term *knowledge* more than doubled over the 4 decades (**Figure 5A**). This trend suggests an increased focus on the people who are engaging in agroforestry, different types of knowledge, and the transfer of knowledge between practitioners (e.g., Isaac et al., 2007). Trends in *knowledge* may also aggregate the concepts of local ecological knowledge, traditional knowledge, and Indigenous knowledge, potentially indicating rising attention in the literature to the Indigenous forest-agriculture practices that precursor the word *agroforestry*, such as streubost in Germany (Dupraz and Newman, 1997), taungya in the Indo-Burma region (Menzies, 1988), and pākukui on Hawaiʻi Island (Lincoln, 2020). Increasing use of the term *knowledge* in these contexts could indicate a shift toward more critical analysis of whose knowledge is prioritized in agroforestry transitions, external actors like government institutions and/or local land stewards, and how that affects biodiversity, food security, and other outcomes (e.g., Jacobi et al., 2017). *Perception* also had a marked increase since 2010. *Perception*, like *knowledge*, is often associated with agroforestry adoption (Meijer et al., 2015a) and therefore the shift might indicate increased focus on farmer decision-making and transitions to agroforestry at the farm scale within the literature. Conversely, the frequency of the word *culture* stayed level, or slightly decreased, and *belief* had a slightly downward trend.

Native, *traditional*, and *Indigenous* all had higher frequencies than the other terms in this group (**Figure 5B**). Surprisingly, *traditional* decreased from a spike in the 1980s. This may be due to a shift from descriptive studies of traditional, Indigenous systems to more experimental studies of cash crops and mechanized systems. The word *native*, which is often used to describe trees, forests, plants, and other biodiversity, increased markedly in the early 2000s. This timing follows the signing of the Convention on Biological Diversity in 1993 (UN, 1992), rising global recognition of the importance of biodiversity, and concerns over biodiversity loss. The trends suggest that agroforestry research has increasingly sought to understand how native biodiversity is conserved in agroforestry

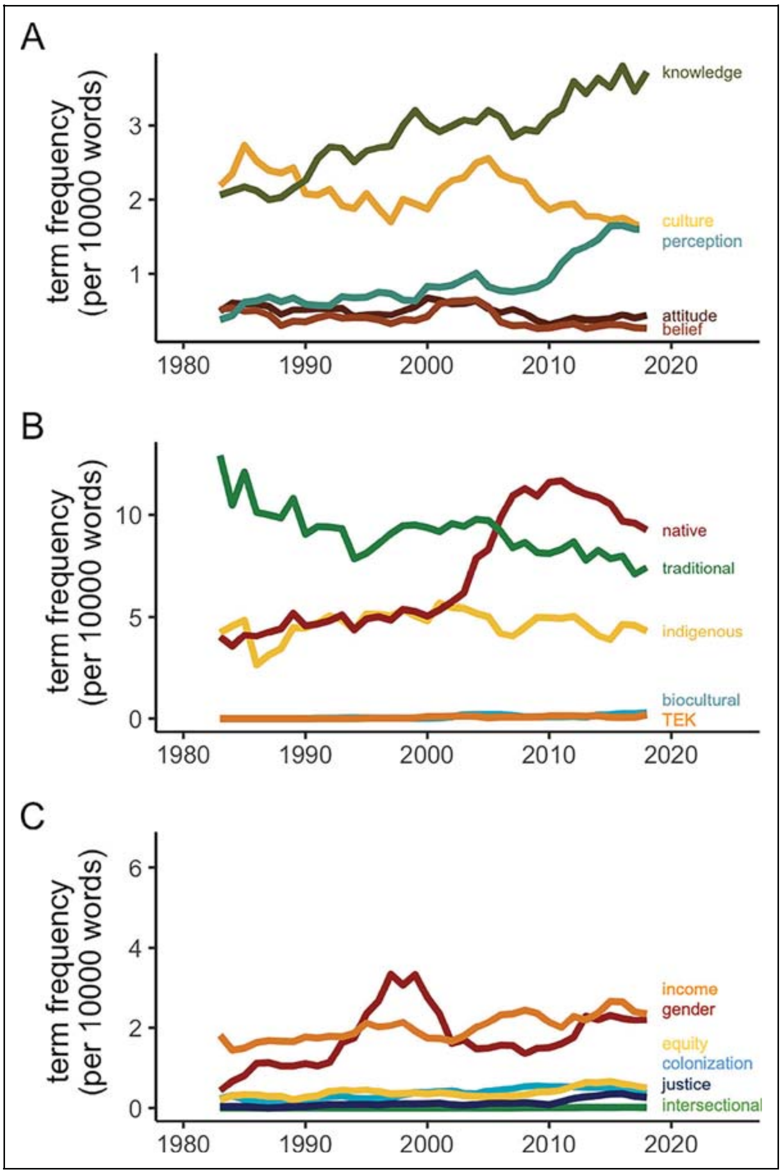

Figure 5. Frequency of curated sets of terms related to knowledge, culture, and equity in an agroforestry corpus. Frequency of terms related to (A) knowledge and behavioral factors affecting decision-making, (B) Indigenous facets of agroforestry systems, and (C) dimensions of identity, power, and equity. Note that the term labels sometimes represent multiple related terms. For a full list of terms and nested, related words, see Table S1.

systems relative to native forests (e.g., Bhagwat et al., 2008; Tadesse et al., 2014). *TEK* (*traditional ecological knowledge*) and *biocultural* are noticeably absent from the literature. However, some mentions of *biocultural* appear slightly after the term was coined in the early 2000s. Studies of biocultural restoration, or the mutually reinforcing restoration of ecosystems and human connections to place (Kimmerer, 2011), through agroforestry in particular have increased in recent years (Moreno-Calles et al., 2016; Hastings et al., 2023).

Terms related to identities and equity all had relatively low frequency (**Figure 5C**). *Gender* increased over the 4 decades and spiked around 2015. This spike may be due to a suite of publications by the World Agroforestry Center (ICRAF) on gender in agroforestry during that time period (Meijer et al., 2015b). *Income* had a higher frequency in the corpus than *gender*, *power*, or *equity*. This trend reflects the focus of agroforestry research on understanding how agroforestry systems can improve livelihoods at the same time as providing ecological benefits. Notably, indicators of who gets to access agroforestry practices—including *equity*, *colonization*, *justice*, and *intersectionality*—are missing in the literature. *Justice*, however, increased slightly within the last decade.

Frameworks and methods

Our results show that 3 common frameworks for studying agricultural land use change—*adoption, transition*, and *transformation*—increased in frequency in the agroforestry literature since the 1980s (**Figure 6A**). The word *transition* increased at a faster rate than *transformation* and *adoption* between 1980 and 2000. After 2005, however, the frequency of *transformation* and *adoption* surpassed *transition*. In the most recent decade, *adoption* had the highest

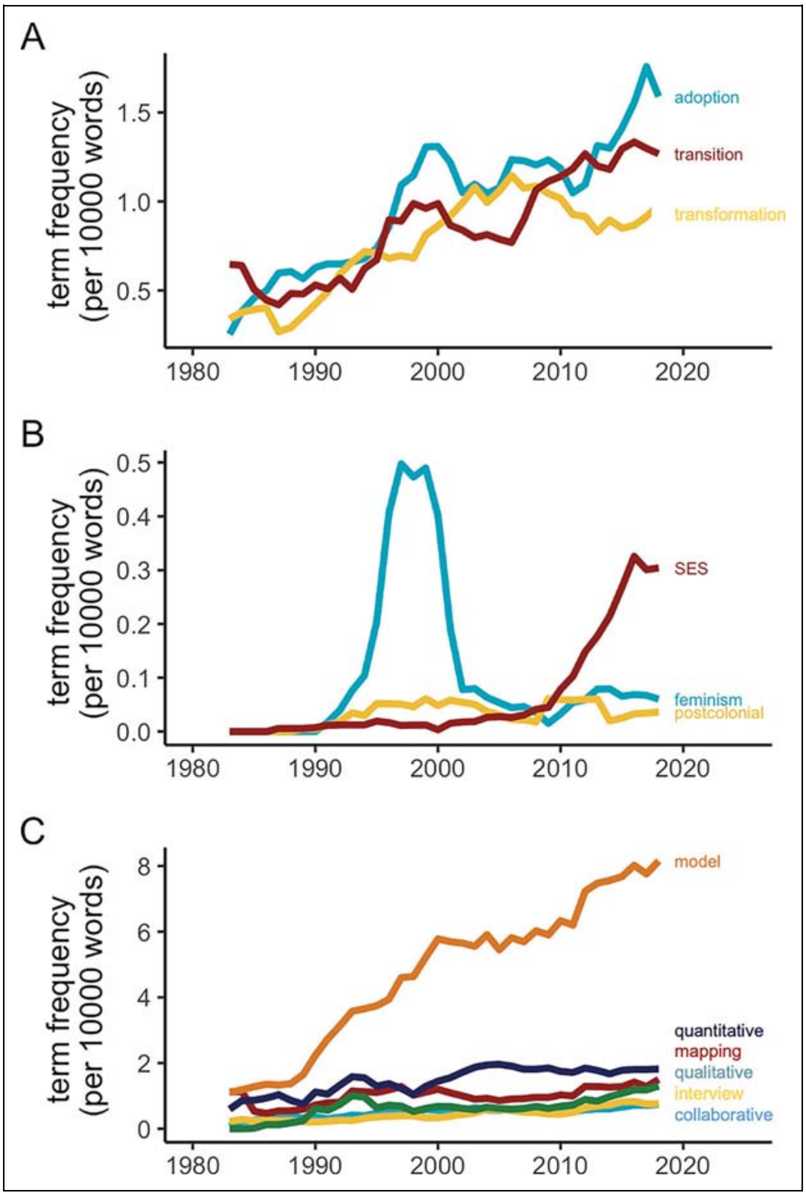

Figure 6. Frequency of curated sets of terms related to frameworks and methods in an agroforestry corpus. Frequency of terms related to (A) frameworks commonly used to study agricultural land use change, (B) frameworks more broadly used for understanding social dynamics in land use systems, and (C) methods used in agroforestry research. Note that the term labels sometimes represent multiple related terms. For a full list of terms and nested, related words, see Table S1.

frequency. Although *adoption* has been the most common of these 3 change frameworks for most of the past 4 decades, and represents an important body of literature (e.g., Pattanayak et al., 2003; Mercer, 2004; Amare and Darr, 2020), the concept has been critiqued for being an oversimplified model of change that centers individual farmer behavior and plot level land use change often neglecting the effects of social networks, institutions, and other structural factors that influence decision-making and landscape scale change (Glover et al., 2016; Glover et al., 2019). *Transition* and *transformation* have been presented as more inclusive frameworks for agricultural land use change (Anderson et al., 2019; Scoones et al., 2020; Ollinaho and Kröger, 2021), which has likely contributed to their rise in frequency. However, the frequencies of all 3 terms are considerably lower than most other terms we analyzed, suggesting that studies of adoption, decision-making, and transitions to agroforestry are less frequent than, for example, studies of ecosystem services of agroforestry systems.

Three other frameworks for understanding social dynamics in land use systems—*feminism*, *postcolonial*, and *SES*—had the lowest frequencies of all terms in our analysis (**Figure 6B**). We found that *feminism* had the highest frequency in comparison to *postcolonial* and *SES* between 1990 and the early 2000s. Within this decade, several important studies used a feminist political ecology approach to understand gender power dynamics in agroforestry practices and development (Rocheleau and Edmunds, 1997; Schroeder, 1999). After 2000, the term frequency of *feminism* fell. The usage of *SES* increased rapidly in the corpus starting in 2010, concordant with the development of the *SES* framework. Although the first definition of *SES* or the *SES* framework was established in the late 1980s (Cherkasskii, 1988) and thoroughly defined in the late 1990s (Berkes and Folke, 1998), a detailed discussion of how to use the framework to assess the sustainability of local resources did not come until the late 2000s (Ostrom, 2009; McGinnis and Ostrom, 2014; Colding and Barthel, 2019). Agroforestry research has since applied the SES framework to identify key system attributes, including social and biophysical dimensions of an ecosystem, that impact decision-making such as agroforestry land cover change, temporal dynamics, and historical sociopolitical legacies (e.g., Djanibekov et al., 2016), and the effects of feedbacks between various components of the system (e.g., Jerneck and Olsson, 2013; López et al., 2017).

The term *model* had the highest frequency of all the research method terms we analyzed (**Figure 6C**). While all terms had similar frequencies in the first decade, by the mid-1990s, *model* occurred more than twice as frequently as any other term. This is likely due to the rise in several different types of modeling applications in agroforestry systems including modeling tree, crop, and management interactions (Chen et al., 2016; Luedeling et al., 2016), especially in decision support tools (e.g., Ellis et al., 2004); land suitability for agroforestry (e.g., Ahmad et al., 2020; Wotlolan et al., 2021); ecosystem service benefits (e.g., Kay et al., 2018); financial and economic potential (e.g., García de Jalón et al., 2018); and adoption and decision-making (e.g., Pattanayak et al., 2003). *Quantitative* and *survey* were the next most frequent terms, closely followed by *mapping*, *qualitative*, *interview*, and *collaborative*. The frequency of the term *collaborative* included the related words *participatory, co-production*, and *PAR* (*participatory action research*) revealing that collectively these forms of engaging practitioners in research were noticeably absent from the agroforestry literature in the corpus.

Relative word frequencies across all subthemes in research articles versus reports

Our results indicate that research articles were more focused on individual types of agroforestry and ecological outcomes than reports, which more frequently referenced social themes and larger scales (**Figure 7**). First, research articles mentioned types of agroforestry practices

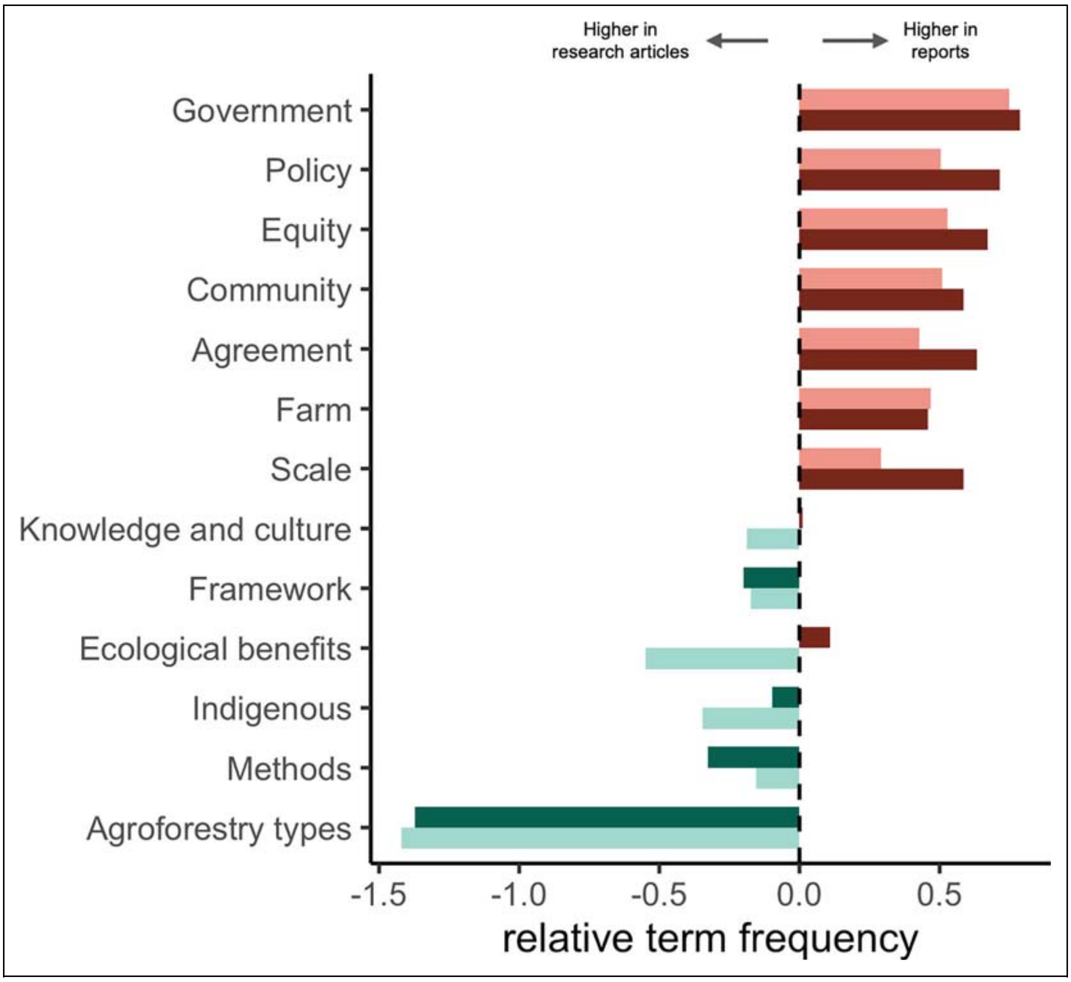

Figure 7. Frequency of curated sets of terms, grouped into subthemes, in reports relative to research articles. Frequency is shown over the last 4 decades (dark) and since 2010 (light). Red bars indicate higher term frequency within reports than articles. Green bars illustrate higher term frequency in articles than reports. For a full list of terms and nested, related words within each subtheme, see Table S1.

(e.g., *silvopasture*, *multistory*, *homegarden*) nearly 1.5 times more frequently than reports. This trend could indicate a higher tendency of academic studies to focus on the ecology and/or management of particular agroforestry practices rather than how agroforestry practices in general affect development outcomes. This idea is further reinforced by the second finding, that the subtheme ecological benefits—which included the terms *restoration*, *conservation*, *afforestation*, *sustainability*, *biodiversity*, *resilience*, and *multifunctional*—was considerably higher in academic articles than reports since 2010, although the total frequency of ecological benefits over the 4 decades was slightly higher in reports. Additionally, subthemes related to decision-making and scales, including government, policy, community, agreement, farm, and scale, were all higher in reports than in academic articles. This difference may indicate that reports were written more for policymakers and decision-makers at scales broader than the farm scale and with more applicability to international agreements. For example, many reports in the corpus have been published by the CIFOR and World Agroforestry (ICRAF), a now joint research and development institution that works collaboratively with stakeholders to deliver solutions to major global challenges (CIFOR-ICRAF, 2022). Finally, terms related to identities and social and economic power in the subtheme equity—which included *intersectionality*, *power*, *race*, *gender*, *access*, *sovereignty*, *justice*, *colonization*, *equity*, and *income*—were considerably higher in reports than in academic articles. This may suggest an important opportunity for future research to build on what has been documented in reports and contribute to socially just transitions to agroforestry (Ollinaho and Kröger, 2021). Both the subtheme knowledge and culture—which included *culture*, *knowledge*, *belief*, *perceptions*, and *attitude*—and the subtheme framework—which included *adoption*, *transition*, and *transformation*—had similar relative term frequencies between research articles and reports. This is likely because these terms occurred infrequently in either body of literature.

Synthesis and recommendations

Understanding the social dimensions of agroforestry transitions is critical for enabling sustainable and just land use change to meet global climate targets. We analyzed word frequency in a corpus of 9,664 agroforestry publications to understand trends in the study of the social dimensions of agroforestry transitions over the 4 decades since the word *agroforestry* was coined. Our results show that despite the most frequently used terms in the entire corpus being primarily ecological (e.g., *forest*, *species*, *soil*), the lexicon used in agroforestry literature has expanded to incorporate more social, economic, and political elements (e.g., *livelihood*, *knowledge*, *community*) over time, and as agroforestry has become more important to climate change adaptation and mitigation targets globally. This trend mirrors a similar transition the field of agroecology has undergone over the same time period, from a focus on mainly ecological systems to including increasingly more social and political dimensions (Méndez et al., 2013; Gliessman et al., 2022). While this overarching trend is positive for agroforestry transitions, since social elements are critical to expanding and sustaining agroforestry on landscapes, trends within 4 key social dimensions of agroforestry point to important knowledge gaps and opportunities for future research.

First, although agroforestry research has remained solutions-oriented over the last 4 decades, the policy mechanisms for translating societal goals and agreements into increased agroforestry on the ground remain underrepresented in the literature. This suggests an opportunity for more research on the efficacy of different policy interventions to reduce barriers and enable agroforestry transitions. For example, national and regional policy analyses (e.g., Place et al., 2012; Buttoud, 2013; Chenyang et al., 2021) and empirical case studies (e.g., Nishizawa et al., 2022) have both produced important recommendations for agroforestry interventions, and more research in this area is needed. Additionally, future research could track the longitudinal effects of policy interventions aimed at enabling agroforestry transitions to evaluate their efficacy.

Second, the scales and decision-making agents of interest in agroforestry publications have become more diverse; however, important keywords related to community level and farm labor remained infrequent in the literature. For example, despite the fact that farmer networks are important spaces for exchanging knowledge about how to start and maintain agroforestry practices (Isaac et al., 2007), the words *network* and *cooperative* were infrequently found in the corpus. More analyses of agroforestry social networks and the dynamics within and between them is needed, and could, for example, support more transparent and accountable network governance (Lin et al., 2021). Similarly, understanding how producer cooperatives may facilitate market creation for diverse agroforestry products and thus aid in equitable agroforestry transitions is an important area of future research (Ollinaho and Kröger, 2021). Further, the availability of skilled labor and the ability to pay competitive wages to people working in agroforestry systems can constrain agroforestry transitions (Pattanayak et al., 2003; Glover et al., 2013), yet *labor* occurred infrequently in the corpus. Empirical research on the labor dimensions of site-specific models of agroforestry could allow new generalizable lessons for agroforestry scaling to emerge.

Third, the corpus contained a low frequency of terms related to identity and equity, potentially signaling that the increasing trend in framing agroforestry as a climate solution has not been met with an increase in attention to equitable and just transitions to agroforestry. Since effective transformations to sustainability require consideration of diverse knowledge, plural pathways, and the political nature of transformation (Scoones et al., 2020), future research could explore these dimensions as well as other aspects of equity in agroforestry transitions. More research on social justice dimensions of agroforestry systems, especially indicators of who gets to access agroforestry practices—including *equity*, *colonization*, *justice*, and *intersectionality*—could reveal drivers, constraints, and structural changes necessary for transitions to agroforestry (Schroeder and Suryanata, 1996; Jacobi et al., 2017;

Hastings et al., 2021). Future research on these dimensions is especially important in the context of agroforestry as a nature-based solution to climate change.

Fourth, several important frameworks and methods for understanding agroforestry transitions were underrepresented in the literature, pointing to important areas for future research. Although discussions of transformation, transition, and adoption are all increasing, adoption is still the primary focus in the agroforestry literature. Studies that focus on adoption may investigate the social and institutional factors that influence decision-making to a lesser extent than individual behavioral factors (Yoder et al., 2019), suggesting an opportunity to engage in more research which conceptualizes adoption as a broader process of innovation, transformation, or transition (e.g., Glover et al., 2019). Additionally, modeling methods have increased considerably, whereas collaborative methodologies that engage practitioners and other community members from the onset of research (e.g., participatory, co-production) are relatively much less frequently used, despite evidence showing that community engagement improves research quality (Dumont et al., 2019). Although usage of the SES framework has increased dramatically within the last decade, the term had one of the lowest frequencies of any keywords in the analysis. Applying the SES framework to evaluate agroforestry transitions can help identify levers of change and assess how interventions targeted at those levers create feedback loops, thereby affecting other components of the system, making it an important framework for future agroforestry research.

Our results indicate that research articles focused more on agroforestry types and ecological outcomes compared to reports, which more frequently referenced social themes and larger scales. This distinction may be attributed to the fact that research publications and reports have different target audiences; reports may be more often written for policymakers and institutions. However, this discrepancy between publication types points to an opportunity for researchers, institutions, and policymakers to work together to resolve some of the gaps in the social dimensions of agroforestry that are included more often in reports than research articles. Collaborative research approaches such as co-production (Norström et al., 2020; Chambers et al., 2021) may be a useful approach to increase academic research engagement in social dimensions of agroforestry transitions.

Finally, our results highlight the influence of intergovernmental agreements on the framing and focus of agroforestry research. Increasing trends in several terms in the agroforestry corpus coincided with related intergovernmental agreements. Most notably, we found a significant increase in *biodiversity* and *native* following the signing of the Convention on Biological Diversity in 1993 (UN, 1992), *climate* coinciding with the 2007 Nobel Peace Prize awarded to the IPCC for their Fourth Assessment Report (IPCC, 2007), and *livelihoods* coinciding with the 1992 United Nations Conference on Environment and Development (Krantz, 2001) and later the Millennium Development Goals (UN, 2000). The ballooning of specific terms used in these large-scale agreements suggests that agreements play an important role in providing the language for governments to frame, and potentially set, national research agendas. It also reveals that agroforestry has been consistently framed as a solution to global issues since the term was coined and that the field has been highly responsive to changing global priorities, adjusting the framing, and potentially study, of what agroforestry is a solution to in order to align with current priorities.

Our results include some important caveats. First, our analysis of the corpus was limited to English 1-grams, and therefore excluded multigram terms, such as *climate change* or *ecosystem services*, and literature published in a language other than English. While 2-grams could have provided more nuance to our analysis, our 1-gram analysis still allowed important generalizable trends in the literature to emerge. Future studies could examine and compare trends in agroforestry literature published in other languages. Second, the JSTOR corpus (JSTOR, 2022) is missing some agroforestry-specific journals (e.g., *Agroforestry Systems*); however, our analysis still highlights important trends in a body of 9,664 agroforestry publications. Third, publications that focused on integrated forest-agriculture practices, but did not use the term *agroforestry*, were not included in our analysis. Future studies could explore trends in literature associated with other words for agroforestry (e.g., *silvopasture*, *tree intercropping*). Additionally, since our corpus contained substantially more academic articles ($n = 9358$) than reports ($n = 306$)—and excluded reports published by governments and NGOs and movements that are not policy institutes and/or do not contribute to the JSTOR reports collection—the comparison of relative frequencies of themes between these 2 groups should be considered a preliminary assessment, worthy of future analysis with a larger sample size. Finally, our analysis tracks the frequency of term use in the agroforestry literature, yet frequency does not necessarily match the importance of related concepts to the field. For example, some terms may be frequently used in the framing of the publication but may not be the focus of the research. Despite these limitations, our analysis provides an important first step in understanding trends in the social dimensions of a diverse and growing body of agroforestry literature.

Conclusion

Our analysis of trends in agroforestry research reveals a solutions-oriented field, responsive to global challenges and policy priorities, with opportunities for increased attention to the social dimensions of agroforestry transitions. Our review has highlighted how the framing and focus of agroforestry research has shifted from conservation and development toward biodiversity and climate change corresponding with the evolving global priorities set in intergovernmental agreements. We found that the shift in framing toward agroforestry as a climate solution has corresponded with a change in scale, toward landscape and community levels; however, it has not yet been met with increases in other important social dimensions of agroforestry transitions, such as equity and justice, policy mechanisms, and social networks. Future research could benefit from addressing these gaps as well as increasing collaborative engagement with practitioners, institutions, and policymakers, for example through co-production or participatory action research, as terms related to these concepts occurred infrequently in the corpus. Equitably increasing and sustaining agroforestry on the scale needed to meet global climate targets requires understanding the social-ecological dynamics of agroforestry transitions. Strengthening the study of these linkages in agroforestry research, in particular through increasing attention to the social dimensions, could play an important role in supporting sustainable and just agroforestry transitions for climate change mitigation and adaptation.

Data accessibility statement
All code and data to reproduce analysis is available at https://github.com/milliechapman/agroforestry-review.

Supplemental files
The supplemental files for this article can be found as follows:

Table S1. Table containing themes, subthemes, and search terms for text analysis of an agroforestry corpus.

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Competing interests
The authors have no competing interests to declare.

Author contributions
Contributed to conception and design: ZHS, XSO, MC, LH, KS.

Contributed to acquisition of data: MC.

Contributed to analysis and interpretation of data: ZHS, XSO, MC, LH.

Drafted and/or revised the article: ZHS, XSO, MC, LH, KS.

Approved the submitted version for publication: ZHS, XSO, MC, LH, KS.

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